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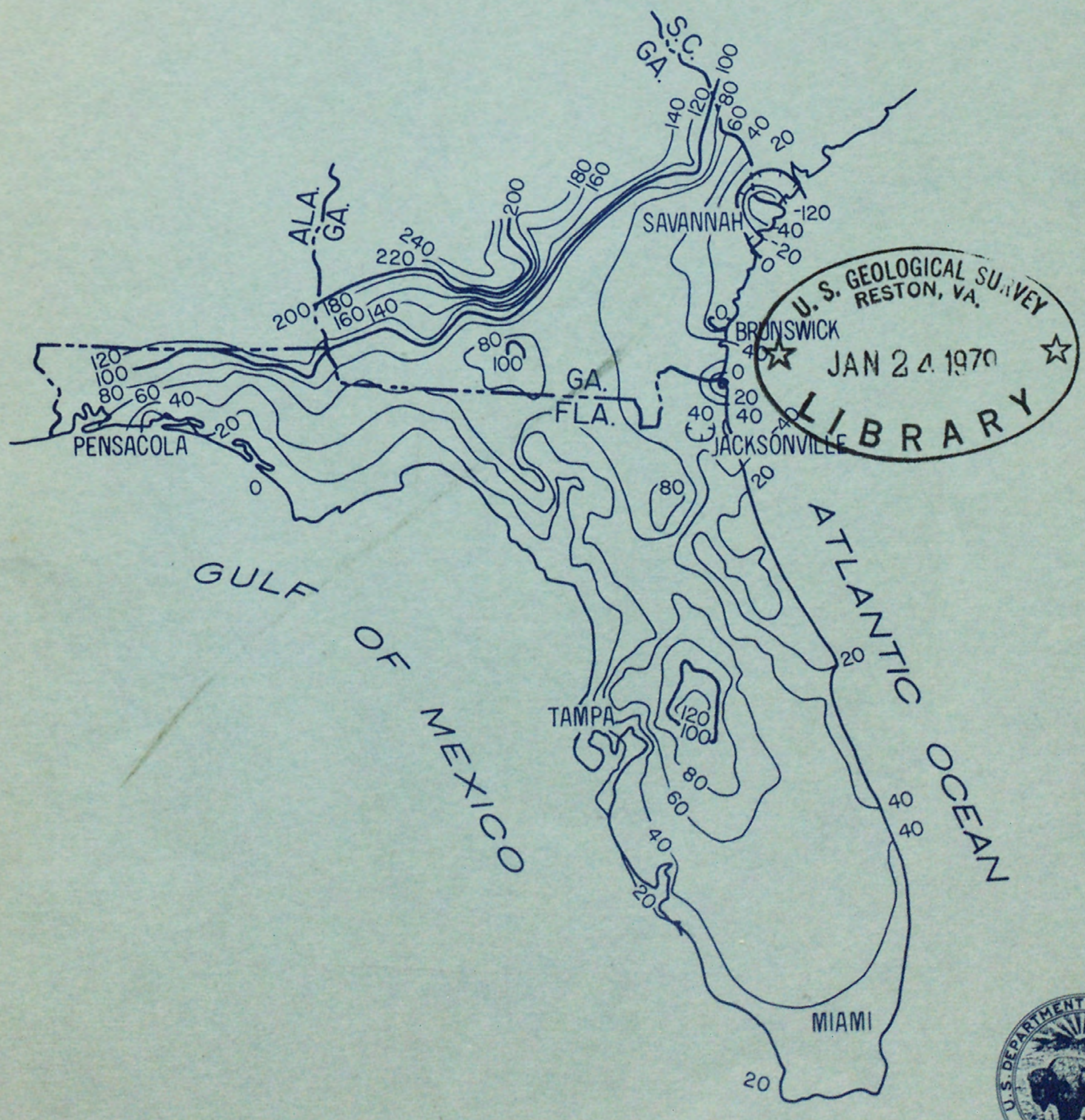
U.S. GEOLOGICAL SURVEY

OPEN-FILE REPORT FL 78-516

PLANNING REPORT FOR THE SOUTHEASTERN LIMESTONE REGIONAL AQUIFER SYSTEM ANALYSIS



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UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PLANNING REPORT FOR THE SOUTHEASTERN LIMESTONE REGIONAL AQUIFER SYSTEM ANALYSIS

By Richard H. Johnston

Open-File Report 78-516

1978

UNITED STATES DEPARTMENT OF THE INTERIOR

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GEOLOGICAL SURVEY

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PLANNING REPORT FOR THE SOUTHEASTERN LIMESTONE REGIONAL AQUIFER SYSTEM ANALYSIS

By

Richard H. Johnston

ABSTRACT

The southeastern limestone aquifer system is one of the major sources of ground water in the United States. Over 3 billion gallons of water are pumped daily making the aquifer the principal source of municipal, industrial, and agricultural water supply in large parts of Florida and Georgia and to a lesser extent in South Carolina, and Alabama. Another important use is the disposal of industrial wastes and treated sewage into parts of the limestone system containing saline water. A variety of problems have developed in the aquifer in recent years, principally declining water levels, saltwater intrusion in coastal areas, water-quality degradation, and inadequate supplies of fresh ground water locally.

In 1978 the U.S. Geological Survey began a study whose goal is to provide a complete description of the hydrogeologic framework, geochemistry, and regional flow system of the limestone aquifer. A 4-year effort is planned that will include: (1) synthesis of all existing data and presentation on a series of regional hydrogeological and geochemical maps; (2) obtaining new hydrogeological information to fill data voids -- particularly where ongoing State and Federal programs are not likely to generate such data; and (3) design and calibration of a regional digital model of the aquifer system and detailed models of problem areas. Computer simulation will be used extensively to assess the effects of large withdrawals of ground water and waste injection into the aquifer.

INTRODUCTION

The prolific southeastern limestone aquifer system is one of the major sources of ground-water supplies in the United States. The aquifer underlies all of Florida, southeastern Georgia, and small parts of adjoining Alabama and South Carolina -- a total area of about 82,000 square miles. It provides water supplies for many cities including Daytona Beach, Jacksonville, Orlando, Tallahassee, and St. Petersburg in Florida and Brunswick and Savannah in Georgia.

In many areas it is the sole source of freshwater. Industrial and agricultural pumpage is even larger than for public supply. Withdrawals for irrigation have increased sharply in recent years. For example, pumpage for irrigation in a five-county area of southwest Georgia was more than 1 billion gallons per day for a short period during 1977. In all an average of about 3 billion gallons per day is withdrawn from the aquifer. The major centers of pumping are shown in figure 1.

Another important use of the aquifer is for subsurface storage of wastes. Industrial wastes and treated sewage are being injected into parts of the aquifer containing saline water. Drainage wells are being used to divert surface runoff into upper parts of the aquifer containing freshwater. Major sites of subsurface waste storage and disposal are shown in figure 2. In south Florida, the aquifer is also used to supply slightly saline water for desalting plants.

Hydrogeologic Setting

The southeastern limestone aquifer, although predominantly limestone, contains dolomite as well as clay, sand and marl. The aquifer system includes several formations principally the Tampa, Suwannee, Ocala, Avon Park, Lake City, and Oldsmar Limestones (fig. 3). Ranging in age from Eocene to Miocene these units combine to form a continuous carbonate sequence which is hydraulically connected in varying degrees. Thickness of the carbonate rocks varies from a featheredge at the outcrop to more than 1,500 feet downdip where the aquifer is confined. Generally the southeastern limestone aquifer is referred to as the principal artesian aquifer in Alabama, Georgia, and South Carolina, and as the Floridan aquifer in Florida.

The aquifer is unconfined in the bordering outcrop areas of Alabama, Georgia, and South Carolina. Unconfined conditions also exist in northwest peninsular Florida where a structural high (Ocala uplift) has exposed the limestone. In these unconfined areas, discharge from the aquifer supplies many of the largest springs in the United States.

The transmissivity of the aquifer apparently varies by at least three orders of magnitude as shown in figure 4. This map shows representative values of transmissivity as reported in the literature and is intended only as a broad overview because many of the values were obtained from wells that did not penetrate the entire limestone system. Values of transmissivity range from less than 500 ft^2/d for the freshwater-filled part of the aquifer at Fort Walton Beach to at least 3,000,000 ft^2/d in a highly cavernous unit (locally termed "boulder zone") at Miami. In the highly productive and heavily pumped areas of the aquifer at Jacksonville, Tallahassee, and near Tampa-St. Petersburg, transmissivities are about 50,000 to 150,000 ft^2/d.

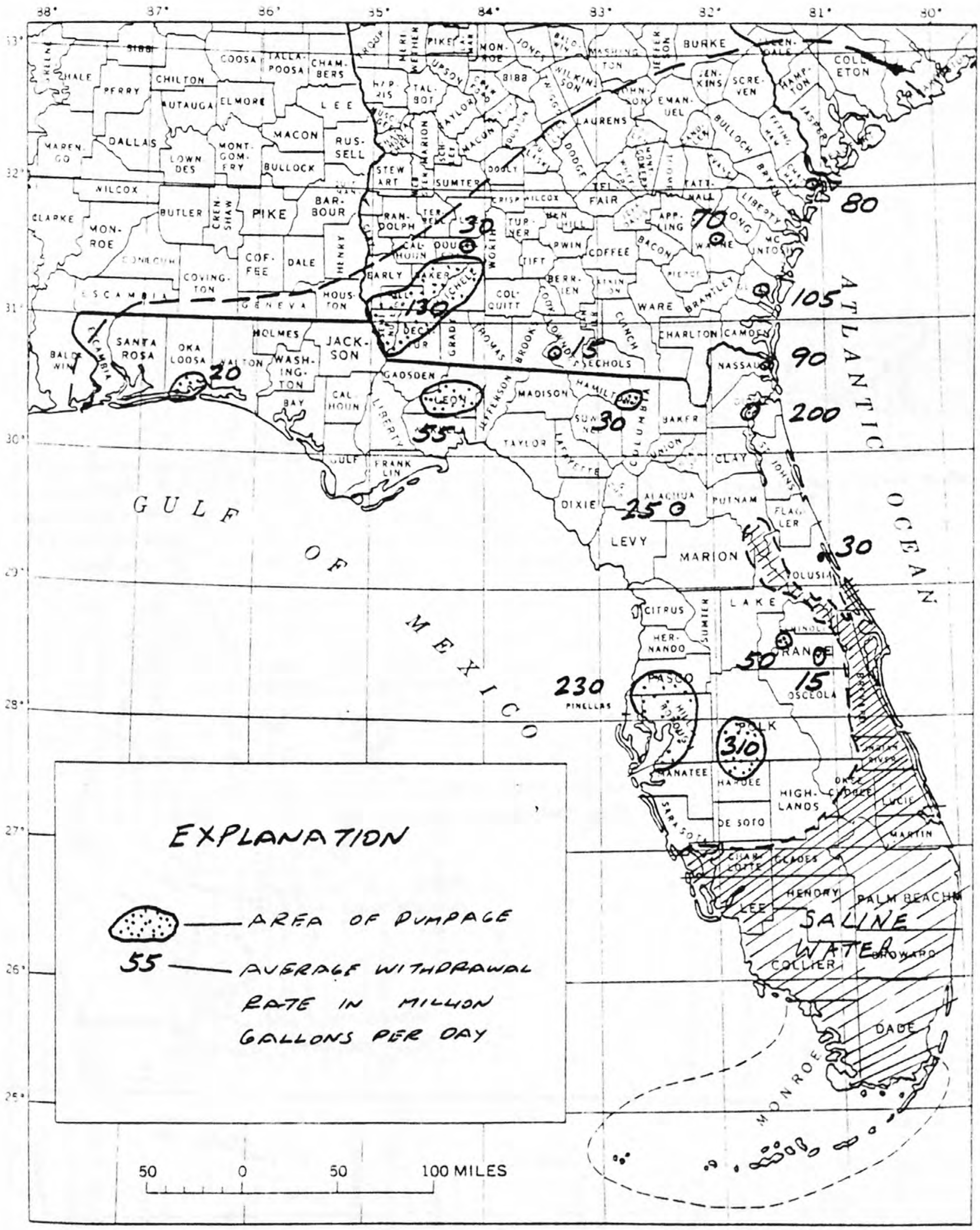

Figure 1. Important centers of pumpage from the southeastern limestone aquifer.

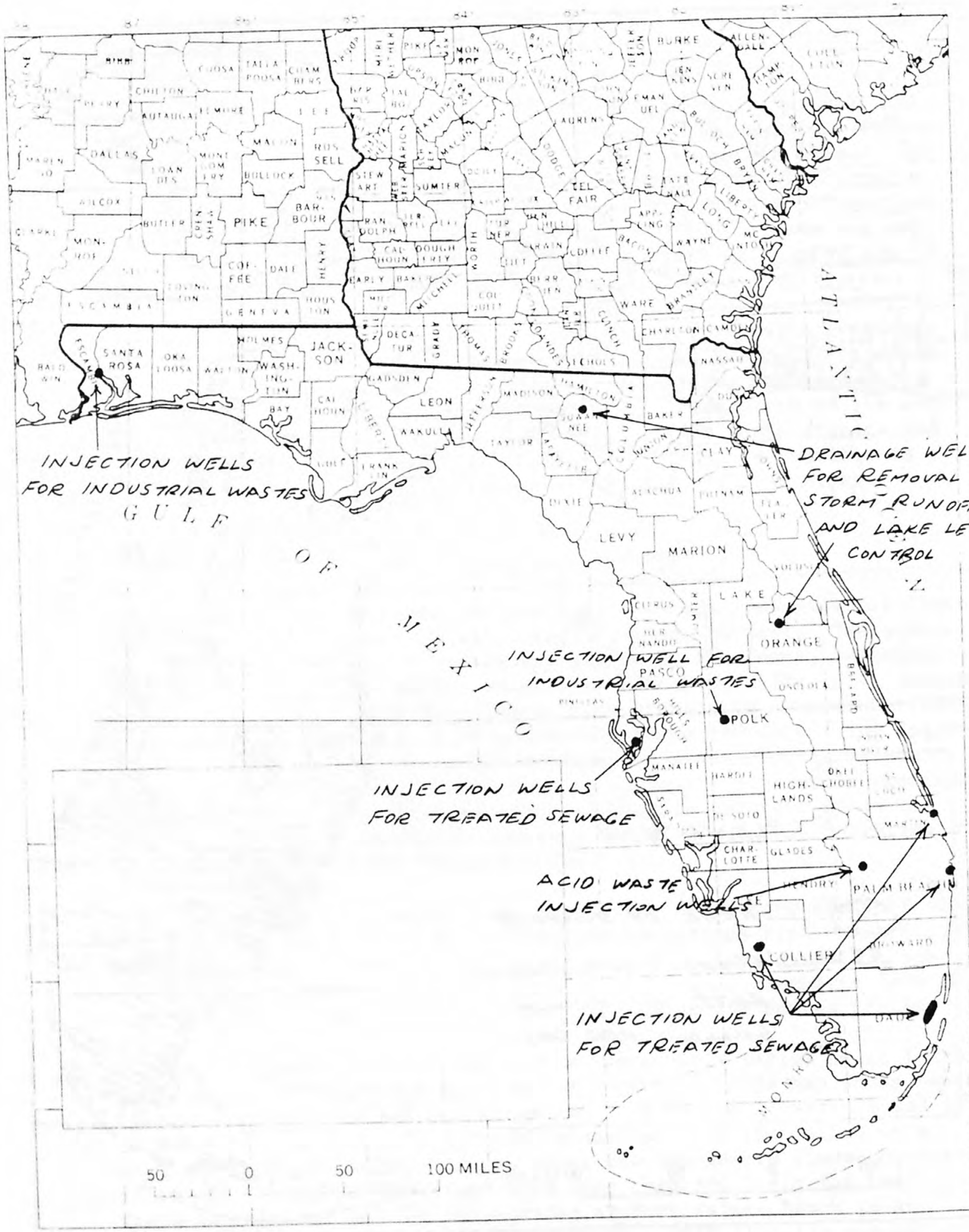

Figure 2. Major sites of subsurface waste disposal in the southeastern limestone aquifer.

System	Series	Florida: Panhandle	Florida: Peninsula	Georgia	South Carolina
Quaternary	Holocene and Pleistocene	Terrace deposits	Alluvium and terrace deposits; upper part of Biscayne aquifer	Alluvium and terrace deposits	Alluvium and terrace deposits; Waccamaw Formation
Tertiary	Pliocene	Citronelle Formation	Caloosahatchee Marl; Alachua Formation \ Tamiami Formation	Charlton Formation \ Duplin Marl	Duplin Marl
	Miocene	Unnamed coarse clastic; Shoal River Formation; Pensacola clay; Chipola Formation	Miccosukee Formation; Hawthorn Formation	Hawthorn Formation	Hawthorn Formation
		Tampa Limestone and equivalents		Tampa Limestone	Tampa (?) Limestone[2]
	Oligocene	Chickasawhay Limestone; Suwannee Limestone; Byram Formation; Marianna Limestone	Suwannee Limestone	Flint River Formation; Suwannee Limestone	Flint River Formation / Cooper Marl (upper part)
	Upper Eocene	Ocala Limestone[1]		Cooper Marl (lower part); Ocala Limestone (lower part grades into Barnwell Formation up dip)	Cooper Marl (lower part); Barnwell Formation (up dip)
	Middle Eocene		Avon Park Limestone; Tallahassee Limestone[2]; Lake City Limestone[2]	Claiborne Group[3]: Gosport (?) Sand; Lisbon Formation (McBean Formation up dip); Tallahatta Formation	McBean Formation (up dip); Santee Limestone; Warley Hill Marl (up dip); Congaree Formation (up dip)
	Lower Eocene	Undifferentiated	Oldsmar Limestone[2]	Wilcox Group[3]: Hatchetigbee Formation; Tuscahoma Sand; Nanafalia Formation	Black Mingo Formation
	Paleocene	Undifferentiated	Cedar Keys Limestone[2]	Clayton Formation	Undifferentiated

[1]Also present in southeast Alabama
[2]Does not crop out
[3]In southeast Georgia only

(Dotted box) Southeastern limestone aquifer system. Referred to in Florida as the Floridan aquifer; also has been referred to in Alabama, Florida, Georgia, and South Carolina as the principal artesian aquifer (Stringfield, 1966).

Figure 3. Stratigraphy of the southeastern limestone aquifer system (after Cederstrom and others, 1979).

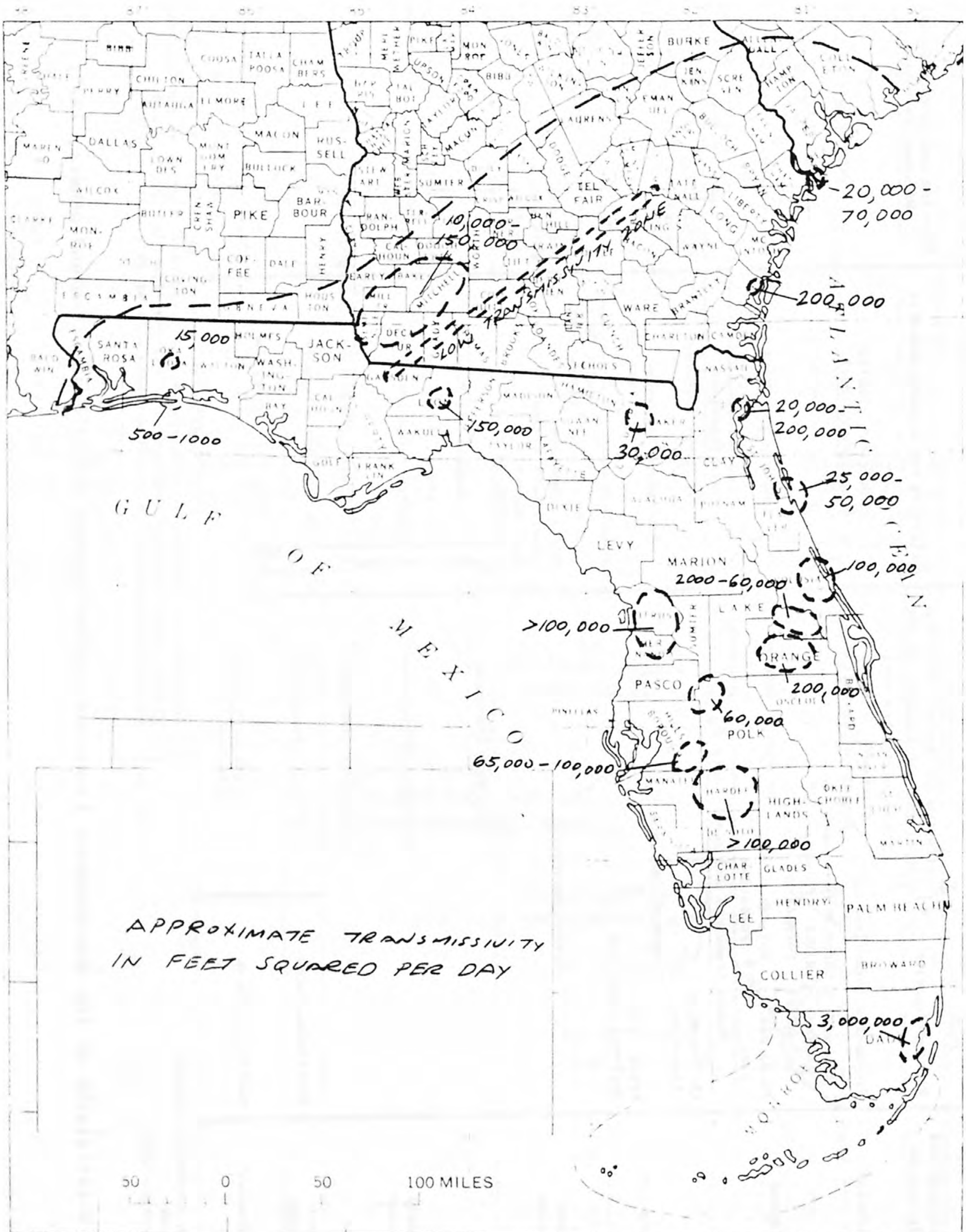

Figure 4. Representative values of transmissivity in the southeastern limestone aquifer.

In addition to large areal variations in transmissivity, the aquifer is characterized by significant differences in vertical hydraulic conductivity due to solution enlargement of vertical fractures. These solution features provide avenues for "short-circuit" vertical flow and they may occur in areas of layered carbonate rocks with otherwise poor vertical connection.

As may be expected, well yields in the limestone system are variable and locally very high; yields of several thousand gallons per minute are common in the more transmissive sections.

Problems

A variety of problems have developed in the limestone aquifer system in recent years. Declining water levels, saltwater intrusion in coastal areas, water-quality degradation, inadequate supplies of fresh ground water locally, and potential effects of waste injection are the principal problems.

Solution channeling of the limestone particularly along vertical fractures provides the avenues for movement of poor quality water in the deeper parts of the aquifer upwards into pumped zones. Declining heads caused by long-term pumpage have apparently caused upward movement of salty water (connate water?) through a fracture zone at Brunswick, Ga. Upconing of mineralized water is also occurring at Cocoa and probably also at Jacksonville, Fla.

In some areas of south Florida, such as the Florida Keys, freshwater supplies are unobtainable. However, water in the upper part of the limestone system is much less saline than seawater; this slightly saline water is desirable for feed to desalting plants or for blending with good quality imported water. What effect, if any, present and planned sewage injection into deep, saline parts of the aquifer will have is unknown.

Ground-water pollution by way of sinkholes is occurring in agricultural and urbanized areas; however, the problem is largely unstudied. Sudden collapse of sinkholes, although spectacular, is not a widespread problem.

Land subsidence has occurred in the Savannah, Ga., area and possibly in the Brunswick, Ga., area due to ground-water withdrawals. However, subsidence has amounted to only a few tenths of a foot in this century and is probably not a serious problem.

Competition for ground-water supplies is a long-range problem in some areas. For example, in west-central Florida, substantial increases in ground-water pumpage for phosphate mining operations are planned. Such increases will compete with greater public supply demands in the fast-growing coastal communities south of Tampa, including Sarasota, and with increasing irrigation demands.

Lake levels have declined in recent years in the Orlando area. The cause is probably ground-water pumpage in combination with long-term precipitation deficiency; however, this has not been demonstrated. In some areas where the confining bed is very leaky, or where the aquifer is unconfined, changes in wetlands with consequent biological damage can occur due to heavy ground-water withdrawals.

Drainage wells are utilized in the Orlando area as an effective method of disposing of surface runoff. Currently about 50 Mgal/d of surface runoff is diverted into wells tapping the upper part of the aquifer. Although some water-quality changes have occurred, the effect on the limestone aquifer is uncertain.

Injection of treated sewage into saline parts of the aquifer system may influence circulation patterns in the freshwater sections. This method of sewage disposal is being used in place of ocean outfalls in the Tampa-St. Petersburg area and along the southeast coast (fig. 2). Large increases in sewage injection are planned in the coming years.

Objectives and Approach

The overall objectives of the study include: (1) a complete description of the hydrogeologic framework and geochemistry of the limestone aquifer system, (2) definition of the regional flow system, and (3) assessment of the effects of large withdrawals of ground water and waste injection into the aquifer. Computer simulation will be used extensively to evaluate the flow system and hopefully computer models will be useful for assessing water management alternatives.

Locally there is abundant information on the geologic framework and aquifer hydraulic characteristics. In several areas, models have been developed with predictive capability. However, the greatest amounts of data and the modeling efforts tend to be clustered around a few problem areas. In some areas where there are large untapped ground-water supplies, data are scanty.

A regional approach to investigating the limestone aquifer system is proposed that will include the following activities:

1. Assembly and analysis of all existing data and presentation on a series of regional hydrogeologic and geochemical maps of the aquifer system.

2. Obtaining new information to fill data voids -- particularly where ongoing U.S. Geological Survey, State, and local programs are not likely to generate such data.

3. Development of a data file for computer storage and retrieval of hydrologic and geologic data.

4. Design and calibration of a regional digital model (covering approximately 80,000 square miles) intended to simulate the system in a gross fashion and particularly to appraise hydrologic boundaries between more detailed subareal models.

5. Design and calibration of more detailed models of problem areas which can be used for assessing water-management alternatives.

Advances in digital modeling of ground-water flow have been rapid during the past few years; thus it is unrealistic to state specifically the kinds of models that will be used in this study. For some problems, such as the modeling of a moving freshwater-saltwater interface, models which are currently under development, will probably be perfected during the course of the study.

PLAN OF STUDY

The Southeastern Limestone Aquifer Study will be a 4-year effort beginning in fiscal year 1979. The study area, as outlined on figures 1 and 2, includes all of Florida, southeast Georgia, and small parts of adjoining Alabama and South Carolina. A tentative schedule of project activities and their relationship to proposed funding and personnel requirements is presented on figure 5. As shown, emphasis in the first year will be on the compilation and analysis of existing data and design of computer models. The following 2 years will be spent on acquisition of new data and refinement of models. During the fourth year, the models will be used to test water-management alternatives. Reports will be prepared throughout the study.

Definition of the Aquifer System

Preparation of Hydrogeologic and Geochemical Maps

A description of the geologic, hydraulic, and geochemical characteristics of the aquifer system will be an important part of the study. This system definition will take the form of regional hydrogeologic and geochemical maps, detailed maps of the highly stressed areas, plus cross sections and fence diagrams as needed. One of the most important aspects will be a description of the system boundaries for

PRINCIPAL PROJECT ACTIVITIES FOR FISCAL YEARS 1979-1982

	1979	1980	1980	1982
Data acquisition and interpretation	Assembly and interpretation of existing geologic and hydrologic data	Acquisition of new data with exploratory drilling, aquifer testing, geophysical surveys, and so forth		Data analysis
Digital computer models	Preliminary model design and trial runs	Revision, "tuning," and final calibration of model(s)		Predictive model runs
Report preparation		Preliminary reports (WRI or Open-File)	Journal Articles	Professional Paper Series

FUNDING AND PERSONNEL

	1979	1980	1980	1982
Budget	Low $600,000	High $1,300,000	High $1,100,000	Low $500,000
Hydrologists (Man years)	10	13½	13½	8½

Figure 5. Schedule of project activities as related to funding and personnel requirements.

modeling. Particular attention will have to be paid to geologic relations and permeability changes where the aquifer system merges into the lower Tertiary sand-limestone aquifer of Georgia and adjoining parts of South Carolina and Alabama. This work will utilize extensive published data but will also require a fresh look at geophysical logs and lithologic logs as well as drill cuttings, cores, and so forth.

Review and compilation of all existing data on the hydraulic properties of the aquifer system and related confining beds (where present) will be done. In some areas such as coastal Georgia, the Jacksonville area, the Southwest Florida Water Management District, and the counties surrounding Orlando, considerable aquifer hydraulic data exists. Some of this data has been reanalyzed taking advantage of recent methods of aquifer test analysis; however, a reevaluation of a considerable amount of older data is needed. The greatest lack of data is in the offshore sections of the limestone system where the geology, water quality, heads, and hydraulic characteristics are almost completely unknown.

Compilation and preparation of maps and sections showing distribution of naturally occurring ions (chloride, sulfate, and so forth), dissolved-solids concentration, temperature, and other chemical quality parameters are needed. Small-scale state-wide maps have been prepared for Florida showing distribution of some ions and chemical parameters -- these compilations will be highly useful for the study.

An important task will be the identification of boundaries within the system that affect lateral flow (such as faults and facies changes) and vertical flow (solution enlargement along vertical joints and faults, breaching of confining beds, and so forth). In particular the upward movement of poor quality water through presumed solution-enlarged conduits is an important problem. The quantifying of extremely abrupt changes in vertical permeability, that is converting geologic data to modeling parameters will require innovative ideas.

Regional hydrogeological maps will be prepared at 1:1,000,000 scale and will probably include the following:

1. Areal extent and thickness of the limestone aquifer system (isopach map).

2. Structure contour maps showing base and top (where confined) of the limestone aquifer system.

3. Transmissivity map of the limestone aquifer system.

4. Leakance (or vertical hydraulic conductivity) maps; thickness of confining bed(s) maps.

5. Map showing internal boundaries and inhomogeneities -- lithofacies, structural boundaries, major solution features, and so forth.

Geologic cross sections and fence diagrams will be used as needed to show facies changes, correlation of geologic units, and so forth. Geochemical maps showing the distribution of principal ions in ground water, temperature, and other physical parameters will also be prepared at 1:1,000,000 scale. Large scale hydrogeologic and geochemical maps, cross sections, and fence diagrams will be prepared as needed for detailed studies of problem areas.

Description of the Flow System

The areal distribution of heads in the aquifer and historical changes in water levels are reasonably well documented in most of the area. However, locally there may be considerable variation in vertical head distribution. The applicability of existing potentiometric maps to the regional analysis of the flow system will have to be carefully considered. In particular, it must be determined whether a reported head is a composite for the full section of aquifer or if a head is representative of only one water-bearing zone. Water level measurements are made once or twice each year and potentiometric maps are prepared as part of the ongoing programs in Florida and Georgia. Within major pumping centers such as Savannah, Ga., and the Tampa-St. Petersburg area, there is excellent well control to document changes in the potentiometric surfaces. For model calibration, existing head data (properly evaluated) should be adequate.

In the offshore extensions of the aquifer system, artesian heads and the position of the saltwater-freshwater interface are unknown. For modeling, knowledge of the position of the interface is highly desirable.

Knowledge of inflow-outflow rates for the limestone system is spotty. Pumpage, except for agriculture, is reasonably well known, especially in Florida. An extensive water-use inventory has been started recently by the U.S. Geological Survey and this should provide more accurate withdrawal rates, particularly for irrigation.

Total runoff is well known; however, the ground-water component (base flow) has not been determined in most areas. Present knowledge of the natural outflow from the limestone aquifer system may be summarized as follows:

1. Spring discharge is known; much discharge data exist.

2. Ground-water evapotranspiration is unknown but it may possibly be determined from streamflow records by analytical methods.

3. The ground-water component of streamflow (base flow) is not generally known and will have to be estimated using hydrograph separation techniques.

4. Ground-water discharge to the sea is unknown.

Recharge rates are largely rough estimates. It would be highly desirable for calibrated digital models to be able to duplicate inflow-outflow rates in addition to potentiometric surface configuration. However, much more accurate data on outflow rates will be required before modeling is possible.

The nature of some regional controls on the flow system are not understood and will be investigated during the course of the study. For example, there is a band of closely spaced contours on the potentiometric surface of the aquifer in southeast Georgia (variously known as the Gulf Trough or Suwannee Strait and shown as a low transmissivity zone on figure 4). This feature, which is associated with low yielding wells and poor quality water may be due to faulting or facies change. The feature may be a major barrier to the regional flow of ground water and its nature will be investigated during the study.

Exploratory Drilling and Aquifer Tests

The need for exploratory drilling and aquifer tests cannot be stated definitely until compilation of hydrogeologic data is reasonably complete and modeling has been initiated. However, data deficiencies are known to exist in coastal South Carolina, parts of Georgia inland from the coast, northwest Florida, much of south Florida except for the Miami-Palm Beach area and the entire offshore area. The seriousness of these data gaps should be evident following trial model runs.

Priorities for exploratory drilling and for aquifer tests will be given to these items:

1. Obtaining transmissivity and leakance values from aquifer tests in areas where difficulties in calibrating models are being experienced.

2. Obtaining subsurface geologic information in the aquifer boundary areas of Georgia and South Carolina.

3. Obtaining stratigraphic, artesian head, and salinity data in the offshore extensions of the limestone aquifer. A proposed shallow drilling program on the Continental Shelf (by the Conservation Division, U.S. Geological Survey) may begin during the study and provide some of this data.

Regional Simulation

A regional "coarse mesh" digital model of the limestone aquifer system will be designed early in the study. The purpose of this model will be:

1. To take an overall look at the important features of the flow system.

2. To assess the importance of hydrologic boundaries separating the six subproject model areas.

3. To investigate very large stresses located near subproject boundaries and whose effects may extend beyond the boundaries.

A computerized data file will be created for storage of all hydrologic data required for the development of the regional model. Because of the very large area to be modeled (about 82,000 square miles), computer storage limitations and cost considerations will probably rule out a true three-dimensional model which considers storage changes in both aquifers and confining beds. Alternatively the system may be treated as: (1) a one-layer problem on a large scale utilizing a moderately coarse mesh two-dimensional (2-D) model, or (2) a multilayer aquifer system utilizing a very coarse mesh three-dimensional (3-D) model which considers storage changes in the aquifers but not in confining beds. In many areas the limestone system consists of two or three well-defined permeable zones and the use of a 3-D model is indicated. However, 2-D models have been used successfully in part of the study area (see for example the 2-D model of the limestone system at Brunswick, Ga., which has three water-bearing zones — Krause and Counts, 1975).

One of the keys to simulating the limestone system will be handling the problem of (localized) vertical flow between two or three important water-bearing zones within the system. Modeling will have to consider vertical shafts, solution enlargement along faults and joints, and breaching of confining beds by sinkholes. Considerable experimentation and program modification is expected before a usable regional model is developed.

Subproject Studies

To appraise the important water problems, the study has been broken down into six subprojects. The breakdown is based on similarity of problems and the location (assumed) of natural hydrologic boundaries. The six subproject areas and their characteristics are shown in figure 6. Subregional models will be designed for at least five of the areas. In area 6 (south Florida) where the aquifer contains saline water and is stressed very lightly at present (largely waste injection), the design of an areal model may be neither feasible nor very useful. In south Florida more detailed local models may be used to assess waste injection.

Coastal Georgia - South Carolina - Jacksonville, Florida Area

Saltwater contamination in coastal areas, declining water levels, and water-quality degradation locally, are the important problems in this area. In general, the limestone aquifer system is highly transmissive (20,000 to 200,000 ft^2/d) and contains two or three important water-bearing zones that are hydraulically connected in varying degrees.

At Savannah, the aquifer contains two major and three minor water-bearing zones with combined transmissivity ranging from 20,000 to 70,000 ft^2/d. Lateral intrusion of seawater and minor land subsidence have followed the development of a regional cone of depression. At Brunswick, the aquifer is more transmissive (about 200,000 ft^2/d) and although pumpage is similar to Savannah, water-level declines are considerably less. Saltwater contamination is occurring which has been attributed to upward movement of saline (connate?) water through fractures. Detailed hydrologic analyses have been made in the Savannah and Brunswick areas involving digital modeling. Although these models are two-dimensional (aquifer considered as one water-bearing zone), the models have successfully duplicated past water-level declines. Future modeling efforts in these localities should be directed towards modeling moving saltwater-freshwater interfaces.

At Jacksonville, the aquifer includes several water-bearing zones with an aggregate transmissivity of 20,000 to 200,000 ft^2/d. The decline of artesian head is relatively small despite current pumpage of 200 Mgal/d (head decline since 1960 is 20 feet). However, localized increases in chloride content of the freshwater, thought to be due to upward movement of saline water, is a recent problem. A three-dimensional model of the limestone system has been designed and is currently being calibrated. A research project to determine regional rates of ground-water movement (utilizing carbon-14 dating) is in progress.

At Beaufort, S.C., saltwater encroachment is occurring which may be caused by both lateral movement and upconing.

Explanation for Figure 6

Characteristics of the subproject area

Area 1 (Coastal Georgia and South Carolina - Jacksonville, Florida area):

1. Declining water levels and saltwater intrusion along the Georgia coast
2. Pollution problems in sinkhole areas
3. Limestone aquifer has low to very high transmissivity

Area 2 (Southwest Georgia - Tallahassee, Florida area)

and

Area 3 (Florida Panhandle - Southwest Alabama area):

1. Much untapped ground water
2. Increased irrigation in Georgia and to a lesser extent in Florida
3. Limestone aquifer has low transmissivity locally
4. Minor saltwater intrusion problems

Area 4 (East-Central Florida area):

1. Shortage of freshwater locally
2. Local saltwater intrusion
3. Drainage wells into aquifer

Area 5 (West-Central Florida area):

1. Increased pumpage for industrial development, municipal supplies, and irrigation
2. Declining water levels and saltwater intrusion locally
3. Deep well injection of treated sewage
4. Shortage of freshwater locally

Area 6 (South Florida area):

1. Aquifer contains saline water
2. Deep well injection of sewage and industrial wastes
3. Brackish water and desalting plants
4. Energy potential from cold and hot water zones

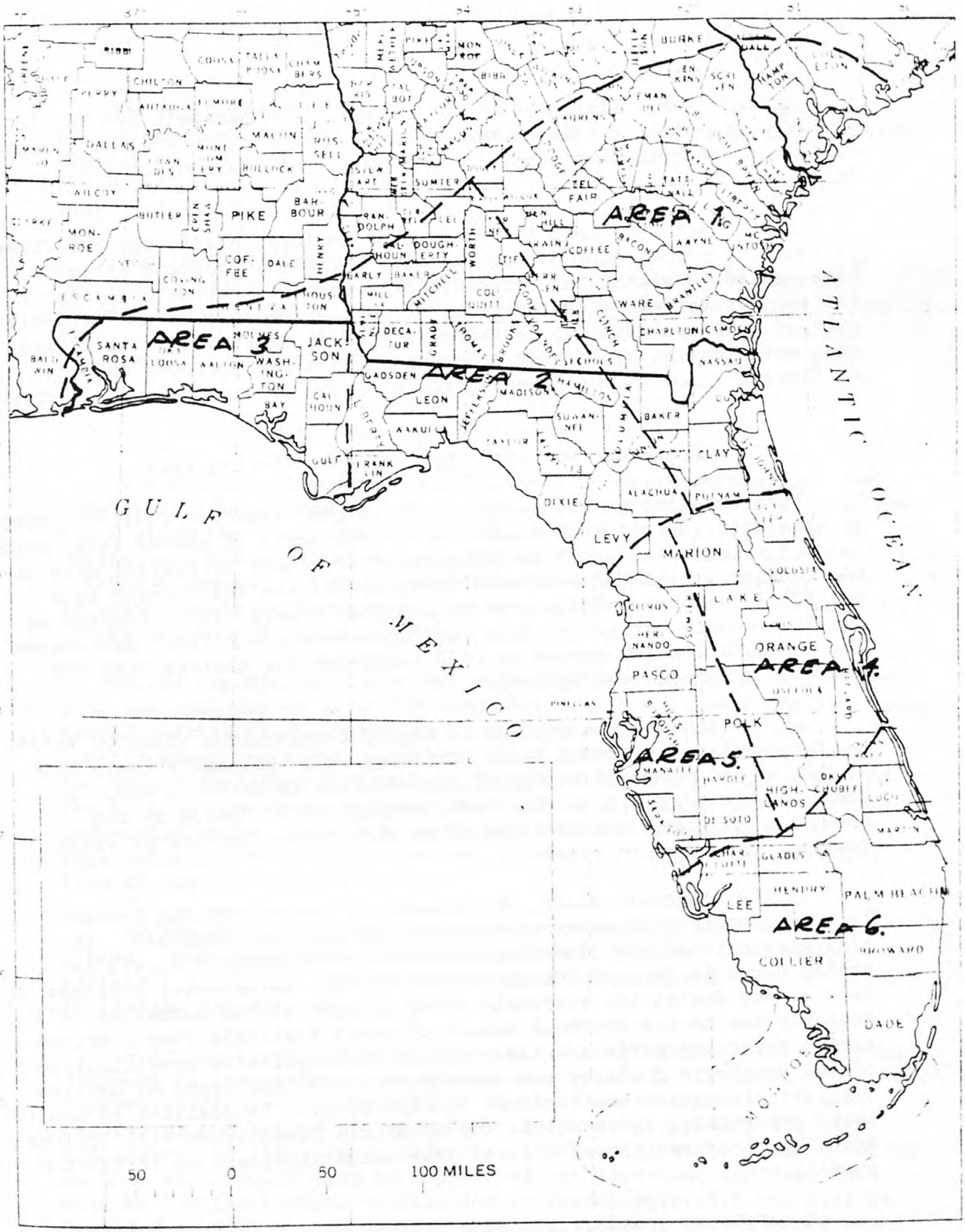

Figure 6. Subproject areas and their characteristics.

Inland from coastal Georgia and Florida, withdrawals are smaller; problems are quality related rather than due to water-level declines. Pollution problems in sinkhole areas and high sulfate water occur locally.

A high priority need is for data on geology, heads, and chlorides in the offshore segment of the aquifer. Previous modeling attempts have relied completely on estimated data and an inferred position of the saltwater-freshwater interface offshore. Because of the very high cost of offshore drilling, the acquisition of these data will depend upon coordination with other programs such as the proposed shallow drilling program by the Conservation Division of the Geological Survey.

Southwest Georgia - Tallahassee, Florida Area

Much untapped ground water occurs in the limestone aquifer system in this area. At present significant withdrawals of ground water occur in only three areas: (1) an intensive five-county irrigation area in the Dougherty Plain of southwest Georgia, (2) the Tallahassee area, and (3) a phosphate mining area in Hamilton County, Fla. Pumpage in the five-county irrigation area was reportedly 1.4 billion gallons per day during a 2-month period in 1977 (although the average rate for the year was about 130 Mgal/d).

At Tallahassee the aquifer is highly transmissive (150,000 ft^2/d) and is overlain by a very leaky confining bed. Present pumpage of 55 Mgal/d has produced no significant decline in water levels. In Hamilton County, Fla., to the east, pumpage of 30 Mgal/d by the phosphate industry has also caused no significant decline of water levels.

In the Dougherty Plain, the aquifer is unconfined and hydraulically connected to several major streams and Lake Seminole. The transmissivity of the limestone aquifer is not known in detail but probably ranges from 10,000 to 150,000 ft^2/d. Water-level declines were modest during the extremely heavy pumping in the summer of 1977; probably due to the enormous amount of water available from combined ground-water and surface-water storage. A cooperative investigation of the Dougherty Plain by the Geological Survey and State of Georgia will greatly assist the regional aquifer study. In addition to aquifer tests and pumpage inventories, the Dougherty Plain study will include modeling to assess the effects of very large increases of irrigation pumpage.

A northwest-trending geologic feature (the so-called Gulf Trough or Suwannee Strait) crosses the area just south of the Dougherty Plain. This structural feature may be a trough or graben and is associated with abrupt changes in transmissivity (30,000 ft^2/d to the north and

150,000 ft^2/d to the south) and poor quality water. The feature itself has low transmissivity as indicated by low-yielding wells and closely spaced contours on the potentiometric surface map. The hydrologic nature of this structural feature is unknown and exploratory drilling and aquifer tests will be needed to evaluate it.

The lack of pressing water problems in northwest Florida plus the desirability of awaiting results of the Dougherty Plain study suggest a delay in the start of the regional limestone study in the area. Accordingly, work done in fiscal year 1979 will be limited to assembly and compilation of existing data in northwest Florida.

Florida Panhandle - Southwest Alabama Area

The Florida panhandle - Alabama area is characterized by comparatively low pumpage and local minor water problems. Most problems occur along the coast where adequate well yields are difficult to obtain in low transmissivity tracts and where localized saltwater intrusion occurs. Inland, difficulty has been experienced in constructing wells in karst areas; poor quality water being a common occurrence in old sinkhole areas.

Along the Florida coast the carbonate section thickens to the east and includes an upper (freshwater) zone and a lower (saline) zone. Transmissivity of the upper zone ranges from less than 1,000 ft^2/d locally along the coast to 15,000 ft^2/d inland. Major stresses on the system include withdrawal of 20 Mgal/d (from the upper zone) in the Fort Walton area and injection of about 4 Mgal/d of mostly acid industrial wastes (into the lower zone) in the Pensacola area. A regional pressure mound in the potentiometric surface has resulted from 15 years of waste injection.

In the Alabama segment, pumpage is relatively light and widespread. Localized cones of depression have resulted from pumpage for municipal supplies. However, substantial increases in pumpage for irrigation are expected.

Hydrologic and geologic data are probably adequate for modeling purposes in the western part of the area particularly along the coast. However, serious data voids exist in the eastern segment (Holmes, Washington, Jackson, Calhoun, and Gulf Counties in Florida). Some exploratory drilling and aquifer tests are a prerequisite to modeling in this area. Work done in support of the limestone aquifer study will be limited to data compilation in fiscal year 1979 but will be expanded to include exploratory drilling, aquifer testing, and modeling in the final 3 years.

East-Central Florida Area

Although the limestone system contains abundant freshwater in this area, saline water occurs locally both inland and along the coast. Most of the salty water is considered to be unflushed seawater. However, along the coast saltwater intrusion caused by pumping is occurring at Daytona Beach and nearby beach resorts. The crux of the modeling study in this area is to determine how much freshwater is available from the system and where it can be best developed.

Previous studies indicate pumpage is a substantial percentage of present-day recharge in some areas. Thus methods of preserving natural recharge or the use of artificial recharge methods need to be investigated.

At Orlando, pumpage of about 50 Mgal/d appears to be balanced by a similar rate of injection into the aquifer through drainage wells. As a result, water-level declines in the aquifer are negligible. However, the drainage wells bring untreated surface runoff into the limestone system and the resulting water quality changes, if any, are unknown. The injection zone is separated from the water-bearing zone used for public water supply by a semiconfining bed which may be an effective barrier to the movement of poor quality water. The drainage well problem has not been investigated thoroughly and more data will probably have to be obtained to effectively model the aquifer's response to injection.

In Volusia County, large increases in ground-water withdrawals are anticipated for public supply in the fast growing coastal area and for irrigation. In a recently completed investigation, digital model studies showed that additional large supplies could be obtained from well fields inland from the coast. In the northwest part of Volusia County, 200 to 300 wells are pumped for short periods to provide frost protection for ferns; peak withdrawal rate is about 450 Mgal/d. A year-long aquifer test involving nine observation wells is currently in progress in Volusia County that should provide much useful data on aquifer coefficients.

In this subproject area, modeling ideally will evaluate: (1) the movement of unflushed seawater in response to increased pumping; (2) the effects on lake levels of increased pumpage; and (3) the effects of various types of land use on recharge rates and ultimately on the availability of fresh ground water.

West-Central Florida Area

The west-central Florida segment is roughly equivalent to the jurisdictional area of the Southwest Florida Water Management District (SWFWMD). This area probably has more potential problems, more available hydrologic data, and more on-going hydrologic studies than any of the other subproject areas. Competition for ground-water supplies between industry, agriculture, and municipalities is the most important water problem in the area. This competition is expected to occur in Manatee, Sarasota, Hardee, and DeSoto Counties in the next decade. Declining water levels, saltwater intrusion along the coast, and local water-quality degradation have resulted from increased pumping.

Highly useful to modeling efforts will be the semiannual potentiometric surface maps of the limestone aquifer and a recent compilation of aquifer test analyses that includes many transmissivity and leakance values. Much new hydrologic data are being collected during the construction of a regional observation well network by SWFWMD. The network will consist of 122 sites with most having both a shallow and deep well. During 1978, construction of 38 observation wells is scheduled. Hydrologic data are being compiled by the Geological Survey and geologic studies are being made by the University of Florida.

Digital modeling of the limestone aquifer system has been done in more than one-half of the west-central Florida area. A regional 2-D model has been used to predict water-level declines resulting from increased ground-water withdrawals by phosphate mining operations (Wilson, 1977). The model was used to evaluate the effects of two alternative plans for phosphate development. Localized models have been designed and calibrated to assess the effects of proposed municipal well fields.

The disposal of treated sewage into saline parts of the aquifer system through injection wells is expected to increase to more than 50 Mgal/d during the next 20 years. A current Geological Survey investigation involves hydraulic testing at injection well sites with arrays of observation wells. The study will utilize the 3-D subsurface waste disposal model recently developed by Intercomp, Inc., for the Geological Survey.

The major activity of the aquifer study in west-central Florida will be a redesign and enlargement of the phosphate mining areal model into a multilayered regional model that will consider increased municipal and agricultural pumpage, waste-water injection, and a moving saltwater-freshwater interface in the coastal area.

South Florida Area

In south Florida the top of the limestone aquifer system is several hundred feet below land surface and the aquifer contains saline water. Water supplies for the populous coastal cities are obtained from shallower aquifers. However, the limestone system is used for other purposes, particularly for disposal of treated sewage through injection wells and to supply slightly saline water for low-cost desalting plants. Other uses under consideration include temporary storage of surplus freshwater in the aquifer and the use of cold saline water from deep parts of the aquifer near the Florida Straits for cooling purposes.

The major stress on the system in south Florida will be the planned injection of more than 100 Mgal/d of treated sewage into the aquifer. Waste is injected into wells tapping a highly permeable cavernous limestone unit at the base of the system (locally termed "boulder zone") which contains water chemically similar to seawater. Environmental requirements for disposal of treated sewage make deep-well disposal more attractive than the use of ocean outfalls. However, the effect of these disposal wells, and increasing rates of sewage injection in the future are uncertain.

The limestone aquifer system is not well understood because of a scarcity of hydrologic data. Little is known of the hydraulic characteristics of the limestone aquifer and related confining beds. However, differences of static head, temperature, and salinity, suggest a layered system. The "boulder zone" is considered to be extremely permeable; however, only one transmissivity value has been determined to date -- $3x10^6$ ft^2/d.

The reasons for the shortage of data have been summarized by F. W. Meyer (written commun., September 1978) as follows:

1. Adequate supplies of freshwater are generally obtained from shallow, unconfined aquifers; therefore, exploration for deep artesian water has been unfeasible.

2. Artesian water in southern Florida is generally too saline for most purposes, especially for potable supplies.

3. There has been relatively no impetus in the past to conduct investigations specifically designed to yield a regional appraisal of the artesian system.

The initial phase of the south Florida portion of the aquifer study will be to describe the limestone system using data from existing artesian wells, oil tests, and waste-injection wells plus evaluation of data from new injection wells as available. Exploratory drilling, geophysical logging, and aquifer tests are highly desirable in the areas where no subsurface data exists. An attempt will be made to design and calibrate a regional model which can be interfaced with models of the freshwater system to the north. However, this may not be possible and perhaps only localized models of specific sites are feasible.

Reports

The findings of the study will be presented in a professional paper prepared at the conclusion of the study. However, throughout the study, preliminary hydrogeologic and geochemical maps and preliminary model analyses will be presented in open-file reports. Journal articles will be used to describe interesting facets of the study.

The professional paper will consist of eight chapters with the following tentative titles:

A. Summary Discussion of the Southeastern Limestone Aquifer System and Water Management Alternatives

B. Hydrogeologic Framework of the Southeastern Limestone Aquifer System

C. Hydrogeology and Digital Model Analysis of the Southeastern Limestone Aquifer System in Coastal Georgia and South Carolina and Northeast Florida

D. ...in Northwestern Florida, Southwestern Georgia, and Adjoining Alabama

E. ...in East Central Florida

F. ...in West Central Florida

G. ...in South Florida

H. Geochemistry of the Southeastern Limestone Aquifer System

Chapter A will be prepared as a summary report with a discussion of the principal features of the flow system. It will present results of the regional simulation ("coarse mesh" model) and will describe predicted effects of various water-management alternatives. Important regional problems will be highlighted.

Chapter B will provide a complete description of the geologic framework and hydraulic characteristics of the aquifer system. Regional maps showing lithofacies, structure contour, isopachs, transmissivity, leakance, potentiometric surfaces, and so forth will be presented. Extensive use of cross sections and fence diagrams will be used to describe the subsurface framework.

Chapters C through G will present hydrogeologic system descriptions and hydrologic analyses of the six subareas with emphasis on computer simulation of local problems. Format for these chapters will vary from area to area.

Chapter H will describe the natural geochemical system, and as with B will present regional maps. The relationship between natural changes in water chemistry and the flow system will be discussed. Geochemical changes brought about by pumping (such as saltwater intrusion) and by waste disposal will be discussed extensively.

It is intended to prepare a nontechnical report for planners, economists, politicians, and so forth. This report will discuss simulation results with a minimum of hydrologic and geologic jargon. If possible, the relation of economic factors to ground-water management will be given in this report.

ORGANIZATION AND STAFFING

The project organization will consist of a core staff of four hydrologists at the Southeastern Regional Headquarters in Atlanta plus four hydrologists at field offices in Florida and Georgia. Additional hydrologists will be added full or part time as the work load varies throughout the 4-year life of the project.

Figure 5 shows the relation of staffing needs to project activities. During the first year when activity will be mostly interpretation of existing data and during the final year when report writing will be the major activity, the staff will consist of the eight full-time hydrologists with minimal part-time hydrologist assistance. During the middle 2 years when new data acquisition will be underway, hydrologist support from the Alabama, Florida, Georgia, and South Carolina districts will increase.

In addition to a project chief, the regional staff will include a hydrogeologist, a modeling specialist, and a geochemist. Four full-time hydrologist-modelers will be assigned to field offices in Doraville, Ga., and Orlando, Tampa, and Miami, Fla., to act as subproject chiefs. They will be responsible for completing investigations in subproject areas 1, 4, 5, and 6 respectively (see fig. 6). The work activity will be less in areas 2 and 3 because of ongoing studies and because water problems are less pressing. Central project staff with part-time help from field offices will be responsible for project work in areas 2 and 3.

The eight hydrologists assigned for the duration of the study are expected to begin full-time project work between October 1 and December 31, 1978. Administrative supervision of subproject chiefs will come from district or subdistrict chiefs.

Technical coordination of all subproject activities will be from the project chief of the limestone study and frequent communications between central project staff and subproject chiefs and also between adjoining subproject staffs is anticipated. In particular the modeling specialist and geochemist at Atlanta will be advising subproject chiefs on a regular basis.

A technical advisory committee will be formed and will meet with project staff probably every 6 months. The committee will provide an overview of the project and will be composed of Geological Survey specialists in ground-water hydraulics, digital modeling, hydrogeology, and geochemistry.

A liason committee of State, Federal, and local agencies concerned with ground water will be set up and include the principal cooperative agencies in Florida, Georgia, Alabama, and South Carolina. This committee will provide a forum to advise interested people on the progress of the limestone study and also to coordinate project activities with ongoing cooperative studies.

SELECTED REFERENCES

Callahan, J. T., 1964, The yield of sedimentary aquifers of the Coastal Plain, Southeast River Basins: U.S. Geological Survey Water-Supply Paper 1669-W.

Cederstrom, D. J., Boswell, E. H., and Tarver, G. R., 1979, Summary appraisals of the Nation's ground-water resources -- South Atlantic-Gulf Region: U.S. Geological Survey Professional Paper 813-O, (in press).

Counts, H. B. and Krause, R. E., 1976, Digital model analysis of the principal artesian aquifer, Savannah, Georgia area: U.S. Geological Survey Water-Resources Investigations 76-133.

Healy, H. G., 1974, Potentiometric surface and areas of artesian flow of the Floridan aquifer in Florida, May 1974: Florida Department of Natural Resources, Bureau Geology Map Series 73.

Krause, R. E. and Counts, H. B., 1975, Digital model analysis of the principal artesian aquifer, Glynn County, Georgia: U.S. Geological Survey Water-Resources Investigations 1-75.

Lichtler, W. F., 1972, Appraisal of water resources in the east-central Florida region: Florida Department of Natural Resources, Bureau Geology Report Investigations 61.

Miller, J. A., and others, 1978, Impact of potential phosphate mining on the hydrology of Osceola National Forest, Florida: U.S. Geological Survey Water-Resources Investigations 78-6.

Parker, G. G., Ferguson, G. E., and Love, S. K., and others, 1955, Water resources of southeastern Florida, with special reference to the geology and ground water of the Miami area: U.S. Geological Survey Water-Supply Paper 1255.

Stringfield, V. T., 1966, Artesian water in Tertiary Limestone in the Southeastern States: U.S. Geological Survey Professional Paper 517.

Wilson, W. E., 1977, Simulated changes in ground-water levels resulting from proposed phosphate mining, West-Central Florida -- Preliminary results: Tallahassee, Florida U.S. Geological Survey Open-File Report 77-882.