Effects of Tidal Stage and Ground-Water Levels on the Discharge and Water Quality of Springs in Coastal Citrus and Hernando Counties, Florida

By Dann K. Yobbi

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Conversion Factors, Vertical Datum, Abbreviated Water-Quality Units, and Acronyms

Multiply	By	To obtain
inch (in.)	25.4	millimeter
inch per year (in/yr)	2.54	centimeter per year
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows: °C = 5⁄9 × (°F-32)

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD 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.

Abbreviated water-quality units:

°C	degrees Celsius
L	liter
µm	micrometer
µS/cm	microsiemens per centimeter at 25°C
mg/L	milligrams per liter
ppt	parts per thousand
pCi/L	picocuries per liter
δ	delta units

Acronyms:

SWFWMD	Southwest Florida Water Management District
EM	electromagnetic
R^2	coefficient of determination
SMOW	standard mean ocean water
^{18}O	oxygen-18
D	deuterium

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ABSTRACT

Coastal Citrus and Hernando Counties are located along the west-central coast of peninsular Florida. The area is primarily a zone of ground-water discharge and contains 3 first-order-magnitude springs (springs that discharge 100 cubic feet per second or more) and at least 23 smaller springs. The Upper Floridan aquifer is the source of these springs, and discharge is from a regional flow system that encompasses an area of about 3,400 square miles.

Mean discharge per spring is about 26 cubic feet per second based on measurements at 25 springs. Most springs have similar seasonal flow patterns, with peak discharges in late summer and early fall followed by gradual declines in flow toward winter and spring. Flow from springs is related to the altitude of ground-water levels in the Upper Floridan aquifer. Tides in the Gulf of Mexico affect the flow of most springs. Flow in tidal springs is generally greater at low tidal stages than at high or intermediate tidal stages.

Most tidal springs lie near or within the zone of diffusion in the Upper Floridan aquifer and discharge a mixture of saltwater and freshwater. The chloride concentrations of spring water generally decrease with distance from the coast as a result of higher fresh ground-water levels and a deeper saltwater-freshwater interface.

Sampled springs discharge three types of water: calcium bicarbonate, sodium chloride, and a transitional water type. The primary processes affecting the chemistry of spring waters are solution of carbonate minerals and mixing with saltwater. There is a significant seasonal difference in water chemistry in some of the springs. Generally, the seasonal variability in water chemistry increases with the salinity of spring discharge. Sampled springs have similar stable-isotope and tritium concentrations that also are similar to concentrations in ground water in the basin. No appreciable variation in isotope composition of the freshwater feeding the springs was observed between sampling periods, and ground water flowing to the springs is of very recent origin.

Springs at the coast are subject to wide variation in specific conductance and stage. Specific conductance can increase by 5,000 to 20,000 microsiemens per centimeter in a few hours between low and high tides, whereas stage can increase by 1 to 2 feet between low and high tides. Multilinear regression models were developed by using independent variables that were suspected to affect specific conductance of spring waters. The model that accounted for the greatest variation in specific conductance included tidal stage and ground-water levels. The regression models indicate that changes in specific conductance are caused primarily by changes in ground-water levels.

Spring-water quality and quantity could change with continued development of ground water. A program of long-term monitoring at selected springs would provide a data base for assessing regional effects of increased development.

INTRODUCTION

Coastal west-central Florida is undergoing rapid urban development that has increased the demand for freshwater. As demands for freshwater increase in coastal areas, new regional well fields may be used to augment present supplies. There is concern that saltwater intrusion may occur as a result of pumping and exporting ground water from future well fields to urban centers. The problem of saltwater intrusion is likely to increase as population rapidly increases and greater demands are placed on the water resources in west-central Florida.

Recognizing that an evaluation of the probable effects of an increase in water withdrawals would require an increased knowledge of the estuarine resources of the area, the U.S. Geological Survey (USGS), in cooperation with the Southwest Florida Water Management District (SWFWMD), conducted a study during 1983-86 to investigate the effects of river discharge and high-tide stage on saltwater intrusion in four of the major spring-fed estuarine rivers in the area

(Yobbi and Knochenmus, 1989a, b). As part of the study, a digital ground-water flow model was developed to simulate the response of flow of spring-fed rivers to large manmade stresses (Yobbi, 1989). Results of the model simulations indicate that total and individual spring flows could be reduced significantly under certain pumping conditions. Under the stressed conditions simulated with the model, ground-water levels in the coastal area would decline, causing decreased spring flow and increased salinity in water discharging from coastal springs.

Because the potential for saltwater intrusion increases with ground-water use, it is important to develop a good understanding of relations between coastal springs and the hydrology of the area. Most of the available hydrologic data on coastal springs is at least 15 years old, and there is a need to update and expand the data base to include temporal changes in salinity and spring flow associated with tides and seasons.

This project is a continuation of hydrologic investigations by the USGS in selected estuarine areas of west-central Florida. This study was initiated in 1987, in cooperation with the SWFWMD, to characterize the discharge, water quality, and tidal characteristics of coastal springs that discharge to the estuarine rivers in Citrus and Hernando Counties.

Throughout this report, statements are made concerning the salt content of water. Water having a specific conductance of not more than 1,000 μS/cm is referred to as fresh. Water having a specific conductance in excess of 1,000 μS/cm is referred to as brackish. If the specific conductance approaches 51,000 μS/cm, the water has a salt content close to that of the ocean and is referred to as saltwater.

Purpose and Scope

This report contains hydrologic data collected at springs and wells in coastal areas of Citrus and Hernando Counties from 1987 to early 1989. The data were collected to meet three principal objectives:

1. to define the quantity, quality, and variability of water discharging from springs in the study area;
2. to evaluate the relations among ground-water levels, tides, and variations in specific conductance of spring discharge; and
3. to use this information to design a program to monitor changes in the quantity and quality of spring flow.

The report presents information on discharge, water quality, and water-level variations for springs in the study area. Also described, on the basis of data collected at the springs, are analyses of the effects of tides and ground-water levels on discharge, water quality, and water-level fluctuations of springs. The report also describes the variability of the quality of water discharging from springs in the study area and discusses the mixing patterns, age, and origins of the water. Daily discharge was estimated at four springs, and relations among high tides, ground-water levels, and daily maximum specific conductance of spring water were evaluated by use of regression techniques.

Description of Study Area

The study area extends along the gulf coast of Florida from near Homosassa Springs southward to the Pasco-Hernando County line (fig. 1). The study area lies within the Gulf Coastal Lowlands physiographic province as described by Vernon (1951). Marine terraces and sand dunes are the dominant topographic features. Along the coast, saltmarshes with palm-covered islands dominate. The coast is low, and land altitudes range from sea level at the gulf coast to about 30 ft above sea level along the eastern edge of the study area. The coast is broad and flat, dotted with many small islands that are separated by shallow bays.

The most distinctive topographic feature is the well-defined Pamlico Terrace (White, 1970, p. 143), an ancient shoreline 25 to 30 ft above present sea level, 2 to 15 mi inland from the coast, which generally parallels the present shoreline. It extends beneath the present sea level to a submerged shoreline. East of the Pamlico Terrace are sandhills dotted with sinkholes and springs. The saltmarshes and swamps along the coast grade into a hardwood hammock belt with sand pine and oak forests inland from the terrace scarp.

The study area is underlain by a thick sequence of honeycombed and fractured limestone and dolomite of Tertiary age (table 1). The carbonate rocks are at or near land surface. Where they are in the subsurface, they are covered by unconsolidated, porous sands that range in thickness from less than 5 ft near the coast to more than 30 ft along the Pamlico Terrace.

The near offshore areas of the Gulf of Mexico are shallow (less than 20 ft average depth) and exhibit little relief. The bottom is covered by a thin, discontinuous sediment veneer and is characterized by a karst platform with limestone outcrops, sinks, and a few submarine springs. Many of the sinks and springs have been filled by sand transported by a current flowing northward in the Gulf of Mexico (Wetterhall, 1964). The number of karst features seems to decrease away from shore (Brooks, 1973).

Rainfall in the area averages about 56 in/yr, of which about 34 in. falls during the 5-month period May through September. July is the wettest month and November is the driest. The mean annual temperature is about 71°F, and monthly means range from 80°F in August to 60°F in January (National Oceanic and Atmospheric Administration, 1983).

Hydrogeology

Surface drainage in the study area is minimal and most water movement is through the Upper Floridan aquifer. The few perennial streams that do exist are supplied almost entirely by spring discharge. The area contains 3 first-order-magnitude springs (springs that discharge 100 ft^3/s or more) and at least 23 smaller springs. The springs discharge a total of about 650 ft^3/s of water to coastal rivers, saltmarshes, and swamps along the Gulf of Mexico.

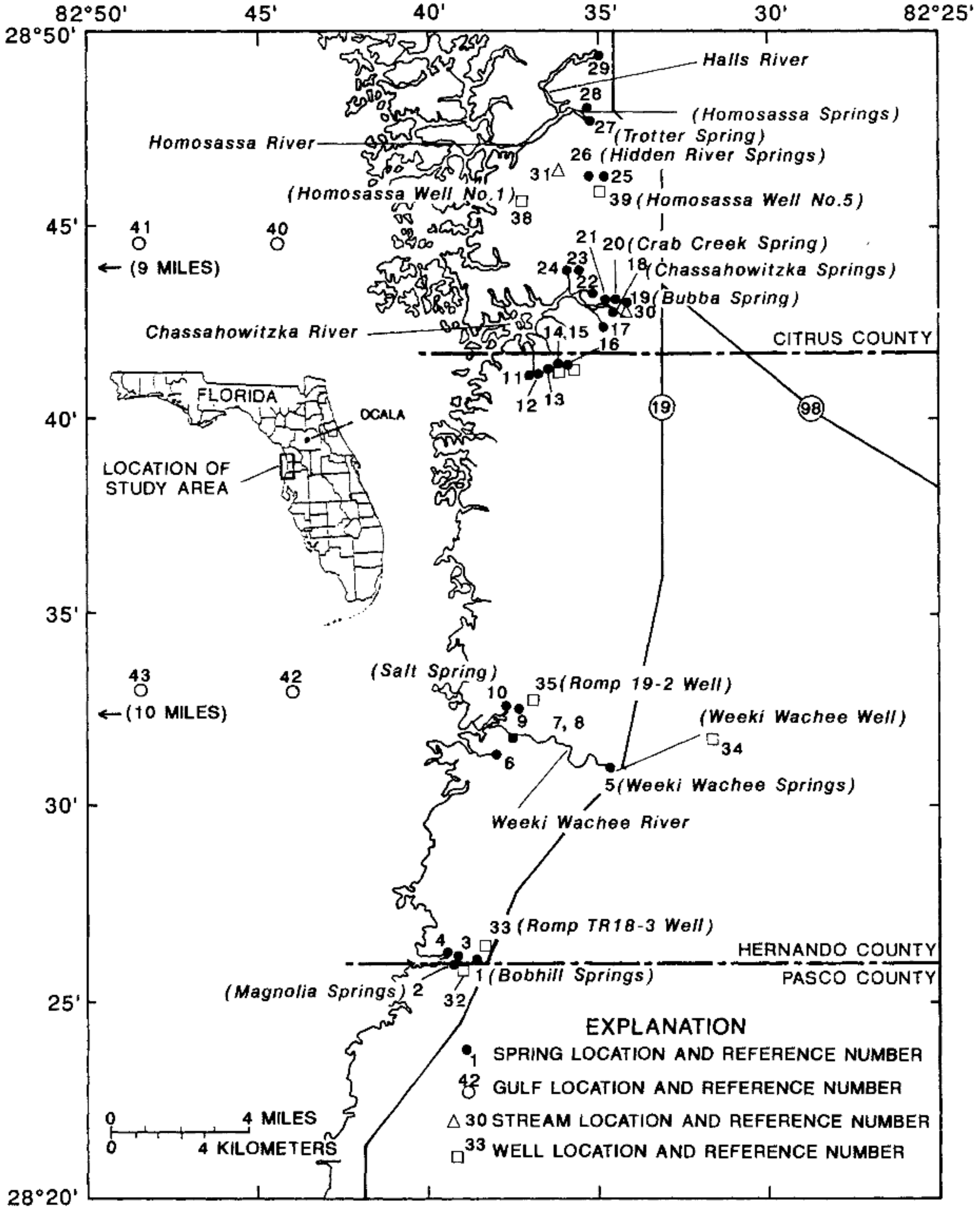


Figure 1. Location of the study area and data-collection sites.

Table 1. Lithologic descriptions and chart showing correlation of major geologic and hydrogeologic units
[Modified from Ryder, 1985, table 1]

System	Series	Stratigraphic unit	General lithology	Major lithologic unit	Hydrogeologic unit
Quaternary	Holocene and Pleistocene	Surficial sand, terrace sand, phosphorite	Predominantly fine sand; interbedded clay, marl, shell, limestone, and phosphorite.	Sand	Surficial aquifer
Tertiary	Pliocene	Undifferentiated deposits	Clayey and pebbly sand; clay, marl, shell, phosphatic.	Clastic deposits	Intermediate confining unit
	Miocene	Hawthorn Formation	Dolomite, sand, clay, and limestone; silty, phosphatic.	Carbonate and clastic deposits	
	Oligocene	Suwannee Limestone	Limestone, sandy limestone, fossiliferous.	Carbonate deposits	Upper Floridan aquifer
	Eocene	Ocala Limestone	Limestone, chalky, foraminiferal, dolomitic near bottom.		
		Avon Park Formation	Limestone and hard brown dolomite; intergranular evaporite in lower part in some areas.		Middle confining unit
		Oldsmar Formation	Dolomite and chalky limestone with intergranular gypsum and anhydrite in most areas.	Carbonate, with intergranular evaporite deposits	Lower Floridan aquifer

The Upper Floridan aquifer is the source of these springs, as well as virtually all water used in the area. The aquifer consists of several geologic formations that function as a single hydrologic unit. Those formations are, from bottom to top, the Avon Park Formation, the Ocala Limestone, and the Suwannee Limestone (table 1). The top of the aquifer is about 80 ft below land surface in the sand ridges east of the springs, but is at or near land surface along the coast. The base of the Upper Floridan aquifer in the study area is considered to be at the first occurrence of vertically persistent evaporites, which generally occur about 600 ft below sea level in the lower part of the Avon Park Formation.

A surficial aquifer, separate from the Upper Floridan aquifer, occurs as a discontinuous unit within the coastal springs basin (Fretwell, 1983). Some perched water-table aquifers of limited extent occur locally in these sands. The surficial deposits, however, generally are too thin or clayey to constitute an important aquifer.

The potentiometric surface of the Upper Floridan aquifer in the ground-water drainage area of the coastal springs basin is shown in figure 2. Arrows on the map indicate the general direction of flow in the aquifer in the area. Ground water generally flows westward toward the Gulf of Mexico, normal to the contour lines, from areas of high potential to areas of low potential.

Recharge to the aquifer occurs east of the springs as percolation through surficial deposits and drainage into sinkholes. Annual recharge to the Upper Floridan aquifer was estimated to range from 10 to 30 in. by using a regional flow model (Yobbi, 1989). Recharge is high because the area is internally drained and little water runs off landward of the springs. This has led to an active shallow flow system where water quickly flows into and out of the limestone (Bush, 1982).

The study area is mostly a zone of ground-water discharge. Three major rivers—the Homosassa, the Chassahowitzka, and the Weeki Wachee—originate from springs, as do many smaller streams. Discharge is from a regional flow system that encompasses an area of about 3,400 mi^2 and extends 30 to 40 mi beyond the eastern edge of the coastal springs basin boundary (fig. 2). At the coast, ground water flows upward through solution cavities to discharge as springs or as diffuse upward leakage into low-lying coastal swamps. Solution cavities commonly are large and interconnected by conduits, some large enough to accommodate extremely large flows (Sinclair, 1978).

Most springs in coastal Citrus and Hernando Counties lie near or within the zone of diffusion and discharge a mixture of saltwater and freshwater. The potentiometric surface of the Upper Floridan aquifer in the coastal springs area during May 1988 and the chloride concentrations of spring waters measured in June and July 1988 are shown in figure 3. A clear relation between water levels in the Upper Floridan aquifer and chloride concentrations of springs is not apparent. This is because the springs terminate at different depths within the aquifer. Generally, however, the higher potentiometric-surface contours are associated with lower chloride concentrations of spring waters.

Dynamics of Saltwater-Freshwater Mixing

The relation of saltwater to freshwater in coastal aquifers in contact with the sea has been recognized for many years. Under hydrodynamic equilibrium, saltwater underlies freshwater in a wedge that decreases in thickness landward. Theoretically, for every foot of freshwater head above sea level measured at the saltwater-freshwater interface, the interface is depressed 40 ft below sea level (Hubbert, 1940). A sharp interface between freshwater and saltwater does not exist in coastal aquifers because of tidal fluctuations or water-level fluctuations caused by changes in recharge or pumpage with time.

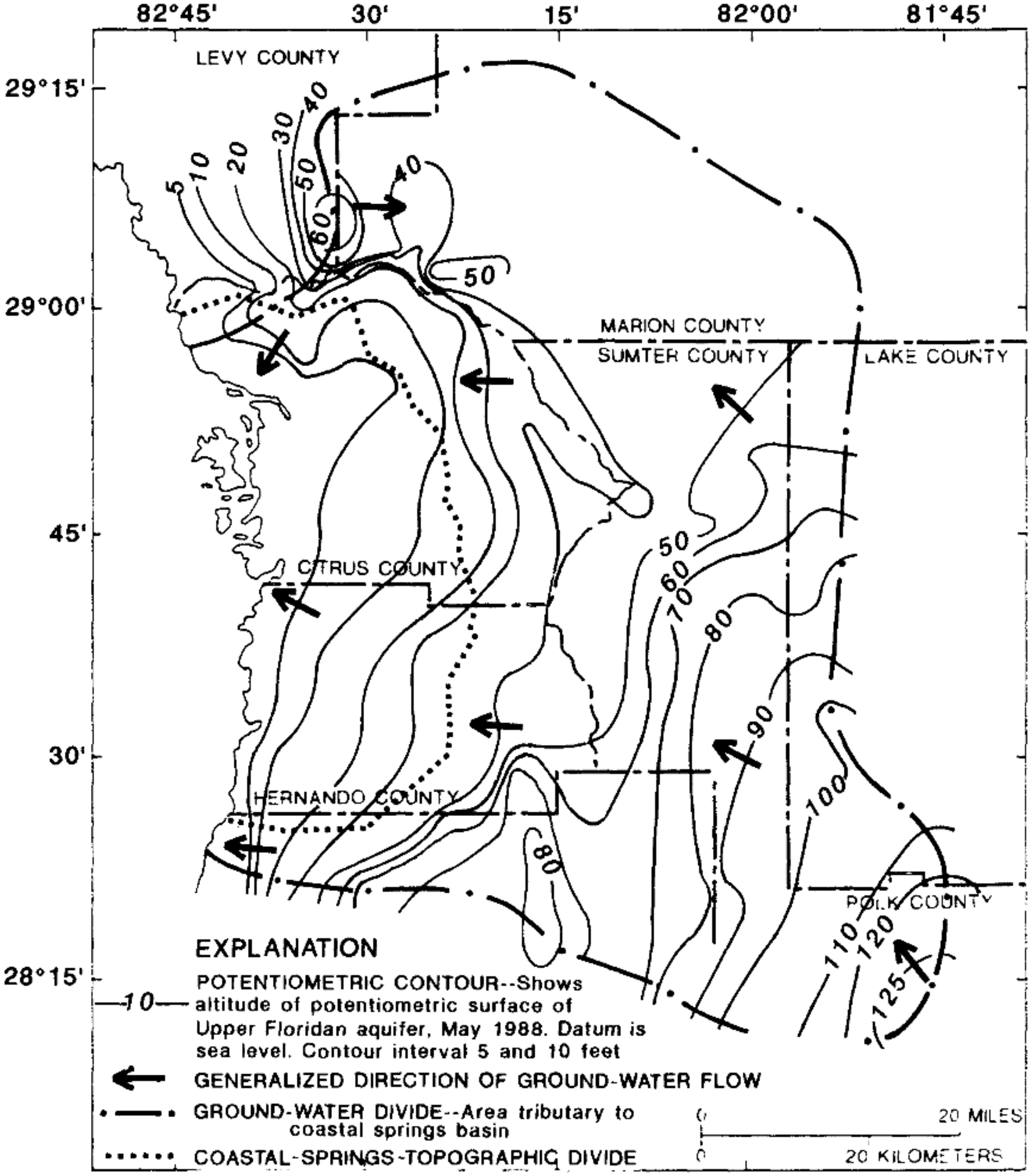


Figure 2. Ground-water drainage area of the coastal-springs basin and related potentiometric surface of the Upper Floridan aquifer, May 1988. (Modified from Lewelling, 1988.)

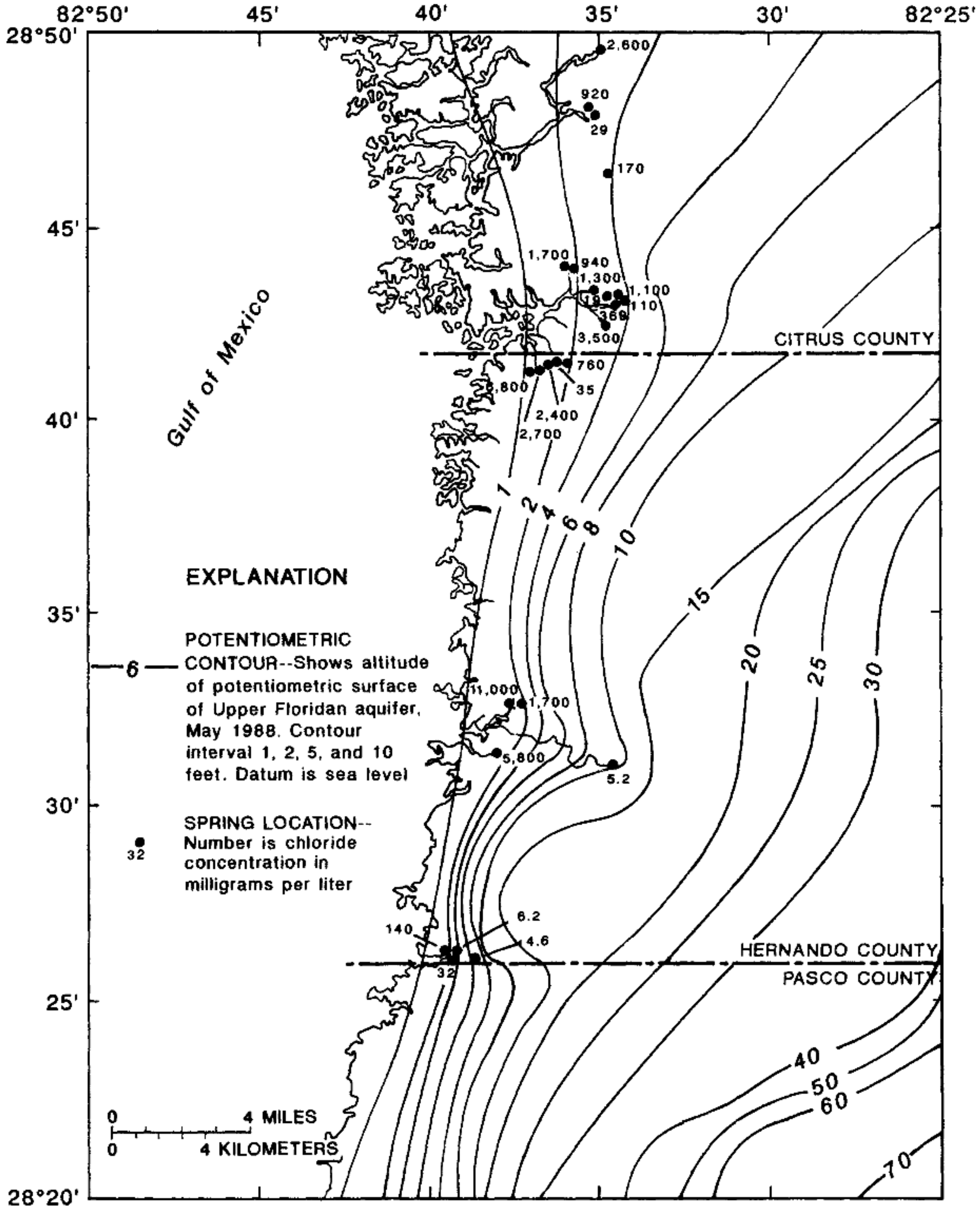


Figure 3. Potentiometric surface of the Upper Floridan aquifer, May 1988 (modified from Lewelling, 1988), and chloride concentrations of springs, June and July 1988.

Instead, a dynamic equilibrium has been established that causes freshwater and saltwater to mix and form a transition zone between freshwater and saltwater. In the transition zone, the saltwater is not static but flows in a perpetual cycle from the sea floor into the zone of transition and back to the sea floor (Cooper and others, 1964).

The slope and thickness of the saltwater-freshwater transition zone along the coast of the study area are shown in figure 4. The sections were constructed from well data collected within 5-mi-wide bands. Most data are from 1980, but data from as early as 1965 have been used to define the shape of the interface. The shape of the transition zone varies between the sections. The slope of the transition zone is lower in Citrus County than in Hernando County because of a decrease in the hydraulic-head gradient with distance from the coast that allows higher chloride concentrations at shallower depths.

The approximate position of the 250-mg/L line of equal chloride concentration at a depth of 100 ft below sea level in the Upper Floridan aquifer is shown in figure 5. The line is based on chloride concentrations in water collected from wells and springs from 1964 through 1975 by Mills and Ryder (1977) and by Causseaux and Fretwell (1982), who added data on chloride concentrations through 1980. Coastward from this line, saltwater generally occurs at depths of less than 100 ft, and ground-water levels in the aquifer generally are less than 2.5 ft above sea level. Inland from this line, ground-water levels in the Upper Floridan aquifer generally are more than 2.5 ft above sea level, and water containing more than 250 mg/L of chloride generally occurs at a depth greater than 100 ft. Figure 5 also shows the position of the saltwater-freshwater interface (200-300 mg/L chloride) relative to sea level. The line is based on results of transient electromagnetic (EM) soundings made during 1982 (Stewart and Gay, 1983).

Surface geophysical methods have been used successfully to locate the saltwater-freshwater interface in Citrus and Hernando Counties. The interface is denoted by steep, decreasing gradients of low resistivity. Bisdorf and Zohdy (1979) mapped resistivities to depths of more than 1,000 ft and were able to define saltwater along a line near Homosassa Springs (fig. 6). By using EM soundings, Stewart (1982), Stewart and Gay (1983), and L.A. Knochenmus (U.S. Geological Survey, written commun., 1989) were able to map the deep and shallow parts of the saltwater-freshwater interface in coastal Pasco, Hernando, Citrus, and Levy Counties (figs. 5, 7, and 8). The most distinctive features of the geophysical data are the landward reentrants of low-resistivity contours near Crystal River Springs, Halls River Springs, and Homosassa Springs. Apparently, these major ground-water discharge points create a very steep saltwater-freshwater interface in their vicinity (Stewart, 1982).

In general, the chloride-concentration and geophysical data indicate an interface that is parallel to the coast with significant landward reentrants at major springs and gulfward extensions of the interface between springs. The presence of the springs has lowered hydraulic heads, permitting higher chloride concentrations at shallower depths. High salt content of many brackish springs indicates that gulf water has intruded through interconnected solution conduits gulfward of the springs.

METHODS OF STUDY

Methods used to collect and analyze data in this study are briefly described in this section. Data collection included measurement of discharge, laboratory analysis of water-quality samples, and field measurements of water levels and specific conductance. Methods used for statistical analysis of these data are also described.

Discharge Measurements

Discharge measurements were made below each spring pool by using Price current meters and standard USGS streamflow-measuring techniques. Discharge was measured periodically and during water-quality sampling events. Springs that show the effects of tides are called tidal springs.

Relations between discharge and other hydrologic variables were developed for two tidal springs (Crab Creek Spring and Salt Spring) and two nontidal springs (Weeki Wachee Springs and Bobhill Springs). At Crab Creek Spring and Salt Spring, several sets of continuous tidal discharge measurements were made during the study. At Weeki Wachee Springs and Bobhill Springs, discharge measurements were made periodically over a range of hydrologic conditions. Because unique stage-discharge relations do not exist for springs in the study area, daily discharge was estimated from relations between individual discharge measurements and concurrent ground-water and tidal levels.

Water-Quality Analyses

Water was sampled for chemical and physical analyses at 25 springs, 3 wells, and 4 surface-water sites in the Gulf of Mexico. Most spring sites were sampled twice—once near the end of the dry season (June and early July) and once near the end of the wet season (October and November). The wells and surface-water sites in the Gulf of Mexico were sampled once. Samples were analyzed for an extensive suite of chemical and physical properties, including total nitrogen, total phosphorous, and environmental isotopes.

Temperature, pH, Eh, dissolved oxygen, alkalinity, and specific conductance were measured in the field. The pH meter was calibrated for the 4 to 7 pH range, and the specific-conductance meter was calibrated with a range of standards to encompass the specific conductance of water from the sites sampled.

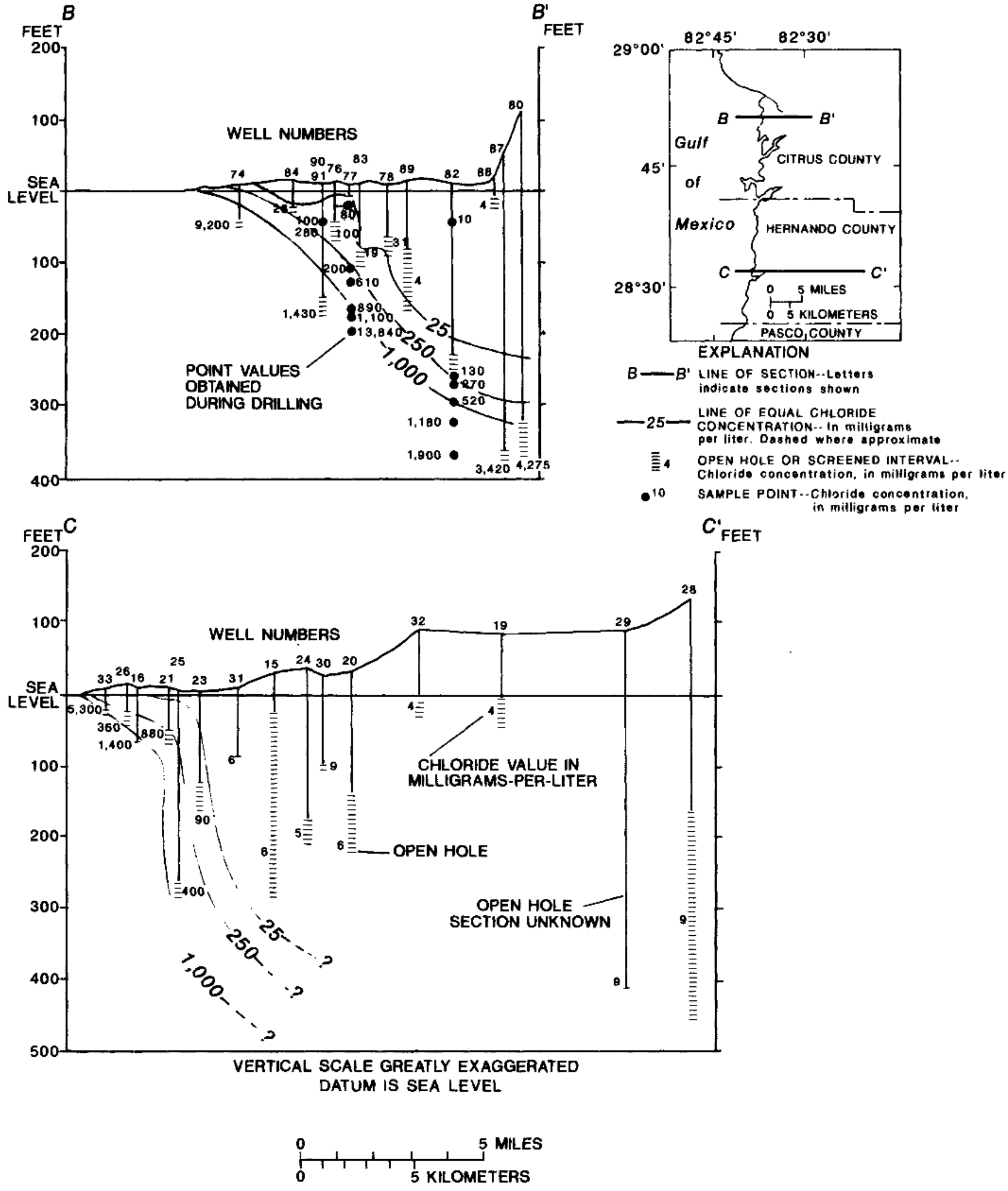


Figure 4. Chloride concentrations in the coastal margin of Citrus and Hernando Counties. (Modified from Fretwell, 1983.)

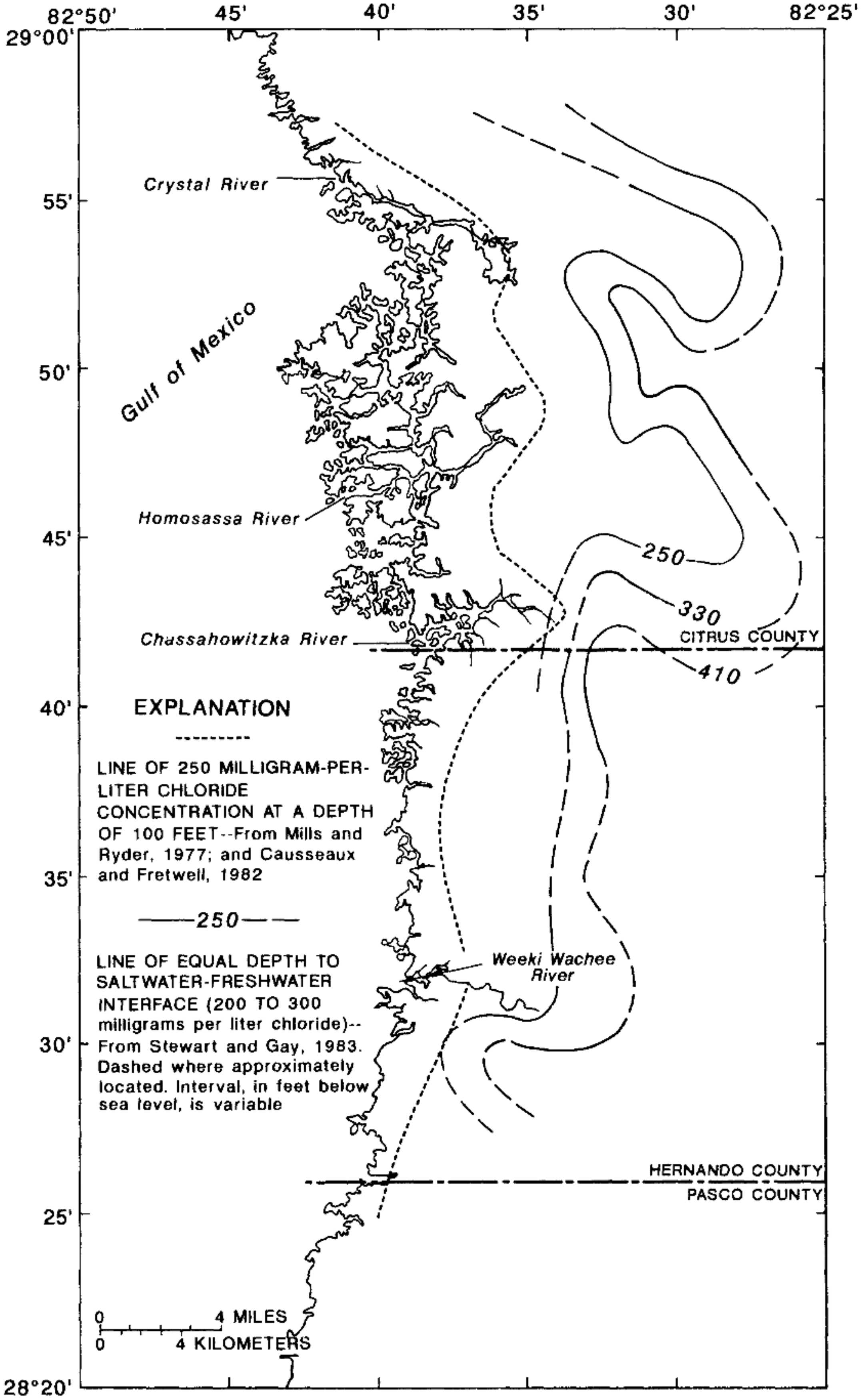


Figure 5. Depth to saltwater-freshwater interface.

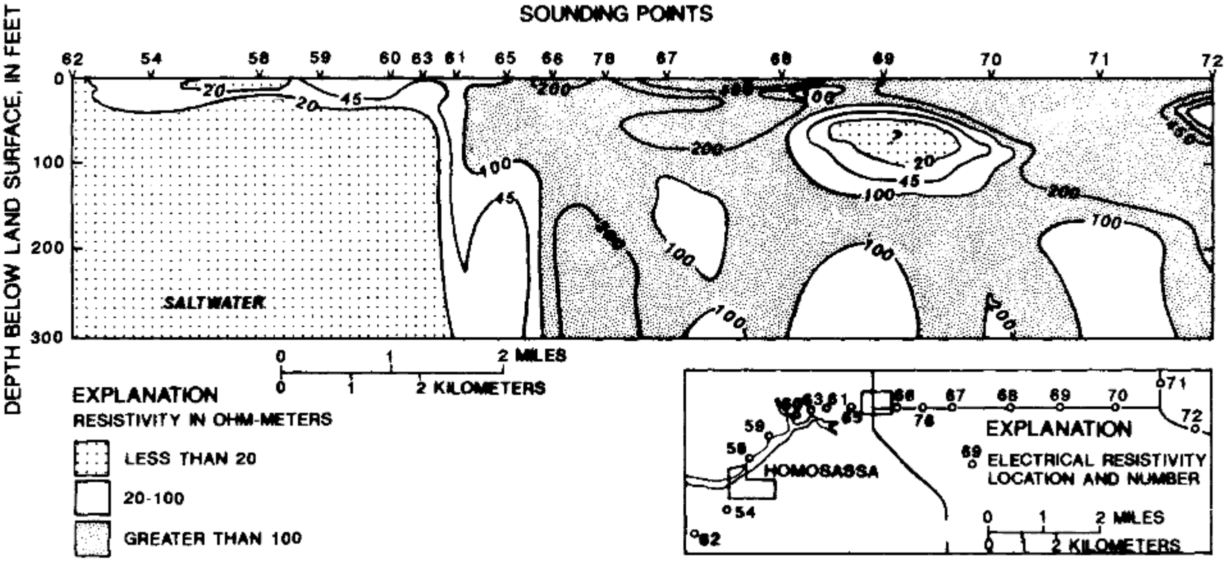


Figure 6. Geoelectric section near Homosassa Springs. (Modified from Fretwell, 1983.)

Water samples were collected at the source of each spring with a peristaltic pump. A weighted sampling tube was lowered into the spring vents from 5 to 20 ft below the water surface. The water was then circulated in a flow-through sample chamber to prevent contact with the atmosphere.

All samples analyzed for dissolved constituents were filtered through a 0.45-µm filter. Samples for cation analysis were acidified to a pH of 2 or less with nitric acid. Samples for nitrogen and phosphorous analysis were treated with mercuric chloride and then chilled for shipment. Samples for sulfide analysis were unfiltered and treated with zinc acetate and sodium hydroxide. Samples for analysis of hydrogen and oxygen isotopes were treated with mercuric chloride and sealed with electrical tape to prevent atmospheric contamination prior to analysis at the laboratory. Samples for tritium analysis were collected in a nitrogen-gas-flushed 1-L polyethylene bottle and sealed with electrical tape.

Water-quality analyses were performed by the USGS and the University of Miami water-quality laboratories. Most analytical methods used by the USGS for inorganic determinations are described by Skougstad and others (1979), methods for organic determinations are described by Goerlitz and Brown (1972), and methods for radiochemical determinations are described by Thatcher and others (1977).

Water-Level and Specific-Conductance Measurements

Tidal stage and specific conductance were measured continuously at Salt Spring and Crab Creek Spring for 1 year. At 19 other spring sites, four water-level and specific-conductance monitors were rotated twice among springs at intervals of 3 to 6 weeks to determine daily and seasonal variations in stage and specific conductance. Continuous-record sites were equipped with instruments that measured and recorded data at 15-minute intervals. Specific conductance was measured in microsiemens per centimeter at 25°C.

Recorders were installed on ROMP 19-2 well and Homosassa well no. 1 (fig. 1) to obtain continuous records of water levels and specific conductance of water in the Upper Floridan aquifer. The recorders were operated for about 1 year to determine aquifer response to recharge, discharge, and tidal effects. Ground-water levels also were measured twice (May and September) in a network of wells to define the potentiometric surface of the Upper Floridan aquifer.

Statistical Analysis

A linear-regression analysis was used to determine relations among ground-water levels, tidal stages, and discharge or specific conductance of springs. The technique determines a best-fit equation between one dependent variable and one or more independent variables.

The statistics used to evaluate the regression analysis are the coefficient of determination (R^2) and the standard error. R^2 is the proportion of variance in the independent variable that is explained by the regression, and the standard error is a measure of the reliability of the regression. Approximately 67 percent of the values estimated by the regression are within one standard error of the measured value of the independent variable, assuming normality of the residuals of the regression. For this study, the level of significance used to determine whether the regression coefficients are statistically different from zero was set to equal 0.05.

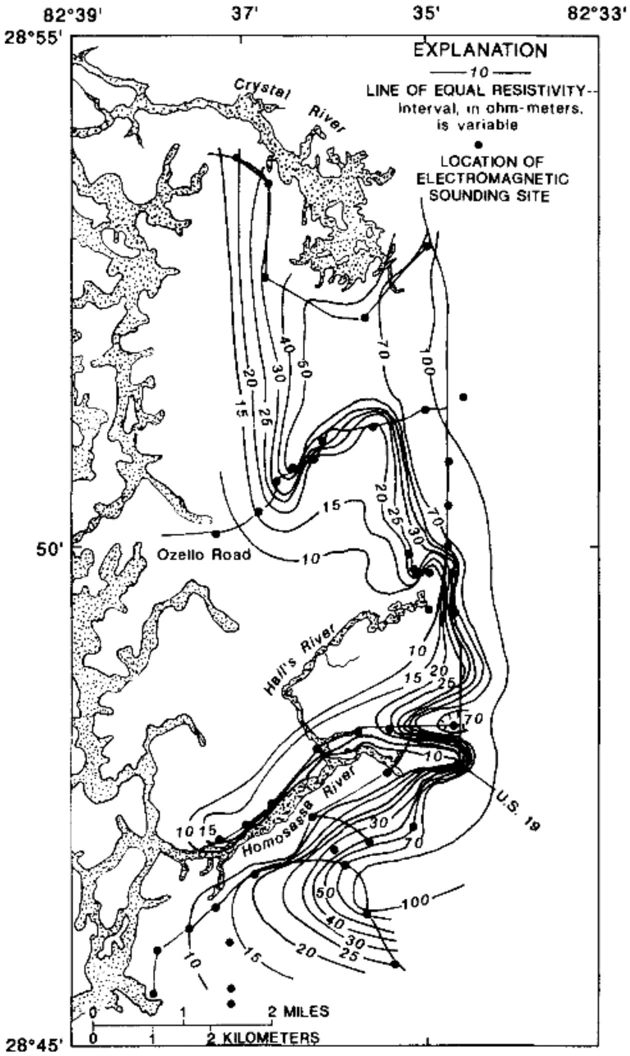


Figure 7. Electromagnetic resistivity determined with 20-meter vertical coil orientation near Homosassa Springs. (Modified from Stewart, 1982.)

Five wells were selected to provide information on ground-water levels and fluctuations. The change in water levels in Weeki Wachee well, Homosassa well no. 1, and ROMP TR18-3 well is representative of the nontidal regional water-level fluctuations in the Upper Floridan aquifer. The effect of tides on ground-water levels is represented by water-level fluctuations in Homosassa well no. 3 and ROMP 19-2 well. These five wells were chosen from the many wells in the area because of their proximity to the springs and the coast, length of record, and frequency of data collection.

SPRING DISCHARGE

Prior to this study, flow of springs in coastal Citrus and Hernando Counties had not been studied in detail; thus, it was not known to what extent spring flow is affected by tides and to what extent fluctuations in ground-water levels affect the flow. The purpose of this section is to describe (1) a statistical technique to estimate spring flow at tidal and nontidal springs and (2) the quantity and seasonal variability of water discharging from springs in the study area.

Estimation of Flow

Springs usually cannot be rated by means of a simple stage-discharge rating. The altitude of ground water near the springs, along with other variables, can be used to estimate instantaneous discharge. The method used in this report to estimate instantaneous discharge is linear-regression analysis.

The results of regression analysis for estimating instantaneous discharge for Weeki Wachee Springs, Bobhill Springs, Crab Creek Spring, and Salt Spring are summarized in table 2. Similar analysis was not undertaken for other springs because sufficient discharge data or ground-water data were not available for use in the regression analysis. For Weeki Wachee Springs, individual discharge measurements made during 1964-84 were regressed against concurrent water levels in Weeki Wachee well. For Bobhill Springs, individual discharge measurements made during 1988 were regressed against concurrent water levels in ROMP TR18-3 well. For Crab Creek Spring and Salt Spring, multiple regression models were developed by using independent variables that were suspected to affect discharge of the tidal springs. Variables were added in the following order: first, the daily maximum water level in Weeki Wachee well; then the instantaneous water level in ROMP 19-2 well and Homosassa well no. 1; and, finally, the instantaneous spring-pool altitude of Crab Creek Spring or Salt Creek Spring. Variables that did not contribute to the model were omitted. Values of R^2 ranged from 0.81 to 0.99, and the standard error ranged from 0.07 to 11.6 ft^3/s. The equation obtained in the regression analysis was used to compute the daily discharge of Weeki Wachee Springs, Bobhill Springs, Crab Creek Spring, and Salt Spring for the period April 1988 through March 1989.

Quantity and Seasonal Variability

Discharge was measured at 25 springs and at 2 spring-fed stream sites (fig. 1). A list of the site numbers, with a corresponding identification number based on latitude and longitude, is given in appendix A. Also included in appendix A is the USGS downstream order number, where applicable.

The range in instantaneous discharge measurements for 25 springs was -50.8 ft^3/s at Mud Spring during January 1989 to 221 ft^3/s at Weeki Wachee Springs during October 1988 (table 3); the mean discharge was 25.9 ft^3/s. Measurements of instantaneous discharge and instantaneous specific conductance from March 1988 to April 1989 are listed in appendix B.

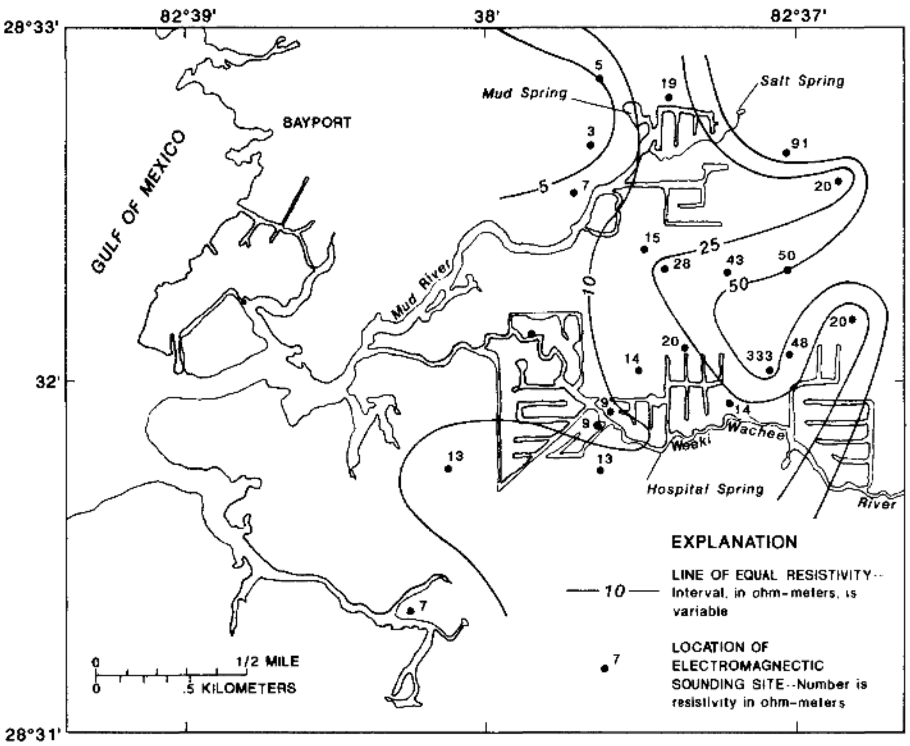


Figure 8. Electromagnetic resistivity determined with 20-meter vertical coil orientation near Bayport.

Table 2. Multiple regression models for estimation of instantaneous discharge

[N, number of observations; R^2, coefficient of determination; ft^3/s, cubic feet per second]

Spring name	N	Predictive equation	Statistics	
			R^2	Standard error (ft^3/s)
Weeki Wachee Spring	128	$Q = 12.35(WW) - 48.07$	0.87	11.6
Bobhill Springs	5	$Q = 0.67(RTR) - 6.69$	.99	.07
Salt Spring	20	$Q = 2.08(WW) + 7.88(R19\text{-}2) - 51.08$	.82	1.51
Crab Creek Spring	12	$Q = 1.14(WW) - 7.90(ST) + 36.88$	.81	1.66

where Q is instantaneous discharge, in cubic feet per second;

WW is daily maximum water level in Weeki Wachee well, in feet above sea level;

RTR is daily maximum water level in ROMP TR18-3 well, in feet above sea level;

R19-2 is instantaneous water level in ROMP 19-2 well (lagged 120 minutes), in feet above sea level; and

ST is instantaneous spring-pool altitude of Crab Creek Spring, in feet above sea level.

Relations between flow of Weeki Wachee Springs, Bobhill Springs, and Hidden River Springs and water levels in nearby wells that tap the Upper Floridan aquifer are shown in figure 9. For every foot of water-level change in Weeki Wachee well, a change in discharge of about 12.5 ft^3/s occurs at Weeki Wachee Springs. For every foot of water-level change in Homosassa well no. 3, a change in discharge of about 10.5 ft^3/s occurs at Hidden River Springs, and for every foot of water-level change in ROMP TR18-3, a change in discharge of about 0.7 ft^3/s occurs at Bobhill Springs.

Discharge hydrographs for the four daily discharge spring sites are shown in figure 10 for the period April 1988 through March 1989. This period includes dates of most of the water-quality and discharge determinations shown and discussed in this report. Also shown in figure 10 is the mean monthly discharge of Weeki Wachee Springs for the period 1966-84.

Spring flow is seasonal, with a peak discharge in late summer and early fall, followed by a gradual decrease in flow toward winter and spring, as shown in figure 10. Spring flow was highest in September and October, at the end of the wet season, and lowest in July, at the end of the dry season. The flow pattern is apparent in hydrographs for the tidal springs (Crab Creek Spring and Salt Spring) and in the nontidal springs (Weeki Wachee Springs and Bobhill Springs). The graph also indicates that, during the study period, spring flow at Weeki Wachee Springs was greater than the mean flow for the 1966-84 period.

To show the response of spring flow to recharge from summer rains, discharge was measured at 21 springs near the end of the dry season (June and July 1988) and again near the end of the wet season (October and November 1988). Fifteen of the 21 springs averaged about a 35-percent increase in flow from dry-season to wet-season measurements. Spring flow remained virtually unchanged for the other six springs, indicating that the increase in spring flow during wet periods is not always proportional to the increase in rainfall as a result of storage in the aquifer. It is likely that, if a comparison could have been made over several years for each June-July and October-November period, a more significant relation between discharge of springs and recharge would have been found.

SPRING-WATER QUALITY

The degree of mineralization of spring water in the study area is determined largely by the mixing of saltwater with freshwater and by the composition and solubility of soil and rocks through which precipitation passes. This section describes the quality and variability of the quality of water discharging from springs in the study area and discusses the mixing patterns, age, and origins of the water.

Salinity

Salinity refers to the salt content of water or, more precisely, the concentration of dissolved solids in water. Forch and others (1902) define salinity as "the total amount of solid material in grams contained in one kilogram of sea

Table 3. Instantaneous discharge and specific conductance of coastal springs, 1988-89
[ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; — no data]

Site name	Site number (fig. 1)	Number of discharge measurements	Instantaneous discharge (ft^3/s)		Specific conductance (µS/cm)	
			Average	Range	Average	Range
Baird Creek Head Spring	17	8	5.59	1.37 — 6.33	8,580	5,870 — 13,900
Beteejay Head Spring	14	3	6.36	5.52 — 6.85	424	407 — 440
Beteejay Lower Spring	15	2	[1]10.4	8.39 — 12.5	440	—
Blue Run Head Spring	13	13	6.58	5.51 — 7.81	6,430	2,990 — 9,820
Boat Spring	4	7	1.25	[2]-6.74 — 3.10	2,980	269 — 19,800
Bobhill Springs	1	5	2.56	1.49 — 3.35	242	227 — 270
Crab Creek Spring	20	20	48.7	40.1 — 54.6	3,860	2,410 — 5,950
Chassahowitzka Springs	18	1	92.6	—	694	390 — 1,320
Gator Spring	3	2	.26	0.21 — 0.31	240	240 — 240
Halls River Head Spring	29	4	6.79	4.28 — 6.67	4,300	3,190 — 6,670
Hidden River Head Spring	25	—	—	—	795	739 — 855
Hidden River	26	7	[3]9.29	5.05 — 20.1	1,040	362 — 2,263
Homosassa Springs	28	11	104	56.4 — 122	2,943	1,980 — 4,750
Hospital Hole	7	—	—	—	21,900	19,800 — 29,100
Hospital Spring	8	5	.38	0.29 — 0.53	5,800	4,180 — 7,580
Magnolia Springs	2	7	.69	0 — 1.08	379	252 — 441
Mud Spring	10	5	45.0	[2]-50.8 — 78.4	21,100	9,570 — 28,900
Potter Spring	24	14	[4]18.6	0 — 30.2	7,460	3,040 — 15,300
Rita Maria Spring	16	7	4.78	4.04 — 5.11	1,270	690 — 7,040
Ruth Spring	23	14	13.3	10.1 — 17.2	1,650	964 — 4,160
Ryle Creek Head Spring	11	9	2.48	0.39 — 3.72	14,900	4,850 — 19,400
Ryle Creek Lower Spring	12	10	[5]11.8	0.39 — 15.5	11,800	5,460 — 20,400
Salt Spring	9	34	33.4	27.7 — 40.4	6,340	692 — 28,400
Salt Creek Head Spring	22	9	.61	0 — 0.91	7,290	4,590 — 13,000
Trotter Spring	27	12	7.36	5.47 — 9.25	307	280 — 340
Unnamed tributary above Chassahowitzka Springs	30	13	[6]30.0	21.0 — 44.8	538	434 — 597
Weeki Wachee Springs	5	6	185	164 — 221	284	278 — 290

[1] Includes flow of Beteejay Head Spring.

[2] Negative sign indicates upstream flow.

[3] Includes flow of Hidden River Head Spring and numerous uninventoried springs.

[4] Includes flow of Ruth Springs.

[5] Includes flow of Ryle Creek Head Spring.

[6] Includes flow of Bubba Spring and numerous uninventoried springs.

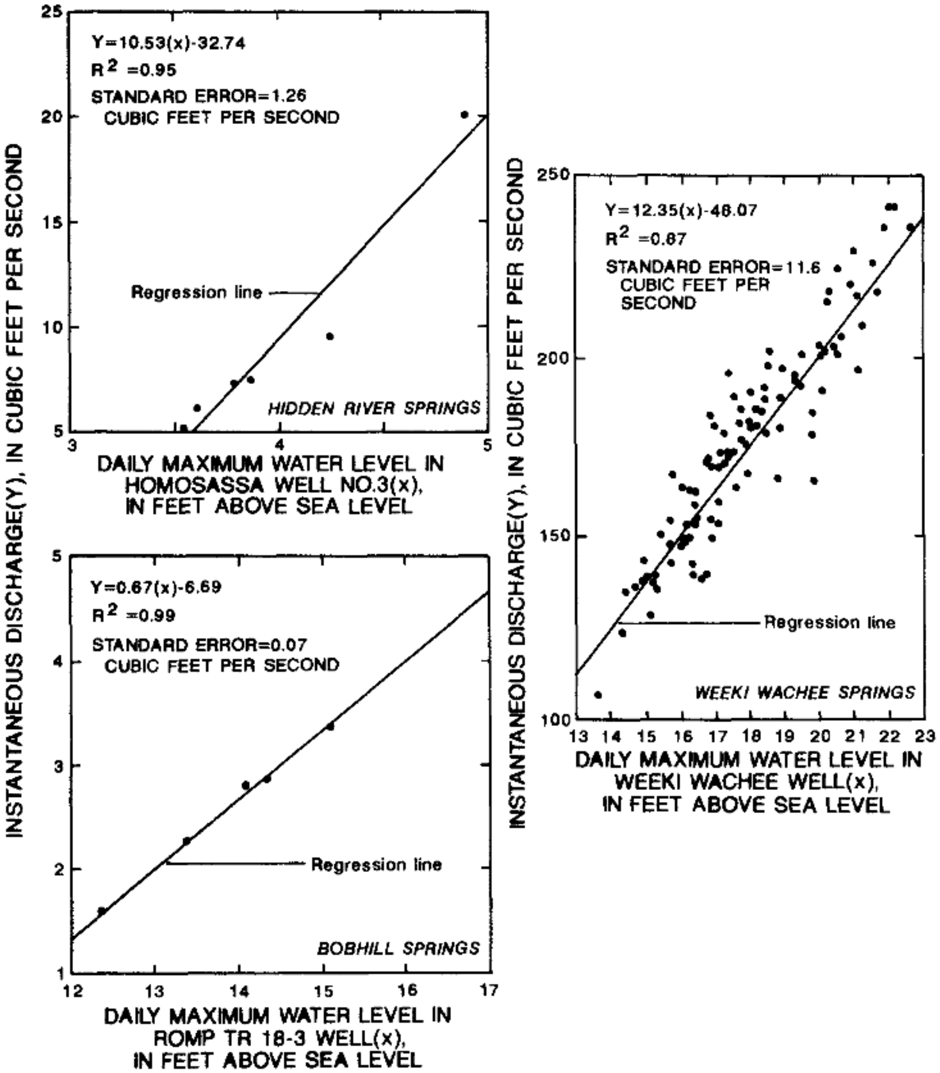


Figure 9. Relation between instantaneous discharge of Bobhill Springs, Hidden River Springs, and Weeki Wachee Springs and daily maximum water levels in ROMP TR18-3 well, Homosassa well no. 3, and Weeki Wachee well.

water when all the carbonate has been converted to oxide, the bromide and iodine replaced by chlorine, and all organic matter completely oxidized." Salinity is generally expressed as a concentration of dissolved solids, in parts per thousand or milligrams per liter of seawater (1,000 mg/L is approximately equal to 1 ppt).

The salinity of water can be estimated from measurements of specific conductance. The specific conductance, measured in microsiemens per centimeter at 25°C, is proportional to the dissolved-solids concentration of water. Specific-conductance measurement is a convenient and rapid way to determine the approximate amount of dissolved solids in water.

Specific conductance also can be used to estimate individual ionic concentrations. Relations between specific conductance and selected ionic concentrations and dissolved solids in spring waters of coastal Citrus and Hernando Counties are shown in figure 11. All major constituents and dissolved solids have significant regression relations with specific conductance. The regression equations given in table 4 can be used to estimate the concentration of certain dissolved constituents in spring water if specific conductance is known.

Major-Ion Chemistry

Results of the chemical analyses of water from 25 springs are listed in appendix C. The springs that were sampled are shown in figure 1; the site numbers correspond to those in appendix A. In addition to the 25 samples of spring water, appendix C includes results of analyses of four water samples from the Gulf of Mexico and analyses of water samples from three coastal wells.

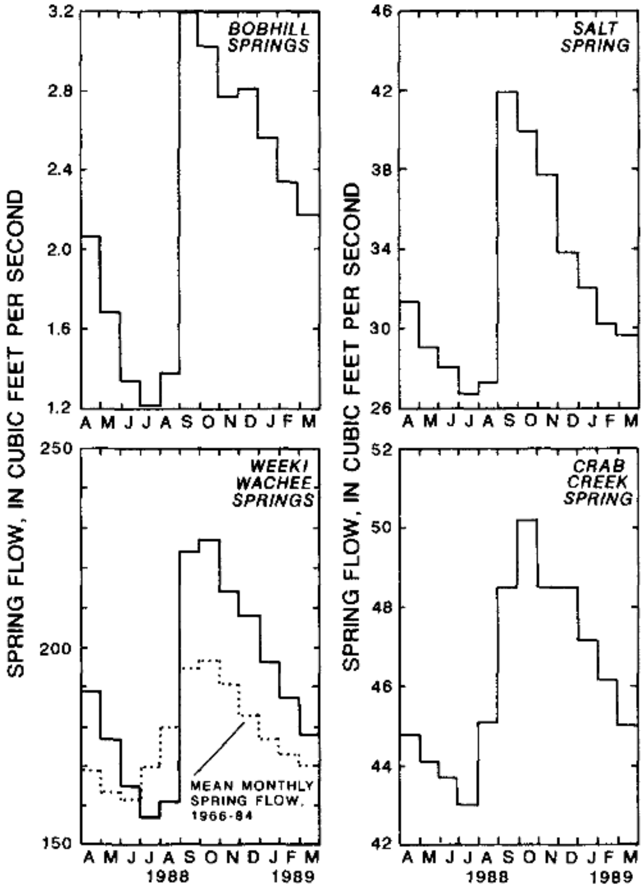


Figure 10. Monthly mean spring flow of Weeki Wachee Springs, Crab Creek Spring, Bobhill Springs, and Salt Spring, April 1988 through March 1989.

Springs in coastal Citrus and Hernando Counties discharge three different types of water: calcium bicarbonate, sodium chloride, and a transitional type whose chemical quality is intermediate between the two water types. The gradation in water types is illustrated in the plot of major cation and anion equivalent concentration percentages on the trilinear diagram in figure 12. Trilinear diagrams are used to indicate water-quality variations, classification of water masses, and resultant water types from water mixing. Water from Weeki Wachee Springs is typical of a calcium bicarbonate water. It contains low concentrations of sodium, chloride, and dissolved solids. The dominant ion is bicarbonate, which is characteristic of a carbonate aquifer. Water from Bubba Spring is typical of a transitional water that does not contain any individual cation or anion species in a concentration exceeding 50 percent of the total ionic concentration. Water from Salt Spring is representative of a sodium chloride water. Water of this type contains high concentrations of sodium, chloride, and dissolved solids. The dominant ion is chloride.

It is apparent from examining the diamond part of figure 12 that the primary processes affecting the chemical quality of spring water are the solution of carbonate minerals and the mixing with saltwater. Waters that have the lowest chloride concentrations (Weeki Wachee Springs) plot in the typical calcium bicarbonate position of water from carbonate aquifers (Back and Hanshaw, 1971). As the percentage of chloride increases, the position of each succeeding analysis describes a near straight line to the position of Gulf of Mexico water (fig. 1, site 41).

To further illustrate the mixing relation, the ratio of magnesium to calcium concentrations, in milliequivalents, was plotted as a function of the chloride concentration for each sample (fig. 13). The straight line in figure 13 shows the magnesium to calcium ratio and chloride equivalent concentration that would result if gulf water were added in increasing amounts to water from Weeki Wachee Springs. As chloride concentration increases, a corresponding increase in magnesium to calcium ratio occurs. The near straight-line plot demonstrates that the source of magnesium is gulf water rather than a source relatively richer in magnesium than gulf water.

Water chemistry of some springs varied between the dry-season and wet-season sampling periods. The springs generally discharged fresher water during the wet-season sampling period than during the dry-season sampling period. Lower chloride concentrations are correlated with lower variation in major-ion concentrations between the two sampling periods. Springs with chloride concentrations less than 50 mg/L had only small variations in water chemistry between the two sampling periods. Weeki Wachee Springs is an example of a spring in the study area that had little change in major ion chemistry (fig. 14). Springs with chloride concentrations greater than 50 mg/L generally had significant decreases in major-ion concentrations between the two sampling periods as a result of the lower saltwater content of the springs in late summer and early fall. Of the 25 springs sampled, Jenkins Creek Spring had the greatest variation in water chemistry. Potter Spring, Ryle Creek Lower Spring, and Salt Creek Head Spring exhibited increases in major-ion concentrations between the two sampling periods.

Total Nitrogen and Total Phosphorus

Results of the analyses of samples for total nitrogen and total phosphorus are listed in appendix C. Springs and wells were sampled once in June or July, near the end of the dry season, for analysis for these constituents. Concentrations of total nitrogen were small (less than 0.5 mg/L) and were within ranges expected for ground water in the study area (Fretwell, 1983). Concentrations of total phosphorus in samples from the study area were minimal. Concentrations of total phosphorus were near analytical detection limits and did not indicate contamination problems.

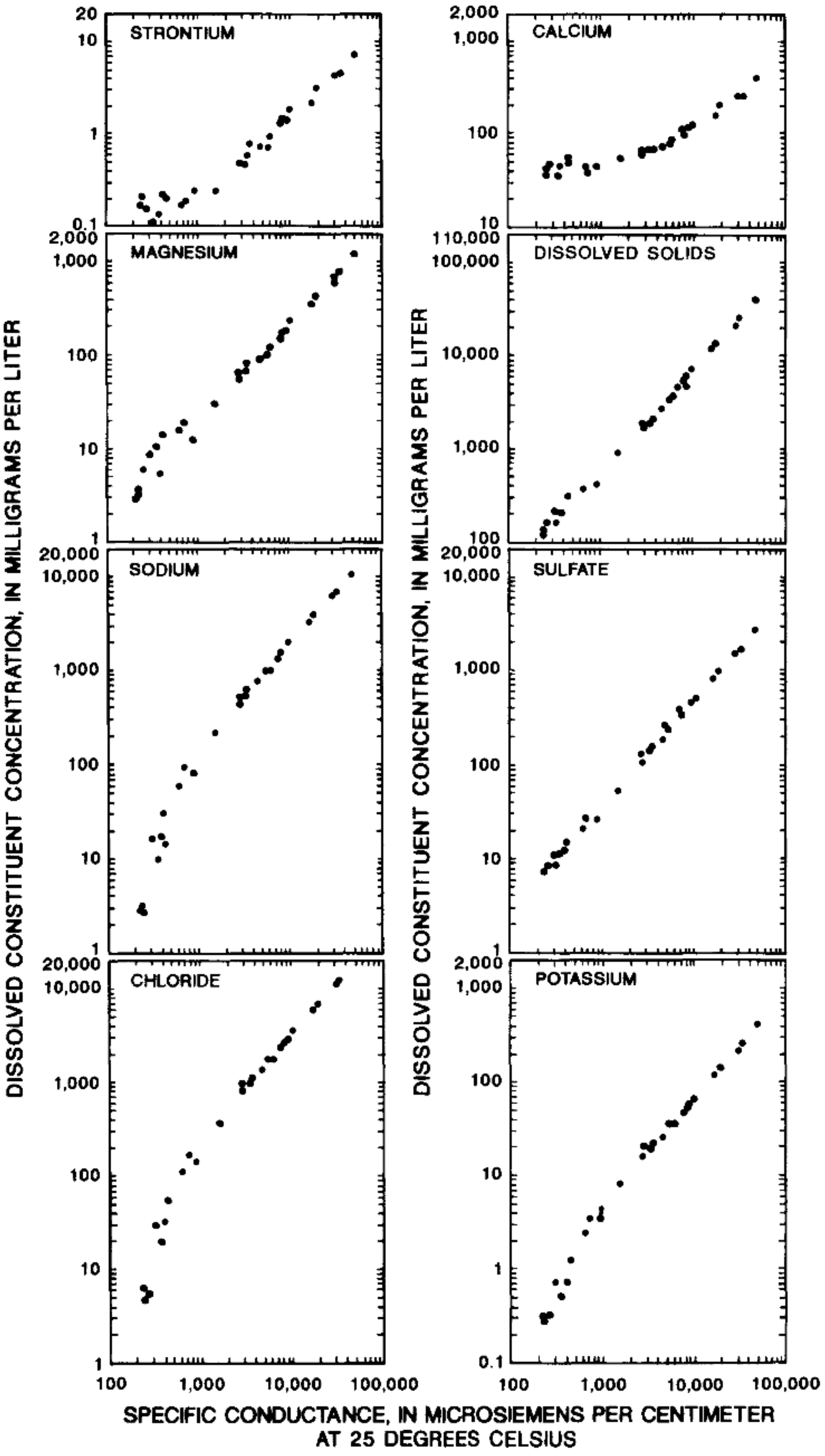


Figure 11. Relation between specific conductance and major ionic species and dissolved solids in spring water in coastal Citrus and Hernando Counties.

Table 4. Summary of the results of the regression analysis relating the concentration of dissolved constituents to specific conductance of water from springs

[mg/L, milligrams per liter; SC, specific conductance; °C, degrees Celsius]

Constituent	Concentration range (mg/L)	Predictive equation	Statistics		
			Number of samples	Coefficient of determination (R^2)	Standard error of estimate (mg/L)
Calcium (Ca)	34 — 400	Ca = 0.0072(SC) + 41.6	55	0.99	8.4
Magnesium (Mg)	3 — 1,200	Mg = 0.0234(SC) – 10.6	55	.99	15.2
Sodium (Na)	3 — 11,000	Na = 0.205(SC) – 147	55	.99	184
Chloride (Cl)	5 — 19,000	Cl = 0.367(SC) – 262	55	.99	292
Sulfate (SO_4)	6 — 2,700	SO_4 = 0.051(SC) – 27.6	55	.99	35.8
Potassium (K)	0.2 — 420	K = 0.008(SC) – 6.43	55	.99	6.5
Strontium (Sr)	0.1 — 7.4	Sr = 0.0001(SC) + 0.14	55	.99	.2
Dissolved solids (residue at 180 °C)	128 — 38,000	DS = 0.71(SC) – 269	55	.99	739

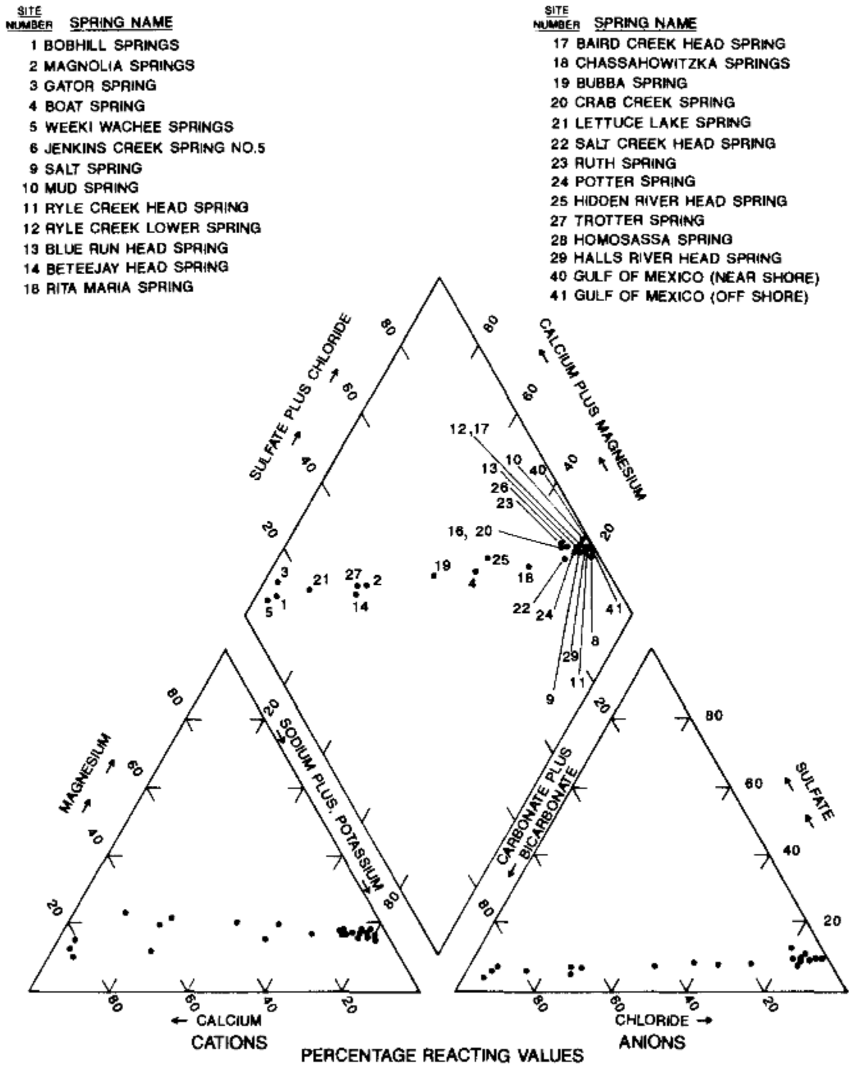


Figure 12. Water-quality diagram for coastal springs in Citrus and Hernando Counties.

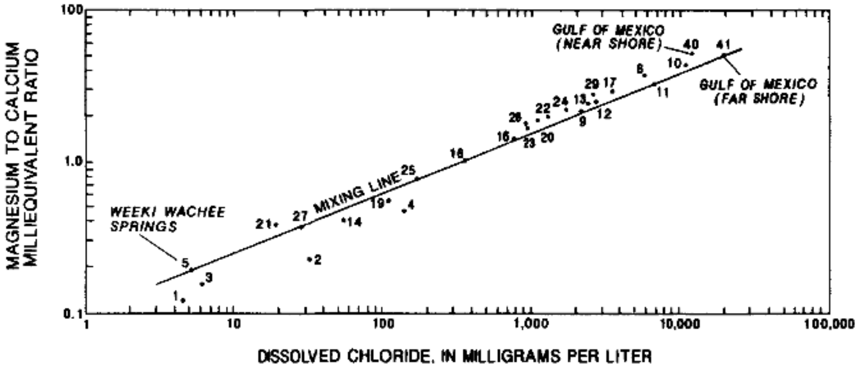


Figure 13. Magnesium to calcium milliequivalent ratio as a function of chloride concentration.

Environmental Isotopes

Isotopic composition can be used to indicate the age, origin, and mixing patterns of water. Samples of water from springs, wells, and the Gulf of Mexico were collected for analysis for tritium and the stable isotopes oxygen-18 (^{18}O) and deuterium (D). Stable isotope ratios are reported relative to a standard as delta units (δ) in parts per thousand (permil). For hydrologic purposes, the reference standard composition is that of average seawater (SMOW, standard mean ocean water) (Hem, 1985). Larger negative value for $\delta^{18}O$ and δD indicate greater depletion of ^{18}O and D relative to the standard. Analytical results for these isotopes and tritium in samples collected at 25 springs and 4 sites in the Gulf of Mexico from 1987 through 1989 are given in table 5. Two of the gulf sites are about 1 and 30 mi west of the mouth of the Homosassa River; the other two sites are about 5 and 50 mi west of the mouth of the Weeki Wachee River (fig. 1).

Tritium is a radioisotope of hydrogen. It has a half-life of approximately 12.4 years and is derived from both natural sources and human activities. Prior to extensive atmospheric thermonuclear testing between 1952 and 1963, background tritium levels in precipitation were about 6.4 to 32 pCi/L, depending on geographic location (Kaufman and Libby, 1954). Beginning in 1952, relatively large amounts of tritium were introduced into the atmosphere, and, by 1963, tritium concentrations in rain were reported to be 3,800 pCi/L at Ocala, Fla. (International Atomic Energy Agency, 1981). Since the ban on atmospheric nuclear testing became effective in 1963, tritium levels in precipitation have declined each year, and, in 1988, the amount of tritium was not significantly different from the estimated prebomb concentration of 16 pCi/L (Robertson and Cherry, 1989).

Tritium is a useful tool for hydrologic studies because it provides a convenient marker for relatively young water in the hydrologic cycle. Ground water in west-central Florida with a concentration greater than 160 pCi/L would have to contain a large proportion of water that fell as precipitation between 1962 and 1965 (Swancar and Hutchinson, 1992). Ground water recharging between 1962 and 1970 is expected to have a concentration of more than 48 pCi/L, and water greater than 70 years old would have only background concentrations of tritium (Swancar and Hutchinson, 1992).

Assuming a prebomb input concentration of 16 pCi/L and a half-life of 12.4 years, the concentrations of tritium in samples collected in 1988 during selected years would be as follows (Swancar and Hutchinson, 1992):

Year	Tritium concentration, in pCi/L
1910	0.2
1920	.4
1930	.6
1940	1.1
1950	1.9

The stable-isotope composition also is used in ground-water investigations to indicate origins and mixing patterns. In general, $\delta^{18}O$ and δD are different for waters of different origins. Mixing equal parts of seawater with freshwater results in a water whose isotope composition is midway between that of seawater and that of freshwater. As a result, a linear relation exists between chloride concentration and the stable-isotope content (Coplen, 1988).

A high correlation exists between the isotope composition and chloride concentration of spring water in the study area (fig. 15). Increased chloride content corresponds to decreased tritium content and increases in both $\delta^{18}O$ and δD values along a typical mixing line between local ground water and gulf water.

From the chloride content and isotope content of the springs and the isotope content of seawater, it was possible to estimate the isotope index of the freshwater discharging from the springs. The isotope content of the freshwater discharging from the springs can be estimated by means of the following mass-balance equation:

$$I_{fw} = \frac{I_o - (\%_{sw})(I_{sw})}{\%_{fw}} \tag{1}$$

where I_{fw} is the isotope content of freshwater, in parts per thousand or picocuries per liter;

I_o is the observed isotope content of spring water, in parts per thousand or picocuries per liter;

$\%_{sw}$ is the percentage of saltwater;

$\%_{fw}$ is the percentage of freshwater; and

I_{sw} is the isotope content of saltwater, in parts per thousand or picocuries per liter.

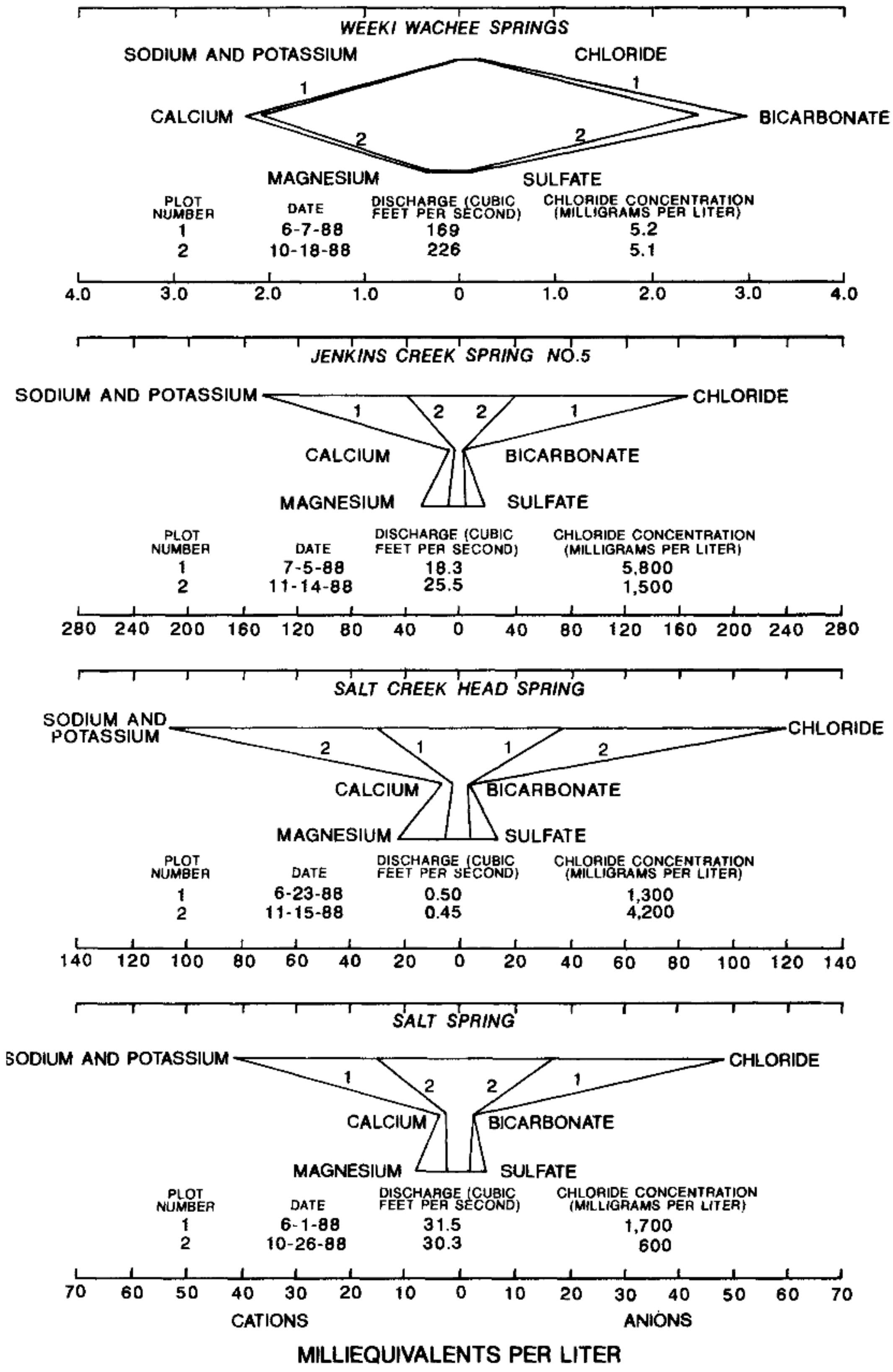


Figure 14. Seasonal variation in water chemistry at four springs.

Table 5. Results of analyses of samples collected at 25 springs and 4 miscellaneous sites in the Gulf of Mexico for deuterium, oxygen-18, and tritium

[δ, delta units, which represent difference in concentration relative to that of Standard Mean Ocean Water; D, deuterium; ^{18}O, oxygen-18; ^3H, tritium; ‰, permil; pCi/L, picocuries per liter; mi, mile; —, no data; NA, not applicable]

Site number (fig. 1)	Site name	Sampling date	δD (‰)	$\delta^{18}O$ (‰)	^3H (pCi/L)	Percent saltwater	Saltwater correction		
							δD (‰)	$\delta^{18}O$ (‰)	^3H (pCi/L)
1	Bobhill Springs	3-28-88	-16.0	-3.20	26	0.0	NA	NA	NA
		10-17-88	-16.0	-3.30	22	.0	NA	NA	NA
2	Magnolia Springs	6-07-88	-16.5	-3.15	22	.1	NA	NA	NA
		10-19-88	-15.0	-3.15	24	.1	NA	NA	NA
3	Gator Spring	6-06-88	-15.0	-3.00	23	.0	NA	NA	NA
		10-17-88	-15.5	-3.15	22	.0	NA	NA	NA
4	Boat Spring	6-06-88	-16.0	-3.05	23	.7	NA	NA	NA
		10-17-88	-16.0	-3.25	24	.2	NA	NA	NA
5	Weeki Wachee Springs	6-07-88	-16.0	-3.35	24	.0	NA	NA	NA
		10-18-88	-15.0	-3.30	22	.0	NA	NA	NA
6	Jenkins Creek Spring No. 5	7-05-88	-12.0	-2.15	11	29.8	-19.0	-2.80	16
		11-14-88	-18.0	-2.70	15	7.6	-20.0	-3.00	16
9	Salt Spring	6-01-88	-15.5	-3.20	21	8.6	-16.5	-3.60	23
		10-26-88	-16.5	-3.30	20	3.0	-17.0	-3.40	21
10	Mud Spring	7-05-88	- .4	-1.05	7.6	57.1	-14.5	-3.30	18
		11-14-88	-8.4	-1.55	12	42.4	-17.5	-3.15	21
11	Ryle Creek Head Spring	6-29-88	—	—	14	35.0	—	—	22
		11-15-88	-13.0	-2.65	17	17.9	-16.5	-3.35	21
12	Ryle Creek Lower Spring	6-29-88	-15.0	-2.95	11	13.8	-18.0	-3.55	13
		11-15-88	-11.0	-2.15	15	27.8	-13.5	-3.05	21
13	Blue Run Head Spring	6-24-88	-16.0	-3.05	18	12.2	-19.0	-4.15	21
		10-20-88	-16.0	-3.00	19	11.2	-18.5	-4.10	21
14	Beteejay Head Spring	6-29-88	-18.0	-3.55	19	.3	NA	NA	NA
		10-20-88	-17.5	-3.50	22	.1	NA	NA	NA
16	Rita Maria Spring	6-30-88	-17.5	-3.35	20	3.9	-18.5	-3.50	21
		10-20-88	-16.5	-3.50	22	.9	NA	NA	NA
17	Baird Creek Head Spring	6-22-88	-14.0	-2.80	19	17.9	-18.0	-3.55	23
		11-15-88	-16.0	-2.25	21	10.2	-18.0	-2.60	23
18	Chassahowitzka Springs	7-06-88	-18.0	-3.45	19	1.8	NA	NA	NA
		10-27-88	-17.5	-3.50	23	.6	NA	NA	NA
19	Bubba Spring	6-08-88	-17.0	-3.40	22	.5	NA	NA	NA
		10-27-88	-18.5	-3.45	22	.3	NA	NA	NA
20	Crab Creek Spring	6-01-88	-16.5	-3.30	20	5.6	-17.5	-3.55	21
		10-26-88	-15.0	-3.25	20	4.9	-16.0	-3.45	21
21	Lettuce Creek Spring	6-22-88	-18.5	-3.45	21	.1	NA	NA	NA
		10-26-88	-15.0	-3.40	25	.1	NA	NA	NA
22	Salt Creek Head Spring	6-23-88	-15.5	-3.30	19	6.6	-17.0	-3.60	20
		11-15-88	-12.5	-2.45	16	21.5	-17.0	-3.30	20
23	Ruth Spring	6-21-88	-15.5	-3.45	20	4.8	NA	NA	NA
		10-27-88	-17.5	-3.40	21	1.2	NA	NA	NA
24	Potter Spring	6-21-88	-14.0	-3.00	19	8.6	-15.5	-3.35	21
		10-27-88	-14.0	-2.95	19	10.7	-16.0	-3.40	21
25	Hidden River Head Spring	6-01-88	-17.9	-3.60	22	.8	NA	NA	NA
27	Trotter Spring	6-30-88	-18.0	-3.55	22	.1	NA	NA	NA
		10-19-88	-18.0	-3.55	21	.1	NA	NA	NA
28	Homosassa Springs	6-07-88	-17.0	-3.25	21	4.7	-18.0	-3.45	22
		10-18-88	-16.0	-3.30	20	4.4	-17.0	-3.50	21
29	Halls River Head Spring	6-30-88	-16.0	-2.90	17	13.3	-19.0	-3.45	20
		10-19-88	-16.5	-3.40	21	5.1	-17.5	-3.60	22
40	Gulf of Mexico, 1 mi west of Homosassa River	7-20-88	10.9	1.15	30	62.4	NA	NA	NA
41	Gulf of Mexico, 30 mi west of Homosassa River	7-20-88	4.0	.65	14	100	NA	NA	NA
42	Gulf of Mexico, 10 mi west of Weeki Wachee River	1-09-89	0	.19	39	62.4	NA	NA	NA
43	Gulf of Mexico, 50 mi west of Weeki Wachee River	1-08-89	4.5	.95	10	100	NA	NA	NA

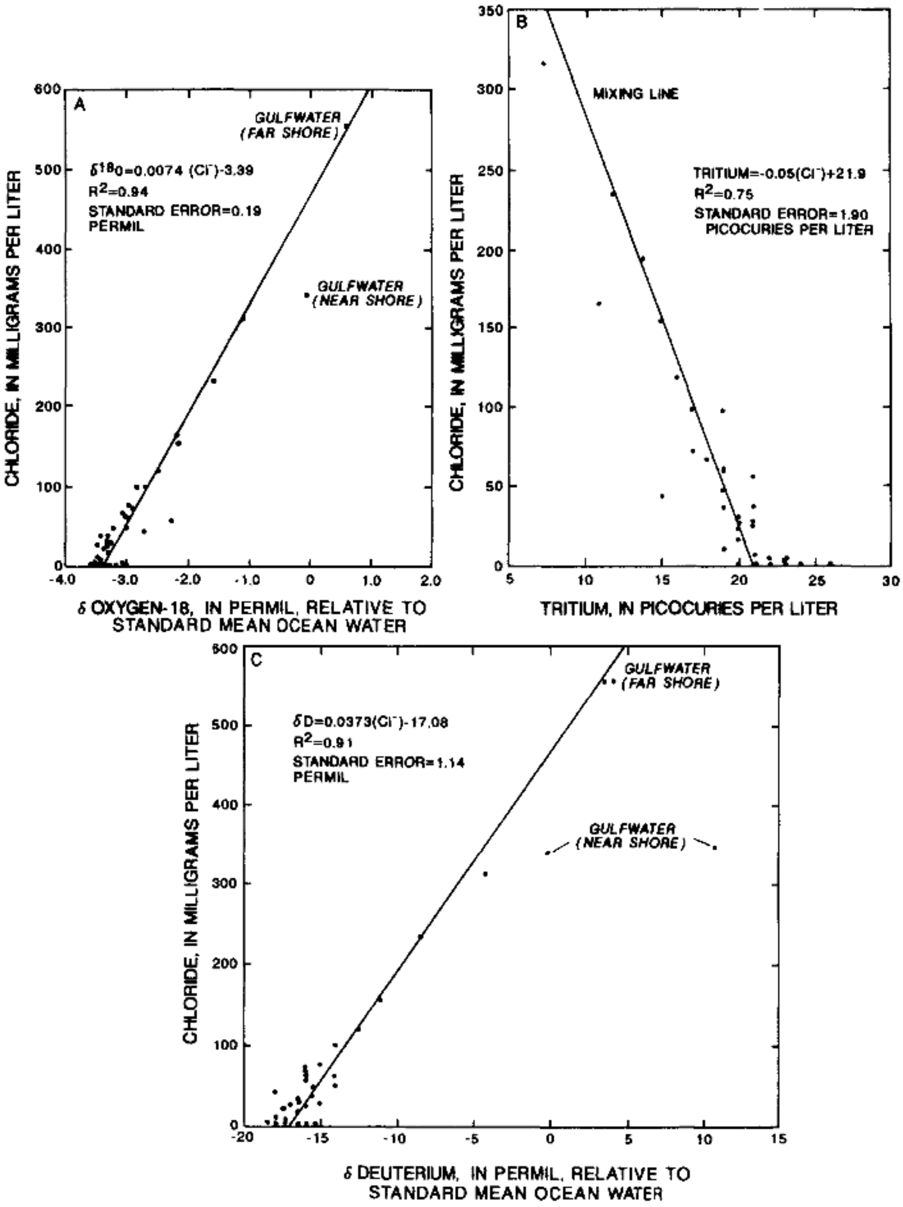


Figure 15. Relations between delta oxygen-18 and chloride, tritium and chloride, and delta deuterium and chloride.

The percentage of saltwater in each sample was determined from chloride concentrations. Given the molarities of chloride in freshwater, saltwater, and the mixture, the fraction of saltwater in the mixture can be estimated from the following equation (Plummer and Back, 1980):

$$\text{percentage of saltwater} = \frac{M_{cl,mix} - M_{cl,fw}}{M_{cl,sw} - M_{cl,fw}} \qquad (2)$$

where $M_{cl,mix}$, $M_{cl,fw}$, and $M_{cl,sw}$ are the molarities of chloride in the mixture, the freshwater, and the saltwater, respectively.

The isotope composition of seawater was estimated to be 0 pCi/L for tritium, 4 ppt for δD, and 0.70 ppt for $\delta^{18}O$. These values were estimated from the regression equations in figure 15, assuming a chloride concentration of seawater of 555 millimoles.

Results of analyses for tritium indicate that the freshwater discharging from coastal springs is predominantly post-1952 in age and of very recent origin. Tritium concentrations in the freshwater discharging from the springs averaged about 21 pCi/L for all spring samples and ranged from 13 pCi/L at Ryle Creek Lower Spring to 26 pCi/L at Bobhill Springs. Of the samples analyzed for tritium, only Jenkins Creek Spring no. 5 had an average value for the two sampling periods of less than 20 pCi/L. The tritium data indicate that freshwater springs discharge water that is less than 70 years old.

No appreciable variation in tritium concentration in the freshwater discharging from the sampled springs was observed between the two sampling periods. Tritium concentrations varied an average of less than 2 pCi/L between

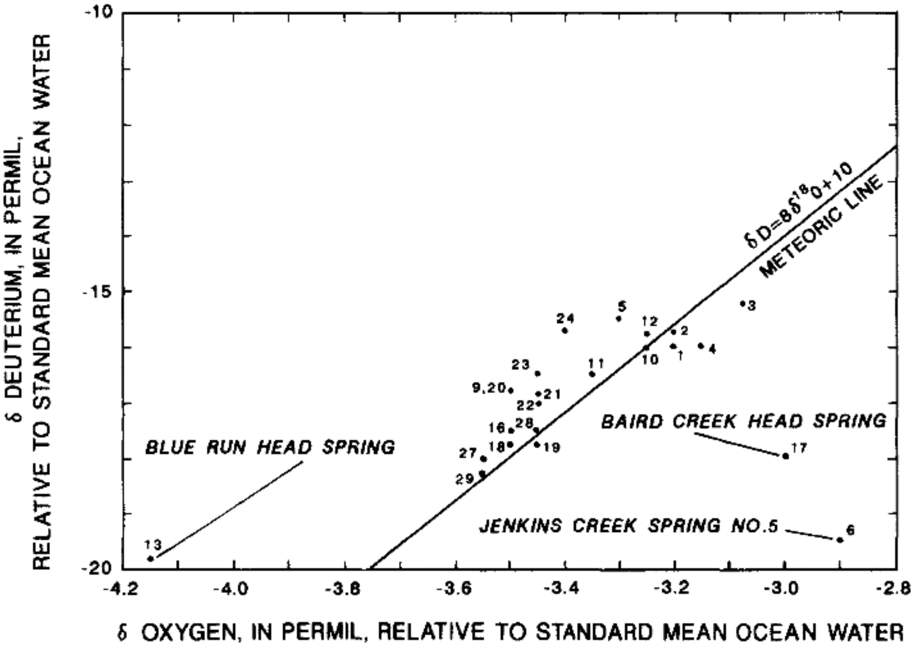


Figure 16. Relation between delta oxygen-18 and delta deuterium.

sampling periods, although tritium concentrations in rainfall in spring and summer are 3 to 10 times greater than those in fall and winter (International Atomic Energy Agency, 1981). This implies that tritium concentrations in spring water are affected little by their seasonal variation in rainfall. The cause of the unusual change in tritium concentrations at Ryle Creek Lower Spring (13-21 pCi/L) is unknown.

The stable-isotope composition of the freshwater discharging from the springs varies little. The stable-isotope composition of water from each spring is plotted in figure 16. The values plotted are means for the two sampling periods, and, where appropriate, the values plotted have been corrected for the presence of seawater in order to reflect the isotope composition of the freshwater component of the mixture. Values generally range from -3.1 to -3.5 ppt for $\delta^{18}O$ and from -15 to -18 ppt for δD. Exceptions are values for Baird Creek Head Spring, Jenkins Creek Spring no. 5, and Blue Run Head Spring. Most rain that falls in the basin originates as evaporation from the gulf, and, because it has been through only one evaporation-condensation cycle, it is slightly depleted in oxygen-18 and deuterium as compared to seawater.

Variations in $\delta^{18}O$, δD, and tritium in the ground water in the coastal springs ground-water basin, sampled as part of a concurrent study (Swancar and Hutchinson, 1992), are shown in figure 17. The isotope compositions of ground water and spring water are similar. This implies that ground-water flow paths are relatively short and continuously open to recharge. Average $\delta^{18}O$ in springs is about -3.3 ppt, compared to an average of about -3.5 ppt for ground water in the basin. Average δD in springs is about -16.5 ppt, compared with an average of about -17 ppt for ground water in the basin. Tritium concentrations average about 21 pCi/L in the springs and about 25 pCi/L in the ground water in the basin. The noted exceptions are in northern Polk County and in the southern counties where the isotope composition of ground water is characteristic of a mixture of young and older water.

EFFECTS OF TIDAL STAGE AND GROUND-WATER LEVELS ON SPRINGS

The following sections include a summary of specific-conductance and stage data for continuous-record spring sites, and an analysis of the effects of tides and ground-water levels on specific conductance of spring water and water-level fluctuations of springs. The discussion also includes a statistical technique for estimating daily maximum specific conductance in springs on the basis of ground-water levels and tides.

Discharge

Tides in the Gulf of Mexico affect flow of most coastal springs by raising and lowering water levels in both the spring and the aquifer. The flow of tidal springs is greater at low tide stage than at high or intermediate tide stage (fig. 18). At low tide, the head in a tidal spring decreases more than the head in the aquifer. This increases the gradient between the aquifer and the spring and permits water to flow out of storage, thereby increasing spring flow. At high tide, the head in a tidal spring increases more than the head in the aquifer. This decreases the gradient between the aquifer and the spring, thereby decreasing spring flow.

Weeki Wachee Springs, Bobhill Springs, and Hidden River Springs are not tidally affected. Their relatively high spring-pool altitude effectively blocks tidal movement upstream.

A double-mass plot was used to determine whether seasonal variations in tides affect discharge (fig. 19). In the analysis, the accumulated mean monthly flows of two springs were plotted against each other. A change in slope in the relation would imply a change in flow in one of the springs. The plots of flow of the tidally affected Salt Spring and Crab Creek Spring against the flow of Weeki Wachee Springs indicate a relatively constant relation. The variation of seasonal tides does not seem to affect monthly discharges of the tidally affected Salt Spring and Crab Creek Spring. A change in slope of the Weeki Wachee-Bobhill Springs plot occurs between August and September 1988. The break in slope is due to the presence of a control structure at the outlet of Bobhill Springs that affects low flows.

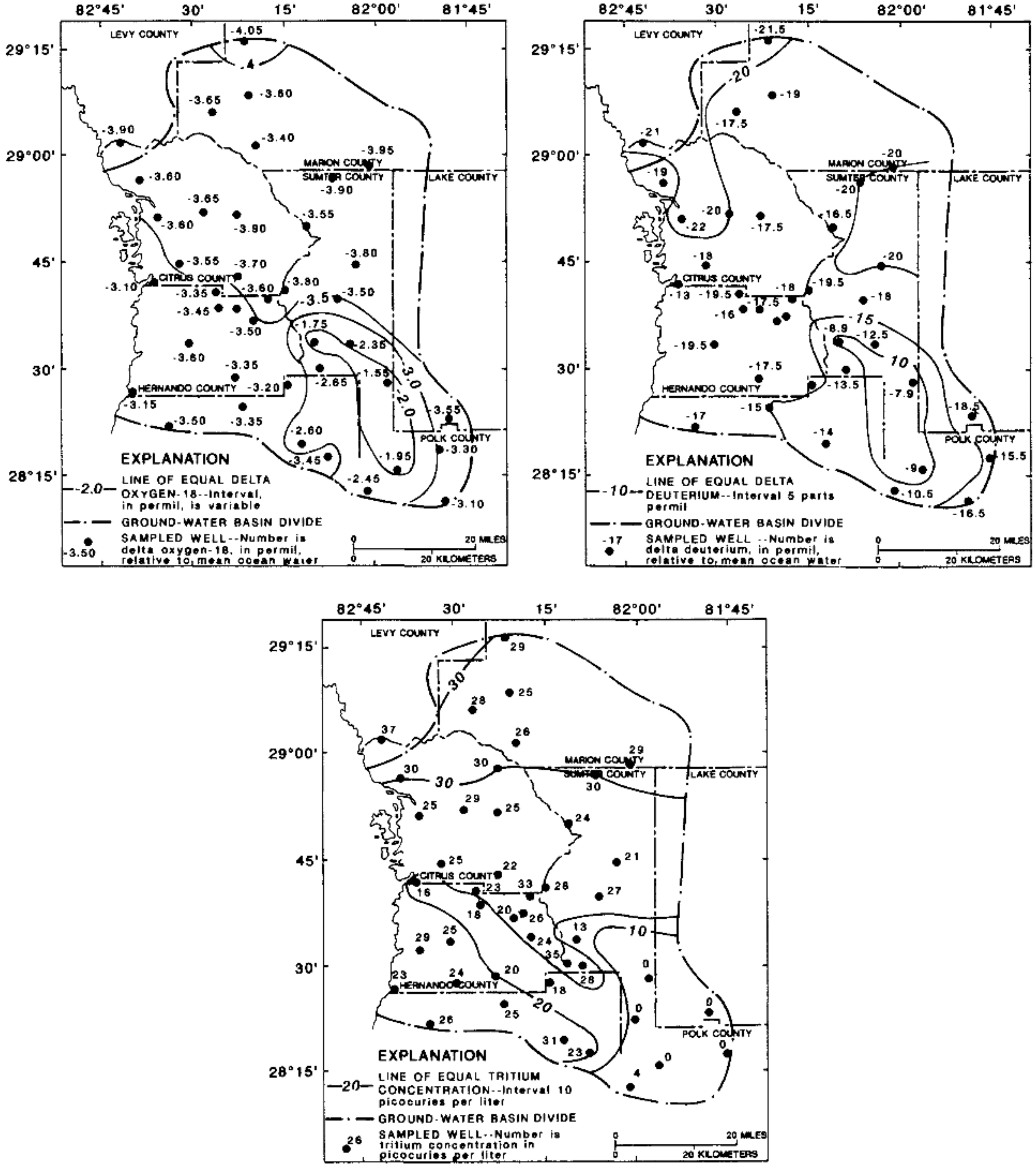


Figure 17. Variations of delta oxygen-18, delta deuterium, and tritium concentrations in ground water in the coastal springs basin.

Water Quality

Specific-conductance variation in springs is controlled by the dynamic balance between the denser saltwater and the level of freshwater above sea level and the diurnal tidal cycle (Mann and Cherry, 1969). The influence of ground-water levels is largely seasonal, whereas tides fluctuate hourly and influence specific conductance in a more short-term, cyclic manner. Specific conductance can increase by 5,000 to 20,000 µS/cm in a few hours between low and high tide, whereas stage can increase 1 to 2 ft.

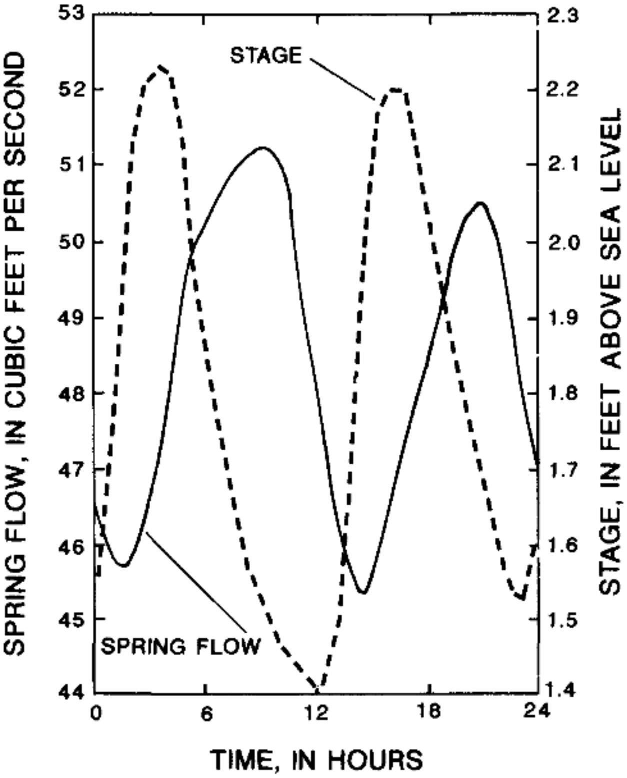


Figure 18. Spring flow and stage at Crab Creek Spring, October 24, 1988.

A summary of specific-conductance and stage data for continuous-record spring sites during the period of study is listed in table 6. Instantaneous specific conductance for 23 springs ranged from 227 µS/cm at Bobhill Springs to 29,700 µS/cm at Mud Springs. Mean daily specific conductance ranged from 242 µS/cm at Bobhill Springs to 21,900 µS/cm at Hospital Hole. The average diurnal stage range was about 0.75 ft and varied from 0.07 ft at Hidden River Head Spring to 2.81 ft at Boat Spring.

The variation in daily maximum water levels in Weeki Wachee well and daily maximum specific conductance of Salt Spring and Crab Creek Spring during April 1988 through March 1989 is shown in figure 20. The graphs show that the seasonal fluctuations in specific conductance were

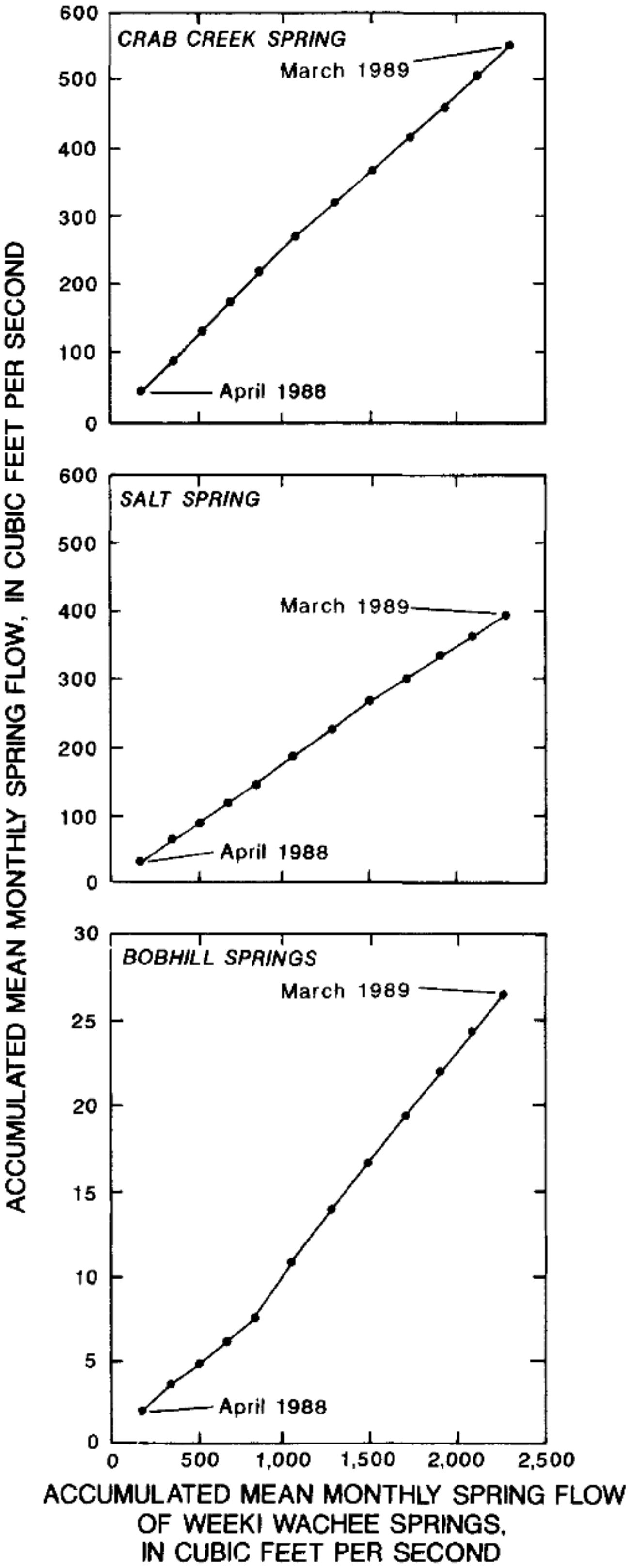


Figure 19. Correlation of spring flow of Bobhill Springs, Salt Spring, and Crab Creek Spring with flow at Weeki Wachee Springs, April 1988 through March 1989.

Table 6. Summary of specific-conductance and stage data for continuous-record spring sites, 1988-89
[µS/cm, microsiemens per centimeter at 25 degrees Celsius; ft, feet]

Site name	Site number (fig. 1)	Days of record	Specific conductance (µS/cm)						Stage (ft)		
			Maximum	Minimum	Mean	Daily range			Daily range		
						High	Low	Mean	High	Low	Mean
Baird Creek Head Spring	17	43	13,900	5,870	8,580	2,590	70	582	0.33	0.05	0.11
Blue Run Head Spring	13	43	9,820	2,990	6,430	2,780	150	1,500	1.64	.19	.48
Boat Spring	4	52	19,800	269	2,980	19,100	209	9,520	3.92	.91	2.81
Bobhill Springs	1	36	270	227	242	18	5	11	.79	.01	.09
Crab Creek Spring	20	302	5,950	2,410	3,860	1,160	280	439	1.65	.02	.48
Chassahowitzka Springs	18	41	1,320	390	694	529	7	154	1.34	.15	.83
Halls River Head Spring	29	43	6,670	3,190	4,300	2,040	20	337	.26	.03	.08
Hidden River Head Spring	25	35	855	739	795	26	3	10	.18	.01	.07
Hidden River Spring No. 6	26	24	2,260	362	1,040	1,590	77	569	.40	.03	.10
Homosassa Springs	28	41	4,750	1,980	2,940	4,400	360	1,260	2.48	.55	1.01
Hospital Hole	7	17	29,100	19,800	21,900	7,200	0	1,030	2.72	1.04	1.76
Hospital Spring	8	25	7,580	4,180	5,800	1,650	70	669	2.17	.34	1.27
Magnolia Springs	2	53	441	252	379	75	6	19	1.27	.01	.49
Mud Spring	10	28	29,700	21,100	9,570	7,000	2,600	4,600	1.82	.35	1.48
Potter Spring	24	56	15,300	3,040	7,460	8,370	600	2,710	2.40	.12	1.17
Rita Maria Spring	16	63	7,040	1,270	690	4,670	31	493	.57	.03	.11
Ruth Spring	23	33	4,160	964	1,650	1,130	20	227	.72	.09	.53
Ryle Creek Head Spring	11	37	19,400	4,850	14,900	11,500	1,200	5,340	1.58	.41	1.19
Ryle Creek Lower Spring	12	28	20,400	5,460	11,800	14,200	2,400	6,550	1.58	.41	1.19
Salt Spring	9	350	29,400	692	6,340	25,500	1,050	9,700	.85	.06	.13
Salt Creek Head Spring	22	42	13,000	4,590	7,290	5,580	960	1,520	1.19	.02	.71
Trotter Spring	27	30	340	280	307	21	5	10	1.46	.26	.87
Bubba Spring	18	38	597	484	538	35	6	15	1.78	.19	.54

substantial. Minimum specific-conductance values occurred in fall when ground-water levels generally are the highest, and maximum values occurred in summer when ground-water levels are the lowest. The large daily fluctuations in specific conductance in both springs are the result of daily differences in high tides in the Gulf of Mexico.

The saltwater-freshwater interface along Citrus and Hernando Counties moves horizontally and vertically in the aquifer in response to changes in ground-water levels and tides in the gulf. This movement creates a zone of varying specific conductance that changes seasonally and with tides. For example, samples collected from Hospital Hole (fig. 1, site 7) at low-water conditions on November 9, 1988, had specific-conductance values of 850 µS/cm at the surface, 8,200 µS/cm at a depth of 50 ft, and 17,600 µS/cm at a depth of 80 ft. At high-water conditions and lower tide on March 18, 1989, the specific conductance of samples from Hospital Hole was 424 µS/cm at the surface, 5,000 µS/cm at a depth of 50 ft, and 15,800 µS/cm at a depth of 80 ft.

Diagrams showing how movement of the saltwater-freshwater interface could cause variations in specific conductance of water discharging from springs are presented in figure 21. At times of high water levels in the aquifer, the interface is at its greatest depth, and discharge from the springs tends to be freshest. At times of low water levels, the depth to the interface is at its shallowest level. Under these conditions, saltwater in the aquifer mixes with freshwater flowing upward toward the spring openings, causing increased specific conductance in the spring discharge.

Although it was expected that springs would be fresher when ground-water levels were high and saltier when ground-water levels were low, an opposite condition was observed in several of the springs. Specific conductance of Halls River Head Spring, Potter Spring, and Chassahowitzka Springs was higher at high ground-water levels than at low ground-water levels. The reason for this is unclear. It may reflect variations in the proportion of the total flow of the spring that is derived from each formation or producing zone. When water levels are high, the head in shallower formations may be slightly less in some places than the head in deeper formations. This difference in head could increase the contribution from the deeper, more saline formation, thereby increasing the salt content of the water. However, a longer sampling period would be needed to verify these conditions.

Tides in the Gulf of Mexico cause short-term, regular fluctuations of stage and specific conductance of springs. Tides are of the mixed semidiurnal type; a higher high and lower high tide as well as a higher low and lower low tide are possible each day. Tides in the gulf, as well as gage height and specific conductance of water at Boat Spring on June 1-2, 1988, are shown in figure 22. Maximum and minimum specific-conductance values were measured just after maximum and minimum tide stage.

Diurnal fluctuations in stage and specific conductance of spring water due to tides occur in most springs in the study area (table 6) and vary considerably depending on distance upstream from the gulf. Near the coast, the effects of tides on stage and specific-conductance fluctuations are large. With increasing distance from the coast, the effect of the tide diminishes. At Boat Spring (fig. 1, site 4), 1.0 mi upstream from the gulf, mean daily tide and specific conductance are about 2.8 ft and 9,520 µS/cm, respectively; at Hospital Spring (fig. 1, site 8), 2.4 mi upstream from the mouth of the Weeki Wachee River, the means are about 1.3 ft and 669 µS/cm; and at Rita Maria Spring (fig. 1, site 15), 3.5 mi from the mouth of the Chassahowitzka River, the means are about 0.10 ft and 493 µS/cm (table 6). Water levels at Weeki Wachee Springs, about 7.5 mi from the coast, do not show any apparent tidal influence.

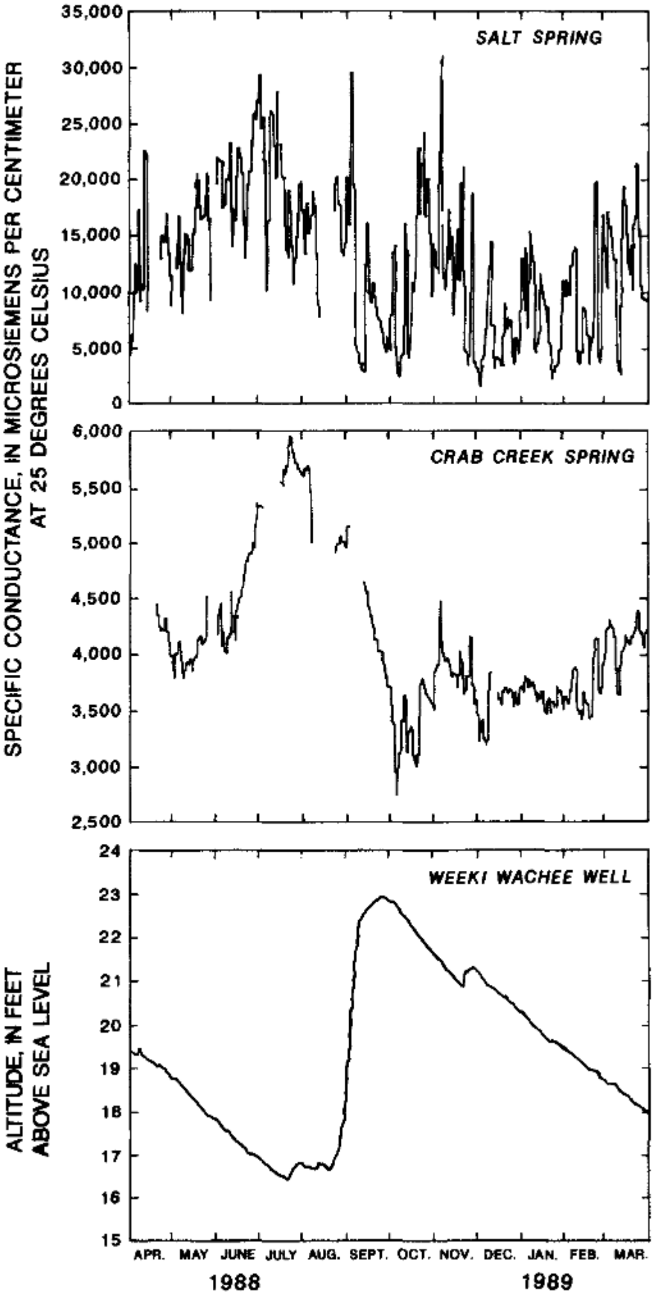
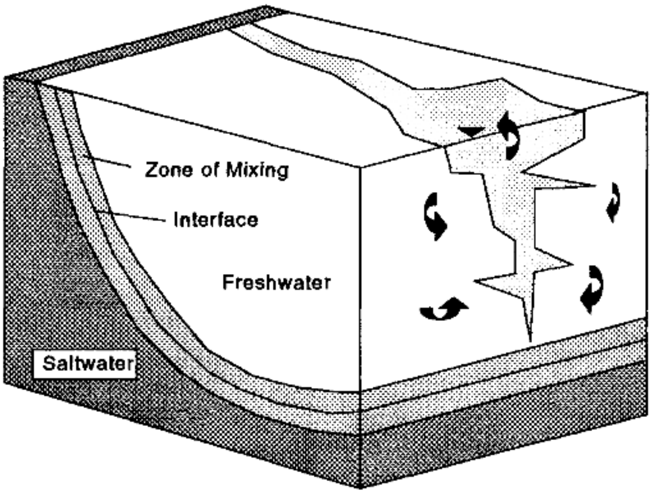
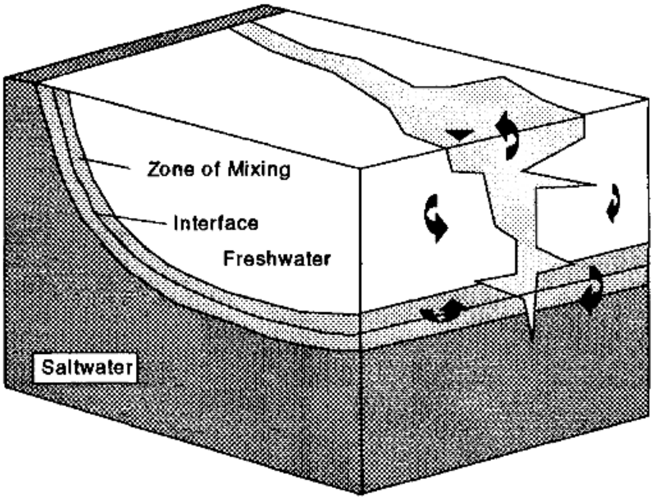


Figure 20. Variation in daily maximum water levels in Weeki Wachee well and daily maximum specific conductance in Salt Spring and Crab Creek Spring, April 1988 through March 1989.



A. HIGH FRESHWATER LEVELS



B. LOW FRESHWATER LEVELS

Figure 21. Movement of freshwater-saltwater contact at a spring vent. (Modified from Mann and Cherry, 1969.)

Salt Spring, Boat Spring, and Mud Spring, at the coast, had the widest range in specific conductance of the 23 springs monitored. The measured daily range in specific conductance of water in Salt Spring was 1,050 to 25,500 µS/cm; in Boat Spring, the range was 209 to 19,100 µS/cm; and in Mud Spring, the range was 2,600 to 7,000 µS/cm. The wide range in specific conductance in Salt Spring is the result

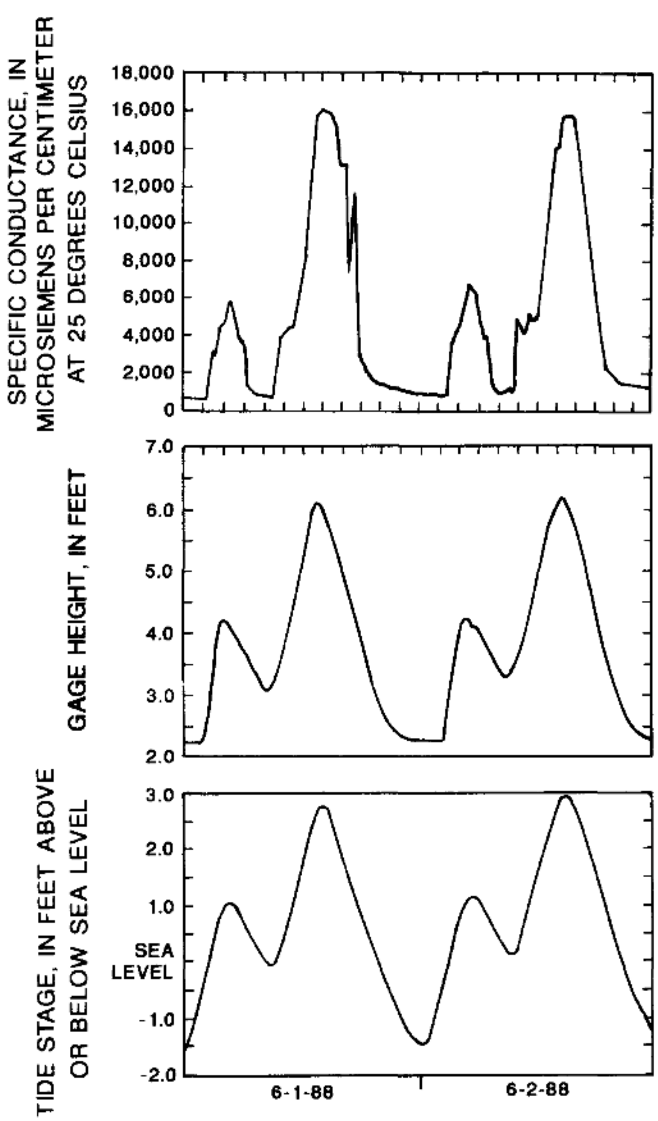


Figure 22. Observed variations of tide stage for the Gulf of Mexico at Bayport and gage height and specific conductance at Boat Spring, June 1-2, 1988.

of the presence of cave passages through which saltwater moves freely in response to tides. At Boat Spring, saltwater from the gulf flows upstream during floodtides to the springhead. At Mud Spring, a combination of these two processes occurs.

Specific-conductance duration curves for the continuous-record spring sites for various time periods between April 1988 and March 1989 are shown in figure 23. Time periods for continuous measurements are representative of a wide range of tide conditions. The graphs show that most of these springs are brackish (water having a specific conductance of at least 1,000 µS/cm) most of the time. Only Hidden River Head Spring, Bubba Spring, Magnolia Springs, Trotter Spring, and Bobhill Springs were fresh during the entire continuous-measurement periods.

An attempt was made to determine the relations among ground-water levels, high tides, and the daily maximum specific conductance in the brackish springs. Multiple-regression models were developed by using independent variables that were expected to affect water quality. The variables added to the regression models were as follows: first, the daily maximum water levels in Weeki Wachee well; then, the daily high water level in ROMP 19-2 well or Homosassa well no. 1; and, finally, the daily maximum spring-pool stage of the springs. Variables that did not contribute to the models were omitted.

A summary of the predictive equations and statistics of the regression analysis is given in table 7. The models that accounted for the most variation in specific conductance include water levels in Weeki Wachee well and tides represented in ROMP 19-2 well or Homosassa well no. 1. Although spring-pool stage intuitively seems to be an important factor in variations in specific conductance, it was significant in only 5 of the 15 spring models. Values of R^2 ranged from 0.25 to 0.97, and the standard error ranged from 169 to 2,677 µS/cm.

Specific-conductance variations for selected springs for various high-tide and water-level conditions, based on equations in table 7, are shown in figure 24. In Salt Spring, a change of about 14,000 µS/cm occurs for every 1 ft of water-level change, whereas a change of about 450 µS/cm occurs in Baird Creek Head Spring for every 1 ft of water-level change. As indicated earlier, the anomalous relation between water level and specific conductance in Potter Spring and Halls River Head Spring may be the result of variations in the proportion of the total flow that is derived from individual producing zones.

NEED FOR ADDITIONAL DATA COLLECTION

Hydrologic data collected as part of this investigation seem to be adequate for defining the current hydrologic conditions of springs in the study area. The analyses are useful as an initial approach; however, continued data collection to monitor long-term changes in the quality and quantity of spring water resulting from the effects of increasing ground-water use would help safeguard the fresh ground-water resources.

Future identification, analysis, and explanation of trends will be contingent on an adequate data-collection program. A program of long-term monitoring at selected springs would provide a data base for assessing the regional effects of human activities. A typical data-collection network would include one or more springs to monitor the position of the transition zone in the aquifer and provide a record of variations in spring flow and water quality. The sampling intervals could be daily, weekly, monthly, or longer, depending on the rate of water-level change and the effects of this change on specific conductance.

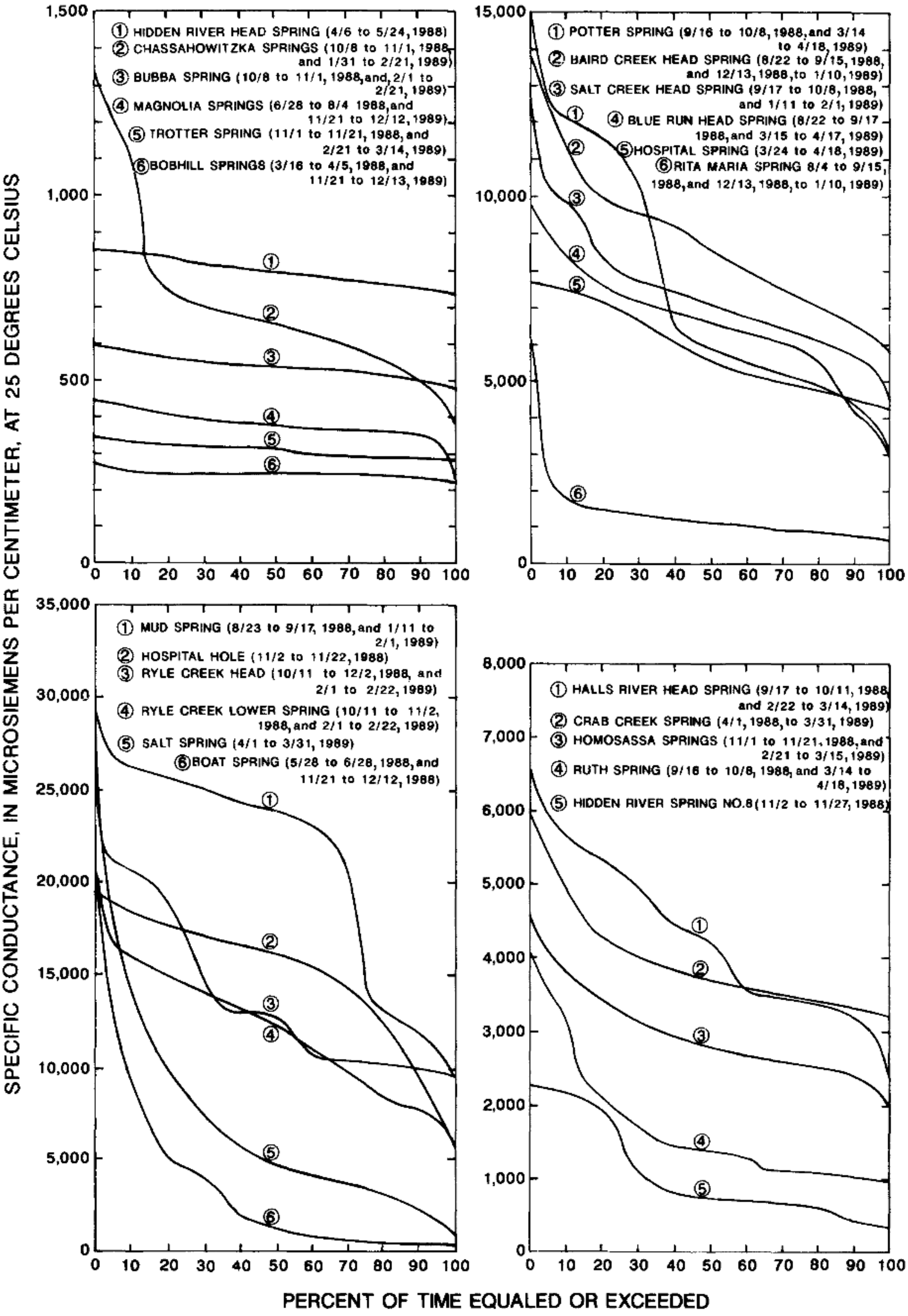


Figure 23. Specific-conductance duration curves for continuous-record spring sites, 1988-89.

Table 7. Multiple regression models for daily maximum specific conductance of springs
[N, number of observations; R^2, coefficient of determination; μS/cm, microsiemens per centimeter at 25 degrees Celsius]

Site name	Site number (fig. 1)	Predictive equation	Statistics N	R^2	Standard error (μS/cm)
Baird Creek Head Spring	17	K = -457(WW) + 1,577(HO) + 15,184	35	0.69	726
Blue Run Head Spring	13	K = -765(WW) + 1,723(RO) + 11,038	31	.73	922
Chassahowitzka Springs	18	K = 70(WW) + 281(ST) – 1,255	38	.50	169
Crab Creek Spring	20	K = -236(WW) + 1,360(MHO) – 1,396(MST) + 9,699	62	.76	330
Halls River Head Spring	29	K = 419(WW) + 813(HO) – 5,425	41	.83	438
Homosassa Springs	28	K = 1,126(ST) – 202(WW) – 478(HO) + 2,613	37	.81	294
Mud Spring	10	K = -4,076(WW) + 2,063(ST) – 4,939	18	.97	1,234
Potter Spring	24	K = 1,522(WW) + 1,797(HO) – 23,941	52	.96	836
Rita Maria Spring	16	K = 1,503(RO) – 223(WW) + 3,786(ST) – 15,648	62	.76	595
Ruth Spring	23	K = -289(WW) + 670(RO) + 3,701	29	.68	480
Salt Creek Head Spring	22	K = -1,046(WW) + 909(ST) – 2,043(RO) + 39,520	40	.72	1,152
Salt Spring	9	K = 14,012(RO) – 1,728(WW) – 40,214	67	.82	2,677
Hospital Spring	8	K = -3,745(RO) + 2,169(ST) + 24,869	24	.26	967
Ryle Creek Head Spring	11	K = -809(WW) + 33,964	31	.47	1,250
Ryle Creek Lower Spring	12	K = -5,333(HO) – 1,367(WW) + 52,397	25	.25	2,208

where K is daily maximum specific conductance, in microsiemens per centimeter at 25 degrees Celsius;
HO is daily maximum water level in Homosassa well No. 1, in feet above sea level;
WW is daily maximum water level in Weeki Wachee well, in feet above sea level;
RO is daily maximum water level in ROMP 19-2 well, in feet above sea level;
ST is daily maximum spring-pool stage, in feet;
MHO is daily mean water level in Homosassa well No. 1, in feet above sea level; and
MST is daily mean spring-pool stage, in feet.

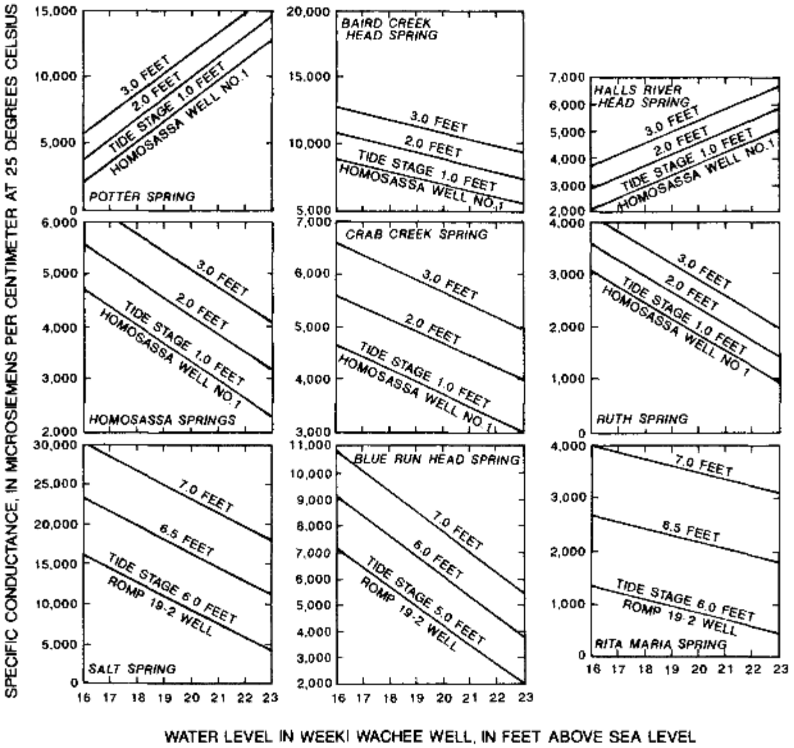


Figure 24. Relation between daily maximum water levels in Weeki Wachee well and daily maximum specific conductance in selected springs for maximum water levels in Homosassa well no. 1 and ROMP 19-2 well.

SUMMARY AND CONCLUSIONS

A study was conducted from 1987 to early 1989 in coastal Citrus and Hernando Counties to characterize the discharge, water chemistry, and tidal and salinity variations of coastal springs. The study area is experiencing rapid growth, and increasing demands are being made on the water resources. There is concern that increased saltwater intrusion may occur in springs as a result of pumpage from future well fields and export of the ground water to urban centers. Because of the potential for increased saltwater intrusion as the result of increasing use of ground water, an understanding of coastal springs and their relation to the hydrology of the area is essential.

The study area is along the gulf coast of Florida and is primarily a zone of ground-water discharge. The few perennial streams that exist are supplied almost entirely from spring discharge. The area contains 3 first-order-magnitude springs (springs that discharge 100 ft^3/s or more) and at least 23 smaller springs. The springs discharge about 650 ft^3/s of water to coastal water, saltmarshes, and swamps along the Gulf of Mexico. Most spring flow is derived from the Upper Floridan aquifer, primarily through solution cavities in the limestone and dolomite strata of the aquifer, which is at or near land surface in the area. Spring flow in most of the area is affected by tidal fluctuations in the gulf. Springs discharge freshwater, saltwater, or a mixture of the two.

Along the coast, a zone of diffusion exists between freshwater and saltwater. This zone moves horizontally and vertically in the Upper Floridan aquifer in response to changes in freshwater head and tides in the gulf. The influence of freshwater head is largely seasonal, whereas tides fluctuate hourly and influence the interface in a more short-term, cyclic manner.

Geophysical and chloride-concentration data indicate a saltwater-freshwater interface that is parallel to the coast with landward reentrants at major springs and gulfward extensions of the interface between springs. The springs have lowered hydraulic heads, permitting higher chloride concentrations at shallow depths.

Discharge was measured at 25 springs in the study area. Instantaneous flow ranged from -50.8 to 221 ft^3/s. Most springs have a similar flow pattern with a peak discharge in late summer and early fall followed by a gradual decline in flow toward winter and spring. Spring flow is related to the altitude of ground water in the Upper Floridan aquifer. Spring flow during wet periods is not always proportional to the increase in rainfall as a result of storage in the aquifer. The flow of most springs in the study area is affected by tides in the gulf. Flow is generally greatest at low stage and is a function of the difference in head between the aquifer and the spring pool. Most springs in the area lie near or within the zone of diffusion in the Upper Floridan aquifer and discharge a mixture of saltwater and freshwater. In general, chloride concentrations in spring water decrease with distance from the coast because of higher water levels in the Upper Floridan aquifer and a deeper saltwater-freshwater interface.

Springs in the study area discharge water of three different types: calcium bicarbonate, sodium chloride, and a transitional type. The primary processes affecting the chemical quality of spring water are the solution of carbonate minerals and mixing with underground saltwater. Seasonal variation in water quality is not constant from spring to spring. Generally, the higher the salinity of the spring water, the greater the variation in its major-ion chemistry. Bicarbonate concentration was fairly constant in the springs. Concentrations of total dissolved nitrogen and total phosphorus were small and were within ranges expected in ground water in the study area.

Results of analyses of water samples for tritium indicated that water of post-1952 age issues from all springs in the study area. No appreciable seasonal variation in tritium concentration of the freshwater component was observed in the sampled springs.

All the springs have a similar stable-isotope composition. Delta oxygen-18 and delta deuterium values, representing differences in concentrations relative to Standard Mean Ocean Water, generally ranged from -3.1 to -3.6 ppt for oxygen-18 and from -15 to -20 ppt for deuterium. These values are comparable to isotopic values for ground water in the basin. Results of analyses for tritium indicate that water flowing to the springs is of recent origin.

Water from springs at the coast is subject to greater variations in specific conductance than water from inland springs. This is the result of lower ground-water levels and a shallow saltwater interface at the coast. Specific conductance was measured continuously at 23 spring sites. The range in instantaneous specific conductance for continuous-record spring sites was 227 to 29,700 µS/cm.

Diurnal fluctuations in stage and specific conductance of spring water due to tides occur in most coastal springs in the area. Specific conductance can increase by 5,000 to 20,000 µS/cm in a few hours between low and high tide, whereas stage can increase by 1 to 2 ft. Tide ranges vary with distance from the coast. The range in mean daily tides was 0.07 to 2.81 ft.

Predictive equations to estimate specific conductance of spring water from tide stage, spring pool stage, and ground-water levels were developed for 15 springs using regression techniques. The model that accounted for the greatest variation in specific conductance was one that included ground-water levels. Spring stage was significant in 5 of the 15 spring models. Values of R^2 ranged from 0.25 to 0.97, and the standard error ranged from 169 to 2,677 µS/cm. The regression models indicate that seasonal changes in specific conductance in most springs are caused primarily by seasonal changes in ground-water levels.

The coastal-springs area is a small but important segment of a large ground-water flow system. Results of this study demonstrate that the chemical quality and flow rate of springs depend on head in the Upper Floridan aquifer. Continued development of ground-water resources within the coastal-springs ground-water basin will modify flow and chemical characteristics of the springs and downstream estuaries. Long-term monitoring at selected springs is needed to assess the long-term effects of human activities.

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APPENDIX A

Appendix A. Data-collection sites at springs, streams, and wells

Site No. (fig. 1)	Identification No.	Site name	Downstream order No.
1	282607082383400	Bobhill Springs	02310405
2	282558082392600	Magnolia Springs	02310410
3	282558082392500	Gator Spring	
4	282621082392900	Boat Spring	02310380
5	283100082342500	Weeki Wachee Springs	
6	283120082380400	Jenkins Creek Spring No. 5	
7	283155082373800	Hospital Hole	
8	283154082373800	Hospital Spring	
9	283246082370900	Salt Spring	02310562
10	283240082370100	Mud Spring	
11	284114082365200	Ryle Creek Head Spring	
12	284113082365000	Ryle Creek Lower Spring	
13	284113082360600	Blue Run Head Spring	
14	284130082353500	Beteejay Head Spring	
15	284131082353500	Beteejay Lower Spring	
16	284126082352800	Rita Maria Spring	
17	284230082344000	Baird Creek Head Spring	
18	284254082343500	Chassahowitzka Springs	
19	284254082343800	Bubba Spring	
20	284300082343400	Crab Creek Spring	02310652
21	284308082343700	Lettuce Creek Spring	
22	284323082350600	Salt Creek Head Spring	
23	284357082354800	Ruth Spring	
24	284354082354800	Potter Spring	
25	284607082344500	Hidden River Head Spring	
26	284603082350700	Hidden River Spring No. 6	
27	284747082351000	Trotter Spring	
28	284758082352000	Homosassa Springs	02310678
29	284935082345000	Halls River Head Spring	
30	284254082343800	Unnamed tributary above Chassahowitzka Springs	02310655
31	284559082352000	Hidden River Springs	02310675
32	282600082392601	Magnolia Springs well	
33	282613082381702	ROMP TR18-3 well	
34	283201082315601	Weeki Wachee well	
35	283243082365701	ROMP 19-2 well	
36	284113082352801	Rita Maria Spring well	
37	284130082353501	Beteejay Spring well	
38	284532082371001	Homosassa well no. 1	
39	284551082345301	Homosassa well no. 3	

APPENDIX B

Appendix B. Discharge and specific conductance of springs, 1988-89

[ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; —, no data]

Site name	Site No. (fig. 1)	Date	Time	Flow rate (ft^3/s)	Specific conductance (µS/cm)
Baird Creek Head Spring	17	6-22-88	1415	1.37	11,080
		11-15-88	1730	6.20	6,690
		12-19-88	1125	5.89	7,260
		12-19-88	1230	6.20	6,960
		12-19-88	1330	6.33	6,910
		12-19-88	1430	6.30	6,880
		12-19-88	1530	6.25	6,840
		12-19-88	1630	6.20	6,800
Beteejay Head Spring	14	6-29-88	1610	6.85	440
		10-20-88	1125	6.71	407
		1-18-89	1245	5.52	--
Beteejay Lower Spring	15	6-29-88	1655	[1]12.5	--
		1-18-89	1330	[1] 8.39	440
Blue Run Head Spring	13	6-24-88	1215	7.81	8,400
		10-20-88	1400	7.70	7,550
		12-21-88	1220	5.51	6,490
		12-21-88	1330	5.75	6,340
		12-21-88	1430	6.26	6,140
		12-21-88	1545	7.10	6,080
		12-21-88	1630	7.45	5,960
		3-21-89	1145	6.01	7,460
		3-21-89	1315	5.53	7,880
		3-21-89	1445	6.76	8,230
		3-21-89	1615	5.86	8,020
		3-21-89	1715	6.50	7,760
		3-21-89	1815	7.34	7,550
Boat Spring	4	6-06-88	1320	[2] .50	935
		9-30-88	1515	1.71	650
		10-17-88	1410	3.10	--
		12-08-88	1100	.94	700
		12-08-88	1200	[3]-6.74	2,430
		12-08-88	1300	[3]-5.69	5,190
		12-08-88	1350	.00	6,250
Bobhill Springs	1	3-28-88	1600	2.27	243
		5-24-88	1730	1.49	--
		9-22-88	1630	3.35	--
		10-17-88	1125	2.81	247
		12-08-88	1600	2.87	249
Chassahowitzka Springs	18	10-24-88	1645	92.6	--
Crab Creek Spring	20	3-23-88	1150	47.2	3,840
		3-23-88	1300	47.0	3,820
		3-23-88	1420	46.9	3,850
		6-01-88	1445	51.4	3,770
		7-26-88	1045	46.3	5,770
		7-26-88	1240	41.5	5,690
		7-26-88	1410	40.1	5,530
		7-26-88	1525	44.2	5,510
		10-24-88	1300	53.1	3,600
		10-24-88	1415	49.2	3,740
		10-24-88	1530	45.8	3,610
		10-24-88	1645	43.6	3,250
		10-24-88	1800	45.4	3,190
		10-26-88	1405	53.6	3,400
		2-15-89	1200	55.9	3,060
		2-15-89	1300	54.2	3,180
		2-15-89	1400	52.6	3,220
		2-15-89	1515	52.6	3,320

Footnotes are at end of appendix.

Appendix B. Discharge and specific conductance of springs, 1988-89–Continued

Site name	Site No. (fig. 1)	Date	Time	Flow rate (ft^3/s)	Specific conductance (µS/cm)
Crab Creek Spring–Continued		2-15-89	1630	51.6	3,320
		2-15-89	1735	52.2	3,320
Gator Spring	3	6-06-88	1100	.21	240
		10-17-88	1545	.31	240
Halls River Head Spring	29	6-30-88	0900	4.28	6,600
		9-29-88	1515	8.70	4,730
		10-19-88	1315	7.51	3,770
		3-08-89	1110	6.67	2,910
Hidden River Springs	31	4-06-88	1445	7.54	1,610
		4-20-88	1220	9.52	1,700
		4-20-88	1300	9.41	1,700
		5-06-88	1350	7.34	1,540
		5-24-88	1425	6.04	1,520
		6-01-88	1930	5.05	--
		9-30-88	1100	20.1	1,260
Homosassa Springs	28	6-07-88	1325	98.8	2,900
		10-18-88	1145	105	2,940
		11-07-88	1235	122	2,820
		11-07-88	1400	122	2,730
		11-07-88	1520	110	2,650
		11-07-88	1600	96.5	2,580
		11-07-88	1700	56.4	2,520
		3-08-89	1315	107	2,620
		3-08-89	1445	118	2,620
		3-08-89	1620	109	2,650
		3-08-89	1705	101	2,610
Hospital Spring	8	3-07-89	1015	.41	4,800
		3-07-89	1115	.53	4,810
		3-07-89	1315	.36	4,820
		3-07-89	1415	.29	4,825
		3-07-89	1515	.33	4,830
Jenkins Creek Spring no. 5	6	7-05-88	1240	18.3	17,100
		11-14-88	1205	25.5	5,340
Lettuce Creek Spring	21	6-22-88	1150	3.52	364
		10-26-88	1450	7.03	366
Magnolia Springs	2	6-07-88	1635	1.08	299
		8-01-88	1020	.47	379
		8-01-88	1545	0	373
		10-19-88	1610	1.03	342
		12-08-88	1105	.76	307
		12-08-88	1240	.77	308
		12-08-88	1345	.70	306
Mud Spring	10	1-23-89	1030	4.65	23,500
		1-23-89	1130	59.4	24,100
		1-23-89	1300	80.0	23,500
		1-23-89	1430	29.8	22,000
		1-23-89	1630	[3]-52.1	22,300
Potter Spring	24	6-21-88	1515	[4]21.2	4,490
		9-27-88	1245	30.2	3,390
		9-27-88	1540	25.7	3,460
		9-27-88	1855	20.5	2,790
		10-27-88	1510	28.6	3,040
		1-24-89	1200	22.8	2,850
		1-24-89	1330	21.3	2,730
		1-24-89	1445	22.0	2,680
		1-24-89	1600	22.0	2,650
		1-24-89	1715	19.1	2,680
		3-22-89	1315	8.84	2,820
		3-22-89	1415	0	2,880

Appendix B. Discharge and specific conductance of springs, 1988-89–Continued

Site name	Site No. (fig. 1)	Date	Time	Flow rate (ft^3/s)	Specific conductance (μS/cm)
Potter Spring–Continued		3-22-89	1545	0	2,860
		3-22-89	1800	17.7	2,330
Rita Maria Spring	16	6-30-88	1710	4.04	2,610
		10-20-88	1605	5.11	960
		12-19-88	0940	4.83	715
		12-19-88	1045	4.87	715
		12-19-88	1241	4.72	675
		12-19-88	1325	4.86	670
		12-19-88	1501	5.06	680
Ruth Spring	23	6-21-88	1230	12.4	3,450
		9-27-88	1150	17.2	1,260
		9-27-88	1500	17.2	1,230
		9-27-88	1820	16.4	1,200
		10-27-88	1635	16.4	1,160
		1-24-89	1200	13.9	1,090
		1-24-89	1330	14.7	1,090
		1-24-89	1445	14.8	1,090
		1-24-89	1600	14.1	1,080
		1-24-89	1715	14.1	1,070
		3-22-89	1230	12.9	1,740
		3-22-89	1445	10.8	1,740
		3-22-89	1615	9.95	1,730
		3-22-89	1715	10.1	1,750
Ryle Creek Head Spring	11	10-25-88	1325	3.67	9,650
		10-25-88	1425	3.72	11,750
		10-25-88	1525	3.46	12,050
		10-25-88	1625	2.25	10,400
		10-25-88	1730	.39	8,850
		2-16-89	1200	2.78	18,200
		2-16-89	1330	2.51	19,000
		2-16-89	1445	1.77	19,000
		2-16-89	1630	1.82	18,800
Ryle Creek Lower Spring	12	6-29-88	1350	[5]9.0	4,650
		10-25-88	1325	16.9	5,330
		10-25-88	1425	19.4	5,420
		10-25-88	1525	14.0	11,400
		10-25-88	1625	11.7	--
		10-25-88	1730	.39	--
		2-16-89	1200	14.8	16,400
		2-16-89	1330	15.2	16,200
		2-16-89	1445	7.66	16,400
		2-16-89	1630	8.32	16,400
Salt Spring	9	3-25-88	1005	33.7	--
		3-25-88	1100	34.1	3,460
		3-25-88	1205	33.5	3,610
		4-21-88	1245	35.2	4,710
		4-21-88	1345	36.5	4,890
		4-21-88	1445	37.8	5,660
		4-21-88	1545	38.5	6,420
		4-21-88	1745	35.3	10,520
		4-21-88	1900	34.1	12,410
		4-21-88	1945	34.1	11,890
		5-31-88	1205	33.3	5,240
		5-31-88	1315	33.6	7,120
		5-31-88	1450	29.8	11,400
		5-31-88	1610	28.2	14,710
		5-31-88	1735	27.8	11,950
		6-01-88	0915	30.9	5,540
		6-01-88	1110	31.5	5,800
		10-26-88	1055	30.3	2,460
		11-08-88	1045	34.1	2,760

Appendix B. Discharge and specific conductance of springs, 1988-89–Continued

Site name	Site No. (fig. 1)	Date	Time	Flow rate (ft³/s)	Specific conductance (µS/cm)
Salt Spring–Continued		11-08-88	1145	35.7	3,510
		11-08-88	1245	37.8	4,270
		11-08-88	1345	40.4	4,800
		11-08-88	1445	38.4	5,300
		11-08-88	1545	37.5	5,510
		11-08-88	1645	37.0	5,300
		11-08-88	1745	35.4	4,990
		4-06-89	1100	30.5	2,800
		4-06-89	1200	29.8	2,300
		4-06-89	1300	30.6	2,300
		4-06-89	1400	32.1	3,100
		4-06-89	1500	31.1	5,100
		4-06-89	1600	27.7	12,000
		4-06-89	1700	29.1	10,800
		4-06-89	1800	29.5	9,600
Salt Creek Head Spring	22	6-23-88	1240	.50	4,770
		9-26-88	1440	.76	6,710
		9-26-88	1605	0	6,260
		11-15-88	1530	.45	13,270
		1-23-89	1140	.89	7,720
		1-23-89	1300	.69	7,470
		1-23-89	1400	.68	7,160
		1-23-89	1500	.72	6,900
		1-23-89	1600	.74	7,210
Trotter Spring	27	6-30-88	1155	7.38	332
		10-19-88	1030	6.83	308
		11-07-88	1255	9.25	280
		11-07-88	1445	8.94	280
		11-07-88	1550	8.45	280
		11-07-88	1700	8.62	280
		3-06-89	1100	6.76	325
		3-06-89	1230	7.10	324
		3-06-89	1400	7.88	323
		3-06-89	1530	6.68	321
		3-06-89	1645	5.47	321
		3-06-89	1745	5.47	322
Unnamed tributary above Chassahowitzka Springs	30	6-08-88	1325	[6]25.2	525
		10-24-88	1330	39.9	518
		10-24-88	1445	37.3	540
		10-24-88	1555	33.4	530
		10-24-88	1655	35.7	510
		10-24-88	1800	44.8	482
		2-15-89	1205	28.7	529
		2-15-89	1245	29.2	528
		2-15-89	1330	24.6	528
		2-15-89	1430	21.0	527
		2-15-89	1545	24.6	525
		2-15-89	1630	22.9	524
		2-15-89	1745	22.7	522
Weeki Wachee Springs	5	4-06-88	--	182	--
		8-10-88	--	164	--
		10-19-88	--	221	--
		12-14-88	--	199	--
		2-15-88	--	174	--
		4-13-89	--	171	--

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[1] Includes flow of Beteejay Head Spring.

[2] Estimated.

[3] Negative sign indicates upstream flow.

[4] Includes flow of Ruth Spring and Potter Spring.

[5] Includes flow of Ryle Creek Head Spring.

[6] Includes flow of Bubba Spring and numerous unnamed springs.

(p. 41 follows)

APPENDIX C

Appendix C. Results of chemical analyses of water from springs, wells, and the Gulf of Mexico

[°C, degrees Celsius; mv, millivolts; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; mv, millivolts; pCi/L, picocuries per liter; —, no data; , less than; ‰, permil]

Site name	Identification No.	Date	Water temperature (°C)	Oxidation reduction potential (mv)	Specific conductance (µS/cm)	Oxygen, dissolved (mg/L)	pH (standard units)	Alkalinity, field (mg/L as $CaCO_3$)	Nitrogen, NO_2+NO_3 total (mg/L as N)	Phosphorus, total (mg/L as P)
Baird Creek Head Spring	284230082344000	6-22-88	24.0	331	10,100	2.3	7.36	146	0.210	0.020
		11-15-88	22.5	386	6,860	4.2	7.39	135	—	—
Beteejay Head Spring	284130082353500	6-29-88	23.5	387	440	2.1	7.44	194	.260	.020
		10-20-88	21.5	373	407	1.4	7.35	142	—	—
Blue Run Head Spring	284113082360600	6-24-88	23.5	382	8,000	2.0	7.47	159	.280	.030
		10-20-88	21.5	265	7,550	1.4	7.23	161	—	—
Boat Spring	02310380	6-08-88	26.0	301	935	3.2	7.45	114	.490	.030
		10-17-88	23.0	344	467	3.6	7.48	114	—	—
Bobhill Springs	02310405	3-28-88	24.5	352	243	2.4	7.60	105	.390	.020
		10-17-88	24.0	362	247	2.0	7.82	105	—	—
Bubba Spring	02310655	6-08-88	23.5	370	650	4.6	7.56	142	.380	.030
		10-27-88	22.5	351	525	5.5	7.68	141	—	—
Chassahowitzka Springs	284254082343500	7-06-88	23.5	239	1,590	3.9	7.60	140	—	.030
		10-27-88	22.0	286	698	6.0	7.63	139	—	—
Crab Creek Spring	02310652	6-01-88	22.5	235	3,630	5.0	7.27	141	.430	.030
		10-26-88	22.5	248	3,500	5.2	7.51	146	—	—
Gator Spring	282558082392500	6-06-88	26.5	306	240	2.2	7.93	—	.040	.030
		10-17-88	23.5	377	240	3.7	7.57	101	—	—
Halls River Head Spring	284935082345000	6-30-88	24.0	354	8,500	3.3	7.64	109	.240	.040
		10-19-88	23.5	321	3,770	4.2	7.69	108	—	—
Hidden River Head Spring	284607082344500	6-01-88	23.0	287	733	4.2	7.60	112	.45	.030
Homosassa Springs	02310678	6-07-88	24.5	274	2,900	4.5	7.57	107	.340	.030
		10-18-88	23.0	176	2,940	4.7	7.67	106	—	—
Jenkins Creek Spring no. 5	283120082380400	7-05-88	24.0	330	17,200	1.0	7.53	113	.230	.020
		11-14-88	23.0	286	5,550	1.3	—	115	—	—
Lettuce Creek Spring	284308082343700	6-22-88	23.0	314	368	4.1	7.53	145	.390	.021
		10-26-88	22.5	373	375	5.2	7.36	148	—	—
Magnolia Springs	02310410	6-07-88	24.0	270	408	.5	7.73	101	.220	.020
		10-19-88	23.0	368	342	1.4	7.79	107	—	—
Mud Spring	283240082370100	7-05-88	25.0	346	32,000	1.3	7.27	118	.160	.040
		11-14-88	22.5	209	24,300	3.2	—	115	—	—
Potter Spring	284354082354800	6-21-88	23.0	231	6,090	2.8	7.48	144	.350	.300
		10-27-88	22.0	189	7,410	4.0	7.27	146	—	—
Rita Maria Spring	284126082352800	6-30-88	23.0	250	2,930	3.1	7.45	158	.300	.020
		10-20-88	22.5	357	960	4.3	7.42	156	—	—
Ruth Spring	284357082354800	6-21-88	23.0	300	3,450	3.6	7.59	138	.350	.030
		10-27-88	22.0	380	1,160	4.0	7.52	137	—	—
Ryle Creek Lower Spring	284113082365000	6-29-88	22.0	252	8,850	.5	7.01	183	.030	.050
		11-15-88	21.0	203	15,600	.6	6.97	178	—	—
Ryle Creek Head Spring	284114082365200	6-29-88	22.0	204	19,200	.5	7.03	175	.020	.030
		11-15-88	20.5	213	11,600	.7	7.00	184	—	—
Salt Creek Head Spring	284323082360600	6-23-88	24.0	346	4,770	3.6	7.47	146	.390	.040
		11-15-88	22.0	313	13,800	3.3	7.28	147	—	—
Salt Spring	02310562	6-01-88	—	319	5,800	1.8	7.55	120	.330	.020
		10-26-88	23.0	248	2,450	2.2	7.67	120	—	—
Trotter Head Spring	284747082351000	6-30-88	23.0	359	320	3.7	7.73	105	.330	.030
		10-19-88	24.0	362	308	4.3	7.86	106	—	—
Weeki Wachee Springs	02310545	6-07-88	24.0	364	265	2.2	7.74	157	.270	.030
		10-18-88	23.0	343	294	2.4	7.78	131	—	—
Magnolia Springs well	282600082392601	7-14-88	23.0	61	332	.5	7.55	135	<.020	.020
Rita Maria Spring well	284113082362801	7-14-88	21.0	52	520	.5	7.05	255	<.021	.030
Beteejay Spring well	284130082353501	1-13-89	23.5	—	459	.7	7.38	172	—	—
Gulf of Mexico	283256083071700	1-08-89	17.5	379	51,000	7.1	8.20	117	—	—
Gulf of Mexico	283258082440800	1-09-89	19.0	391	35,000	10.0	8.19	127	—	—
Gulf of Mexico	284340082443600	7-20-88	31.0	349	34,000	6.2	8.26	127	.021	.030
Gulf of Mexico	284341083050500	7-20-88	30.0	325	51,100	5.9	8.08	121	<.021	.041

Appendix C. Results of chemical analyses of water from springs, wells, and the Gulf of Mexico–Continued

Site name	Date	Sulfide, total (mg/L as S)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)	Fluoride, dissolved (mg/L as F)
Baird Creek Head Spring	6-22-88	<1.0	130	230	1,900	0.70	3,500	500	0.20
	11-15-88	<1.0	90	140	1,100	43	2,000	290	.20
Beteejay Head Spring	6-29-88	1.5	53	13	29	1.2	55	15	.10
	10-20-88	<1.0	53	10	11	.40	21	6.0	.30
Blue Run Head Spring	6-24-88	<1.0	110	160	1,300	49	2,400	330	.30
	10-20-88	<1.0	100	150	1,200	46	2,200	310	.30
Boat Spring	6-06-88	—	43	12	80	3.2	140	27	.10
	10-17-88	<1.0	42	6.9	33	1.4	55	16	.20
Bobhill Springs	3-28-88	<1.0	40	2.9	3.0	.30	4.6	7.2	.10
	10-17-88	<1.0	39	3.0	3.2	.30	5.1	6.3	.10
Bubba Spring	6-08-88	< .5	46	15	60	2.3	110	21	.10
	10-27-88	<1.0	45	12	37	1.3	67	17	.20
Chassahowitzka Springs	7-06-88	—	55	30	210	8.0	360	56	.10
	10-27-88	<1.0	46	15	64	2.4	120	22	.20
Crab Creek Spring	6-01-88	<1.0	70	80	580	22	1,100	150	.10
	10-26-88	<1.0	75	65	520	20	970	140	.20
Gator Spring	6-06-88	.6	36	3.2	2.8	.30	6.2	7.2	.10
	10-17-88	<1.0	36	3.1	3.0	.30	5.5	5.8	.20
Halls River Head Spring	6-30-88	2.5	100	170	1,500	53	2,600	390	.20
	10-19-88	<1.0	55	65	560	22	1,000	140	.20
Hidden River Head Spring	6-01-88	<1.0	39	18	92	3.4	170	27	.10
Homosassa Springs	6-07-88	< .5	60	64	500	20	920	130	.10
	10-18-88	<1.0	50	60	460	17	860	120	.20
Jenkins Creek Spring no. 5	7-05-88	<1.0	160	360	3,200	120	5,800	820	.20
	11-14-88	<1.0	75	100	860	32	1,500	220	.20
Lettuce Creek Spring	6-22-88	<1.0	45	10	10	.50	19	11	.10
	10-26-88	<1.0	45	10	11	.50	20	7.9	.20
Magnolia Springs	6-07-88	.8	37	4.9	17	.70	32	12	.10
	10-19-88	<1.0	37	5.4	21	1.0	33	11	.10
Mud Spring	7-05-88	<1.0	260	680	6,300	220	11,000	1,500	.40
	11-14-88	<1.0	220	540	4,700	180	8,200	1,200	.40
Potter Spring	6-21-88	<1.0	90	120	940	36	1,700	260	.20
	10-27-88	<1.0	96	140	1,200	44	2,100	300	.20
Rita Maria Spring	6-30-88	<1.0	65	55	420	16	760	110	.10
	10-20-88	<1.0	52	20	100	3.8	180	34	.20
Ruth Spring	6-21-88	<1.0	68	68	500	19	940	140	.10
	10-27-88	<1.0	48	24	140	5.2	250	42	.20
Ryle Creek Lower Spring	6-29-88	1.3	120	180	1,500	57	2,700	420	.30
	11-15-88	<1.0	180	360	3,100	120	5,400	820	.30
Ryle Creek Head Spring	6-29-88	<1.0	200	420	3,700	140	6,800	970	.20
	11-15-88	<1.0	140	230	1,900	77	3,500	510	.40
Salt Creek Head Spring	6-23-88	<1.0	75	90	710	26	1,300	180	.20
	11-15-88	<1.0	140	280	2,400	91	4,200	630	.20
Salt Spring	6-01-88	<1.0	77	100	920	35	1,700	220	.10
	10-26-88	<1.0	50	45	340	12	600	95	.20
Trotter Head Spring	6-30-88	<1.0	35	7.8	16	.70	29	11	< .10
	10-19-88	<1.0	34	7.4	13	.60	24	6.3	.20
Weeki Wachee Springs	6-07-88	.8	47	5.3	2.6	.30	5.2	8.1	.10
	10-18-88	<1.0	45	5.3	2.8	.20	4.8	6.5	.20
Magnolia Springs well	7-14-88	<1.0	41	12	7.0	.70	18	8.3	.10
Rita Maria Spring well	7-14-88	<1.0	78	14	8.6	.50	13	5.6	.30
Beteejay Spring well	1-13-89	<1.0	56	11	14	.70	25	9.2	.10
Gulf of Mexico	1-08-89	<1.0	400	1,200	11,000	420	19,000	2,700	1.1
Gulf of Mexico	1-09-88	<1.0	290	830	7,100	170	12,000	1,700	.70
Gulf of Mexico	7-20-88	<1.0	260	800	6,500	260	12,000	1,600	.90
Gulf of Mexico	7-20-88	<1.0	400	1,200	10,000	410	19,000	2,600	1.4

Appendix C. Results of chemical analyses of water from springs, wells, and the Gulf of Mexico–Continued

Site name	Date	Silica, dissolved (mg/L as SiO_2)	Iron, dissolved (µg/L as Fe)	Strontium, dissolved (µg/L as Sr)	Tritium, total (pCi/L)	Solids, residue at 180°C, dissolved (mg/L)	Delta deuterium (‰)	Delta oxygen-18 (‰)	Specific conductance, lab (µS/cm)
Baird Creek Head	6-22-88	7.7	40	1,900	19	7,200	-14.0	-2.80	11,500
Spring	11-15-88	8.1	20	1,100	21	3,930	-16.0	-2.25	6,850
Beteejay Head	6-29-88	9.0	10	210	19	326	-18.0	-3.55	508
Spring	10-20-88	9.1	30	180	22	245	-17.5	-3.50	393
Blue Run Head	6-24-88	8.8	40	1,300	18	4,750	-16.0	-3.05	7,830
Spring	10-20-88	8.8	150	1,200	19	4,440	-16.0	-3.00	7,320
Boat Spring	6-06-88	6.4	10	250	23	408	-16.0	-3.05	838
	10-17-88	6.2	<10	220	24	250	-16.0	-3.25	450
Bobhill Springs	3-28-88	6.4	10	220	26	138	-16.0	-3.20	237
	10-17-88	6.2	10	180	22	148	-16.0	-3.30	236
Bubba Spring	6-08-88	8.6	20	170	22	374	-17.0	-3.40	660
	10-27-88	8.8	<10	160	22	296	-18.5	-3.45	517
Chassahowitzka	7-06-88	8.4	—	250	19	918	-18.0	-3.45	1,540
Springs	10-27-88	8.8	10	180	23	395	-17.5	-3.50	694
Crab Creek Spring	6-01-88	9.0	20	800	20	2,260	-16.4	-3.30	3,830
	10-26-88	8.8	40	500	20	1,980	-15.0	-3.25	3,460
Gator Spring	6-06-88	5.4	20	180	23	126	-15.0	-3.00	229
	10-17-88	5.8	10	190	22	135	-15.5	-3.15	227
Halls River Head	6-30-88	7.7	20	1,400	17	5,440	-16.0	-2.90	8,340
Spring	10-19-88	7.5	<10	550	21	2,060	-16.5	-3.40	3,660
Hidden River Head Spring	6-01-88	8.6	20	190	19	468	-17.9	-3.60	828
Homosassa Springs	6-07-88	8.1	30	500	21	1,870	-17.0	-3.25	3,220
	10-18-88	8.3	30	500	20	1,750	-16.0	-3.30	3,010
Jenkins Creek	7-05-88	6.7	50	2,200	11	11,800	-12.0	-2.15	16,600
Spring no. 5	11-14-88	7.3	<10	850	15	3,040	-18.0	-2.70	5,350
Lettuce Creek	6-22-88	9.0	20	140	21	204	-18.5	-3.45	369
Spring	10-26-88	9.0	10	140	25	208	-15.0	-3.40	355
Magnolia Springs	6-07-88	6.4	10	230	22	168	-16.5	-3.15	322
	10-19-88	6.4	<10	230	24	190	-15.0	-3.15	328
Mud Spring	7-05-88	6.4	110	4,400	7.6	21,000	-.4	-1.05	28,800
	11-14-88	6.8	80	3,400	12	16,400	-8.4	-1.55	24,500
Potter Spring	6-21-88	8.8	80	950	19	3,600	-14.0	-3.00	6,110
	10-27-88	8.6	170	1,200	19	4,270	-14.0	-2.95	7,140
Rita Maria Spring	6-30-88	8.9	10	500	20	1,690	-17.5	-3.35	2,720
	10-20-88	8.8	10	200	22	537	-16.5	-3.50	946
Ruth Spring	6-21-89	8.8	20	600	20	1,950	-15.5	-3.45	3,430
	10-27-88	9.0	10	240	21	638	-17.5	-3.40	1,140
Ryle Creek Lower	6-29-88	7.1	340	1,400	11	5,810	-15.0	-2.95	9,960
Spring	11-15-88	8.1	350	2,800	15	10,600	-11.0	-2.15	16,800
Ryle Creek Head	6-29-88	6.8	890	3,200	14	13,600	—	—	18,900
Spring	11-15-88	8.8	250	1,900	17	6,860	-13.0	-2.65	11,400
Salt Creek Head	6-23-88	8.8	30	750	19	2,670	-15.5	-3.30	4,710
Spring	11-15-88	8.6	40	2,300	16	8,350	-12.5	-2.45	13,600
Salt Spring	6-01-88	7.5	40	750	21	3,430	-15.5	-3.20	5,750
	10-26-88	7.9	20	450	20	1,300	-16.5	-3.30	2,380
Trotter Head	6-30-88	7.9	<10	110	22	226	-18.0	-3.55	325
Spring	10-19-88	8.3	<10	110	21	176	-18.0	-3.55	300
Weeki Wachee	6-07-88	7.9	10	160	24	164	-16.0	-3.35	287
Springs	10-18-88	8.3	10	170	22	178	-15.0	-3.30	282
Magnolia Springs well	7-14-88	15	180	220	23	190	-15.9	-3.15	333
Rita Maria Spring well	7-14-88	10	900	290	16	294	-13.0	-3.10	514
Beteejay Spring well	1-13-89	9.0	170	200	20	219	-17.9	-3.60	431
Gulf of Mexico	1-08-89	.30	170	7,100	10	36,600	4.5	.95	50,800
Gulf of Mexico	1-09-89	.40	110	4,000	39	24,200	0	-.19	35,400
Gulf of Mexico	7-20-88	2.5	120	4,600	30	23,200	10.9	1.15	33,400
Gulf of Mexico	7-20-88	.20	230	7,400	14	38,000	4.0	.65	51,100

*U.S. Government Printing Office: 1993 — 733-120/80009