HYDROGEOLOGY, WATER QUALITY, AND WATER-RESOURCES DEVELOPMENT POTENTIAL OF THE UPPER FLORIDAN AQUIFER IN THE VALDOSTA AREA, SOUTH-CENTRAL GEORGIA

By James B. McConnell and Charles M. Hacke

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BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY

Robert M. Hirsch, Acting Director

For additional information, write to

District Chief
U.S. Geological Survey
3039 Amwiler Road
Suite 130
Peachtree Business Center
Atlanta, GA 30360-2824

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CONVERSION FACTORS

Length

Multiply	by	to obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer

Area

Multiply	by	to obtain
acre	0.4047	hectare
square mile (mi^2)	2.590	square kilometer

Volume

Multiply	by	to obtain
gallon (gal)	3.785	liter
million gallons (Mgal)	3,785	cubic meter

Flow

Multiply	by	to obtain
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
gallon per minute (gal/min)	0.06309	liter per second
million gallons per day (Mgal/d)	0.0438	cubic meter per second

Transmissivity

Multiply	by	to obtain
foot squared per day (ft^2/d)[1]	0.09290	meter squared per day

Concentrations

Multiply	by	to obtain
tritium units (TU)	3.2	picocuries per liter

Temperature

Temperature in degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) as follows:

$$°C = 5/9\ (°F-32)$$

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[1]Standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness $[(ft^3/d)/ft^2/ft]$. In this report, the mathematically reduced form foot squared per day (ft^2/d) is used for convenience.

ACRONYMS AND DEFINITIONS OF TERMS

EPD Georgia Department of Natural Resources, Environmental Protection Division

MCL Maximum contaminant level--maximum permissible level of a contaminant in water which is delivered to any user of a public water system

SMCL Secondary maximum contaminant level--a contaminant level that affects the aesthetic quality of drinking water.

TOC Total organic carbon

TU Tritium unit--A unit of measurement for tritium concentration. Tritium concentration also is expressed in picocuries per liter. One TU equals 3.2 picocuries per liter

USGS U.S. Geological Survey

VERTICAL DATUM

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929--a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called "Sea Level Datum of 1929".

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ABSTRACT

The quality of water in the Upper Floridan aquifer in the Valdosta, Georgia, area is affected by direct recharge from the Withlacoochee River. Water enters the Upper Floridan aquifer along a short reach of the Withlacoochee River where sinkholes have formed in the streambed. The river water receives little filtration as it recharges the Upper Floridan aquifer, and naturally occurring organic material in the river provides a readily available source of energy for the growth of microbiota in the aquifer. The microbiota are catalysts for reactions that produce methane and hydrogen sulfide as the river water mixes with ground water and moves downgradient in the aquifer. Also, humic substances associated with the organic material in the water can form trihalomethanes when the ground water is chlorinated for drinking-water supplies. In addition to water-quality concerns related to natural conditions, ground water in the Upper Floridan aquifer in the Valdosta area might be vulnerable to contamination from human activities in the drainage basin upstream of the sinkhole area because the river water receives little filtration as it is recharged through sinkholes directly to the aquifer.

Recharge at the sinkhole area is a major source of water to the Upper Floridan aquifer in the Valdosta area. All flow of the Withlacoochee River is lost to the Upper Floridan aquifer through the sinkholes when streamflow is less than 50 cubic feet per second (ft^3/s). Flow loss increases as flow in the river increases from 50 to about 300 ft^3/s, but the percentage of flow loss compared to total streamflow becomes smaller. At streamflows greater than 300 ft^3/s, loss to the aquifer is (on average) about 82 ft^3/s. Losses to the aquifer for streamflows less than about 50 ft^3/s have not changed appreciably between 1975 and 1989, when this study was completed. However, the average loss during high streamflow conditions decreased from about 300 ft^3/s in 1976, to about 82 ft^3/s in 1989. Also, the average streamflow loss was 112 ft^3/s for the period from 1932-75, compared to about 60 ft^3/s for the period from 1933-89 determined in this study. The amount of organic material that enters the aquifer through sinkholes, expressed as the average total organic carbon load, was about 2.6 tons per day for the period from 1972-89.

Recharge to the Upper Floridan aquifer through the sinkholes during periods of high streamflow forms a ground-water mound in the vicinity of the sinkhole area. Movement of recharge water is laterally downgradient, primarily in a south-southeasterly direction from the sinkhole area.

Recharge to the Upper Floridan aquifer occurs regionally north of the study area, and ground-water flow generally is towards the southeast. However, recharge from this area probably is not a major source of water to the Upper Floridan in the study area, because regional flow is impeded north of the study area by the Gulf Trough, a northeast-southwest trending geologic feature. The aquifer can receive recharge from infiltration of precipitation in the area between the Gulf Trough and the study area, but probably receives little recharge from infiltration in the study area because recharge is retarded by confining units in the overlying sediments.

Areal distributions of total organic carbon, total sulfide, and methane in water of the Upper Floridan aquifer were mapped and used to identify areas where ground-water quality is affected by recharge from the Withlacoochee River. Areas where concentrations of total organic carbon, total sulfide, and methane in ground water are greater than 2.0 milligrams per liter, 0.5 milligrams per liter, and 100 micrograms per liter, respectively, are considered affected by recharge from the river. An assessment of mixing using chloride concentrations of river water and ground water from the Upper Floridan aquifer in a simple mixing model indicates that water from wells in the Valdosta area ranges from 0 to 61 percent river water and averages about 4-percent river water.

The Bemiss and Bay Branch areas, located northeast and northwest of the sinkholes and outside the areas affected by river recharge, were considered to have relatively high potential for additional development of ground-water resources. Ground-water quality in these areas and the generally excellent water-bearing properties of the Upper Floridan aquifer (transmissivity about 100,000 feet squared per day), indicate that the aquifer in the Bemiss and Bay Branch areas could provide large quantities of water suitable for most uses. The relatively low density of photolineaments and relatively low concentrations of total organic carbon, total sulfide, and methane in ground water in these areas indicates little movement of river-affected ground water to the areas.

INTRODUCTION

The Upper Floridan aquifer is the sole source of water supply for the city of Valdosta, Ga., and much of the surrounding area. The aquifer yields an ample supply of water; however, water quality is a concern to users and developers of ground-water resources in the area. In some areas, the aquifer contains water having high color, high concentrations of iron and hydrogen sulfide, and undesirable bacteria, protozoa, and fungi (Krause, 1979). The water also contains relatively high concentrations of organic material in some areas. Humic substances associated with the organic material in ground water can react with chlorine during water treatment to form compounds referred to as trihalomethanes. Total trihalomethanes have been detected in treated water in concentrations that exceed the maximum contaminant level of 100 micrograms per liter (μg/L) for drinking-water supplies established by the Georgia Department of Natural Resources, Environmental Protection Division (EPD, 1990).

In the Valdosta area, ground-water-quality concerns generally are related to direct recharge of water from the Withlacoochee River to the Upper Floridan aquifer through sinkholes in the river channel north of Valdosta. Furthermore, because the river water receives little filtration as it recharges the aquifer, ground water in the Valdosta area might be vulnerable to contamination as a result of human activities within the Withlachoochee River basin. To address these concerns, the U.S. Geological Survey (USGS), in cooperation with the city of Valdosta, Ga., in 1988, entered into an investigation of water quality and water-supply potential of the Upper Floridan aquifer in Valdosta and the surrounding area.

Purpose and Scope

The purpose of this report is to present the results of a study of the occurrence and quality of ground water in a karst terrain in the Valdosta area in south-central Georgia. The specific objectives of the study were to (1) define the hydrogeologic framework in the Valdosta area and describe ground-water flow paths in the Upper Floridan aquifer, (2) determine average rates of recharge from the Withlacoochee River to the Upper Floridan aquifer and the effects of recharge on the ground-water quality in the Valdosta area, and (3) evaluate the development potential of ground-water resources in the area.

This report describes the hydrogeology of the study area, the water-quality conditions of the Withlacoochee River, rates of recharge to the Upper Floridan aquifer from the river, and the effects of the recharge on the movement and quality of ground water. Maps are presented showing areas where the quality of ground water is affected by local recharge and where the greatest potential exists for future ground-water resources development.

Tables are included that summarize the surface- and ground-water-quality data collected by the USGS since 1963, as well as data collected during 1988-90 as a part of this study. Data collected from wells during this study provide basis for a more detailed examination of the geologic framework and stream-aquifer relations than was possible in previous investigations.

Area of Study

The study area encompasses about 250 mi^2 in the Coastal Plain physiographic province in south-central Georgia near Valdosta (fig. 1), and includes the areas north, northwest, and northeast of Valdosta, where previous studies by Krause (1976, 1979) indicated that ground-water development potential of the Upper Floridan aquifer is minimally affected by recharge from the Withlacoochee River.

The topography of the study area is characterized by low, rolling hills, and land-surface altitudes that range about 110 to 220 ft above sea level. The terrane is karst and marked by sinkholes and sinkhole lakes. Much of the area is wetlands, containing swamps and bogs. The Withlacoochee River is the major surface drainage feature in the study area. The Withlacoochee River flows from north to south through part of the study area and flows into the Suwannee River about 30 mi south of Valdosta. Sinkholes have developed adjacent to, and within, the streambed along a one-mile reach of the Withlacoochee River north of Valdosta.

Previous Investigations

Previous studies by Krause (1976, 1979) identified water-quality problems, mapped areas where wells open to the Upper Floridan aquifer yielded water high in color and hydrogen sulfide concentrations, examined streamflow and ground-water interactions in the Valdosta area, and described the geology of a three-county area with emphasis on the Valdosta area. Ground-water samples were collected in the Valdosta area by the USGS in 1979, 1982, 1983, 1984, and 1985 and analyzed for major ions, organic compounds, and dissolved gases as part of a data-collection program conducted in cooperation with the city of Valdosta. Past studies by the USGS provide important background information on the hydrogeology of the area and on the processes that affect the water quality of the Upper Floridan aquifer in the Valdosta area. Herrick (1961) and Herrick and Vorhis (1963) studied the geology of the Coastal Plain, including part of the Valdosta area. Miller (1986) investigated the hydrogeologic framework of the Floridan aquifer system in Florida and parts of Georgia (including the Valdosta area), Alabama, and South Carolina. Huddlestun (1988) reported on the geology of the Coastal Plain, including specific areas west and east of Valdosta.

Acknowledgments

Appreciation is extended to the many landowners who permitted the use of their wells for the collection of borehole geophysical data and ground-water samples. A special thanks to Mr. Art Daniel, Valdosta City Engineer, for his support and assistance, and to Mr. Raymond Sutton, Water Plant Superintendent, for his assistance in sampling city wells. The authors also thank Mr. Frank Creasy and Mr. William Garner, well contractors in the area, for their assistance in locating wells and providing well-construction data. The authors also appreciate the assistance provided by Eurybiades Busenberg and L. Neil Plummer of the USGS who provided unpublished chemical and isotopic data for ground-water samples collected in the Valdosta area during 1988.

Well and Surface-Water Station Numbering System

In this report, wells are numbered by a system based on the USGS 7 1/2-minute quadrangle topographic maps. Each 7 1/2-minute map in Georgia has been given a number and letter designation beginning at the southwestern corner of the State. Numbers increase eastward through 39 and letters increase alphabetically northward through "Z", then become double-letter designations "AA" through "PP". The letters "I", "O", "II", and "OO" are not used. Wells inventoried in each quadrangle are numbered sequentially beginning with "1". For example, plates 1 and 2 consist of four 7 1/2-minute quadrangle maps (Valdosta (19E), Indianola (20E), Hahira East (19F) and Bemiss (20F)). Thus, the 10th well inventoried in the Valdosta quadrangle is designated 19E010.

Surface-water stations are identified by a numbering system used for all USGS reports and publications since October 1, 1950. The order of listing stations is in a downstream direction along the main stream. All stations on a tributary entering upstream from a mainstream station are listed before that station. Each surface-water station is assigned a unique number. For example, the station number 02317749 (Withlacoochee River above Valdosta, Ga.), includes a two-digit part number "02", plus the downstream order number "317749".

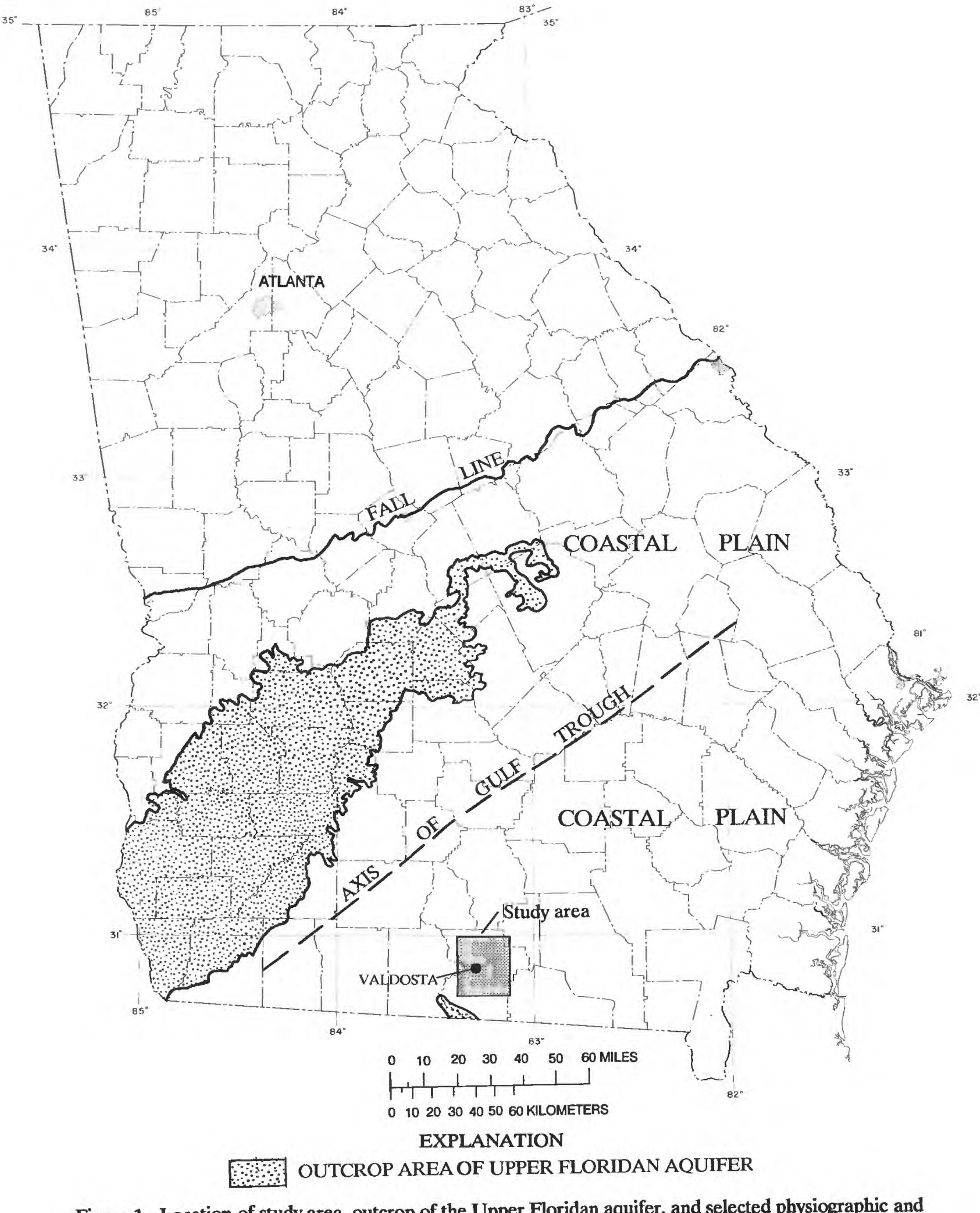


Figure 1.--Location of study area, outcrop of the Upper Floridan aquifer, and selected physiographic and structural features.

DATA COLLECTION

Streamflow, water quality, ground-water level, and borehole geophysical and lithologic data were collected at numerous sites during this study (plates 1, 2). Site data for wells sampled and for wells having borehole geophysical and lithologic data are summarized in tables 1 and 2.

Streamflow

Data from gaged and measured sites on the Withlacoochee River, and streamflow records from the Alapaha River in an adjacent basin (not in the study area) were used to estimate the average long-term streamflow loss (recharge) to the Upper Floridan aquifer. Gaged sites on the Withlacoochee River include Withlacoochee River near Bemiss (station number 02317748) and Withlacoochee River at U.S. Highway 41 near Valdosta (station number 02317755) (plate 1). The streamflow gaging stations were established in October 1976; however, the station near Bemiss was discontinued in December 1981 and the station at U.S. Highway 41 was discontinued in September 1978. A gaging station, Withlacoochee River at McMillan Road near Bemiss (station number 023177483), was established June 1988 about half a mile downstream of the discontinued station near Bemiss. The streamflow gaging station at U.S. Highway 41 was reactivated in August 1988 as part of this study. In addition, streamflow was measured at several points along the reach of the river from the gaging station at McMillan Road to the gaging station at U.S. Highway 41 during selected periods of low flow.

Water Quality

Water samples were collected monthly from the Withlacoochee River above Valdosta (station number 02317749) since November 1974 as part of a data-collection program conducted by the USGS in cooperation with the EPD. Samples were collected in accordance with techniques described by Ward and Harr (1990), and analyzed by the EPD water-quality laboratory, Atlanta, Ga. Water-quality data from the cooperative study with EPD that were used in this study include specific conductance, pH, color, and total organic carbon (TOC). In addition, the USGS collected water samples from the Withlacoochee River during 1988-90 as part of an investigative study with the city of Valdosta.

Water-quality data from the Withlacoochee River were used to characterize the chemical quality and physical properties of the river water where it enters the Upper Floridan aquifer through sinkholes. Organic-carbon data collected since 1974, and long-term streamflow records were used to estimate the amount of organic carbon introduced into the Upper Floridan aquifer by recharge through these sinkholes.

Tritium data were collected periodically from December 1988 to February 1990 at Withlacoochee River above Valdosta and during 1988 at ground-water sampling sites. These data provided information for tracing ground-water movement in the Upper Floridan aquifer. Tritium is a radioactive isotope of hydrogen that occurs naturally in the environment. Concentrations in the atmosphere, and consequently in surface water, were elevated above natural background concentrations in the late 1950's and early 1960's due to nuclear-weapons testing. Thus, elevated tritium concentrations in ground water indicate the presence of water that has entered the Upper Floridan aquifer since the late 1950's.

The Upper Floridan aquifer was sampled adjacent to, and within, areas that were delineated by Krause (1979) as yielding water high in color and hydrogen sulfide concentrations. Water samples were collected periodically from June to December 1988 from 59 privately owned and public water-supply wells open to the Upper Floridan aquifer. In June 1989, samples were collected from a test well (19F100) at the city of Valdosta well-field development site.

Wells from which water samples were collected, generally, were cased to the top of the Upper Floridan aquifer and left uncased in the aquifer. Well depths ranged from 109 to 450 ft, and casing depths ranged from 48.5 to 220 ft below land surface (table 1). Because of the variation in well depth, casing depth, and pumping rate of the wells sampled, water samples from the wells represented a mixture of water from several permeable zones in the open-hole interval; these zones might have contained water dissimilar in chemical character. Thus, the analysis of a water sample from a well is only a general representation of the chemical character of the ground water at that well. The analyses of water from 59 wells provide a general representation of water-quality conditions in the Upper Floridan aquifer in the study area.

Table 1.-- Site data for wells having water-quality data in the Upper Floridan aquifer

[PW, public or business water supply; OBS-REC, observation well equipped with a recorder; D, domestic supply; S, steel; P, polyvinyl chloride (PVC); altitude, in feet, refers to distance above sea level; --, no data]

Well number	Well name	Latitude	Longitude	Land surface (feet)	Well depth (feet)	Casing depth (feet)	Casing material	Number of samples	Well use	Years sampled
19E005	Valdosta well 3	30°51'41"	83°17'02"	226	348	168	S	6	PW	1982-84
19E010	Valdosta well 4	30°49'39"	83°16'58"	200	400	178	S	11	PW	1974, 1979, 1982-85, 1988
19E017	Lloyd Jackson	30°48'23"	83°17'57"	223	251	216	S	2	D	1985, 1988
19E041	Valdosta well 7	30°50'56"	83°19'19"	215	346	187	S	13	PW	1970, 1974, 1979, 1982-85, 1988
19E055	Lowdnes Glass Co.	30°49'52"	83°18'39"	197	230	189	S	1	PW	1985
19E061	WGOV Radio Station	30°48'14"	83°21'21"	228	215	165	S	1	PW	1988
19E063	J. Henley	30°46'02"	83°16'05"	193	220	155	S	1	D	1985
19E067	Process Engineers	30°47'35"	83°16'47"	185	250	190	P	1	PW	1985
19E068	Howard Dasher	30°51'39"	83°18'28"	192	225	199	S	1	D	1985
19E069	Valdosta State College	30°51'02"	83°17'20"	208	290	190	S	2	PW	1985, 1988
19E070	Jack Neece	30°48'12"	83°15'02"	169	200	160	S	2	D	1985, 1988
19E071	Russell Simpson	30°51'11"	83°21'23"	142	109	48.5	S	2	D	1988
19E072	Valdosta Sanitary Landfill	30°49'27"	83°21'38"	200	--	--	S	1	PW	1988
19E073	Greg Small	30°48'46"	83°20'30"	230	240	135	S	1	D	1988
19E074	Valdosta Sewage Treatment Plant	30°50'00"	83°21'37"	144	256	--	S	2	PW	1988
19E081	Airport Beacon	30°47'01"	83°16'06"	196	--	--	S	3	PW	1985, 1988
19F011	Dan Johnson	30°54'07"	83°19'00"	138	112	82	S	1	D	1985
19F018	Valdosta Vocational School	30°53'24"	83°21'14"	194	230	144	S	4	PW	1963, 1974, 1988
19F031	Shell Service Station	30°53'38"	83°21'15"	230	180	158	S	2	PW	1985, 1988
19F038	M.E. Thompson, Oak Street well 2	30°53'16"	83°16'45"	215	300	180	S	7	PW	1974, 1982-84
19F049	Big D Building Materials	30°52'46"	83°18'02"	204	188	153	S	1	PW	1988
19F055	Valdosta well 11	30°54'09"	83°15'53"	220	400	200	S	5	PW	1984, 1985, 1988, 1989
19F057	Charles Woodall	30°53'52"	83°15'08"	225	220	190	P	1	D	1985
19F058	Mineola Motor Home Park	30°54'16"	83°20'24"	195	195	60	S	1	PW	1985
[1]19F061	Scott Holton	30°55'42"	83°20'15"	193	207	130	S	2	D	1988
19F062	J.R. Ziegler	30°56'45"	83°16'21"	156	160	130	S	2	D	1988
[1]19F063	Lucas (original owner)	30°56'11"	83°19'34"	144	180	140	S	2	D	1988
[1]19F064	Ronnie Gray	30°55'23"	83°20'06"	195	200	165	P	1	D	1988
[1]19F065	Pendleton	30°56'00"	83°18'50"	171	160	130	P	1	D	1988
19F066	Edwin Turner	30°54'33"	83°18'48"	147	130	120	S	1	D	1988

Table 1.--Site data for wells having water-quality data in the Upper Floridan aquifer--Continued

[PW, public or business water supply; OBS-REC, observation well equipped with a recorder; D, domestic supply; S, steel; P, polyvinyl chloride (PVC); altitude, in feet, refers to distance above sea level; --, no data]

Well number	Well name	Latitude	Longitude	Land surface (feet)	Well depth (feet)	Casing depth (feet)	Casing material	Number of samples	Well use	Years sampled
19F069	Cherry Creek Baptist Church	30°54'56"	83°15'46"	179	277	172	S	1	PW	1988
19F070	Fenis Miller	30°55'48"	83°15'51"	205	175	127	S	2	D	1988
19F073	J.R. Ziegler	30°56'15"	83°15'51"	221	--	--	--	1	D	1988
19F075	Mrs. Charles Ray	30°52'50"	83°16'24"	234	240	185	S	2	D	1988
19F080	S. Burson and K. Doty (Mini-K)	30°54'14"	83°20'17"	193	165	135	S	1	D	1988
1/19F081	James Miley, Jr.	30°57'35"	83°21'22"	232	180	171	S	1	D	1988
19F082	Jim Fisher	30°53'51"	83°17'59"	175	161	138	S	1	D	1988
1/19F083	Andy Bonner	30°57'46"	83°17'30"	193	132	124	S	1	D	1988
1/19F090	Hubert Parrish	30°57'19"	83°17'58"	188	240	220	P	1	D	1988
19F096	United Pentacostal Church	30°54'20"	83°15'54"	198	190	160	P	1	PW	1988
19F097	J.C. Cowart	30°54'21"	83°15'30"	223	330	210	S	1	OBS-REC	1988
19F100	Valdosta Production test well	30°54'50"	83°15'03"	203	450	195	S	1	PW, unused	1989
19F108	Pineridge Subdivision	30°53'21"	83°16'18"	239	300	190	S	1	PW	1985
20E013	Sidney Dasher	30°49'50"	83°11'32"	192	240	155	S	2	D	1985, 1988
20E016	R.C. Prine	30°45'08"	83°13'30"	180	164	120	S	2	D	1985, 1988
20E017	Bobby Stracener	30°51'36"	83°13'12"	220	250	190	--	2	D	1985, 1988
20E018	Ronnie Fender	30°46'40"	83°13'52"	185	190	--	S	2	D	1985, 1988
20E019	Mud Creek Sewage Treatment Plant	30°48'31"	83°13'34"	180	280	169	S	2	PW	1985, 1988
20F007	Moody U.S. Air Force well 7	30°57'23"	83°11'59"	210	195	182	S	2	PW	1974, 1988
20F024	Glenn Orton	30°53'53"	83°11'52"	212	210	172	S	1	D	1988
20F028	John Morris	30°52'31"	83°13'14"	212	208	177	S	1	D	1988
20F029	Donald Summers	30°53'43"	83°13'56"	200	290	--	S	1	D	1985
20F030	David Ulrich	30°54'25"	83°12'12"	209	185	177	S	2	D	1988
20F031	Charles Ray	30°54'53"	83°14'23"	204	240	180	S	2	D	1988
20F037	Bemiss Methodist Church	30°56'15"	83°14'30"	245	270	200	S	2	PW	1988
20F038	Frank Creasy	30°56'47"	83°13'54"	232	280	190	P	1	D	1988
20F043	William Prince	30°54'51"	83°12'27"	219	250	195	P	1	D	1988
20F046	J. Gartman (GTS Auto Service)	30°58'12"	83°12'59"	230	250	200	P	1	PW	1988
20F048	Academy Acres Subdivision	30°53'42"	83°15'00"	226	350	200	S	1	PW	1988

1/Wells that are not affected by recharge from the Withlacoochee River and represent background water-quality conditions of the Upper Floridan aquifer in the study area.

Table 2.--Site data for wells having borehole geophysical and lithologic data in the study area

[PW, public or business water supply; OBS, observation; OBS-REC, observation well equipped with a recorder; DES, well destroyed; D, domestic supply; I, irrigation supply; S, steel; P, polyvinyl chloride (PVC); altitude, in feet, refers to distance above sea level; --, no data]

Well number	Well name	Latitude	Longitude	Land surface (feet)	Well depth (feet)	Casing depth (feet)	Casing diameter (inches)	Casing material	Well use
19E001	Valdosta well 1	30°49'44"	83°16'54"	215	408	152	15	S	PW
19E004	Valdosta well 2	30°49'44"	83°16'57"	210	367	168	--	S	PW
19E005	Valdosta well 3	30°51'41"	83°17'02"	226	348	168	16	S	PW, unused
19E006	Valdosta test well 2	30°51'35"	83°17'09"	214	334	157	12	S	PW, DES
19E007	Valdosta test well 3	30°51'44"	83°17'19"	195	230	74	8	S	PW
19E008	Sunset Cemetery	30°50'25"	83°17'32"	191	126	120	18	S	PW, unused
19E009	Valdosta observation well	30°49'51"	83°16'58"	213	342	200	20	S	OBS-REC
19E011	Valdosta well 5	30°49'30"	83°16'50"	197	400	190	20	S	PW
19E014	Lowndes County Middle School	30°47'29"	83°15'44"	197	200	170	4	S	PW
19E017	Lloyd Jackson	30°48'23"	83°17'57"	223	251	216	4	S	D
19E018	K.B. Cowart	30°50'27"	83°17'57"	195	220	220	4	S	D
19E026	Ed Hightower	30°50'04"	83°18'55"	192	213	158	4	S	D
19E043	USGS, Lowndes County test well	30°51'49"	83°17'28"	178	965	195	8	S	OBS
19E079	Bob Hooker	30°51'02"	83°21'32"	142	115	104	4	S	D, unused
19E082	H. Stephenson	30°50'22"	83°19'16"	203	193	152	4	S	D, unused
19E083	Lowndes County well 12	30°45'24"	83°16'45"	195	--	--	--	--	test hole
19E085	Jimmy Winters	30°48'42"	83°17'31"	222	179	169	4	S	D
19F020	Hahira, Ga.	30°58'58"	83°22'12"	221	360	126	12	S	PW
19F024	Frank Lindsey	30°59'38"	83°21'07"	212	292	230	4	S	D, unused
19F039	Valdosta well 8	30°52'41"	83°15'46"	222	450	350	16	S	OBS-REC
19F047	Robert Troutman	30°57'18"	83°17'32"	170	162	159	4	S	PW
19F072	Weldon irrigation well	30°59'50"	83°19'41"	230	385	200	--	S	I, unused
19F076	Mineola Church of God	30°54'04"	83°20'08"	190	133	132	4	P,S	PW
19F077	R. Steveson	30°59'33"	83°19'09"	188	121	116	4	S	P, unused
19F078	Mineola Church of God	30°54'04"	83°20'08"	191	65	58	2	P	P, unused
19F084	T.R. Smith	30°54'20"	83°20'13"	193	154	122	4	S	D
19F085	Hubert Parrish	30°57'19"	83°17'58"	188	96	86	4	S	D, unused
19F086	Hubert Parrish well 1	30°57'20"	83°17'58"	188	154	147	4	S	D, unused
19F087	Northlake Golf Course well 1	30°53'49"	83°21'23"	225	296	12	6	S,P	I
19F088	Bellmeade North well 2	30°53'12"	83°18'10"	177	261	116	4	P	D
						137	4	S	

Table 2.--Site data for wells having borehole geophysical and lithologic data in the study area--Continued

[PW, public or business water supply; OBS, observation; OBS-REC, observation well equipped with a recorder; DES, well destroyed; D, domestic supply; I, irrigation supply; S, steel; P, polyvinyl chloride (PVC); altitude, in feet, refers to distance above sea level; --, no data]

Well number	Well name	Latitude	Longitude	Land surface (feet)	Well depth (feet)	Casing depth (feet)	Casing diameter (inches)	Casing material	Well use
19F089	Billy Harnage	30°57'20"	83°19'54"	200	236	141	4	P	D
19F091	Lowndes County well 2	30°55'02"	83°19'28"	143	104	--	--	--	test hole
19F092	Lowndes County well 3	30°57'14"	83°19'46"	195	100	--	--	--	test hole
19F093	Lowndes County well 4	30°59'34"	83°20'57"	215	100	--	--	--	test hole
19F095	J.T. Stalvey/ Hunt Petroleum	30°59'25"	83°15'08"	157	8,550	147	13	S	oil test
19F097	J.C. Cowart	30°54'21"	83°15'30"	223	330	210	8	S	OBS-REC
19F098	Hunt/Murray well 1	30°54'21"	83°16'52"	191	240	180	--	--	D
19F099	Hunt well 1	30°54'21"	83°16'52"	191	5,000	154	13.4	S	oil test
19F100	Valdosta production test well	30°54'50"	83°15'03"	203	450	195	24	S	PW, unused
19F101	Valdosta deep observation well	30°54'51"	83°15'05"	206	450	180	6	S	OBS-REC
19F102	Valdosta shallow observation well	30°54'50"	83°15'05"	205	154	60	12	S	OBS-REC
						60-102	6	S	
19F103	City of Valdosta	30°54'51"	83°15'10"	206	50	30	4	P	D, unused
19F107	Wendy Cornelius	30°57'53"	83°19'09"	212	227	154	4	P	D
20E010	Norfolk and Southern Railroad well 2	30°46'17"	83°13'15"	192	218	169	4	S	I, unused
20E022	Elmer Warren (new home)	30°49'21"	83°14'33"	195	201	162	4	P	D
					--	183	4	S	
20E023	Lowndes County well 1	30°47'27"	83°12'49"	185	--	--	--	--	test hole
20E025	L.P. Shelton	30°50'54"	83°11'16"	200	5,000	185	16	S	oil test
						185-1,385	9.6	S	
20F004	Moody U.S. Air Force well 4	30°58'39"	83°12'15"	224	342	220	6	--	PW
20F006	Moody U.S. Air Force well 3	30°58'38"	83°12'32"	228	440	225	10	S	PW
20F041	Lowndes County well 6	30°54'46"	83°09'05"	215	--	--	--	--	test hole
20F042	Lowndes County well 9	30°55'57"	83°14'27"	243	--	--	--	--	test hole
20F049	Holiday Markets	30°56'22"	83°14'16"	223	240	213	4	P	PW
20F050	T.L. Webb	30°54'45"	83°14'09"	192	142	103	4	P	I
20F057	Nathaniel Burgman well 2	30°57'01"	83°14'49"	224	276	186	4	P	D

Water was sampled from a spigot at the well head after each well was purged by pumping. Specific conductance, pH, temperature, and dissolved oxygen were monitored to determine when the water chemistry stabilized. Water samples were collected after about 20 to 30 minutes of purging, which generally was sufficient time for the water-quality properties and constituent concentrations to stabilize. The water samples were subsequently analyzed for a variety of physical properties and chemical constituents. Concentrations of major ions, trace elements, and tritium were determined by L.N. Plummer and E. Busenburg (unpublished data on file at U.S. Geological Survey, Eastern Region Branch of Regional Research, Reston, Va., 1988).

Water-quality data collected by the USGS from 1963 to 1989 characterizes the physical and chemical properties of ground water in south-central Georgia. Data collected in 1988 were used to construct maps that depict the areal distribution of constituent concentrations in the Upper Floridan aquifer and to delineate areas where ground-water quality in the aquifer is affected by recharge from the Withlacoochee River.

Ground-Water Levels

Water-level data were collected in July and September 1988 in about 70 wells and used to construct potentiometric surface maps of the Upper Floridan aquifer. A potentiometric surface is the altitude at which the water level would have stood in tightly cased wells that penetrate an aquifer. Potentiometric-surface maps show the effect of recharge and discharge on water levels in the study area and were used to estimate the general direction of ground-water flow in the Upper Floridan aquifer.

Physical Properties of Geologic Materials

Borehole geophysical data were collected in 24 wells during this study. These data consisted of caliper, focused resistivity, point resistance, neutron porosity, and natural gamma radiation logs. These data, and geophysical logs collected in 30 additional wells prior to this study, and borehole cuttings were used to describe the hydrogeologic framework in the study area. Sediment cores and cuttings collected from wells 19F100 and 19F101 (plate 2), drilled during this study, were used to determine stratigraphic contacts and correlate changes in stratigraphy with changes on the geophysical logs. Transmissivity of the Upper Floridan aquifer at well 19F100 north of Valdosta near Bemiss (plate 2) was determined by the USGS from aquifer-test data collected by a consulting firm under contract with the city of Valdosta.

GEOLOGIC SETTING

The study area is underlain by sedimentary rocks of pre-Cretaceous through Quaternary age that consist of limestone, dolostone, clay, and sand of varying degrees of lithification and mixtures that extend to a depth of at least 5,000 ft (Miller, 1986). Sediments of late Eocene age and younger are discussed in this section of the report. From oldest to youngest, these geologic units in the area are the Ocala Limestone of late Eocene age, the Suwannee Limestone of Oligocene age, the Hawthorne Group of Miocene age, the Miccosukee Formation of Pliocene age, and undifferentiated sediments of Quaternary age (fig. 2). The geologic names used in this report for the strata of Miocene and Pliocene age are those of the Georgia Department of Natural Resources, Georgia Geologic Survey, and do not conform to current use of the USGS. The sediments are depicted in two hydrogeologic sections in the study area (plate 3). A description of the core and cuttings from borehole 19F101 is summarized in Appendix I at the back of this report.

Ocala Limestone

The Ocala Limestone unconformably overlies carbonate rocks of the Avon Park Formation (fig. 2), and generally consists of bioclastic, fossiliferous limestone containing layers of dolostone in the upper part of the formation. The Ocala ranges in thickness from about 350 ft in the northeastern part to about 500 ft in the northwestern part of the study area (Miller, 1986). The top of the Ocala ranges in altitude from about 200 ft below sea level in the southern part to about 265 ft below sea level in the eastern part of the study area, and generally slopes to the northeast.

Suwannee Limestone

The Suwannee Limestone unconformably overlies the Ocala Limestone (plate 3). The lithology of both formations near the contact consists of brown dolostone interlayered with fossiliferous limestone; however, the presence of the Eocene-age index fossil, *Asterocyclina sp.*, helps to distinguish the contact within the similar lithologies. Overlying the basal dolostone is soft, porous, bioclastic, and ubiquitously phosphatic limestone. Layers of brown dolostone, not associated with the basal dolostone, are present within the lower half of the Suwannee Limestone in the northern part of the study area (well 20F006, plate 3). The Suwannee Limestone ranges in thickness from about 200 ft in the northern part to about 250 ft in the central part of the study area. The top of the Suwannee Limestone ranges in altitude from about 40 ft above sea level in the southern part to about 40 ft below sea level in the eastern part of the study area (fig. 3). The formation dips to the northeast.

Hawthorne Group

The Hawthorne Group in the study area consists of the Chattahoochee, Parachucla, Marks Head, and Coosawatchie Formations (P.F. Huddlestun, Georgia Geologic Survey, oral commun., 1989). Previous studies (Herrick, 1961; Herrick and Vorhis, 1963; Krause, 1979; and Miller, 1986) referred to Miocene-age sediments in the study area as Miocene undifferentiated or Hawthorn Formation.

The Chattahoochee Formation (Huddlestun, 1988) paraconformably overlies the Suwannee Limestone (fig. 2). Core samples from well 19F101 in the north-central part of the study area (near Bemiss) indicate that the Chattahoochee Formation consists of a thin, basal bed of fine to medium quartz sand, overlain by a 15-ft thick section of sparsely sandy, argillaceous, slightly phosphatic dolostone. Small, blue clasts of clay are common in the formation. The Chattahoochee Formation increases in thickness from about 10 ft in the southern part to about 40 ft in the northern part of the study area (plate 3). The top of the Chattahoochee ranges in altitude from about 42 ft above sea level in the southern part to about 25 ft below sea level in the eastern part of the study area. The formation dips to the northeast.

The Parachucla Formation (Huddlestun, 1988) conformably overlies the Chattahoochee Formation (fig. 2) and consists of phosphatic, sandy, macrofossiliferous limestone overlain by a sandy clay bed. The Parachucla Formation has a higher percentage of sand, phosphate, and macrofossils than the Chattahoochee Formation. The Parachucla Formation has a uniform thickness of about 15 to 20 ft in the study area (plate 3). The altitude of the top of the Parachucla ranges from about 65 ft above sea level in the south-southwestern part of the study area to about 5 ft below sea level in the eastern part (not shown on plate 3). The formation dips to the northeast.

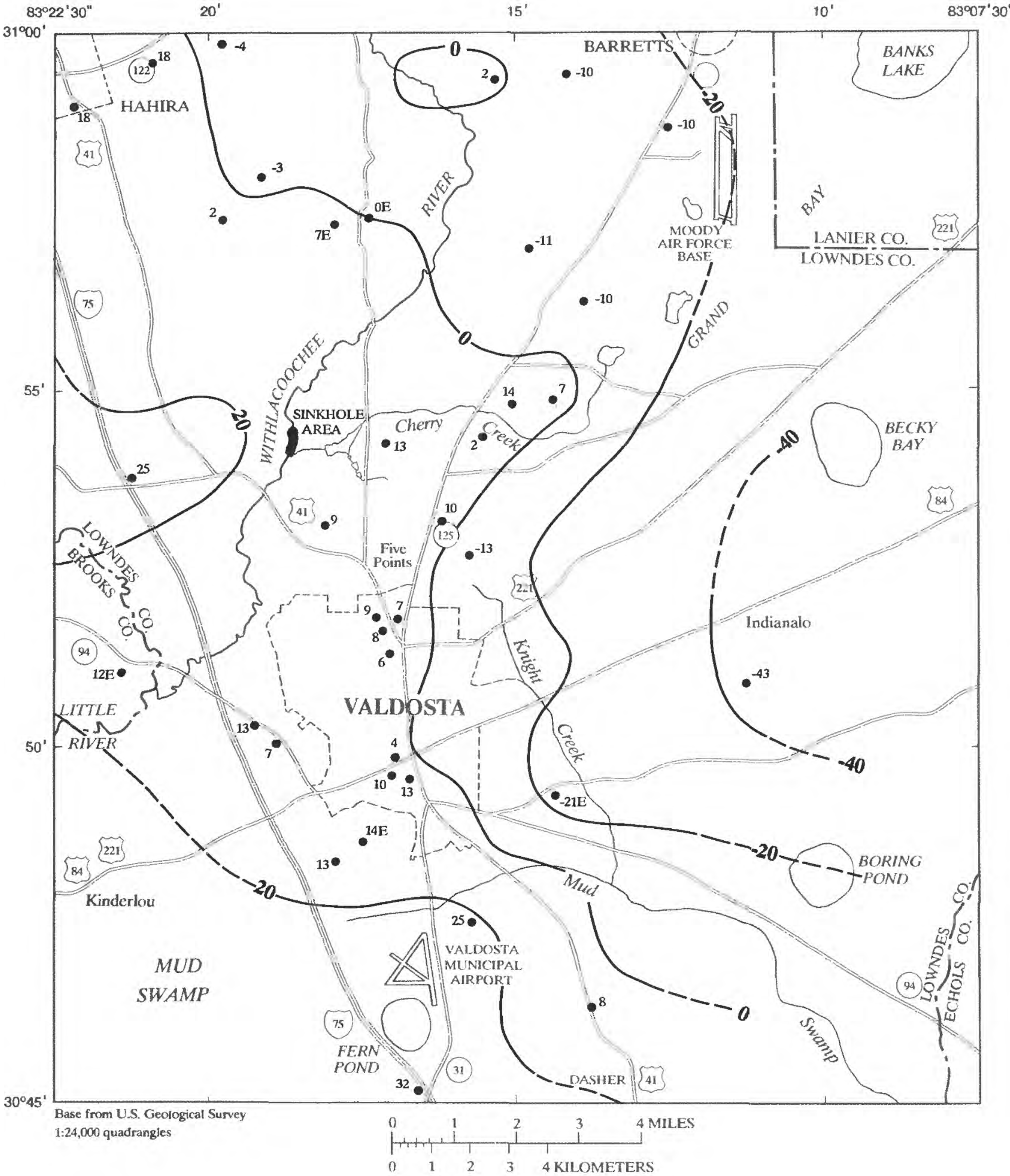
ERATHEM	SYSTEM	SERIES		FORMATION	HYDROGEOLOGIC UNIT	REMARKS
CENOZOIC	QUATERNARY	Holocene		Undifferentiated deposits	Surficial aquifer	Restricted to stream valleys. Provides water for domestic use in some areas.
		Pleistocene	Late		Confining unit	Clayey material of variable thickness in study area. Erosion has removed confining unit in some stream and river valleys in western part of study area.
			Early			
	TERTIARY	Pliocene	Late	Miccosukee Formation[1]	Unnamed aquifer	Provides water for domestic and irrigation needs in northeastern part of study area. Water is slightly acidic. Erosion has removed confining unit in some stream and river valleys in western part of study area
			Early		Confining unit	
		Miocene	Late			Sandy, silty, phosphatic clay.
			Middle	Hawthorne Group[2]: Coosawatchie Formation		Provides water for domestic and irrigation needs in northern part of study area. Water is slightly acidic. Aquifer exposed in stream and river valleys in western part of study area.
			Early	Marks Head Formation	Unnamed aquifer	
					Confining unit	Dense dolostone and phosphatic, cherty, clay.
				Parachucla Formation	Upper water-bearing zone of Upper Floridan aquifer	
				Chattahoochee Formation		
		Oligocene		Suwannee Limestone[3]		Prolific water-bearing zone. The major source of ground water in the Valdosta area. Water is slightly basic. Water type is calcium-magnesium-bicarbonate.
					Confining unit	Dense dolostone.
		Eocene	Late	Ocala Limestone	Lower water-bearing zone of Upper Floridan aquifer	Wells generally not open to this zone.. Water yield decreases, and the potential for poor water quality increases with depth.

[1] Henry and Yon (1967).

[2] Originally defined by Huddlestun (1988) to include only the Parachucla, Marks Head, and Coosawatchie Formations; Chattahoochee Formation included later (P.F. Huddleston, Georgia Geologic Survey, oral commun., 1989).

[3] P.F. Huddleston, Georgia Geologic Survey, written commun., 1991.

Figure 2.--Generalized stratigraphy, water-bearing properties, and water-quality characteristics of formations underlying the Valdosta area.



EXPLANATION

—40— — STRUCTURE CONTOUR--Shows altitude of top of Suwannee Limestone. Dashed where approximately located. Contour interval 20 feet. Datum is mean sea level

13 ● WELL--Number indicates the altitude of top of Suwannee Limestone, in feet above sea level; E, indicates estimated altitude

Figure 3.--Altitude of the top of the Suwannee Limestone.

The Marks Head Formation (Huddlestun, 1988) paraconformably overlies the Parachucla Formation (fig. 2). The lower part of the Marks Head Formation consists of dense, sandy, phosphatic dolostone overlain by sandy, silty, phosphatic, cherty clay. The upper part generally consists of argillaceous, silty, phosphatic sand. At well 19F101, the thickness of the dolostone, clay, and sand layers is about 3.5, 18, and 36 ft, respectively. The Marks Head Formation increases in thickness from south to north in the study area. The formation is about 25 ft thick in the Withlacoochee River valley west-southwest of Valdosta, where erosion has removed much of the formation, and about 60 ft thick in the northern part of the study area. The formation has been breached along part of the Withlacoochee River north of Valdosta, and sinkholes have formed in the streambed (plate 2). The top of the Marks Head formation ranges in altitude from about 133 ft above sea level in the southern part (plate 3) to about 90 ft above sea level in the eastern part of the study area and dips to the northeast.

The Coosawatchie Formation (Huddlestun, 1988) paraconformably overlies the Marks Head Formation (fig. 2) and consists of silty, sandy, calcareous, phosphatic clay. The Coosawatchie Formation ranges in thickness from about 30 ft in the southern part to about 80 ft in the northern part of the study area. In stream valleys in the western part of the study area, the Coosawatchie Formation has been removed by erosion. The top of the Coosawatchie Formation ranges in altitude from 170 ft above sea level in the southern part to about 155 ft above sea level in the eastern part of the study area. The formation dips to the east-northeast.

Miccosukee Formation

The Miccosukee Formation (Huddlestun, 1988) unconformably overlies the Coosawatchie Formation (fig. 2). The lower part of the Miccosukee Formation consists of coarse sand and the upper part consists of clay. At well 19F101, the thickness of the sand and clay is about 33 ft and 25 ft, respectively (plate 3). The thickness has been reduced by erosion because the Miccosukee Formation is exposed at land surface over much of the study area. In some of the stream and river valleys in the western part of the study area, the formation has been completely removed by erosion. The maximum thickness of the Miccosukee Formation is about 98 ft at Bemiss where the land-surface altitude is about 250 ft above sea level and the base of the formation is about 152 ft above sea level.

Undifferentiated Sediments of Quaternary Age

Locally undifferentiated sediments of Quaternary age unconformably overlie older sediments in stream valleys throughout the study area. These sediments generally consist of thin beds of alluvial sand and silt.

HYDROGEOLOGY

Aquifers in the study area include the surficial aquifer, unnamed aquifers of Pliocene and Miocene age, and the Upper Floridan aquifer. The unnamed aquifers that overlie the Upper Floridan aquifer are much less productive and supply minor quantities of water for domestic and agricultural uses. The surficial aquifer generally is an unreliable source of water and is not discussed in this report. The Upper Floridan aquifer is highly transmissive and is the major source of ground water in the area.

Unnamed Aquifer of Pliocene Age

An unnamed aquifer of Pliocene age is present in the basal sand of the Miccosukee Formation (fig. 2 and plate 3). The unnamed aquifer is confined above by the clayey upper part of the Miccosukee Formation, and below by the clayey upper part of the Coosawatchie Formation. This aquifer ranges in thickness from about 20 to 25 ft in the study area. The areal extent of the aquifer is limited to areas where the land-surface altitude is greater than about 150 ft above sea level. Where the land-surface altitude is less than 150 ft, as in some of the stream valleys, the aquifer material has been removed by erosion.

Most recharge to this unnamed aquifer probably is from infiltration of precipitation where the aquifer crops out in the northern part of the study area and farther north beyond the study area boundary. Circular shaped wetland areas called bays in the northern part of the study area also may be a source of recharge when water levels decline in the aquifer. As ground-water levels decline, the altitude of the water surface in the bays is higher than the water level in the unnamed aquifer; thus, creating a potential for recharge from the bays into the aquifer.

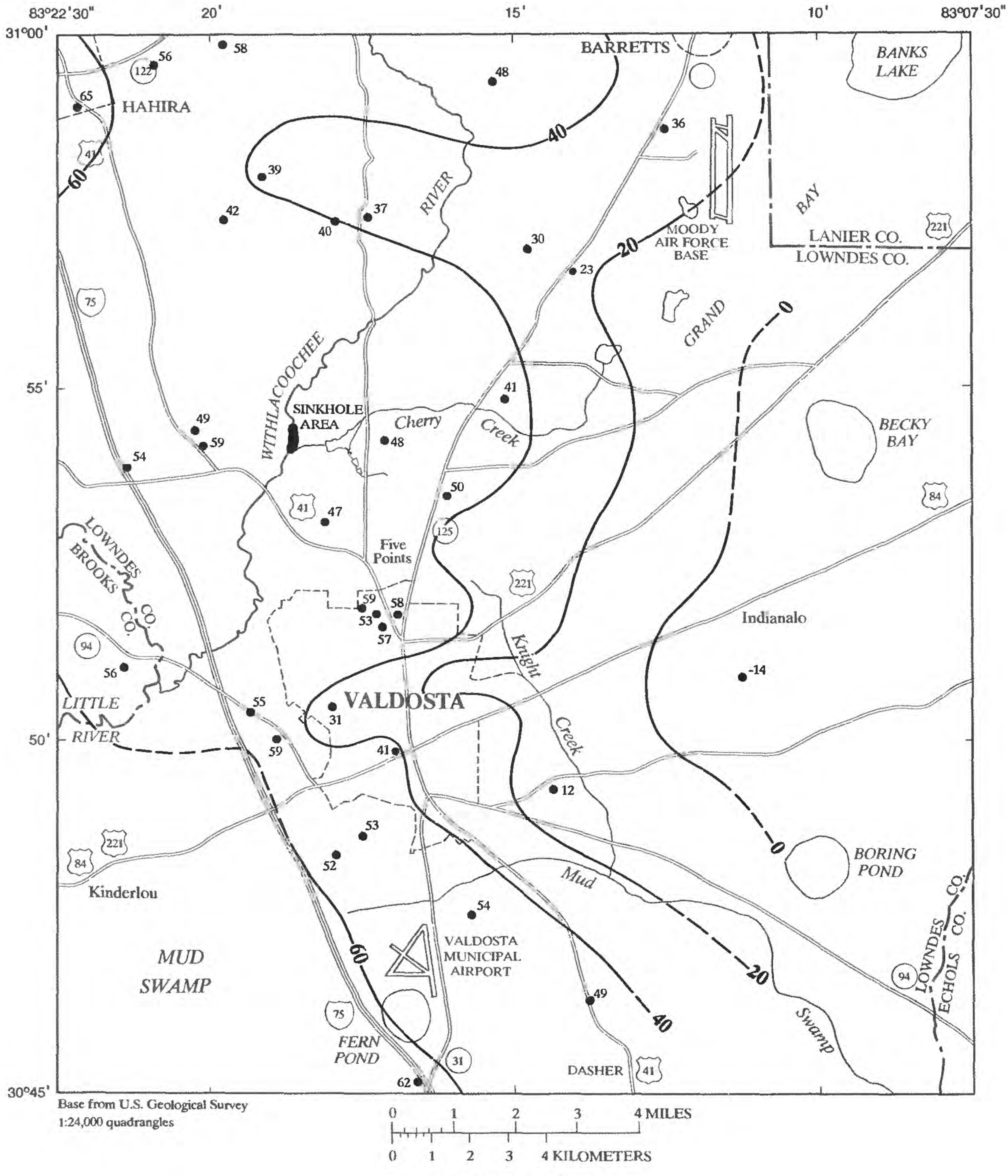
The unnamed aquifer primarily is a water-supply source for domestic and agricultural use on small farms. The water is slightly acidic, making it desirable for the irrigation of crops, such as blueberries, that prefer acidic conditions.

Unnamed Aquifer of Miocene Age

An unnamed aquifer of Miocene age is in sand and clayey sand in the upper part of the Marks Head Formation (fig. 2). This unnamed aquifer is confined above by the clay of the Coosawatchie Formation and below by the clay and dolostone in the lower part of the Marks Head Formation. At well 19F101 in the north-central part of the study area (near Bemiss), the top of the aquifer is about 100 ft below land surface, and the aquifer is about 36 ft thick. Generally, the aquifer ranges in thickness from about 20 ft in the southern part to about 36 ft in the northern part of the study area, and dips to the northeast. The unnamed aquifer is recharged where the aquifer crops out north of the study area, and to a lesser degree, where it crops out south of the study area. Recharge primarily occurs where precipitation directly infiltrates the permeable beds of the Marks Head Formation. The aquifer is a minor source of domestic water supply. In the northeastern part of the study area, wells completed in the aquifer are used to supply water for irrigation of blueberry crops. Water from this aquifer is slightly acidic.

Upper Floridan Aquifer

The Upper Floridan aquifer is part of the Floridan aquifer system that extends over Florida and parts of Georgia, South Carolina, and Alabama. In the study area, the Upper Floridan aquifer is utilized for municipal and industrial water supply. The altitude of the top of the Upper Floridan aquifer in the study area ranges from about 62 ft (fig. 4) above sea level at well 19E083 south of the Valdosta Municipal Airport (plate 2), to about 14 ft below sea level in the eastern part of the study area, near the community of Indianola. The Upper Floridan aquifer dips to the northeast (fig. 4).



EXPLANATION

—40— — STRUCTURE CONTOUR--Shows altitude of top of the Upper Floridan aquifer. Dashed where approximately located. Contour interval 20 feet. Datum is mean sea level

48 ● WELL--Number indicates the altitude of top of the Upper Floridan aquifer, in feet above sea level

Figure 4.--Altitude of the top of the Upper Floridan aquifer.

Water-bearing zones

In the study area, the Upper Floridan aquifer has two distinct water-bearing zones--herein called the upper and lower water-bearing zones (fig. 2). The identity of the upper and lower water-bearing zones is based on borehole geophysical logs or geologic cuttings, or both, from wells in or near the study area (fig. 5). Data indicate that the upper and lower water-bearing zones consist of porous limestone that is separated by about 50 ft of less porous dolostone of late Eocene age.

The upper water-bearing zone consists of sandy limestone of the Parachucla Formation, dolostone of the Chattahoochee Formation, and limestone and dolostone of the Suwannee Limestone (fig. 2). This zone is confined above by the clay beds of the upper part of the Parachucla Formation and by dolostone and clay in the lower part of the Marks Head Formation (plate 3). The lower part of the Hawthorne Group (identified as the Parachucla and Chattahoochee Formations in this study) was excluded regionally as part of the Floridan aquifer system by Miller (1986). However, core, borehole geophysical, and water-level data indicate that the lower part of the Hawthorne Group is water bearing, and hydraulically connected to the underlying Suwannee Limestone; and therefore, is considered part of the Upper Floridan aquifer in this report. Additionally, aquifer-test data from well 19F100 (a water-supply well recently constructed and developed by the city of Valdosta) indicate that the Parachucla and Chattahoochee Formations are permeable and yield water to the wells completed in the upper water-bearing zone.

The upper water-bearing zone of the Upper Floridan aquifer is thickest in the central part of the study area and thins outward in all directions (fig. 5). Within the study area, the thickness ranges from about 282 ft in the central part of the study area to less than 250 ft near the northern and southern boundaries of the study area.

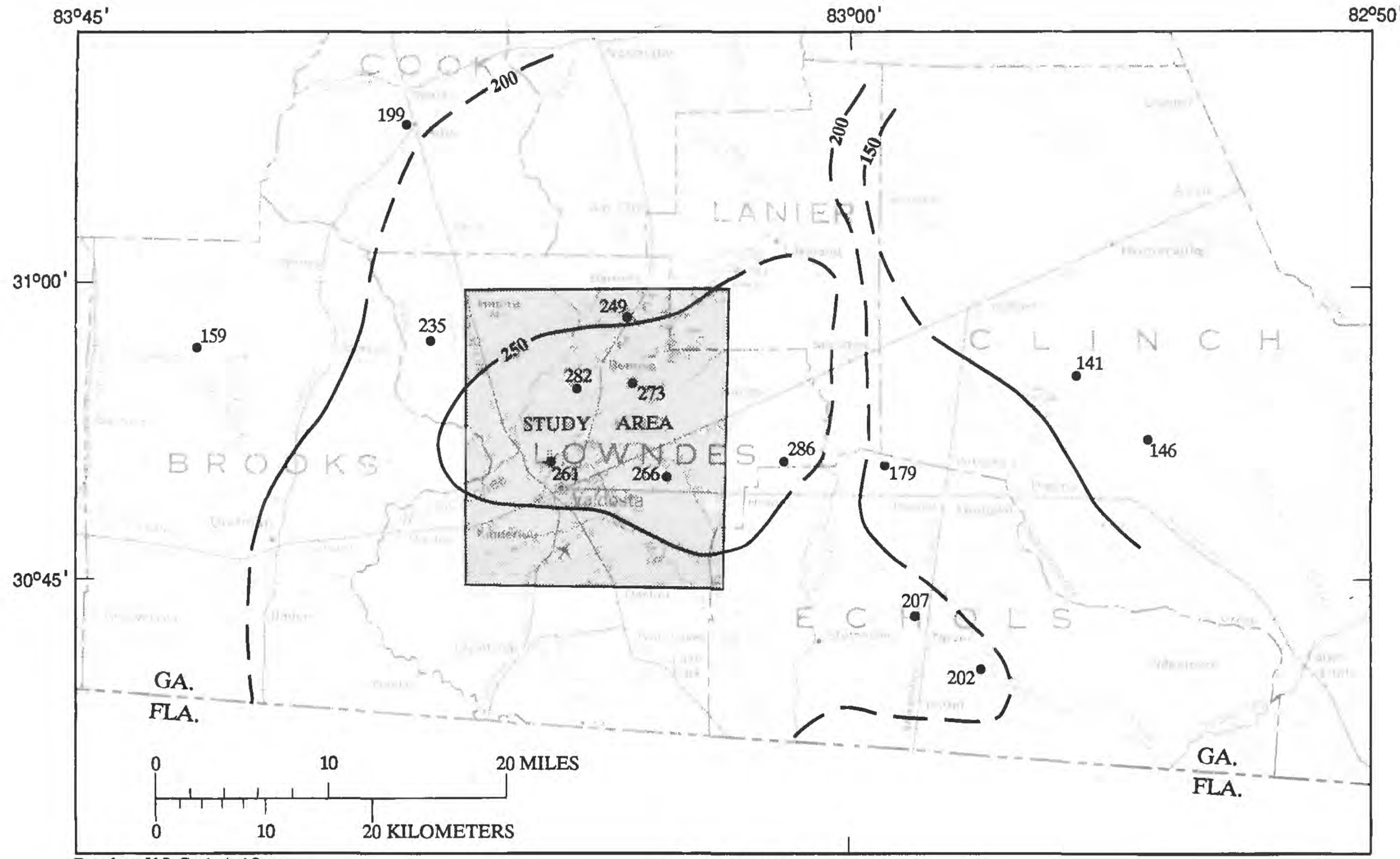
The lower water-bearing zone consists of the Ocala Limestone and is confined above by the dolostone at the top of the Ocala Limestone and below by the gypsiferous limestone of either the Ocala Limestone or the Avon Park Formation (fig. 2). Borehole geophysical data and cuttings from wells indicate the top of the zone ranges from about 240 to 270 ft below sea level. Data are insufficient to estimate the thickness of the lower water-bearing zone in the study area. Water-supply wells generally are not completed in the lower zone because the potential for water-quality problems increases with well depth in this zone, and because the upper water-bearing zone generally provides an ample supply of water suitable for drinking and industrial uses.

Recharge and discharge

The Upper Floridan aquifer is recharged locally north of Valdosta along a short reach of the Withlacoochee River where sinkholes in the streambed allow water to enter the aquifer directly (plate 1). Recharge through the sinkholes is rapid and provides a substantial quantity of water to the upper water-bearing zone of the Upper Floridan in the Valdosta area. The Upper Floridan aquifer in the Valdosta area probably receives little recharge from direct infiltration of rainfall or leakage from overlying aquifers. Although the potetiometric surface of overlying aquifers is higher in altitude than that of the Upper Floridan aquifer (a situation which favors the downward movement of water), confining units that separate the aquifers retard that movement.

The Upper Floridan aquifer that underlies the study area is recharged regionally northwest of Valdosta. The area of greatest recharge probably is between the Gulf Trough, a northeast-southwest trending geologic feature (Zimmerman, 1977; Miller, 1986) (fig. 1), and the study area. Recharge to the Upper Floridan aquifer also occurs in the area northwest of the Gulf Trough where the aquifer is either exposed or is near the land surface (Zimmerman, 1977) (fig. 1). However, simulation of the Floridan aquifer system (Bush and Johnston, 1988; Krause and Randolph, 1989) indicates negligible flow through the Upper Floridan aquifer across the Gulf Trough upgradient of the study area.

Loss of water from the Upper Floridan aquifer occurs naturally as discharge to springs and seeps along the Withlacoochee River south and southwest of the study area, and from withdrawals by wells in the Valdosta area (Krause, 1979). The rate of natural discharge varies as the potentiometric surface of the aquifer increases or decreases. Data are not available to estimate natural discharge in the study area. Pumpage from the aquifer in the study area during 1990 was about 21.8 Mgal/d, which includes about 11.6 and 7.5 Mgal/d withdrawal for industrial use and for drinking water in the vicinity of Valdosta, respectively (J.L. Fanning, USGS, written commun., 1991).



Base from U.S. Geological Survey
State base map 1:500,000, 1970

EXPLANATION

— 250 — — LINE OF EQUAL THICKNESS OF UPPER WATER-BEARING ZONE OF THE UPPER FLORIDAN AQUIFER--Dashed where approximately located. Interval 50 feet

• 179 WELL--Number indicates thickness of upper water-bearing zone, in feet above sea level

Figure 5.--Thickness of upper water-bearing zone of the Upper Floridan aquifer.

Hydraulic characteristics

The upper water-bearing zone of the Upper Floridan aquifer in the study area is highly permeable and capable of transmitting large quantities of water. The high permeability is the result of an innerconnected labyrinth of fractures, conduits, and solution openings in the limestone.

The transmissivity of an aquifer is a measure of its ability to transmit water. Transmissivity estimates from specific capacity data ranged from 100,000 to 220,000 ft^2/d for the Upper Floridan aquifer at the (then) Owens-Illinois plant near Clyattville (10 mi southwest of Valdosta) (Krause, 1979). During this study, a transmissivity of 94,000 ft^2/d for the upper water-bearing zone of the Upper Floridan aquifer was determined from an aquifer test conducted at test well 19F100, 1 1/2-mi south of Bemiss. Test data were analyzed using the Theis equation for non-leaky confining beds (Lohman, 1972). Pumpage of about 1.0 Mgal/d from a well (19F055) near Bemiss resulted in comparatively little water-level decline in nearby wells, providing additional evidence that the aquifer is highly transmissive. Although determinations of transmissivity of the Upper Floridan aquifer are limited, high yields from municipal and industrial wells, and uniform lithology and thickness of the upper water-bearing zone, indicate that the zone probably is highly transmissive throughout the study area.

STREAM-AQUIFER RELATION

Water that enters the Upper Floridan aquifer from sinkholes in and adjacent to the bed of the Withlacoochee River disperses rapidly throughout a large part of the aquifer in the Valdosta area. Water flows through a complex array of passages that developed as a result of dissolution along joints, bedding planes, or other openings in the limestone. A generalized section of the sinkhole and solution-conduit system illustrates sinkhole development and the connection between the river and the Upper Floridan aquifer (fig. 6).

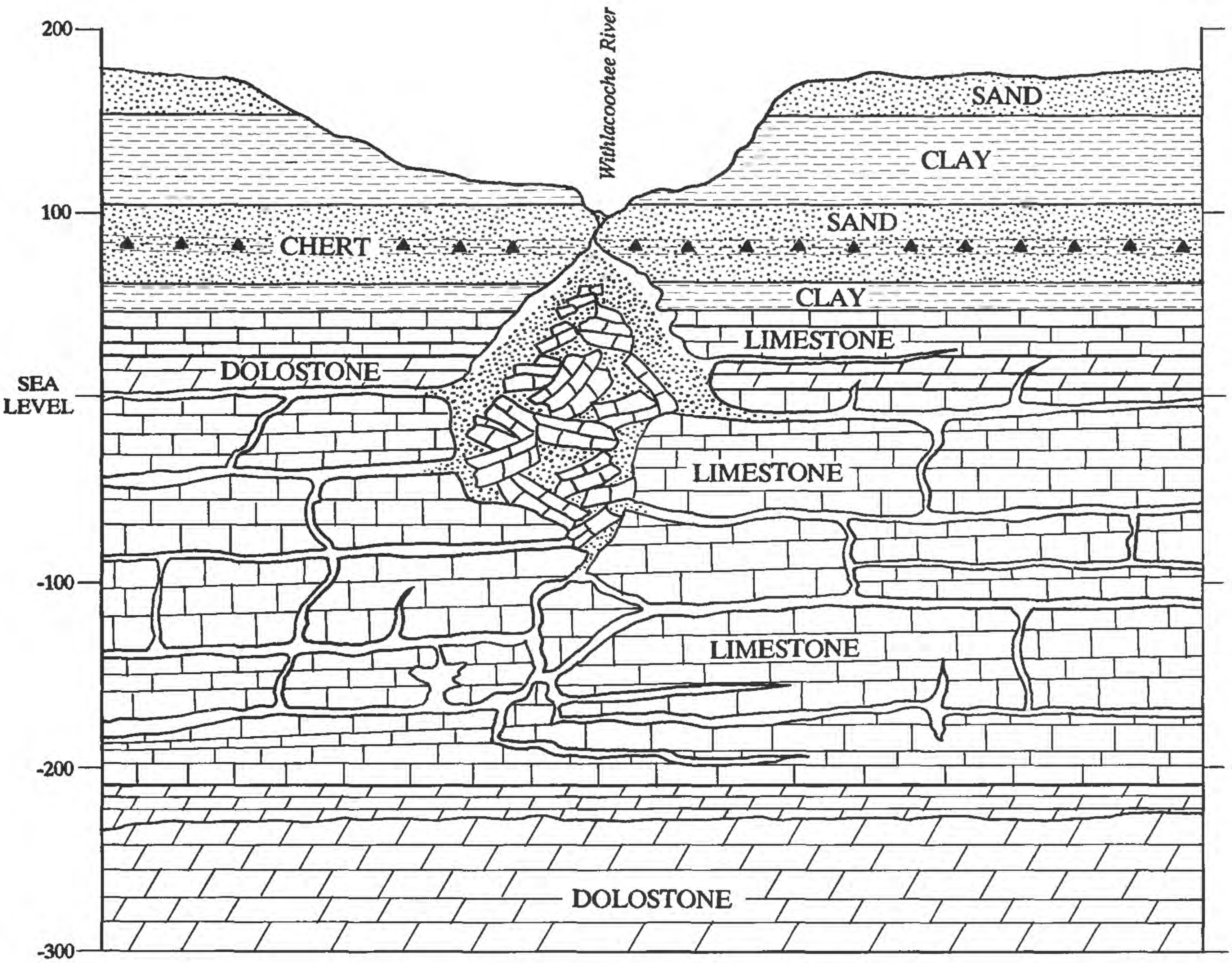


Figure 6.--Generalized section of sinkhole and solution conduit development in the Valdosta area.

The hydraulic connection between the Withlacoochee River and the Upper Floridan aquifer is shown by the rapid response of water levels in the aquifer to seasonal and short-term fluctuations in streamflow of the Withlacoochee River. Krause (1979) reported a correlation between seasonal fluctuations in recharge at the sinkholes and water levels in the aquifer near the recharge area. Rapid increases in water levels in the Upper Floridan aquifer are particularly noticeable during recharge events in the summer and fall when water levels in the aquifer are generally lower than at other times of the year. At well 19E009, about 5 mi south-southeast of the sinkhole area, water levels responded to variations in streamflow at Withlacoochee River at McMillan Road near Bemis (fig. 7). Similar water-level responses of the Upper Floridan aquifer have been monitored in wells 19F039, 19F097, and 19F101, which are equipped with continuous water-level recorders and are nearer the sinkholes than well 19E009 (plate 1).

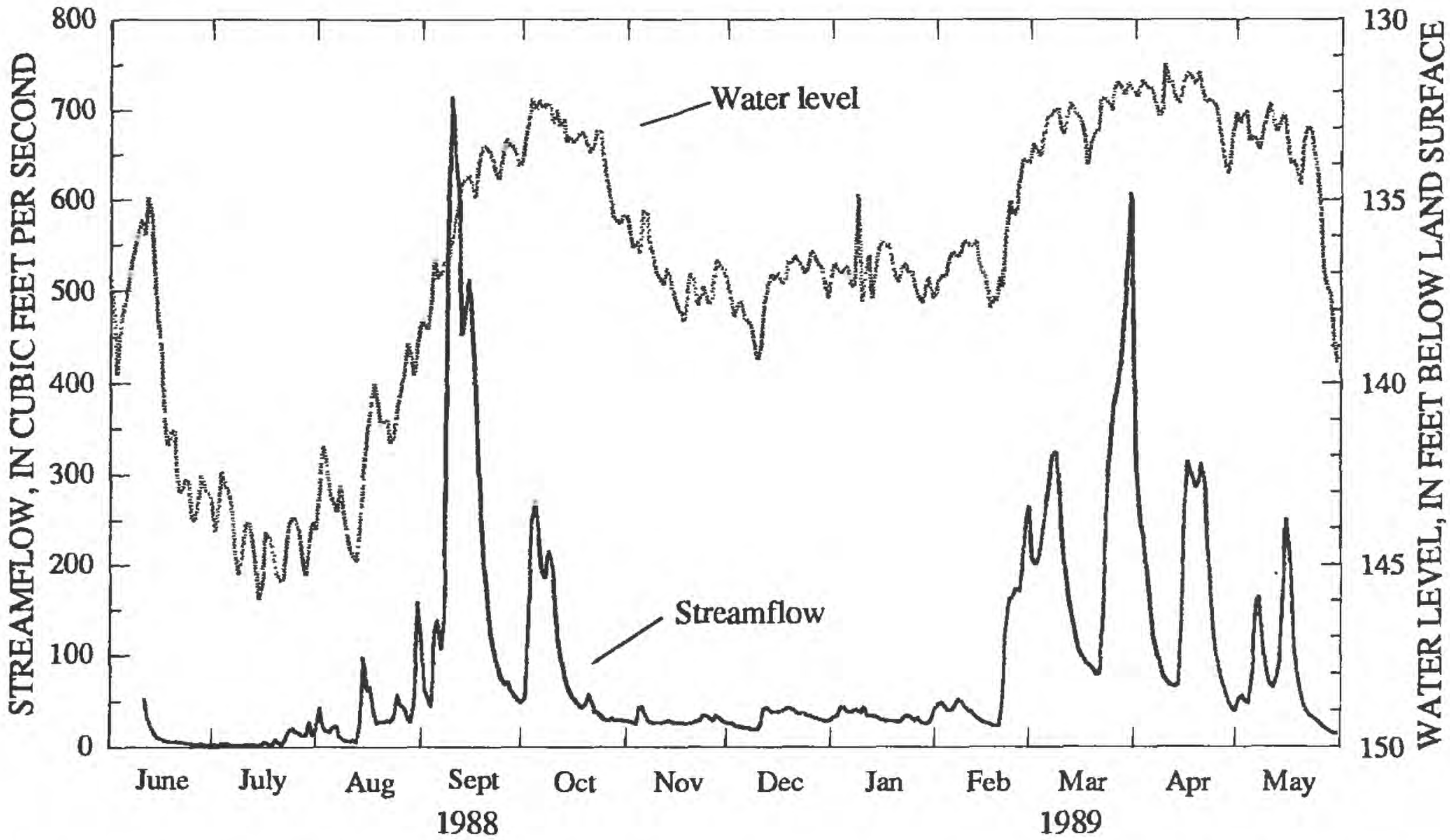


Figure 7.--Streamflow of Withlacoochee River at McMillan Road near Bemiss (023177483) and water level in well 19E009, open to the Upper Floridan aquifer, June 1988 through May 1989.

Streamflow Loss to the Upper Floridan Aquifer

Streamflow data were collected upstream and downstream of the sinkhole area for the purpose of computing streamflow loss and documenting changes in the relation between streamflow of the river and loss to the Upper Floridan aquifer since 1975-76, when Krause (1979) collected similar data. The upstream gaging stations were Withlacoochee River near Bemiss (02317748) (discontinued December 1981), about 5 mi upstream of the sinkhole area; and Withlacoochee River at McMillan Road near Bemiss (023177483) (established June 1988), also about 5 mi upstream of the sinkhole area. The downstream gaging station was Withlacoochee River at U.S. Highway 41 near Valdosta (02317755), about 1 mi downstream from the sinkhole area (plate 1).

Streamflow loss to the Upper Floridan aquifer was determined by (1) selecting concurrent maximum and minimum daily mean discharges from the annual hydrographs of the upstream and downstream stations, (2) calculating 3-day averages from the maximum and minimum daily mean flow and the daily mean flow that precedes and follows the maximum and minimum, and (3) subtracting the concurrent upstream and downstream 3-day averages to determine streamflow loss. Because the drainage area at the sinkholes is about 7-percent greater than at upstream gaging stations, the 3-day average streamflows were increased by 7 percent to represent 3-day average streamflows immediately upstream of the sinkhole area. The difference between the 3-day average immediately upstream of the sinkhole area and the 3-day average at the downstream station is a measure of streamflow loss to the aquifer. Differences were determined for 21 maximum and 15 minimum 3-day averages.

The relation between streamflow in the river and loss to the Upper Floridan aquifer was examined using concurrent streamflow data collected at upstream and downstream gaging stations in 1976-77 and 1988-89; and streamflow measured along the sinkhole reach in July and November 1975 (Krause, 1979), and on four separate occasions in September 1988. Data plotted on figure 8 indicate that all streamflow is lost to the Upper Floridan aquifer through the sinkholes when flow upstream of the sinkhole area is less than about 50 ft^3/s. Measurements of streamflow loss in July and September 1975 (Krause 1979) indicate that the relation at low-flow conditions has not changed appreciably from 1975 to 1989. Flow loss increases when streamflow increases from 50 to about 300 ft^3/s, but the percentage of the streamflow loss becomes increasingly smaller compared to the total flow. Also, the uncertainty in the relation increases at higher streamflows, as indicated by the scatter in the data points about the line in figure 8. At streamflows greater than 300 ft^3/s, the curve plotted on figure 8 flattens, indicating that the average maximum loss to the aquifer is about 82 ft^3/s. The average maximum loss of 82 ft^3/s is substantially less than the 300 ft^3/s (or greater) in 1976 (Krause, 1979).

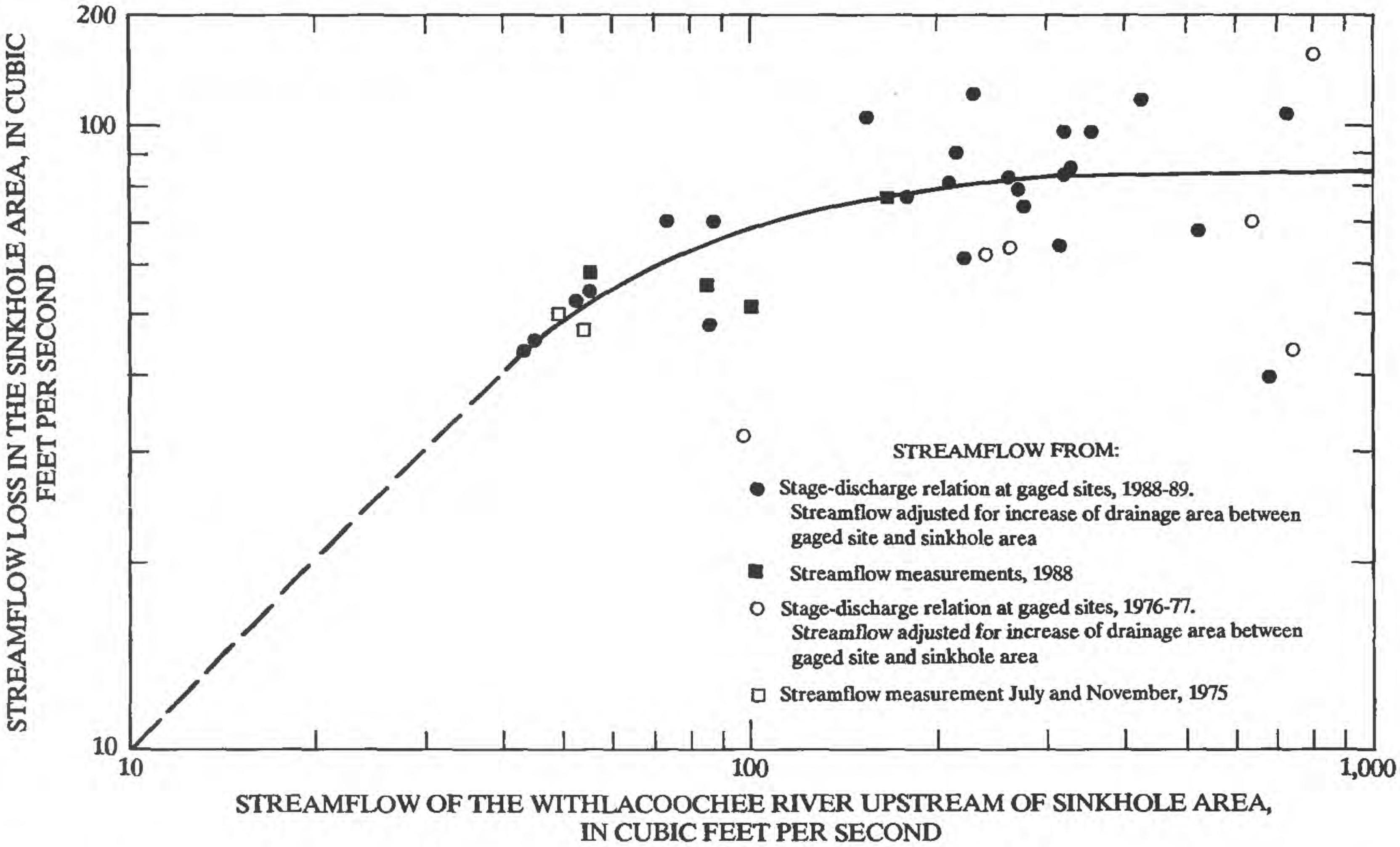


Figure 8.--Relation between streamflow of the Withlacoochee River upstream of the sinkhole area, and streamflow loss to the Upper Floridan aquifer in the sinkhole area.

Streamflow loss is controlled by the physical size of the sinkhole openings and the extent of plugging by debris and sediment, and varies with streamflow (stage) of the river and altitude of the potentiometric surface of the Upper Floridan aquifer. The rate of streamflow loss increases with increasing streamflow, and presumably decreases with increasing altitude of the potentiometric surface of the aquifer. The difference in maximum streamflow loss between studies in 1976 by Krause (1979) and this study may be attributed to better estimates of loss at higher streamflows. Estimates of streamflow loss may have improved in this study, because the downstream gaging site is about 4 mi closer to the sinkhole area than the site used by Krause (1979), and more streamflow data were available to calculate streamflow loss. The altitude of the potentiometric surface of the Upper Floridan aquifer probably was not a major factor contributing to the difference in streamflow loss. The maximum observed altitude of the potentiometric surface was similar in both studies (about 97 ft above sea level) and the minimum observed altitude was lower (71 ft in this study; 87 ft in the study by Krause). The lower altitude presumably would increase the rate of streamflow loss. Also, part of the difference in rate of streamflow loss may be attributed to partial plugging of the sinkholes since the study by Krause (1979).

Long-term streamflow-loss characteristics of the Withlacoochee River in the sinkhole area were evaluated by means of a flow-duration curve. The flow-duration curve is a cumulative frequency curve that shows the percent of time for which specified discharges were equaled or exceeded during a given period. A long-term flow-duration curve (1933-89) for the Withlacoochee River at McMillan Road was constructed by adjusting relatively short-term streamflow records at this site using long-term records at another site by the index-station method described by Searcy (1959). The Alapaha River at Statenville (an adjacent basin outside the study area) was used as the index station. A flow-duration curve for streamflow loss at the sinkhole area (fig. 9) was constructed using the long-term flow-duration curve at McMillan Road gaging station and the streamflow-loss curve shown in figure 8. The long-term average streamflow loss (recharge) to the Upper Floridan aquifer was determined by dividing the area under the flow-duration curve for streamflow loss (fig. 9) by 100 (base of curve--100 percent of time) (Searcy, 1959). The long-term average streamflow loss to the Upper Floridan aquifer is about 60 ft^3/s (1933-89), compared to 112 ft^3/s (1932-75) reported by Krause (1979).

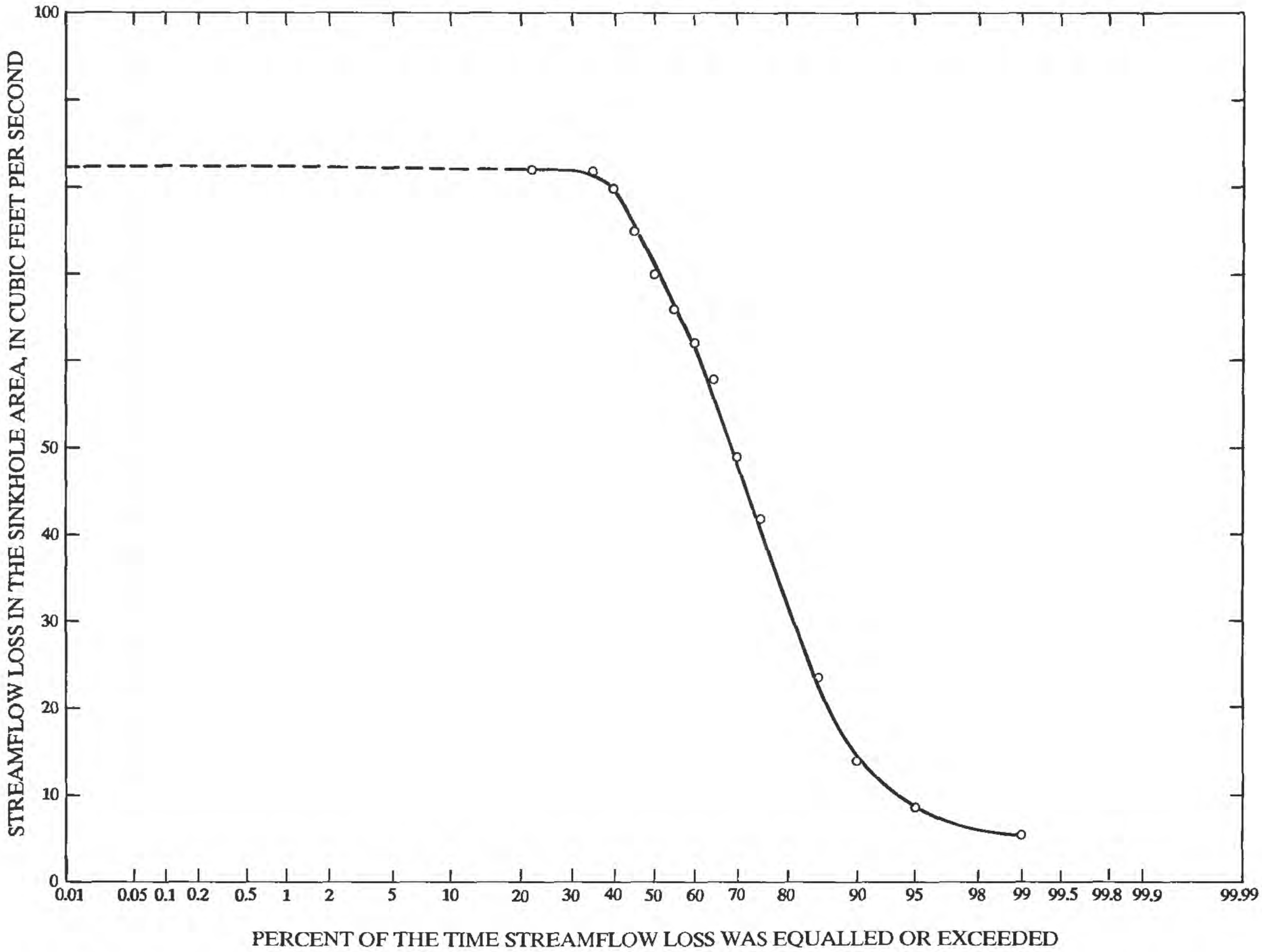
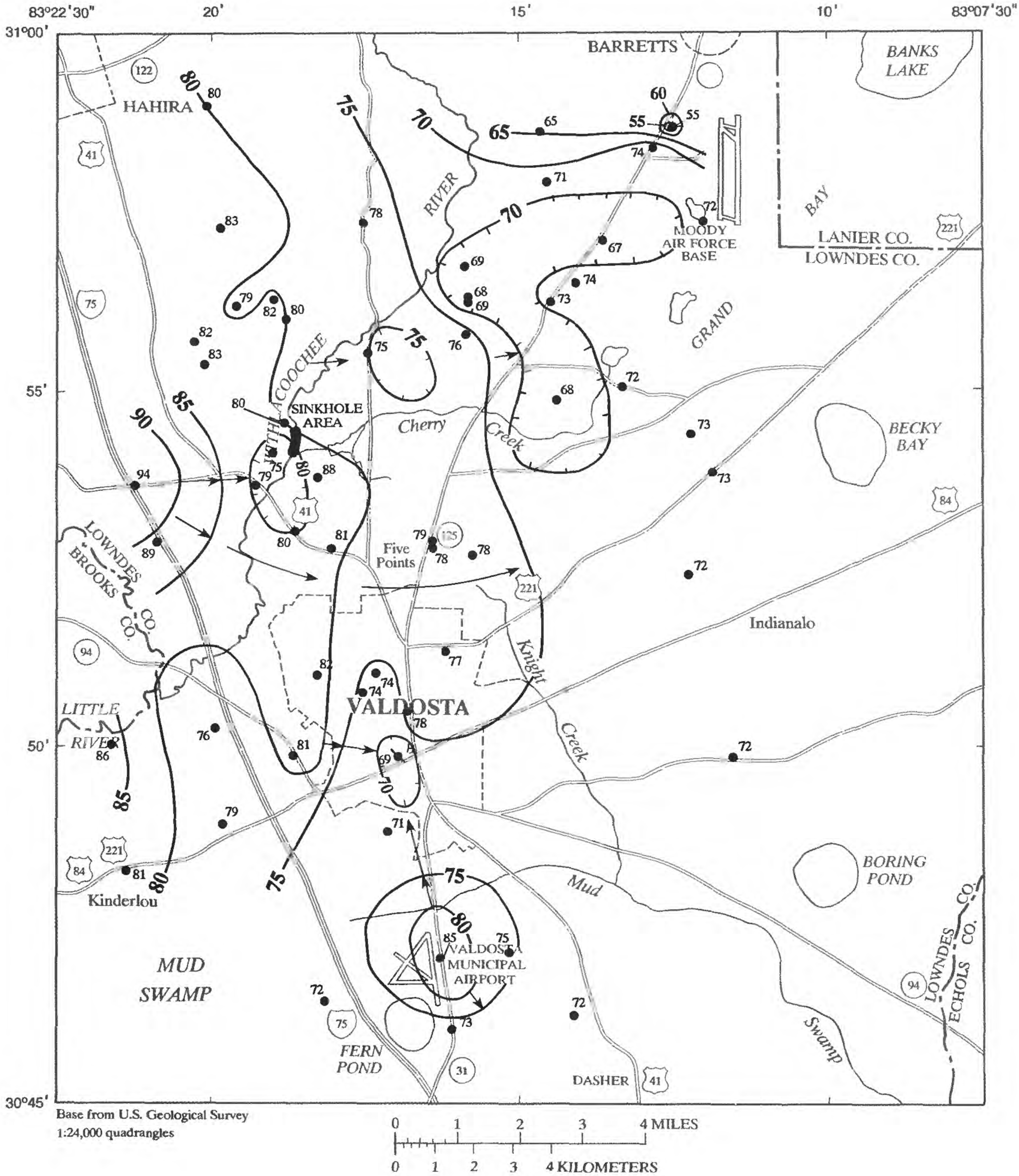


Figure 9.--Duration curve of daily streamflow loss from the Withlacoochee River in the sinkhole area, 1933-89.

Direction of Ground-Water Flow

The idealized path of ground-water flow in an aquifer is downgradient along flow lines drawn perpendicular to the potentiometric surface. In the study area, idealized ground-water-flow paths in the Upper Floridan aquifer are depicted on potentiometric-surface maps developed from water-level measurements made in July and September 1988 (figs. 10 and 11).

The potentiometric-surface map for September 1988 (fig. 11) indicates that the direction of ground-water flow was laterally downgradient in several directions from a mound of ground water (area of elevated ground-water levels) that developed in the aquifer near the sinkhole area. The mound formed as the result of recharge through the sinkholes prior to the measurement period. In July, the mound was absent because recharge was extremely low or nonexistent prior to the measurement period; consequently, the potentiometric surface and the inferred direction of ground-water flow in the aquifer were poorly defined. Flow conditions at Withlacoochee River at McMillan Road near Bemiss that include these time periods are shown in figure 7. Although the potential for ground-water flow is in several directions from the sinkhole area during times of recharge, water-quality data (discussed in a later section) indicate that the flow is predominantly in a south-southeasterly direction from the sinkhole area.



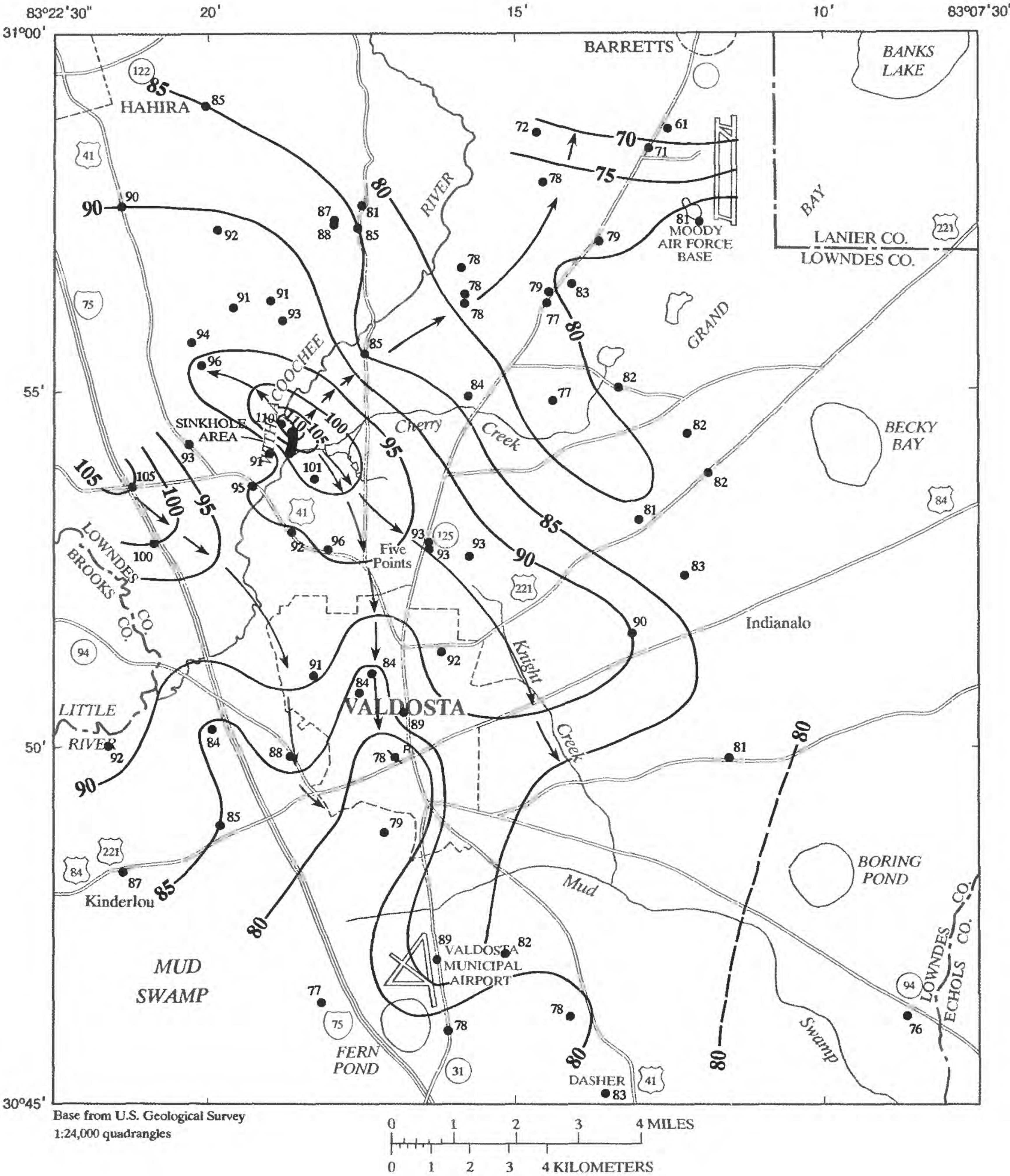
EXPLANATION

— 75 – – POTENTIOMETRIC CONTOUR--Shows altitude at which water level would have stood in tightly cased wells. Dashed where approximately located. Hachures indicate depressions. Contour interval 5 feet. Datum is sea level

⟶ DIRECTION OF GROUND-WATER FLOW

● WATER-LEVEL MEASURING SITE

Figure 10.--Potentiometric surface and direction of ground-water flow in the Upper Floridan aquifer, July 1988.



EXPLANATION

—— 85 — — POTENTIOMETRIC CONTOUR--Shows altitude at which water level would have stood in tightly cased wells. Dashed where approximately located. Hachures indicate depressions. Contour interval 5 feet. Datum is sea level

——→ DIRECTION OF GROUND-WATER FLOW

WATER-LEVEL MEASURING SITE

Figure 11.--Potentiometric surface and direction of ground-water flow in the Upper Floridan aquifer, September 1988.

WATER QUALITY

Water quality in the Upper Floridan aquifer south, southeast, and east of the sinkhole area is markedly affected by recharge from the Withlacoochee River at the sinkholes. The mixing of river water with ground water and ensuing microbially mediated oxidation-reduction (redox) reactions in the aquifer result in ground-water-quality conditions in the Upper Floridan aquifer that are characteristically different from water-quality conditions of either the river water or ground water that is unaffected by recharge from the river.

Naturally occurring organic material in the river water that enters the aquifer at the sinkhole area has a major affect on water-quality conditions in the Valdosta area. The organic material provides a readily available energy source for the growth of microbiota in the aquifer. The microbiota mediate reactions that oxidize organic material and produce high concentrations of hydrogen sulfide by sulfate reduction, and high concentrations of methane by reduction of carbon dioxide. The organic material also is a source of humic substance that can react with chlorine during the water-treatment process to form carcinogenic compounds called trihalomethanes.

Water Quality of the Withlacoochee River

The water quality of the Withlacoochee River that enters the Upper Floridan aquifer was determined from analysis of samples collected at Withlacoochee River above Valdosta (02317749) (about 3 mi upstream from the sinkhole area) from November 1974 through September 1990. Water-quality data are summarized in table 3. Water-quality conditions at this site are considered to be representative of water entering the aquifer through the sinkholes because the intervening area largely is undeveloped and inflow from this area (based on the percentage of intervening area above the sinkholes) is only about 3 percent of the total river flow at the sinkholes.

Physical properties and constituent concentrations of water from the Withlacoochee River are less than maximum contaminant levels (MCL) and secondary maximum contaminant levels (SMCL) for drinking water established by EPD (1990), except for color and iron, which exceed the SMCL. Water in the river is classified as a sodium chloride-sulfate type, because sodium, chloride, and sulfate constitute more than 50 percent of the total cations and anions (Hem, 1985). Median concentrations of sodium, chloride, and sulfate are 15, 14, and 14 mg/L, respectively (table 3).

The median concentration of dissolved solids in samples from the river (80 mg/L, table 3) is low compared to that of water from the Upper Floridan aquifer (151 mg/L, table 4). Water from the river contains large amounts of organic material, as indicated by high concentrations of TOC; is high in iron content; and is highly colored. The median concentrations of TOC and dissolved iron were 16 mg/L and 920 μg/L, respectively. The median color was 110 color units. Organic material, iron, and color are naturally occurring and typical of water from streams in the swampy areas of the lower Coastal Plain.

Organic Carbon Discharge to the Upper Floridan Aquifer

Large quantities of organic material from the Withlacoochee River are discharged to the aquifer in the sinkhole area. For this report, the quantity of organic material discharged to the aquifer was computed as the product of the long-term average TOC concentration in the river water (16 mg/L) and the long-term average streamflow loss to the aquifer (60 ft^3/s). Long-term average TOC concentration of river water was derived from the flow- duration curve method described by Searcy (1959). Based on this method, the area under the duration curve of TOC concentration divided by 100 (100 percent of the time) is the long-term average TOC concentration in the river water. Because TOC concentration varies with streamflow, the TOC concentration used to construct the duration curve was derived from the relation between TOC concentration and streamflow of the Withlacoochee River (fig. 12). TOC concentration increases as streamflow increases and the relation is defined by the regression equation

$$TOC = 4.30 \log Q + 7.09, \qquad (1)$$

where TOC is the average total organic carbon concentration in mg/L, and Q is the instantaneous streamflow in ft^3/s. The correlation coefficient (*r*) is 0.57.

The long-term average TOC load entering the Upper Floridan aquifer through the sinkholes was computed as 2.6 tons per day or 950 tons annually for the period from 1972 to 1989. The computed TOC load likely is a low estimation of the total load entering the aquifer because the water samples analyzed for TOC contained only soluble and fine particulate organic material. Larger particulate material, such as leaves, twigs, and other vegatative debris that could easily be carried to the aquifer through the sinkholes, were not sampled. Decay of the debris in the aquifer likely provides a source of soluble organic carbon to ground water.

Table 3.--Summary of water-quality data, Withlacoochee River above Valdosta, Ga. (02317749), 1974-90

[Dissolved, analysis of filtered sample; total, analysis of unfiltered sample; mg/L, milligrams per liter; µg/L, micrograms per liter; ° C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 °C; $CaCO_3$, calcium carbonate; <, less than; N/A, not applicable]

					Georgia Department of Natural Resources Rules for Safe Drinking Water, December 24, 1990	
Property or constituent and units	Number of analyses	Median value	Minimun value	Maximum value	Maximum contaminant level	Secondary maximum contaminant level
		Properties				
Alkalinity, as $CaCO_3$, mg/L	167	14	1.0	88	N/A	N/A
Color, platinium-cobalt units	186	110	5	300	N/A	15
pH, standard units	197	6.5	5.2	8.0	N/A	N/A
Specific conductance, at 25° C, µS/cm	170	95	29	760	N/A	N/A
Water temperature, ° C	190	19.2	4.0	32.5	N/A	N/A
		Major inorganic constituents				
Bicarbonate, dissolved, mg/L	167	17	1.2	107	N/A	N/A
Calcium, dissolved, mg/L	16	6.0	2.9	14	N/A	N/A
Chloride, dissolved, mg/L	16	14	9.2	36	N/A	250
Dissolved solids, residue at 180° C, mg/L	6	80	68	84	N/A	500
Fluoride, dissolved, mg/L	16	0.1	0.1	0.3	4.0	N/A
Magnesium, dissolved, mg/L	4	2.2	2.0	2.3	N/A	N/A
Nitrite + nitrate, dissolved, as nitrogen, mg/L	4	.17	.06	.29	10	N/A
Orthophosphate phosphorus, dissolved, as phosphorus, mg/L	4	.18	.14	.26	N/A	N/A
Potassium, dissolved, mg/L	16	2.5	.6	5.7	N/A	N/A
Silica, dissolved, mg/L	14	6.8	1.0	13	N/A	N/A
Sodium, dissolved, mg/L	16	15	5.9	67	N/A	N/A
Sulfate, dissolved, mg/L	20	14	4.8	74	N/A	250
		Trace elements				
Aluminium, dissolved, µg/L	14	125	4	1,200	N/A	N/A
Arsenic, dissolved, µg/L	2	2	1	2	50	N/A
Barium, dissolved, µg/L	14	38	16	92	1,000	N/A
Cadmium, dissolved, µg/L	4	0.6	0.1	1.0	10	N/A
Copper, dissolved, µg/L	2	10	10	10	N/A	1,000
Iron, total, µg/L	14	390	170	1,200	N/A	300
Iron, dissolved, µg/L	8	920	340	1,600	N/A	300
Lead, dissolved, µg/L	2	1.1	.8	1.4	50	N/A
Lithium, dissolved, µg/L	2	.5	.3	.7	N/A	N/A
Manganese, total, µg/L	14	5.0	2.0	83	N/A	50
Manganese, dissolved, µg/L	8	38	20	67	N/A	50
Mercury, dissolved, µg/L	3	<.1	<.1	.2	2	N/A
Strontium, dissolved, µg/L	14	35	16	72	N/A	N/A
Zinc, dissolved, µg/L	3	8.0	3.0	18	N/A	5,000
		Other constituents				
Organic carbon, total, mg/L	183	16	1.0	32	N/A	N/A
Tritium, tritium units	13	10.1	7.4	14.4	N/A	N/A

Table 4.--Summary of water-quality data for sampled wells in the Upper Floridan aquifer, 1963-89

[Dissolved, analysis of filtered sample; total, analysis of unfiltered sample; mg/L, milligrams per liter; µg/L, micrograms per liter; ° C, degrees Celsius; µS/cm, microsiemens per centimeter; $CaCO_3$, calcium carbonate; <, less than; N/A, not applicable]

NOTE: Group A wells--Wells (52) in the study area excluding wells used to define background water-quality conditions. Analyses of samples from these wells are used to describe the general water-quality conditions of the Upper Floridan aquifer in the study area.

Group B wells--Wells (7) north of the sinkhole area where water-quality of the Upper Floridan aquifer is unaffected by recharge from the Withlacoochee River. Analyses of samples from these wells are used to define background water-quality conditions of the Upper Floridan aquifer in the study area.

Property or constituent and units	Group	Number of analyses	Median values	Minimum values	Maximum values	Georgia Department of Natural Resources Rules for Safe Drinking Water, December 24, 1990: Maximum contaminant level	Secondary maximum contaminant level
			Properties				
Alkalinity, as $CaCO_3$, mg/L	A	49	114	69	156	N/A	N/A
	B	12	114	102	135		
Color, platinium-cobalt units	A	110	5	<1	60	N/A	15
	B	12	<5	<5	5		
pH, standard units	A	120	7.9	7.1	8.3	N/A	N/A
	B	12	7.9	7.4	8.1		
Specific conductance,	A	120	220	135	380	N/A	N/A
at 25 ° C, µS/cm	B	12	220	200	230		
Water temperature, ° C	A	110	21.5	18	23.5	N/A	N/A
	B	12	21.5	21	22.0		
			Major constituents				
Bicarbonate, disssolved, mg/L	A	49	139	84	190	N/A	N/A
	B	12	139	124	165		
Bromide, dissolved, mg/L	A	49	.02	<.01	0.03	N/A	N/A
	B	12	.01	<.01	.02		
Calcium, dissolved, mg/L	A	66	31	17	57	N/A	N/A
	B	12	29	24	32		
Chloride, dissolved, mg/L	A	65	3.3	2.5	9.6	N/A	250
	B	12	2.8	2.5	3.0		
Dissolved solids, residue	A	102	151	87	260	N/A	500
at 180 ° C, mg/L	B	8	149	131	185		
Fluoride, dissolved, mg/L	A	65	.3	<.1	0.8	4.0	N/A
	B	12	.4	.2	1.1		
Magnesium, dissolved, mg/L	A	66	8.7	3.6	14	N/A	N/A
	B	12	10	8.1	12		
Nitrite + nitrate, dissolved,	A	66	<.02	<.02	1.3	10	N/A
as nitrogen, mg/L	B	12	<.02	<.02	.02		
Orthophosphate phosphorus, as	A	57	.03	.01	.33	N/A	N/A
phosphorus, mg/L	B	8	.02	.01	.07		
Potassium, dissolved, mg/L	A	66	.7	.2	1.5	N/A	N/A
	B	12	.9	.7	1.1		
Silica, dissolved, mg/L	A	97	31	9.9	74	N/A	N/A
	B	12	33	28	48		
Sodium, dissolved, mg/L	A	66	3.3	2.1	7.7	N/A	N/A
	B	12	3.1	2.4	4.7		
Sulfate, dissolved, mg/L	A	111	2.8	<.1	110	N/A	250
	B	12	0.9	0.2	5.2		

Table 4.--Summary of water-quality data for sampled wells in the Upper Floridan aquifer, 1963-89--Continued

[Dissolved, analysis of filtered sample; total, analysis of unfiltered sample; mg/L, milligrams per liter; µg/L, micrograms per liter; ° C, degrees Celsius; µS/cm, microsiemens per centimeter; $CaCO_3$, calcium carbonate; <, less than; N/A, not applicable]

NOTE: Group A wells--Wells (52) in the study area excluding wells used to define background water-quality conditions. Analyses of samples from these wells are used to describe the general water-quality conditions of the Upper Floridan aquifer in the study area.

Group B wells--Wells (7) north of the sinkhole area where water-quality of the Upper Floridan aquifer is unaffected by recharge from the Withlacoochee River. Analyses of samples from these wells are used to define background water-quality conditions of the Upper Floridan aquifer in the study area.

Property or constituent and units	Group	Number of analyses	Median values	Minimum values	Maximum values	Georgia Department of Natural Resources Rules for Safe Drinking Water, December 24, 1990: Maximum contaminant level	Secondary maximum contaminant level
			Trace elements				
Aluminium, dissolved, µg/L	A	55	10	1	70	N/A	N/A
	B	12	10	<1	170		
Barium, dissolved, µg/L	A	50	19	6	83	1,000	N/A
	B	12	9	2	22		
Cadmium, dissolved, µg/L	A	65	0.1	<.1	6.0	10	N/A
	B	8	.1	<.1	1.1		
Iron, total, µg/L	A	44	50	8	500	N/A	300
	B	7	30	<20	900		
Iron, dissolved, µg/L	A	105	15	<3	480	N/A	300
	B	12	11	<3	600		
Lead, dissolved, µg/L	A	56	1	<1	5	50	N/A
	B	8	1	<1	3		
Lithium, dissolved, µg/L	A	49	4	1	8	N/A	N/A
	B	12	4	2	6		
Manganese, total, µg/L	A	44	11	<1	210	N/A	50
	B	7	14	3	62		
Manganese, dissolved, µg/L	A	79	10	<1	210	N/A	50
	B	12	12	3	65		
Mercury, dissolved, µg/L	A	63	.1	<.1	1.4	2	N/A
	B	8	<.1	<.1	.2		
Strontium, dissolved, µg/L	A	52	57	30	98	N/A	N/A
	B	12	42	34	52		
Zinc, dissolved, µg/L	A	62	10	<3	180	N/A	5,000
	B	8	31	5	580		
			Other constituents				
Methane, µg/L	A	26	50	2	1,820	N/A	N/A
	B	6	<1	<1	16		
Organic carbon, total, mg/L	A	107	1.7	.1	8.7	N/A	N/A
	B	9	.4	.3	.6		
Sulfide, total, mg/L	A	81	.3	<.1	2.9	N/A	N/A
	B	12	<.1	<.1	.1		
Tritium, tritium units	A	27	.4	<.1	7.0	N/A	N/A
	B	4	<.1	<.1	.3		

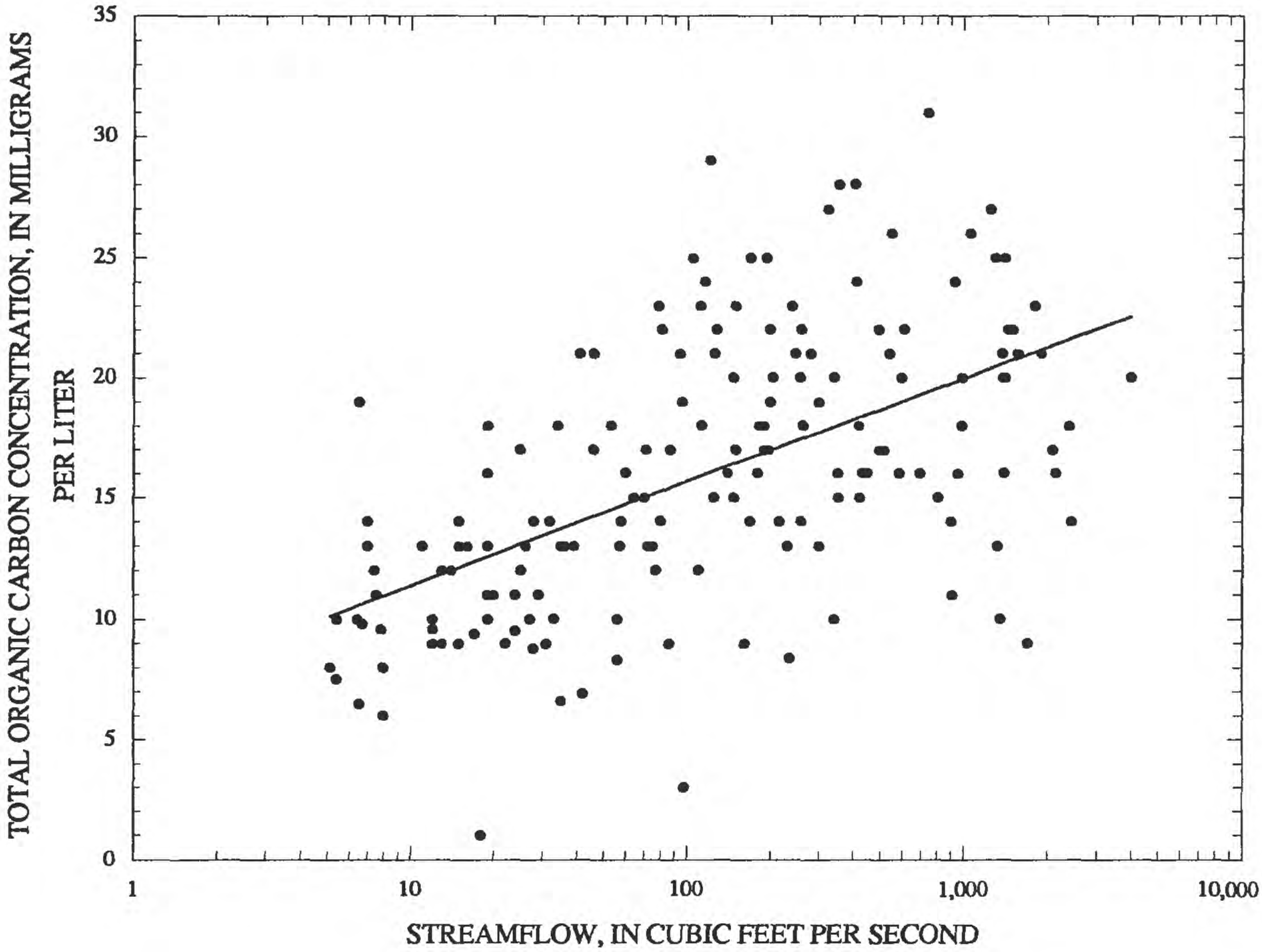


Figure 12.--Relation between streamflow and total organic carbon concentration, Withlacoochee River above Valdosta (02317749), water years 1975-89.

Effects of Recharge on Ground-Water Quality

Water-quality conditions of the Upper Floridan aquifer in the study area were determined from analysis of samples collected periodically at 59 wells from 1963 to 1989. The water-quality data are summarized in table 4. Water-quality data from 7 of the wells located north-northwest of the sinkhole area (table 1, plate 1) are considered representative of regional background water-quality conditions (table 4; group B wells). Water quality in the Upper Floridan aquifer in this area presumably is unaffected by recharge in the sinkhole area because water entering the aquifer at the sinkholes flows predominately in a south-southeasterly direction. Water-quality data for the 52 wells in group A in table 4 are indicative of the general physical and chemical quality of water in the Upper Floridan aquifer in the study area.

The water from the Upper Floridan aquifer wells (group A and B wells) is a calcium-magnesium-bicarbonate type. Properties and constituent concentrations in water from both groups of wells listed in table 4 are less than MCL and SMCL for drinking water established by the EPD (1990) except for color, iron, and manganese, which have maximum values that exceed the SMCL of 15 color units, 300 µg/L and 50 µg/L, respectively (table 4).

Concentrations of TOC, chloride, total sulfide, and methane in regional ground water (represented by concentrations in group A wells) are affected markedly by river water entering the Upper Floridan aquifer in the sinkhole area. Median and maximum concentrations for these constituents are substantially higher for group A wells than for group B wells (table 4). Graphic summaries of these constituents for the river and group A and B wells are shown on figure 13. Elevated concentrations of TOC and chloride in group A wells are caused by mixing of river water having relatively high TOC and chloride concentrations with ground water having low concentrations of these constituents. Elevated concentrations of total sulfide and methane in group A wells are the result of microbially mediated reactions in mixed waters downgradient of sinkhole area. Concentrations of total sulfide and methane in the river are below the level of analytical detection; and thus, not shown in the graphic summary (fig. 13).

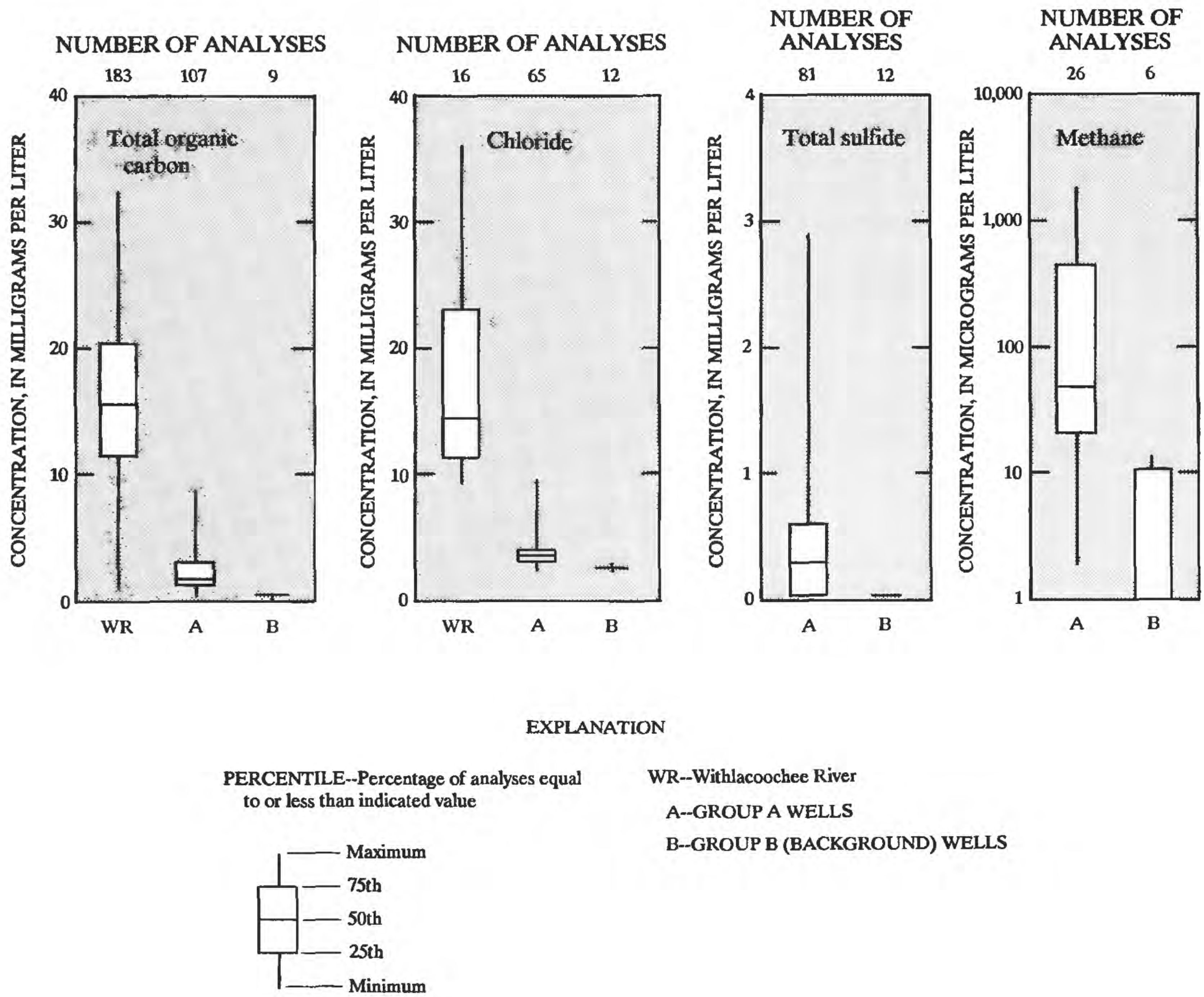


Figure 13.--Summary of selected water-quality constituents in the Withlacoochee River and the Upper Floridan aquifer.

Relatively high concentrations of chloride and tritium in ground water also indicate the effects of river recharge on ground-water quality. Ground water having chloride concentrations greater than about 3 mg/L (about the median chloride concentration for Group B wells) probably represent a mixture of river and ground water. Tritium concentrations greater than 2 TU in ground-water samples from the Valdosta area indicate that the ground water contains some post-1950's water (L.N. Plummer, U.S. Geological Survey, written commun., 1989).

Samples from four wells in the study area (19E010, 19E070, 19F049, and 19F018) have chloride and tritium concentrations greater than 3 mg/L and 2 TU, respectively (fig. 14). The Withlacoochee River probably is the source of chloride and tritium in ground water from wells 19E010, 19E070, and 19F049. These wells are located south of the sinkhole area along the general direction of ground-water flow and have relatively high TOC concentrations (greater than 2.0 mg/L). Relatively high chloride and tritium concentrations in water from these wells also could indicate rapid flow through caverns or other large solution openings. In such passages, river water has less opportunity to mix with the ground water than in parts of the Upper Floridan aquifer where the river water is more diffusely dispersed. Chloride and tritium in water from well 19F018, located about 4 mi west of the sinkhole area, may be from surface sources other than direct recharge at the sinkholes because the TOC concentration in the water sample from this well was low (0.3 mg/L).

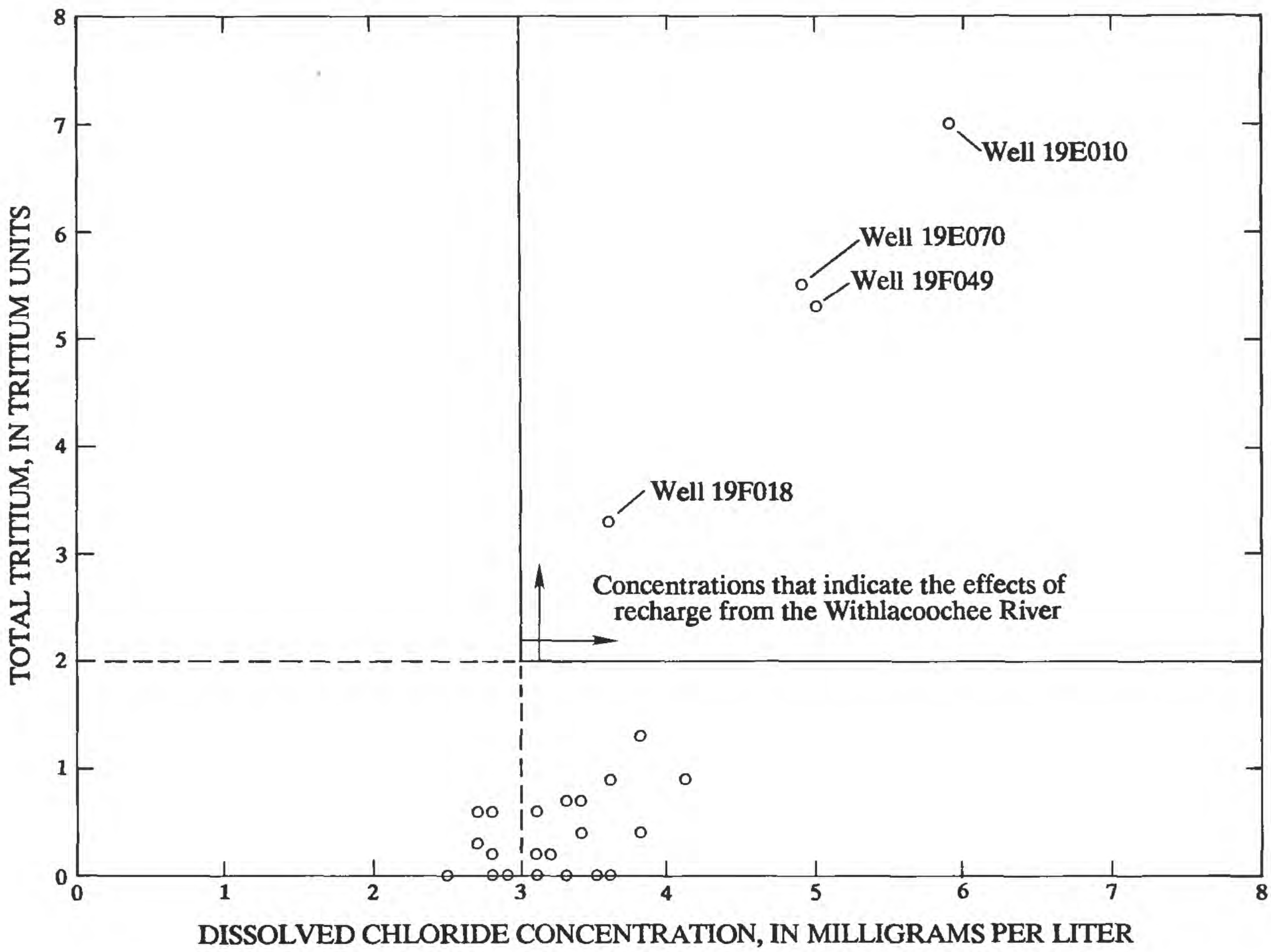


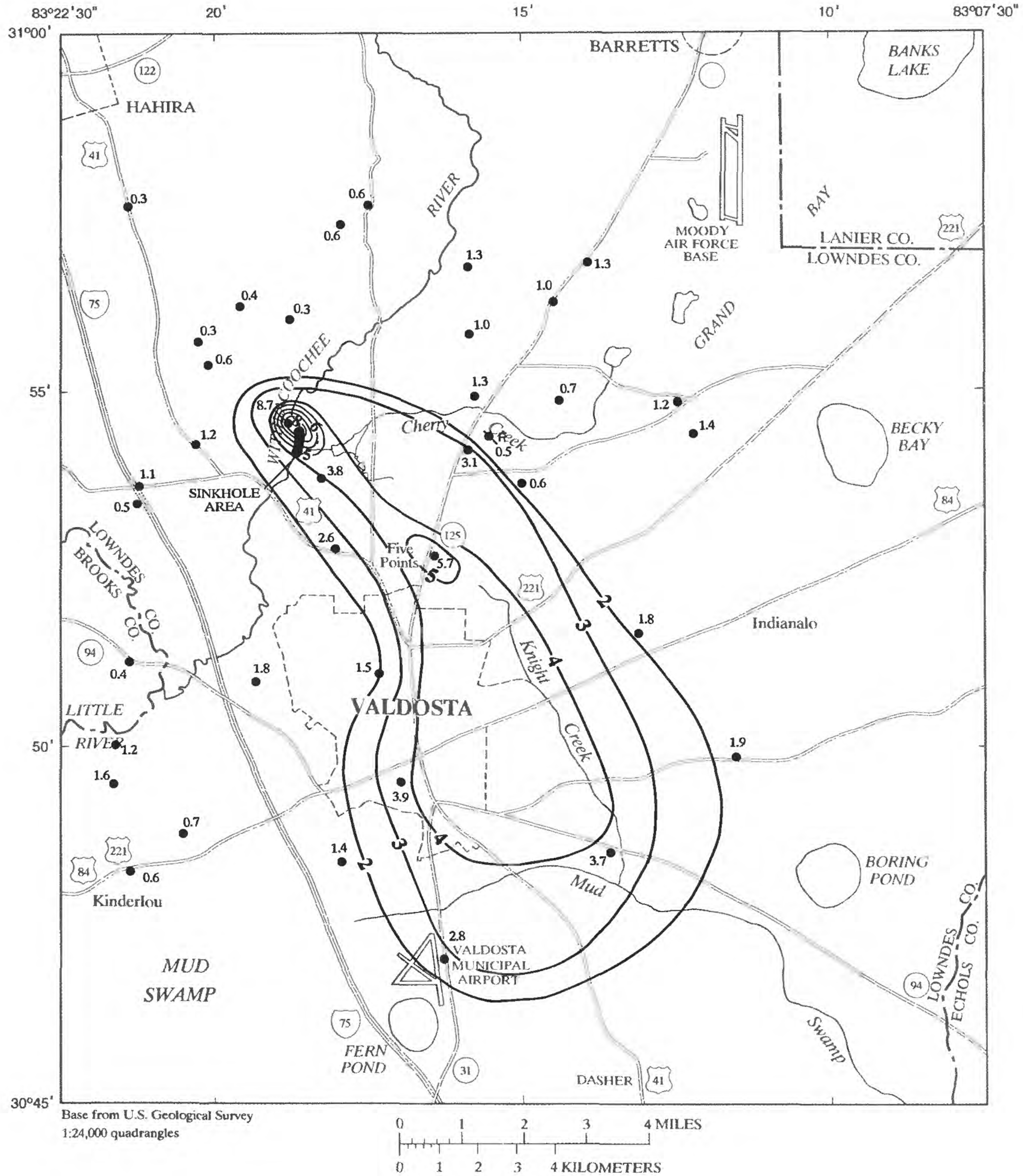
Figure 14.--Relation between chloride and tritium concentrations in water from wells open to the Upper Floridan aquifer, August 1988.

Total Organic Carbon, Total Sulfide, and Methane Distribution in Ground Water

The areal distributions of TOC, total sulfide, and methane concentrations in ground water in the Upper Floridan aquifer in the vicinity of Valdosta indicate the general areas affected by recharge from the river. TOC concentrations were highest (about 8 mg/L) near the sinkhole area, and an elongated plume of relatively high TOC concentration extended southward from the sinkhole area (fig. 15). Total sulfide concentrations were less than 0.5 mg/L in the vicinity of the sinkhole area, but increased more than 2 mg/L in the central Valdosta area, south of the sinkholes (fig. 16). Methane concentrations were high (about 1,700 µg/L) near the sinkhole area, and a plume of relatively high methane concentration extended southeastward from the sinkhole area (fig. 17). Areas having concentrations of total sulfide and methane of 0.5 mg/L and 100 µg/L or greater, respectively, also were mapped northeast of the sinkhole area (figs. 16 and 17).

The distribution of TOC in the aquifer (fig. 15) indicates that river water is a major source of TOC in ground water in the Valdosta area. The configuration of the lines of equal TOC concentration in figure 15 indicate the water entering the aquifer at the sinkhole area predominately flows in a south-southeasterly direction, which is supported by the potentiometric-surface map of September 1988 (fig. 11). High concentrations of sulfide and methane (figs. 16 and 17) also identify parts of the aquifer that are affected by recharge from the river, because the microbiota that mediate sulfide- and methane-producing reactions presumably obtain their source of energy for growth from the river-borne organic material. The relatively high concentrations of sulfide and methane in ground water northeast of the sinkhole area and the direction of flow based on the potentiometric-surface map of September 1988 (fig. 11) indicates a northeasterly movement of recharge water as well as south-southeasterly movement. However, the TOC concentration is relatively low to the northeast of the sinkhole area and the areas of high sulfide and methane concentrations are small, indicating that ground-water quality northeast of the sinkhole area probably is less affected by recharge from the river than is ground-water quality in areas to the south-southeast.

Local recharge of water containing organic carbon from tributary streams and wetlands and subsequent microbially mediated chemical reactions is a possible, but unlikely, explanation for the high sulfide and methane concentrations in ground water northeast of the sinkhole area. Local recharge of surface water to the Upper Floridan aquifer seems to be retarded by confining units in the sediments that overlay the Upper Floridan aquifer (fig. 2), except in the sinkhole area along the Withlacoochee River where the confining units are breached. Also, TOC concentrations indicate no substantial local recharge of water containing high concentrations of organic material to the Upper Floridan aquifer northeast of the sinkhole area.

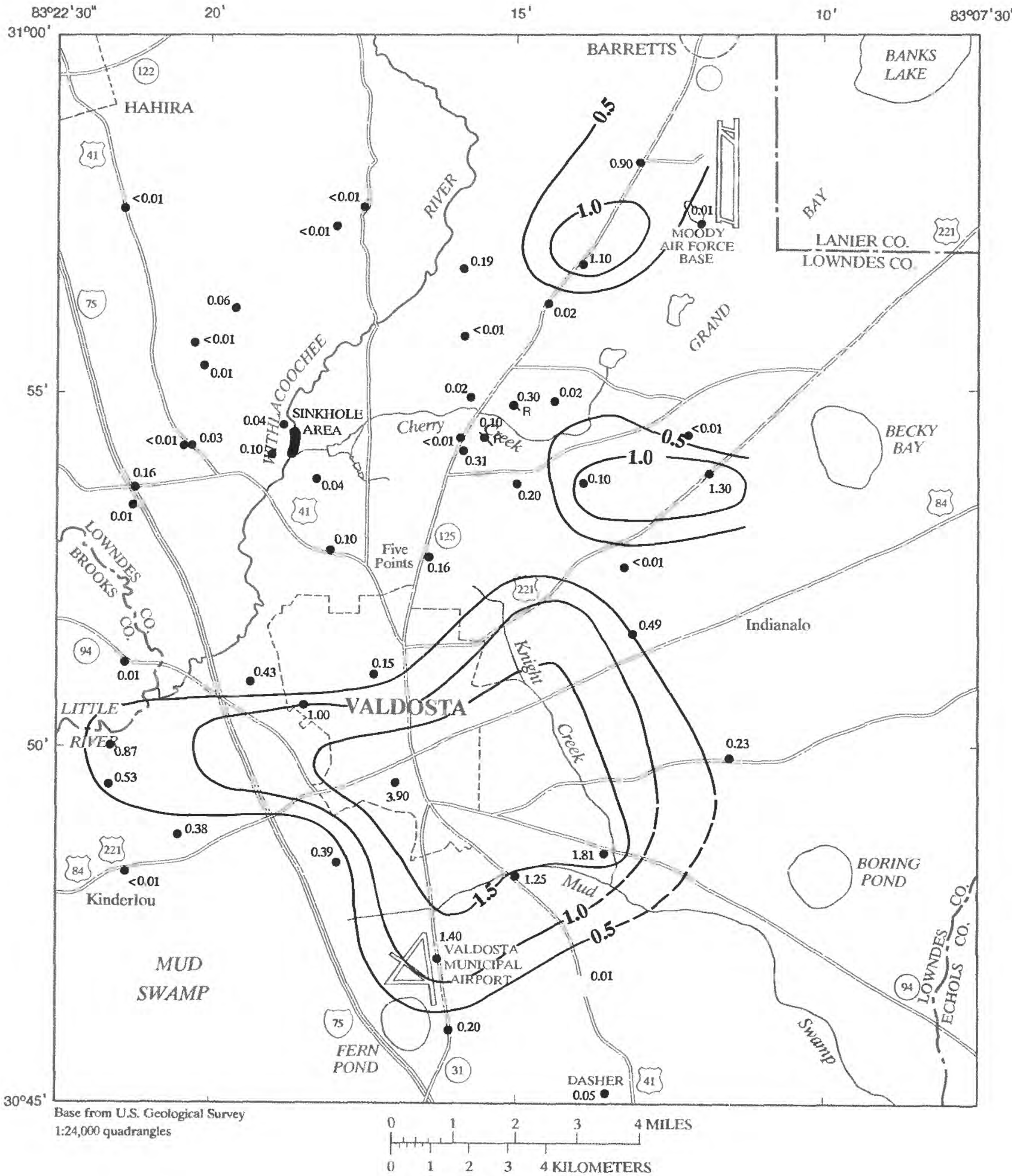


EXPLANATION

—— 2 — — LINE OF EQUAL TOTAL ORGANIC CARBON CONCENTRATION-- Dashed where approximately located. Interval 1.0 milligram per liter

● 2.8 WELL--Number indicates total organic carbon concentration, in milligrams per liter

Figure 15.--Total organic carbon concentration in water from the Upper Floridan aquifer, 1988.

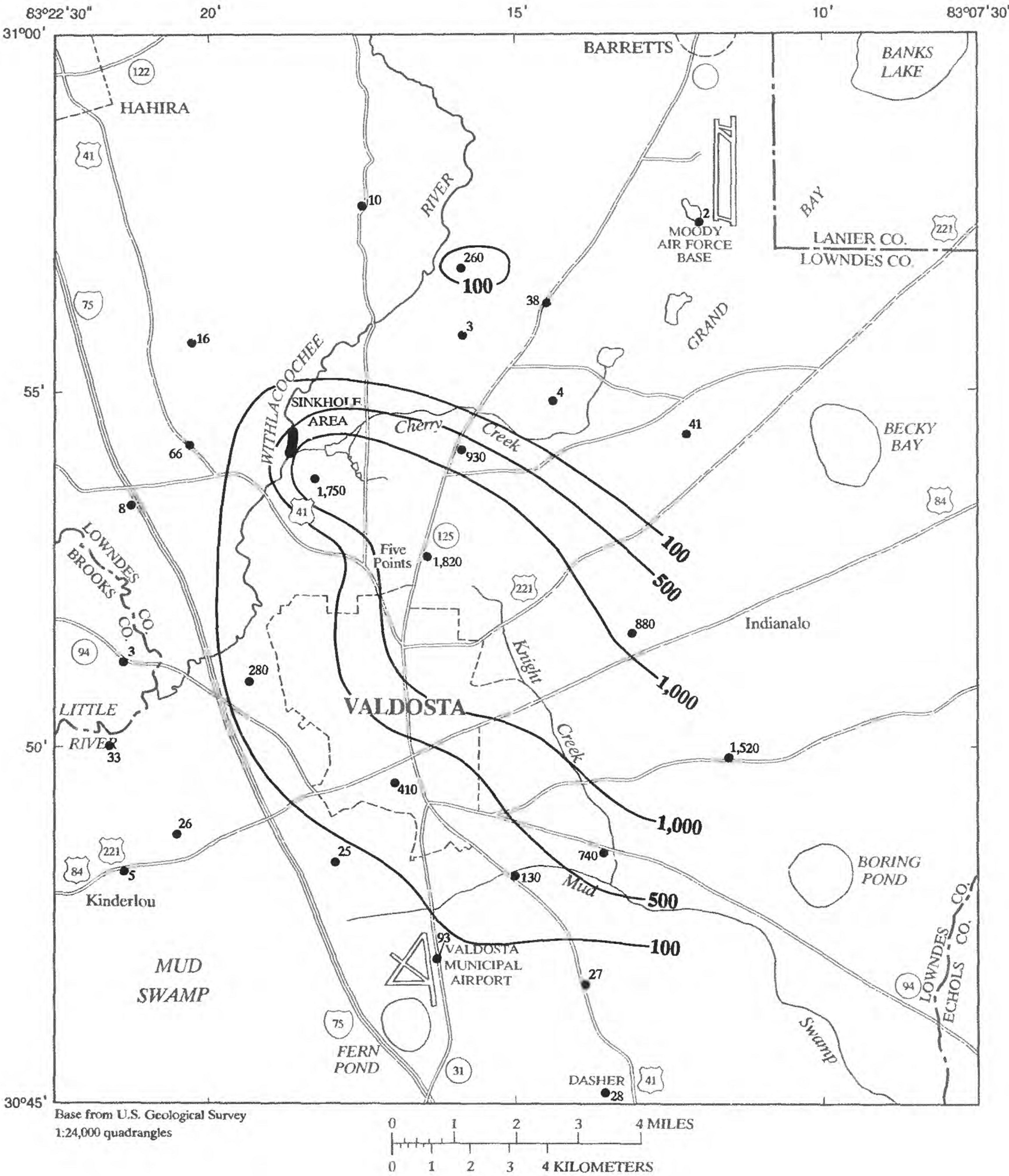


EXPLANATION

——1.5—— — — LINE OF EQUAL TOTAL SULFIDE CONCENTRATION-- Dashed where approximately located. Interval 0.5 milligram per liter

● GROUND-WATER SAMPLING SITE

Figure 16.--Total sulfide concentration in water from the Upper Floridan aquifer, 1988.



EXPLANATION

——100—— —— LINE OF EQUAL METHANE CONCENTRATION-- Dashed where approximately located. Interval varies, in micrograms per liter

• GROUND-WATER SAMPLING SITE

Figure 17.--Methane concentration in water from the Upper Floridan aquifer, 1988.

Estimate of Mixing from Chloride Concentrations

Chloride concentration in water from the Withlacoochee River and the Upper Floridan aquifer was used in a simple two-component mixing model to estimate the percentage of river water in ground water. The concentration of any element X in a two-component mixture is defined as

$$X_m = (X_a)f + X_b(1-f)\,, \qquad (2)$$

where X_a and X_b are the concentrations of element X in components a and b, respectively, and f is the mixing parameter. The mixing parameter f represents the proportion of component a in the mixture and is defined as

$$f = \frac{a}{a+b}\,, \qquad (3)$$

where a and b are the volumes of the two components in the mixture. By rearranging equation (2) and multiplying by 100, the mixing parameter becomes

$$f_p = \frac{X_m - X_b}{X_a - X_b} \times 100\,, \qquad (4)$$

where fp is the percentage of component a in the mixture. In this form, the mixing parameter can be calculated from the concentrations of end-member components and the concentration of the mixture of the components.

Water from Withlacoochee River above Valdosta (02317749) and water from parts of the Upper Floridan aquifer not affected by recharge from the river (water from group B wells) represent end-member components in the model. The assumptions are that the chloride concentrations of the end members mix to produce the chloride concentration in ground water that is affected by recharge at the sinkholes, and that the chloride concentration of the mixture is not modified by reactions or processes after mixing has taken place.

Chloride was selected for use in the model because it is a mobile, nonreactive element, and concentrations in water of the Upper Floridan aquifer in the study area are not significantly altered by precipitation of chloride salts or dissolution of the limestone. Also, chloride concentrations of the end-member components and the mixture are markedly different. Chloride concentrations in samples from Withlacoochee River above Valdosta (02317749) ranged from 9.2 to 36 mg/L with a median concentration of 14 mg/L (table 3). Chloride concentrations in samples from group B wells (unaffected by recharge from the river) ranged from 2.5 to 3.0 mg/L with a median concentration of 2.8 mg/L. Chloride concentrations in samples from group A wells (the potential mixture) ranged from 2.5 to 9.6 mg/L with a median of 3.3 mg/L (table 4).

Median chloride concentrations of end members and the minimum, maximum, and median chloride concentration of samples from group A wells were used in the mixing model to estimate percentages of river water in ground water in the study area. Median chloride concentrations for Withlacoochee River above Valdosta (X_a = 14 mg/L) and group B wells (X_b = 2.8 mg/L); and the minimum, maximum, and median chloride concentrations in group A wells (X_m = 2.5 mg/L; X_m = 9.6 mg/L), X_m = 3.3 mg/L), substituted into equation (4) yield percentages of river water in ground water (fp) that range from 0 to 61 percent with a median of 4 percent. Water from well 19F066 located nearest the sinkhole area had the highest percentage of river water (61 percent). At this location, water entering the aquifer through the sinkholes has little opportunity to mix with the ambient ground water. A water sample from well 19E010 about 5 mi south of the sinkhole (plate 1) was 28-percent river water and had a chloride concentration of 5.9 mg/L (fig. 14). The relatively high percentage of river water at that well indicates the well probably penetrates a solution opening in the limestone that is connected to the sinkholes. Water from wells 19F049 and 19E070 also have high percentages of river water (20 and 22 percent, respectively). These wells are located between the sinkhole area and well 19E010 (plate 1) and also presumably penetrate limestone solution openings connected to the sinkholes. The percentages of river water in water from 6 wells in group A could not be determined because the chloride concentrations were equal to or less than the median value of the ground-water end member.

WATER-RESOURCES DEVELOPMENT POTENTIAL OF THE UPPER FLORIDAN AQUIFER

Water-resources development potential of the Upper Floridan aquifer is defined as the ability of the aquifer to provide water of suitable quality and quantity for public supply or other large volume uses without adversely affecting water quality or producing excessive drawdown in water levels at well fields or other areas of major pumping. Factors considered in evaluating the potential for ground-water resources development were (1) ground-water quality (2) potential for ground water affected by recharge from the Withlacoochee River to move toward areas of water-supply development, and (3) yields of the Upper Floridan aquifer. The factors were evaluated using ground-water-quality data, photolineament maps, potentiometric-surface maps, and hydraulic-properties of the aquifer.

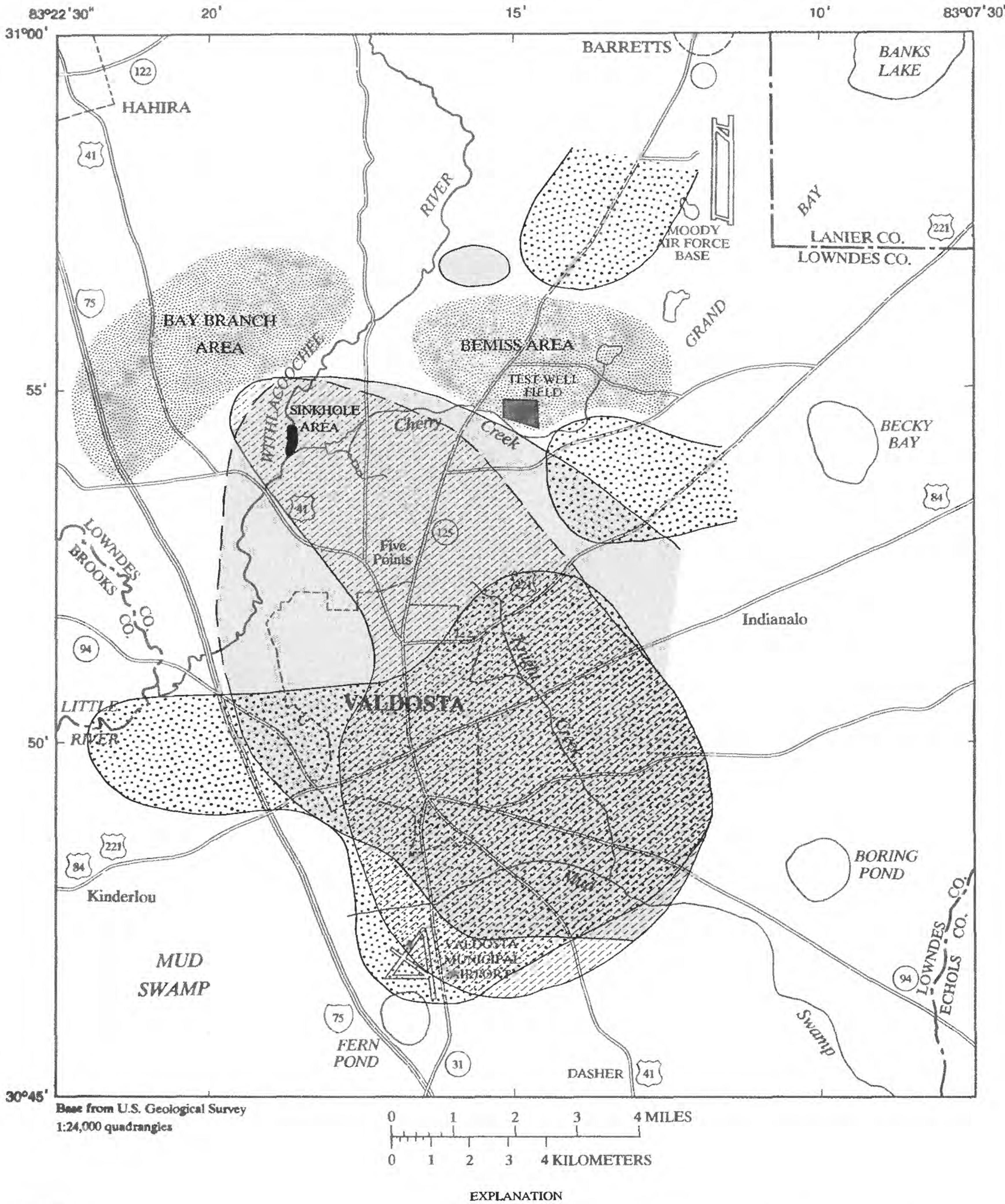
Distribution of sampled wells determined the areal coverage of the water-resources evaluation. Wells were not sampled in areas of the extreme northern, southwestern, and eastern part of study area; and thus, these areas were not included in the water-resources development evaluation. Generally, the location of sampled wells did not extend north of latitude 30°57'30" or east of longitude 83°10'30" (plate 1).

TOC, total sulfide, and methane concentrations in ground water were used to delineate areas where ground-water quality of the Upper Floridan aquifer was appreciably affected by recharge from the river. The areal distributions of these concentrations in ground water are shown in figures 15, 16, and 17. For this report, ground water having TOC, total sulfide, and methane concentrations greater than 2.0 mg/L, 0.5 mg/L, and 100 µg/L, respectively, are considered to be appreciably affected by river recharge. Areas having concentrations that exceed these limits are the least desirable for potential water-supply development (fig. 18). Water-quality data from sampled wells indicate that the Upper Floridan aquifer northeast and northwest of the sinkholes in the Bemiss and Bay Branch areas, respectively, have the greatest potential for water-supply development.

Potential for movement of water and contaminants from the sinkhole area in a northwesterly and northeastly direction seems to be less than in a south-southeasterly direction. The mounding of the ground water in the vicinity of the sinkhole in September 1988 (fig. 11) created a hydraulic gradient of about 6 to 7 ft/mi in the direction of the Bemiss and Bay Branch areas. However, the gradient was about 2 to 3 ft/mi in a south-southeasterly direction from the sinkhole area, indicating that recharge water moves more freely in that direction than in a northeasterly or northwesterly direction. Gradients were poorly defined in July 1988 (fig. 10) because recharge was low or nonexistent during a period of extremely dry weather prior to the water-level measurements.

Structual features (such as fractures) in the Upper Floridan aquifer also affect the direction of ground-water flow from the river by providing conduits for the vertical and lateral movement. Photolineaments (linear features that appear on aerial photographs and can represent surface manifestations of fractures or fracture zones) mapped in the Valdosta area indicate fewer geologic structural features in the Bemiss and Bay Branch areas than in the area south-southeast of the sinkholes (fig. 19).

Although concentrations of TOC, total sulfide, and methane in the Upper Floridan aquifer are low in the Bemiss area, concentrations of these constituents are elevated in nearby areas (fig. 18). During periods of higher recharge, hydraulic gradients likely would be steeper and the potential for movement of water from the sinkhole area toward the Bemiss area could increase. Also, natural flow paths in the Upper Floridan aquifer can be altered and rates of flow increased by large ground-water withdrawals in the vicinity of the recharge area; thereby increasing the potential for drawing river water toward the pumping centers. The potential for movement of recharge water in the Upper Floridan aquifer toward areas of heavy pumping requires additional data; and therefore, was not evaluated in this report.



EXPLANATION

AREA WHERE TOTAL ORGANIC CARBON CONCENTRATION IS GREATER THAN 2.0 MILLIGRAMS PER LITER. Boundary dashed where approximately located

AREA WHERE METHANE CONCENTRATION IS GREATER THAN 100 MICROGRAMS PER LITER. Boundary dashed where approximately located

AREA WHERE TOTAL SULFIDE CONCENTRATION IS GREATER THAN 0.5 MILLIGRAM PER LITER. Boundary dashed where approximately located

GENERAL AREA OF GREATEST WATER-RESOURCES DEVELOPMENT POTENTIAL. Boundary is arbitrary

Figure 18.--Areas where water-quality of the Upper Floridan aquifer is effected by recharge from the Withlacoochee River and general areas of greatest water-resources development potential.

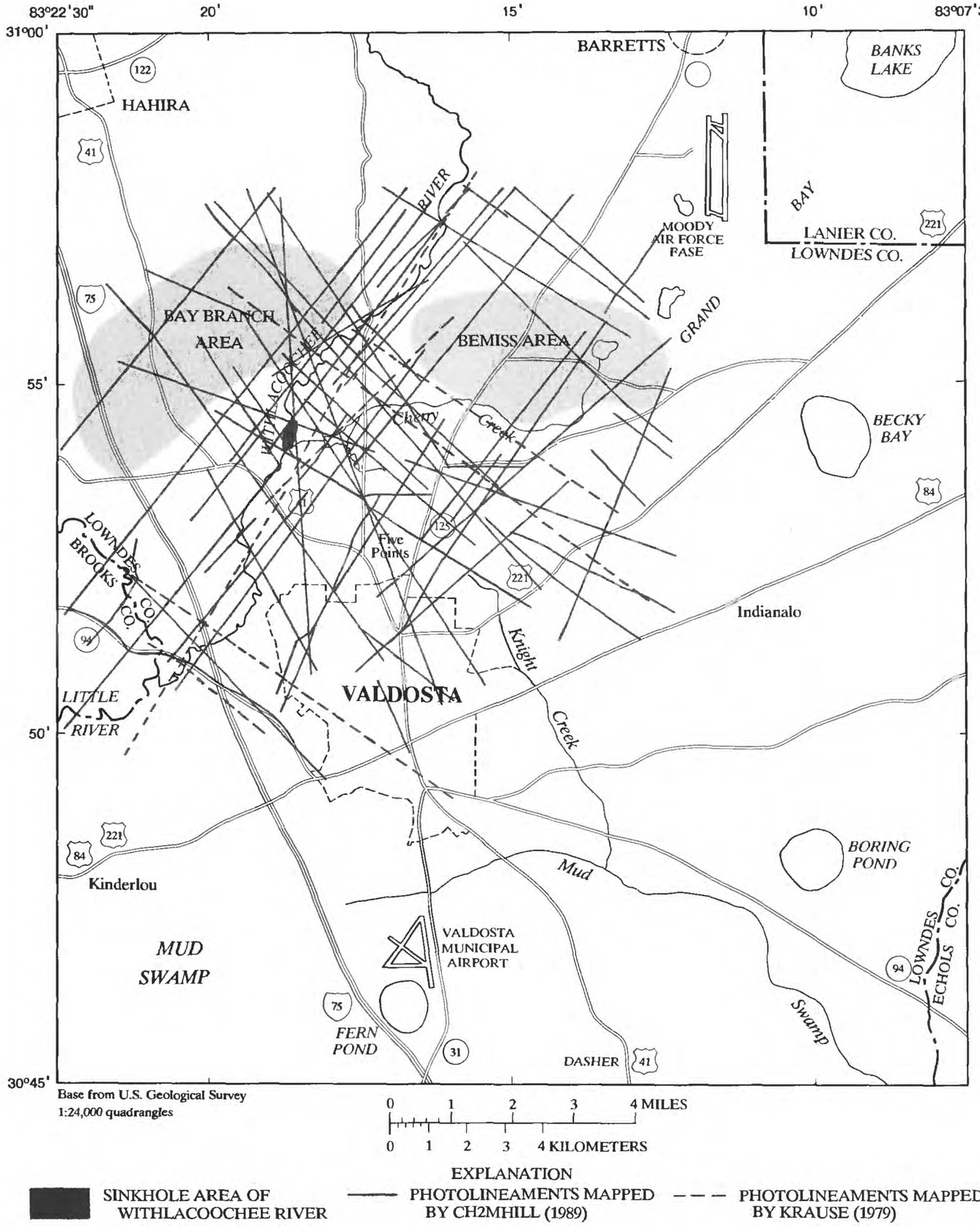


Figure 19.--Photolineaments in the Valdosta area.

Water-bearing properties of the Upper Floridan aquifer in the Bemiss and Bay Branch areas probably are similar to the generally excellent water-bearing properties of the Upper Floridan aquifer throughout the Valdosta area. During the course of this study, the city of Valdosta installed test wells at a 268-acre site near Bemiss that is being considered for development as a well field (fig. 18). Data collected at these wells indicated that water-production and water-quality characteristics were suitable for potential water-supply development. Aquifer-test and water-quality data from test well 19F100 near Bemiss indicate that the Upper Floridan aquifer will yield large quantities of water suitable for drinking. The capacity of the aquifer to transmit water is high, as indicated by a transmissivity of 94,000 ft^2/d. Water collected during the aquifer test had TOC concentrations that ranged from 1.0 to 1.3 mg/L, and averaged 1.1 mg/L. Total sulfide ranged from 0.3 to 0.7 mg/L, and averaged 0.5 mg/L. Although aquifer tests were not conducted northwest of the sinkholes, the generally excellent water-bearing properties of the aquifer throughout the area indicate that the Upper Floridan in the Bay Branch area also may provide an adequate water supply.

SUMMARY AND CONCLUSIONS

The Upper Floridan aquifer is the sole source of water supply for the city of Valdosta, Ga., and much of the surrounding area. The aquifer yields an ample supply of water; however, water quality is a concern to users and developers of ground-water resources in the area. The Upper Floridan aquifer is recharged regionally where the rocks of the Ocala and Suwannee Limestones crop out in south-central Georgia. However, recharge from this area probably is not a major source of water to the Upper Floridan aquifer in the study area because regional flow could be impeded north of the study area by the Gulf Trough. The aquifer probably receives the most recharge regionally from infiltration of precipitation in the area between the Gulf Trough and the study area.

The Upper Floridan aquifer is recharged locally north of Valdosta where sinkholes in the channel bed of the Withlacoochee River have breached the confining sediments that overlie sediments of the Hawthorne Group and Suwannee Limestone. The Upper Floridan aquifer in the Valdosta aera probably receives little recharge by direct infiltration of rainfall because overlying confining layers of clay and clayey sand inhibit downward movement of water.

Recharge at the sinkhole area is a major source of water to the Upper Floridan aquifer in the Valdosta area. The long-term average streamflow loss (recharge) from the Withlacoochee River to the Upper Floridan aquifer is about 60 cubic feet per second (ft^3/s). All streamflow in the river is lost to the aquifer through sinkholes when streamflow is less than about 50 ft^3/s and the rate of loss at low-flow conditions has not changed appreciably from 1975 to 1989. However, the average maximum loss (loss during periods of high flow) from the river has decreased from about 300 ft^3/s in 1976 to 82 ft^3/s during 1989. The long-term average streamflow loss was 112 ft^3/s (1932-75) reported by Krause (1976) compared to 60 ft^3/s (1933-89) reported in this study. The differences in long-term average streamflow loss determined in this study and by Krause (1979) are attributed to better estimates of loss at higher streamflows and possibly partial plugging of the sinkholes since 1975.

The movement of recharge water downgradient along connected bedding planes or fractures and the subsequent enlargement of the openings by partial dissolution of the limestone has formed a complex ground-water-flow system. During periods of high streamflow, recharge through the sinkholes forms a ground-water mound in the vicinity of the sinkhole area and movement of the recharge water is laterally downgradient primarily south and southeast from the sinkholes. Water-quality data also indicate that water movement is primarily in a south-southeasterly direction from the sinkhole area.

Water from the Withlacoochee River that enters the Upper Floridan aquifer through the sinkholes contains large quantities of organic carbon. During the period from 1972 to 1989, an average total organic carbon (TOC) load of about 2.6 tons per day or 950 tons annually was transported to the Upper Floridan aquifer. The organic material provides a readily available source of energy for the growth of microbiota in the aquifer. Microbially mediated chemical reactions involving the oxidation of organic material, the reduction of sulfate ions to form hydrogen sulfide, and reduction of carbon dioxide to form methane result in relatively high concentrations of sulfide and methane in the aquifer downgradient of the sinkhole area.

The distribution of TOC, total sulfide, and methane in the Upper Floridan aquifer that result from river recharge provides a means to evaluate areas where ground-water quality is affected by recharge and to identify flow paths of the recharge water. Maps showing concentrations of TOC, total sulfide, and methane in the Upper Floridan aquifer indicate that recharge from the Withlacoochee River affects the quality of ground water in a large area of the aquifer south-southeast of the sinkholes. Relatively high concentrations of chloride and tritium in ground water from several wells south and southwest of the sinkholes also indicate that the ground water in these areas contains relatively high percentages of post-1950's river water. A simple two-component mixing model analysis of chloride concentrations in water from the Withlacoochee River and the Upper Floridan aquifer indicates that the percentages of river water in ground water ranged from 0 to 61 percent with a median value of 4 percent. The proportion of river water in ground water generally was highest in wells near the sinkhole area and in some more distant wells thought to penetrate solution openings connected to the sinkholes.

Areas northeast and northwest of the sinkholes in the Bemiss and Bay Branch areas, respectively, probably have the greatest potential for ground-water-supply development. The quality of ground water and the generally excellent water-bearing properties of the Upper Floridan aquifer throughout the area indicate that the aquifer in these areas may provide an adequate supply of water suitable for large withdrawal uses. The low density of photolineaments and relatively low concentrations of TOC, total sulfide, and methane in these areas indicates that the potential for movement of river-affected ground water to the areas probably is low. However, the area of the aquifer affected by river recharge can vary as flow paths and rates of flow are altered by seasonal fluctuations of streamflow in the Withlacoochee River. Flow paths in the Upper Floridan aquifer also can be altered and rates of flow increased by large ground-water withdrawal in the vicinity of the sinkhole area, thereby increasing the potential for drawing river water toward the pumping centers. The potential for movement of recharge water in the Upper Floridan aquifer toward areas of heavy pumping is beyond the scope of this study, but can be evaluated by using chemical tracers and conducting aquifer tests to analyze the directional components of flow. Knowledge of the direction and rate of ground-water flow under natural and pumping conditions would be useful in developing strategies to protect drinking-water supplies from ground water degraded by natural or human-related activities.

REFERENCES CITED

Bush, P.W., and Johnston, R.H., 1988, Ground-water hydraulics, regional flow, and ground-water development of the Floridan aquifer system in Florida and in parts of Georgia, South Carolina and Alabama: U.S. Geological Survey Professional Paper 1403-C, 80 p.

CH2M Hill, 1989, Water-system improvements, program master plan: Valdosta, Ga., Engineering Report, 167 p.

Georgia Department of Natural Resources, 1990, Rules for safe drinking water: Atlanta, Ga., Environmental Protection Division, chap. 391-3-5, p. 601-682.

Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural water: U.S. Geological Survey Water-Supply Paper 2254, *3rd Ed.*, 263 p.

Hendry, C.W., Jr., and Yon, J.W. Jr., 1967, Stratigraphy of the Upper Miocene Miccosukee Formation, Leon and Jefferson Counties, Florida: Bulletin of the American Association of Petroleum Geologists, v. 51, no. 2, p. 250-256.

Herrick, S.M., 1961, Well logs of the Coastal Plain of Georgia: Georgia Geologic Survey Bulletin 70, 462 p.

Herrick, S.M., and Vorhis, R.H., 1963, Subsurface geology of the Georgia Coastal Plain: Georgia Geologic Survey Information Circular 25, 80 p.

Huddlestun, P.F., 1988, A revision of lithostratigraphic units of the Coastal Plain of Georgia: Georgia Geologic Survey Bulletin 104, 162 p.

Krause, R.E., 1976, Occurrence and distribution of color and hydrogen sulfide in water from the principal artesian aquifer in the Valdosta area, Georgia: U.S. Geological Survey Open-File Report 76-378, 11 p.

---- 1979, Geohydrology of Brooks, Lowndes, and western Echols Counties, Georgia: U.S. Geological Survey Water-Resources Investigations Report 78-117, 48 p.

Krause, RE. and Randolph, R.B., 1989, Hydrology of the Floridan aquifer system in southeast Georgia and adjacent parts of Florida and South Carolina: U.S. Geological Survey Professional Paper 1403D, 65 p.

Lohman, S.W., 1972, Ground-water hydraulics: U.S. Geological Survey Professional Paper 708, 91 p.

Michael, R.L., 1989, Tritium deposition in the continental United States, 1953-83: U.S. Geological Survey Water-Resources Investigations Report 89-4072, 51 p.

Miller, J.A., 1986, Hydrogeologic framework of the Floridan aquifer system in Florida and in parts of Georgia, Alabama, and South Carolina: U.S. Geological Survey Professional Paper 1403-B, 91 p.

Searcy, J.K., 1959, Flow-duration curves: U.S. Geological Survey Water-Supply Paper 1542-A, 33 p.

Ward, J.R., and Harr, A.C., 1990, Methods for collection and processing of surface-water and bed-material samples for physical and chemical analyses: U.S. Geological Survey Open-File Report 90-140, 71 p.

Zimmerman, E.A., 1977, Ground-water resources of Colquitt County, Georgia: U.S. Geological Survey Open-File Report 77-56, 41 p.

APPENDIX I

Description of Core and Cuttings from Well 19F101

[Core and cuttings from city of Valdosta deep monitoring well;
latitude 30°54′51″, longitude 83°15′05″; land-surface altitude, 206 ft above sea level
from Hahira East U.S. Geological Survey topographic map, 1:24,000, 1961, photo revised 1971)]

Depth below land surface (feet)			Material	Hydrologic characteristics of interval
00	-	35	clay	confining to leaky
35	-	52	sand	water bearing (aquifer)
52	-	65	clay	confining
65	-	70	sand	leaky
70	-	100	clay	confining
100	-	117	sand	water bearing (aquifer)
117	-	124	clay	leaky
124	-	136	sand	water bearing (aquifer)
136	-	154.5	clay	confining
154.5	-	158	dolostone	leaky
158	-	161	clay	confining
16	-	170	limestone	water bearing (aquifer)
170	-	177	sandstone	water bearing (aquifer)
177	-	192	dolostone	water bearing (aquifer)
192	-	192.5	sand	water bearing (aquifer)
192.5	-	418	limestone	water bearing (aquifer)
418	-	450	dolostone, limestone	leaky