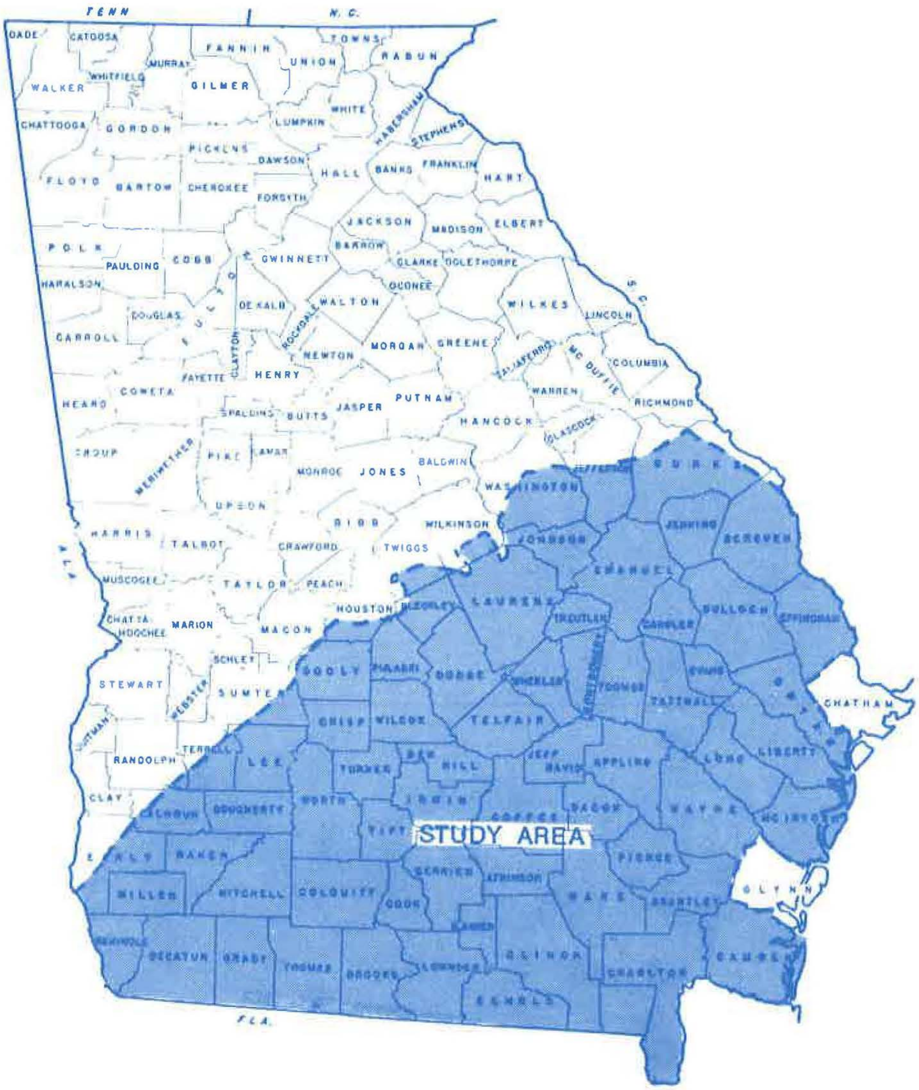
AMBIENT GROUND-WATER CHEMISTRY AND QUALITY IN THE FLORIDAN AQUIFER SYSTEM IN GEORGIA

William M. Steele



The preparation of this report was financed in part through a grant from the U.S. Environmental Protection Agency under the provisions of Section 106 of the Federal Water Pollution Control Act of 1972, as amended.

Department of Natural Resources
J. Leonard Ledbetter, Commissioner

Environmental Protection Division
Harold F. Reheis, Assistant Director

Georgia Geologic Survey
William H. McLemore, State Geologist

Atlanta
1989

HYDROLOGIC ATLAS 17

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ATLANTA
1989

HYDROLOGIC ATLAS 17

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ABSTRACT

The goal of this atlas is to define the ambient water chemistry and quality of the Floridan aquifer system in the Georgia Coastal Plain. Ground-water quality of the Floridan was defined and characterized with 233 analyses obtained from a published data report. This atlas presents the results of a regional investigation and, therefore, does not identify localized areas of anomalous water chemistry.

The Floridan is the most heavily used aquifer system in Georgia. In 1985, approximately 755 million gallons of water per day (mgd) were withdrawn for industrial, agricultural, public supply, domestic and thermoelectric purposes. The Floridan aquifer system consists of predominantly carbonate rocks of Eocene to Miocene age.

Ambient ground-water chemistry and quality of the Floridan aquifer system is generally good. Ground water in the Floridan outcrop/recharge areas is relatively low in dissolved constituents. Downgradient, particularly in southeast Georgia, the concentration of dissolved constituents increases as a result of the longer residence time of ground water. Water from near-recharge areas is probably from the "uppermost zone" and water from southeast Georgia is most likely from the "intermediate zone." "Uppermost" and "intermediate" zone designations refer to ground-water circulation and do not necessarily refer to a particular portion of the aquifer system. In the Colquitt County area, the concentration of dissolved constituents in ground water is anomalously high. Here, the flow-restricting influence of the Gulf Trough probably increases the residence time of ground water and results in increased mineralization.

INTRODUCTION

The purpose of this atlas is to define and illustrate the ambient ground-water chemistry and quality of the Floridan aquifer system in the Coastal Plain of Georgia. Concise information on ambient water chemistry and quality is beneficial because the Floridan aquifer system (formerly known as the principal artesian aquifer system) is the most heavily used aquifer system in Georgia (U.S. Geological Survey, 1985). This investigation assessed the regional ambient water chemistry of the Floridan aquifer system, focusing on the major ionic species. Variations in water chemistry caused by landfill leachate, agricultural chemicals, leaking storage tanks, animal wastes, drainage fields, etc. cannot be identified from the data base.

The study area encompasses a large part of the Coastal Plain Physiographic Province of Georgia. The northwestern boundary, as shown in Figure 1, is the approximate updip limit of the Floridan aquifer system. The southeastern boundary is the Atlantic Ocean and the southern boundary is the Georgia-Florida border. The Georgia-South Carolina border represents the northeastern limit of the study area, while the southwestern boundary is the Georgia-Alabama and Georgia-Florida border. Chatham and Glynn Counties were not included in the study. The chemistry of ground water in these areas varies greatly; therefore, existing, detailed studies of these counties provide more useful information. Information on the water quality of Chatham County is included in publications by: Counts and Donsky (1963), McCollum and Counts (1964) and Clarke and others (1985). Information on the quality of water in Glynn County can be obtained from publications by: Stewart

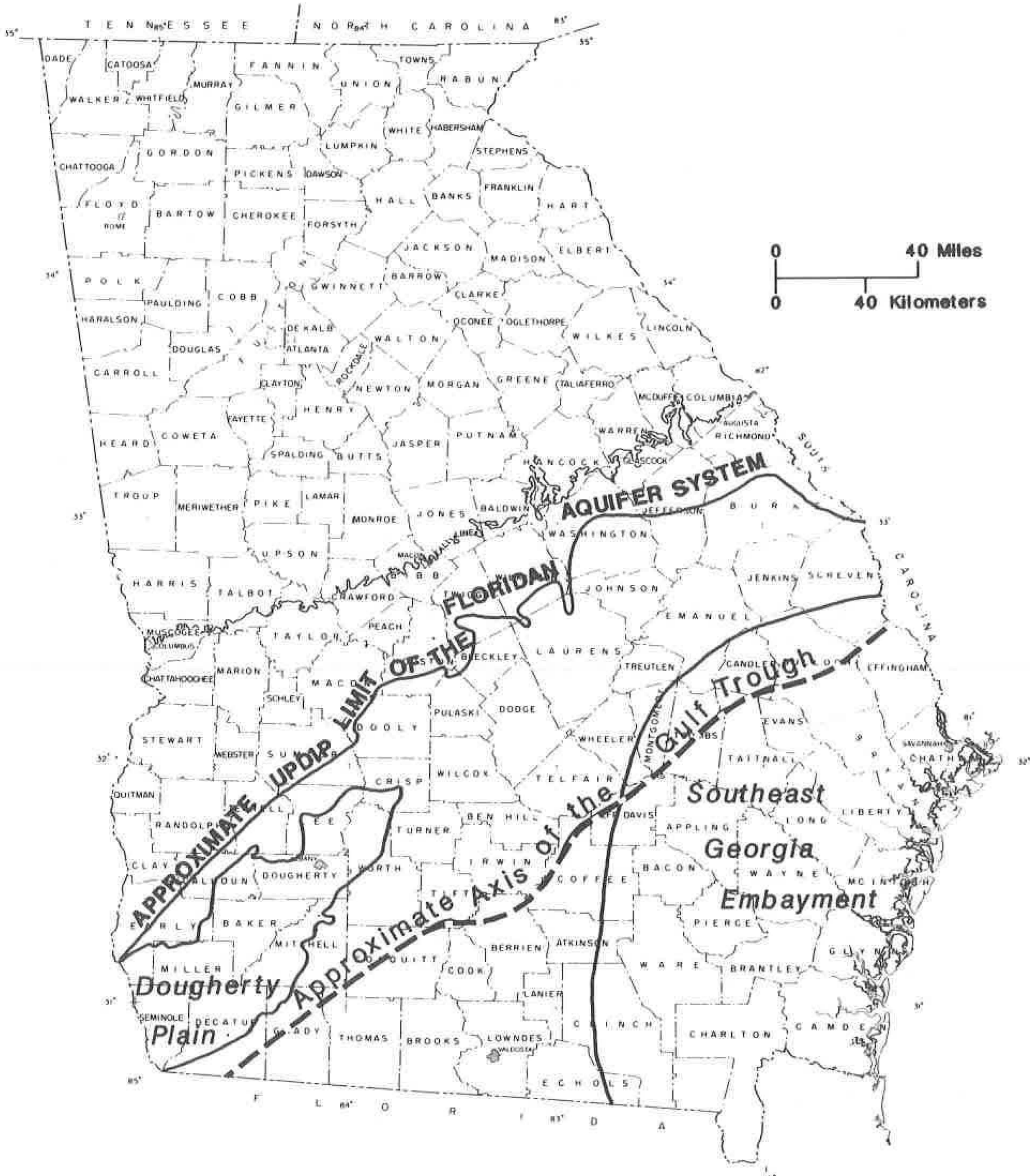


Figure 1. Location of Study Area, Major Structural Features and the Dougherty Plain Physiographic District in the Coastal Plain of Georgia.

(1960), Krause and Gregg (1972), Wait and Gregg (1973) Gregg and Zimmerman (1974) and Clarke and others (1985).

Analytical results from 233 water samples collected from the Floridan aquifer system were used to compile this publication. These data, published by Grantham and Stokes (1976), were used to evaluate the regional ambient water chemistry in the Floridan aquifer system. Analyses of water from multi-aquifer wells were not used because these analyses represent composite samples and do not accurately reflect the true chemical composition of water from the Floridan aquifer system.

Major dissolved constituents (calcium, magnesium, sodium, potassium, bicarbonate, sulfate and chloride) were reported in milligrams per liter (mg/l). Constituent values of each analysis were converted from mg/l to milliequivalents per liter (meq/l) to construct Stiff diagrams (Plate 1) and to meq/l percentages to construct trilinear diagrams (Plate 2). An analysis reported in meq/l has unit concentrations of all ions that are chemically equivalent (Hem, 1985).

GENERAL GEOLOGY - AQUIFER FRAMEWORK

The study area is located in the Coastal Plain Physiographic Province. A series of Cretaceous to Quaternary age sediments outcrop in the Coastal Plain. In general, older sedimentary units crop out in the northern portion of the Coastal Plain and younger units to the south-southeast.

The Floridan aquifer system consists of a sequence of predominantly carbonate rocks of Eocene to Miocene age. Major water-bearing units are the Ocala Group and the Suwannee Limestone. Major depositional and structural features of the Floridan aquifer system include the regional, gentle south to southeast dip, the Gulf Trough and the southeast Georgia embayment. The Floridan aquifer system generally is thinnest in outcrop areas and thickens to the southeast, roughly in the direction of dip. The Gulf Trough is a buried, trough-shaped, depositional feature characterized by the thickness anomalies and facies changes in the middle and upper Eocene, Oligocene and lower Miocene rocks (Kellam, M.F., written communication, 1987). The approximate axis of the Gulf Trough, in Georgia, extends from southeastern Decatur County in a northeasterly direction to just south of the Screven-Effingham County line, as shown on Figure 1. The southeast Georgia embayment is described by Miller (1986) as a "...shallow east- to north-east plunging syncline..." The axis of the embayment is located in the Glynn-Camden County area.

The late Eocene age Ocala Group generally consists of granular to bioclastic, variably macrofossiliferrous limestone and dolostone (Huddlestun and others, 1987) throughout most of the study area. However, in the northern part of the study area (in general, southern Washington, Jefferson, Burke, Bleckley, Laurens, Johnson, Treutlen, Emanuel, Jenkins and Screven Counties) sand and clay of the Barnwell Group is the Ocala Group equivalent. The Clinchfield and Dry Branch Formations along with the Tobacco Road Sand make up the Barnwell Group (Huddlestun and Hetrick, 1985). The Barnwell is the updip, clastic facies of the carbonate Ocala Group. The Ocala Group outcrops throughout most of the Dougherty Plain Physiographic District, in southwestern Georgia. The Barnwell Group outcrops in the northeastern portion of the study area, just south of the Fall Line (Figure 2).

The Oligocene age Suwannee Limestone overlies the Ocala Group throughout most of the study area. The Suwannee is a pale orange,

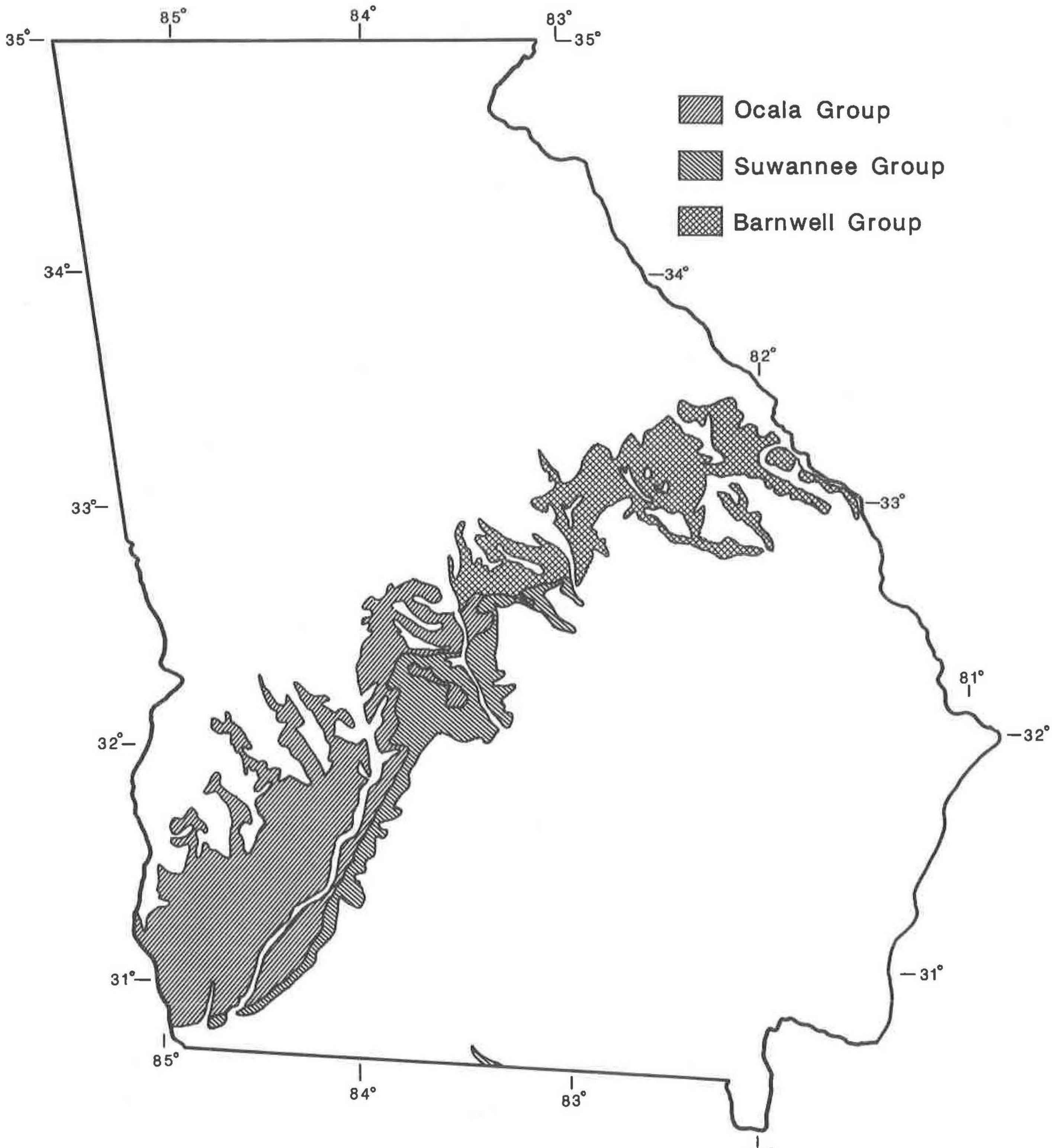
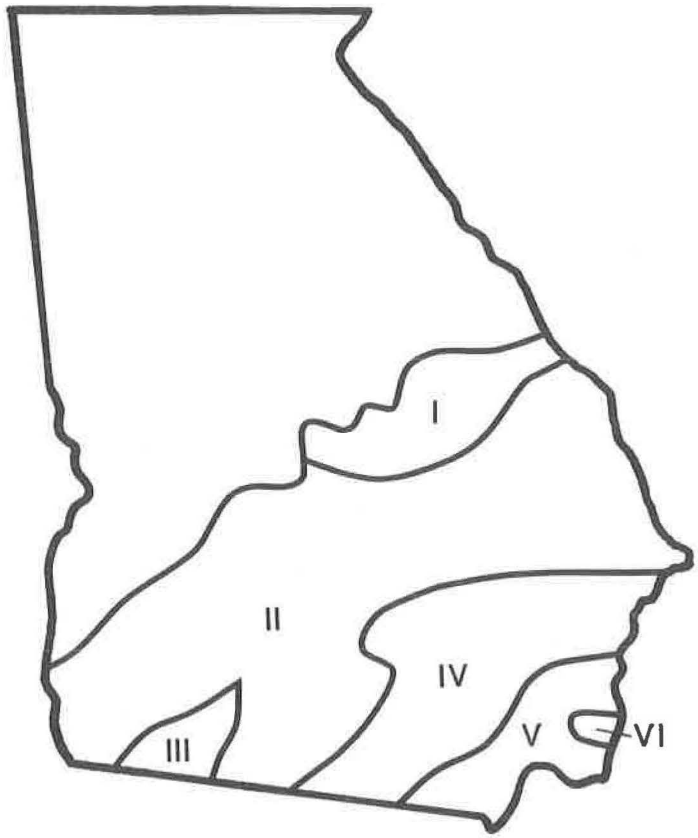


Figure 2. General Outcrop Area Map of Upper Eocene and Oligocene Age Deposits in Georgia (Modified from Lawton, 1977).

massive, structureless to thickly bedded, finely to coarsely granular limestone (Huddlestun and others, 1987). The Suwannee Limestone intermittently outcrops from the eastern Dougherty Plain area north to an area in the Dooly, Pulaski, Bleckley, Wilcox County region (Figure 2). Less extensive outcrops occur in the southern Twiggs, Wilkinson and northern Laurens County area.

The Floridan aquifer system is overlain by the Miocene age Hawthorne Group which is the upper confining unit throughout most of the study area. Where the Floridan aquifer system is at or near land surface; in the Valdosta area; and along the Flint and Chattahoochee Rivers, where the Hawthorne has been eroded away, the aquifer system is not confined (Krause and Hayes, 1981). Lithologically, the Hawthorne Group is dominated by argillaceous, fine-grained, well-sorted sand and fine sandy clay (Huddlestun and others, 1987).

Basal confinement of the Floridan aquifer system varies areally, as shown on Figure 3. The Floridan is confined below by upper Eocene calcareous clay in the northeastern portion of the study area (Area I). In Area II, sand and clay of the middle Eocene Claiborne Group underlies the aquifer system. In the southwestern portion of the study area (Area III), pore spaces in the lower part of the Ocala Group are filled with secondary gypsum (Miller, 1982; modified by Curtin, 1984). Here, the Ocala Group acts as a confining unit and is not a productive part of the aquifer. In Area IV the Floridan is confined below by fine-grained sand and lignitic clay of the Wilcox Group and equivalent fine-grained limestone. Paleocene fine-grained limestone and gypsiferous dolostone underlie the Floridan aquifer system in Area V. In extreme southeastern Georgia (Area VI), upper Cretaceous chalk underlies the Floridan aquifer system.



I Upper Eocene Clay

II Middle Eocene Claiborne Group and Equivalents

III Upper Eocene Ocala Limestone

IV Lower Eocene and Upper Paleocene Wilcox Group and Equivalent Limestone

V Paleocene Cedar Keys Formation

VI Upper Cretaceous Chalk

(after Miller, 1982)

Figure 3. Lower Confining Units of the Floridan Aquifer System (Miller, 1982; modified by Curtin, 1984).

HYDROLOGY

The Ocala Group is the most productive portion of the Floridan aquifer system. With the exception of those localities that are in and near outcrop areas, the Floridan is under confined conditions. Hydraulic properties vary because of the aquifer systems differing geologic characteristics.

The Floridan aquifer system is recharged primarily from direct infiltration of precipitation occurring in the outcrop areas. Additional recharge is contributed by the Withlacoochee River in the Lowndes-Brooks County area (Figure 2) where material overlying the aquifer is thin or absent (Krause, 1979). Leakage through overlying units may also recharge the aquifer system.

Natural discharge is to streams that are hydraulically interconnected to the aquifer and have flow stages lower than the potentiometric surface of the aquifer system (Krause and Hayes, 1981). Natural discharge also occurs offshore where submarine outcrops of the aquifer system exist. Man-induced discharge is by pumping. Major centers of pumping include the Savannah, Brunswick, Doctortown and St. Marys areas. Significant declines in hydraulic head have occurred in the Savannah and Brunswick areas.

Hydraulic properties such as yield, specific capacity and transmissivity vary due to the aquifer system's differing geologic characteristics. The water-bearing potential of the Floridan aquifer system is largely increased by solutioning of carbonate rocks by circulating ground water (Krause and Hayes, 1981). Solutioning along fractures increase the secondary permeability of the aquifer. High-yielding wells generally occur in areas where secondary permeability has been developed in the limestone. The yield of wells tapping the Floridan range from 500 to 10,000 gpm (Krause and Hayes, 1981). Specific capacity is an expression of well and aquifer productivity. The specific capacity of Floridan wells ranges from 1 gallon/minute/foot (gal/min/ft) drawdown in Burke County, to 1,250 gal/min/ft drawdown in Grady County (Tuohy and Kellam, 1984). Transmissivity values also vary widely over the study area and have been reported to be as high as 1.3 million square feet per day (ft^2/d) in the Dougherty Plain area of southwestern Georgia (Hayes and others, 1983).

Almost 755 million gallons per day (mgd) were withdrawn from the aquifer system in 1985, making the Floridan the most highly used ground-water supply in Georgia (Georgia Water Use Program, J.L. Fanning, oral communication, 1987). Water from the aquifer system is primarily used for industrial, agricultural and public supply purposes.

WATER CHEMISTRY AND QUALITY

The concentration and type of dissolved minerals in ground water is dependent on rock composition and solubility and on the length of time ground water has been in contact with the rock. As water flows through soil and rock media, minerals are dissolved at variable rates. In general, the longer ground water has been in contact with minerals, the greater the amount of dissolved solids. Ground-water residence time is comparatively short in and near recharge/outcrop areas and generally increases in the downgradient direction. Low transmissivity can affect water quality due to decreased flow rate and resulting increased residence time of water which can cause dissolved constituents to increase. Conversely, high transmissivity, particularly in aquifers where conduit flow occurs, can result in water with low dissolved constituents due to decreased residence time and the increased flow rate of the water.

Ambient ground-water chemistry and quality of the Floridan aquifer system, in Georgia, is generally good in terms of the concentration of major dissolved constituents [calcium, magnesium, sodium, potassium, bicarbonate, sulfate (250 mg/l drinking water maximum), chloride (250 mg/l drinking water maximum) and total dissolved solids (500 mg/l drinking water maximum]. One exception to this is water from one well located in Moultrie (Colquitt County) that has sulfate (SO_4) and total dissolved solids (TDS) concentrations of 405 mg/l and 704 mg/l, respectively, (Plates 7 and 9) which is in excess of State drinking water standards (250 mg/l and 500 mg/l, respectively). These high concentrations are probably the result of low transmissivity and corresponding restricted flow in the Gulf Trough. Another exception is a well in Charlton County with water that has TDS concentrations of 508 mg/l (Plate 9) which also exceeds drinking water maximums (500 mg/l). This high concentration is probably the result of comparatively long residence time of ground water in the southeastern Georgia area. Chloride concentrations range from 0 to 52 mg/l (Plate 6), which are well below the drinking water maximum. Calcium levels vary from 0.4 to 102 mg/l, as shown on Plate 3. Magnesium ranges in concentrations from 0.1 to 47 mg/l; and levels, generally, increase from near outcrop/recharge areas to the southeast (Plate 4). Sodium levels vary from 0.8 to 40 mg/l; with concentrations, generally, increasing to the southeast (Plate 5). Bicarbonate concentrations range from 6 to 220 mg.1, as shown on Plate 8.

Water from areas near outcrop/recharge areas in the Floridan aquifer system is generally low in dissolved constituents primarily because of the relatively short residence time of water. Ground water from these areas is probably from the "uppermost zone" described in Domenico (1972). The "uppermost zone" is characterized by high circulation through well-leached rocks. Water from this zone is bicarbonate in type and relatively low in dissolved constituents.

Ground water from the Floridan aquifer system in southeastern Georgia is consistently higher in dissolved constituents than in near-recharge areas. These higher values are a result of the longer residence time of ground water in the southeastern Georgia area. The concentration of dissolved constituents in ground water indicate that the flow system of the Floridan in this part of the State may be classified as an "intermediate zone," as described by Domenico (1972). The "intermediate zone" generally contains ground water of the sulfate type and has a higher concentration of dissolved constituents than ground water in the "uppermost zone." Zone designations (i.e., "uppermost zone," "intermediate zone") described in this report are generic terms that refer to ground water circulation and water quality. These terms apply to the Floridan aquifer system as well as other extensive aquifer systems.

Because of the flow-restricting influence of the Gulf Trough, ground water in the Floridan in the Colquitt County area is relatively high in dissolved constituents. Restricted ground-water flow results in a longer residence time and generally produces a higher concentration of dissolved constituents. The hypothesized Ochlockonee fault has also been mentioned by Zimmerman (1977) as a possible cause of higher dissolved constituents in the Colquitt County area. However, the flow-restricting Gulf Trough is the most likely cause of increased dissolved constituents in Colquitt County.

SUMMARY AND CONCLUSIONS

This report defines and illustrates the ambient ground-water chemistry and quality of the Floridan aquifer system in the Coastal Plain of Georgia.

The Floridan aquifer system consists of a sequence of predominantly carbonate rocks of Eocene to Miocene age. The aquifer system is thinnest in the outcrop area and thickens downdip to the southeast. With the exception of outcrop and near-outcrop areas, the aquifer system is under confined conditions. The late Eocene age Ocala Group is the most productive part of the aquifer system.

Recharge to the Floridan aquifer system is primarily by direct infiltration of precipitation on outcrop areas. Natural discharge is to streams hydraulically connected to the Floridan, while man-induced discharge is by pumping. Well yields are reported to range from 500 to 10,000 gpm; specific capacity values range from 1 to 1,250 gal/min/ft and transmissivity values are reported to be as high as 1.3 million ft^2/d. Approximately 755 mgd were withdrawn from the Floridan aquifer system in 1985.

In terms of concentrations of major dissolved constituents, the ambient ground-water chemistry and quality of the Floridan aquifer system is good. State drinking water standards are exceeded in water from only two of the 233 wells. Ground water from in and near recharge areas is comparatively low in dissolved constituents due to the relatively short residence time of water. This water is from the "uppermost zone." Bicarbonate type water that is highly circulated through well-leached rocks is characteristic of water from the "uppermost zone." Higher constituent values in extreme southeastern Georgia are due to the longer residence time of ground water. Water from southeastern Georgia is from the "intermediate zone." Higher concentrations of dissolved constituents, less intensive circulation and sulfate-type water are characteristic of the "intermediate zone." Ground water in the Floridan, in the Colquitt County area, contains a high concentration of dissolved constituents as a result of increased mineralization caused by the flow-restricting characteristics of the Gulf Trough.

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DEPARTMENT OF NATURAL RESOURCES
ENVIRONMENTAL PROTECTION DIVISION
GEORGIA GEOLOGIC SURVEY

STIFF DIAGRAMS OF SELECTED FLORIDAN AQUIFER SYSTEM WATER ANALYSES

Stiff diagrams are a common method used to present water-quality data in a graphic format. The area enclosed by these diagrams is an approximation of ionic content in milliequivalents per liter (meq/l) (Hem, 1985). Note that cations are plotted left of the zero axis while anions are plotted on the right.

Analyses from 22 wells were selected to illustrate water-quality data on Stiff diagrams. Wells chosen are spread somewhat equally over the study area. Limitations on plate size restricted the number of diagrams that could be displayed.

Water from wells located near the northwestern limit of the Floridan aquifer system is, as shown on this map, of calcium bicarbonate type and is comparatively low in dissolved constituents. Similarly, water from a well in Lowndes County (Valdosta, Ga., 7) is also low in dissolved constituents and of calcium bicarbonate type. Note that these wells are located near recharge areas. Water from wells located near the coast is, in general, calcium-magnesium sulfate-bicarbonate type and is comparatively high in dissolved constituents. This water is at least 75 miles from recharge areas. Other analyses shown on this diagram are, for the most part, relatively low in dissolved constituents and are of a calcium-bicarbonate type. An exception is water from Well FA-84 (Colquitt County) which is relatively high in dissolved constituents and is a calcium-magnesium sulfate type.

Water from a large part of the Floridan aquifer system in Georgia is relatively low in dissolved constituents because of the comparatively short residence time of the water. These waters are probably from the "uppermost zone", as described in Domenico (1972). The uppermost zone is characterized by high water circulation through leached rocks. Water from this zone is bicarbonate type and is low in dissolved constituents. Water from some counties near the coast is higher in dissolved constituents due to the longer residence time. As described by Domenico, this water is from the "intermediate zone". This zone is characterized by less intensive circulation and higher dissolved constituents. It is sulfate in type. Higher concentrations of dissolved constituents in water from well FA-84 (Colquitt County) may result from the flow-restricting influence of the Gulf Trough. Water from well FA-84 is probably from the "intermediate zone", described by Domenico (1972).

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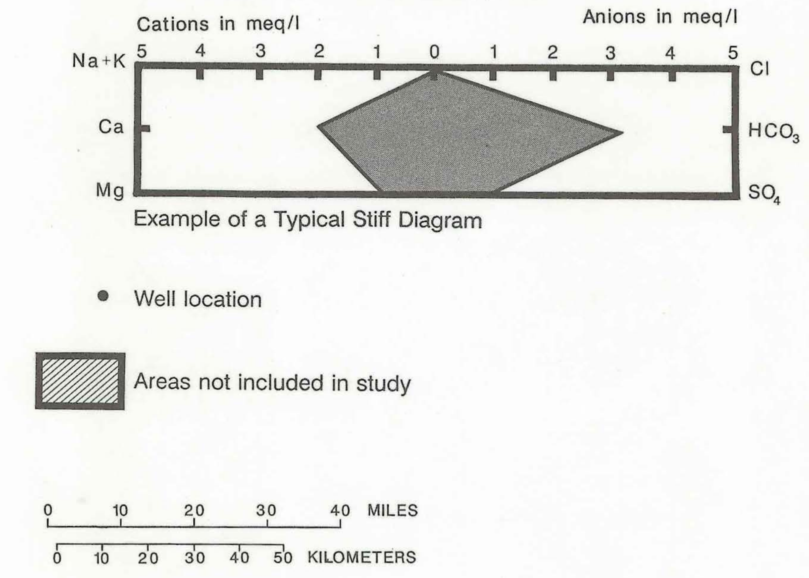
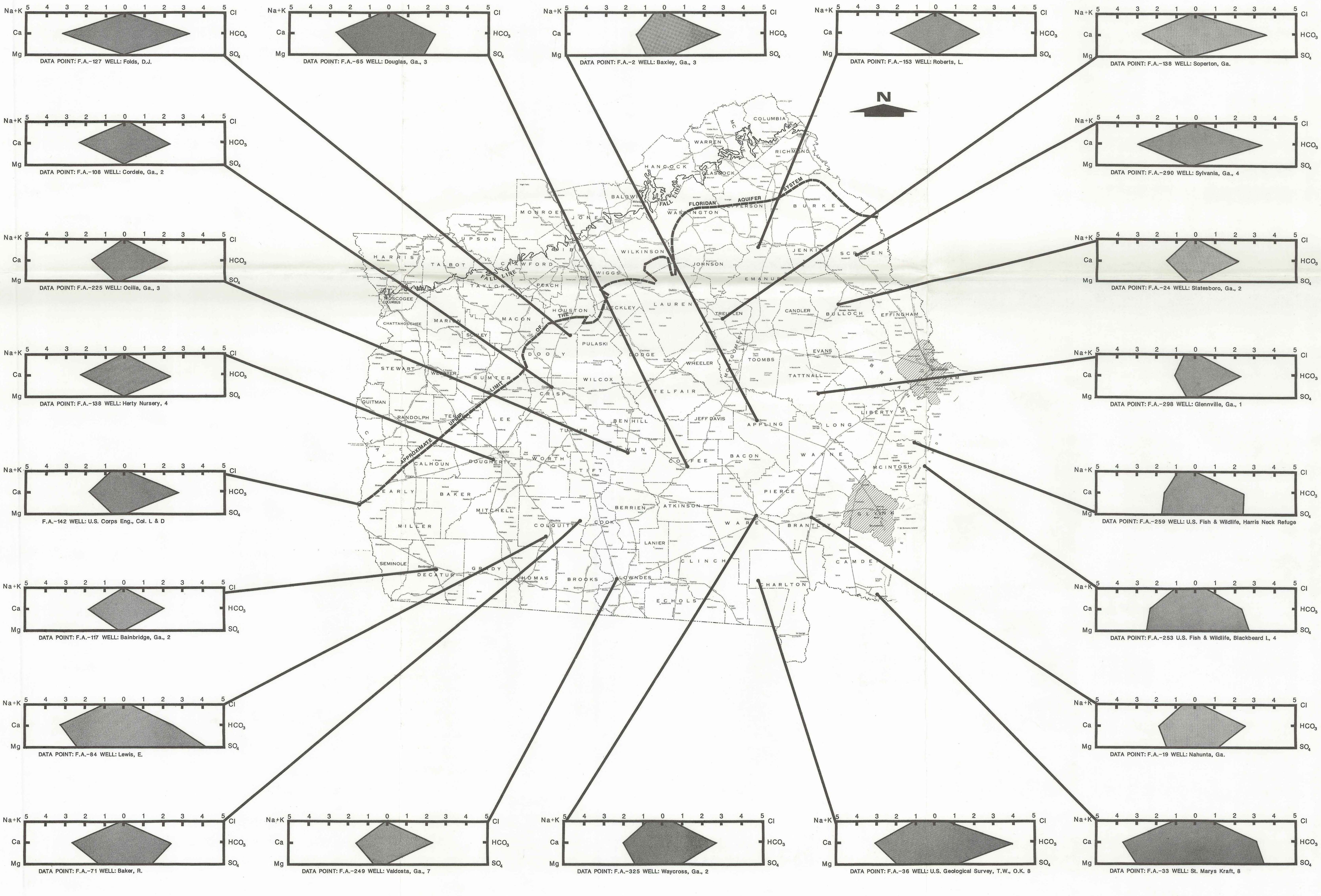
EXPLANATION





TRILINEAR DIAGRAMS OF SELECTED FLORIDAN AQUIFER SYSTEM WATER ANALYSES

Trilinear diagrams, also known as Piper diagrams, are a common method used to present water-quality data in a graphic format. These diagrams show the percentage composition of major ions; namely, calcium, magnesium, sodium, potassium, chloride, sulfate and bicarbonate. The apexes of the triangles represent a 100 percent concentration of a constituent. When all three constituent groups are present, the data will plot in the interior of the triangles. The diamond shaped diagrams show the combined percentages of both cations and anions.

Seven counties were selected to illustrate water quality data on trilinear diagrams. Counties were selected on the basis of consistency of analyses, number of analyses and geographic location. Counties chosen are near recharge areas, far from recharge areas and in between.

Strongly calcium-bicarbonate type water is dominant in Dooly, Lowndes and Screven Counties. Note that these three counties are located near recharge areas. Water from Liberty and McIntosh Counties is calcium-magnesium-bicarbonate type, while calcium-magnesium-sulfate type water dominates in Camden County. Camden, Liberty and McIntosh Counties are all located at least 75 miles from recharge areas. Water from the Floridan in Colquitt County varies so greatly in type, as shown here, that it is not possible to classify.

Water from counties located near recharge areas (Dooly, Screven and Lowndes), along with water from Liberty County and some water from McIntosh County, is probably in the "uppermost zone" as described in Domenico (1972). Water from this zone is bicarbonate in type, as shown on the trilinear diagrams. Water from Camden County, and some water from McIntosh County, is probably in the "intermediate zone" (Domenico, 1972). Sulfate type water dominates in this zone. It is not possible to assign water from Colquitt County to any particular zone because water types differ so greatly. This differing water quality could be the result of some water being taken from within the flow-restricting Gulf Trough and some water being taken from outside the Gulf Trough.

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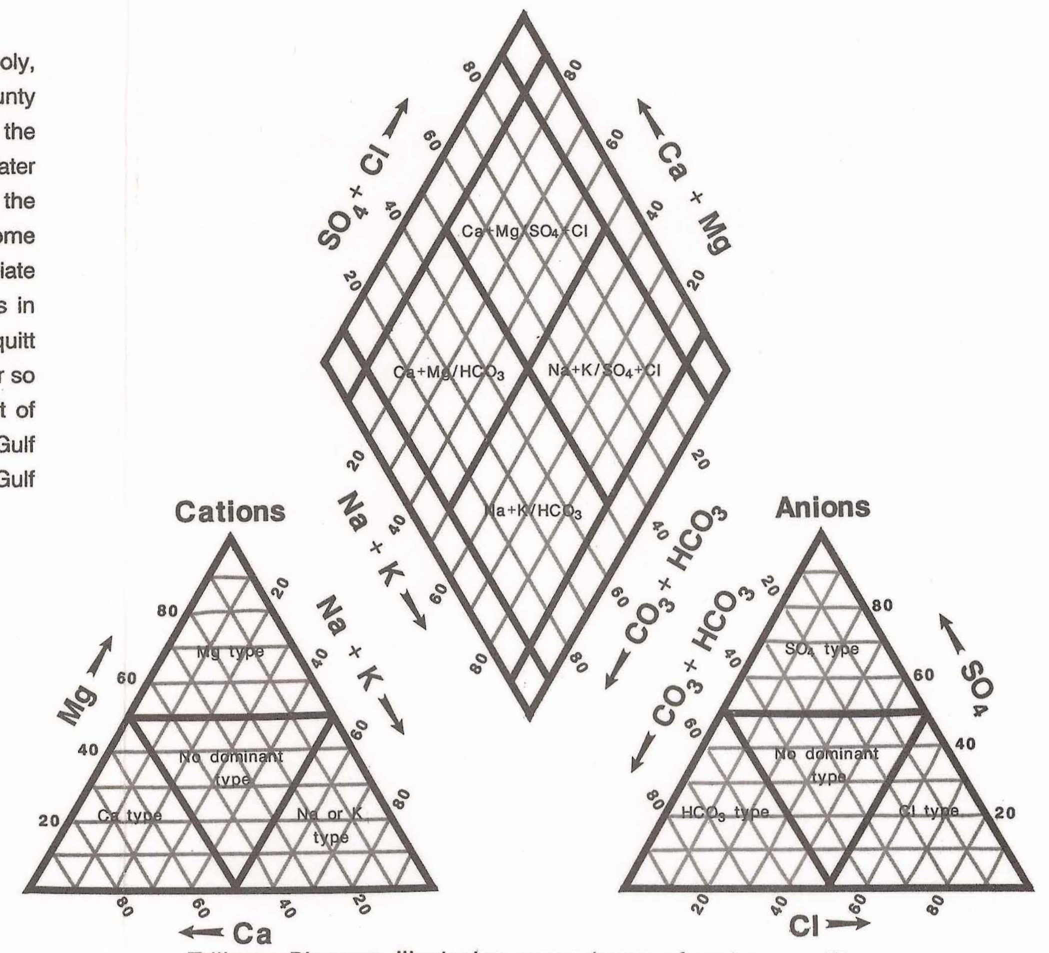
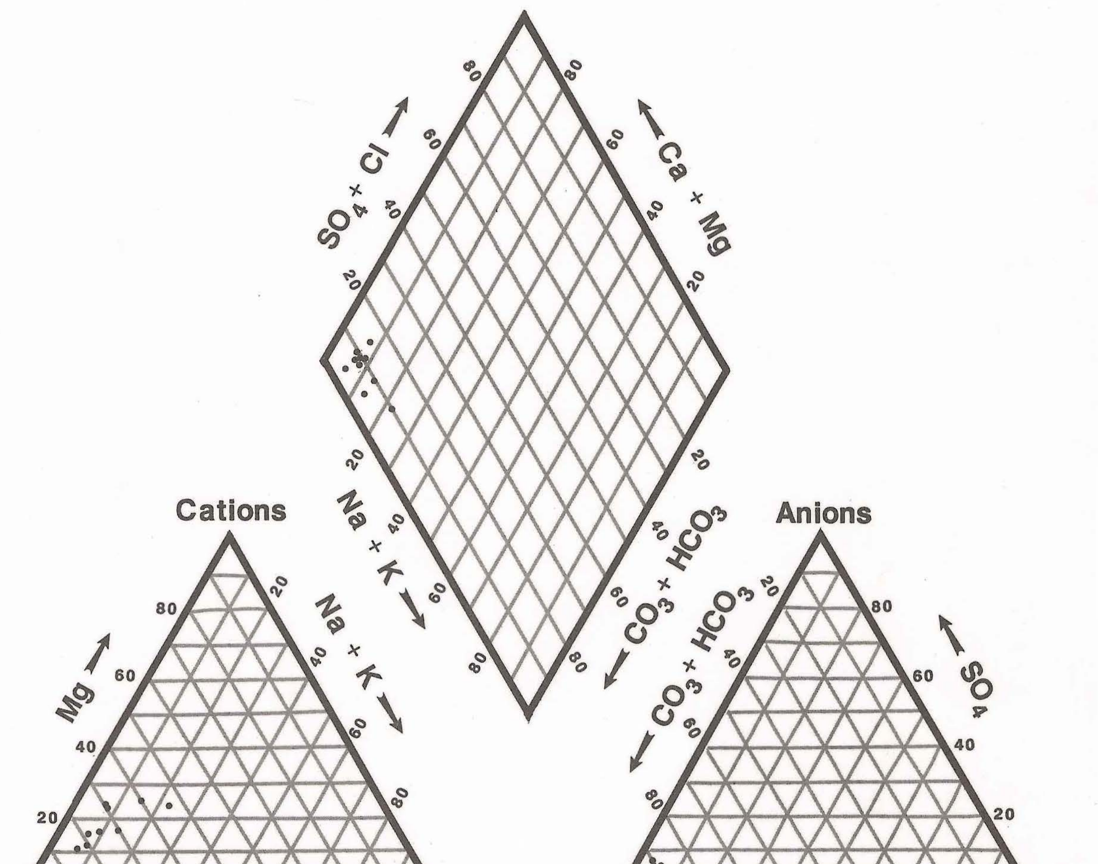


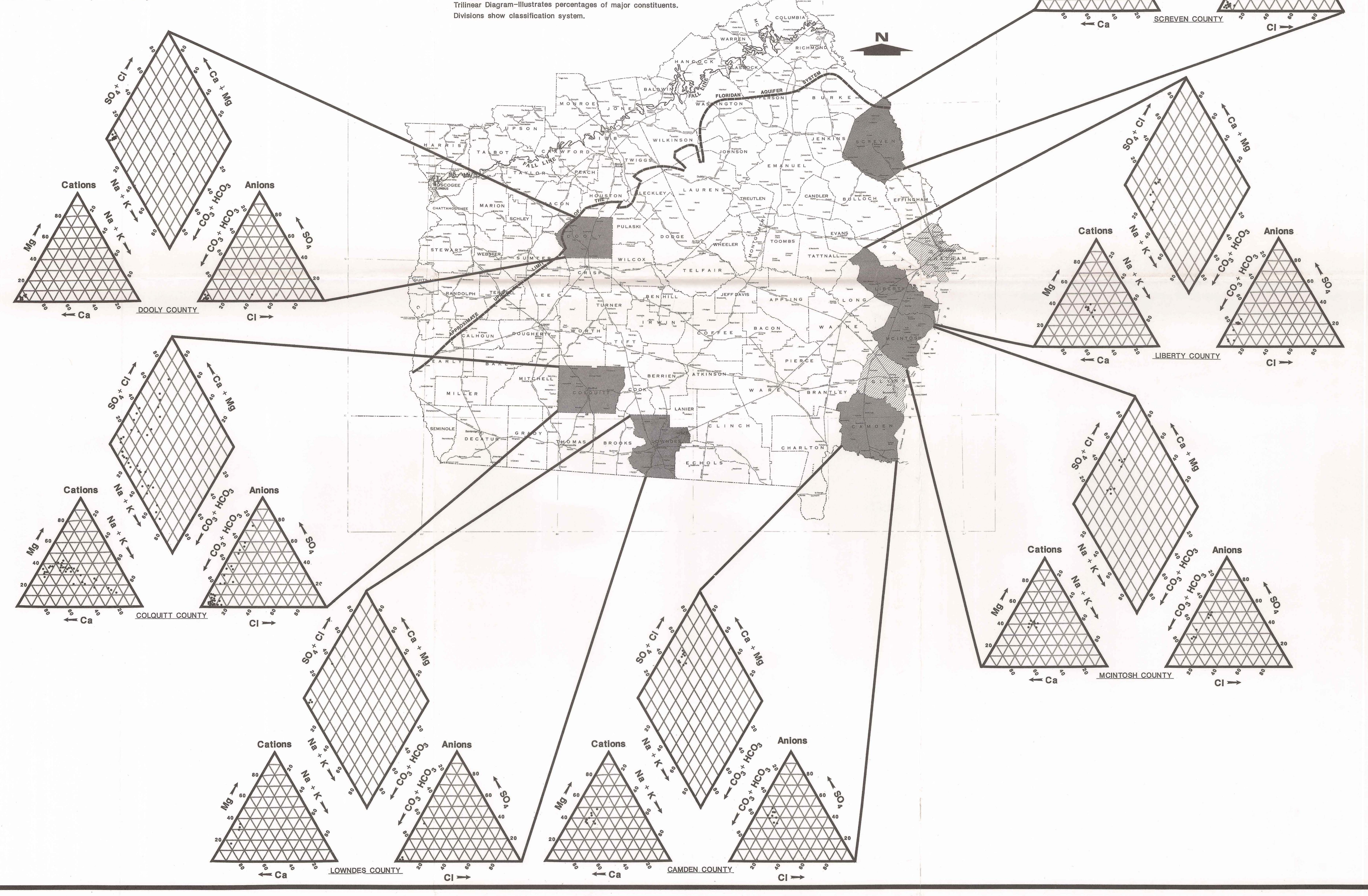
Trilinear Diagram–Illustrates percentages of major constituents. Divisions show classification system.

EXPLANATION

County of interest.

Areas not included in study.





ISOCONCENTRATION MAP OF CALCIUM LEVELS IN THE FLORIDAN AQUIFER SYSTEM

This map shows calcium (Ca) concentrations in milligrams per liter (mg/l) in the Floridan aquifer system. There is no drinking water standard for calcium, in fact, water with as much as 1000 mg/l of calcium may be harmless (Davis and DeWiest, 1966). Concentrations range from 0.4 to 102 mg/l in the study area. The majority of values are in the "normal" range of 10 to 100 mg/l as reported in Davis and DeWiest (1966). Lower levels of calcium are, in most cases, not concentrated in any one region but are spread throughout the study area. However, the northern Colquitt-southern Tift County area, within the hatched 20 mg/l contour, is comparatively low in calcium levels. Several areas of relatively high values (greater than 50 mg/l) are shown. These are as follows:

1. The southern Early, western Miller and western Seminole County area.
2. The southeastern Dougherty, northeastern Mitchell and western Worth County region.
3. A large area located near the northwestern limit of the Floridan aquifer system.
4. A small area centered around Soperton in Treutlen County.
5. A small, oblong region in western Screven County.
6. An area extending from Coolidge (Thomas County) to Moultrie (Colquitt County).
7. An oblong area extending from eastern Colquitt County to central Coffee County in south-central Georgia.
8. The extreme southeastern Georgia region.

As shown on this map, areas of higher concentrations of calcium are not confined to any particular part of the study area.

The primary source of calcium is the carbonate rocks of the Floridan aquifer system. Higher-than-normal concentrations in southeastern Georgia are probably a result of the relatively long residence time of water. Higher concentrations south of Moultrie (Colquitt County), and the oblong area from eastern Colquitt to Coffee County, could be the result of long residence time of water because these areas are in the Gulf Trough where ground-water flow is restricted. These two areas also coincide with thick sequences of upper Eocene age deposits. Higher concentrations of calcium in the remaining areas may be due to greater solubility of carbonate rocks.

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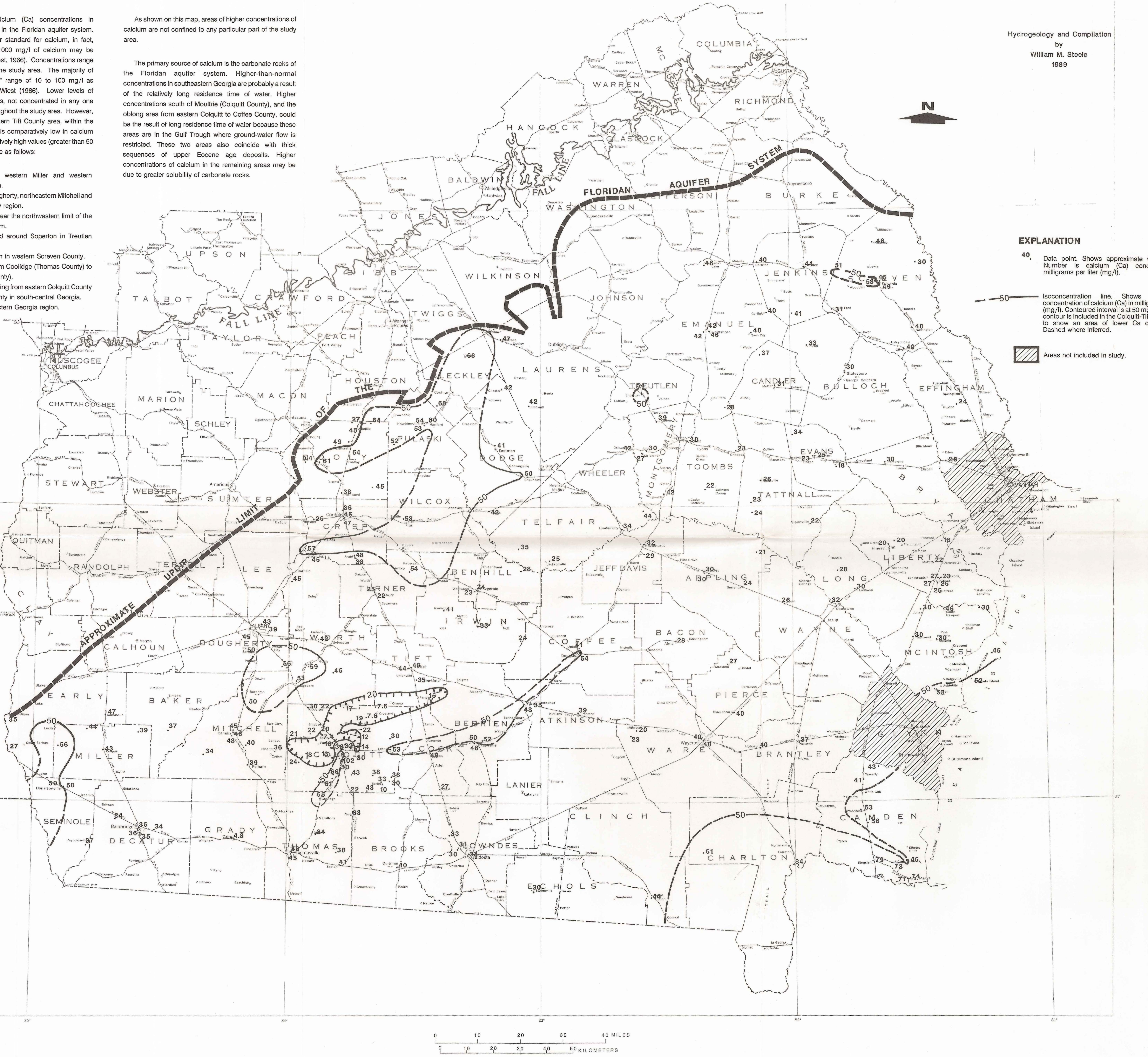

EXPLANATION

40. Data point. Shows approximate well location. Number is calcium (Ca) concentration in milligrams per liter (mg/l).

—50— Isoconcentration line. Shows approximate concentration of calcium (Ca) in milligrams per liter (mg/l). Contoured interval is at 50 mg/l. A 20 mg/l contour is included in the Colquitt-Tift County area to show an area of lower Ca concentration. Dashed where inferred.

Areas not included in study.

ISOCONCENTRATION MAP OF MAGNESIUM LEVELS IN THE FLORIDAN AQUIFER SYSTEM

Magnesium (Mg) concentrations, in milligrams per liter (mg/l), are shown on this map. There is no drinking water standard for magnesium, but water containing over 125 mg/l of dissolved magnesium is not recommended for drinking (Davis and DeWiest, 1966). Concentrations in ground water commonly range from 1 to 40 mg/l (Davis and DeWiest, 1966). Within the study area, concentrations vary from 0.1 to 47 mg/l, most of the values are within the 1 to 40 mg/l range mentioned above. Lowest levels of magnesium are generally near the northwestern limits of the study area. Other areas of low concentrations, relative to the surrounding area, include northern Colquitt County, a small area in southeastern Colquitt County, a small area in western Ware County and a larger area in eastern Brooks and central Lowndes County. Note that Lowndes County is a recharge area for the Floridan aquifer system. A localized area of high magnesium concentrations occurs in the Moultrie to Thomasville area of Colquitt and Thomas Counties. The highest concentration of magnesium in the study area (47 mg/l) is in Moultrie. Concentrations are generally lower in the northwestern portion of the study area and increase to the southeast. Note that isoconcentration lines are subparallel to the approximate northwestern limit line.

The most common source of magnesium in sedimentary rocks is dolomite; however, limestone commonly yields a substantial amount of magnesium (Davis and DeWiest, 1966). Low concentration regions located near the northwestern limit of the aquifer system and the Lowndes-Brooks County area are probably a result of the relatively short residence time of ground-water in those near-recharge areas. The cause of comparatively low magnesium content in the northwestern Colquitt County area is unknown. However, this region of low magnesium concentration corresponds with a similar area of low calcium concentration (Plate 3). The high concentration area from Moultrie (Colquitt County) to Thomasville (Thomas County) could be caused by increased residence time of ground-water as a result of the flow-restricting Gulf Trough. The gradual increase in magnesium content to the south-southeast is most likely due to the increasing residence time of water.

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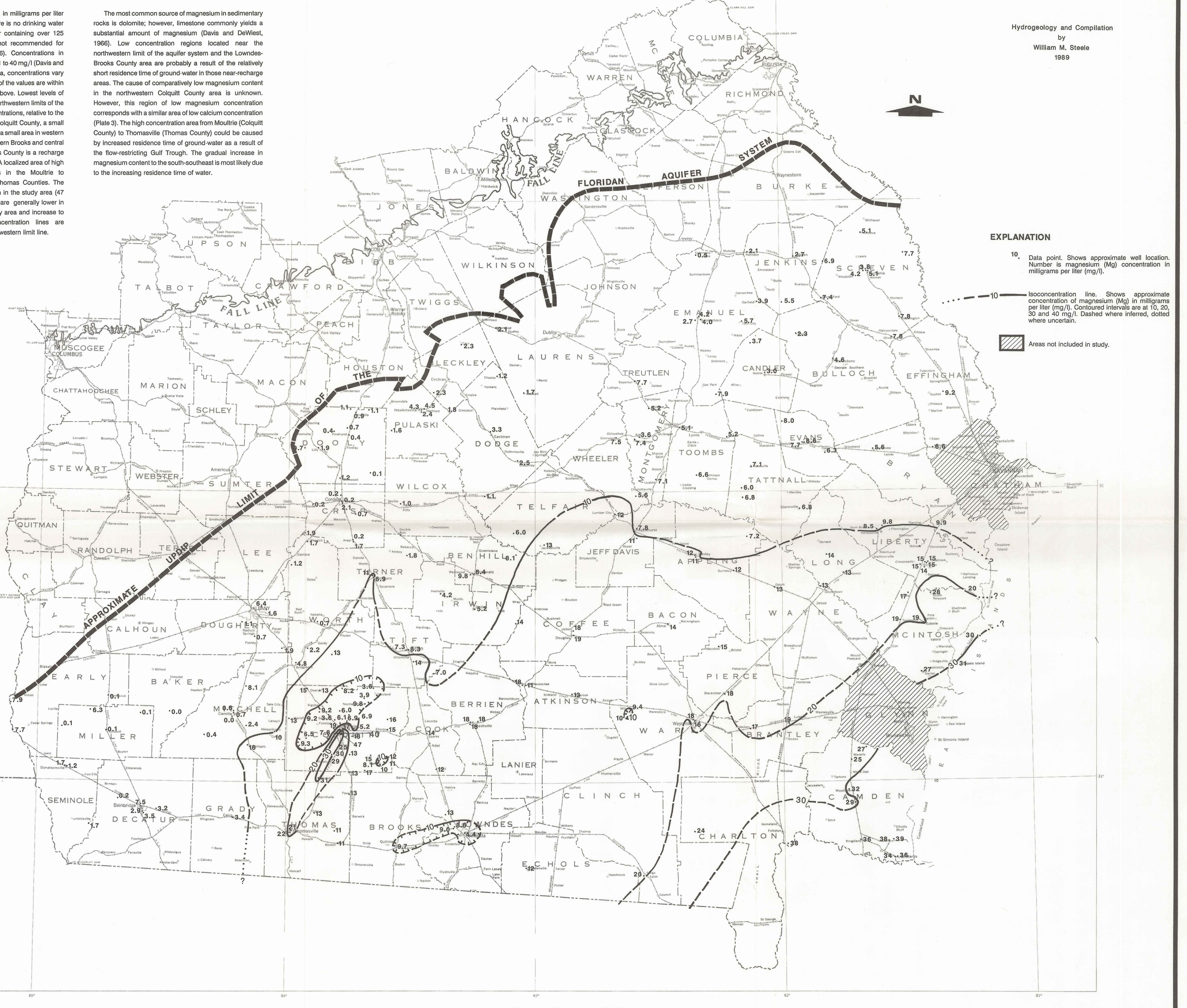

EXPLANATION

10. Data point. Shows approximate well location. Number is magnesium (Mg) concentration in milligrams per liter (mg/l).

— 10 — Isoconcentration line. Shows approximate concentration of magnesium (Mg) in milligrams per liter (mg/l). Contoured intervals are at 10, 20, 30 and 40 mg/l. Dashed where inferred, dotted where uncertain.

Areas not included in study.

ISOCONCENTRATION MAP OF SODIUM LEVELS IN THE FLORIDAN AQUIFER SYSTEM

Sodium (Na) concentrations are illustrated on this map in milligrams per liter (mg/l). There is no drinking water standard for sodium, however, 200 mg/l is the recommended maximum content (Davis and DeWiest, 1966). Sodium values range from 0.8 to 40 mg/l in the study area. Lower values are, in general, near the northwestern limit of the Floridan aquifer system. Higher-than-normal levels occur in extreme southwestern Early County. A large area of high sodium values is centered in Colquitt County. Southeastern Georgia is the largest area of comparatively high sodium concentrations.

In general, the primary source of sodium in natural water is from the weathering of plagioclase feldspars. Secondary sources are from clay minerals (Davis and DeWiest, 1966) and salt water. Possible sources of sodium in the study area are clay units within the system, leached sodium from weathered plagioclase feldspar and minor amounts of sodium in the limestone.

Low sodium concentrations, near the northwestern limit/outcrop area, are most likely due to the relatively short residence time of the ground-water. Increasing concentrations near the coast are probably due to the water's longer residence time. Higher sodium levels in the Colquitt County area could be due to restricted ground-water flow and longer residence time in the Gulf Trough area. This area is also underlain by thick sequences of upper Eocene and Oligocene age sediments.

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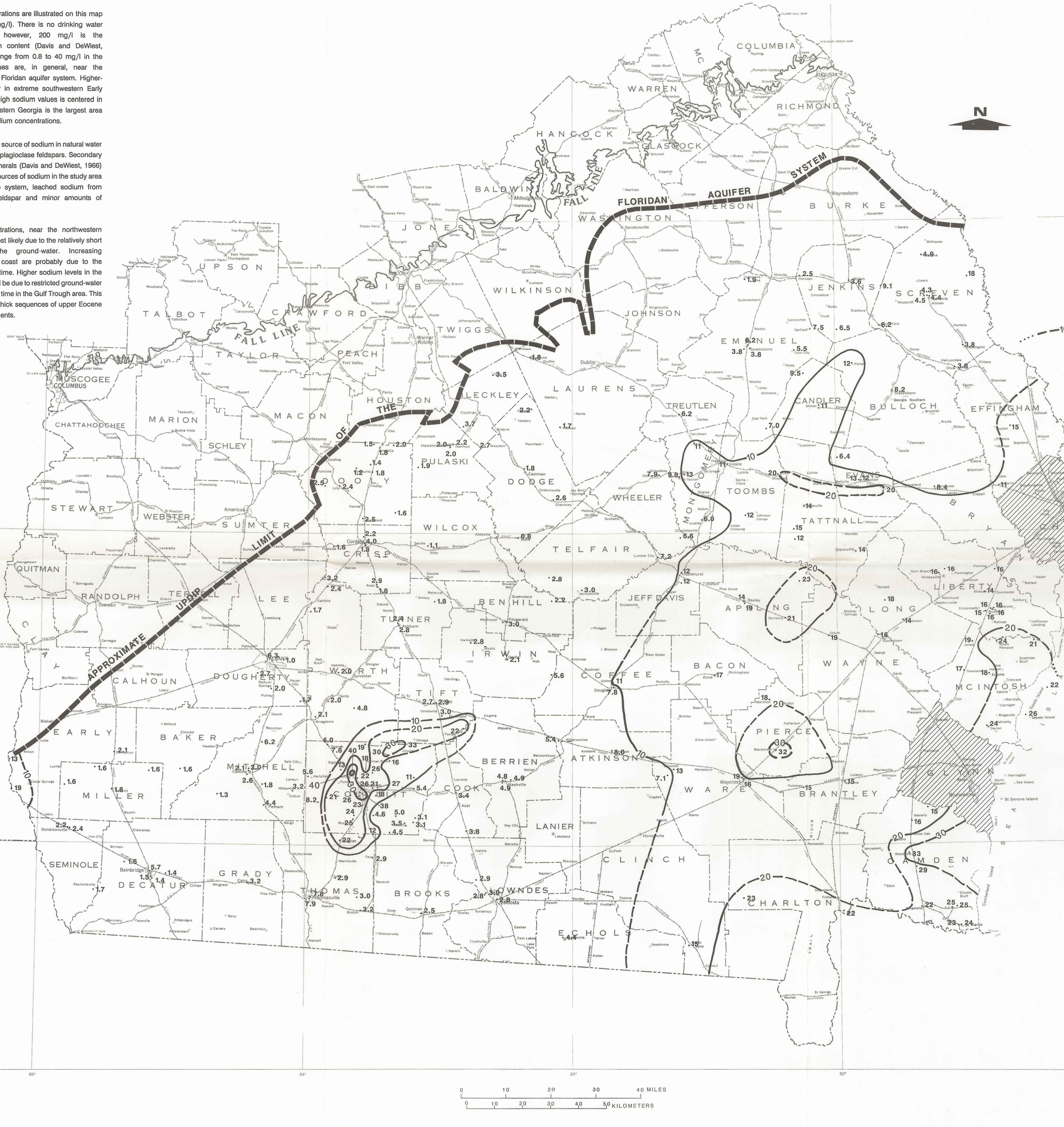

EXPLANATION

11. Data point. Shows approximate well location. Number is sodium (Na) concentration in milligrams per liter (mg/l).

—10— Isoconcentration line. Shows approximate concentration of sodium (Na) in milligrams per liter (mg/l). Contoured intervals are at 10 and 20 mg/l. Dashed where inferred, dotted where uncertain.

Areas not included in study.

ISOCONCENTRATION MAP OF CHLORIDE LEVELS IN THE FLORIDAN AQUIFER SYSTEM

This map illustrates chloride (Cl) levels in the Floridan aquifer system in milligrams per liter (mg/l). Levels do not exceed the 250 mg/l state drinking water standard, ranging only from 0 to 52 mg/l. Lowest levels of chloride are, in most cases, near recharge and/or outcrop areas. Areas of higher chloride levels include the Moultrie-Colquitt County area, northeastern Appling County, the Pierce County area around Blackshear, smaller areas around Nashville (Berrien County) and southeastern Screven County. The largest area of high concentration is the extreme southeastern Georgia region along the coast. Here chloride levels increase from less than 10 mg/l in Liberty County to over 50 mg/l in Camden County. The most significant increase is seen in the Camden County area.

There are three possible sources of chloride in the Floridan aquifer system. These are: older ground-water containing higher levels of chloride, leached chloride from sediments and small amounts of chloride contained in rainfall. Lower levels of chloride, observed near the updip limit of the aquifer system, are due to shorter residence time of the ground-water. Increasing levels near the coast are primarily due to longer residence time of the water. A secondary cause of these high levels could be the mixing with deeper ground-water that has higher chloride content. Slightly higher levels in Colquitt County could be due to longer residence time of water as a result of the flow-restricting Gulf Trough.

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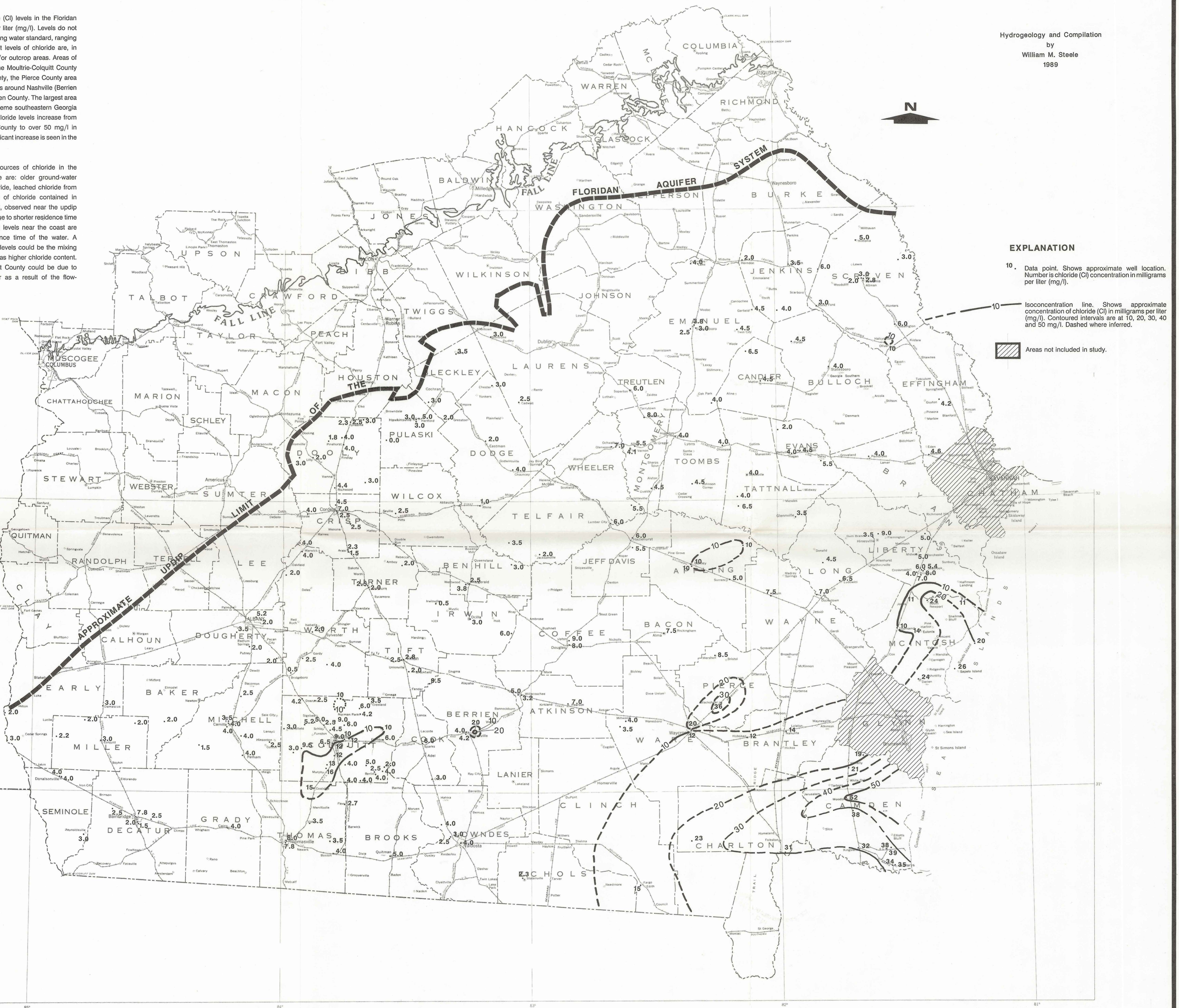

EXPLANATION

10 . Data point. Shows approximate well location. Number is chloride (Cl) concentration in milligrams per liter (mg/l).

—10— Isoconcentration line. Shows approximate concentration of chloride (Cl) in milligrams per liter (mg/l). Contoured intervals are at 10, 20, 30, 40 and 50 mg/l. Dashed where inferred.

Areas not included in study.

ISOCONCENTRATION MAP OF SULFATE LEVELS IN THE FLORIDAN AQUIFER SYSTEM

This map shows sulfate (SO_4) concentrations in the Floridan aquifer system in milligrams per liter (mg/l). Levels range from 0 to 405 mg/l and only in water from one well do these levels exceed the 250 mg/l state drinking water standard. Sulfate concentrations are usually relatively low near outcrop/recharge areas. Areas of higher concentration include; the Moultrie (Colquitt County) to Thomasville (Thomas County) region, the area from eastern Colquitt County to westernmost Atkinson County, the region around Douglas (Coffee County) and extreme southeastern Georgia. Only water from one well (Moultrie, 3) exceeds drinking water standards. Sulfate concentration increases near the coast, similar to other constituents in this study.

Sources of sulfate in ground-water include organic shales, oxidation of pyrite, marcasite, gypsum, small levels in precipitation and human activities. Primary sources of sulfate in the Floridan aquifer system are possibly organic shales, gypsum and small levels contained in rain that recharges the aquifer. Low sulfate levels near the northwestern limit of the aquifer system are primarily the result of shorter residence time of the ground-water. Conversely, higher levels near the coast are most likely due to the longer residence time of ground-water. In the Moultrie (Colquitt County) to Thomasville (Thomas County) area, the area from eastern Colquitt County to westernmost Atkinson County and the Coffee County area, higher sulfate levels are probably caused by longer residence time of water due to the flow-restricting Gulf Trough. These areas are also underlain by thick sequences of upper Eocene age sediments.

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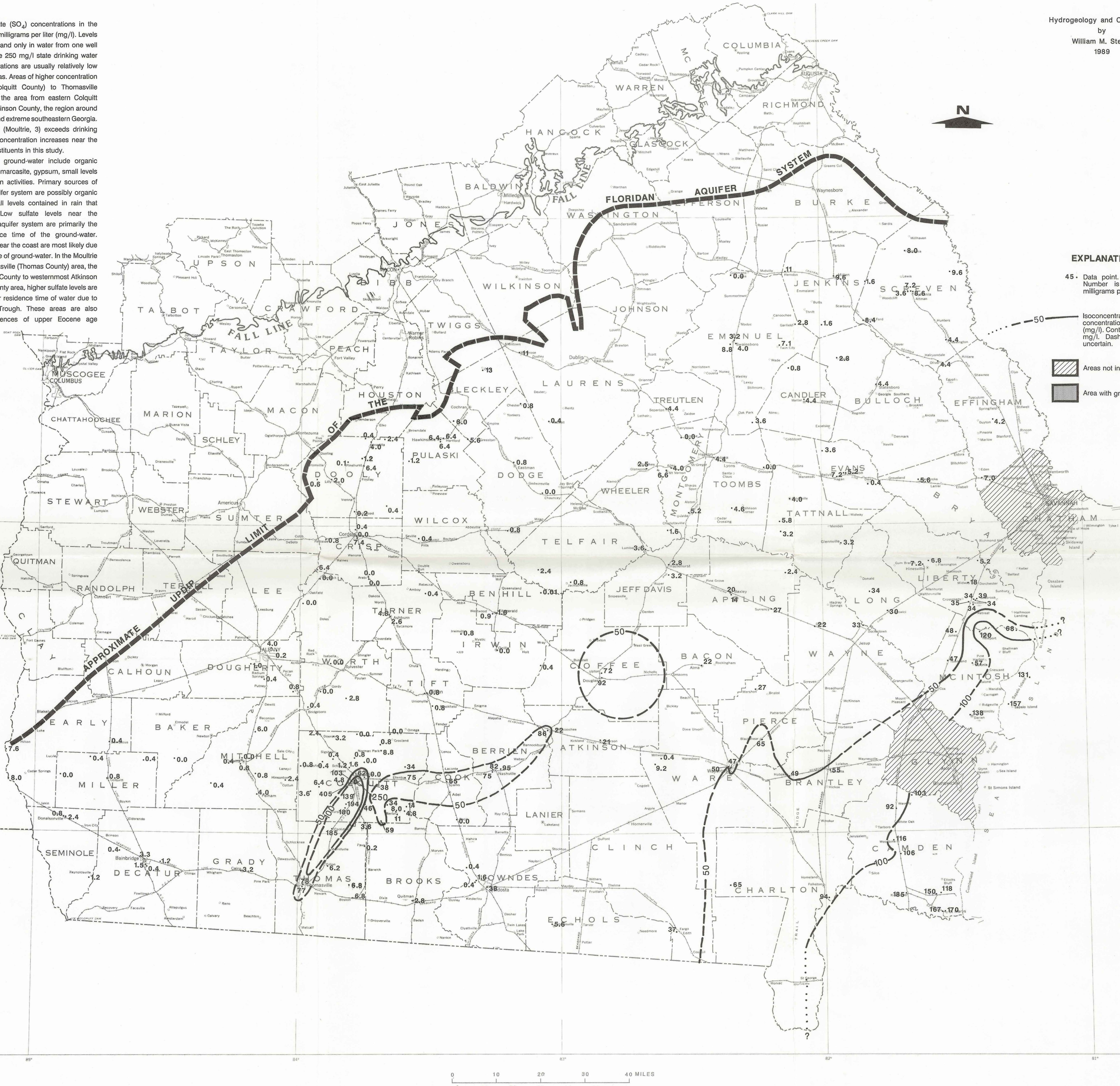

EXPLANATION

45 • Data point. Shows approximate well location. Number is sulfate (SO_4) concentration in milligrams per liter (mg/l).

—50— Isoconcentration line. Shows approximate concentration of sulfate (SO_4) in milligrams per liter (mg/l). Contoured intervals are at 50, 100 and 250 mg/l. Dashed where inferred, dotted where uncertain.

Areas not included in study.

Area with greater than 250 mg/l sulfate content.

ISOCONCENTRATION MAP OF BICARBONATE LEVELS IN THE FLORIDAN AQUIFER SYSTEM

This map shows bicarbonate (HCO_3) levels in the Floridan aquifer system in milligrams per liter (mg/l). Bicarbonate ions dominate where pH values are between 4.5 and 8.2, which is the case in the study area. Bicarbonate concentrations range from 6 to 220 mg/l in the study area. There is no drinking water standard for bicarbonate. Concentrations of bicarbonate in ground water commonly range from 50 to 400 mg/l (Davis and DeWiest, 1966). The major sources of bicarbonate are limestone and dolomite (Zimmerman, p. 33).

Lower bicarbonate levels occur without regard to location relative to recharge and discharge areas. The Bleckley-Pulaski-Dodge County and western Screven County regions are both high in bicarbonate values and are near recharge areas. The northern Mitchell-southern Worth County area is somewhat high in bicarbonate and is located approximately 40 miles from the recharge areas. The extreme southeastern Georgia region is both high in bicarbonate and located relatively far from recharge areas.

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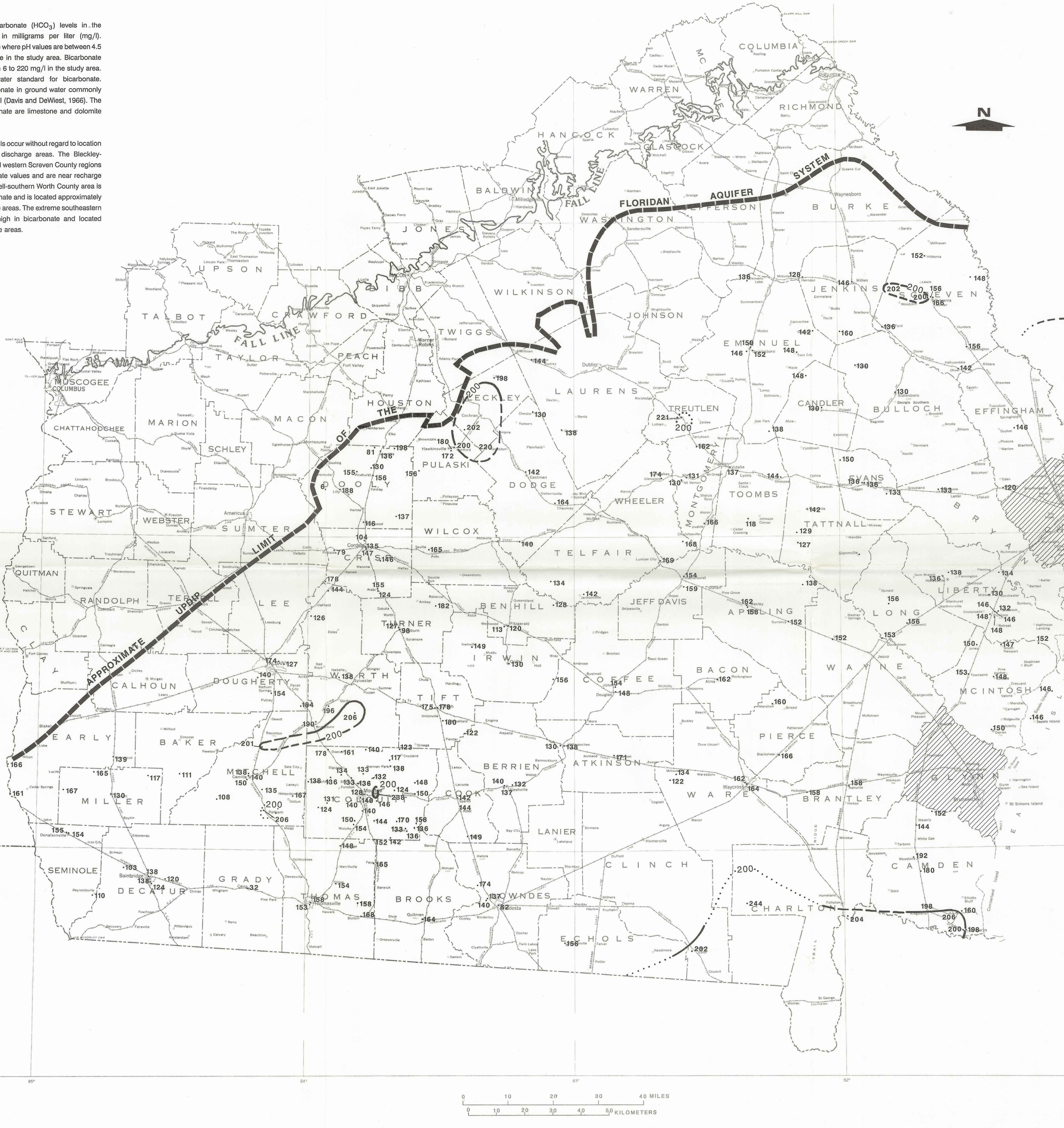

EXPLANATION

200. Data point. Shows approximate well location. Number is bicarbonate (HCO_3) concentration in milligrams per liter (mg/l).

—200— Isoconcentration line. Shows approximate concentration of bicarbonate (HCO_3) in milligrams per liter (mg/l). Contoured interval is at 200 mg/l. Dashed where inferred, dotted where uncertain.

Areas not included in study.

ISOCONCENTRATION MAP OF TOTAL DISSOLVED SOLIDS IN THE FLORIDAN AQUIFER SYSTEM

This map illustrates total dissolved solids (TDS) concentrations in the Floridan aquifer system in milligrams per liter (mg/l). TDS values include all materials in solution (Davis and DeWiest, 1966). The 500 mg/l drinking water maximum for TDS is exceeded only in Moultrie (Colquitt County) and eastern Charlton County. TDS levels range from 16 to 704 mg/l. Lower levels of TDS are generally near the approximate northwestern limit of the aquifer system; however, there are two relatively small areas in the Dooly-Pulaski-Bleckley County area that are slightly higher in TDS levels when compared to other near-recharge areas. The extreme south-central Georgia region is comparatively low in TDS with respect to surrounding areas. Areas of higher concentrations are the south-central Colquitt County area and the southeast Georgia region. Increasing concentrations in extreme southeastern Georgia are most likely due to the relatively long residence time of ground-water. Conversely, areas of lower concentration near the northwestern limit and the Lowndes County area are due to relatively short residence time of ground-water in these near-recharge areas. The area of high concentration south of Moultrie (Colquitt County) could be due to the flow-restricting Gulf Trough. The Gulf Trough could also be the cause of higher TDS concentrations (200 mg/l and greater) in the area from eastern Colquitt County to Coffee County. These areas are also underlain by thick sequences of upper Eocene age sediments.

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William M. Steele
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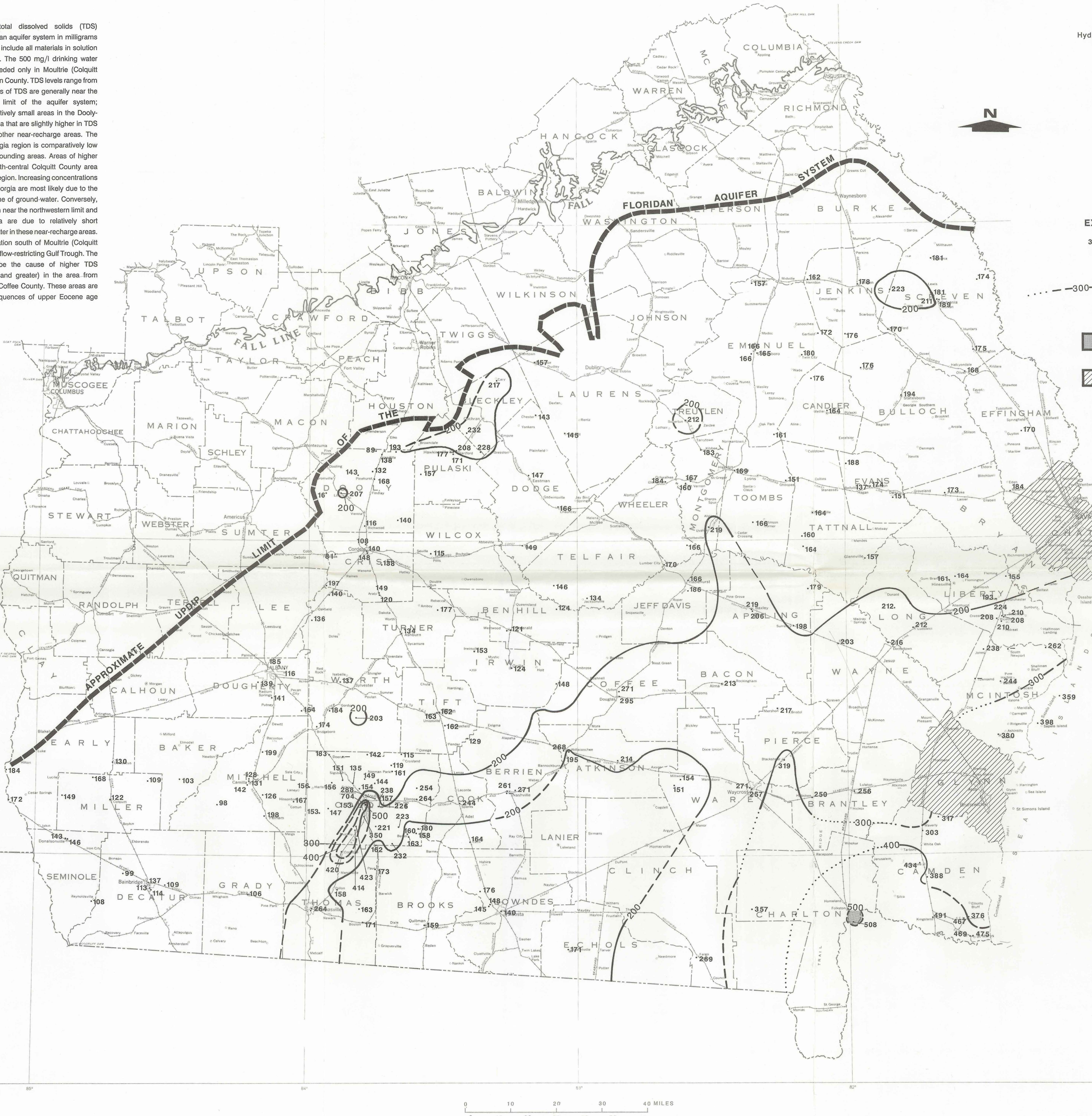

EXPLANATION

303. Data point. Shows approximate well location. Number is total dissolved solids (TDS) concentration in milligrams per liter (mg/l).

300 Isoconcentration line. Shows approximate concentration of total dissolved solids (TDS) in milligrams per liter (mg/l). Contoured intervals are at 200, 300, 400 and 500 mg/l. Dashed where inferred, dotted where uncertain.

Areas where total dissolved solids (TDS) concentration exceeds drinking water maximum (500 mg/l).

Areas not included in study.