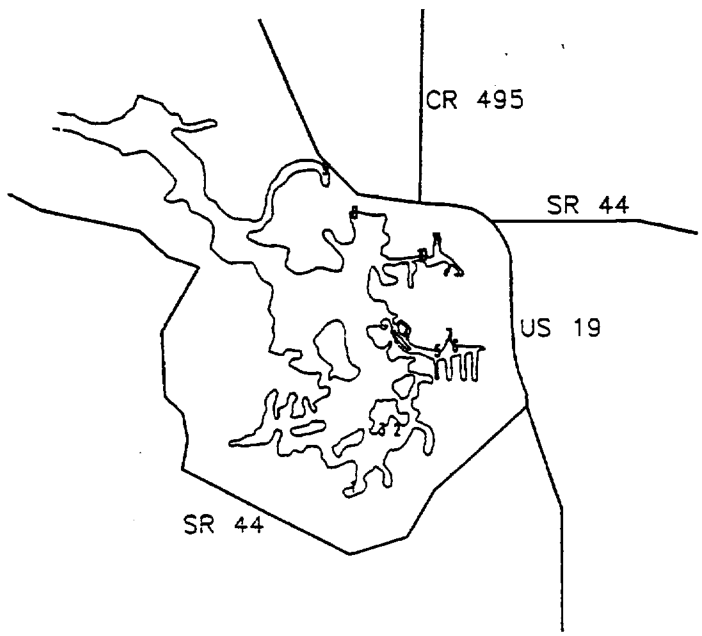
ORIGIN OF NUTRIENTS IN GROUND WATER DISCHARGING FROM THE KING'S BAY SPRINGS



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11 - House Spring

Prepared by the
Ambient Ground-Water
Quality Monitoring Program,

Southwest Florida Water Management District

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PROFESSIONAL GEOLOGIST

The geological evaluation and interpretation contained in the report entitled "Origin of Nutrients in Ground-Water Discharging from the King's Bay Springs" were prepared by or reviewed by a Certified Professional Geologist in the State of Florida.

Gregg W. Jones — 7/7/94
Gregg W. Jones — Date

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July, 1994

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EXECUTIVE SUMMARY

1. Previous studies have determined that the numerous springs and seeps in King's Bay discharge ground water at the rate of approximately 975 ft^3/s (630 mgd).

2. Approximately 196 tons of nitrate as N are contained in ground water discharging from the King's Bay Springs every year.

3. The average nitrate concentration of ground water discharging from the eleven largest springs in King's Bay is approximately 0.2 mg/l NO_3 as N. Although this level is low relative to many springs in more developed counties, it is considerably elevated over nitrate concentrations in ground water in the undeveloped portions of the study area.

4. One hundred and two wells were sampled for nitrate in the study area. Thirty two percent had concentrations between 0.2 to 0.6 mg/l NO_3 as N and seven percent had concentrations exceeding 0.6 mg/l. These figures indicate that areas where nitrate in ground water is significantly elevated above naturally occurring levels (generally < 0.01 mg/l) are widespread.

5. Historical nitrate data for study area spring water and ground water are extremely limited. However, a sample collected in 1975 from Tarpon Hole, the main spring in King's Bay, indicates that nitrate concentrations have increased by a factor of three between 1975 and the present. In addition, 3 dedicated monitor wells sampled for this study in 1992 were also sampled for nitrate in 1985. Although the 1992 sampling indicates that nitrate concentrations are still low relative to the drinking water standard of 10 mg/l, they have shown rapid and significant increases in the intervening 7 years.

6. Ground water in the springs is largely derived from the drainage basin bounded by the Withlacoochee River and a flow-line divergence in south-central Citrus County. Water in the Floridan aquifer to the north of this divergence will discharge in the vicinity of the King's Bay Springs while water south of the line will discharge in the vicinity of Homosassa Springs.

7. Sulfate concentration and isotopic data reflect a shallow flow system. Water that is discharging from the King's Bay Springs entered the Floridan aquifer flow system within the last 50 years.

8. Sodium/chloride, nitrogen-concentration, and hydrochemical facies data show significant ground-water recharge in the Beverly Hills area.

EXECUTIVE SUMMARY (continued)

9. Ground water in the Coastal Swamp and Brooksville Ridge physiographic provinces is nutrient- and TOC-rich, indicating local recharge.

10. Nutrient data from ground water suggest that losses from Lake Tsala Apopka may have served as a low-level natural nitrogen source for the springs for thousands of years.

11. A plume of what is probably naturally occurring nitrogen is moving toward the springs from Lake Rousseau. Because the lake was constructed relatively recently, it has probably not yet affected the springs.

12. Nitrogen isotopic data suggest that a portion of the nitrogen in the springs and ground water in the study area is natural.

13. There are small, localized sources of development-related nitrogen in the eastern portion of the City of Crystal River. This development-related nitrogen along with naturally occurring nitrogen are probably the sources of the low levels of nitrogen in ground water discharging from the springs.

14. The nitrogen sources on the eastern side of the City of Crystal River should be located and mitigated.

15. The many nitrogen releases resulting from land uses that exist in the study area are elevating ground-water nitrogen concentrations. Ground water that has been enriched in nitrogen from both development-related and natural sources is moving toward the coast in well-defined plumes from the east-central and north-central portions of the study area. Within 20 years this nitrogen will reach the King's Bay Springs and probably increase nitrogen concentrations significantly.

16. Ten development-related sources of nitrogen common to the study area were investigated. Of these, four sources (septic-tank effluent, effluent disposal from sewage treatment, golf-course fertilization, and residential turf fertilization) are probably contributing the majority of nitrogen to ground water. These sources are associated with residential and commercial development and can be correlated to areas where nitrogen concentrations are elevated in ground water. Although the nitrogen contributed by these sources is significantly attenuated by the various vegetative and soil-removal mechanisms, enough reaches ground water to elevate concentrations to the 0.5 to 1.0 mg/l range, the upper concentration limits in the developed portion of the study area.

EXECUTIVE SUMMARY (continued)

17. The rapid increase in the number of the four principal sources listed above insures that nitrogen concentrations will continue to increase.

18. Planning for elimination of septic tanks in central Citrus county should begin immediately, with a target for county sewer service by the year 2015. First priority should be given to the areas where high nitrogen is present in the Floridan aquifer.

19. Municipal wastewater treatment facilities should either go to advanced wastewater treatment (AWT) or other nutrient-removal technologies.

20. Monitor-well networks should be installed around golf courses and residential areas to determine the effect of turf fertilization on ground-water quality.

21. Stormwater runoff in the karst terrain may be responsible for feeding fertilizer-derived nitrogen into the ground-water system.

22. Stormwater runoff should not be routed directly to sinkholes. Runoff retention and plant fixation of nutrients is a necessary management alternative for sinkholes that receive stormwater from suburban and urban areas.

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INTRODUCTION

It has recently been determined that ground water discharging from numerous subaqueous springs in Kings Bay in Citrus County Florida (Figure 1) is the source of 94 percent of the total nitrogen and 84 percent of the total phosphorus entering the bay (Romie, 1990). Comparison of a nitrite value obtained in 1975 and recent nitrate data from Tarpon Hole, the main spring of the King's Bay group, indicates that the current nitrate concentration of 0.18 mg/l NO_3 as N is three times higher than the 1975 level.

A possible deleterious effect of the increasing nutrient loading from spring discharge is the increased growth of Lyngbya majuscula, a filamentous blue-green algae (Romie, 1990). This algae forms large floating mats that impair navigation and other recreational uses of the water body. In addition, the mats are unsightly and their decay causes a foul odor.

Ground water discharging in the Kings Bay Springs originates as rainfall in the recharge area inland of the springs. The rainfall infiltrates into the Floridan aquifer and flows seaward toward the springs. The portion of the recharge area that is most likely causing nutrient enrichment at the springs extends from Lake Rousseau and the Withlacoochee River to the north and east to a divergence in ground-water flow lines in southern Citrus County. Comparison of nitrate concentrations in ground water sampled from monitor wells in undeveloped areas of Citrus, Sumter, and Hernando Counties (Jones and others, 1990) with nitrate concentrations from ground water discharging from the springs clearly indicates that the spring-water concentrations significantly exceed natural, background ground-water concentrations. Since enrichment of some of these nutrients to the levels that occur in the discharging spring water appears to be only partially the result of natural processes, human-induced (anthropogenic) contamination of ground water must be occurring somewhere within the recharge area of the King's Bay Springs.

Because the nutrient-rich ground water discharging from the springs is degrading the water quality of King's Bay, the Surface Water Improvement and Management (SWIM) Program of the Southwest Florida Water Management District (SWFWMD) began an investigation of the problem. The investigation, which began in March of 1991 and lasted 2 years, was carried out by the Ambient Ground-Water Quality Monitoring Program (AGWQMP), also of SWFWMD. The scope of the investigation involved (1) delineating the area where nutrients are entering the Floridan aquifer, (2) identifying the land uses that are contributing the nutrients, and (3) determining possible steps that can be taken to slow or reverse the nutrient enrichment of ground water in the area.

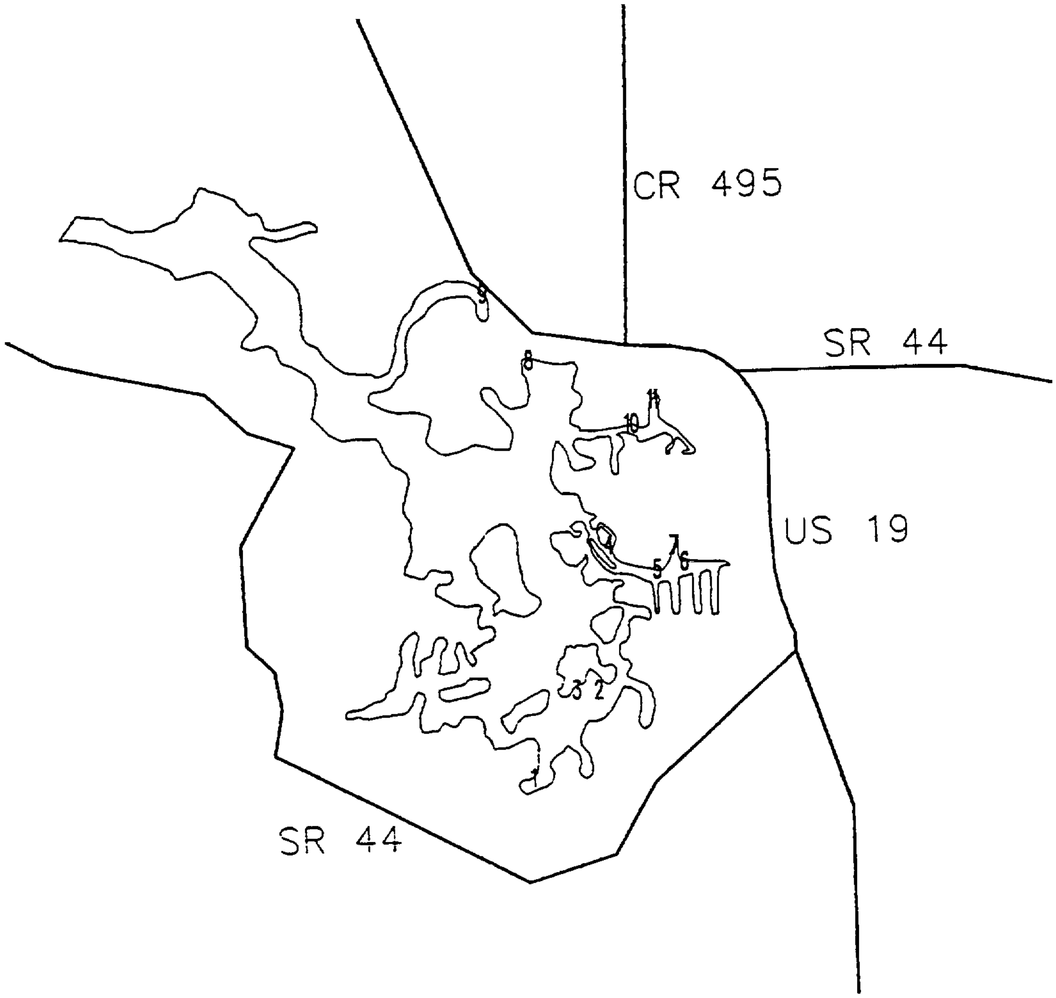

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Figure 1. Location of the Eleven Sampled Springs in King's Bay

DESCRIPTION OF THE STUDY AREA

INTRODUCTION

The project study area encompasses most of the northern two thirds of Citrus County (Figure 2). This region includes most of the ground-water drainage basin serving the King's Bay springs and the regions where human activity is likely to cause nutrient enrichment of ground water. The following sections explain the geographic setting, topography, and drainage, the King's Bay Springs system, the geology and hydrogeology, karst topography, and land uses in the study area.

Geographic Setting, Topography, and Drainage

Citrus County is located on the coast of west-central Florida and is bounded on the west by the Gulf of Mexico, on the north by Levy and Marion Counties, on the east by Sumter County, and on the south by Hernando County (Figure 2). Land surface elevations range from sea level along the coast to an average of 100 feet above NGVD along the Brooksville Ridge. At least two hills exceed an elevation of 250 feet above NGVD.

White (1970) delineated four major physiographic features in Citrus County. These include the Coastal Swamps, the Gulf Coastal Lowlands, the Brooksville Ridge, and the Tsala Apopka Plain (Figure 2). The physiographic areas are primarily a function of topographic relief and underlying sediments. The following is a brief discussion of each area.

The Coastal Swamp Area parallels the coast and extends inland from 2 to 5 miles. It is characterized by both tidal marshes and coastal swamps. Elevations are less than 10 feet, and poorly drained, organic soils directly overlie limestones of the Floridan aquifer system in much of the coastal swamp area.

The Coastal Lowlands lie between the Coastal Swamp and the Brooksville Ridge and range from about 2 to 8 miles in width. Elevations range from sea level to about 100 feet above NGVD. The topography consists of relatively flat plains to rolling hills. The hills consist of dunes and karst features.

The Brooksville Ridge trends north-south and occupies the central part of Citrus County. The Brooksville Ridge ranges from approximately 17 miles in width at the Hernando County line to about 5 miles in width at the Marion County line. Elevations along the ridge range from 70 to about 250 feet above NGVD. The margins of the ridge are characterized by deep, sandy soils. The soils of the ridge interior are a mixture of poorly to well-drained sandy-clayey soils. The entire Brooksville Ridge area overlies a clayey unit that varies between 10 and 30 feet in thickness but allows good hydraulic connection to the underlying Floridan aquifer system via karst features and

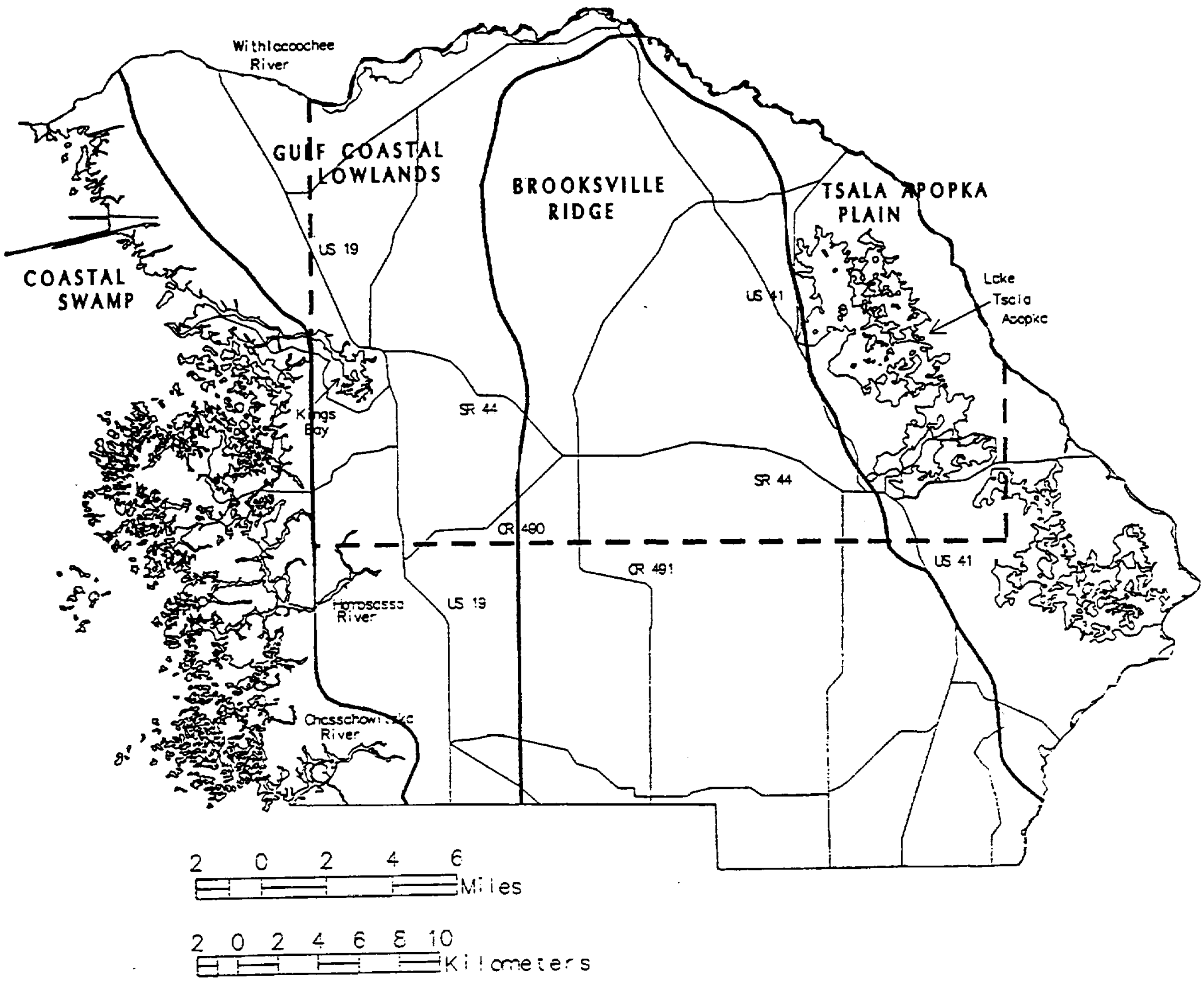


Figure 2. Study Area Within Citrus County and Location of Important Geologic, Hydrologic, and Cultural Features.

fractures. The ridge has an irregular surface due to karst activity and elevations may vary over 100 feet over short distances.

The Tsala Apopka Plain lies between the Brooksville Ridge and the Withlacoochee River. It has a large number of interconnected lakes that are divided by peninsulas and islands. Silicic deposits cover the limestone surface and elevations range from 35 to 75 feet above NGVD. The soils are generally sandy and weakly cemented with organic matter.

The main surface drainage features in the study area are the Withlacoochee River, which forms the eastern and northern borders of the study area and county, and Crystal River, which is located along the Gulf Coast. The Withlacoochee River originates in the Green Swamp, southeast of the study area, and flows northwest to the Gulf of Mexico near Yankeetown. The Withlacoochee River has been dammed, and Lake Rousseau, a relatively small lake, occupies much of the reach of the river between Citrus and Levy Counties.

The source of Crystal River is a number of springs that discharge into King's Bay. The river flows approximately 3 miles from the Bay to the Gulf of Mexico. The lack of rivers and streams in the interior of the study area results from a well-developed underground drainage system in the limestone that underlies the study area. Precipitation falling on the Brooksville Ridge rapidly moves underground through numerous sinkholes and begins moving seaward through an extensive system of conduits.

Land Use

Land use in the study area was determined from detailed analysis of aerial photography flown in 1989-90 (Figure 3). Despite a great deal of growth in the last 20 years, the county still retains a decidedly rural character. Most of the county is covered by coastal swamps, dense woodlands, lakes, scrub, and pasture. However, this is changing as residential development continues to expand at a rapid pace. The extreme western portion of the study area is mainly coastal swamp owned by the state and federal governments and is sparsely populated. Between 5 and 10 miles inland, high densities of residential and commercial land uses exist in the vicinities of the towns of Crystal River and Homosassa Springs. Industrial land uses are minor in this area as well as the rest of the county. North of the City of Crystal River, population densities are low 5 to 10 miles inland.

The central portion of the study area, while still relatively rural, contains a number of rapidly expanding retirement communities. These are characterized by dense residential development and golf courses. In the central to northern portion of this area, entire square-mile sections have been divided into dense networks of streets and platted lots. Although very few houses currently exist in these areas, the potential density of residential development is extremely high. The southern portion of this area is the Withlachoochee State Forest. The area is regularly logged and is virtually uninhabited. Portions of the eastern flank of the Brooksville Ridge were mined for phosphate rock from the late 1800s to the 1960s. These small mines are abandoned and few have been reclaimed.

The eastern portion of the study area is mainly occupied by the wetlands of Lake Tsala Apopka. The City of Inverness is located in the southern portion of this area and is the largest town in the study area. In portions of Lake Tsala Apopka, the many islands have been linked to the mainland by roads. These areas support considerable numbers of single-family homes.

It is important to note that within the entire study area there has been a very pronounced increase in both on-site sewage treatment (septic tank/drain field facilities) and of sewered communities in a relatively short period of time.

Geology

The geology of the study area is relatively simple (Figure 4 and Table 1). Thick sequences of limestone are exposed at or very near (10 to 20 feet) land surface in the eastern and western portions of the study area. Where limestone is near land surface, the thin veneer of sediment that covers the limestone consists of Quaternary-age, unconsolidated to poorly-indurated siliciclastic deposits dominated by quartz sand. These sands are primarily marine terrace deposits and coastal dune trains. Dunes are prevalent in the Coastal Lowlands and along the flanks of the Brooksville Ridge.

The limestone units comprise the Suwannee Limestone of Oligocene age and the Ocala Limestone of Eocene age. Underlying these exposed limestone units is the Avon Park Formation of Eocene age and the Lake City Limestone of Paleocene age. The Avon Park Limestone is the deepest formation containing potable water. The Suwannee and Ocala Limestones and the Avon Park Formation comprise the Floridan aquifer in the study area.

In the central portion of the study area (Brooksville Ridge area), the Floridan aquifer is overlain by undifferentiated, Quaternary quartz sand and Pliocene and Miocene sediments of the Hawthorn Group. The Hawthorn Group sediments were deposited in a variety of environments and consist of sand, silty sand, and waxy green clay. Phosphorite pebbles and fossil oyster bars are common. Much of the Hawthorn in the Brooksville Ridge has been highly weathered, which complicates recognition of the facies originally deposited there.

Weathering of the phosphorite has resulted in dissolution of carbonate-fluorapatite and re-precipitation of carbonate-hydroxylapatite in localized crusts and nodules that are associated with the sinkholes on the east side of the ridge (Upchurch,

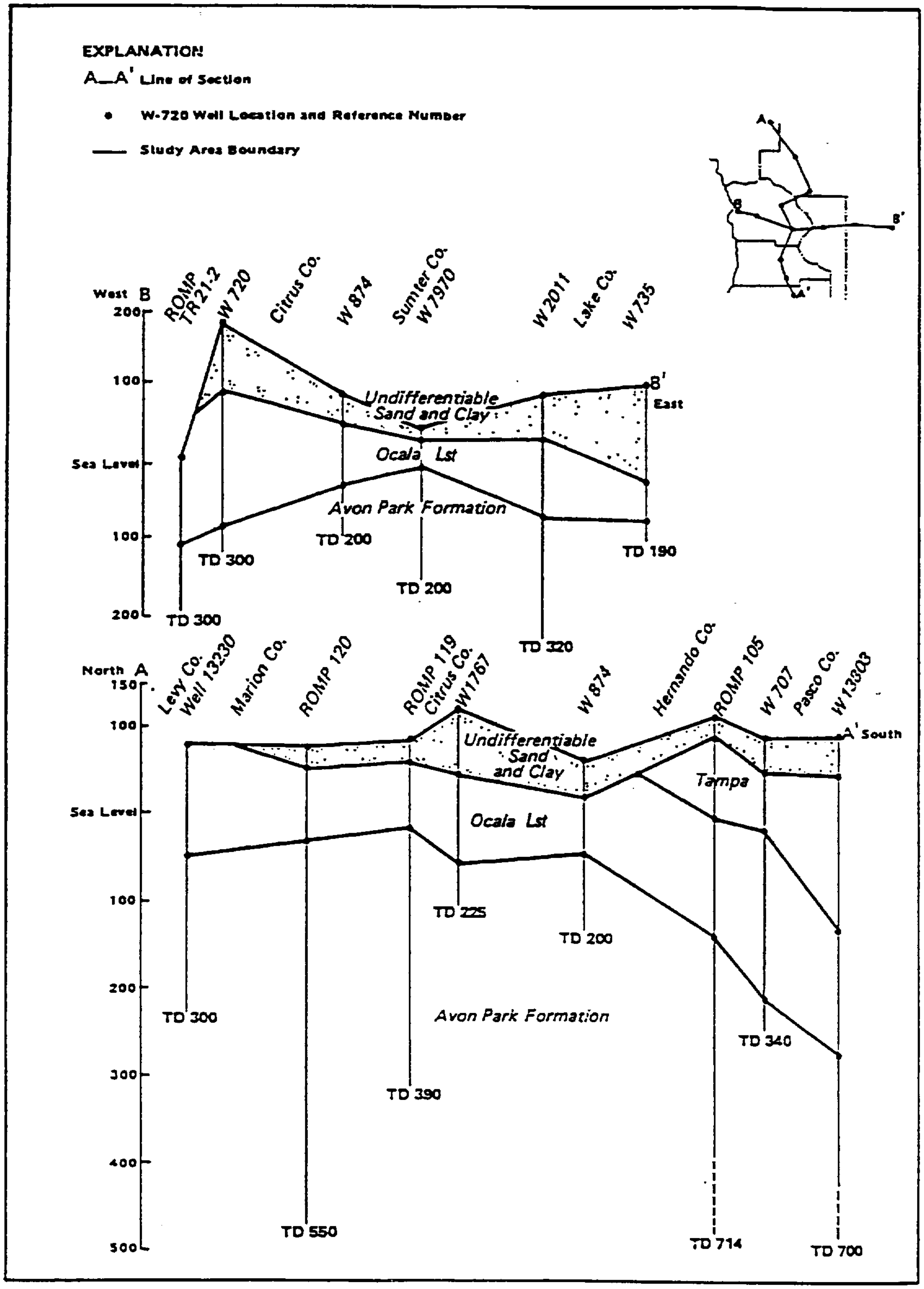


Figure 4. Generalized Geologic Sections of the Northern SWFWMD area (modified from Gilboy, 1982).

Table 1. Generalized Hydrogeology of the Northern SWFWMD Area (Modified from Fretwell, 1985).

SYSTEM	SERIES	STRATIGRAPHIC UNIT	THICKNESS (FEET)	LITHOLOGY	WATER PRODUCING CHARACTERISTICS
Quaternary	Holocene and Pleistocene	Undifferentiated deposits	0 - 100	Soil, sand, and clay of marine and estuarine terraces, alluvial, lake, and windblown deposits	Generally not a source of water.
Tertiary	Pliocene and Miocene	Hawthorn Group	0 - 100	Predominantly clay; some grayish-green, waxy; some interbedded sand and limestone, phosphatic clay, marl, calcareous sandstone, limestone residuum.	Confining layer in some places; generally not a source of water.
Tertiary	Oligocene	Suwannee Limestone	0 - 150	Limestone, cream to tan colored, fine-grained, fossiliferous, thin-bedded to massive, porous.	Many domestic and irrigation wells produce water from the lower part.
Tertiary	Eocene (upper)	Ocala Limestone	100 - 500	Limestone, white to tan fossiliferous, massive, soft to hard, porous.	Yields large quantities of water to wells completed above evaporites.
Tertiary	Eocene (middle)	Avon Park Formation	200 - 800	Limestone and dolomite. Limestone is light to dark-brown, highly fossiliferous, and porosity is variable in lower part. Dolomite is gray to dark-brown, very fine to microcrystalline and contains porous fossil molds, thin beds of carbonaceous material, and peat fragments. Formation generally contains evaporites in lower part.	Yields large quantities of water to wells completed above evaporites.

1992). These deposits of re-precipitated phosphate, which were locally termed "hard-rock phosphate", were extensively mined from the late 1880s through 1966 (Dinkins, 1969). The last mine to close, the Holder Mine, was just south of the Withlacoochee River and east of U.S. 41. None of the mines were large because the deposits were localized on karst features. Open-pit mining was initially by hand, with hand cobbing and sorting, but by the turn of the century steam- and then internal-combustion-engine shovels were used. The deposits, and mines, extended from northern Hernando County into Levy County. The mines were located along U.S.41, at the foot and flank of the Brooksville Ridge.

Ground-Water Hydrology

Karst

A prerequisite to comprehending the ground-water hydrology of the study area is an understanding of the dominant role karst processes play in moving ground water through the Floridan aquifer. The four physiographic provinces in Citrus County (Coastal Swamps, Gulf Coastal Lowlands, Brooksville Ridge, and Tsala Apopka Plain) are areas of intensive karst development. These areas are characterized by numerous sinkholes, lack of surface drainage, and undulating topography. In karst areas, the dissolution of limestone has created and enlarged cavities within the limestone which eventually collapse and form sinkholes. Sinkholes capture surface-water drainage and funnel it underground, which promotes further dissolution of limestone. This leads to progressive integration of voids beneath the surface and allows larger and larger amounts of water to be funneled into the underground drainage system. Dissolution is most active at the water-table or in the zone of water-table fluctuation where carbonic acid contained in atmospheric precipitation and generated by reaction with soil carbon dioxide reacts with limestone and dolostone (Carroll, 1970). Because the altitude of the water table shifted in response to changes in sea level, many vertical and lateral paths have developed in the underlying carbonate strata in the area. Many of these paths or conduits lie below the present water table and greatly facilitate ground-water flow.

Surficial Aquifer

The surficial aquifer system consists of Miocene to Holocene siliciclastic deposits that are contiguous with land surface. The clastics are usually sand, silty sand, and kaolinitic clay. The lower limit of the aquifer coincides with the top of laterally extensive and vertically persistent low permeability beds of the Hawthorn Group or its residuum. These beds are composed of Pliocene and Miocene sand, silty sand, waxy-green clay and phosphorite pebbles. Since the majority of Citrus County has no extensive confining layer, most of the county does not have a surficial aquifer. Figure 5 shows that only about 25 percent of the county is characterized by confining beds greater than 25 feet in thickness.

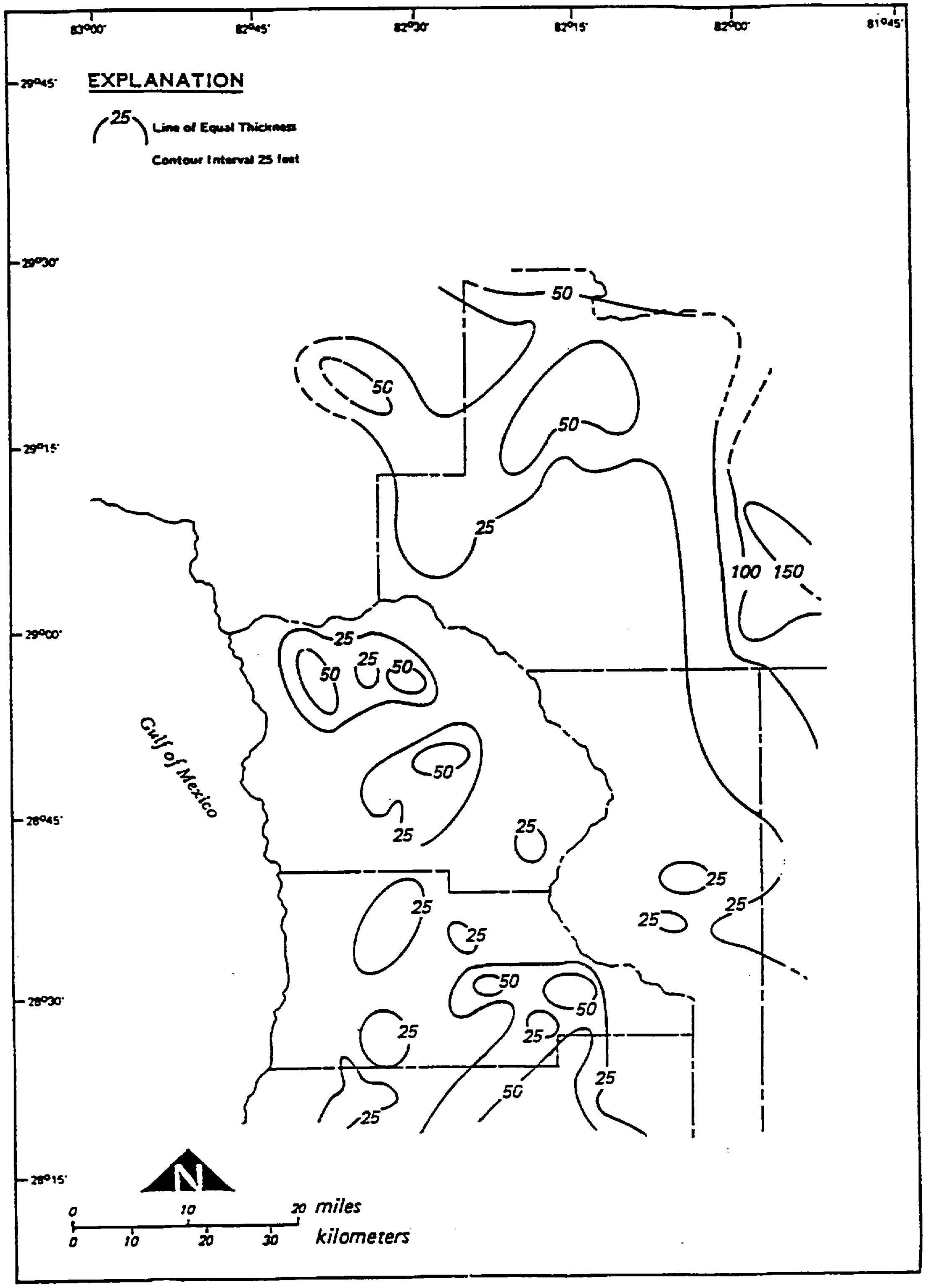


Figure 5. Thickness of the Confining Unit Above the Floridan Aquifer in the Northern District Area (from Faulkner, 1970, and Bono and Others, 1979).

Floridan Aquifer

The Floridan aquifer system is divided into two major hydrostratigraphic horizons. The upper Floridan, which contains potable water, and the lower Floridan which is saline. The upper Floridan, henceforth the Floridan aquifer, is the focus of this report. The Floridan aquifer system is the principal source of water for domestic, agricultural, and industrial supplies in the study area. In north and central Citrus County the freshwater-bearing part of the Floridan aquifer is composed of the Avon Park Formation, the Ocala Limestone, and the Suwannee Limestone, in ascending order. The top of the aquifer is usually defined as the uppermost vertically persistent permeable limestone or dolostone. Where the confining beds that separate the surficial and Floridan aquifers are present, the top of the Floridan coincides with the base of the confining beds. The lower part of the Avon Park Formation contains evaporites consisting of gypsum and anhydrite that reduce permeability of the rock and are considered to be the base of the upper Floridan aquifer.

In general, the Floridan aquifer is unconfined in the study area. However, clay layers in the Brooksville Ridge are sufficiently thick to cause local, semi-confined conditions to exist. A limited surficial aquifer may occur in these areas, but there are probably enough breeches in the clay layer to allow percolation of water from the sand into the underlying limestone. In areas where saturated sand lies directly above limestone, water in the sand is hydraulically connected to the Floridan aquifer.

Recharge

A number of investigators have estimated recharge for the various physiographic regions of Citrus County. The following is a summary of the recharge estimates of Stewart (1980), Ryder (1985), and Adams (1985). Recharge is very low along the coast, where it ranges from -9 (discharge) to 12 inches per year. In the Tsala Apopka area recharge is low to moderate, ranging from 5 to 21 inches per year and averaging 12 inches. In the Brooksville Ridge area recharge is very high, ranging from 14 to 22 inches per year.

Recharge is highest in the Brooksville Ridge because it is a karst terrain with internal drainage to the upper Floridan aquifer (Kimrey and Anderson, 1987). Sinkholes are abundant, the land surface is generally very well drained and the water table is relatively deep. Surface waters are not abundant and there are no permanent streams or extensive wetland areas. These factors maximize recharge because infiltration is rapid and surface runoff is non-existent.

Recharge is lower in the Tsala Apopka area because the potentiometric surface of the Floridan aquifer is close to land surface. This insures that during periods of heavy rainfall the aquifer becomes full, and excess rainfall is lost to overland flow. Figure 6 is an east-west cross section through the Lake Tsala Apopka/Brooksville

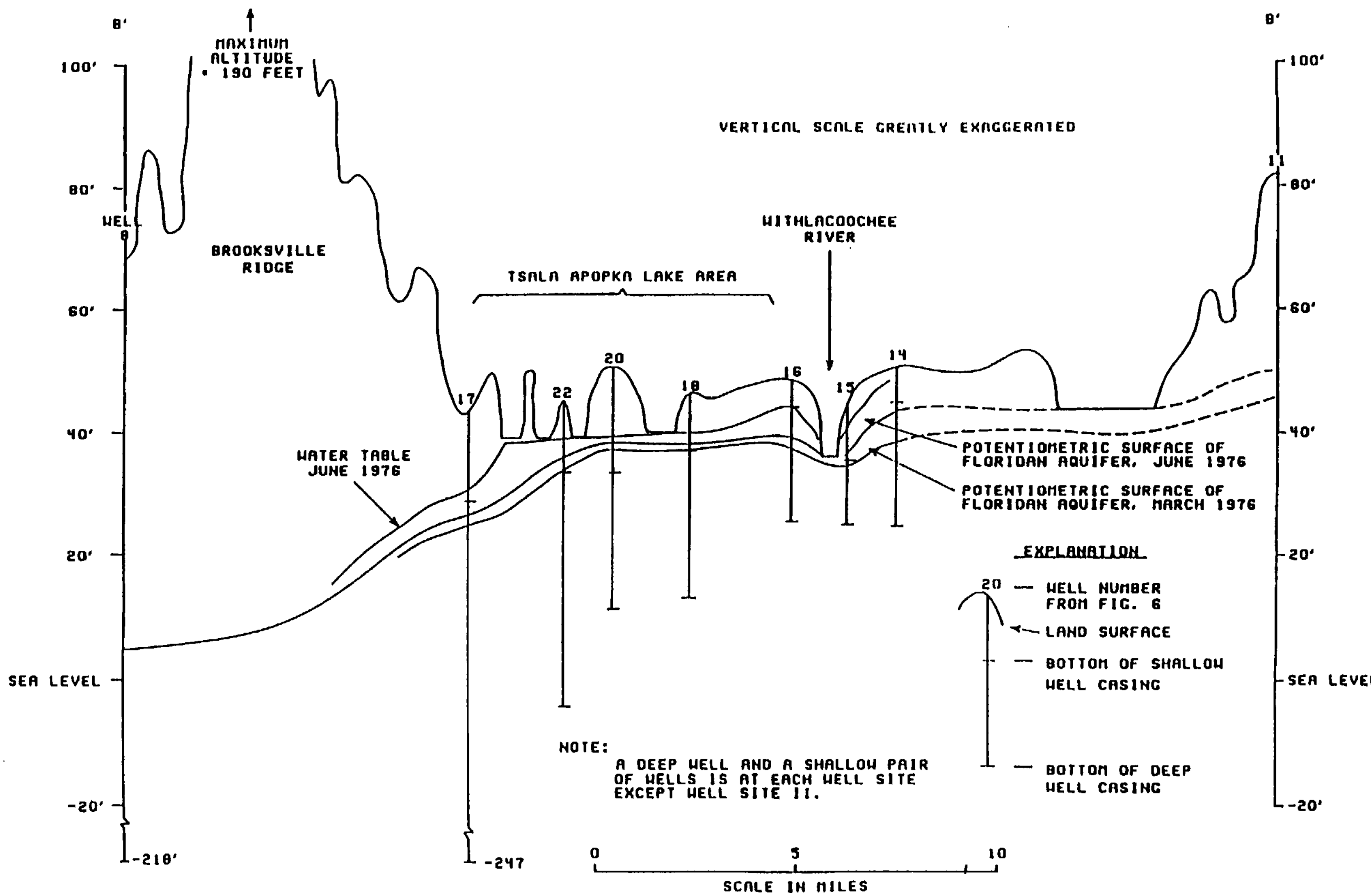


Figure 6. East-West Hydrogeologic Cross Section through Lake Tsala Apopka Showing the Relation of the Potentiometric Surface of the Floridan Aquifer to the Water Table, March and June, 1976 (from Rutledge, 1977).

Ridge area showing that the difference between the water table and the potentiometric surface enables Lake Tsala Apopka to recharge the Floridan aquifer.

King's Bay Springs

Thirty springs in and around King's Bay constitute the headwaters of Crystal River, which discharges to the Gulf of Mexico seven miles west of the bay. Figure 1 depicts the locations of 11 of the springs that were considered important enough to periodically sample. The bay is approximately 600 acres in surface area and ranges from 3 to 10 feet in depth throughout most of its area. Ground-water discharge from the springs accounts for the majority of the 975 cfs (630 mgd) (Yobbi and Knochenmus, 1989) of water flowing from King's Bay to the Gulf of Mexico. The springs discharge through subaqueous vents or flow into the bay over short spring runs. Because the spring discharge comprises a large percentage of the water flowing from King's Bay, it plays an important role in determining the overall water quality of the bay (Romie, 1990).

The largest and best known of the King's Bay springs is Tarpon Spring (Figure 1). Also known as Crystal Spring and Big Hole, it has become a very popular dive location and Manatee viewing area. The spring is subaqueous and is approximately 200 feet in diameter and 65 feet deep. An adjacent spring immediately to the east appears to have a more vigorous flow.

The discharge of the submarine springs of King's Bay is affected by tidal fluctuations (Rosenau et al. 1977). It has not been verified that the water quality of the springs changes with tidal fluctuations. However, Yobbi (1992), has documented changes in specific conductance that range from 5,000 to 20,000 microsiemens per centimeter between low and high tide in nearby coastal springs.

STUDY DESIGN, METHODS, AND DATA COLLECTION

INTRODUCTION

The study design and methods of investigation were formulated in January and February of 1991 by members of the AGWQMP section and SWIM Department of the SWFWMD and Dr. Sam B. Upchurch of the University of South Florida, Department of Geology. The complexity of the problem dictated that the investigation employ a wide variety of geological and geochemical analysis techniques to reach meaningful conclusions. The following is a discussion of these techniques, their implementation, and results.

Delineation of the Study Area

Deductive reasoning leads one to conclude that the nitrate and other nutrients being released to King's Bay are of human origin. Furthermore, travel times in the aquifer systems are such that one would not expect the sources of the nutrients to be more than a few miles from the springs. Flow nets constructed using the U.S. Geological Survey's state-wide 1980 potentiometric surface map (Miller, 1990) indicated that water discharging from the King's Bay Springs in the Floridan aquifer can originate over a wide area. This includes areas where the Floridan aquifer is either unconfined or poorly confined in southwestern Marion County, northern Sumter County, and the Green Swamp in southern Lake and northern Polk Counties. However, it is unlikely that contamination from outside of Citrus County could have travelled to the springs in the 100 to 150 years of intense human activity. Therefore, one or more local sources of nutrients must exist and they must be related to a local recharge area. This was verified following the analysis of nitrate concentrations in samples obtained from the monitor well network. Areas where nitrate was elevated in ground water appear to originate in central to western Citrus County.

The final dimensions of the study area were determined by expanding the boundaries a considerable distance in all directions to make certain that the principal ground-water flow path and potential nitrate-generating land uses were completely encompassed. The boundaries of the study area, therefore, include the Withlacoochee River (and Citrus County line) on the north and east and a divergence in Floridan aquifer flow lines that separates waters that discharge into the Kings Bay Springs from those that discharge to Homosassa Springs on the south. This divergence is in south-central Citrus County. The western boundary is a north-south line in the Coastal Swamp province that is seaward of the Kings Bay spring system and, therefore, unlikely to affect the springs.

With the exception of the areas around the springs and some areas in the Coastal Swamp, the entire study area is characterized by potential for recharge to the

Floridan aquifer. Therefore, the source of nutrients can occur anywhere in the study area.

Collection of Existing Data

Once the most significant portion of the recharge area had been identified, the ground-water data collection phase of the project began. An extensive literature search was conducted to locate ground-water quality data for the springs and wells in the study area. A number of different data sources were utilized, including the defunct Florida State Board of Conservation (1951), the Florida Geological Survey, the Florida Department of Environmental Protection, and the Southwest Florida Water Management District.

Establishment of a Study-Area Monitor-Well Network

The most important tool in determining the source of nutrients in the springs was the water-quality data obtained from the monitor-well network. The network was established partially through a newspaper article stating that well owners in the study area could have their well water tested for a number of different parameters at no cost to them. The response to the article was extremely favorable and 96 private home or business wells were included in the network. Each private water system was carefully evaluated to insure that the water samples were not compromised by treatment systems. Total well depth was known for 87 percent of the wells, and cased depth was known for 28 percent. In addition, 7 existing monitor wells were located in the study area and included in the network. Figure 7 is a map of the locations of sampled wells. Well specifications are listed in Appendix I.

Stratigraphic Evaluation of Open-Hole Intervals of Monitor Wells

Total depth information was available for the majority of the wells in the network. With this information, the wells were evaluated individually in terms of the hydrostratigraphic horizons and formation(s) to which they are open. Figure 8 indicates the stratigraphic interval and aquifer from which each well is receiving water.

Water Quality Sampling of Springs and Monitor Wells

Water-quality sampling of springs and monitor wells by the AGWQMP was the most time consuming and labor intensive aspect of the study. All water quality data obtained from spring and monitor well sampling are included in Appendix I. Methods used are current, U.S.E.P.A.-approved standard methods, where available.

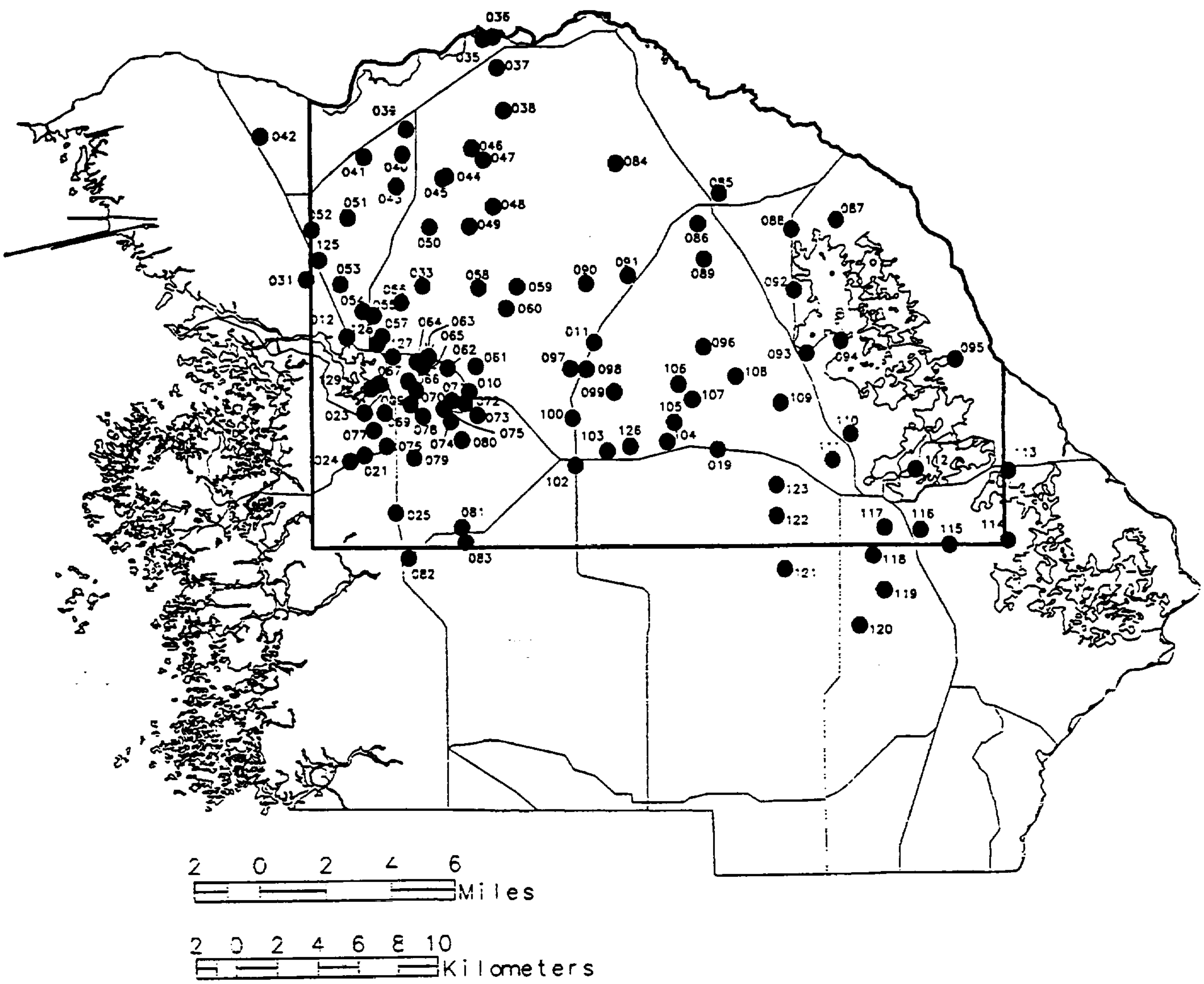


Figure 7. Location of Sampled Wells in the Study Area.

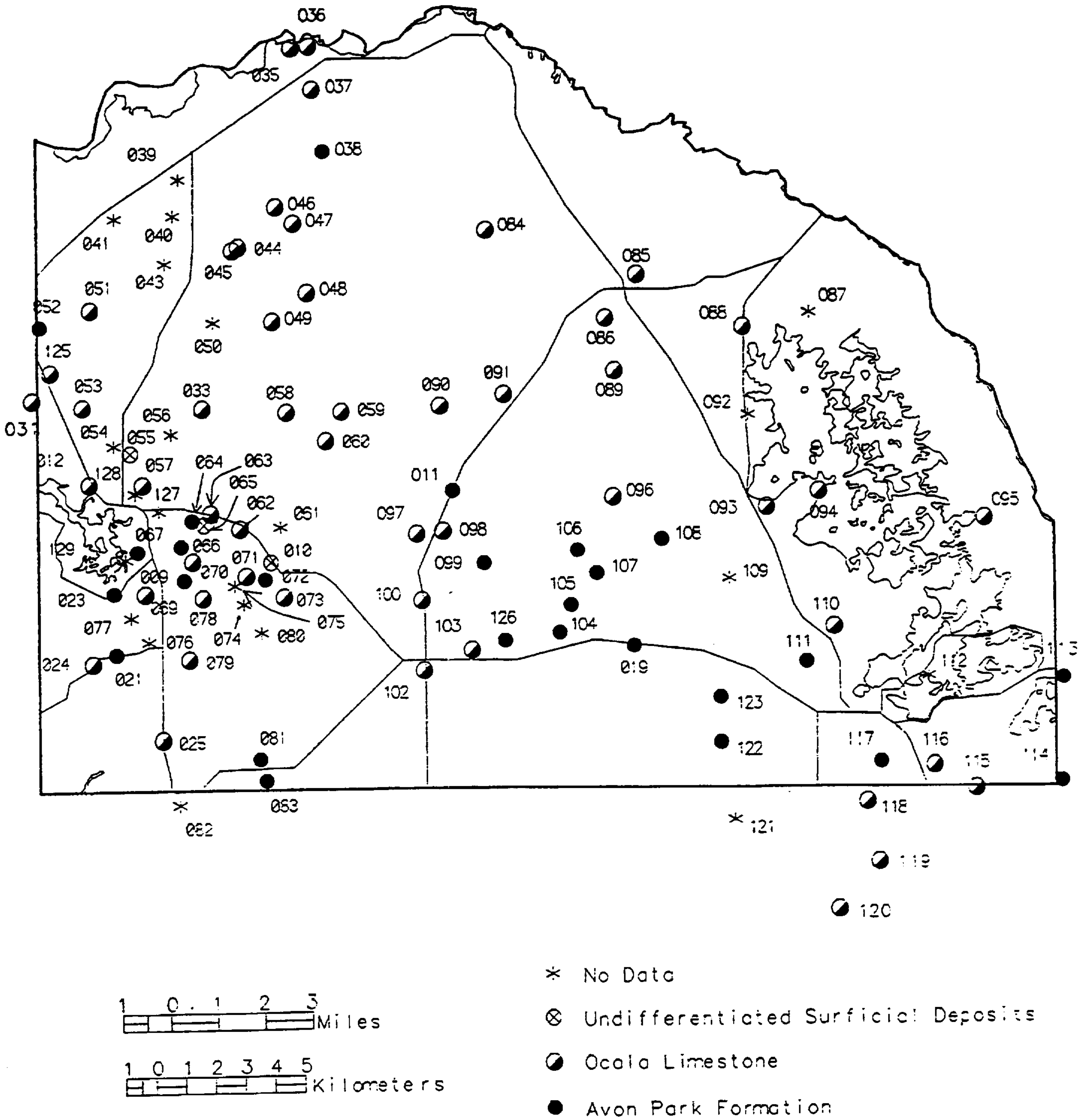


Figure 8. Stratigraphic Interval from Which Network Wells Obtain Water.

Analytes

The list of analytes selected for analysis from spring and well samples are listed in Table 2. In addition to the traditional list of analytes, several isotopic analytes

Table 2. - Analytes Used in the Study.

Ph	Bicarbonate	Orthophosphate
Temperature	Sulfate	Total Phosphorus
Total Dissolved Solids	Chloride	Total Organic Carbon
Specific Conductance	Fluoride	Iron
Calcium	Total Kjeldahl Nitrogen	Uranium
Magnesium	Nitrate Nitrogen	$^{234}U/^{238}U$
Sodium	Nitrate/Nitrite Nitrogen	^{3}H
Potassium	Ammonia Nitrogen	$^{14}N/^{15}N$
	Trace Metals	

were measured for selected samples. Because of the high cost of analysis, the number of samples analyzed for isotopic composition was reduced. Samples were selected to cover the range of land uses and water-quality variability in the study area. The isotopes studied include isotopes of hydrogen (tritium), nitrogen, and uranium.

Tritium - Tritium (^{3}H) is a rare isotope of hydrogen that is formed by cosmic-ray activation of nitrogen. Before 1952, the tritium content of meteoric water ranged from 1 to 10 TU[1] (Kaufman and Libby, 1954). Water recharged in Florida prior to 1952 should have a tritium concentration of less than 2 TU (Yobbi, 1992).

Atmospheric, nuclear-weapons testing has raised tritium activities as much as two orders of magnitude. While tritium began to be introduced in the mid-1940s, the major build-up of tritium began with cold-war testing in the 1950s (Figure 9). This resulted in rainfall concentrations of tritium reaching 1,188 TU at Ocala, Florida, in 1963 (Yobbi, 1992). Tritium activities in meteoric waters increased until the mid-1960s when atmospheric test bans became effective. With the advent of the Nuclear Test-Ban Treaty in 1963, tritium levels have decreased, and in 1988 they averaged about 5 TU. Tritium has a half life of 12.4 years, so decay and cessation of atmospheric testing have resulted in a decline of tritium in precipitation to activities similar to background. Thus, any ground waters that contain tritium above background levels can be assumed to have been recharged in the period from 1950 to 1975. Ground waters with tritium activities less than 10 TU can be assumed to have been recharged before 1952 or within the last 10 years.

[1] A Tritium Unit (TU) is 1 atom of ^{3}H in every 10^{18} hydrogen atoms. One TU is approximately 3.2 μμCi per milliliter of water (3.2 picoCuries per liter).

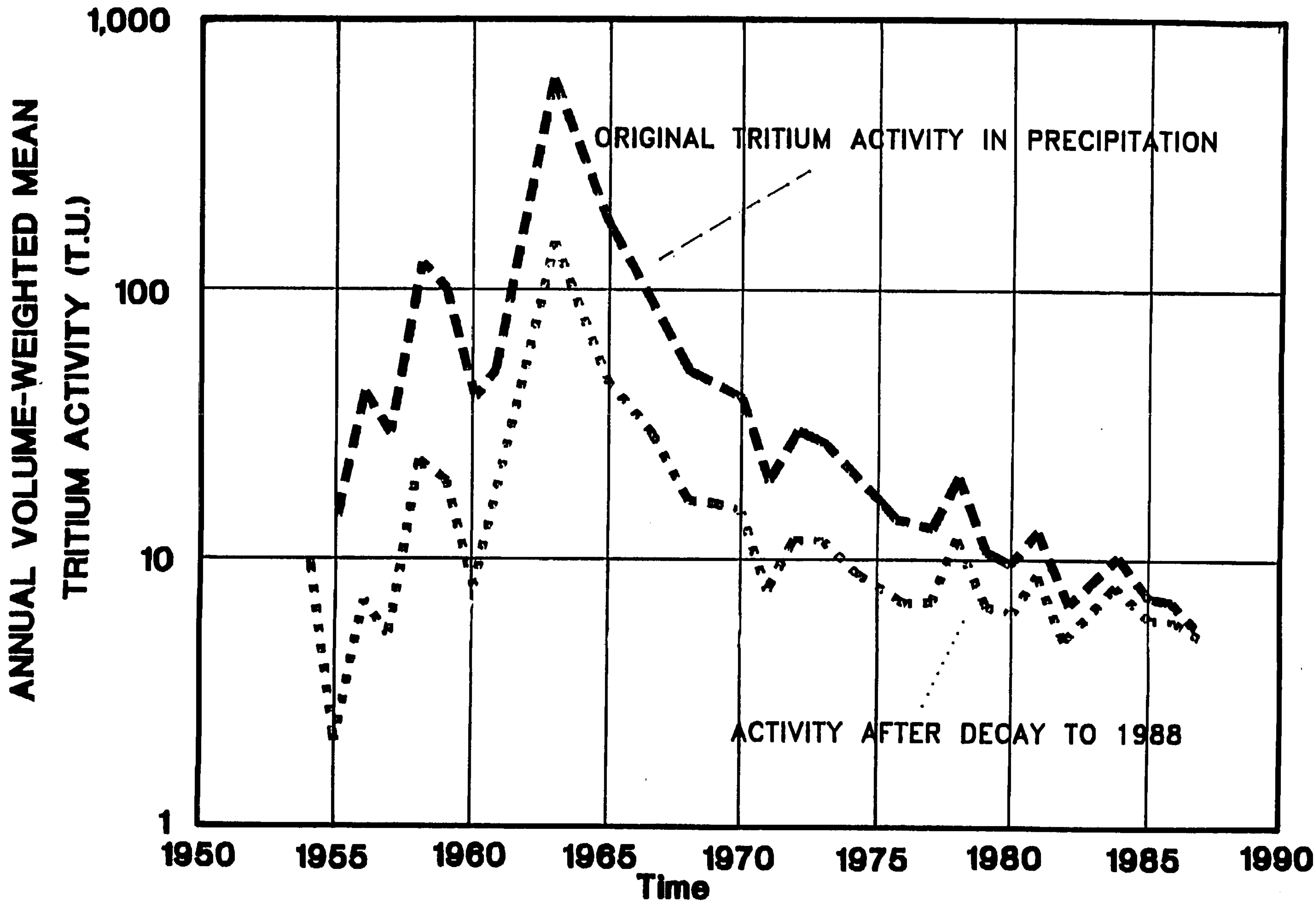


Figure 9. Distribution of Tritium in Precipitation Over Time (modified from Swancar and Hutchinson, 1992)

Tritium activities have been successfully used previously in several studies in the District. Faulkner (1973) found tritium activities in wells and springs near the Cross-Florida Barge Canal as high as 174 TU at the same time (1966-68) that rainfall contained activities as high as 158 TU. Activities in Rainbow and Silver Springs ranged from 38 to 85 TU and 25 to 150 TU, respectively. Swancar and Hutchinson (1992) used tritium to show that Floridan aquifer waters in the northern half of the District are relatively young, with activities of 8 to over 10 TU common. They also concluded that recent recharge water has relatively low tritium concentrations (on the order of 10 TU as opposed to higher activities) because of (1) relatively long periods required for recharge and (2) mixing with older waters in the Floridan aquifer.

Determining the tritium content of ground water in aquifer water helps to determine whether the aquifer is being recharged locally or from a more distant source. Because of the dramatic increase in 1952, tritium provides a useful marker for relatively young water in the hydrologic cycle.

Uranium - The isotopic ratio $^{234}U/^{238}U$ has been successfully utilized by J.K. Osmond and J.B. Cowart (*i.e.*, Osmond and Cowart, 1976; Cowart *et al.*, 1978) of Florida State University to trace ground-water flow systems, determine relative ages of ground-water masses, and determine provenance of water masses. They were contracted to analyze 38 samples from the study area and determine similarities of the ground-water and spring samples, if possible. The discussions that follow are largely from their unpublished report (Cowart and Osmond, 1992).

Uranium concentration can be used to roughly determine age and history of ground water in Florida. Low concentrations (<0.1 µg/L) are typically associated with reducing conditions and deep, slow-moving waters. High concentrations (>0.1 µg/L) are found in oxidizing waters that are typically shallow and relatively young (recently recharged). The ratio of ^{234}U to ^{238}U is also sensitive to ground-water age. Alpha recoil (Osmond and Cowart, 1976) forces ^{234}U into ground water relative to ^{238}U. Thus, older waters tend to have higher $^{234}U/^{238}U$ than do younger waters.

Nitrogen Isotopes - Use of nitrogen isotopes is a new technology that has proven useful in identifying nitrogen derived from animal wastes (Kreitler, 1975; Wolterink *et al.*, 1979). The isotopic ratio of $^{15}N/^{14}N$ is expressed as $\delta^{15}N$, where

$$\delta^{15} N = 1000 \frac{\left(\frac{\alpha_{15_N}}{\alpha_{14_N}}\right)_{sample} - \left(\frac{\alpha_{15_N}}{\alpha_{14_N}}\right)_{air}}{\left(\frac{\alpha_{15_N}}{\alpha_{14_N}}\right)_{air}}$$

and α represents the activity of the isotope in question. The range of $\delta^{15}N$ values for different waste sources varies. Nitrate from septic tanks, feedlots, and barnyards cannot be distinguished from each other, but can be separated from natural soil nitrate (Wolterink *et al.*, 1979). Mean natural soil nitrate $\delta^{15}N$ was found to be about +7 ppt (parts per thousand), while mean $\delta^{15}N$ in septic tanks was approximately +11 and was about +12 in feedlot/barnyard nitrate. Nitrate from municipal irrigation wastewaters averaged about +9.5 $\delta^{15}N$. In order to confirm an animal waste source, Wolterink *et al.* (1979) concluded that the $\delta^{15}N$ must exceed 24 ppt, based on the mean plus three standard deviations.

Wolterink *et al.* (1979) studied two sites in the Tampa Bay area. One was a septic tank site first described by Rea and Upchurch (1980); the other a wastewater spray-irrigation site near the University of South Florida. Based on soil samples from the septic-tank site, nitrate concentrations ranged from 5.7 to 56.0 mg/l, and the $\delta^{15}N$ ranged from -6.3 to +18.8. Raw data from the spray-irrigation facility were not reported.

Springs Network

All springs were initially sampled in late April 1991 for 11 major ions, 6 nutrients, total dissolved solids, total organic carbon, and 6 trace metals (Table 2). Following the initial sampling, the springs were sampled quarterly through February 1992 for the parameters listed above with the exception of the 6 trace metals.

In addition to the conventional parameters, the springs were also sampled for isotopes of hydrogen, nitrogen, and uranium. The selection of isotopes to sample was based on the need to identify young waters, which would have been recharged within the last 50 years, and to correlate land use with nutrient sources.

Monitor-Well Network

Two separate parameter lists were formulated for the 103 wells in the study area that were to be sampled by the AGWQMP. The first list included 10 major ions, 6 nutrients, total dissolved solids, total organic carbon, and iron. A total of 93 wells were sampled for these parameters. The second list included 4 nutrients and total organic carbon. Ten wells were sampled for these parameters.

A small number of homeowner and monitor wells were also sampled for isotopes of hydrogen, nitrogen, and uranium. Fourteen wells were sampled for tritium, 8 for $\delta^{15}N$, and 32 for uranium-234 and -235.

Characterization of the Flow System

The presence of sinkholes, internal drainage, and springs are good indications that a well-developed conduit system exists in the Floridan aquifer. To characterize the system in terms of its extent, the location of major conduits, and rate of movement of ground water through the system, a number of different investigations were performed. These are discussed below.

Sinkhole Reconnaissance

To characterize the extent of the Brooksville Ridge, the area of maximum recharge in the study area, USGS 7.5' topographic quadrangle maps of the Brooksville Ridge were searched for closed-depressions. Locations of the features are plotted in Figure 10. From the figure it is apparent that a large number of very extensive sinkholes, some measuring several miles in length and width, are located within the boundaries of the Brooksville Ridge. Littlefield *et al.* (1984) showed that sinkholes are often aligned along photolinear features[2], or fracture traces.

Potentiometric Surface

The May 1991 potentiometric surface of the Floridan aquifer and directions of ground-water flow (Mularoni, 1992) are depicted in Figure 11. The flow lines indicate that ground water in the study area moves towards the King's Bay Springs from the north, northeast, east, and southeast. Ground water moving toward the King's Bay Springs from south of Inverness may be intercepted by flow toward Homosassa Springs. The spacing of the potentiometric contours indicates that flow gradients are low and transmissivity is high in the Tsala Apopka area. The gradient increases significantly and transmissivity decreases to the west across the Brooksville Ridge. Finally, the gradient flattens out and transmissivity increases west of the Brooksville Ridge.

The potentiometric surface usually shifts slightly gulfward between May and September, as the Floridan aquifer system is recharged by summer rains and pumping is reduced.

Chemical Distributions

Chemical data were machine contoured using the SURFER graphic package. The plot files were written to a DXF file and imported into AUTOCAD and edited to produce hydrogeologically reasonable maps by Upchurch. No changes were made to

[2] Photolinear features are linear, or near linear, features that can be identified by remote imaging, such as aerial photography or satellite imagery. They can be identified by linear arrangements of sinkholes, sinkhole lakes, streams and dry valleys, soil tonal variations, and vegetation. Geophysical studies in central Florida have shown that these are often associated with deep, vertical fractures that have enhanced transmissivities. These fractures (hence the term fracture trace for the photolinear), therefore, represent major conduit systems for ground-water flow.

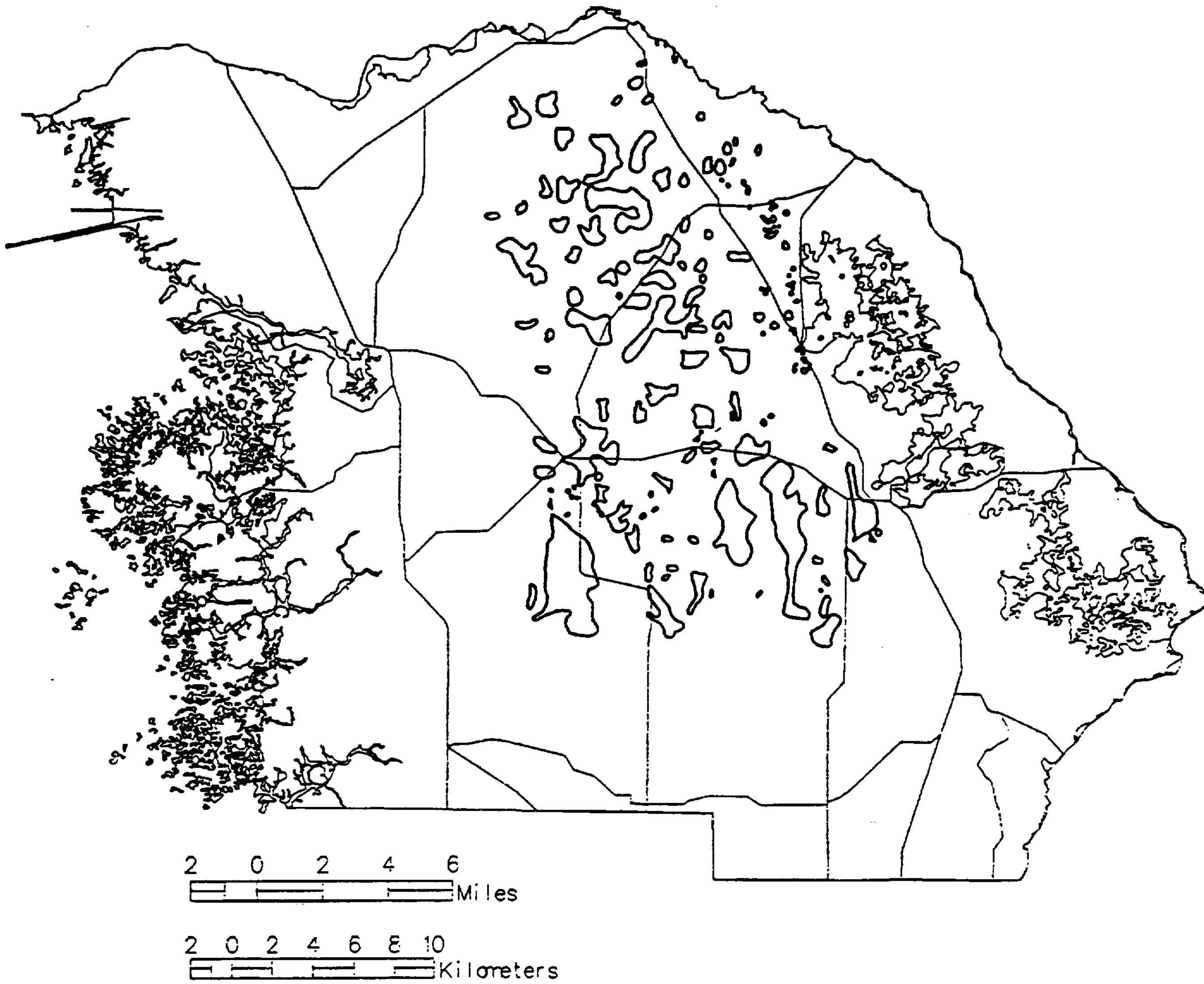


Figure 10. Location of Major Sinkholes in the Study Area.

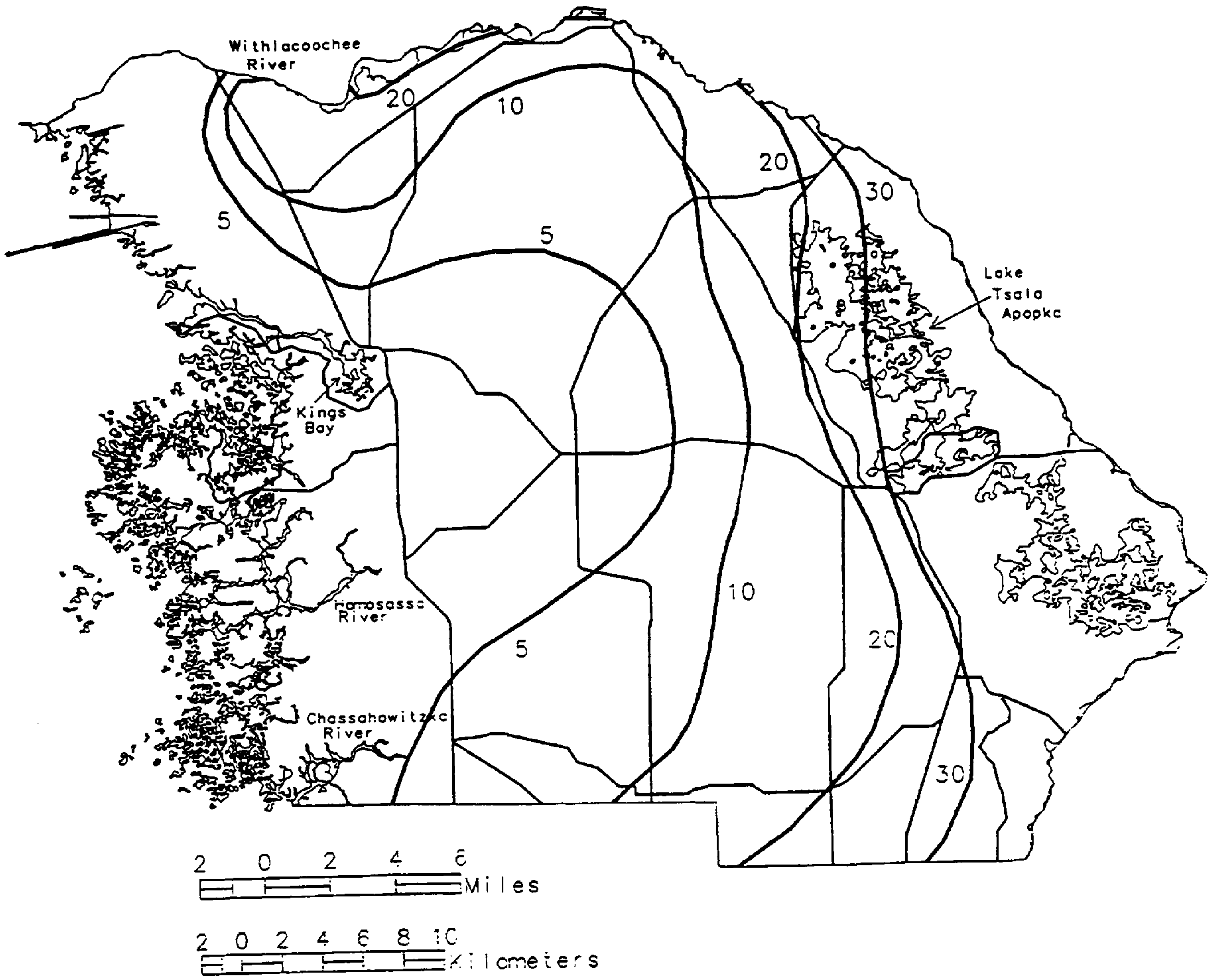


Figure 11. Potentiometric Surface of the Floridan Aquifer in Citrus County, May, 1991 (modified from Mularoni, 1992).

the contour patterns, only unsupported lines and inappropriate contours were changed. The maps, therefore, reflect an independent, quantitative interpretation of the data.

Hydrochemical facies were identified by a plotting the chemical data on a Piper diagram (Piper, 1944), which indicates that well and spring chemical data cluster into several groups. End-member samples from each group were selected for plotting on Stiff diagrams (Stiff, 1951) for interpretation.

RESULTS

CHEMICAL DISTRIBUTIONS

Tritium: An Indicator of Ground-Water Travel Time

Samples obtained from 14 wells in the study area and Tarpon Hole Spring, Catfish Corner Spring, and Idiots Delight Spring were analyzed for tritium. Results of the analyses are included in Table 3. The map reference number relates the well or spring to its location on Figures 1 or 7. Figure 12 shows the spatial distribution of tritium activities.

The tritium activities ranged from 4.1 TU to 25 TU in monitor wells, while the springs ranged from 4.7 TU in Catfish Corner Spring to 9.1 TU in Idiots Delight Spring. The tritium concentrations indicate that water in the Floridan aquifer in area wells entered the aquifer sometime between 1952 and the present. The tritium concentrations are somewhat elevated relative to pre-1952 levels, but not as high as might be expected if recharge had taken place during the early 1960s. Comparison with Figure 9 suggests that activities in the 3 to 6 TU range are likely to have been recharged in the early 1950s, but not earlier, or in the 1990s. Water in the Kelly and Beohl wells was almost certainly recharged in the 1960s. Spring waters are mixtures of sea water and fresh water in varying proportions, so the moderately high tritium contents suggest relatively young water, but do not indicate whether the tritium is in the sea or fresh-water component. Comparison of the bulk water composition and tritium contents of fresh water inland, suggest that the tritium in the springs is from the fresh-water component.

Alternative possibilities to explain why the observed tritium levels are not higher include: (1) the water was recharged in the period of atmospheric nuclear testing, but it has mixed with older, tritium-free waters and (2) that recharge of higher tritium waters is just making its way to the Floridan aquifer in the area [the Swancar and Hutchinson (1992) interpretation]. The preferred interpretation from tritium and other data leads one to conclude that the water is young (<50 years since recharge).

Uranium Isotopes: Indicators of Recharge Areas and Relative Water Ages

The naturally occurring concentrations of uranium and the activity ratio of ^{234}U to ^{238}U in well and spring-water samples were used to determine the source aquifer and recharge area of ground water discharging from the springs. The following are modified excerpts from Cowart and Osmund (1992).

Ground-water in the deep, slow-moving portions of the Floridan aquifer flow

Table 3. Tritium **Activities** for Wells and Springs in the Study Area.

SITE NAME	MAP REFERENCE NUMBER	TRITIUM ACTIVITY (TU)
Tarpon Hole Spring	-	7.5
Catfish Corner Spring	-	4.7
Idiots Delight Spring	-	9.1
Beohl	094	17.5
Hunt	084	5.3
Townsend	102	4.7
Needleman	067	6.6
Sheffield	063	4.1
Kelly Well	037	25.0
Rhame	109	4.7
Cutrone	116	5.0
Frenzel	112	6.2
Case	110	5.6
Houston	123	6.6
Aubin	061	5.9
Arnow	071	6.6
Lisotta	099	7.2
Verona	070	5.6

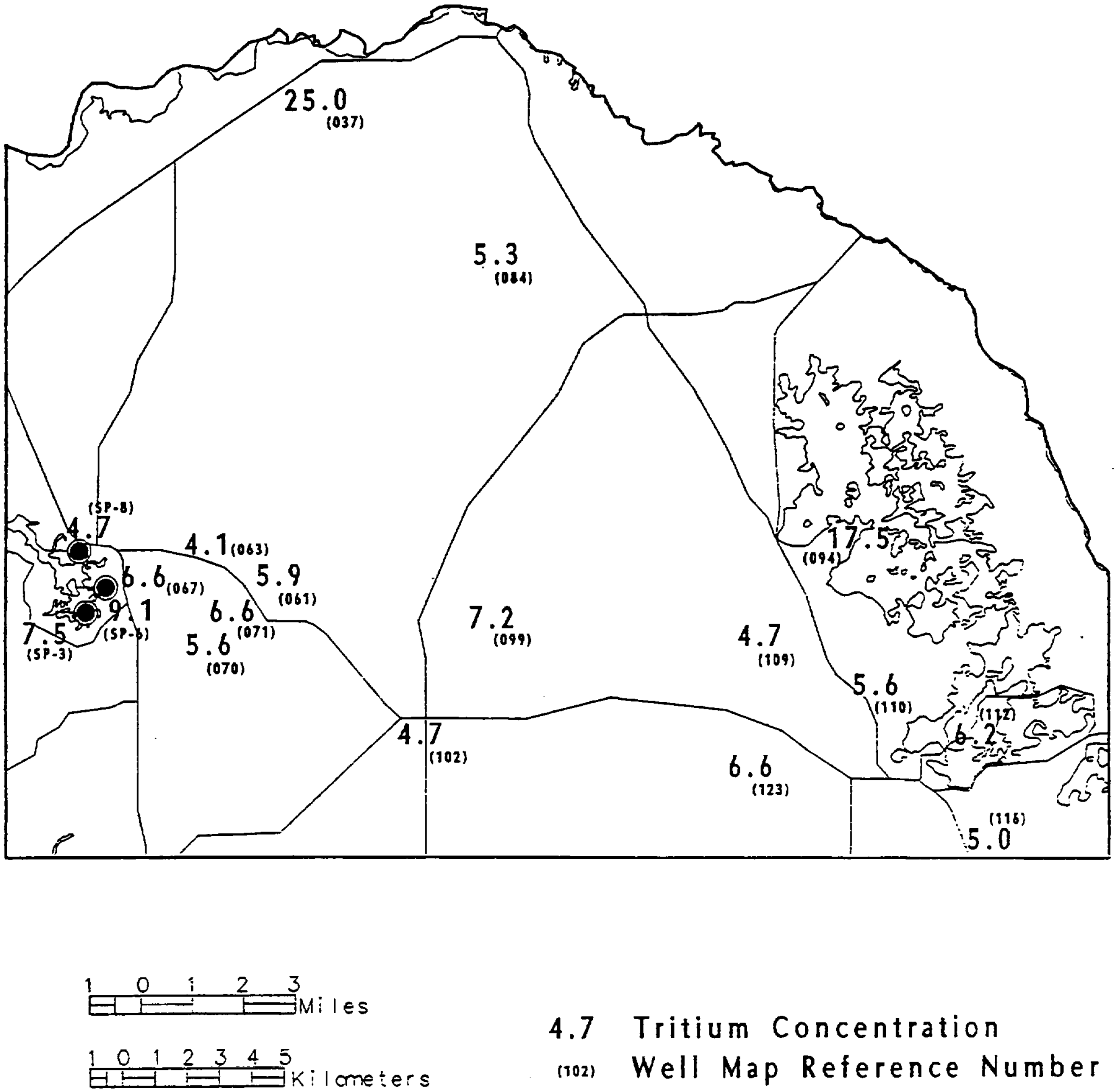


Figure 12. Tritium Activities (TU) in Study Area Ground Water.

system is characterized by low concentrations of uranium (less than 0.1 µg/l) associated with relatively high $^{234}U/^{238}U$ alpha activity ratios (appreciably greater than the equilibrium ratio of 1.0). The reasons for these characteristics are: (1) the solubility of U^{4+}, the ionic state prevalent in deep, chemically reducing waters, is quite low, and the mobilization of the decay product ^{234}U by recoil processes is favored by the intimate water/rock relationship in aquifers, and (2) the effect on the $^{234}U/^{238}U$ activity ratio is more apparent when the leaching component (involving both ^{238}U and ^{234}U) is low.

Rapidly recharging waters in a shallow, karst flow system, which is characteristic of the study area, tend to have a distinctly different character. These waters exhibit higher concentrations of uranium with much lower $^{234}U/^{238}U$ activity ratios (less than the equilibrium value of 1). This results from: (1) the oxidizing nature of the rapidly recharging water mobilizes uranium as a complex of the U^{6+} ion, (2) the resulting high leach component of uranium completely masks the recoil component of ^{234}U, and (3), if the leaching process has just begun on a time scale "short" relative to the half-life of ^{234}U (250 thousand years), then the uranium leached from host-rock surfaces is actually depleted in ^{234}U because of the previous process of recoil mobilization.

Twenty seven wells and 6 springs were sampled for uranium isotopes. The $^{234}U/^{238}U$ activity ratio and uranium concentration data are listed in Table 4. The map reference number relates the spring or well to its location on Figures 1 or 7. The distributions of uranium concentration and isotopic activity ratios are shown in Figure 13.

The approach taken to interpret the uranium data was to compare the activity ratios and concentrations from the spring-water samples with those of well-water samples in the recharge area. All 6 of the sampled springs have uranium activity ratios and concentrations that suggest rapid recharge and flow in a shallow karst aquifer. Wells with uranium concentrations and activity ratios similar to the spring-water samples are considered to be in the immediate recharge area of the springs. The ratios and concentrations depicted in Figure 13 indicate that only the extreme southern portion of the study area may not be a recharge area for the Springs.

Nitrogen Isotopes: Differentiation of Nitrate Sources

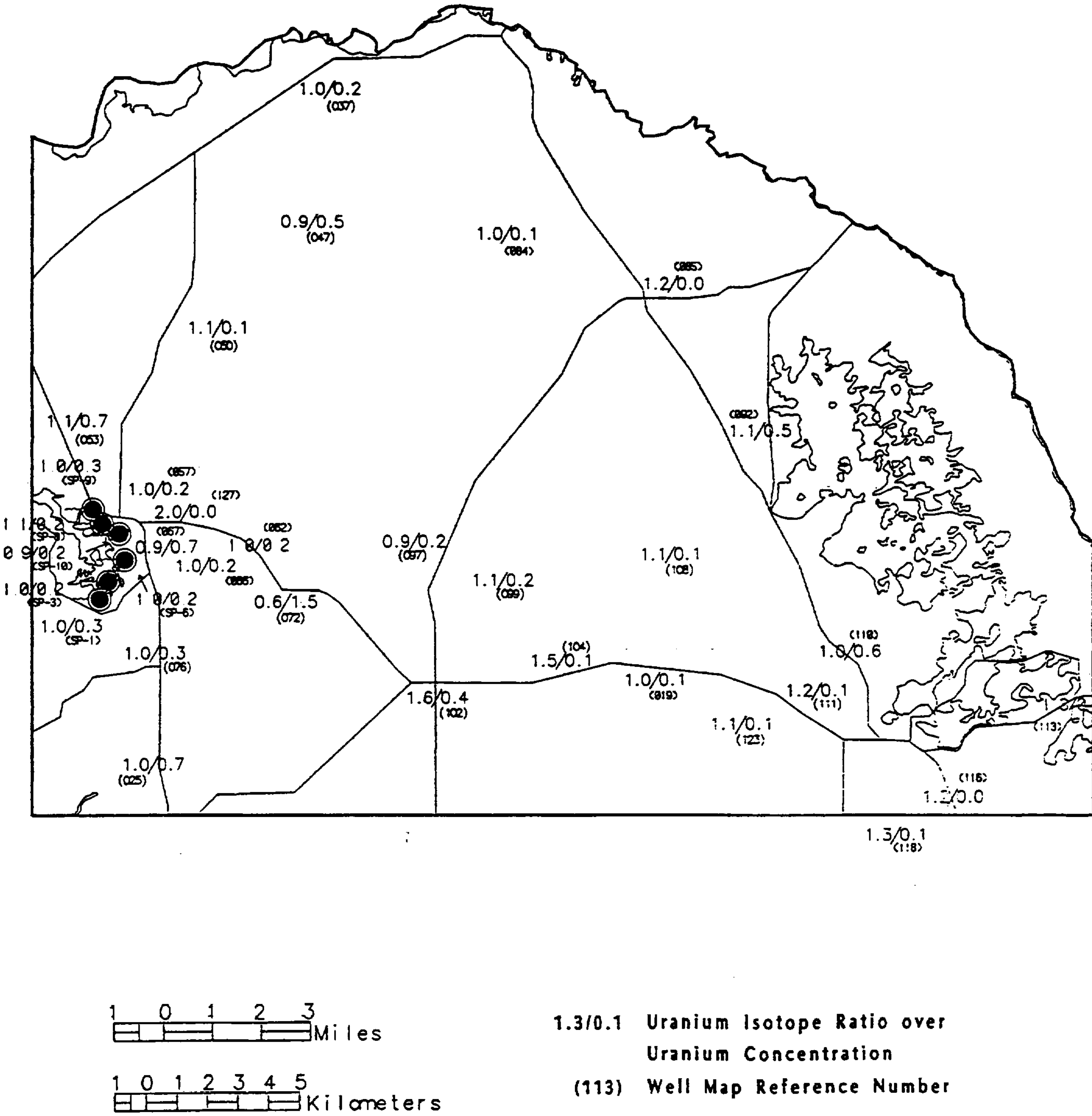
Although many proven sources of nitrate, including septic-tank effluent, treated sewage effluent, commercial and residential landscape fertilizers, land spreading of septage and sewage sludge, and agricultural fertilizers are present in the study area, it is extremely difficult to determine the relative contributions of these sources to the nitrate problem at the springs. The $\delta^{15}N$ ratio in ground-water nitrate can provide a direct indication of the importance of certain nitrate sources. It is especially useful for characterization of animal-waste sources as opposed to inorganic sources. Three

Table 4. Uranium Isotope Activity Ratios and Concentrations for Wells and Springs in the Study Area.

SITE NAME	MAP REFERENCE NUMBER	$^{234}U/^{238}U$ ACTIVITY RATIO	U CONCENTRATION (ug/l)
TARPON HOLE	009	1.0	0.2
BLACK SPRING	011	1.0	0.2
CATFISH SPRING	012	1.1	0.2
MILLER SPRING	013	1.0	0.3
HUNTERS SPRING	014	0.9	0.2
IDIOTS DELIGHT	017	1.0	0.2
BAPTIST CHURCH	025	1.0	0.7
KELLY	037	1.0	0.2
SWEEN	047	0.9	0.5
RUBIN	050	1.1	0.1
HERBERT	053	1.1	0.7
WOOD	057	1.0	0.2
EXLEY	062	1.0	0.2
CLEMENS	066	1.0	0.2
NEEDLEMAN	067	0.9	0.7
LADD	072	0.6	1.5
DYER	076	1.0	0.3
HUNT	084	1.0	0.1
KELLNER	085	1.2	0.0
KREMNITZ	092	1.1	0.5
TOLLE	097	0.9	0.2
LISOTTA	099	1.1	0.2

Table 4. Uranium Isotope Activity Ratios and Concentrations for Wells and Springs in the Study Area (continued).

SITE NAME	MAP REFERENCE NUMBER	$^{234}U/^{238}U$ ACTIVITY RATIO	U CONCENTRATION ug/l
TOWNSEND	102	1.6	0.4
KURTH	104	1.5	0.1
CALLUNDER	108	1.1	0.1
CASE	110	1.0	0.6
GOODWIN	111	1.2	0.1
BLACK	113	1.3	0.0
CUTRONE	116	1.2	0.0
MOTT	118	1.3	0.1
HOUSTON	123	1.1	0.1
ROMERO	127	2.0	0.0
ROMP 113	019	1.0	0.1



1.3/0.1 Uranium Isotope Ratio over Uranium Concentration

(113) Well Map Reference Number

Figure 13. Uranium Isotopic Activity Ratios and Concentrations (ug/l) in Study Area Ground Water.

$\delta^{15}N$ ranges have been defined for nitrate from different sources (Wolterink *et al.*, 1979). The $\delta^{15}N$ values for nitrate from unfertilized, cultivated fields (nitrate resulting from the oxidation of part of the organic nitrogen in the soil from crop plowing) range from $+2^{o}/_{oo}$ to $+8^{o}/_{oo}$. Nitrate from animal-waste nitrogen ranges from $+10^{o}/_{oo}$ to $+20^{o}/_{oo}$. Fertilizers composed of inorganic nitrogen (the type most likely to be used on row crops, citrus, and landscaping) have associated $\delta^{15}N$ ratios of -8 to $+6.2^{o}/_{oo}$, with 90% of the samples ranging from -3 to $2^{o}/_{oo}$ (Kreitler, 1975; Kreitler and Jones, 1975).

Ten wells in the study area and 4 springs were sampled for nitrogen isotopes. The results of the sampling are included in Table 5. The map reference number in Table 5 relates the $\delta^{15}N$ ratio data to the location of the well or spring the sample was obtained from in Figure 1 or 7. Figure 14 shows the spatial distribution of $\delta^{15}N$.

Table 5. $\delta^{15}N$ Ratios for Wells and Springs in the Study Area.

SITE NAME	MAP REFERENCE NUMBER	$\delta^{15}N$
Manatee Sanctuary	-	3.6
Tarpon Hole	-	0.7
Hunters Spring	-	5.2
Idiots Delight	-	3.4
Hunt	084	3.1
Lyons	080	5.0
Romp 113	019	2.6
Lisotta	099	2.8
Clemens	066	3.5
Case	110	5.8
Rhame	109	5.5

The $\delta^{15}N$ ratios for the springs range from 0.7 to 5.2 $^{o}/_{oo}$ (Table 5). The wells have $\delta^{15}N$ values that range from 2.6 to 8.8 $^{o}/_{oo}$. Most of the $\delta^{15}N$ ratios are within the inorganic nitrogen fertilizer range and all but the 8.8 value are within the natural decay in unfertilized soils range. Because the original nitrate concentrations were low it is very difficult to determine the actual source of the nitrogen. This is because the lower the nitrate concentration, (1) the more likely the source could be naturally occurring organic decay and (2) the more difficult it is to isolate the nitrogen isotopes. However, as low as the concentrations are, they are still elevated above background levels. Additionally, the concentrations for the most part are not isolated but occur in well-

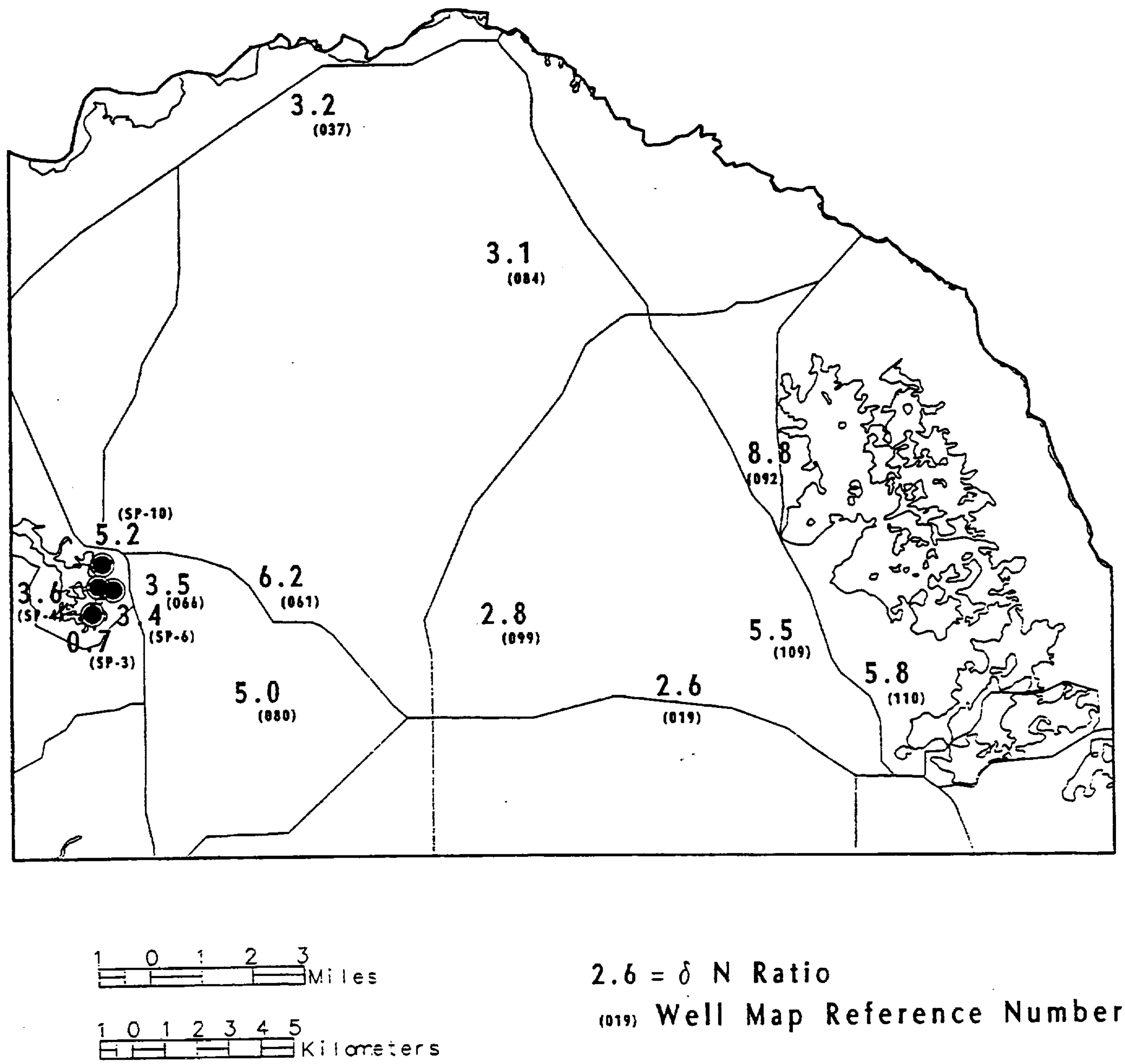


Figure 14. $\delta^{15}N$ Isotopic Ratios in Study Area Ground Water.

defined bands in various parts of the study area indicating that nitrogen loading is occurring in specific areas.

Overall, the low nitrate concentrations and the difficulty in sorting out overlapping sources (i.e. lawn, pasture, golf course, agricultural and septic tank and sewage effluent human waste sources) makes it very difficult to draw meaningful conclusions from the nitrogen isotope data.

Total Dissolved Solids Concentrations

The distribution of total dissolved solids (TDS) in the study area is shown in Figures 15a and b. The data reflect concentrations of calcium, magnesium, sodium, sulfate and chloride in the ground water (Appendix I). The TDS content of ground water reflects four processes: (1) residence time in the aquifer, (2) chemical reactivity of the aquifer rock with the water, (3) mixing with sea water, and (4) human influences (contamination). Limestones and dolostones are relatively reactive, so residence time is the dominant natural process that produces high TDS concentrations inland. Near the coast, mixing with sea water, which contains 33,000 to 35,000 mg/l TDS, produces high TDS concentrations.

As Figure 15a shows, TDS concentrations occur in three north-south domains: (1) moderately high TDS concentrations under Lake Tsala Apopka and the eastern portion of the Brooksville Ridge, (2) low concentrations in central Citrus County, and (3) high TDS at the fresh-water/sea-water transition zone (hereafter termed the transition zone), near the coast. These three domains are represented in the distributions of many of the analytes discussed below. The domains will henceforth be referred to as (1) the ridge domain, (2) the central domain, and (3) the coastal domain.

The coastal domain is easily explained by salt-water mixing. There is a bimodal concentration gradient indicated, with a steep segment nearest the coast, and a shallower gradient near the City of Crystal River. The low TDS zone in the center of the county reflects recently recharged waters that are shallow and have not reacted with the limestone and dolostone of the Floridan aquifer. The ridge domain apparently reflects leakage of surface water into the Floridan. This pattern is repeated in other analytes and strongly suggests a local flow system, with recharge near Tsala Apopka, underflow of the Tsala Apopka water in central Citrus County, and upwelling along the inner margin of the transition zone. The central zone waters that were sampled lie above the Tsala Apopka and regional flow-system waters.

Near the springs (Figure 15b) the two gradients on the transition zone are apparent and there are several TDS highs located within the City of Crystal River. These highs most likely reflect slightly deeper wells that sample higher TDS waters on the inner transition zone at depth.

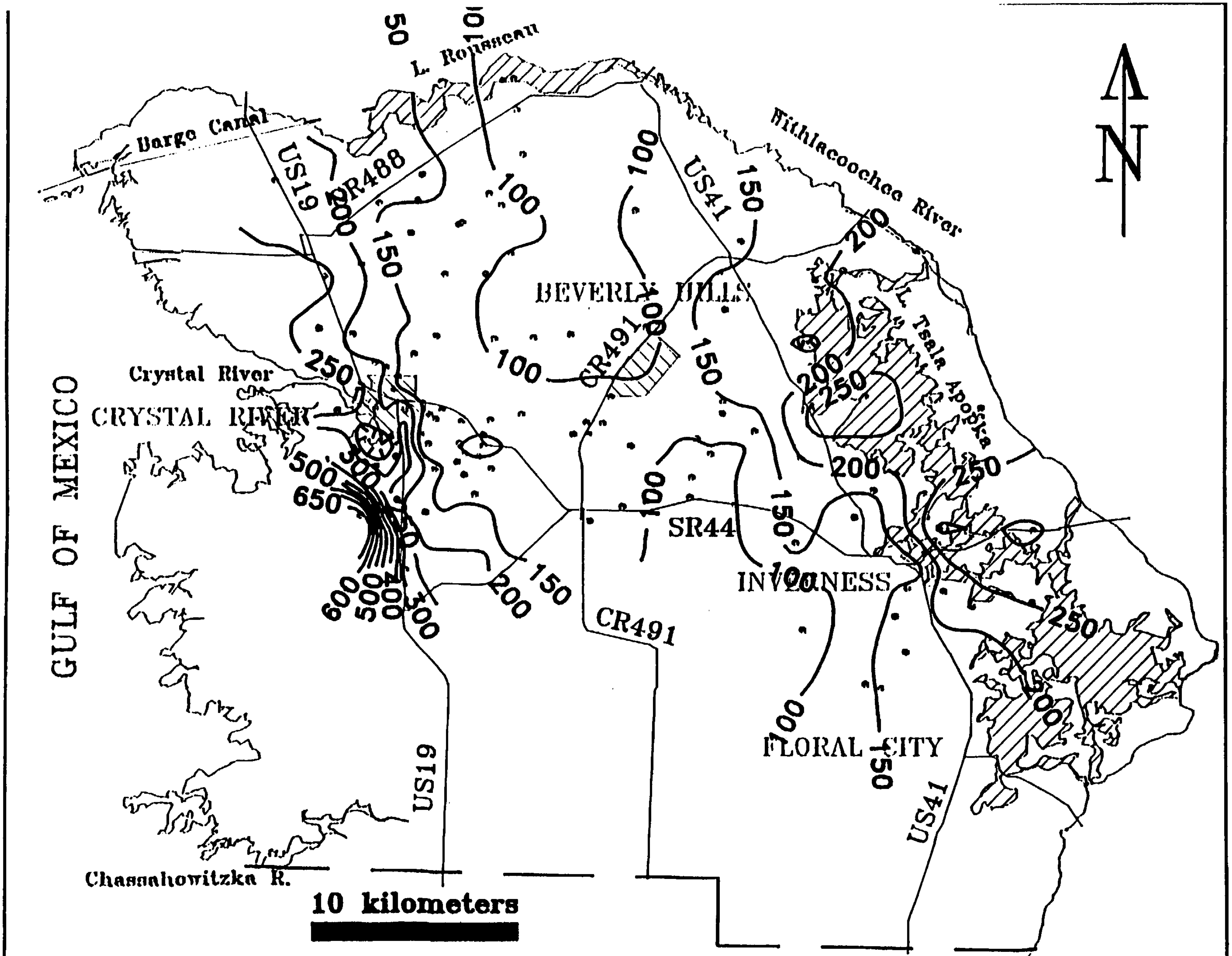


Figure 15a. TDS Concentrations in Study Area Ground Water.

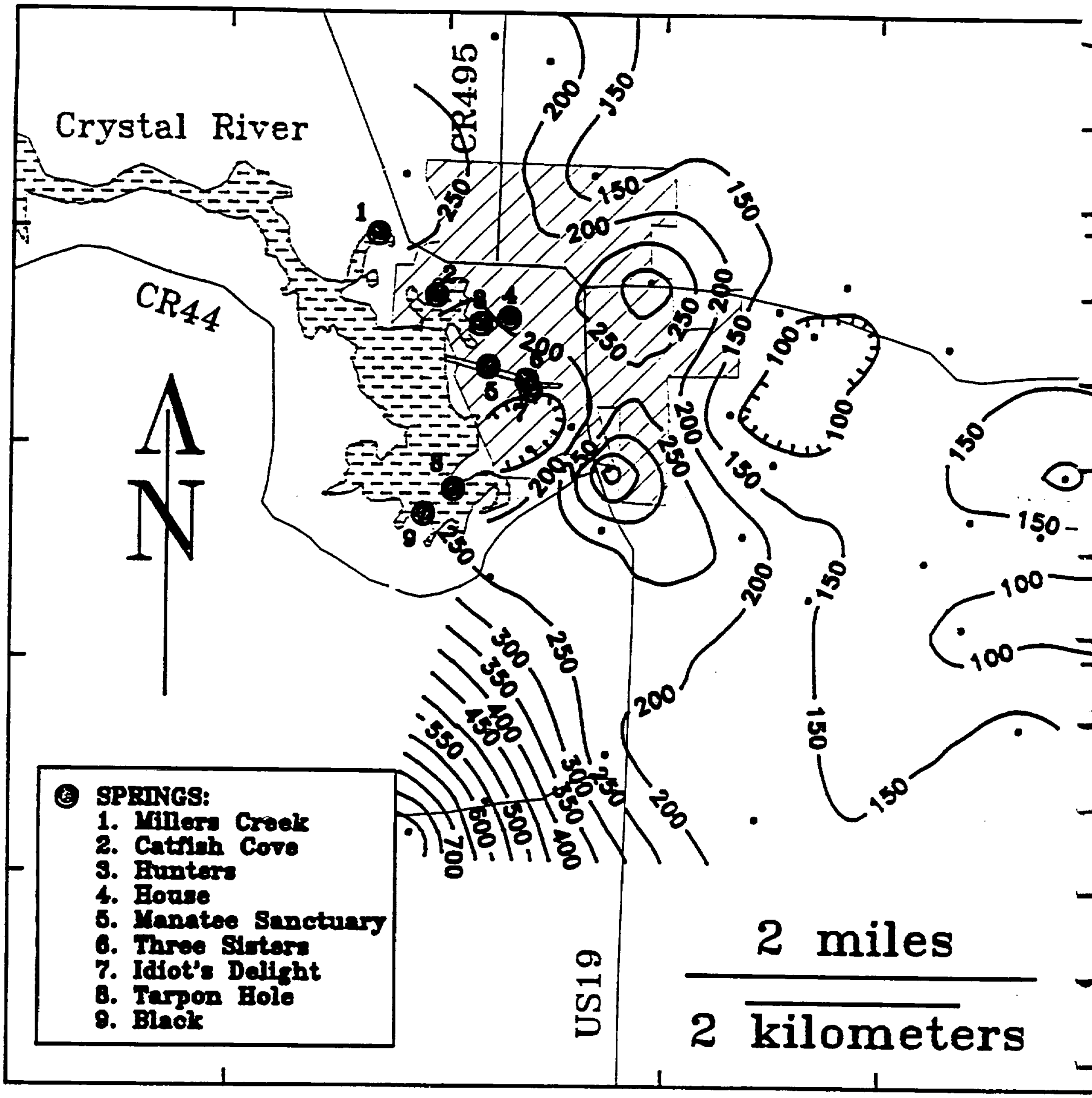


Figure 15b. TDS Concentrations in the Vicinity of the City of Crystal River.

Chloride

Chloride is a chemically conservative[3] element, so it is usually used as a tracer of physical water flow. Figure 16 a and b shows the distribution of chloride in the study area.

Rainfall typically contains less than 10 mg/l chloride (Upchurch, 1992). Thus, most of the area has chloride concentrations similar to rainfall, which suggests shallow, young water. The three domains shown in TDS (Figure 15) are represented in chloride data. The ridge domain has several highs that suggest slightly deeper wells or water that has been concentrated through evapotranspiration. The central domain reflects recently recharged waters that are shallow and have not been in contact with the transition zone. Finally, water in the coastal zone is strongly affected by sea-water mixing. Chloride concentrations in the springs indicate that at low tide the sea-water transition zone may be located along the eastern shore of King's Bay. Since the King's Bay Springs were always sampled at low tide for this project, it is impossible to determine whether the transition zone would migrate inland at high tide. However, Yobbi (1992) has determined that chloride levels in coastal springs can change dramatically over a period of several hours in response to tidal fluctuations. Therefore, it is possible that the transition zone could move well inland at high tide.

There is a small high in chloride represented in two wells in the southern portion of the City of Crystal River (Figure 16b). This is either reflective of slightly deeper wells or a small upconing due to pumpage in the area.

Sulfate

Sulfate (SO_4^{2-}) is formed by oxidation of pyrite (FeS_2), a common mineral in marine sediments; oxidation of organics; and dissolution of gypsum ($CaSO_4.2H_2O$) or anhydrite ($CaSO_4$). See Upchurch (1992) for samples of these reactions. Pyrite is widespread in Florida rocks, and it is especially abundant in the clays of the Hawthorn Group. Oxidation of organics is also universally important. There is minimal gypsum and/or anhydrite in near-surface sediments, but the base of the upper Floridan is characterized by these minerals. Sulfate is also abundant in sea water. Therefore, with the exception of the transition zone, shallow flow-system waters typically contain minor concentrations of sulfate. Deep-flow systems that come in contact with the base of the aquifer may contain significant sulfate, especially near the inner margin of the transition zone (Upchurch, 1992). Therefore, the distribution and concentrations of sulfate can be used to deduce the depth and extent of flow systems and interactions of ground water and host sediments.

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[3] A conservative constituent is one that does not react with rock, water, or organic components of the aquifer system. Conservative constituents are changed in concentration only by dilution or by evaporation or transpiration. Chloride is the most common conservative constituent in water.

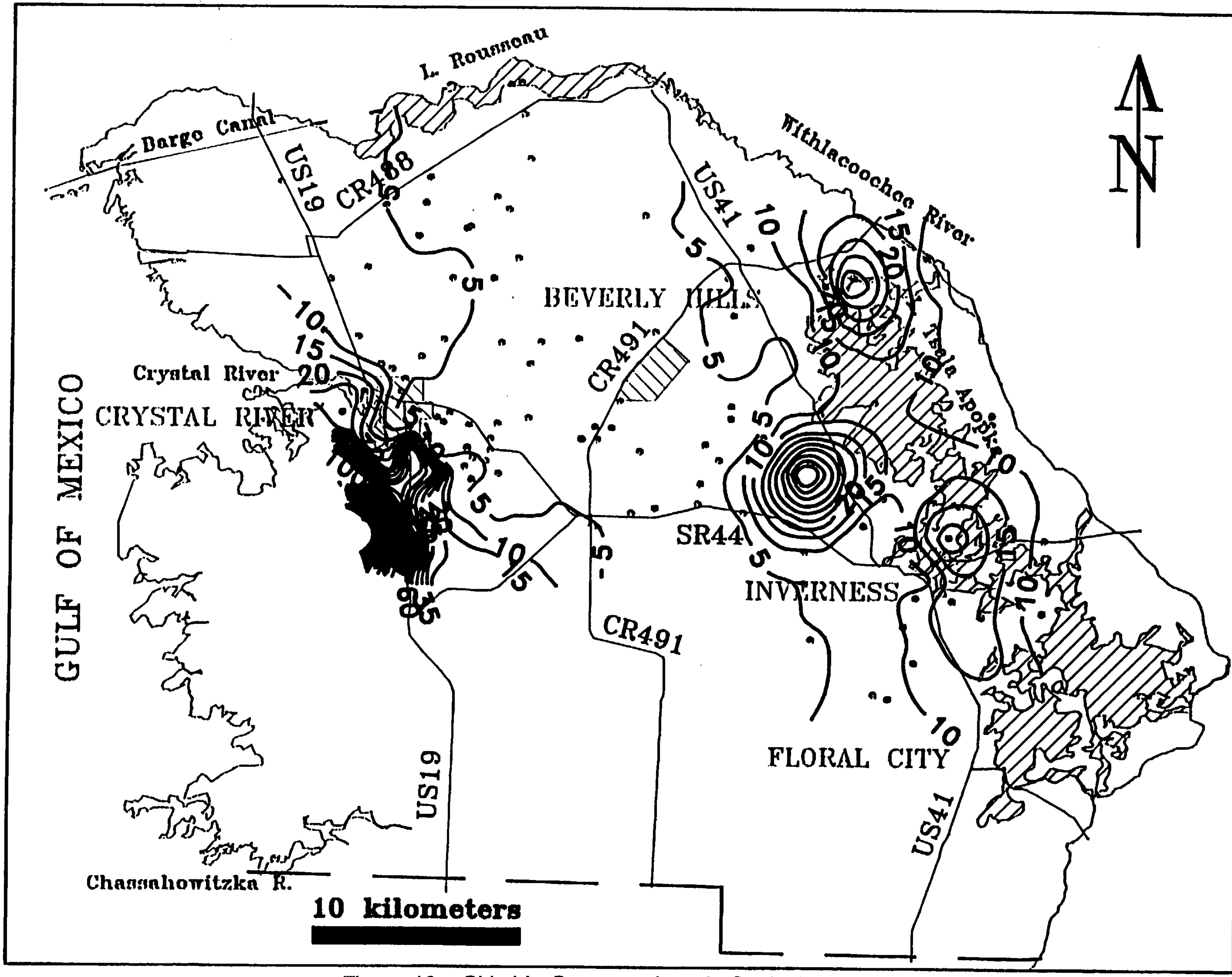

Figure 16a. Chloride Concentrations in Study Area Ground Water.

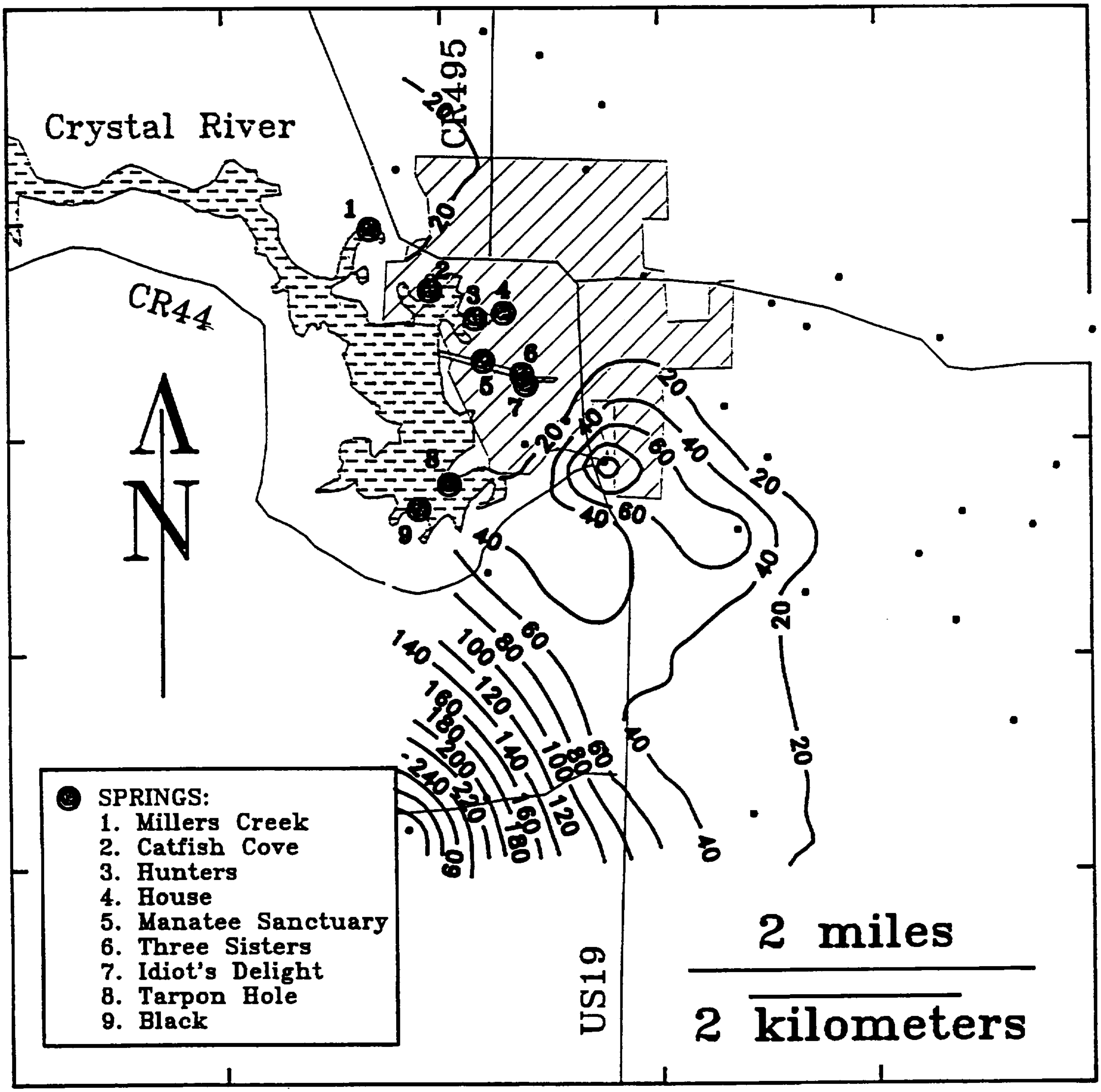

Figure 16b. Chloride Concentrations in the Vicinity of the City of Crystal River.

Figure 17a and b show the distribution of sulfate in ground waters of the study area. High sulfate concentrations near Lake Tsala Apopka in the ridge domain are apparently a result of recharge of organic-rich surface water. Sulfate concentrations are low in the central domain, and there is a complex pattern near the coast (Figure 17b). The pattern in the coastal domain suggests two components. The inner margin of the transition zone is characterized by concentrations that gradually increase from 3 to 15 mg/l. This pattern is not uniform, and there is a corridor of low sulfate concentrations oriented east-west in the vicinity of the springs. This appears to represent a local flow system, perhaps recharged in the ridge and central domains, that does not contact the base of the aquifer. Seaward of the springs (Figure 17a) sulfate increases rapidly, which reflects mixing with sea water and possible upwelling of deeper flow-system water. This part of the transition zone is west of the springs and, since the western coastal domain was not considered to be a significant source for the springs and few wells were available for sampling, was not sampled to show the extent of the belt of high sulfate water.

Hydrochemical Facies

Hydrochemical facies analysis (Upchurch, 1992) is an excellent way to place a series of water-quality analyses into a spatial context. The analysis depends on pattern recognition techniques. Individual samples are plotted on Stiff (1951) diagrams, which show the relative proportions, in milliequivalents per liter, of major ions in a sample. The size of the Stiff diagram is proportional to the total dissolved solids content of the sample, and the shape conveys a rapid impression of the water type, or dominant ions in the sample. All samples are then plotted on a Piper diagram (Piper, 1944), which relates the changes in proportions, but not concentrations, between samples.

Data from Citrus County were selected to illustrate a cross section from Lake Tsala Apopka to the King's Bay Springs (Figure 18). Samples from all of the wells shown in Figure 18 are represented in the Piper diagram (Figure 19), and Stiff diagrams are shown for selected samples (samples 95, 108, 106, 97, 127, and 129).

Examination of the Stiff diagrams (Figure 19) shows an important pattern. Note that, with the exception of the sample from well 106, all samples represent calcium-bicarbonate water. The total dissolved solids content (as indicated by the size of the Stiff figure) is high under the lake and near the coast. Total dissolved solids content is less in the center of the study area. Note also, that there is a modest increase in magnesium and sulfate near the coast, which represents upward flow of deep Floridan water. Sample 106 is anomalous in comparison to the other samples. Sample 106 represents a sodium-bicarbonate water mass. This type of water is typically present in areas where the Hawthorn clays are thick and where ion exchange of calcium and magnesium for sodium on the clays has caused desorption of sodium. Samples from the region enclosed by SR 44, US 41, and CR 491 indicate that this is a typical water

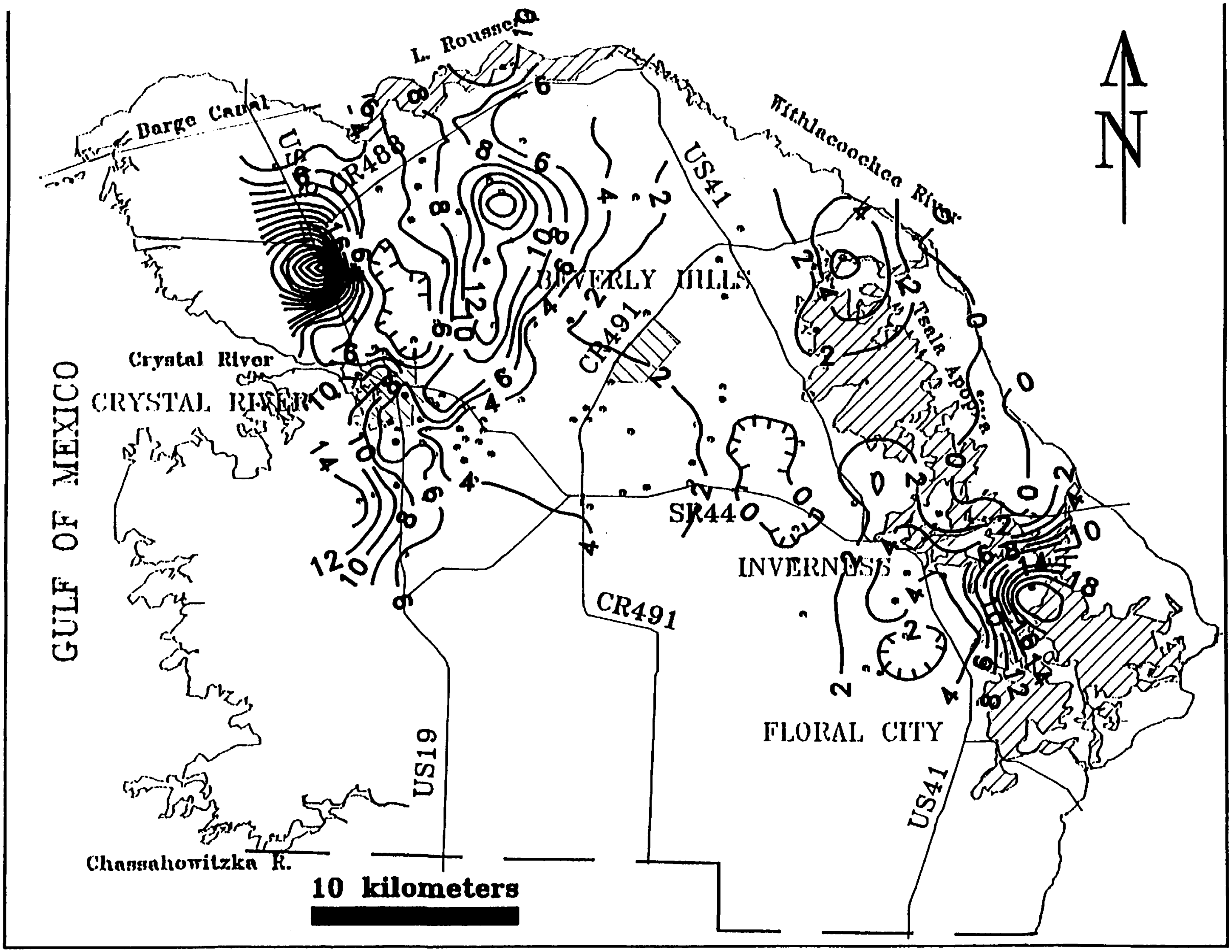

Figure 17a. Sulfate Concentration in Study Area Ground Water.

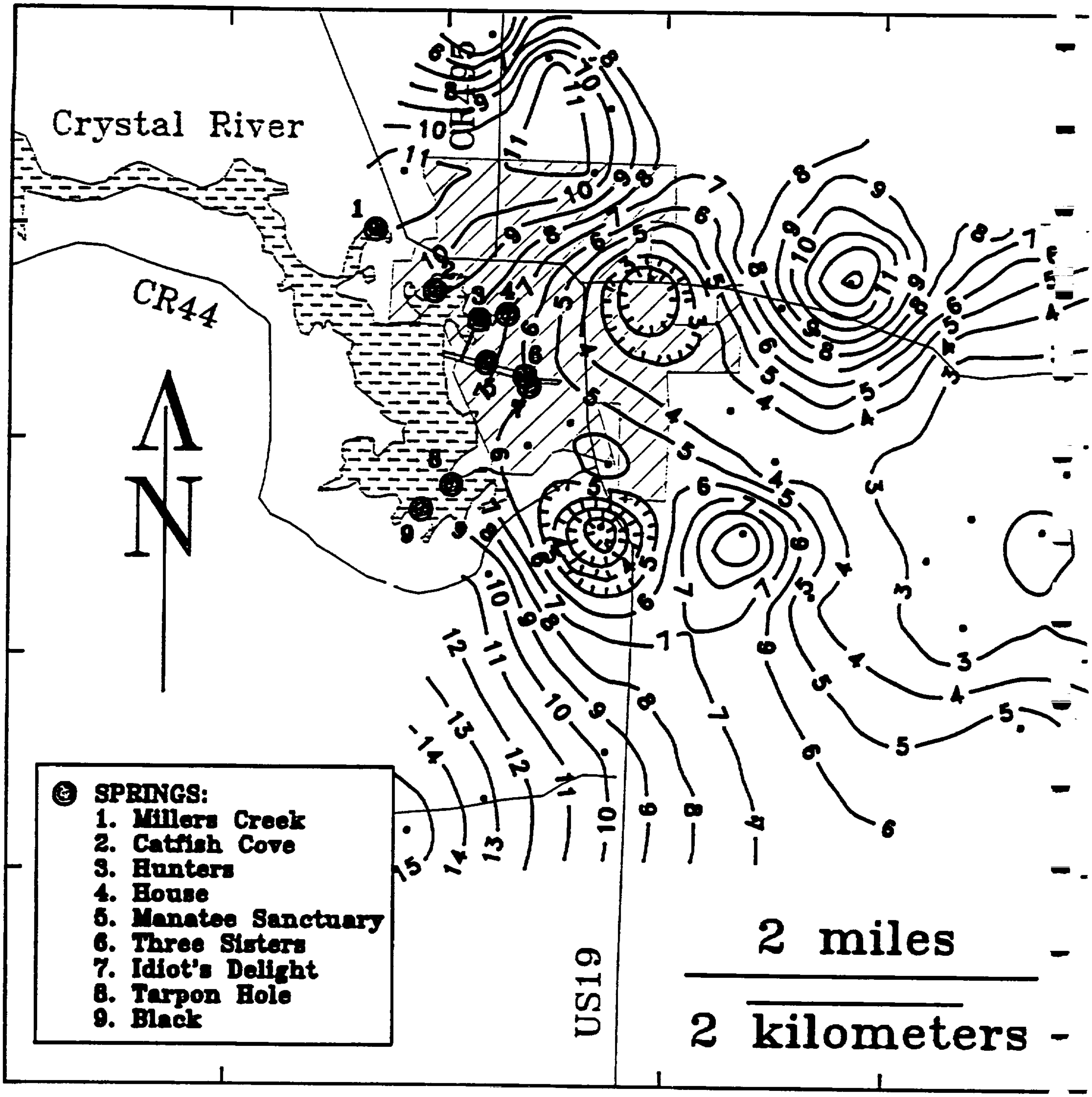

Figure 17b. Sulfate Concentrations in Ground Water in the Vicinity of the City of Crystal River.

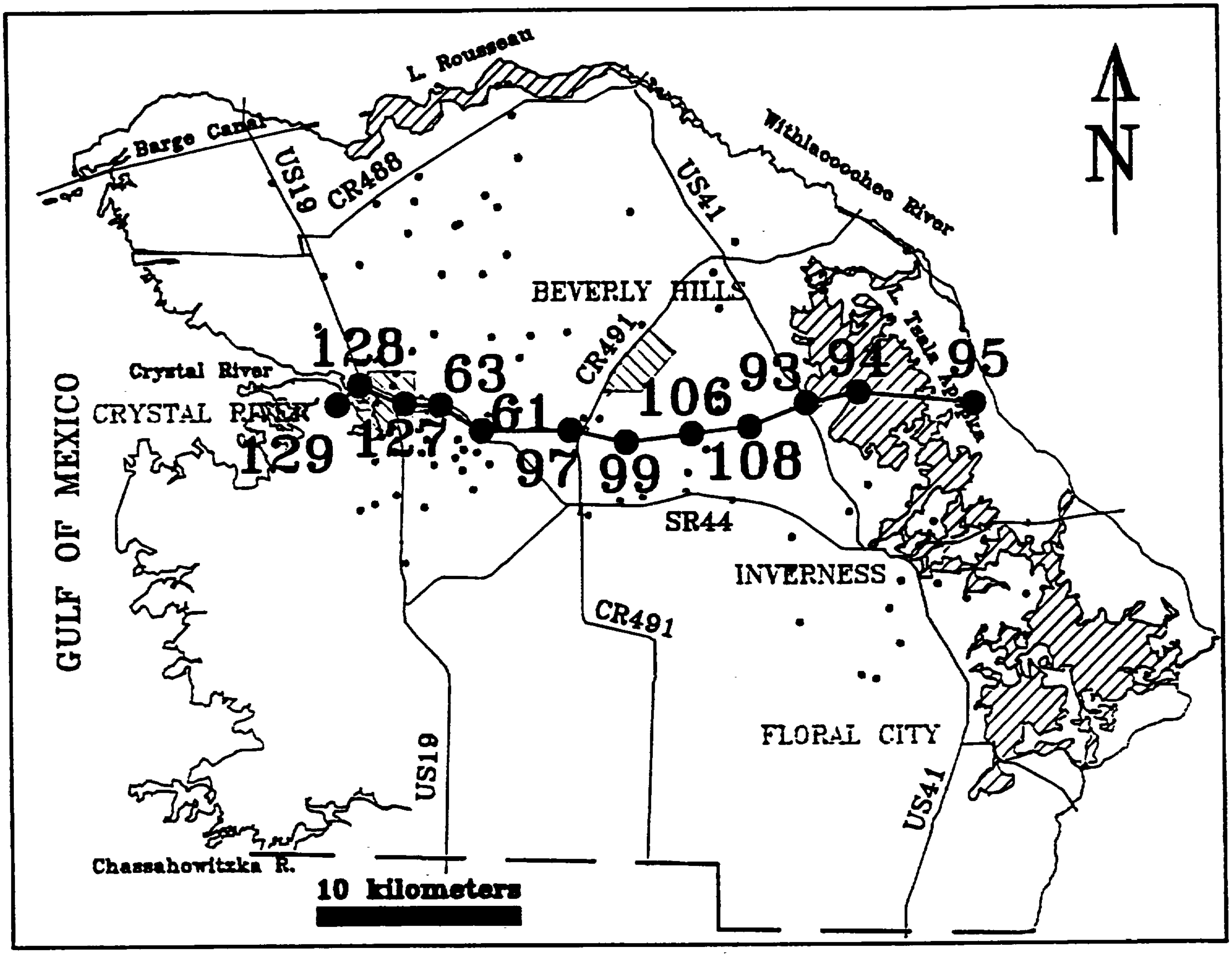

Figure 18. Location of East-West Ground-Water Quality Cross Section through the Study Area. The Water-Quality Analyses from wells in the Cross Section are Depicted in Figure 19 Using Stiff and Piper Diagrams.

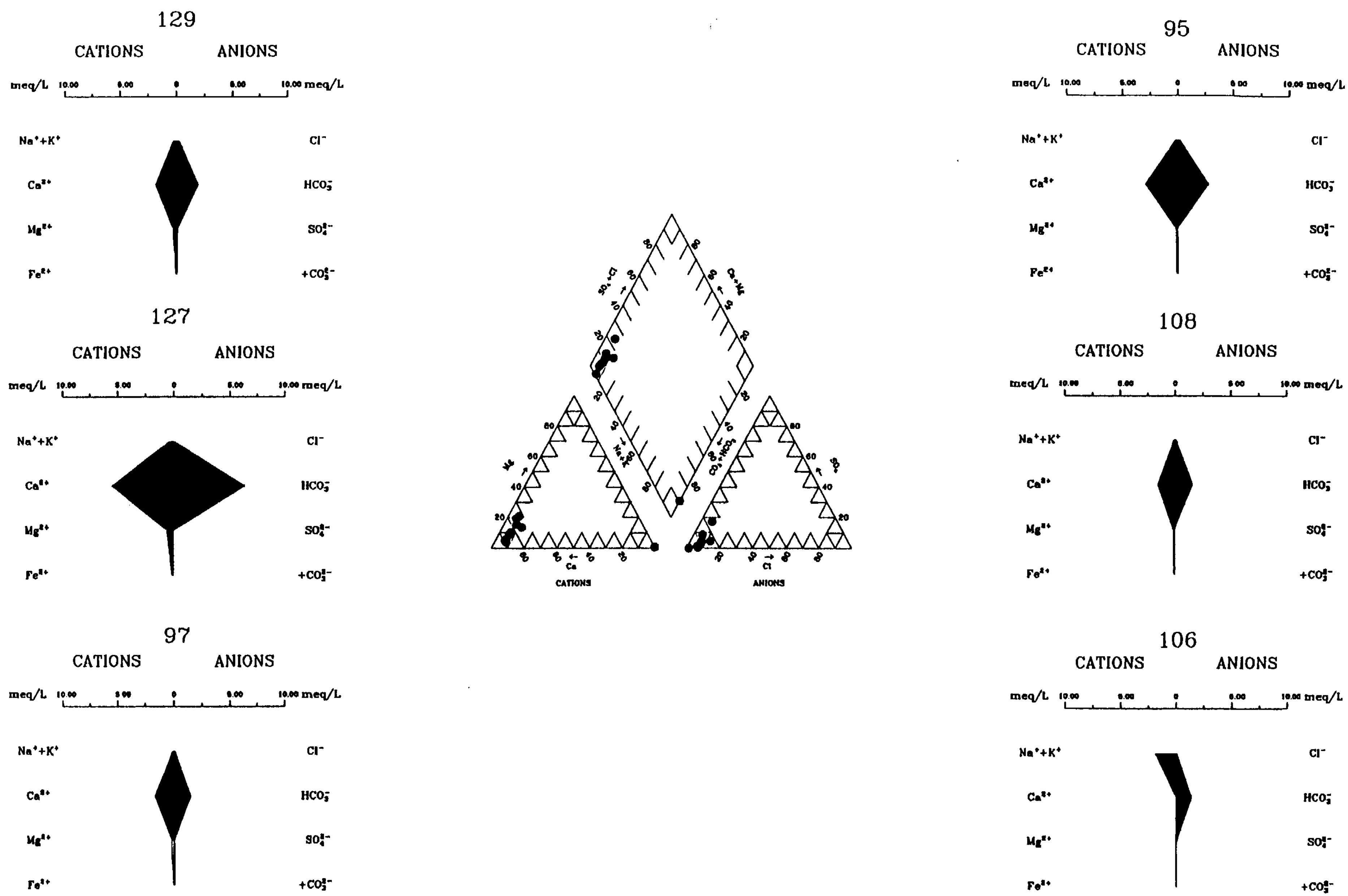

Figure 19. Characterization of Study Area Waters Using Piper and Stiff Diagrams

type in the area and that the water has changed in composition as a result of bathing the Hawthorn clays with a calcium-rich water (Floridan aquifer irrigation water).

The Stiff diagrams suggest that the waters in the center of the study area, including sample 106, are locally recharged, and reflect a local flow system. The water near the lake and the coast is a sub-regional flow system that passes under the local system in the center of the study area.

The Piper diagram (Figure 19) is less useful in this case. There is a minor trend from a calcium-bicarbonate water in the left apex of the central, diamond-shaped graph toward the upper right, which represents a slightly more magnesium- and sulfate-rich solution. This minor increase in sulfate and magnesium is a result of the upward-flowing water along the coast. Sample 106 plots near the lower apex of the diamond and represents a sodium-bicarbonate water.

Sodium to Chloride Ratios

Upchurch (1993) has shown that the mole ratio of sodium to chloride can be utilized as an indicator of ground-water sources. Sea water has a sodium to chloride mole ratio of approximately 0.8. Rainfall in Florida contains marine aerosols, so rain water is a dilute sodium-chloride solution, typically with a mole ratio of 0.8. Evaporation on the land surface and in the surficial aquifer does not change this ratio. As this water percolates through the clays of the Hawthorn Group, however, ion exchange occurs and the ratio changes. If sodium is released, the ratio increases. If sodium is exchanged for calcium, the ratio decreases. Human sources of sodium and chloride can also change the ratio.

Mapping of the sodium to chloride mole ratio (Figure 20a and b) is particularly informative as to sources of water in the springs and causes of the high ratios in some wells. Most of the study area waters have ratios near sea water and marine aerosols. There is a very high ratio area centered between SR44, CR491, and US41, however. This is on the Brooksville Ridge in an area characterized by suburban development and several golf courses (Figure 3). This region of sodium to chloride mole ratio greater than 1 coincides with thick Hawthorn Group sediments, including clays. The elevated sodium is apparently a result of ion exchange as a result of bathing of sodium-saturated clays with calcium-rich Floridan aquifer water through irrigation. In this reaction, calcium or magnesium originally present in the ground water substitutes for sodium sorbed onto the smectitic clays of the Hawthorn according to the reaction

$$\left.\begin{matrix}Na\\Na\end{matrix}\right\rangle clay + Ca^{2+}_{aq.} \rightleftharpoons Ca\text{-}clay + 2Na^{+}_{aq.}.$$

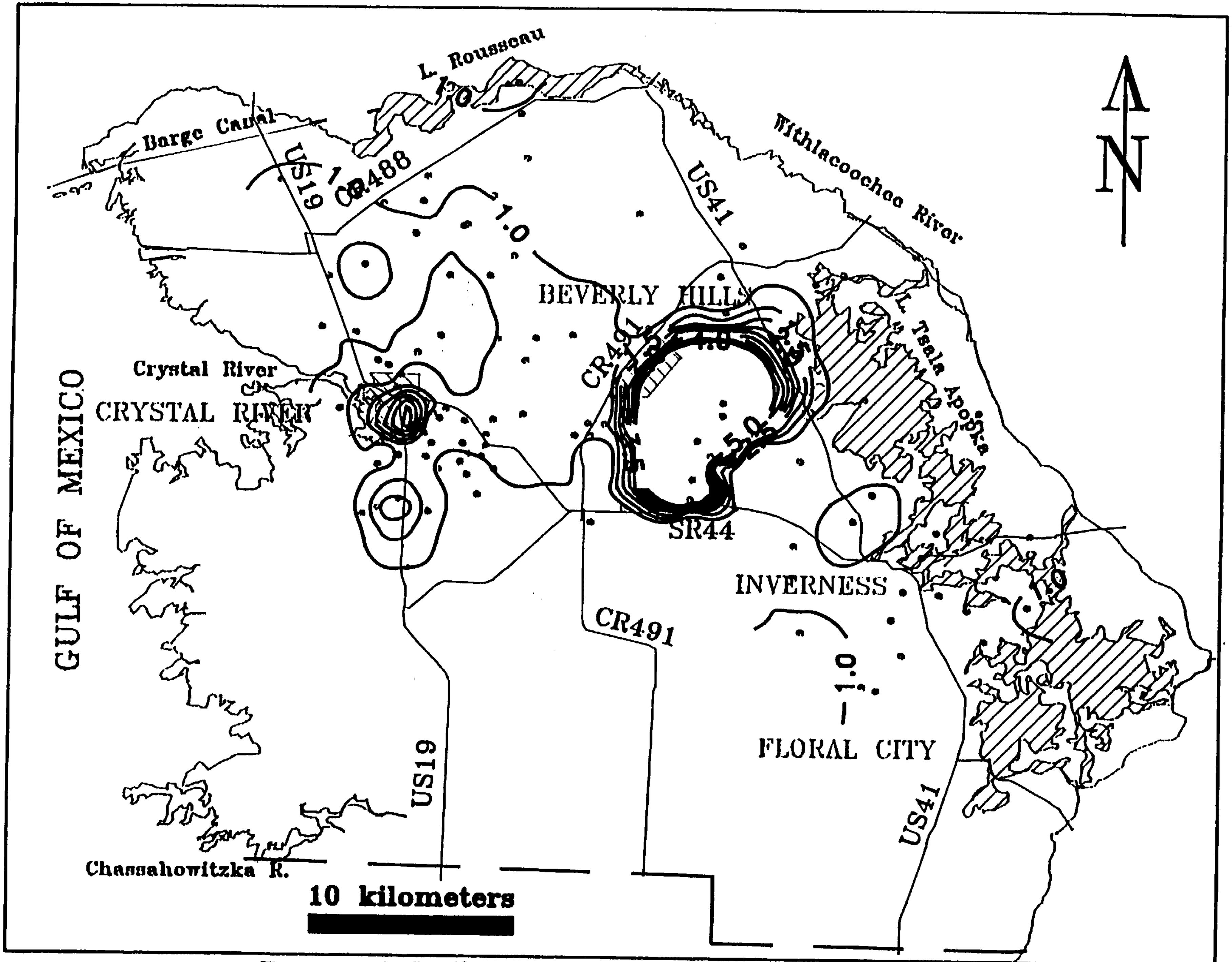

Figure 20a Sodium/Chloride Mole Ratio of Study Area Ground Water.

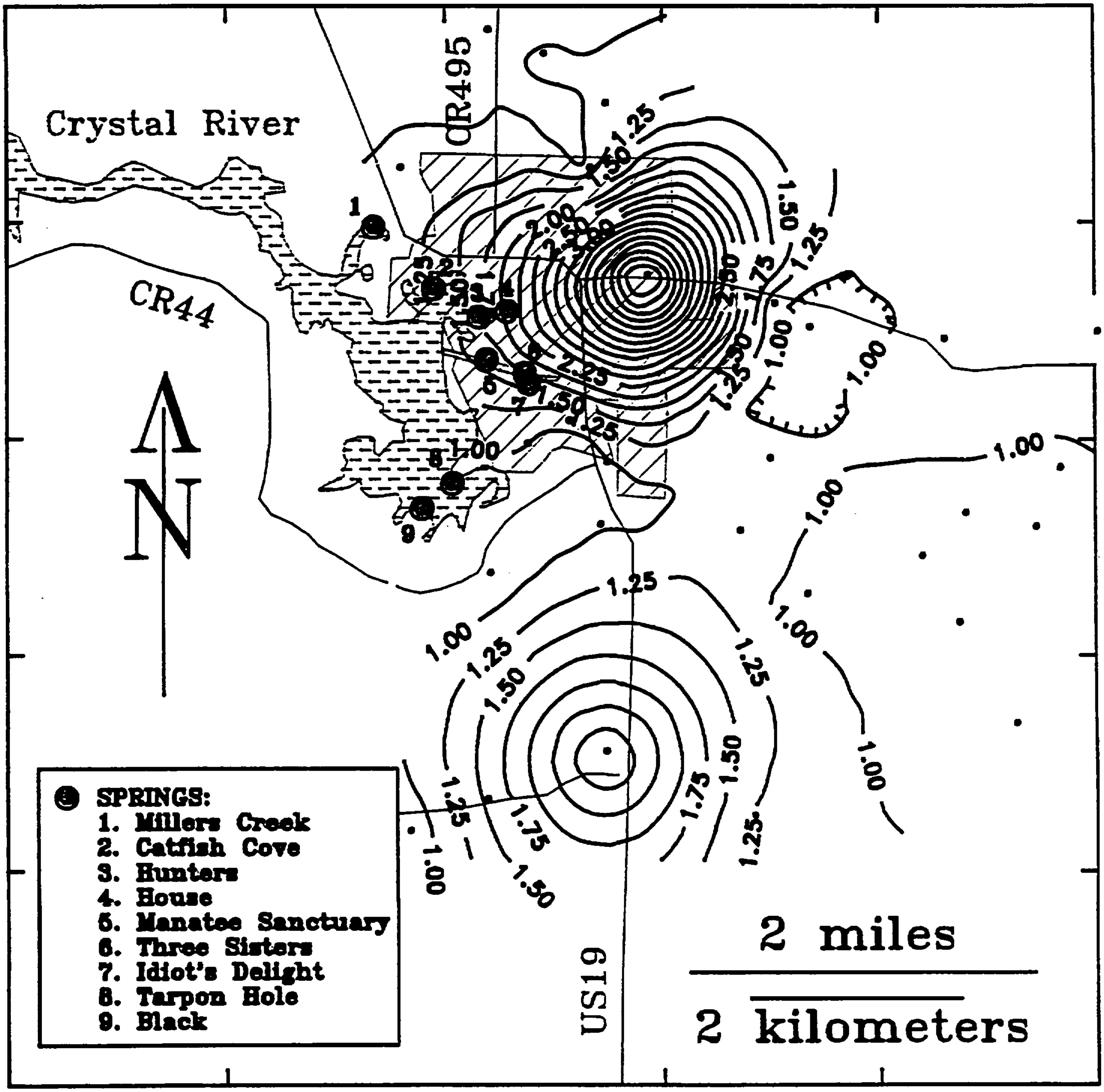

Figure 20b Sodium/Chloride Mole Ratio of Ground Water in the Vicinity of the City of Crystal River.

There are other high-ratio areas near the City of Crystal River (Figure 18b), but they are supported by only one sample each. An erroneous sodium or chloride analysis could, therefore, cause these patterns to occur. There is minimal clay in the area, so ion exchange is not expected to be a major process.

There are two "ridges" of water with ratios in excess of one in the central and coastal domains. One ridge extends northwest-southeast and connects the high ratio waters in the ridge domain with a modest high in the northwestern corner of the coastal domain. The other extends from the high in the ridge domain to the west, toward the King's Bay Springs. These ridges are present in other data and suggest flow paths, especially the east-west ridge that is oriented with the springs.

NITROGEN GEOCHEMISTRY

To understand the loading of nitrogen compounds to ground water, their transformations and movements through the ground-water system, and their ultimate discharge at the King's Bay springs, it is first necessary to discuss a few basic principals of nitrogen aqueous geochemistry. These principals are discussed in the following section, which contains excerpts from Upchurch (1992) and Bicki and Brown (1984).

Nitrate (NO_3^-), which is one of the nitrogen species that has been targeted as a source of nitrogen in the King's Bay system, is one member of a sequence of related nitrogen compounds that also includes nitrogen gas (N_2), nitrogen dioxide gas (NO_2) and other oxides (collectively, NO_X), ammonia and ammonium (NH_3, NH_4^+), nitrite (NO_2^-), a number of other inorganic compounds, and many organics. The gaseous phases exist in the atmosphere and in soil atmospheres, but are not of importance in the saturated zones of aquifers. Ammonia gas (NH_3), for example, is likely to escape into the atmosphere. Ammonia is usually present in ground water as the ammonium ion (NH_4^+) because of prevalent Ph and reduction-oxidation potentials. The complex, organic compounds can occur as soluble organic molecules and as particulates. Concentrations of ammonium and dissolved, organic-nitrogen compounds, including amino acids and proteins, are reported as Total Kjeldahl Nitrogen (TKN) in samples from aqueous systems and soils. Organic nitrogen is determined by subtracting ammonium/ammonia concentrations from TKN concentrations.

Organic nitrogen, ammonium, nitrite, and nitrate are the compounds considered important in ground-water systems. These compounds are related through a sequence of microbially mediated, reduction and oxidation reactions as indicated below

$$\begin{array}{c} \textit{Organic Nitrogen} \rightarrow NH_4^+ \rightarrow NO_2^- \rightarrow NO_3^- . \\ \text{---}\textit{Oxidation}\text{--}\rightarrow \\ \leftarrow\text{--}\textit{Reduction}\text{---} \end{array} \qquad (3)$$

The reduction/oxidation reactions indicated in the above reaction series can be driven by inorganic processes, but the primary mechanisms for the reactions are microbial. If the environment is chemically oxidizing, nitrate will be the final product. In these aerobic environments (>0.3 ppm dissolved O_2) chemically reduced nitrogen is almost immediately oxidized to nitrite and then to nitrate. These oxidation reactions are known as nitrification reactions. In a reducing environment, the organic nitrogen and/or ammonium will persist. Partially oxidizing conditions may also exist in which the nitrogen compounds only progress part way through the sequence. Where dissolved oxygen concentrations are low, nitrate and nitrite are reduced to nitrogen gas by denitrification bacteria. It is the energy yield of these reduction-oxidation reactions which controls nitrogen behavior and hence its state and concentration in a given aquifer or water body.

The largest reservoir of nitrogen is the atmosphere, which is 78.93 percent nitrogen, mostly as N_2 gas. NH_3 and NO_3^- occur naturally in the atmosphere as a result of releases by terrestrial plants (Stallard and Edmond, 1981). Atmospheric nitrogen is also converted to NO_X by lightning. Modern precipitation contains nitrogen-oxide concentrations that are increased over natural levels as a result of combustion of fossil and modern organic fuels. The oxides of nitrogen are then converted by oxidation and hydrolysis reactions to nitric acid (HNO_3), which dissociates to H^+ and NO_3^-. Consequently, precipitation is a source of nitrate and ammonium, derived from both natural and anthropogenic causes. Nitrate in precipitation in Florida ranges from 0.00 to 10.32 mg/l, and the statewide mean in precipitation is 0.97 mg/l (Upchurch, 1992). Ammonium ion ranges from 0.00 to 17.12 mg/l (Upchurch, 1992) and the mean is 0.17 mg/l.

Clearly, conversion of nitrogen compounds in the atmosphere followed by precipitation introduces nitrogen to the ground-water system. Modern rainfall, however, cannot be used as an argument for high nitrogen in the study area. This is because of the long time intervals involved in ground-water flow and because of the uptake of nitrogen by plants. Travel times calculated as part of this study and by others show that most of the ground water in the area was recharged prior to the onset of "air pollution". Also, the low nitrogen-species concentrations and sporadic loading through rainfall events supplies nitrogen to the plant cover, and there is apparently little excess nitrogen to pass into the ground-water system. Direct recharge of storm runoff through sinkholes, drainage wells, or other sources may introduce some of this nitrogen to the aquifer systems.

Certain microbes can fix nitrogen gas in soils. These microbes, in conjunction with plants such as the legumes, directly convert nitrogen compounds into tissues and nitrogenous by-products. Plants require nitrate as a major nutrient, and they are responsible for removal of much of the nitrate that is taken from soils and ground water. Average nitrogen content of living organisms is 16 percent. These living tissues contain amino acids and other nitrogen compounds that can be released back into the environment upon death or waste elimination.

Animal wastes and decaying plant tissues release ammonia and ammonium, nitrite, nitrate, urea[4], and a number of nitrogenous organic molecules. Soil and

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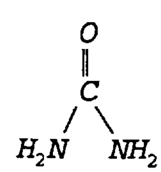
[4] Urea is a principal nitrogen product in urine. It has the formula 

. Urea is a by-product of the liver.

aquifer microbes metabolize these according to the reduction-oxidation potential of the soils and aquifers. Under reducing conditions, microbes convert these compounds to ammonium, and other reduced-nitrogen species. Under oxidizing conditions, they are converted to nitrate, usually with an intermediate nitrite step.

Therefore, in reducing environments, such as water-saturated, reducing soils and aquifers, ammonium may persist and become a part of the ground-water system. Under these circumstances, ammonium can travel considerable distances before sorption, microbe metabolism, dilution, or dispersion reduce concentrations to below detection limits. Ammonium tends to sorb onto clays and soil particles, so some soil and aquifer materials mitigate ammonium migration. Septic-tank systems, land-application waste-treatment systems, and feed-lot wastes can, under circumstances of overloading or failure of sorption systems, cause widespread ammonium contamination.

Oxidizing conditions are necessary for microbes to produce the complex reactions required to make the nitrogen useable for plants. These aerobic microbes convert the ammonium and complex, organic-nitrogen molecules to nitrite and then nitrate. Ammonium and organic-nitrogen compound concentrations are low in most aquifers because oxidizing conditions are widespread near the land surface, where these nitrogen compounds are generated and quickly utilized by plants. Oxidizing conditions occur in oxygenated soils, vadose environments and shallow, oxygenated portions of aquifers.

If nitrate is available in small amounts near the land surface, plants will utilize it. There are also microbes that denitrify soils by conversion of nitrate to nitrogen gas. If nitrate production from ammonium and more complex nitrogen compounds is not completed within the root zone, if the nitrate is unavailable to plants and denitrifying microbes, or if nitrate is produced in quantities too great for biological agents to fix, nitrate migrates with the ground water. With the exception of plant and microbial activity, there are few mechanisms for nitrate removal in aquifers. Once nitrate enters the aquifer and is isolated from environments where denitrification and plant fixation occur, nitrate behaves more-or-less conservatively and can move long distances in aquifers.

Ideal, land-based, waste-disposal practices include sufficient vadose zone and biomass to convert nitrogen compounds to nitrate and then to utilize the nitrate. Unfortunately, high water tables, plugging of soils by particulate matter, under-design of treatment facilities, crowding of waste-disposal facilities or animals on too small a tract of land, and many other factors tend to lead to failures of natural nitrogen-removal mechanisms. Under such circumstances, nitrate, ammonium, and other nitrogen compounds may enter the ground-water system and travel long distances.

Swamps and organic horizons in soils can also contribute natural ammonium and/or nitrate to aquifers. Under most circumstances, however, decay of the organics is sufficiently slow that the nitrogen compounds are utilized within the wetland and adjacent aquifers. High nitrate and ammonium concentrations in aquifers are more likely to be caused by inadequate soil and aquifer conditions and contamination by human or animal wastes.

For microbial decomposition of nitrogenous compounds to occur, there must be a source of organic carbon, and other nutrients. The role of nitrogen-utilizing microbes in deep aquifers has not been adequately evaluated. It appears that microbial transformations analogous to sulfate reduction may occur. Availability of organic carbon and nitrogen compounds is limited in deeper portions of the Floridan aquifer system, so nitrogen-utilizing microbes are probably ineffective in the same way as are sulfate-reducing microbes. Our present concepts suggest that the majority of nitrogen fixation occurs in shallow, oxidizing aquifers and soils.

The presence of nitrate, and the other nitrogenous compounds in ground water, is not considered to be a result of interaction of aquifer system water with surrounding rock materials. Nitrate in ground water is a result of specific land uses. If the land use is widespread, a body of nitrate-enriched water that is large enough to be contoured may result. Otherwise, detection of nitrate is an isolated phenomenon.

The only nitrogen compound for which there is a standard or guidance criterion in ground water in Florida is nitrate. Nitrate is subject to the Primary Drinking Water Standard (Florida Department of Environmental Regulation, 1989). The limit under the Primary standard is 10 mg/l as N, or 44 mg/l as NO_3^-. There is a health advisory for nitrate at 1 mg N/l (4.4 mg NO_3^-/l), as well. The major cause of concern is methemoglobinemia, an excess of methemoglobin[5], which causes oxygen deprivation. This condition is especially hazardous in infants and young children, where it produces a condition known as "blue baby syndrome" (Hersh, 1968; Hem, 1986). There are no standards for ammonium or other nitrogenous decay products in ground water (Florida Department of Environmental Regulation, 1989).

Each of the nitrogen species in ground water can cause problems where present in excess. If nitrification of ammonia does not deplete oxygen, it may form excess nitrate. Nitrate is very soluble and does not interact with soil components under aerobic conditions. It travels through the soil-water environment practically unimpeded. Unless conditions for denitrification exist, nitrate will not undergo further

[5] Methemoglobin (ferrihemoglobin) is the equivalent of hemoglobin with the exception that the iron is oxidized to the ferric state. Methemoglobin is, therefore, incapable of carrying oxygen in the circulatory system.

transformations once in the ground water (Preul and Schroepfer, 1968; Bouma, 1975a; Hall, 1975). Most studies report attenuation of nitrate concentration by dilution only. The concentration of nitrate in ground water decreases as the nitrate diffuses and is dispersed into surrounding waters of lower nitrate content (Walker *et al.*, 1973a,b; Hook *et al.*, 1978).

Organic Nitrogen

Organic nitrogen is defined as Total Kjeldahl Nitrogen (TKN) minus ammonium and ammonia concentrations. Organic nitrogen consists of complex organic molecules, such as amino-containing molecules. Organic nitrogen, therefore, represents the "least reacted" nitrogen species, which should occur nearest the sources. Organic nitrogen is likely to be highest near waste-disposal facilities, animal feedlots, areas where septic tanks are close together, and in extensive swamps.

Figure 21a and b show the distribution of organic nitrogen in the study area. High organic nitrogen concentrations occur in the ridge domain, especially beneath Lake Tsala Apopka. The presence of organic nitrogen beneath the lake strongly suggests that the lake is recharging the Floridan aquifer. There is a second, minor high in the swamps of the coastal domain. Elsewhere, organic nitrogen application rates are either minimal or oxidation is rapid.

Ammonium

Ammonium (NH_4^+) in ground water can be derived from (1) animal waste products, (2) decay of complex organic molecules, and (3) application of inorganic fertilizers. It can only persist in reducing environments and in the immediate vicinity of a source.

While small amounts of ammonium are scattered throughout the area, ammonium is concentrated in the study area in two regions (Figure 22 a and b). There is a large area of ammonium-rich water beneath Lake Tsala Apopka and just east of the Brooksville Ridge. This corresponds with the general area of high organic nitrogen and reflects leakage from the lake. The second high is within the City of Crystal River. The source of this high is unknown, but its presence is consistent with septic tanks and other human/animal wastes.

Nitrite

Nitrite (NO_2^-) is less stable in ground-water than nitrate or ammonium. It is simply a step in the oxidation of ammonium and other nitrogen compounds to nitrate. Nitrite is determined by subtracting nitrate-nitrogen concentrations from nitrate+nitrite-nitrogen concentrations. Nitrite can only persist near a source.

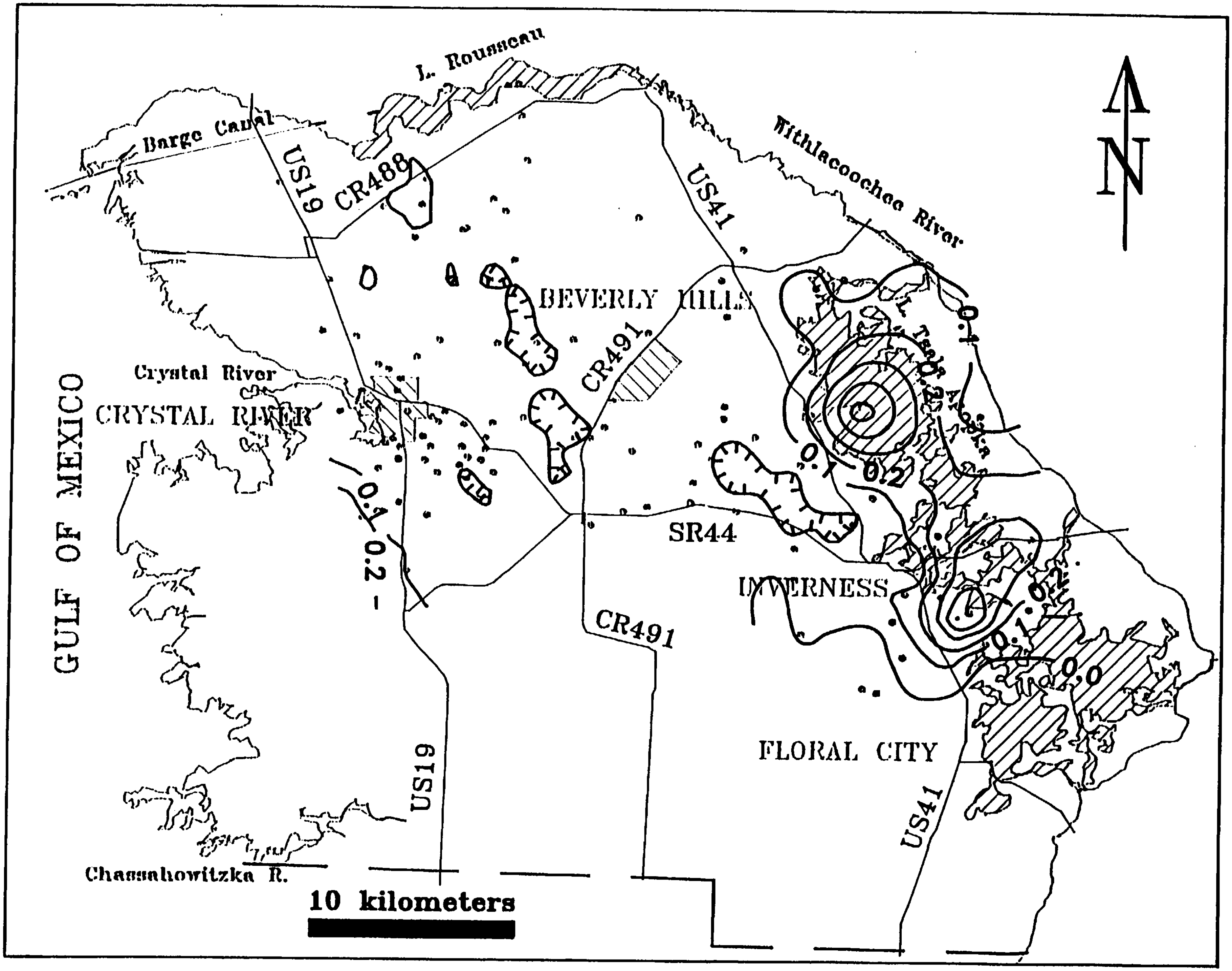


Figure 21a. Organic Nitrogen Concentrations in Study Area Ground Water.

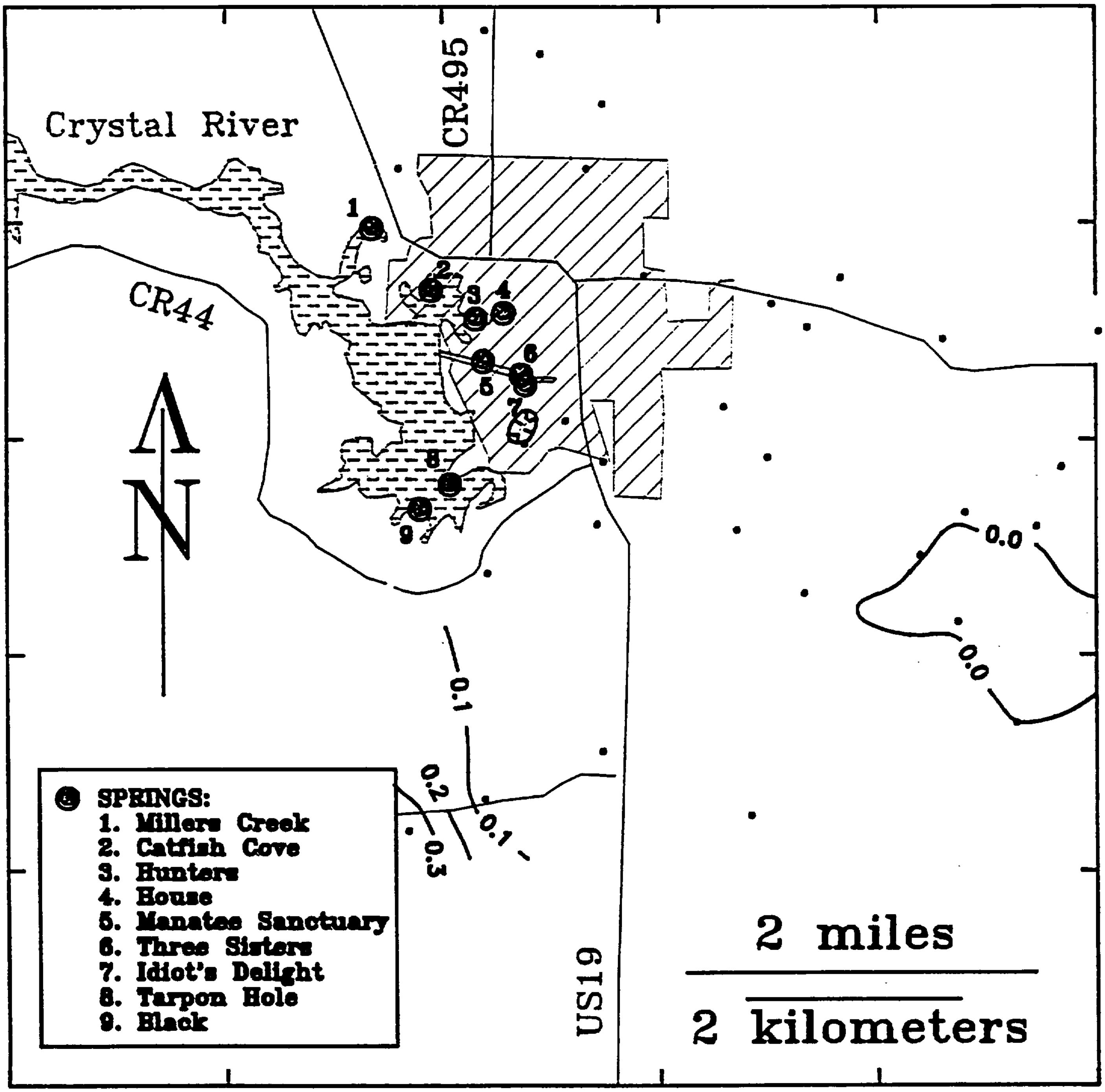


Figure 21b. Organic Nitrogen Concentrations in Ground Water in the Vicinity of the City of Crystal River.

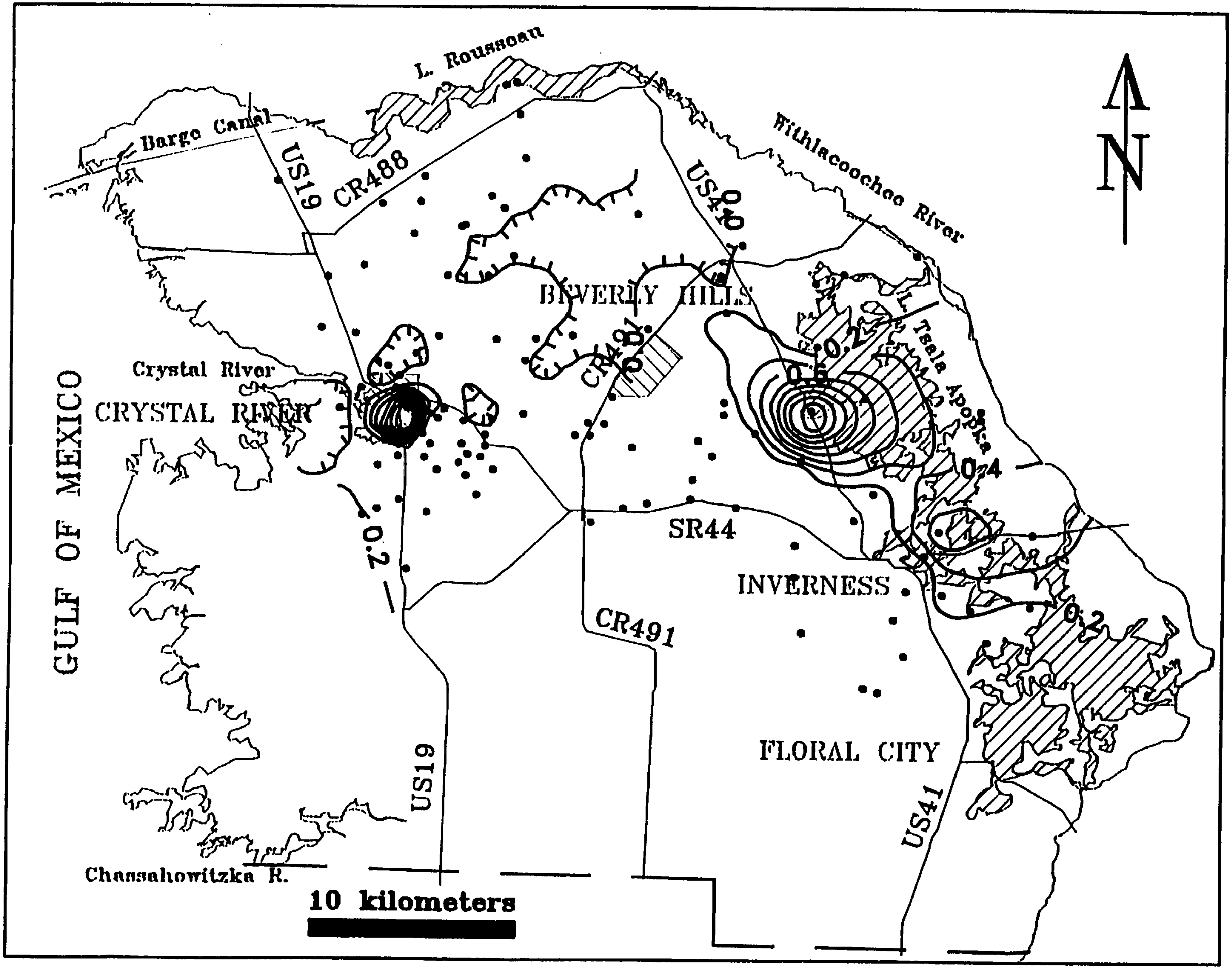


Figure 22a. Ammonium Concentrations in Study Area Ground Water

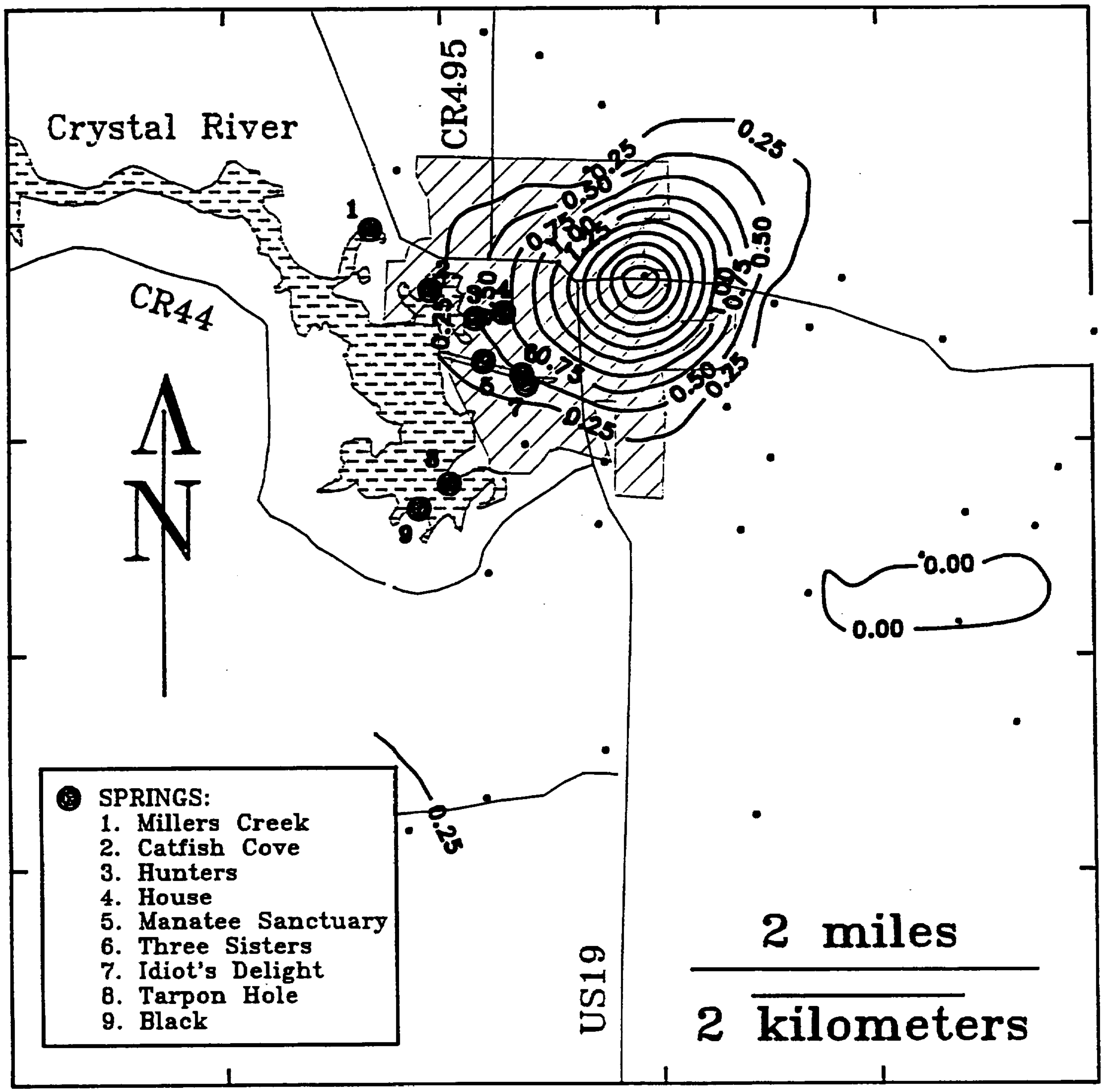


Figure 22b. Ammonium Concentrations in Ground Water in the Vicinity of the City of Crystal River.

Figure 23 shows the distribution of nitrite in the study area. High nitrite was found in only one well, a well just south of the City of Crystal River. This well reflects a local source, not a regional problem.

Nitrate

Along with ammonium, nitrate (NO_3^-) is found in the springs and has been targeted as a cause of nutrient enrichment in King's Bay. It is typically the final oxidation product in ground water. Nitrate can be derived from animal wastes and inorganic fertilizers.

Ground water in the study area is widely enriched in nitrate. Nitrate concentrations of the eleven largest springs in King's Bay are approximately 0.2 mg/l (NO_3 as N). Although this level is low relative to many springs in developed areas (Jones and Upchurch, 1993), it is considerably elevated over nitrate concentrations in ground water in the undeveloped portions of the study area.

One hundred and two wells were sampled for nitrates in the study area. Thirty two percent had concentrations between 0.2 to 0.6 mg/l (NO_3 as N) and seven percent had concentrations exceeding 0.6 mg/l. These figures indicate that areas where nitrate in ground water is significantly elevated above naturally-occurring levels (generally < 0.01 mg/l) are widespread. Elevated concentrations are in the ridge domain, near Lake Tsala Apopka (Figure 24a), where recharge of nitrogen-rich water is widespread. Comparison with Figures 21 and 22 shows that this high nitrate reflects oxidation of reduced nitrogen species leaking from the lake or surrounding sites.

There is a "ridge" of nitrate that runs east-west from Inverness to the King's Bay Springs. This same path was noted previously, where it was suggested that it may reflect a flow path. A second ridge extends northeast-southwest from the vicinity of Holder, just south of Dunnellon. This ridge is based on one sample and may be spurious. There is a third ridge that extends south-southwest from Lake Rousseau. This ridge is represented in other data and may reflect transport along a flow path originating at the lake.

Figure 24b shows the nitrate distribution in the vicinity of the City of Crystal River. Note that there is a corridor of low nitrate that runs southeast-northwest, just south of the springs. There is a minor high just east of the springs, and somewhat high nitrates occur outside of the city limits. The latter phenomenon may reflect use of septic tanks outside of the area served by the city sewer system. There is little evidence for a nitrate source immediately adjacent to the springs, but distal sources are abundant. Given that the springs are fed by recharge in the eastern coastal, central, and ridge domains, there are abundant sources available.

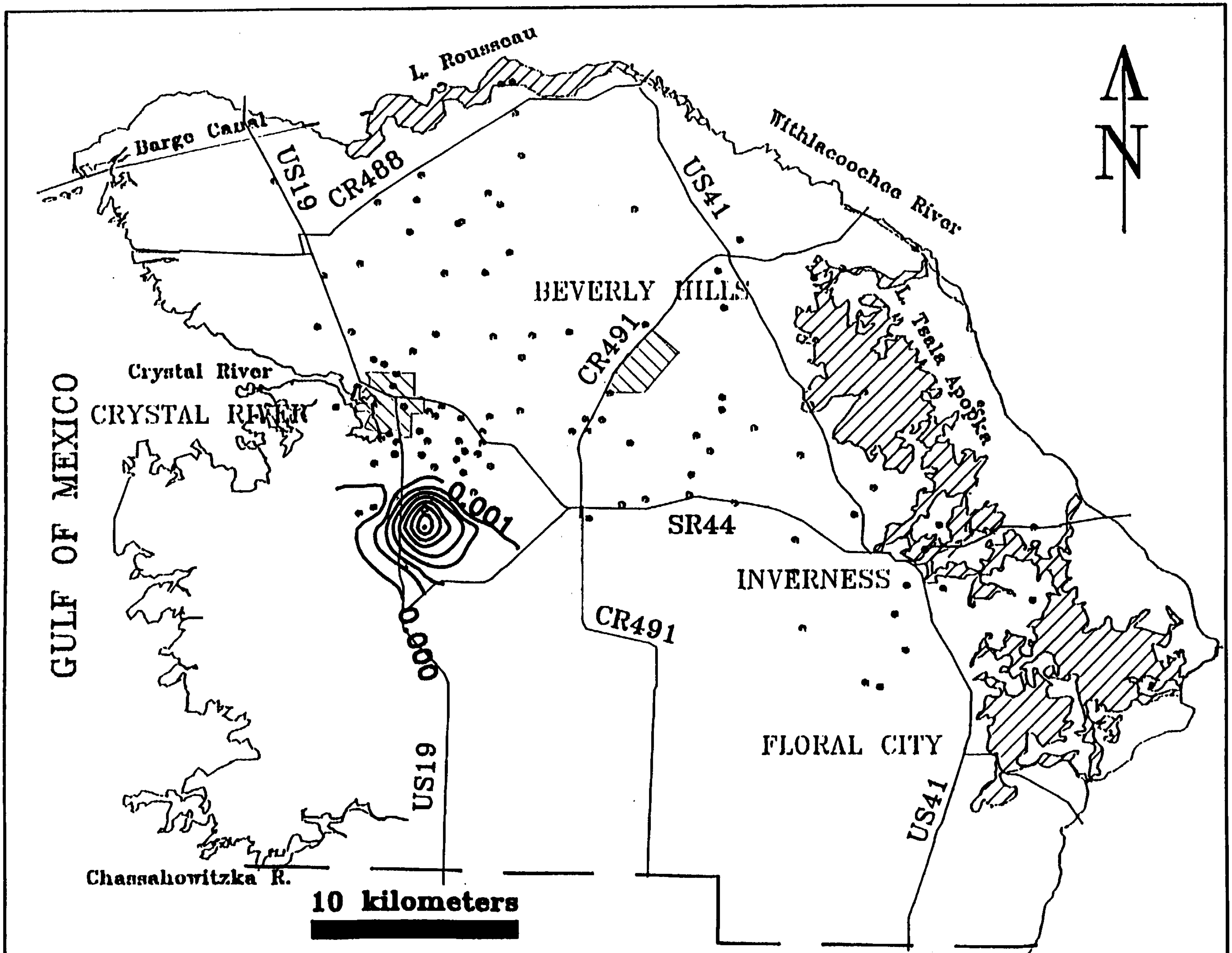


Figure 23. Nitrite Concentrations in Study Area Ground Water.

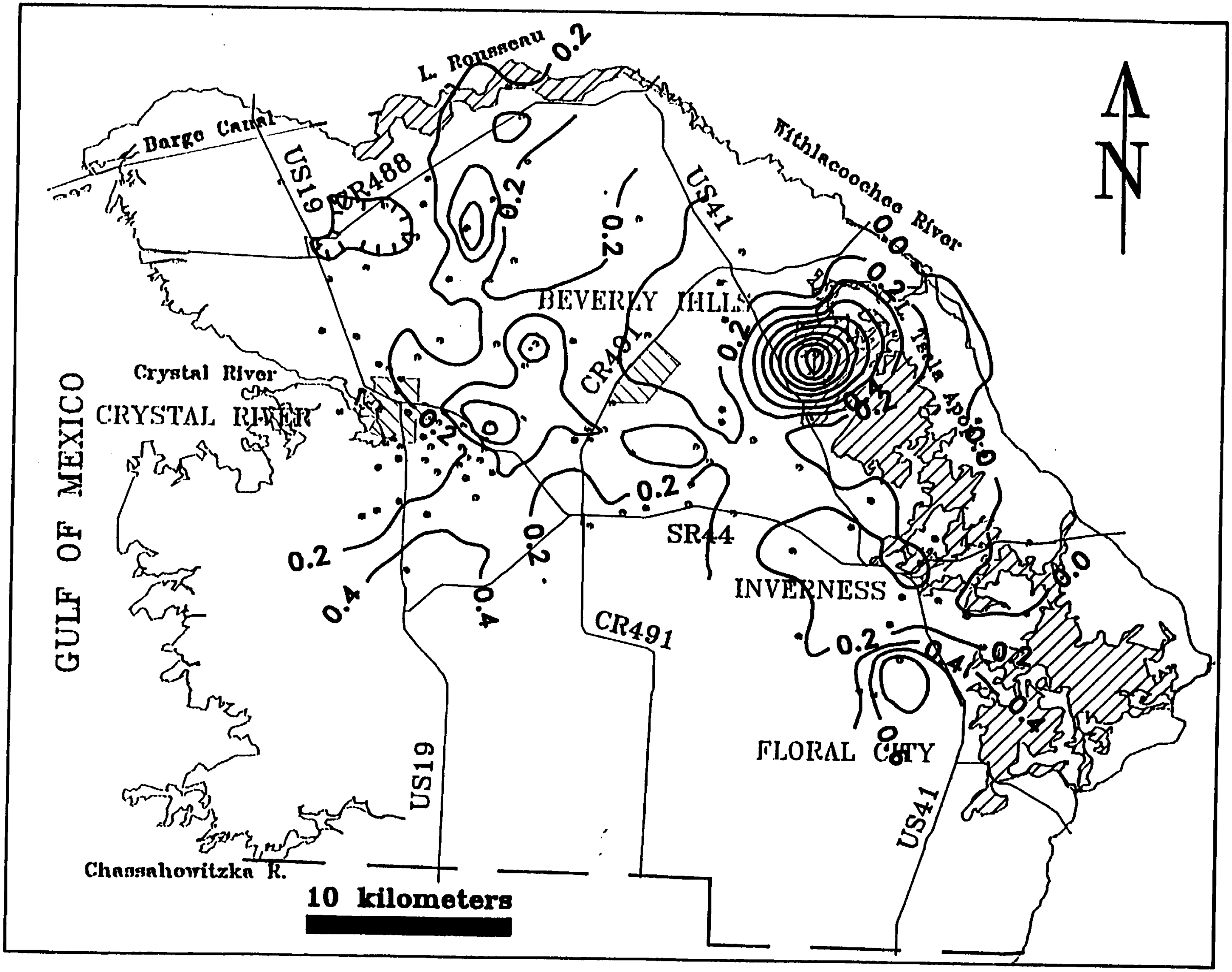


Figure 24a Nitrate Concentrations in Study Area Ground Water

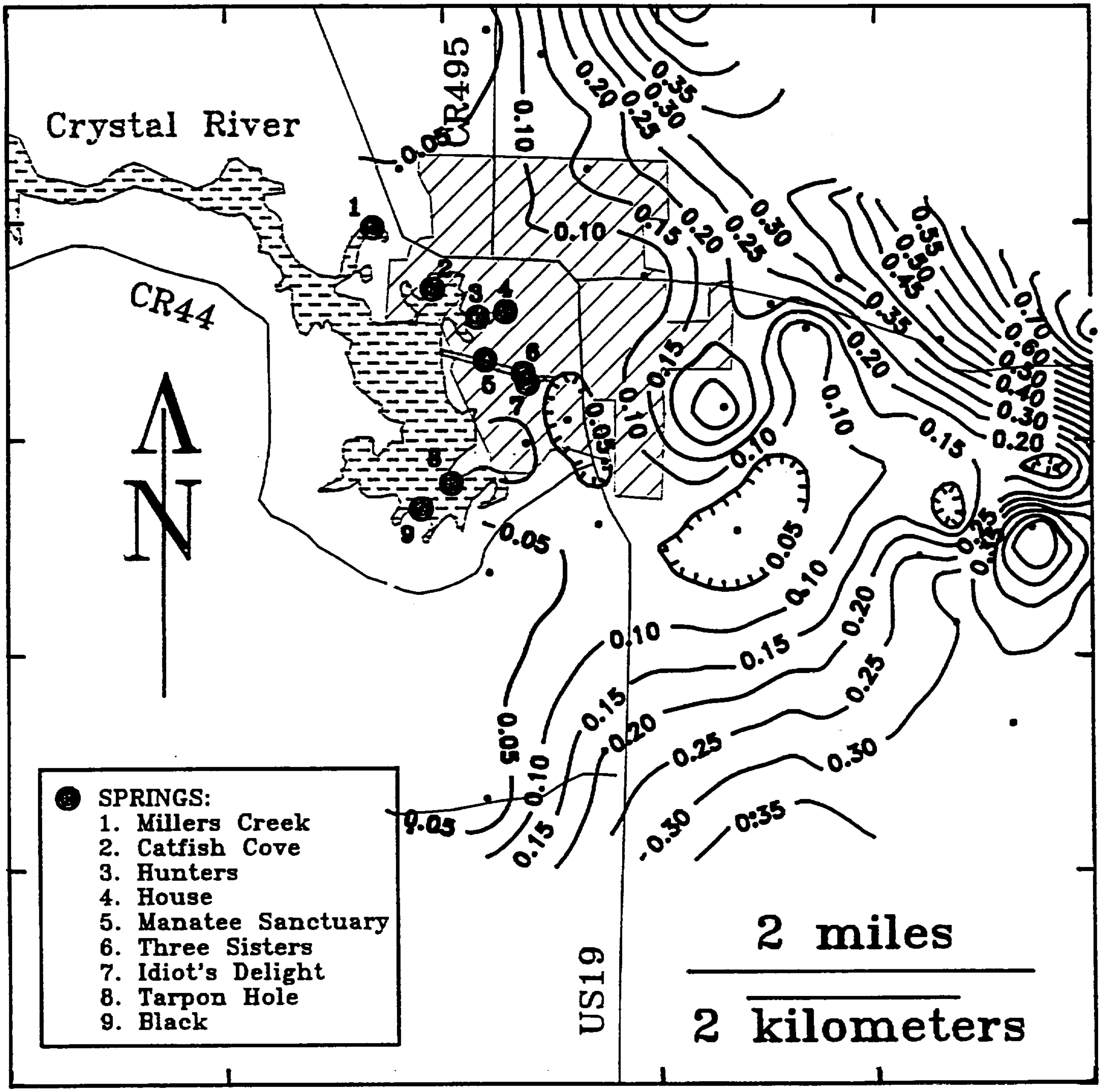


Figure 24b. Nitrate Concentrations in Ground Water in the Vicinity of the City of Crystal River.

Total Nitrogen

Since transformations between nitrogen species are rapid and complex, it is often best to consider total nitrogen. Total nitrogen concentrations represent the summation of all of the previously discussed analytes.

The distribution of total nitrogen (Figure 25a and b) ties several of the pathways previously discussed together. The high nitrogen concentrations that have resulted from leakage for Lake Tsala Apopka are well represented. The east-west, northeast-southwest, and north-south corridors are also strengthened. These corridors correspond with principal directions of fractures and lineaments and suggest that there is a long-term supply of nitrogen heading for the springs. The high in the western portion of the City of Crystal River is contoured with the springs, suggesting a connection.

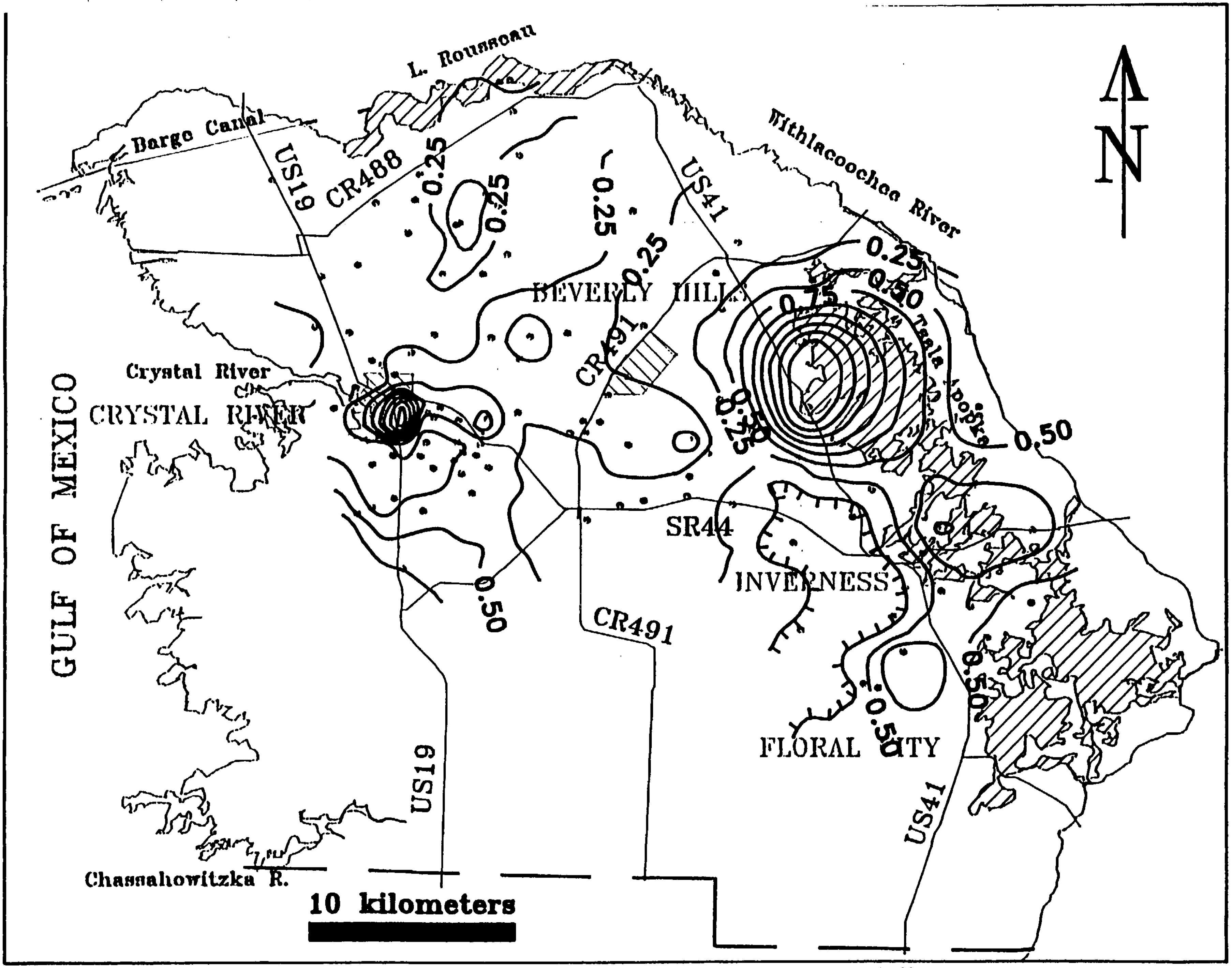


Figure 25a. Total Nitrogen Concentrations in Study Area Ground Water.

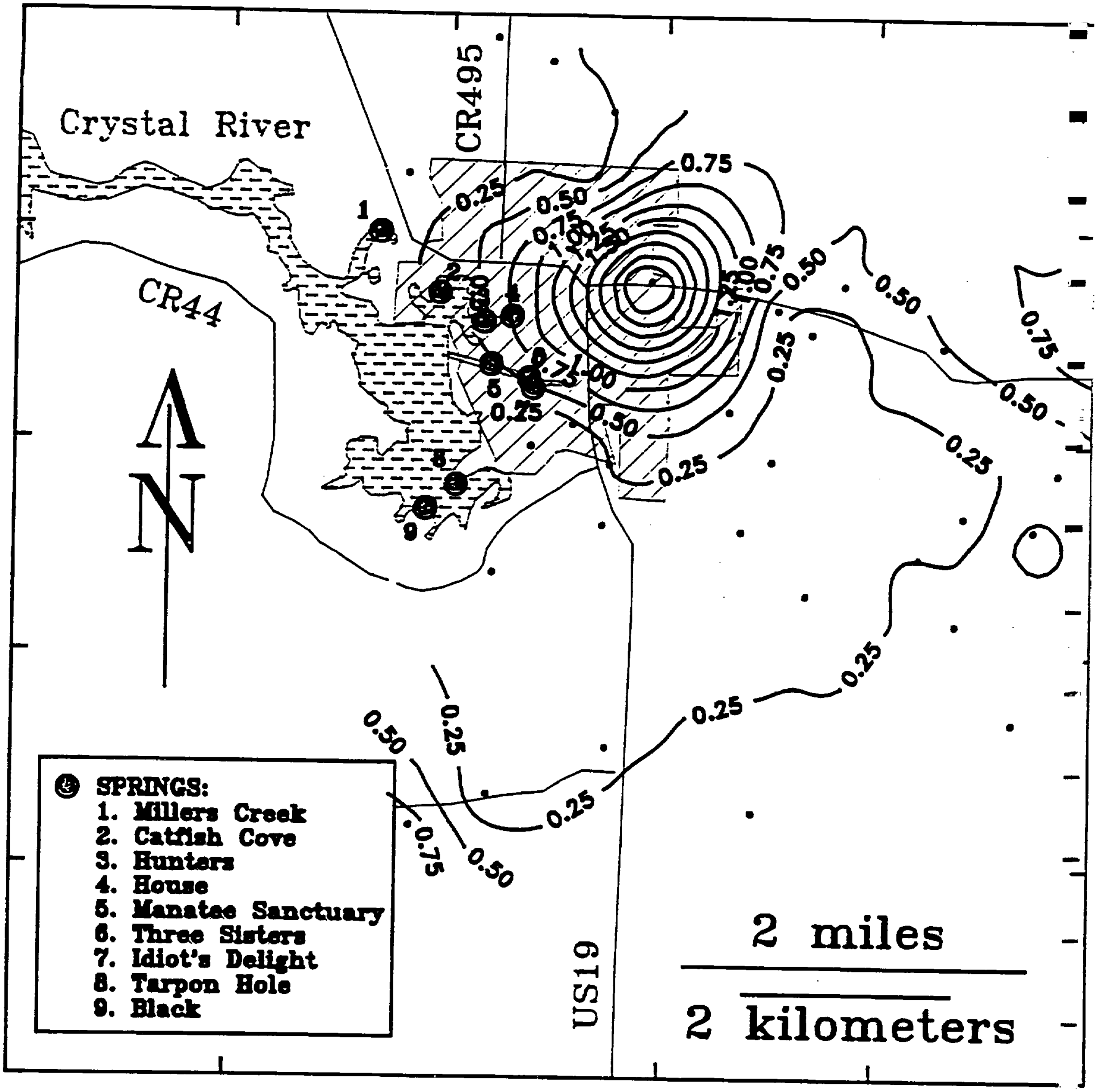


Figure 25b. Total Nitrogen Concentrations in Ground Water in the Vicinity of the City of Crystal River.

ADDITIONAL NUTRIENTS

Total Organic Carbon

Total organic carbon (TOC) is a measure of the complex carbon-compound concentrations in the ground water. Organic carbon can be derived from natural organics (humic substances, Upchurch 1992), synthetic organics, or waste disposal. Synthetic organic compounds are rarely present in sufficient quantities to be reflected in typical TOC concentrations, so TOC reflects natural and waste sources. Upchurch and Lawrence (1984) found that the highest TOC concentrations occur at the base of the Hawthorn escarpment in north Florida. This area is characterized by recharge of surface waters and organic-rich intermediate aquifer waters where confinement is breached.

Figure 26a and b shows the distribution of TOC in the study area. The high nitrogen (especially organic nitrogen and ammonium) water under Lake Tsala Apopka in the ridge domain is also characterized by high TOC. Water in the central domain contains minimal TOC, and there is a high in the coastal domain. The coastal domain corresponds with the high nitrogen waters of the coastal swamp southwest of the King's Bay Springs, but there is also a high within the City of Crystal River. This high was present in the nitrogen data and suggests a source that may be affecting the springs.

Phosphorus Compounds

Total phosphorus and orthophosphate concentrations in ground water were determined throughout the study area. The analyte total phosphorus includes complex organic compounds as well as simple inorganics. It is an indicator of localized contamination by organic sources, such as animal wastes. Orthophosphate (PO_4^{3-}) is derived from certain detergents, decomposition of complex organics, food additives, and weathering of phosphatic minerals in the Hawthorn Group (Upchurch, 1992). Orthophosphate is relatively insoluble in alkaline, carbonate-rich aquifers, and carbonate-fluorapatite is a typical precipitate. If orthophosphate is present in the limestone aquifers of the intermediate or Floridan aquifers, local recharge is often indicated (Upchurch and Lawrence, 1984). Organic phosphorus compounds are destroyed by the microbial reactions discussed previously. Orthophosphate is strongly sorbed onto ferric hydroxides in soils and aquifers and quantitatively precipitated in alkaline waters, so it should also not travel far from its source.

Phosphorus compounds (Figures 27a and b and 28a and b) are present in low concentrations in the eastern half of the area, where the hard-rock phosphate mines once thrived. There are also several small highs in the coastal domain. Of special importance is the high total phosphorus and orthophosphate water that extends

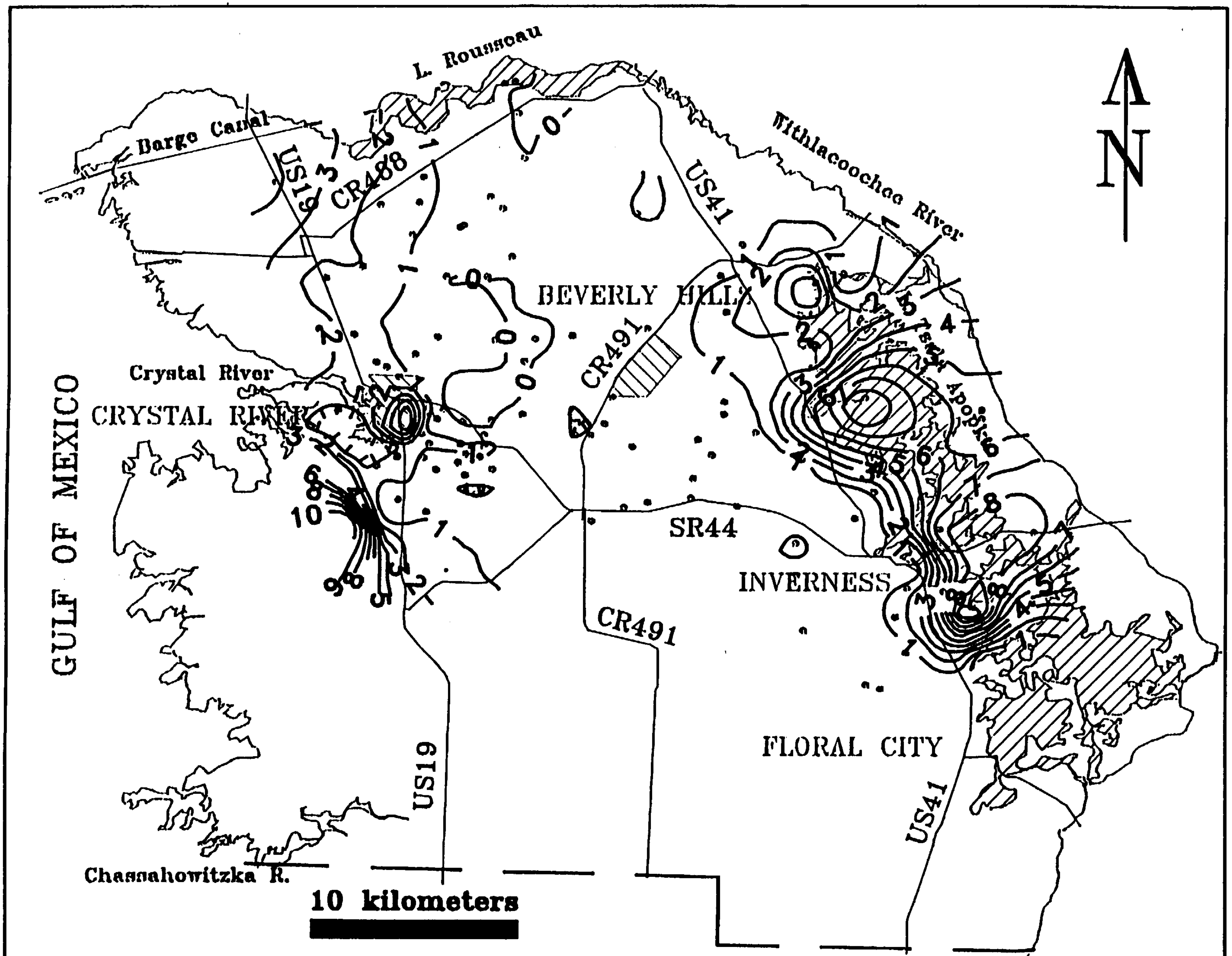


Figure 26a. Total Organic Carbon Concentrations in Study Area Ground Water.

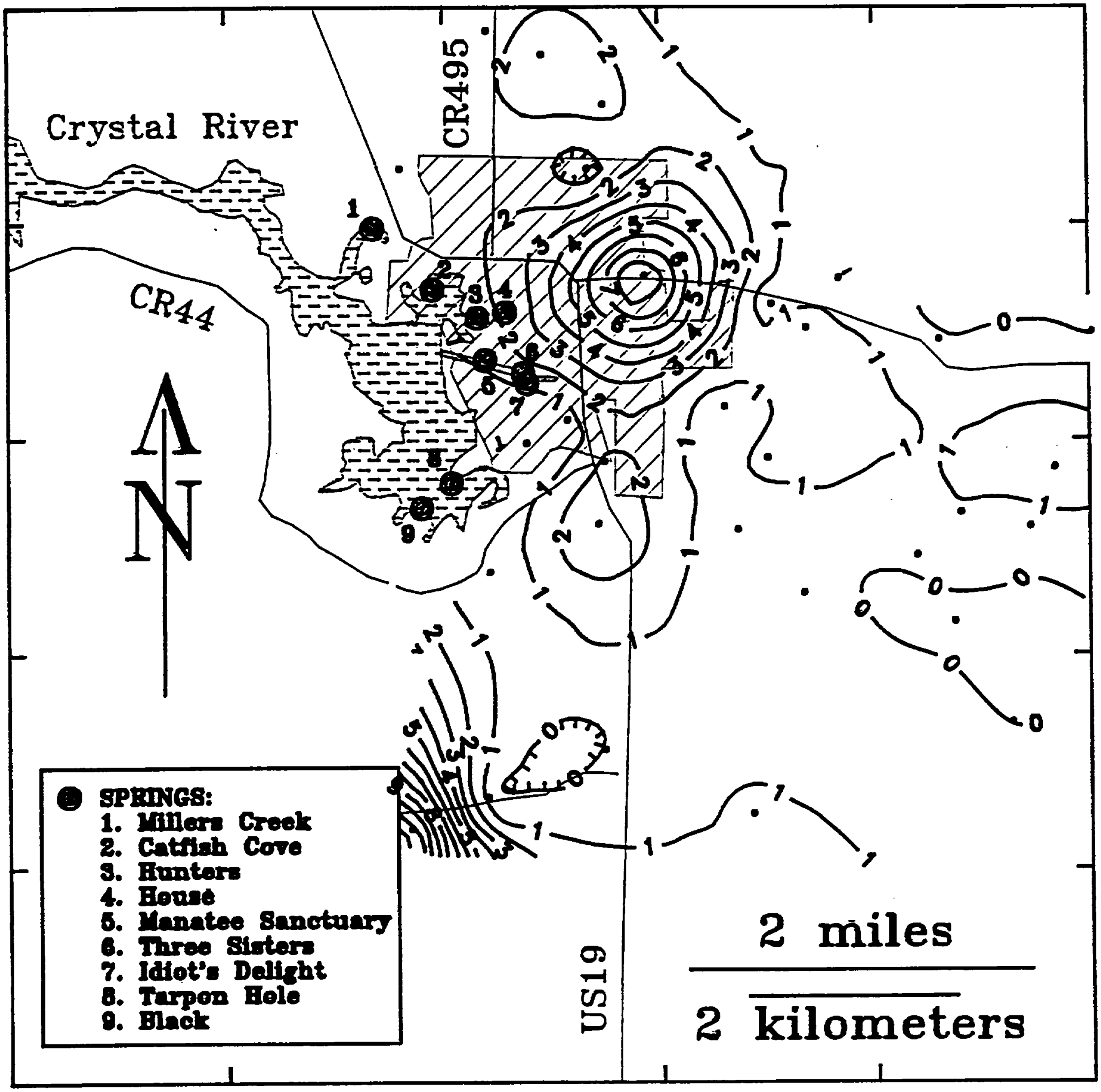


Figure 26b. Total Organic Carbon Concentrations in Ground Water in the Vicinity of the City of Crystal River.

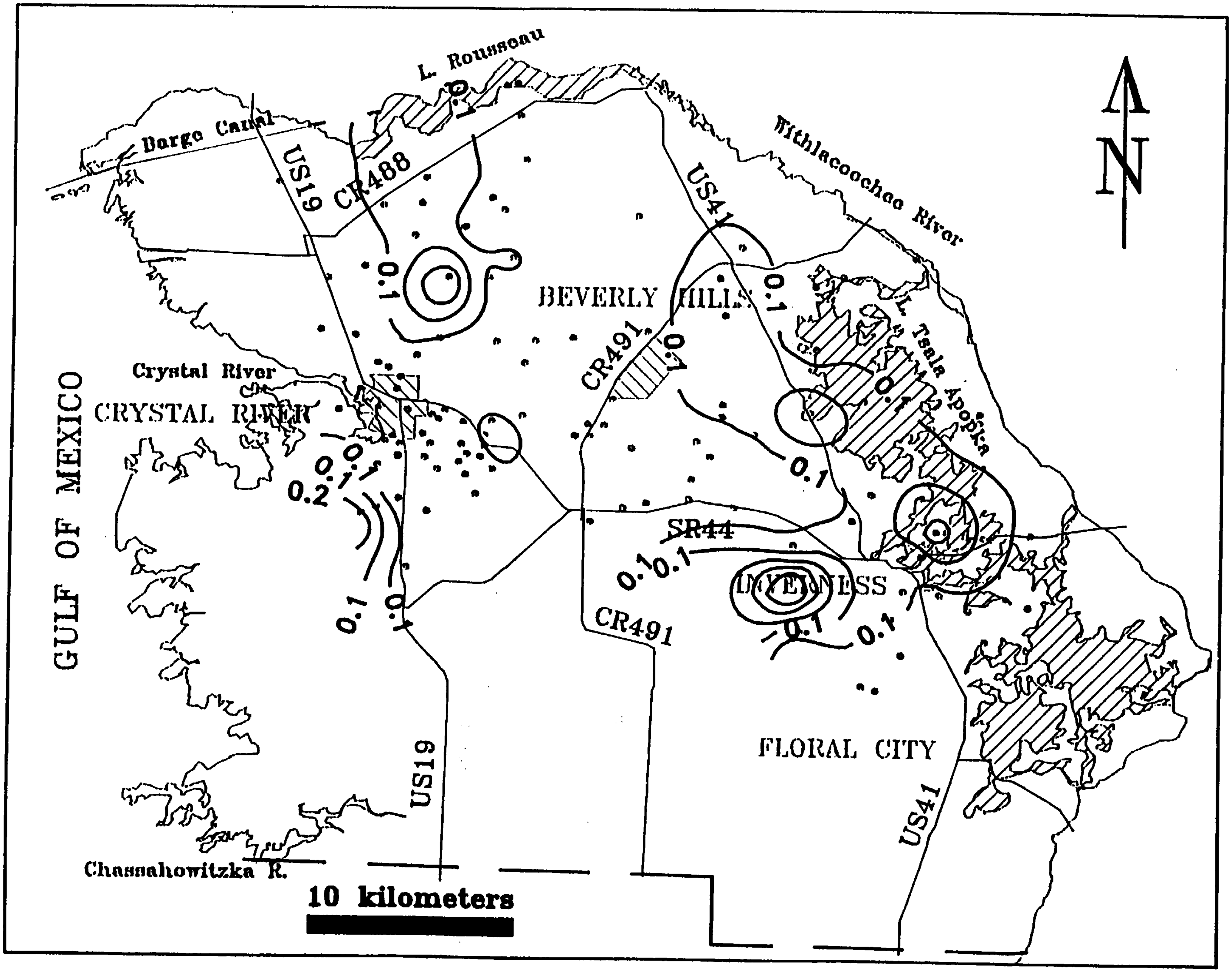


Figure 27a. Ortho Phosphate Concentrations in Study Area Ground Water.

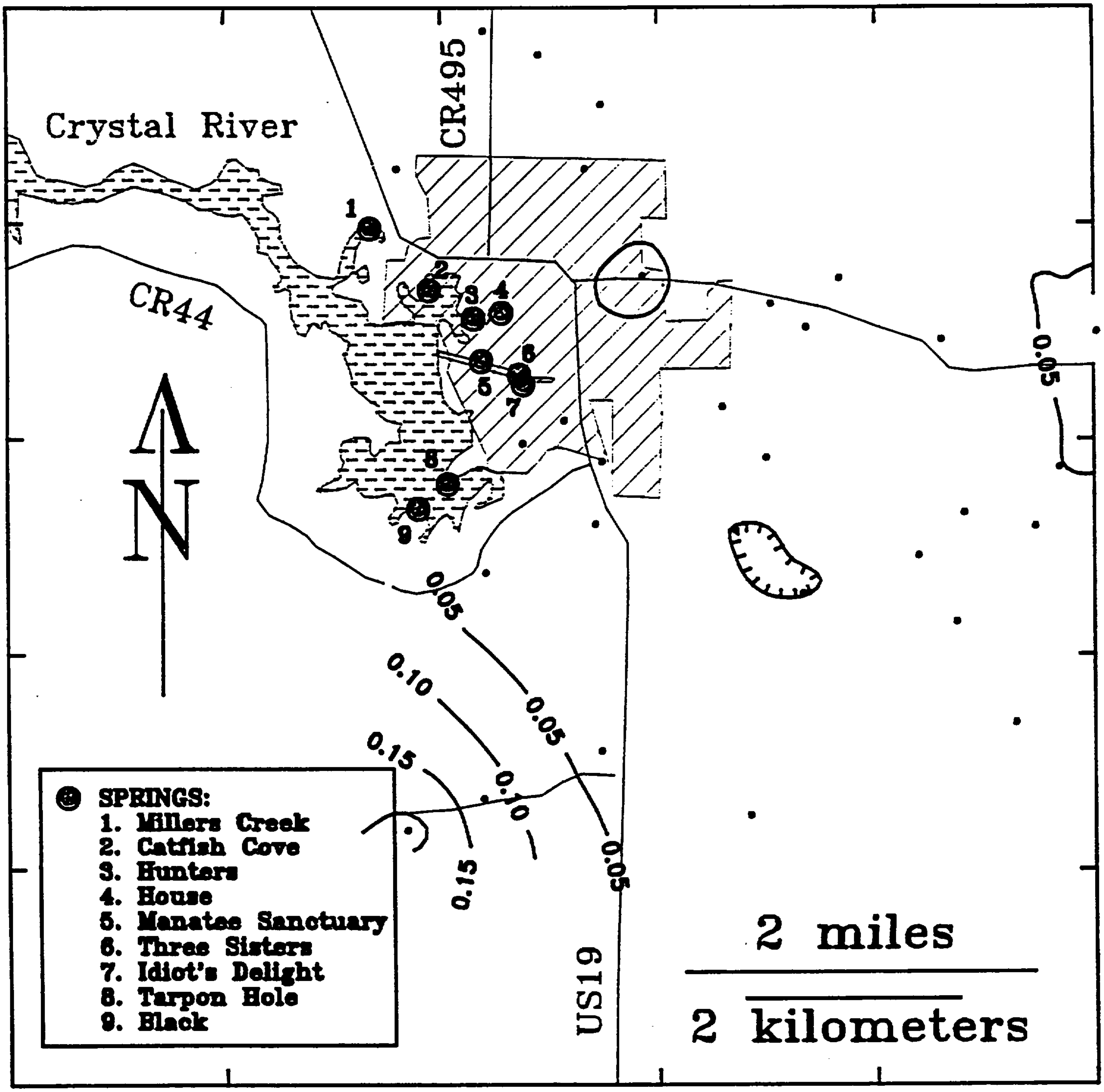


Figure 27b. Ortho Phosphate Concentrations in Ground Water in the Vicinity of the City of Crystal River.

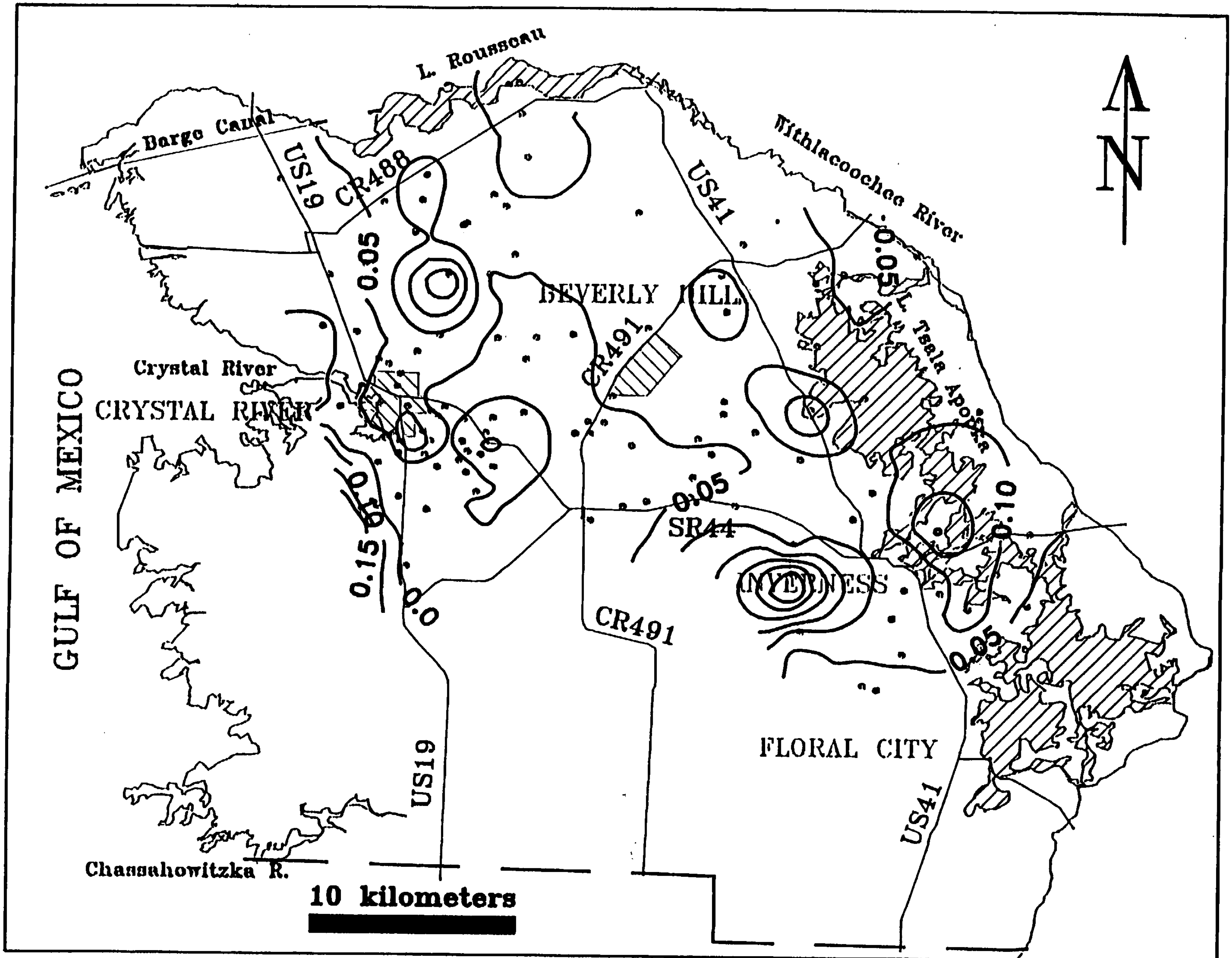


Figure 28a. Total Phosphorous Concentrations in Study Area Ground Water.

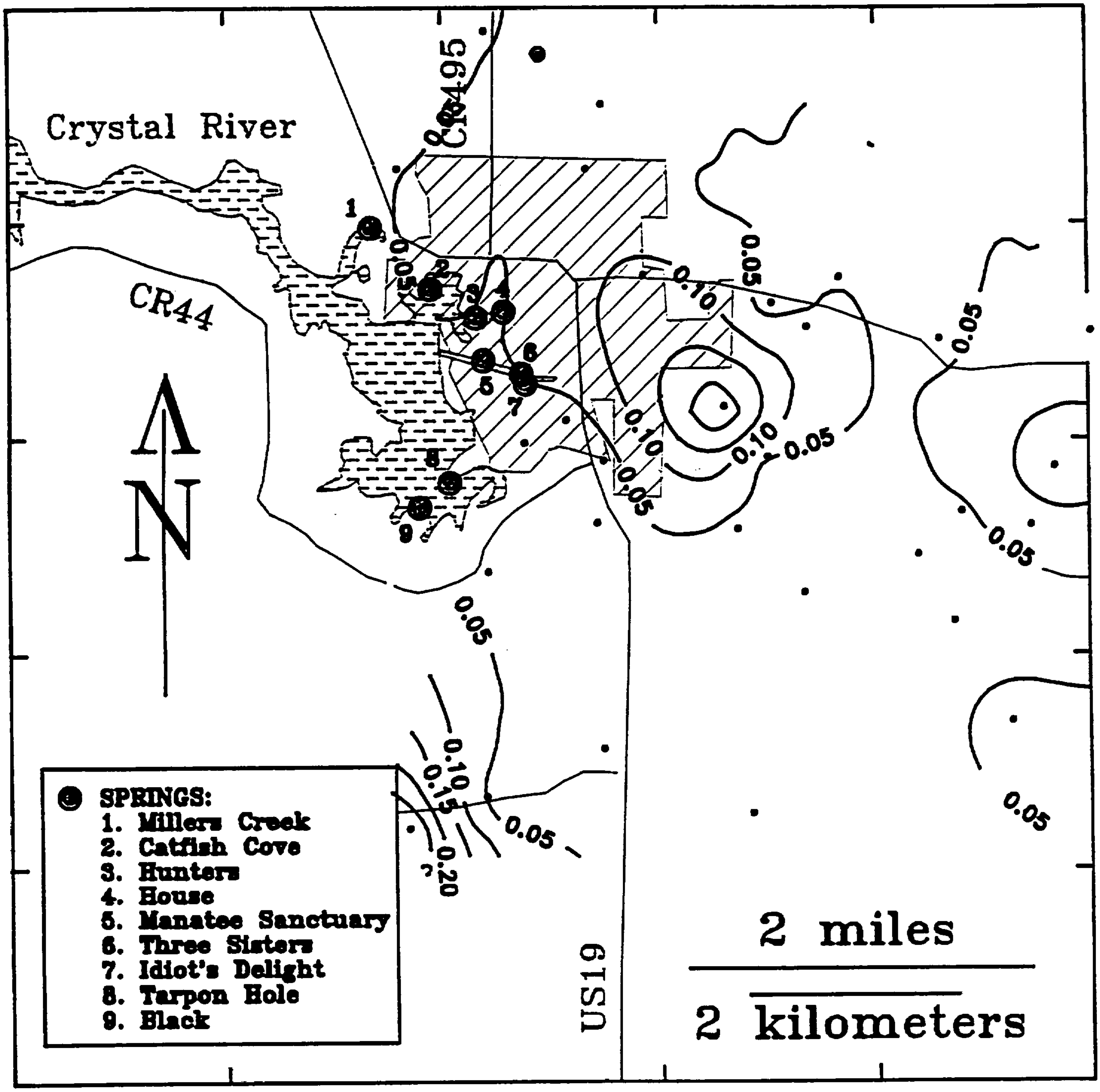


Figure 28b. Total Phosphorus Concentrations in Ground Water in the Vicinity of the City of Crystal River.

southward from Lake Rousseau. There is also a small high in the eastern portion of the City of Crystal River.

CONCEPTUAL FLOW MODEL AND NUTRIENT-SOURCE AREAS

Flow Model

The potentiometric surface of the Floridan aquifer, isotopic data, and the major-constituent chemical data suggest that the springs are fed by Floridan aquifer water that has recharged west of the Withlacoochee River. Major recharge areas exist in the Brooksville Ridge, under Lake Tsala Apopka, and possibly Lake Rousseau and dispersed recharge is prevalent throughout the remainder of the area.

There may be a deeper flow component that is derived from areas further inland, including the Green Swamp potentiometric high, but there is little isotopic or chemical data to support that this is a major component of the King's Bay Springs discharge.

Flow is partially diffuse [6] and partly along fracture traces and lineaments. Diffuse flow occurs as ground water percolates in from the surface, enters the aquifer system, and moves between the grain to grain contacts of the sand and limestone. Upon entering limestone, intergranular (diffuse) flow becomes less important and conduit flow increases in importance. Ultimately, smaller fractures intersect the major fractures that transport water to the springs. These major fractures are also recharged directly by sinkholes located along their length. The fracture flow imparts a pattern of corridors of lower water quality in the Floridan aquifer. Several of these corridors point toward the springs. The most significant are the east-west corridor that extends from Lake Tsala Apopka to the springs and the north-south corridor that appears to be developing from Lake Rousseau.

This flow is focused at the springs in King's Bay. The springs are discharging recently recharged waters that, from the isotopic data, can only have been in the ground a few tens of years. The transition from a steep gradient beneath Lake Tsala Apopka to a nearly flat surface in the central and coastal domains suggest that transmissivities increase greatly toward the coast. It is also noteworthy that several of the largest sinkholes in the Brooksville Ridge have bottoms near sea level and are dry. This also suggests an efficient "plumbing" system with high permeabilities that allows rapid movement to the coast.

Nutrient Source Areas

Nutrient and isotopic data indicate that there are two potential sources for the

[6] Diffuse flow is through small pores that are pervasive throughout the rock. These pores include intergranular spaces and molds and small fractures in the rock. Conduit flow is through larger fractures and caverns and is localized in a rectilinear pattern. Highest permeabilities are when flow is through the fracture and cavern network.

springs. There is a local source on the east side of the City of Crystal River that may be an immediate cause of nutrient enrichment of the springs. The city is surrounded by areas served by septic tanks and small treatment facilities that have also contributed to the low-grade enrichment of the Floridan aquifer near the springs.

There is an even greater problem, however, in that the ground waters distal to the springs are also contaminated and will serve as long-term sources of nutrients to the King's Bay Springs. Lakes Tsala Apopka and Rousseau appear to be introducing organic- and nutrient-rich waters to the Floridan. This process may have been present for hundreds to thousands of years, but added nutrients from human sources may cause exceedance of the nutrient uptake capacity of the bay. Certainly, there is a long-term, low-level source represented by the lakes. In addition to the lakes, the developments along the ridge and in the central domain are apparently affecting ground-water quality. Since most of the developments are sparsely settled, there is a significant potential for accelerated degradation if waste disposal practices are not reevaluated and altered.

Ground-Water Travel Time

Ground-water travel time for the central flow corridor from Lake Tsala Apopka to the King's Bay Springs was estimated using the equation for average linear velocity listed below.

$$\overline{V} = \frac{K\left(\frac{\Delta H}{L}\right)}{n}$$

where:

- $\overline{v}$ = average linear velocity (ft/d);
- K = hydraulic conductivity (g/d/ft^2), calculated from T = 7.48x10^6 g/d/ft and b = 250';
- Δ H = change in head (ft.);
- L = length of flow path (ft.);
- n = porosity (0.15 for karst aquifers)

Aquifer thickness (b) was determined to average approximately 250 ft. This is approximately the thickness of the potable water zone in the upper Floridan aquifer based on water quality tests conducted during the construction of two production wells at the Central Citrus Wellfield in the study area (Atlanta Testing and Engineering, 1991). A 250 foot thickness of the potable water zone was also indicated from water-quality testing during the drilling of five wells in or near the study area for SWFWMD's Regional Observation and Monitoring Program (ROMP). Figure 29 shows the location of the Central Citrus Wellfield wells and ROMP wells and the thickness of the potable

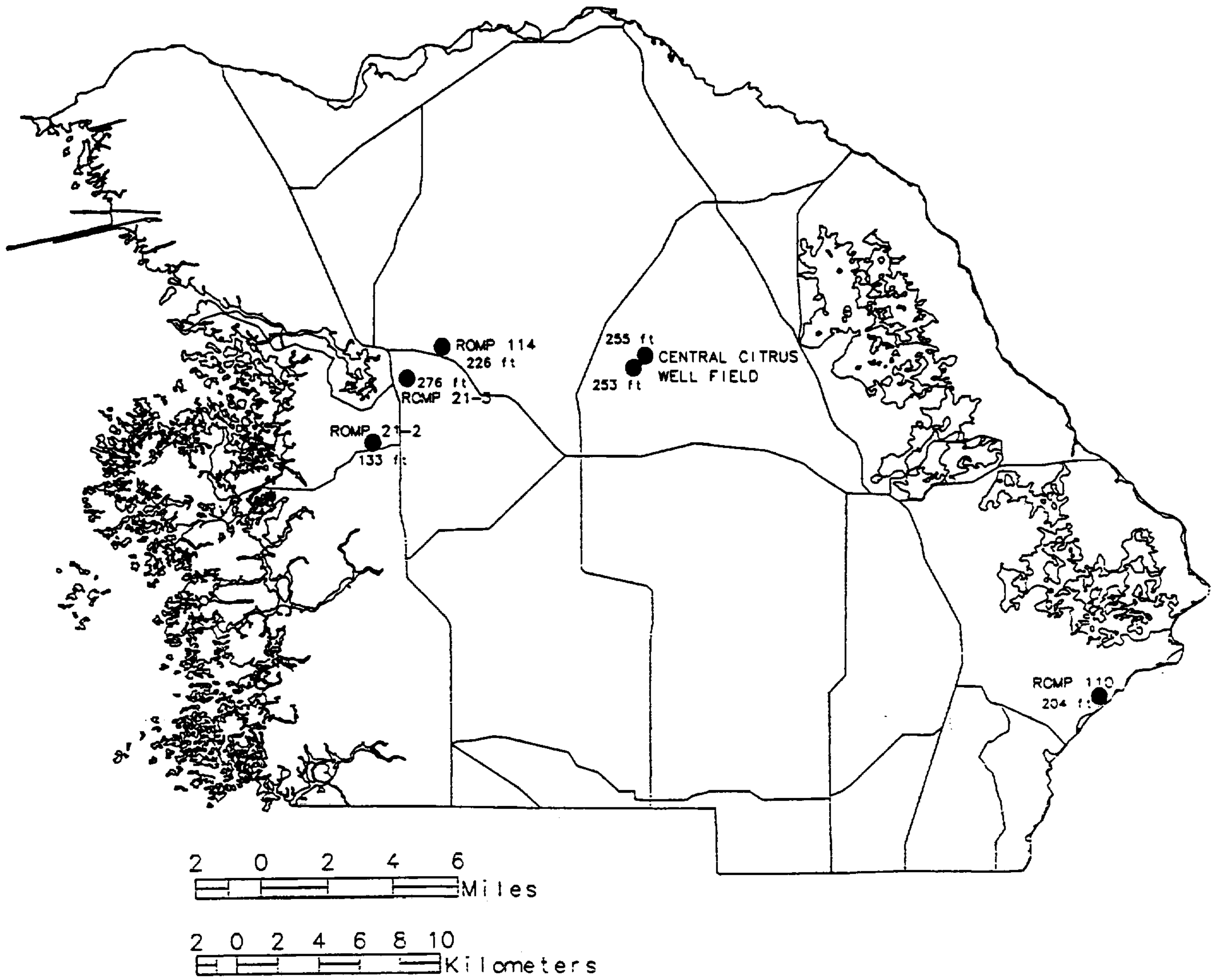


Figure 29. Thickness of the Potable Water Zone in the Floridan Aquifer at Six Wells in Citrus County.

water zone at each well. Mineralized water at the base of the potable-water zone was considered to be the base of the flow system. This is because the mineralized water is probably representative of a stagnant portion of the aquifer below the area of normal ground-water circulation.

Although Causey and Levy (1976) determined the thickness of the potable-water zone to be considerably greater, the information presented above provides a more accurate assessment of the potable water zone thickness. The conclusion that the potable-water zone is considerably thinner than what is described by Causey and Levy is supported by Ryder (1985).

To determine hydraulic conductivity for the equation it was first necessary to obtain an overall transmissivity value for the central corridor. Transmissivities for the Floridan aquifer were obtained from aquifer performance tests conducted in the study area (Atlanta Testing and Engineering, 1989; SWFWMD, 1987) and the ground-water flow model developed by Ryder (1985). Five aquifer performance tests yielded transmissivities ranging from 285,000 to 20,000,000 g/d/ft with an average value of 6,500,000 g/d/ft. This value is very close to the value used by Ryder (7,480,000 g/d/ft) for the study area in his ground-water flow model. Therefore, it was decided that Ryder's value would be used because it is widely accepted among ground-water scientists.

Δ H across the corridor was determined using the May 1991 potentiometric surface map (Mularoni, 1992).

A porosity value (n) of 15 percent was used because this was the porosity chosen for SWFWMD's well head protection model for major public supply wells in Hernando County (SWFWMD, 1993). The value approximates the wide range of porosities that would be encountered over a large area in a fractured Karst aquifer.

The average linear velocity obtained from the equation was used to estimate the time required in years for ground water to move from various points along the central flow corridor to the King's Bay Springs (Figure 30). However, these estimates may be inaccurate because the average linear velocity equation is not appropriate for areas where conduit flow is prevalent. In addition, the diffuse component of flow that may recharge the major fractures is ignored and estimates of aquifer thickness, transmissivity, and the exact gradient across the study area may be inaccurate.

From Figure 30, it is apparent that nitrate entering ground water in the central portion of the Brooksville Ridge requires approximately 37 years to travel the 8 miles between the ridge and the King's Bay Springs. Ground water movement is slowest in this portion of the study area due to a gently sloping gradient. East of this portion of the Brooksville Ridge, ground water moves more quickly because the gradient is considerably steeper. As a result, ground water requires only 4.5 years to travel 6 miles from the eastern boundary of the study area to the central portion of the Brooksville Ridge.

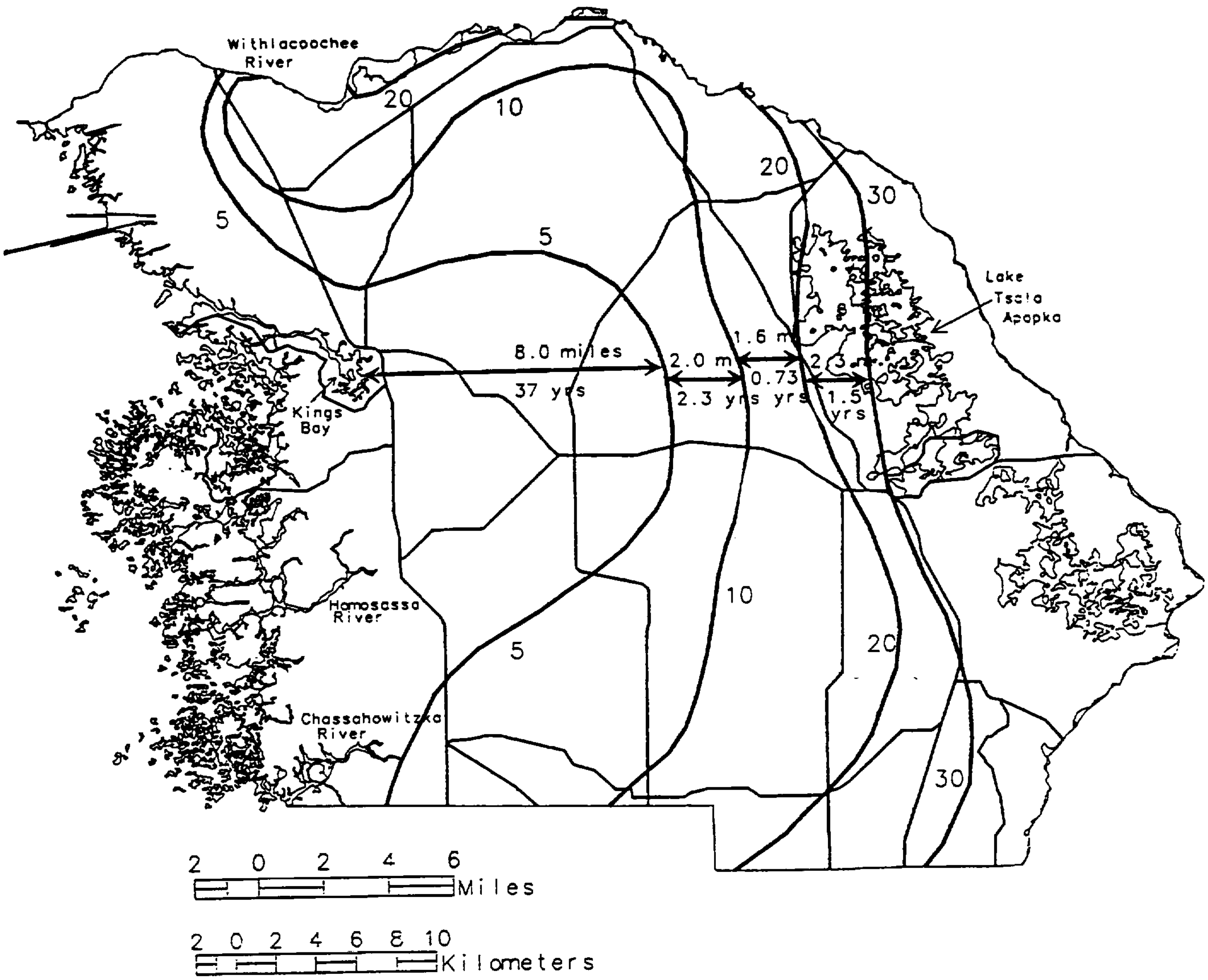


Figure 30. Potentiometric Surface and Travel Time (years) Along the Central Ground-Water Flow Corridor between Lake Tsala Apopka and the King's Bay Springs.

NUTRIENT LOADING OF THE GROUND-WATER SYSTEM

Introduction

It is estimated that approximately 196 tons of nitrate is dissolved in the combined yearly discharge of the King's Bay Springs. From previous discussions it is clear that the majority of nitrate in the waters of the King's Bay Springs enters the Floridan aquifer system within the northern two thirds of Citrus County. A number of sources that have the potential to contribute nitrate to ground water exist in this area. These include: 1) naturally occurring nitrate from organic decay, 2) rainfall, 3) residential and commercial development serviced by septic tanks, 4) fertilization of turf, 5) fertilization of golf courses, 6) sewage effluent disposal, 7) land disposal of sewage sludge, 8) land disposal of septage sludge, 9) pasture, row crop, and citrus fertilization, and 10) beef cattle production. The following section is a discussion and, where possible, a quantification of the contribution of nitrate to the study area from each of these sources. It is important for the reader to remember that discussions of land use and land-use acreage in this section refer to the situation that existed in the study area in late 1989 as depicted in Figure 3.

Naturally Occurring Organic Decay

Nitrogen can be released into the environment through the microbial decomposition of surface biomass, which is largely plant material. However, the actual amount of nitrate contributed to ground water by this process is probably small because microbes and plants in the soil layer utilize and recycle the nitrogen as soon as it is made available. This is verified by the fact that nitrate concentrations in Floridan aquifer ground water average less than 0.01 mg/l in undeveloped and unaffected areas of Citrus County where the only sources of nitrogen are organic decay and rainfall (Jones *et al.*, 1990). Lakes Tsala Apopka and Rousseau apparently constitute sources of natural nitrogen or, if the high productivities in the lakes are of human origin, quasi-natural nitrogen.

Rainfall

The average nitrogen concentration in rainfall in Citrus County was determined using data from a study of the chemical characteristics of rainfall in Florida (Irwin and Kirkland, 1980). Nine rainfall samples collected from a station in north western Citrus County contained an average of approximately 1 mg/l total nitrogen. Using this figure, for the average rainfall year (56 inches), the calculated rainfall load of nitrogen for the 280 square mile immediate recharge area for the King's Bay Springs is approximately 1,146 tons/yr. When broken out by physiographic province the loadings are as follows:

Province		Nitrogen Loading (tons/yr)
Tsala Apopka Plain	=	254
Brooksville Ridge	=	544
Gulf Coastal Lowlands	=	348
Total	=	1,146

This amount of nitrogen, though large, may have little effect on ground water because it is applied in small quantities to plant communities that utilize the nitrogen during numerous rainfall events over the course of a year. It is also probable that a large portion is lost to mineralization, adsorption, other biological uptake, fixation, or volatilization. The assumption that rainfall is not a major contributor of nitrogen to ground water is supported by the fact that many wells in undeveloped portions of the study area have very low concentrations of nitrogen. If rainfall was a significant source of nitrogen, ground water would probably have a uniformly elevated nitrogen concentration across the entire study area.

Septic Tanks

Septic tanks are thought to be a significant source of nitrogen in the study area. Nitrogen is present in high concentrations in septic-tank effluent at a ratio of 75-80% ammonium-nitrogen to 20-25% organic nitrogen (Otis *et al.*, 1975). Total nitrogen concentrations in septic tank effluent vary from 25 to 100 mg/l with the average being in the range of 35 to 45 mg/l (U.S.E.P.A., 1980). Aerial photo analysis and delineation of the extent of sewer systems have indicated that there are at least 17,000 septic tanks in the study area. The density of septic tanks is delineated in Figure 31. Because much of the residential development in Citrus County has been designed for retirees and a significant percentage of the residences may be occupied only during the winter, it is probably reasonable to assume that each septic tank services an average of 2 people. The annual nitrogen contribution per septic tank would then be approximately 37 lbs (Walker *et al.* 1973a). Research indicates that 20 to 40% of the nitrogen in effluent may be removed by mineralization, nitrification, denitrification, adsorption, biological uptake, fixation, or volatilization before the effluent reaches ground water (de Vries, 1972; Andreoli *et al.*, 1979; Harkin *et al.*, 1979; Peavy and Brawner, 1979; Laak, 1982). If 30% removal is achieved then each septic tank contributes approximately 25 lbs/yr of nitrogen to ground water, which, according to Hantzsche and Finnemore (1992), is fully converted to nitrate. Using this figure, the total nitrogen contribution for septic tanks in the study area is approximately 212 tons/yr. When broken out by physiographic province the loadings are as follows:

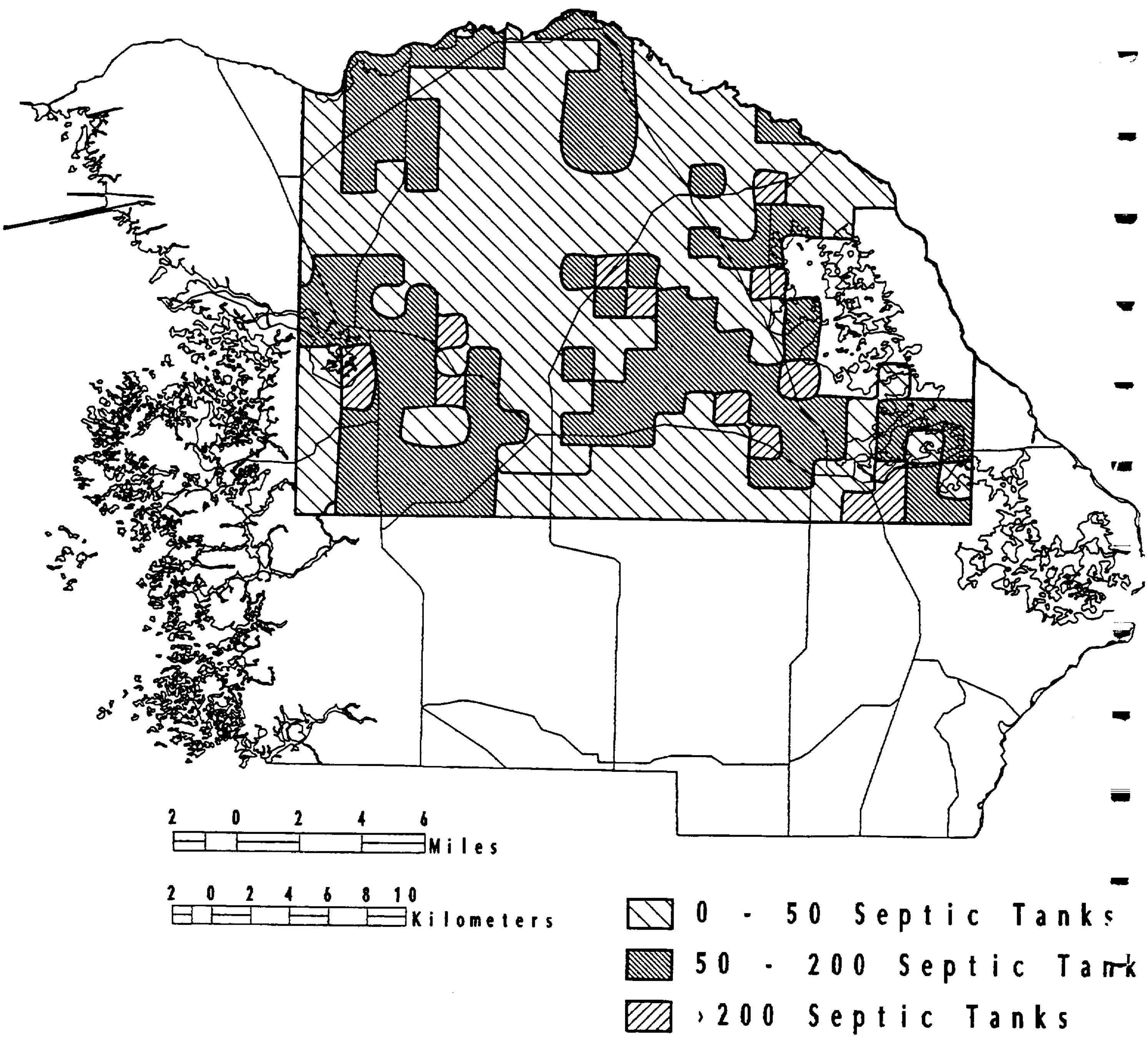


Figure 31. Density of Septic Tanks per square mile in the Study Area.

Province		Nitrogen Loading (tons/yr)
Tsala Apopka Plain	=	58
Brooksville Ridge	=	77
Gulf Coastal Lowlands	=	77
Total	=	212

This is probably an underestimation of the actual value because the uncertainties of identifying structures served by septic tanks from aerial photographs required that estimates of septic tanks numbers be kept conservative.

Although the overall nitrogen loading from septic tanks is considerably lower than some of the other sources, septic tank nitrate takes on increased significance because the calculated value represents the amount of nitrogen that is loaded directly to ground water, rather than to the land surface. The calculated nitrogen loading value from the other sources reflects the amount applied to the surface and the amount of nitrogen that actually reaches ground water is probably significantly less because of the nitrogen removal mechanisms discussed previously.

Turf Fertilization

Approximately 35,000 acres in the study area are occupied by low, medium, and high density residential land uses. A large percentage of this land use has associated landscaping, such as lawns, shrubs, trees, and gardens. Accurately quantifying the nitrogen contribution from the fertilization of landscaping was not considered possible. This is because it is extremely difficult to determine the percentage of landscaping that is maintained with fertilizers, how much fertilizer is applied, and how much of the fertilizer directly percolates to ground water. However, an attempt has been made below to calculate a nitrogen loading estimate for turf fertilization that should be considered a starting point for those interested in pursuing a more accurate number. This number was calculated using several assumptions that may be incorrect. It is left to the reader to judge the validity of the assumptions and recalculate the loading estimate if more accurate data is available.

It is first assumed that the structure, patio, pool, driveway, sidewalk, unfertilized planters, wooded areas, and other unsodded areas take up 65 percent of a residential property. This is an average number that would vary widely from apartment complexes that might have very little turf to single family estate homes of one or more acres that might have a great deal of turf. If 35 percent of the lot is turf, then the total turf acreage in the study area is 12,250 acres. Secondly, if it is assumed that 40 percent of the remaining acreage is owned by individuals that do not fertilize, then the total fertilized turf acreage is 7,350 acres. Since home owners in the study area include a large number of retirees that may have the time, inclination, and income to fertilize regularly, this may not be an unreasonable figure.

The University of Florida Cooperative Extension Service recommends 2 lbs per year of nitrogen per 1000 ft^2 (0.023 acres) of turf. Fertilizing 7,350 acres with this quantity would result in an application of 319 tons of nitrogen to the study area. A study of nitrate sources in a sewered housing development in Long Island New York (Flipse, *et al.* 1984) determined that at least 60 percent of the nitrogen applied as fertilizer to turf is estimated to leach below the root zone and eventually reach ground water. If the results of the Long Island study can be applied to the study area, approximately 191 tons of nitrogen from turf fertilizers could reach ground water. Broken out by physiographic province the application rates would be as follows:

Province		Nitrogen Loading (tons/yr)
Tsala Apopka Plain	=	38
Brooksville Ridge	=	90
Gulf Coastal Lowlands	=	63
Total	=	191

An ongoing study (currently unpublished) conducted by the Ground-Water Quality Monitoring Program (GWQMP) of the Department of Environmental Protection (DEP) monitored ground-water quality in 22 areas across the state that were dominated by specific land uses. Three of the 22 areas were dominated by residential land uses where fertilization of landscaping was prevalent. In one of these areas in Hillsborough County, nitrate levels in ground-water samples obtained from numerous monitor wells generally do not exceed 1.0 mg/l but individual wells can have nitrate concentrations as high as 2 mg/l (it must be noted that other nitrate sources such as septic tanks and golf courses exist in portions of these areas).

Nitrate levels in residential portions of the Citrus County study area are commonly in the range of 0.2 to 0.6 mg/l. It is impossible to separate the portion of nitrate contributed by fertilizers from the portion contributed by septic tanks and golf courses that are also present in residential areas. However, the results of both the Long Island and Florida studies make it reasonable to assume that turf fertilization is enriching the nitrogen content of ground water in the study area. To determine the accuracy of this statement it is recommended that a program of long-term monitoring of ground-water quality in the vicinity of several recently-constructed sewered subdivisions in the study area begin in the near future.

Stormwater runoff from residential areas is high in nitrogen (USEPA, 1983). This indicates that excess nitrogen applied to landscaping is leached out by rainfall and carried away by stormwater. Since stormwater in the study area eventually reaches the Floridan aquifer, it is important to determine the amount of nitrogen contributed to stormwater from turf fertilization and how much of that nitrogen reaches ground water. Although it is not possible to quantify the contribution to ground water, it is possible to quantify the amount of nitrogen contributed to stormwater from residential areas. This figure is 58 tons/yr (calculated on page 104), which is 18 percent of the 319 tons of nitrogen that may be applied to residential areas as fertilizer. Once again, the accuracy of the 319 tons/yr overall figure is very much in doubt. However, if it is "within the ballpark", then only a small amount of nitrogen from turf fertilization is removed by stormwater.

Golf Courses

There are eleven golf courses in the study area (Figure 32) covering approximately 1,865 acres. Determining the amount of nitrogen applied to golf courses as fertilizer is highly problematical. However, a study commissioned by the Sarasota Bay National Estuary Program (1992) estimated that 28 tons/yr of nitrogen is applied to a golf course with 15 acres of tees and greens and 200 acres of fairways. Therefore, the 1,865 acres of golf courses in the study area may be receiving approximately 243 tons/yr of nitrogen. When broken out by physiographic province the loadings are as follows:

Province		Estimated Golf Course Acreage	Nitrogen Loading (tons/yr)
Tsala Apopka Plain	=	190	25
Brooksville Ridge	=	1,300	169
Gulf Coastal Lowlands	=	375	49
Total	=	1,865	243

If this loading estimate is accurate, golf courses are one of the highest contributors of nitrogen to the land surface in the study area. A significant portion of the nitrogen is probably removed by the uptake mechanisms discussed previously. However, it is likely that nitrogen reaching ground water from golf course fertilizers is playing a significant role in elevating concentrations in the study area to the observed levels. To determine the accuracy of this statement it is recommended that a program of long-term monitoring of ground-water quality in the vicinity of golf courses in the study area begin in the near future.

Effluent and Sludge Disposal from Sewage Treatment Plants

There are approximately 42 active wastewater treatment facilities in the study area with a total permitted capacity of 3.6 mgd. Actual waste processed during 1992, as determined from the monthly operating reports of the individual facilities was 2.3 mgd. Figure 33 is a location map of the wastewater facilities. Table 6 contains the

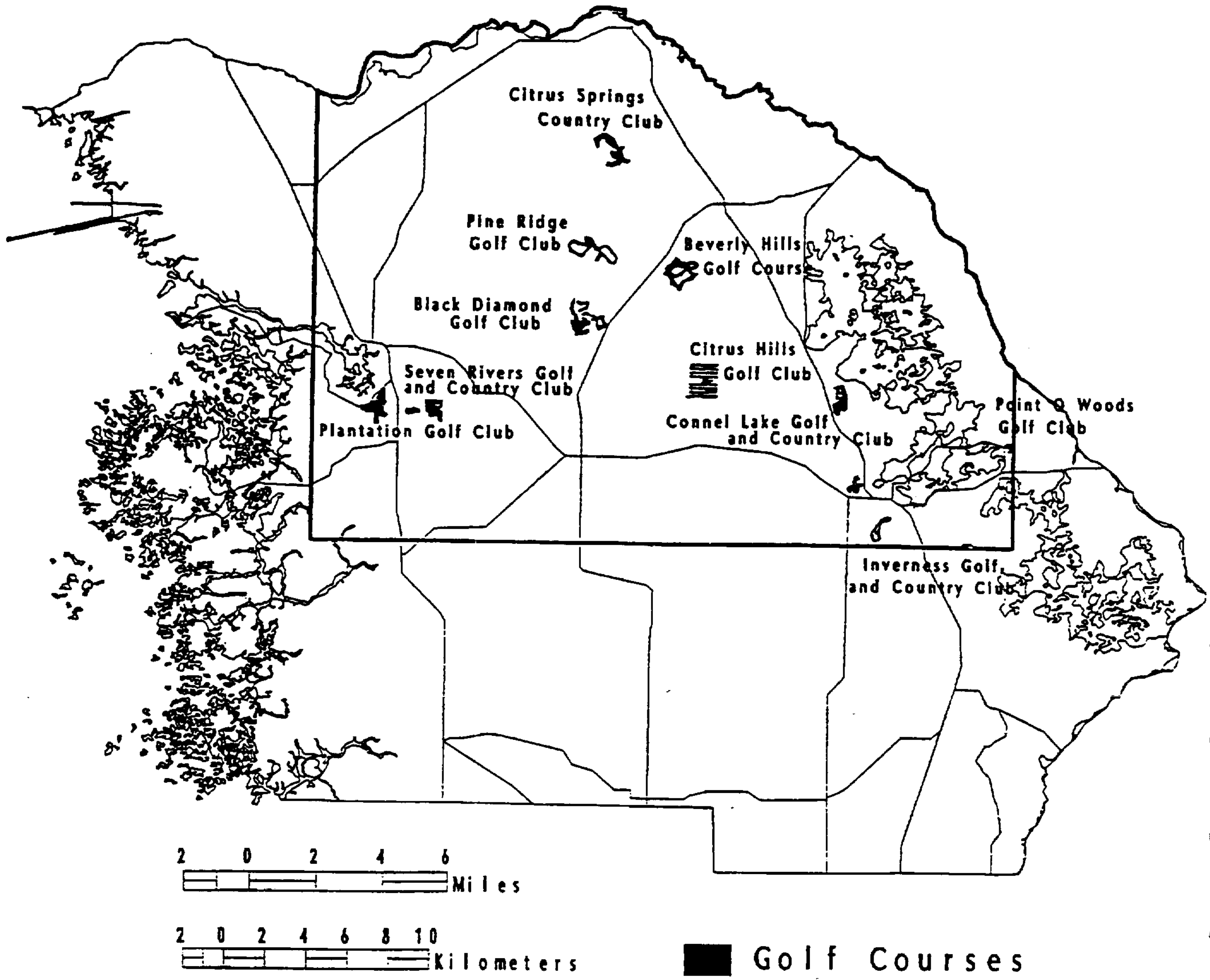


Figure 32. Location of Golf Courses in the Study Area.

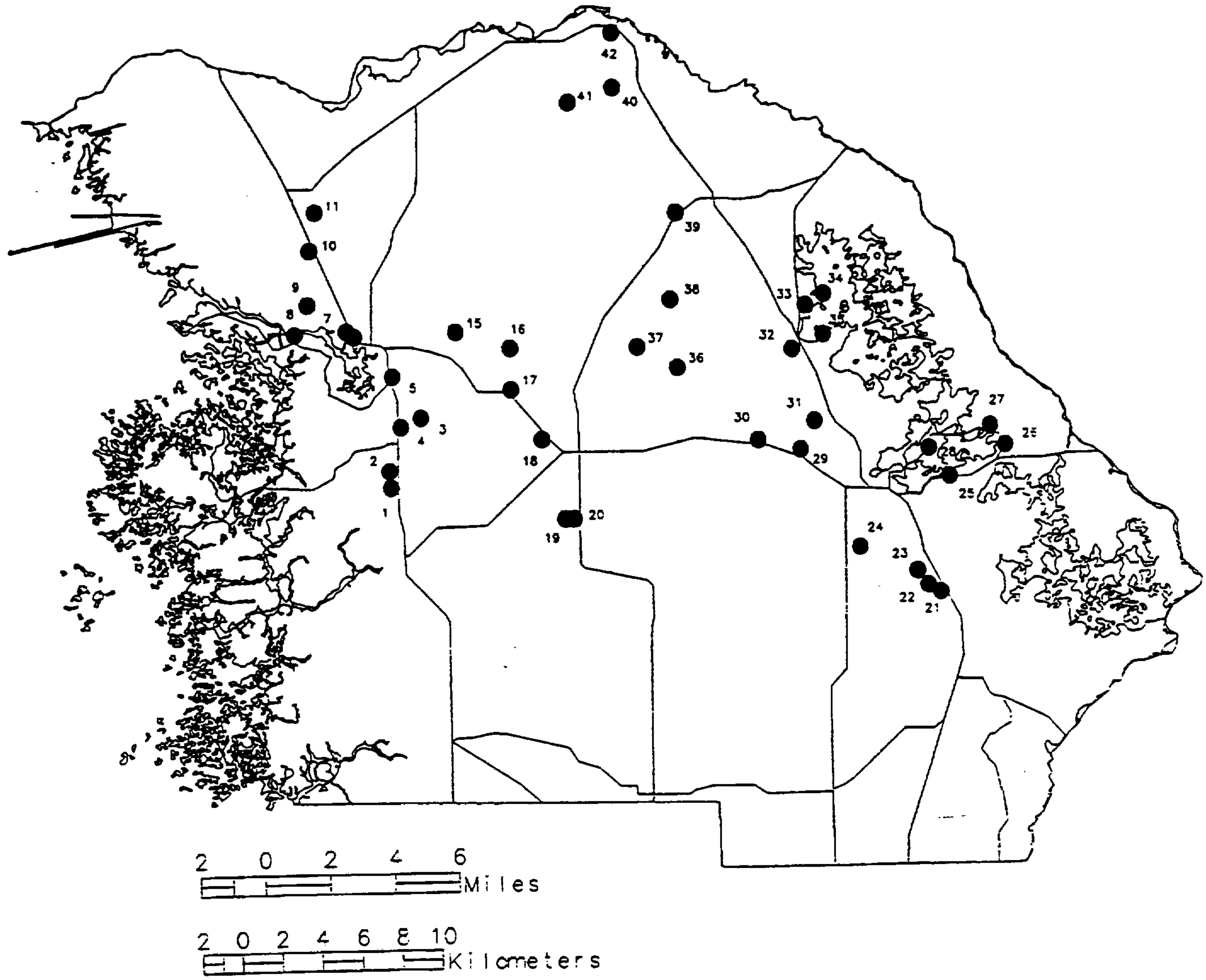


Figure 33. Location of Wastewater Treatment Facilities in the Study Area.

Table 6. Active Wastewater Treatment Facilities in the Study Area.

FACILITY	MAP INDEX	WASTEWATER TREATED IN 1992 (GALLONS)	EFFLUENT DISPOSAL METHOD
IMP. GARDENS MHP	1	790,000	PP
FOREST VIEW MHP	2	4,654,000	PP
SEVEN RIVERS GOLF	3	1,217,000	PP
FLORIDA POWER	4	365,000	PP
PLANTATION INN	5	5,231,000	SF
THUNDERBIRD MHP	6	1,025,000	PP
CITY OF CRYSTAL RIVER	7	273,689,167	SF
CRYSTAL RIVER MHP	8	1,065,000	PP
INDIAN SPRINGS	9	5,475,000	PP
COMFORT INN	10	1,551,000	PP
SEVEN RIVERS COMM. HOSPITAL	11	7,695,000	PP
RIVER LODGE RESORT	12	2,677,000	PP
NORTHWOOD ESTATES	13	3,230,000	PP
LK ROUSSEAU CAMP & FISH	14	2,616,000	PP
CRYSTAL ARMS MHP	15	1,095,000	SF
MEADOW CREST	16	28,257,083	PP
KEY PINE VILLAGE	17	1,003,750	PP
LECANTO HILLS MHP	18	1,003,750	PP
LECANTO SCHOOL COMPLEX	19	12,835,833	PP
PALM TERRACE MHP	20	5,292,500	SF
ENSIGNS OASIS	21	1,125,416	PP

Table 6. Active Wastewater Treatment Facilities in the Study Area (continued).

FACILITY	MAP INDEX	WASTEWATER TREATED IN 1992 (GALLONS)	EFFLUENT DISPOSAL METHOD
FORT COOPER MHP	22	2,701,000	PP
CITY OF INVERNESS	23	237,493,333	PP
ROYAL OAKS	24	3,577,000	PP
OAK POND MHP	25	2,402,917	PP
TWIN LAKES	26	976,375	PP
POINT O' WOODS	27	4,684,166	PP
HARBOR LIGHTS	28	784,750	SF
INVERNESS VILLAGE CONDOS	29	5,627,083	SF
CITRUS CENTER	30	9,672,500	PP
BLANTON MHP	31	2,399,875	SF
HERNANDO ELEMENTARY	32	1,460,000	PP
VENTURA VILLAGE	33	9,855,000	PP
APACHE SHORES	34	3,011,250	PP
LAKEVIEW SCHOOL	35	547,500	DF
GREENBRIAR	36	13,170,416	PP
BRENTWOOD	37	32,667,500	PP
BEVERLY HILLS	38	145,361,250	SF
SANDY OAKS	39	547,500	PP
CITRUS SPRINGS	40	30,180,000	PP
CITRUS SPRINGS ELEMENTARY SCHOOL	41	1,916,250	PP
SOUTH DUNNELLON WASTEWATER FACILITY	42	3,619,583	PP

name, map index number, actual effluent treated in 1992, and effluent disposal method for each facility. The facilities in the study area range from small package plants for mobile home parks and businesses with permitted capacities of 3,000 gpd to the City of Inverness Wastewater Treatment Plant with a permitted capacity of 1.5 million gpd.

The methodology used to estimate the total nitrogen loaded to the study area through the disposal of municipal wastewater from sewage treatment plants is explained in the following paragraphs.

The total volume of municipal wastewater entering treatment plants in the study area is 874 million gallons/yr. Total nitrogen concentrations in municipal wastewater range from 20 to 85 mg/l (U.S.E.P.A, 1981). An important factor that must be considered in determining an accurate value from this range is the degree to which the nitrogen concentration in sewage is diluted by ground-water inflow to buried sewer pipes. Because many areas in Florida have a high water table, ground-water inflow to pipelines is probably significant, which would result in a lower nitrogen concentration. A value of 40 mg/l, which the reference refers to as the median value, was chosen for the total nitrogen content of wastewater. Using 40 mg/l, the total amount of nitrogen in 844 million gallons is 146 tons. All 42 of the wastewater treatment plants currently treat to the secondary level. Secondary treatment typically removes approximately 10 to 40 percent of the total nitrogen from domestic wastewater (Ayers and Associates, 1991). Using an average of 25 percent removal, 36 tons is separated out and incorporated into the sludge fraction of the waste while the remaining 110 tons remains in the effluent fraction.

It is not possible to quantify the amount of nitrogen loaded to ground water from the treatment and disposal of municipal wastewater. However, a discussion of the potential for nitrate to reach ground water from the disposal of both treated effluent and sludge is presented in the following sections.

Effluent

The 110 tons of nitrogen in effluent from treatment facilities in the study area is disposed of in several different ways. Percolation ponds are used at 33 facilities, 7 use spray fields, and 1 uses a drainfield. Since the disposal facilities are near the treatment facilities, the 110 tons of nitrogen loaded to the study area can be broken out by physiographic province. This information is listed on the following page.

Province		Nitrogen Loading (tons/yr)
Tsala Apopka Plain	=	33
Brooksville Ridge	=	34
Gulf Coastal Lowlands	=	43
Total	=	110

According to the Citrus County Public Health Unit, Environmental Health Section, many of the percolation ponds drain extremely rapidly. This may be because several have a porus limestone bottom with no fine-grained filter material. Since the geology of the study area is such that low permeability confining units are either not present or are frequently breached by sinkholes, the treated effluent percolates directly into the Floridan aquifer. This direct connection with the Floridan aquifer is emphasized by the Environmental Health Unit's observation that the water levels in a coastal percolation pond fluctuate with Gulf of Mexico tides. In addition, a sinkhole opened in the percolation pond of the City of Inverness sewage treatment plant in December of 1993. An estimated 3 million gallons of effluent treated to the secondary level drained into the sinkhole within a few hours.

To further substantiate the connection between effluent percolation ponds and the Floridan aquifer, nitrate concentrations were obtained from monitor wells near the Beverly Hills sewage treatment plant. The Beverly Hills development is composed of a large number of single family homes in a relatively small area. The development is located in the Brooksville Ridge physiographic province. As shown in Figure 10, the Ridge is characterized by numerous sinkhole features some encompassing areas as large as several square miles. The Beverly Hills development is almost entirely contained within one of these extremely large sinkhole features and the sewage treatment plant and effluent disposal area are located near the bottom of the feature. The facility is large relative to most treatment facilities in the study area (Table 6) and because it is permitted to treat in excess of 100,000 gpd, monitoring of ground-water quality is required. Six shallow monitor wells, ranging in depth from 47 to 57 feet, encircle the effluent disposal site. Nine additional borings were also constructed to depths as great as 155 feet (Florida Department of Environmental Protection, 1993). Lithologic samples from the monitor wells and borings indicate the site is underlain mainly by fine-grained sands with discontinuous lenses of silty clay. Limestone was encountered in only one boring at a depth of approximately 75 feet. The fact that limestone was not encountered in deeper borings indicates that the limestone surface displays the considerable variation in elevation over short distances that is characteristic of karst terrains.

A nitrate concentration contour map of 1992 nitrate levels indicates that nitrate levels in monitor wells closest to the disposal site exceeded the drinking water standard of 10 mg/l and frequently were as high as 15 mg/l. Since the monitor wells are shallow, it is not possible to determine whether levels are also high beneath the spray field in the Floridan aquifer. However, because a competent confining layer was not indicated by the borings and the data in this report show significant recharge in this area, the relatively inert, sandy sediments are unlikely to attenuate the concentration of nitrate. Therefore, there is little to prevent ground water with high concentrations of nitrate from migrating to the Floridan aquifer. An indication that disposal of treated effluent in the spray field is increasing nitrate concentrations in Floridan aquifer ground water may be the elevated nitrate concentrations in the Beverly Hills production wells. Nitrate concentration data were obtained for eight of the nine production wells. These wells range from 280 to 405 feet deep which places them well within the productive potable zone of the Floridan aquifer. Nitrate concentrations in these wells range from 0.1 to 0.73 mg/l with a mean concentration of 0.44 mg/l. These concentrations, while well below the drinking water standard for nitrate (10 mg/l), are high for ground water in Citrus County and could indicate contamination from the nearby sprayfield. It could also be argued that flow of nitrate-rich water from Lake Tsala Apopka under the Brooksville Ridge could be the source of elevated nitrate in the Beverly Hills production wells. However, comparison of historic and recent water-quality data from Beverly Hills production wells shows that nitrate concentrations increased between 1980 and 1989 in all but one well and the average increase was 0.14 mg/l. The fact that nitrate is increasing in the production wells supports the Beverly Hills spray field and/or septic tank/turf fertilization source and probably rules out the natural lake source. This is because concentrations of nitrate from Lake Tsala Apopka would have been in the system at low, stable levels for thousands of years and would not be responsible for the rapidly increasing levels in the production wells.

The seriousness of the sewage effluent source is underscored by the fact that nitrate concentrations in wells monitoring the waste disposal systems of several other municipalities in the study area also show high levels of nitrogen (Citrus County Public Health Unit, 1993).

Sludge

Sludge generated in the study area is disposed of at four sites in the study area and one site several miles to the south (Figure 34). The Domestic Waste Section of the DEP is responsible for overseeing sludge disposal. The calculations discussed previously indicate that sludge generated in the study area may contain approximately 36 tons of nitrogen. According to the DEP, most of the sludge is disposed of at the Allen Ranch in the Brooksville Ridge province. Beverly Hills disposes sludge at the Hoierman site and is the exclusive user. A small amount is disposed of at the County Landfill and the Cunningham Ranch and the City of Crystal River disposes at the Cason property in the southern portion of Citrus County outside the study area. Since the amount of wastewater treated by each facility, as a percentage of the total volume of wastewater generated in the study area, is known, nitrogen loading to each

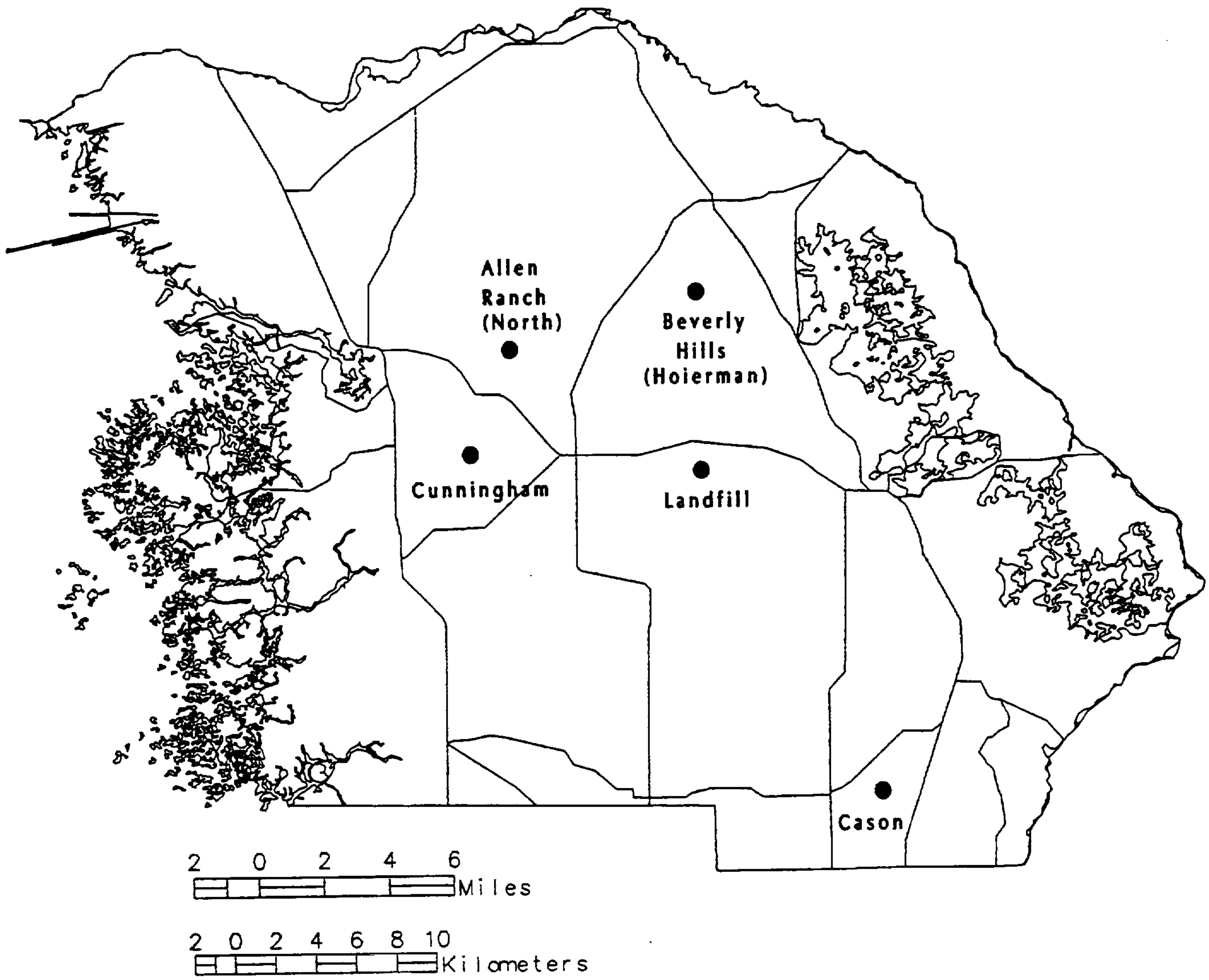


Figure 34. Location of Sewage Sludge Disposal Sites in and near the Study Area

physiographic province from sludge disposal can be determined.

Province		Nitrogen Loading (tons/yr)
Tsala Apopka Plain	=	0
Brooksville Ridge	=	25
Gulf Coastal Lowlands	=	0
Total	=	25

Eleven tons from the Crystal River facility is disposed outside the study area at the Cason property.

Sludge spreading sites in the study area are privately owned agricultural lands (with the exception of the county landfill site). Because the waste has value as fertilizer, the owners of the land grant disposal companies permission to spread the waste on their land. Sludge waste is brought to the spreading sites by disposal companies that contract with the municipalities or the individual treatment plants.

Land spreading of sludge can contaminate ground water because the waste contains high concentrations of nutrients, trace metals, and organic compounds. If the application rate of the sludge exceeds the capacity of the vegetation or soils to utilize or adsorb these compounds, they may percolate downward into ground water (Johnson, 1979). Chapter 17-640 of the Florida Administrative code states that sludge disposal sites on agricultural lands must have an agricultural use plan that details how sludge will be used as a part of a planned agricultural operation. The nitrogen requirements of the crop must be calculated and sludge applications can not exceed this level. Although these stipulations have been carefully formulated to prevent ground and surface-water contamination, it is questionable as to whether the rules are always followed by the land owner or stringently enforced by the DEP. However, even if compliance and enforcement is lax, the quantity of nitrogen in sludge spread on agricultural lands in the study area is small and the effect on ground water probably insignificant.

Septage Spreading

Land spreading of septage waste is regulated by the Citrus County Public Health Unit, Environmental Health Section. Although both septage and sludge wastes can be disposed of at the same site, they must be spread in separate designated areas.

The locations of active and inactive septage spreading sites in the study area are plotted in Figure 35. There are three active and nine inactive sites in the study area. Information concerning acreage and status of each site is listed in

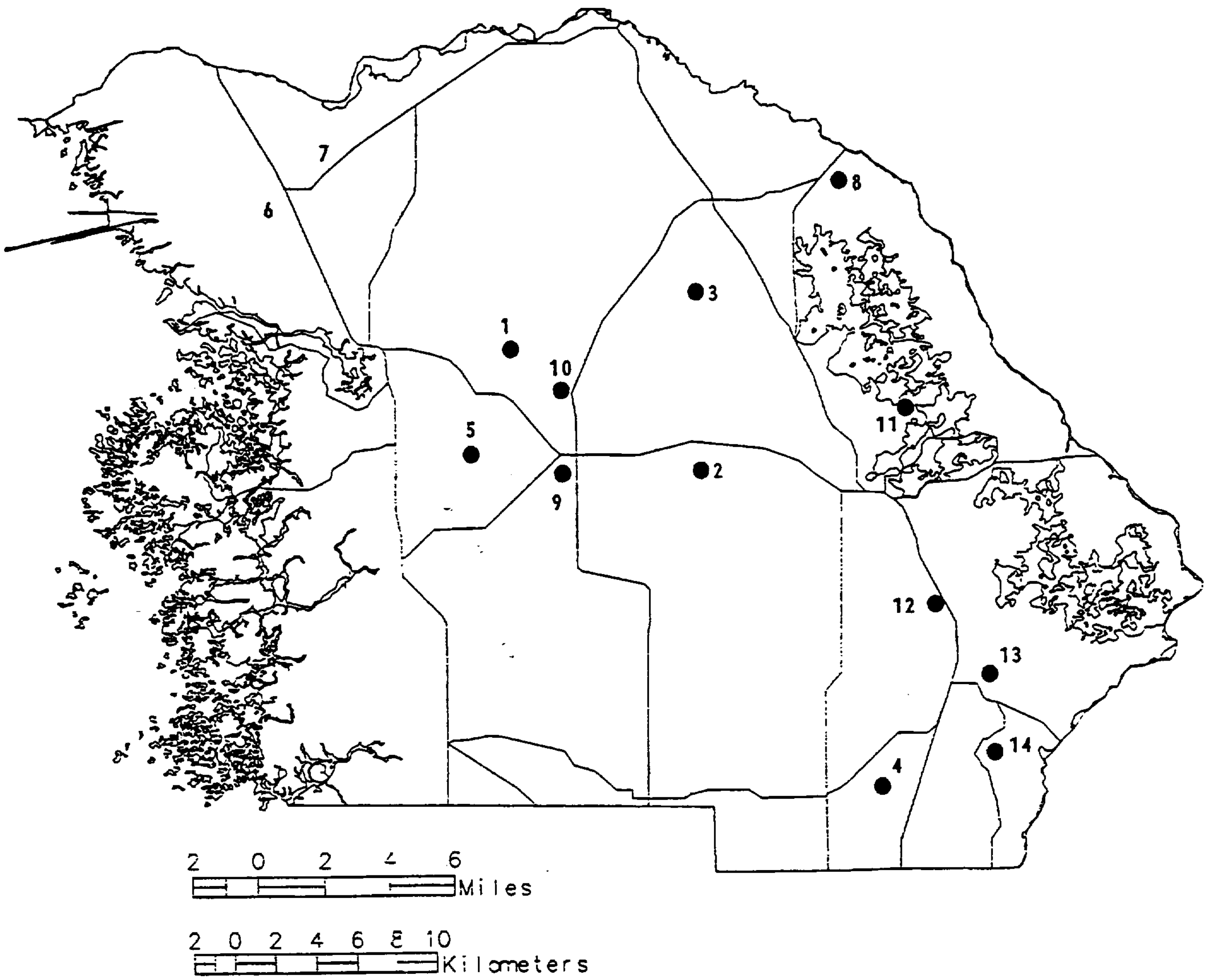


Figure 35. Location of Septage Sludge Disposal Sites in the Study Area.

Table 7 (Citrus County Public Health unit, 1993). Septage sites, similar to sludge sites, are privately owned agricultural lands. Septage waste is brought to the spreading sites by disposal companies that revitalize septic tanks.

Similar to sludge, septage also contains high concentrations of nutrients, trace metals, and organic compounds which can contaminate ground water if the application rate exceeds the capacity of the vegetation or soils to utilize or adsorb these compounds. It is difficult to quantify nitrogen loading to ground water from land spreading of septage waste because no records have been kept as to the frequency and volume of applications. However, enough information exists to allow for a nitrogen loading calculation that can be considered a "ball-park" approximation. These calculations are explained below.

In January of 1993, disposal sites began to be permitted for the maximum amount of septage waste they could accept each year. Using the actual amount applied on the active sites as determined by Citrus County Public Health Unit Environmental Section personnel, a total amount of 964,000 gallons/year was applied in the study area. The county allows approximately 19,200 gallons/acre to be applied each year at each site. This is considered to be the amount of nitrogen that is utilized by 1 acre of Bahia grass each year (Florida Department of Environmental Regulation, 1989). This volume contains approximately 320 lbs of nitrogen. The following amounts of nitrogen are loaded each year at the active sites:

Site	Province	Nitrogen Load (tons/yr)
Allen Ranch (north)	Brooksville Ridge	3.1
Tucker Ranch	Brooksville Ridge	1.6
Cunningham Ranch	Gulf Coastal Lowlands	3.3
Total		8.0

Eight tons/yr of nitrogen spread at three sites in the study area is probably easily removed by the mechanisms discussed previously. Therefore, it is highly unlikely that nitrogen from septage spreading is affecting ground-water quality in any way.

Agriculture

Agricultural loadings of nitrogen in the study area are subdivided into row crops, citrus, and dairies and beef cattle raising.

Row Crops

Row crops are a relatively minor land use in Citrus County covering only about

Table 7. Active and Inactive Septage Spreading Sites in the Study Area.

FACILITY	MAP INDX. NO.	PROVINCE	ACRE	PERMITTED vs ACTUAL AMT SPREAD (gal/yr)	STATUS
Allen Ranch (North)	1	Brooksville Ridge	19.4	372,000/372,000	Active
Cunningham Ranch	2	Gulf Coast Lowlands	450	8,640,000/400,000	Active
Tucker Ranch	3	Brooksville Ridge	10	192,000/192,000	Active
Priest Ranch (West)	4	Gulf Coast Lowlands	?	N/A	Inactive
Priest Ranch (East)	5	Gulf Coast Lowlands	?	N/A	Inactive
Arrowhead	6	Tsala Apopka Plain	?	N/A	Inactive
McKenyon Farm	7	Brooksville Ridge	?	N/A	Inactive
Allen Ranch (Center)	8	Brooksville Ridge	?	N/A	Inactive
Charlie Dean Ranch	9	Tsala Apopka Plain	?	N/A	Inactive
LaPearle Memorial	10	Tsala Apopka Plain	?	N/A	Inactive
Townsend Ranch	11	Tsala Apopka Plain	?	N/A	Inactive
Harrison Farm	12	Tsala Apopka Plain	?	N/A	Inactive
Hale Property	13	Tsala Apopka Plain	?	N/A	Inactive

624 acres in 1993 (Andy Rose, University of Florida Cooperative Extension Service, pers. comm., 1993). The crops include watermelons, tomatoes, strawberries, onions, and blueberries. Most of the row crop acreage, with the exception of watermelons, is south of the study area. As much as 450 acres of watermelons may be planted in the Brooksville Ridge portion of the study area. According to the University of Florida Cooperative Extension Service, watermelons require approximately 120 lbs/ac/yr of fertilizer. This means that approximately 27 tons of nitrogen fertilizer is applied to watermelons in the study area. This amount is insignificant especially when the vegetative uptake and soil removal mechanisms are considered. Historical nitrogen loading from row crops is probably minor since the analysis of historical aerial photographs indicates that row crops were a minor land use in 1965.

Citrus

Studies in Polk and Hillsborough Counties have indicated that citrus production can elevate ground-water nitrogen to very high levels (Jones and Upchurch, 1993; SWFWMD/DEP,1990). Interpretation of historical aerial photographs indicates that citrus in the study area covered approximately 2,600 acres in 1965. According to the University of Florida Cooperative Extension Service, mature trees require approximately 150 lbs/ac/yr of ammonium nitrate fertilizers. This would have resulted in an application of approximately 196 tons of nitrogen annually to the study area.

In 1983 and 85, severe freezes killed most of the trees. According to the University of Florida Cooperative Extension Service, replanting of citrus since 1985 has resulted in approximately 45 acres of new trees in the study area. Because young trees require less fertilizer than mature trees, only about 100 lbs/ac/yr is used. Using the method discussed above, the fertilization of 45 acres of citrus would result in an annual application of approximately 4,500 pounds of nitrogen to the study area.

Overall, current nitrogen loading from citrus production is insignificant in the study area due to the small amount of acreage that remains following freezes in the 1980s. Prior to 1983, nitrogen loading from citrus fertilization was as high as 196 tons/yr at least as far back as 1965. This amount of nitrogen may have significantly elevated nitrate levels in areas where past densities of citrus were high. These areas include the Lake Rousseau area and the Inverness vicinity where fertilization of former citrus areas may have increased the nitrate levels in ground water around the city itself and several miles to the south. This area, however, may be more strongly influenced by high densities of septic tanks, effluent disposal from sewage treatment, and inputs from Lake Tsala Apopka.

Dairy and Beef Cattle Production

Dairies have been determined to be a significant source of nitrate to springs in Hillsborough County (Jones and Upchurch, 1993). However, analysis of aerial photographs and discussions with the U.S. Soil Conservation Service and the Citrus County Agricultural Extension Service indicate that cattle dairies do not exist and have not existed in Citrus County. However, a goat dairy exists in the Brooksville Ridge portion of the study area south of the Lecanto area. Because this is the only dairy in the study area, nitrogen contributions to ground water from the dairy land use are probably insignificant.

Beef cattle raising in Citrus County, although not a major land use, occupies a significant portion of the study area (Figure 3, pasture acreage). There are approximately 15,000 acres of unimproved and improved pasture in the study area (Southwest Florida Water Management District, 1989). According to the Florida Department of Agriculture and Consumer Services (1990), there were approximately 6,000 beef cattle in Citrus County in 1990. According to the Soil Conservation Service (pers. comm, 1990) beef cattle produce 0.33 lbs of nitrogen per day per 1000 lbs of body weight. If it is assumed that the individual cattle weigh an average of 1000 lbs, then the total amount of nitrogen supplied by cattle to Citrus County is approximately 361 tons per year. Although this number seems high, there are several factors that reduce the actual amount of nitrogen that reaches ground water. First, the number of cattle reported by the Florida Department of Agriculture and Consumer Services is for the entire county not just the study area. Citrus County contains approximately 580 square miles that are more or less dry land. The study area is about half this size. If it is assumed that cattle are evenly distributed across the county, then the study area contains only half of the cattle in the county which also halves the amount of nitrogen contributed by cattle to 180 tons. Dividing this figure by the percentage of pasture in each physiographic province of the study area provides the loading amounts below.

Province	Nitrogen Loading (tons/yr)
Tsala Apopka Plain	36
Brooksville Ridge	86
Gulf Coastal Lowlands	58
Total	180

The significance of this amount is reduced because the cattle are widely dispersed and not concentrated into small feedlot areas. Because they are dispersed, the nitrogen in their waste is more likely to be removed by the many uptake mechanisms discussed previously. When all of these factors are taken into account, the amount of nitrogen contributed by beef cattle in the study area is probably insignificant.

In addition to nitrogen from cattle, additional nitrogen is applied to pasture in the form of fertilizers to promote the growth of pasture grasses. It is not possible to determine the amount of nitrogen applied to pasture grass. This is because there is no way to determine how much of the 15,000 acres of pasture in the study area is fertilized. Discussions with University of Florida Cooperative Extension Service personnel have indicated that fertilized pasture acreage is probably a low percentage of the total. In addition, studies indicate that if the recommended amount of fertilizer, approximately 40 to 50 lbs/ac/yr (and ranchers may tend to stay within the recommended level out of economic necessity), is applied to pasture, very little will travel beyond the root zone. Taking these factors into consideration, the amount of nitrogen loaded to ground water as a result of pasture fertilization is probably insignificant.

Stormwater Runoff

In karst areas, stormwater is responsible for transporting a wide variety of highly concentrated pollutants directly into aquifer systems through sinkholes where little or no filtration occurs (Environmental Engineering Consultants, 1990). This problem is exacerbated by the fact that residential and commercial stormwater systems are often designed to funnel stormwater directly to sinkholes because they are the lowest points in an area.

Determining the amount of nitrogen in stormwater is necessary to illustrate the importance of proper storage and treatment of stormwater. It must be noted that storm water is not an additional source of nitrogen. It is simply what runs off during rainfall events from the actual sources of nitrogen calculated previously in this report.

To calculate the nitrogen in stormwater runoff from various land uses, data from the EPA's Nationwide Runoff Program (USEPA, 1983) were utilized. Table 8 lists the event mean concentration (EMC) values for nitrogen loading of stormwater for a number of land uses. It is generally accepted in the field of stormwater management that these values can be used in place of local monitoring programs to quantify nitrogen loading of stormwater (Sarasota Bay National Estuary Program, 1992).

For total nitrogen, the EMC values are highest for golf courses, cropland, citrus, and low-to medium-density single-family residential land uses. This results from the fertilization of these areas. Industrial and commercial areas have the lowest EMC values because they are not fertilized. However, it should be noted that nitrogen loading depends not only on the EMC value but on the volume of surface runoff for a particular land use. Because commercial and industrial land uses have a much greater percentage of impervious area than residential land use, they tend to produce greater loadings in terms of lb/ac/yr, even though they are characterized by lower EMC values.

Table 8. Event Mean Concentration and Runoff Coefficient for Important Land Uses in the Study Area.

LAND USE	RUNOFF COEF	EVENT MEAN CONCENTRATION TOTAL NITROGEN (mg/l)
Golf Courses	0.15	2.70
Residential *	0.15	1.76
Commercial	0.95	1.18
Cropland	0.15	3.74

* includes low, medium, and high density single family residential, multi-family residential, and mobile homes. EMC values of these residential categories were averaged to provide one value of 1.76 mg/l

The only land uses that were included for the stormwater nitrogen calculations were golf courses, residential, commercial, and cropland. Other land uses such as industrial, citrus, pasture, and unimproved areas were not included either because the acreage of the land use in the study area was insignificant or a value for the event mean concentration could not be found.

The equation used to determine nitrogen loading of stormwater from a given land use was obtained from a pollution loading assessment of Sarasota Bay completed by the Sarasota Bay National Estuary Program (1992). This equation is:

$$N = r \cdot EMC \cdot A \cdot R, \qquad (5)$$

where:

N = total nitrogen (lbs/yr) in stormwater from a given land use;

r = runoff coefficient (0.15 for pervious areas and 0.95 for impervious areas);

EMC = event mean concentration (mg/l);

A = area occupied by the land use of interest (acres); and

R = total annual rainfall (gal) occurring over the area of the land use of interest.

Table 9 lists some of the land uses that contribute significant amounts of nitrogen to stormwater and the amount of nitrogen estimated to be contributed annually by each land use to stormwater using the above calculation. Approximately 79 tons of nitrogen is contained in stormwater from the listed land uses in the study area.

Table 9. Stormwater Nitrogen Contribution from Four Important Land Uses in the Study Area.

LAND USE	PHYSIOGRAPHIC PROVINCE			TOTAL NITROGEN (tons/yr)
	T.A.P	B.R.	G.C.L.	
RESIDENTIAL	12	27	19	58
COMMERCIAL	2	6	6	14
GOLF COURSES	1	3	1	5
CROPLAND	0	2	0	2
TOTAL	15	38	26	79

It is impossible to determine how much of the nitrogen in stormwater may actually reach ground water. Many factors such as partially blocked or plugged sinkholes and the many other uptake and removal mechanisms discussed previously could serve to lessen the impact of stormwater nitrogen on ground water.

Nitrogen Loading Summary

Table 10 is a summary of the nitrogen contributions of the various sources in the study area. It must be stressed that the high uncertainty involved in calculating the estimates and the fact that nitrogen contributions from three of the sources could not be quantified at all, brings the accuracy of the estimates into question. It must also be stressed that what is being estimated for each of the sources, with the exception of septic tanks and turf fertilization, is the amount of nitrogen that reaches the land surface, not that reaches ground water. Since the removal mechanisms discussed previously can drastically reduce the amount of nitrogen that actually reaches ground water, the nitrogen loading estimates, except for septic tanks and turf fertilization, give no indication of the degree to which a specific source is enriching the nitrogen content of ground water. The utility of the estimates lies in the information they provide as to the relative nitrogen contributions of the sources. This allows us to ignore sources that produce relatively small amounts of nitrate and concentrate regulatory efforts on those that produce significant quantities. Sources that can be

Table 10. Nitrogen Loading Sources and Nitrogen Loaded By Physiographic Province (tons/yr).

LAND USE	PHYS. PROVINCE T.A.P | B.R. | G.C.L.	SIGNIFICANCE
Naturally Occurring	? | ? | ?	Uncertain - ground-water nitrogen in background areas is low, however, organic decay in Lake Tsala Apopka may contribute large quantities of nitrogen to ground water
Rainfall	254 | 544 | 348 (reaches surface)	Probably insignificant - ground-water nitrogen in background areas is low, most rainfall nitrogen removed by vegetative uptake or immobilized in soil layer
Septic Tanks	58 | 77 | 77 (reaches ground water)	Very significant - these quantities are reaching ground-water
Turf Fertilizer	38 | 90 | 63 (reaches ground water)	Probably significant - if loading estimates are accurate, these quantities are reaching ground water.
Golf Courses	25 | 169 | 49 (reaches surface)	Probably significant - if estimates are accurate, golf courses are one of the highest nitrogen loading sources to the surface in the study area
Sewage Effluent Disposal	33 | 34 | 43 (reaches surface)	Significant - nitrate contamination of ground-water is occurring at sites in the study area
Land Disposal of Sludge	0 | 25 | 0 (reaches surface)	Insignificant - quantity of nitrogen from sewage sludge spread at sites in study area is low
Land Disposal of Septage Sludge	0 | 4.7 | 3.3 (reaches surface)	Insignificant - quantity of nitrogen spread at sites in study area is very low
Row Crops	low | 27 | low (reaches surface)	Insignificant - row crops are a minor land use in the study area
Citrus	low | 2 | low (reaches surface)	Insignificant - citrus industry in study area greatly reduced by freezes in mid 1980s, however, past citrus production may contribute to elevated nitrate levels in the Lake Rousseau and Inverness areas
Fertilized Pasture	? | ? | ?	Insignificant - majority of pasture is not fertilized - where pastures are fertilized, vegetative uptake and soil attenuation remove majority of nitrogen
Beef Cattle	36 | 86 | 58 (reaches surface)	Probably insignificant - cattle widely dispersed, nitrogen in waste is utilized by pasture grasses and attenuated in soil layer

discounted include land disposal of sewage and septage sludge, row crops, and citrus.

The greatest contributor of nitrogen to the study area is rainfall. However, rainfall is discounted as a significant source of nitrogen to ground water because wells in undeveloped portions of the study area generally have very low concentrations of nitrate. If rainfall were a significant source, ground water would probably have a uniformly elevated nitrate concentration across the entire study area. Rainfall nitrogen is probably readily removed because it is applied in small quantities during numerous events to plant communities that utilize it. In addition, a large portion is lost to the many surface removal mechanisms discussed previously.

Similar to the rainfall source, the naturally occurring organic decay source is probably insignificant over most of the study area. This is because microbes and plants in the soil layer utilize and recycle the nitrogen as soon as it is made available. The limited effect of naturally occurring nitrogen on ground water quality is verified by the fact that nitrate concentrations are low in ground water in undeveloped and unaffected areas of Citrus County where the only sources of nitrogen are organic decay and rainfall.

A nitrogen source that may be significant is the flow of nitrogen-rich water from Lake Tsala Apopka and Lake Rousseau into the Floridan Aquifer. Elevated nitrogen in ground water beneath and down gradient of the lakes may be natural, having resulted from decomposition of organic material in the lake. However, nitrogen from anthropogenic sources that have enriched runoff and rainfall may have reached the lakes and increased the amount of nitrogen entering the aquifer. Nitrogen-enriched ground water from Lake Tsala Apopka appears to be moving toward the King's Bay Springs. This water may have been contributing low levels of nitrogen to the springs for thousands of years. However, because Lake Rousseau was constructed relatively recently, it has probably not yet begun to affect the springs.

Pasture fertilization and beef cattle waste probably have a minimal impact on nitrogen concentrations in ground water. Although the amount of nitrogen loaded to the land surface as a result of pasture fertilization is not known, the affect of these fertilizers on ground water quality is probably minimal. This is because fertilized pasture acreage is probably a low percentage of the total pasture acreage. In addition, studies indicate that if the recommended amount of fertilizer for pasture, approximately 40 to 50 lbs/ac/yr is applied, it is not likely to travel beyond the root zone.

The estimate of beef cattle waste nitrogen loaded to the surface of the study area is approximately 180 tons/yr. Although this amount is significant, it may have little effect on ground-water quality because the cattle are widely dispersed in the study area, not concentrated into small feedlot areas. Because they are dispersed, the nitrogen in their waste is more likely to be removed by the many vegetative and soil uptake mechanisms discussed previously.

The remaining sources are probably the most significant contributors of nitrogen to ground water in the study area. In order of importance from most important to least, these are septic-tank effluent, sewage effluent disposal, golf course fertilizers, and landscape fertilizers. These sources are associated with the residential and commercial development boom that has occurred in the study area within the last 20 years. An important indication that these sources contribute the majority of nitrogen to ground water in the study area is the correspondence of the areas of high nitrogen to the areas undergoing rapid commercial and residential development. This is most apparent from the plot of total nitrogen (Figure 25a). Areas of high nitrogen correspond to the developed north-south U.S. 41 corridor from the southern boundary of the study area to the northern most extent of Lake Tsala Apopka. Nitrogen is also elevated in a rapidly developing, 5 to 7 mile-wide, east-west corridor north of S.R. 44 from Lake Tsala Apopka to the City of Crystal River. Finally, nitrogen is high along the north-south U.S. 19 corridor from Homosassa Springs to the City of Crystal River.

Septic-tank effluent may be one of the principal sources of nitrogen because the 17,000 septic tanks in the study area contribute approximately 212 tons/yr of nitrate directly to ground water. Similarly, nitrogen-rich effluent from sewage treatment plants is often disposed of in unlined percolation ponds or spray fields. The sandy, sinkhole-prone terrain insures that the effluent rapidly infiltrates into the Floridan aquifer with relatively little reduction in nitrogen.

Eleven golf courses in the study area contribute approximately 243 tons of nitrogen to land surface in the study area. Because the nitrogen is loaded over a relatively small area, it could overload the vegetative and soil removal mechanisms and reach ground water in significant quantities. To determine the degree to which this is occurring, ground water quality in the vicinity of golf courses should be monitored as it is in several other counties in the state.

The estimated quantity of nitrogen applied to turf in the study area was very high (319 tons/yr). If, as determined by a study conducted in New York, 60 percent of the nitrogen reaches ground water, then 191 tons reaches ground water annually in the study area. However, the methodology utilized to determine the nitrogen loading from turf in the study area was highly problematical and may have resulted in a value that is significantly over or under estimated. In any case, applying the results of studies conducted in New York and Florida to the study area indicates that turf fertilization may be contributing significant quantities of nitrogen to ground water. Similar to golf courses, ground water quality in the vicinity of selected sewered subdivisions should also be monitored to determine the degree to which turf fertilization is enriching nitrate levels.

CONCLUSIONS

1. Previous studies have determined that the numerous springs and seeps in King's Bay discharge ground water at the rate of approximately 975 ft^3/s (630 mgd).

2. Approximately 196 tons of nitrate as N are contained in ground water discharging from the King's Bay Springs every year.

3. The average nitrate concentration of ground water discharging from the eleven largest springs in King's Bay is approximately 0.2 mg/l (NO_3 as N). Although this level is low relative to many springs in more developed counties, it is considerably elevated over nitrate concentrations in ground water in the undeveloped portions of the study area.

4. One hundred and two wells were sampled for nitrate in the study area. Thirty two percent had concentrations between 0.2 to 0.6 mg/l (NO_3 as N) and seven percent had concentrations exceeding 0.6 mg/l. These figures indicate that areas where nitrate in ground water is significantly elevated above naturally-occurring levels (generally < 0.01 mg/l) are widespread.

5. Historical nitrate data for study area spring water and ground water are extremely limited. However, a sample collected in 1975 from Tarpon Hole, the main spring in King's Bay, indicates that nitrate concentrations have increased by a factor of three between 1975 and the present. In addition, 3 dedicated monitor wells sampled for this study in 1992 were also sampled for nitrate in 1985. Although the 1992 sampling indicates that nitrate concentrations are still low relative to the drinking water standard of 10 mg/l, they have shown rapid and significant increases in the intervening 7 years.

6. Ground water in the springs is largely derived from the drainage basin bounded by the Withlacoochee River and a flow-line divergence in south-central Citrus County. Water in the Floridan aquifer to the north of this divergence will discharge at the King's Bay Springs while water south of the line will discharge at Homosassa Springs.

7. Sulfate concentration and isotopic data reflect a shallow flow system. Water that is discharging from the King's Bay Springs entered the Floridan aquifer flow system within the last 50 years.

8. Sodium/chloride, nitrogen-concentration, and hydrochemical facies data show significant ground-water recharge in the Beverly Hills area.

CONCLUSIONS (continued)

9. Ground water in the Coastal Swamp and Brooksville Ridge physiographic provinces is nutrient and TOC-rich, indicating local recharge.

10. Nutrient data suggest that losses from Lake Tsala Apopka may have served as a low-level natural nitrogen source for the springs for thousands of years.

11. A plume of what is probably naturally occurring nitrogen is moving toward the springs from Lake Rousseau. Because the Lake was constructed relatively recently, it has probably not yet affected the springs.

12. Nitrogen isotopic data suggest that a portion of the nitrogen in the springs and in ground water in the study area is natural.

13. There are small localized sources of development-related nitrogen in the eastern portion of the City of Crystal River. This development-related nitrogen along with naturally occurring nitrogen are probably the sources of the low levels of nitrogen in ground water discharging from the springs.

14. The many nitrogen releases resulting from land uses that exist in the study area are elevating ground-water nitrogen concentrations. Ground water that has been enriched in nitrogen from both development-related and natural sources is moving toward the coast in well-defined plumes from the east-central and north-central portions of the study area. Within 20 years this nitrogen will reach the King's Bay Springs and probably increase nitrogen concentrations significantly.

15. Ten development-related sources of nitrogen common to the study area were investigated. Of these, four sources, septic tank effluent, effluent disposal from sewage treatment, golf course fertilization, and turf fertilization are probably contributing the majority of nitrogen to ground water. These sources are associated with residential and commercial development and can be correlated to areas where nitrogen concentrations are elevated in ground water. Although the nitrogen contributed by these sources is significantly attenuated by the various vegetative and soil removal mechanisms, enough reaches ground water to elevate concentrations to the 0.5 to 1.0 mg/l range that is the upper limit in the developed portion of the study area.

16. The rapid increase in the number of the four principal sources listed above insures that nitrogen concentrations will continue to increase.

17. Storm-water runoff in the karst terrain may be responsible for feeding fertilizer-derived nitrogen into the ground-water system.

RECOMMENDATIONS

1. The nitrogen sources on the eastern side of the City of Crystal River should be located and mitigated.

2. Planning for elimination of septic tanks in central Citrus County should begin immediately, with a target for county sewer service by the year 2015. First priority should be given to the areas where high nitrogen is present in the Floridan aquifer.

3. Municipal wastewater treatment facilities should either go to advanced wastewater treatment (AWT) or other nutrient removal technologies.

4. Stormwater runoff should not be routed directly to sinkholes. Runoff retention and plant fixation of nutrients is a necessary management alternative for sinkholes that receive stormwater from suburban and urban areas.

5. Monitor-well networks should be installed around golf courses and selected non-sewered residential areas to determine the effect of turf fertilization on ground-water quality.

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APPENDICES

APPENDIX I

Specifications, Water Quality Data, and Quality Assurance Data for Sampled Wells and Springs

Springs Water-Quality Data

Hunters Spring

Date	AGWQMP ID	Field pH	Field Temp	Field Cond	HCO3 as CaCO3	HCO3 as HCO3	CO3 as CaCO3	Cl	SO4	F	S	Ca	Mg	K	Na	(N) NH3
4/29/91	SP-010	7.80	23.5	380.0	80.0	98.0	-2.00	66.0	16.0	0.06	-0.20	29.0	8.0	1.20	41.0	-0.01
7/29/91	SP-012	8.17	24.0	320.0	65.6	80.0	-2.00	39.0	14.0	0.07	-0.20	29.0	7.8	0.89	23.0	-0.01
10/24/91	SP-014	7.83	24.5	270.0	80.4	98.0	-2.00	28.0	10.0	0.06	-0.01	30.0	5.8	0.70	17.0	0.02
02/11/92	SP-006	8.10	24.0	370.0	80.4	98.0	-2.00	57.0	14.0	0.06	-0.01	30.0	7.2	1.20	32.0	-0.01

Catfish Corner Spring

Date	AGWQMP ID	Field pH	Field Temp	Field Cond	HCO3 as CaCO3	HCO3 as HCO3	CO3 as CaCO3	Cl	SO4	F	S	Ca	Mg	K	Na	(N) NH3
4/29/91	SP-011	7.92	24.0	290.0	98.0	119.0	-2.00	34.0	18.0	0.07	-0.02	27.0	7.2	0.69	21.0	-0.01
7/29/91	SP-013	8.10	24.0	290.0	64.0	78.0	-2.00	26.0	18.0	0.08	-0.20	28.0	8.1	0.61	16.0	-0.01
10/23/91	SP-012	7.83	25.0	280.0	72.2	88.0	-2.00	29.0	16.0	0.07	-0.01	28.0	6.7	0.60	17.0	0.01
02/11/92	SP-005	8.23	24.0	280.0	77.9	95.0	-2.00	29.0	16.0	0.07	-0.01	28.0	6.9	1.00	17.0	-0.01
8/03/92	TRIT-1	8.10	26.0	220.0	76.0	92.7		28.0	15.0			26.0	6.1	0.40	13.0	
04/12/93		7.70	27.1	778.0												0.001

Manatee Sanctuary Spring

Date	AGWQMP ID	Field pH	Field Temp	Field Cond	HCO3 as CaCO3	HCO3 as HCO3	CO3 as CaCO3	Cl	SO4	F	S	Ca	Mg	K	Na	(N) NH3
4/29/91	SP-012	7.89	24.0	400.0	90.0	110.0	-2.00	70.0	13.0	0.05	-0.20	31.0	7.7	1.50	42.0	-0.01
7/30/91	SP-016	7.99	24.0	353.0	72.2	88.0	-2.00	45.0	10.0	0.07	-0.20	32.0	7.5	0.99	28.0	-0.01
10/24/91	SP-015	7.77	24.0	325.0	83.6	102.0	-2.00	42.0	8.0	0.07	-0.01	33.0	6.1	0.90	25.0	-0.01
2/10/92	SP-008	7.87	23.5	440.0	90.2	110.0	-2.00	83.0	11.0	0.05	-0.01	33.0	7.9	1.60	40.0	0.03

Idiots Delight Spring

Date	AGWQMP ID	Field pH	Field Temp	Field Cond	HCO3 as CaCO3	HCO3 as HCO3	CO3 as CaCO3	Cl	SO4	F	S	Ca	Mg	K	Na	(N) NH3
4/29/91	SP-013	7.85	24.0	295.0	92.0	112.0	-2.00	36.0	8.0	0.06	-0.20	32.0	5.2	0.75	21.0	-0.01
7/30/91	SP-017	8.00	23.5	270.0	72.2	88.0	-2.00	22.0	6.0	0.07	-0.20	25.0	5.5	0.50	14.0	-0.01
10/24/91	SP-017	7.74	24.0	250.0	90.2	110.0	-2.00	20.0	4.0	0.07	-0.01	34.0	4.7	0.50	12.0	0.01
02/10/92	SP-011	8.00	23.5	270.0	90.2	110.0	-2.00	26.0	5.0	0.06	-0.01	32.0	4.8	0.70	14.0	-0.01
8/03/92	TRIT-2	7.91	24.0	270.0	93.0	113.4		39.0	7.0			32.0	5.1	0.70	21.0	
04/12/93		7.53	27.3	563.0												0.001

Three Sisters Run

Date	AGWQMP ID	Field pH	Field Temp	Field Cond	HCO3 as CaCO3	HCO3 as HCO3	CO3 as CaCO3	Cl	SO4	F	S	Ca	Mg	K	Na	(N) NH3
4/29/91	SP-014	8.06	24.0	330.0	92.0	112.0	-2.00	47.0	9.0	0.06	0.20	32.0	5.9	1.00	29.0	-0.01
7/30/91	SP-018	7.92	24.0	300.0	73.8	90.0	-2.00	29.0	6.0	0.07	-0.20	25.0	6.2	0.64	22.0	-0.01
10/24/91	SP-019	8.00	24.0	280.0	83.6	102.0	-2.00	24.0	6.0	0.07	-0.01	34.0	5.2	0.60	16.0	-0.01
02/10/92	SP-010	8.10	24.0	330.0	90.2	110.0	-2.00	44.0	7.0	0.06	-0.01	32.0	5.8	1.00	22.0	-0.01

Springs Water-Quality Data

Hunters Spring

Date	AGWQMP ID	(N) NO3	(N) NO2+NO3	(N) ORG N	(P) PO4	(P) P	TDS	TOC	Fe	Mn	Zn	Cd	Cr	Cu	Pb
4/29/91	SP-010	0.24	0.24	-0.05	0.03	0.03	224.0	-1.0	-0.02	-0.01	-0.01	-0.005	-0.005	-0.01	-0.005
7/29/91	SP-012	0.28	0.28	-0.05	0.03	0.03	180.0	-1.0							
10/24/91	SP-014	0.26	0.26	-0.05	0.02	0.04	136.0	-1.0	-0.02						
02/11/92	SP-006	0.22	0.22	-0.05	0.03	0.04	172.0	-1.0	-0.02						

Catfish Corner Spring

Date	AGWQMP ID	(N) NO3	(N) NO2+NO3	(N) ORG N	(P) PO4	(P) P	TDS	TOC	Fe	Mn	Zn	Cd	Cr	Cu	Pb
4/29/91	SP-011	0.22	0.22	0.05	0.03	0.03	174.0	-1.0	-0.02	-0.01	-0.01	-0.005	-0.005	-0.01	-0.005
7/29/91	SP-013	0.22	0.22	-0.05	0.02	0.03	156.0	-1.0							
10/23/91	SP-012	0.24	0.24	-0.05	0.03	0.05	178.0	-1.0	-0.02						
02/11/92	SP-005	0.20	0.20	-0.05	0.02	0.04	134.0	-1.0	-0.02						
8/03/92	TRIT-1						147.0	1.3							
04/12/93		0.240	0.241		0.026	0.027									

Manatee Sanctuary Spring

Date	AGWQMP ID	(N) NO3	(N) NO2+NO3	(N) ORG N	(P) PO4	(P) P	TDS	TOC	Fe	Mn	Zn	Cd	Cr	Cu	Pb
4/29/91	SP-012	0.26	0.26	-0.05	0.02	0.03	238.0	-1.0	-0.02	-0.01	-0.01	-0.005	-0.005	0.01	-0.005
7/30/91	SP-016	0.28	0.28	-0.05	0.03	0.04	192.0	-1.0							
10/24/91	SP-015	0.31	0.31	-0.05	0.03	0.04	166.0	-1.0	-0.02						
2/10/92	SP-008	0.21	0.21	-0.05	0.03	0.04	218.0	-1.0	-0.02						

Idiots Delight Spring

Date	AGWQMP ID	(N) NO3	(N) NO2+NO3	(N) ORG N	(P) PO4	(P) P	TDS	TOC	Fe	Mn	Zn	Cd	Cr	Cu	Pb
4/29/91	SP-013	0.13	0.13	-0.05	0.03	0.03	170.0	1.2	-0.02	-0.01	-0.01	-0.005	-0.005	0.01	-0.005
7/30/91	SP-017	0.17	0.17	-0.05	0.03	0.04	146.0	-1.0							
10/24/91	SP-017	0.18	0.18	-0.05	0.03	0.04	138.0	-1.0	-0.02						
02/10/92	SP-011	0.14	0.14	-0.05	0.03	0.05	142.0	-1.0	-0.02						
3/03/92	TRIT-2						175.0	1.1							
04/12/93		0.211	0.212		0.027	0.029									

Three Sisters Run

Date	AGWQMP ID	(N) NO3	(N) NO2+NO3	(N) ORG N	(P) PO4	(P) P	TDS	TOC	Fe	Mn	Zn	Cd	Cr	Cu	Pb
4/29/91	SP-014	0.11	0.11	-0.05	0.03	0.03	192.0	-1.0	-0.02	-0.01	-0.01	-0.005	-0.005	0.01	-0.005
7/30/91	SP-018	0.17	0.17	-0.05	0.03	0.04	158.0	-1.0							
10/24/91	SP-019	0.20	0.20	-0.05	0.02	0.04	144.0	-1.0	-0.02						
02/10/92	SP-010	0.16	0.16	-0.05	0.03	0.04	176.0	-1.0	-0.02						

Springs Water-Quality Data

Three Sisters Two Spring

Date	AGWQMP ID	Field pH	Field Temp	Field Cond	HCO3 as CaCO3	HCO3 as HCO3	CO3 as CaCO3	Cl	SO4	F	S	Ca	Mg	K	Na	(N) NH3
4/29/91	SP-015	7.84	24.0	380.0	92.0	112.0	-2.00	59.0	11.0	0.06	-0.20	29.0	6.4	1.20	35.0	-0.01
7/30/91	SP-019	8.01	24.0	330.0	73.8	90.0	-2.00	37.0	8.0	0.07	-0.20	23.0	6.7	0.78	23.0	-0.01
10/24/91	SP-018	7.78	24.0	300.0	87.7	107.0	-2.00	34.0	6.0	0.07	-0.01	35.0	5.8	0.70	20.0	0.01
02/10/92	SP-009	7.41	24.0	360.0	90.2	110.0	-2.00	83.0	11.0	0.05	-0.01	33.0	7.9	1.60	40.0	0.03

Tarpon Hole Spring

Date	AGWQMP ID	Field pH	Field Temp	Field Cond	HCO3 as CaCO3	HCO3 as HCO3	CO3 as CaCO3	Cl	SO4	F	S	Ca	Mg	K	Na	(N) NH3
4/30/91	SP-016	7.66	23.5	1500.0	110.0	134.0	-2.00	350.0	61.0	0.08	-0.02	48.0	28.0	7.50	230.0	-0.01
7/29/91	SP-009	7.76	24.0	1200.0	90.2	110.0	-2.00	300.0	51.0	0.09	-0.20	46.0	26.0	5.80	170.0	-0.01
10/23/91	SP-009	7.49	24.0	1200.0	109.9	134.0	-2.00	310.0	40.0	0.08	-0.01	48.0	23.0	6.00	180.0	-0.01
02/11/92	SP-002	7.75	23.0	1450.0	114.8	140.0	-2.00	370.0	51.0	0.11	-0.01	47.0	27.0	7.30	210.0	-0.01
8/3/92	TRIT-3	7.84	23.5	2000.0	117.0	142.7		680.0	100.0			56.0	45.0	14.00	390.0	
04/12/93		7.66	25.4	1820.0												0.001

Tarpon Hole Two Spring

Date	AGWQMP ID	Field pH	Field Temp	Field Cond	HCO3 as CaCO3	HCO3 as HCO3	CO3 as CaCO3	Cl	SO4	F	S	Ca	Mg	K	Na	(N) NH3
4/30/91	SP-017	7.69	23.5	1250.0	110.0	134.0	-2.00	280.0	49.0	0.08	-0.20	45.0	22.0	5.90	170.0	-1.00
7/29/91	SP-010	7.81	24.0	850.0	90.2	110.0	-2.00	180.0	32.0	0.09	-0.20	43.0	18.0	3.70	100.0	-0.01
10/23/91	SP-010	7.54	24.0	1300.0	109.9	134.0	-2.00	320.0	39.0	0.09	-0.01	50.0	24.0	6.30	190.0	0.01
02/11/92	SP-003	7.81	23.0	1100.0	106.6	130.0	-2.00	280.0	40.0	0.08	-0.01	45.0	21.0	5.30	160.0	-0.01

Black Spring

Date	AGWQMP ID	Field pH	Field Temp	Field Cond	HCO3 as CaCO3	HCO3 as HCO3	CO3 as CaCO3	Cl	SO4	F	S	Ca	Mg	K	Na	(N) NH3
4/30/91	SP-018	7.52	23.0	5500.0	130.0	158.0	-2.00	1500.0	260.0	0.11	-0.20	82.0	110.0	28.00	940.0	-0.01
7/29/91	SP-011	7.73	23.5	3700.0	90.2	110.0	-2.00	980.0	170.0	0.12	-0.20	62.0	74.0	20.00	580.0	-0.01
10/23/91	SP-011	7.49	24.0	2750.0	109.9	134.0	-2.00	750.0	97.0	0.11	-0.01	57.0	53.0	15.00	450.0	0.01
02/11/92	SP-001	8.20	23.0	4200.0	114.8	140.0	-2.00	1300.0	190.0	0.11	-0.01	68.0	76.0	23.00	770.0	-0.01
04/12/93		7.43	25.0	4180.0												0.017

Springs Water-Quality Data

Three Sisters Two Spring

Date	AGWQMP ID	(N) NO3	(N) NO2+NO3	(N) ORG N	(P) PO4	(P) P	TDS	TOC	Fe	Mn	Zn	Cd	Cr	Cu	Pb
4/29/91	SP-015	0.17	0.17	0.05	0.03	0.03	210.0	-1.0	-0.02	0.02	-0.01	-0.005	-0.005	-0.01	-0.005
7/30/91	SP-019	0.19	0.19	-0.05	0.03	0.03	168.0	-1.0							
10/24/91	SP-018	0.23	0.23	-0.05	0.03	0.05	162.0	-1.0	-0.02						
02/10/92	SP-009	0.21	0.21	-0.05	0.03	0.04	218.0	-1.0	-0.02						

Tarpon Hole Spring

Date	AGWQMP ID	(N) NO3	(N) NO2+NO3	(N) ORG N	(P) PO4	(P) P	TDS	TOC	Fe	Mn	Zn	Cd	Cr	Cu	Pb
4/30/91	SP-016	0.15	0.15	-0.05	0.03	0.04	840.0	-1.0	0.02	-0.01	-0.01	-0.005	-0.005	-0.01	-0.005
7/29/91	SP-009	0.18	0.18	-0.05	0.03	0.04	714.0	-1.0							
10/23/91	SP-009	0.15	0.15	-0.05	0.03	0.06	704.0	-1.0	0.02						
02/11/92	SP-002	0.15	0.15	-0.05	0.03	0.05	772.0	11.0	-0.02						
8/3/92	TRIT-3						1389.0	1.7							
04/12/93		0.183	0.185		0.024										

Tarpon Hole Two Spring

Date	AGWQMP ID	(N) NO3	(N) NO2+NO3	(N) ORG N	(P) PO4	(P) P	TDS	TOC	Fe	Mn	Zn	Cd	Cr	Cu	Pb
4/30/91	SP-017	0.15	0.15	-0.05	0.03	0.03	674.0	-1.0	0.02	-0.01	-0.01	-0.005	-0.005	-0.01	-0.005
7/29/91	SP-010	0.17	0.17	-0.05	0.03	0.04	482.0	-1.0							
10/23/91	SP-010	0.15	0.15	-0.05	0.03	0.05	738.0	-1.0	0.02						
02/11/92	SP-003	0.14	0.14	-0.05	0.03	0.05	614.0	17.0	-0.02						

Black Spring

Date	AGWQMP ID	(N) NO3	(N) NO2+NO3	(N) ORG N	(P) PO4	(P) P	TDS	TOC	Fe	Mn	Zn	Cd	Cr	Cu	Pb
4/30/91	SP-018	0.28	0.15	-0.05	0.03	0.03	3190.0	1.2	0.03	-0.01	-0.01	-0.005	-0.005	0.01	-0.005
7/29/91	SP-011	0.28	0.28	-0.05	0.02	0.04	2140.0	-1.0							
10/23/91	SP-011	0.25	0.25	-0.05	0.02	0.04	1560.0	-1.0	0.02						
02/11/92	SP-001	0.22	0.22	-0.05	0.02	0.04	2370.0	11.0	-0.02						
04/12/93		0.267	0.269		0.021	0.023									

Springs Water-Quality Data

Millers Creek Spring

Date	AGWQMP ID	Field pH	Field Temp	Field Cond	HCO3 as CaCO3	HCO3 as HCO3	CO3 as CaCO3	Cl	SO4	F	S	Ca	Mg	K	Na	(N) NH3
4/30/91	SP-019	7.36	23.5	1700.0	130.0	158.0	-2.00	360.0	66.0	0.07	-0.20	55.0	30.0	7.40	240.0	-0.01
7/30/91	SP-015	7.69	23.0	1100.0	90.2	110.0	-2.00	260.0	50.0	0.08	0.28	45.0	26.0	5.20	160.0	-0.01
10/24/91	Sp-013	7.31	23.0	800.0	109.9	134.0	-2.00	170.0	29.0	0.08	-0.01	44.0	16.0	3.50	96.0	0.01
01/10/92	SP-004	7.13	22.0	2450.0	139.4	170.0	-2.00	750.0	93.0	0.94	-0.01	65.0	47.0	13.00	410.0	0.02

House Spring

Date	AGWQMP ID	Field pH	Field Temp	Field Cond	HCO3 as CaCO3	HCO3 as HCO3	CO3 as CaCO3	Cl	SO4	F	S	Ca	Mg	K	Na	(N) NH3
4/30/91	SP-020	8.02	25.0	180.0	74.0	90.0	-2.00	3.0	13.0	0.06	-0.20	26.0	4.5	0.21	2.6	-0.01
7/29/91	SP-014	7.95	24.0	190.0	59.0	72.0	-2.00	3.0	14.0	0.07	-0.20	27.0	5.6	0.16	2.7	-0.01
10/24/91	SP-020	7.42	24.0	180.0	72.2	88.0	-2.00	4.3	12.0	0.07	-0.01	29.0	5.0	0.20	2.9	-0.01
02/11/92	SP-007	7.66	24.0	180.0	80.4	98.0	-2.00	4.4	12.0	0.06	-0.01	27.0	4.5	0.50	2.1	-0.01

Springs Water-Quality Data

Millers Creek Spring

Date	AGWQMP ID	(N) NO3	(N) NO2+NO3	(N) ORG N	(P) PO4	(P) P	TDS	TOC	Fe	Mn	Zn	Cd	Cr	Cu	Pb
4/30/91	SP-019	0.07	0.07	0.09	0.03	0.04	852.0	1.9	0.11	0.02	-0.01	-0.005	-0.005	-0.01	-0.005
7/30/91	SP-015	0.16	0.16	-0.05	0.03	0.05	634.0	-1.0							
10/24/91	Sp-013	0.09	0.09	-0.05	0.02	0.06	442.0	1.0	0.02						
01/10/92	SP-004	0.09	0.09	0.06	0.04	0.05	1370.0	1.1	0.04						

House Spring

Date	AGWQMP ID	(N) NO3	(N) NO2+NO3	(N) ORG N	(P) PO4	(P) P	TDS	TOC	Fe	Mn	Zn	Cd	Cr	Cu	Pb
4/30/91	SP-020	0.27	0.27	-0.05	0.02	0.03	94.0	-1.0	-0.02	-0.01	-0.01	-0.005	-0.005	-0.01	-0.005
7/29/91	SP-014	0.26	0.26	-0.05	0.02	0.03	108.0	-1.0							
10/24/91	SP-020	0.30	0.30	-0.05	0.02	0.03	104.0	-1.0	-0.02						
02/11/92	SP-007	0.24	0.24	-0.05	0.02	0.04	88.0	-1.0	-0.02						

Wells - Water-Quality Data

Well Name	AGWQMP ID	Cased Depth	Total Depth	Lat\Long	Date Sampled	Field pH	Field Temp	Field Cond	HCO3 as CaCO3	HCO3 as HCO3	CO3 as CaCO3	Cl	SO4	F	S
Thomas	017PF035	UNK	45	290221/823205	10/7/91	8.23	24.0	200.0	59.9	73.00	-2.00	3.5	11.00	0.06	-0.01
Stefke	017PF038	UNK	300	290026/823127	10/7/91	8.48	24.0	150.0	51.7	63.00	-2.00	3.2	4.00	0.07	-0.01
Eaton	017PF039	UNK	UNK	285955/823428	10/7/91	7.48	23.0	400.0	169.7	207.00	-2.00	4.6	7.00	0.12	-0.01
Wilkey	017PF044	UNK	90?	285840/823313	10/7/91	8.12	23.0	250.0	91.8	112.00	-2.00	4.8	7.00	0.10	-0.01
Wheeler	017PF056	UNK	UNK	285517/823437	10/7/91	7.53	23.0	300.0	100.0	122.00	-2.00	7.0	-2.00	0.09	-0.01
Needleman	017PF067	UNK	80	285306/823518	10/8/91	7.68	23.5	300.0	100.0	122.00	-2.00	15.0	6.00	0.12	-0.01
Julias	017PF069	UNK	50	285220/823507	10/8/91	7.25	23.0	500.0	209.9	256.00	-2.00	13.0	-2.00	0.07	0.03
Clemens	017PF066	UNK	65	285311/823424	10/8/91	7.93	24.0	200.0	87.7	107.00	-2.00	5.2	3.00	0.06	-0.01
Dyer	017PF076	UNK	UNK	285127/823504	10/8/91	7.29	24.0	400.0	119.7	146.00	-2.00	52.0	10.00	0.09	-0.01
Kirkwood	017PF077	UNK	UNK	285152/823527	10/9/91	7.24	23.0	800.0	169.7	207.00	-2.00	120.0	7.00	0.08	0.04
Miller	017PF079	UNK	38-40	285108/823413	10/8/91	7.78	24.0	300.0	129.6	158.00	-2.00	26.0	7.00	0.06	-0.01
Lecanto #7	017YF010	20	30	285254/823230	10/8/91	6.86	24.0	370.0	190.2	232.00	-2.00	3.3	2.00	0.08	-0.01
Crystal Riv Sh	017XF012	3.4	53	285421/823616	10/8/91	6.79	23.0	500.0	219.8	268.00	-2.00	34.0	12.00	0.08	-0.01
ROMP 113	017YF019	130	150	285124/822456	10/8/91	8.01	24.0	140.0	73.8	90.00	-2.00	4.0	-2.00	0.05	-0.01
Parmenter	017PF045	UNK	62	285837/823320	10/9/91	7.84	23.0	240.0	109.9	134.00	-2.00	4.8	9.00	0.11	-0.01
Sween	017PF047	UNK	130?	285907/823204	10/9/91	8.17	23.0	240.0	97.6	119.00	-2.00	4.6	20.00	0.11	-0.11
Thomas	017PF048	UNK	126	285752/823146	10/9/91	8.49	24.0	140.0	44.3	54.00	-2.00	3.2	12.00	0.06	-0.01
Rubin	017PF050	UNK	UNK	285719/823344	10/9/91	7.11	22.5	180.0	76.3	93.00	-2.00	7.1	4.00	0.23	-0.01
Smith	017PF049	UNK	125	285720/823230	10/9/91	8.17	24.0	175.0	65.6	80.00	-2.00	3.7	15.00	0.08	-0.01
Witty	017PF041	UNK	UNK	285911/823545	10/9/91	7.52	23.5	295.0	150.1	183.00	-2.00	5.1	4.00	0.15	-0.01
Hundt	017PF042	UNK	UNK	285944/823852	10/9/91	7.01	23.0	395.0	200.1	244.00	-2.00	7.6	3.00	0.06	0.09
Roberts	017PF043	UNK	UNK	285824/823446	10/10/91	7.91	23.5	175.0	72.2	88.00	-2.00	3.8	7.00	0.13	0.02
Julius	017PF051	UNK	65	285733/823615	10/10/91	7.29	23.5	390.0	190.2	232.00	-2.00	12.0	3.00	0.06	0.03
Pillau	017PF052	UNK	200	285714/823720	10/10/91	7.42	23.5	460.0	200.1	244.00	-2.00	5.7	42.00	0.27	0.18
Kregoski	017PF125	UNK	86	285625/823707	10/10/91	7.30	23.0	390.0	200.1	244.00	-2.00	6.2	-2.00	0.05	0.05
Coon	017DF031	56	58	285554/823730	10/10/91	7.23	22.5	390.0	200.1	244.00	-2.00	12.0	6.00	0.10	0.07
Kellner	017PF085	92	112	285815/822453	10/10/91	7.32	24.0	260.0	129.6	158.00	-2.00	5.9	-2.00	0.08	-0.01
Hogan	017PF086	UNK	110	285726/822532	10/10/91	8.20	24.5	160.0							
Light	017PF091	114	147	285602/822740	10/10/91	7.99	25.0	170.0	65.6	80.00	-2.00	3.4	-2.00	0.04	-0.01
Forget	017PF046	UNK	86	285926/823226	10/10/91	7.83	23.5	160.0							
Azzarati	017PF040	UNK	UNK	285915/823435	10/11/91	8.00	23.5	185.0							
Lewis	017PF128	UNK	UNK	285410/823521	10/14/91	7.42	23.0	245.0	109.9	134.00	-2.00	5.1	10.00	0.07	-0.01
Wood	017PF057	45	50	285422/823512	10/14/91	7.86	23.0	210.0	86.1	105.00	-2.00	4.8	11.00	0.06	-0.01
Hayes	017PF055	UNK	12	285456/823528	10/14/91	7.01	23.0	430.0	219.8	268.00	-2.00	13.0	12.00	0.05	-0.01
Herbert	017PF053	60	81	285546/823628	10/14/91	7.51	22.5	330.0	159.9	195.00	4.00	5.4	7.00	0.09	0.02
Munn	017PF054	UNK	UNK	285503/823547	10/14/91	7.51	23.0	365.0	169.7	207.00	-2.00	9.7	3.00	0.09	0.01
Vaverchak	017PF033	33	45	285544/823357	10/14/91	7.50	23.0	250.0	119.7	146.00	-2.00	5.4	4.00	0.07	0.02
Austin	017PF059	UNK	170	285543/823103	10/15/91	8.32	23.5	100.0	37.7	46.00	-2.00	4.1	2.00	0.03	-0.01
Elherot	017PF060	UNK	200	285508/823122	10/15/91	8.03	24.5	175.0	77.9	95.00	-2.00	3.7	6.00	0.06	-0.01
Ellis	017PF065	UNK	23	285335/823356	10/15/91	7.48	24.0	295.0							
Sheffield	017PF063	UNK	49	285350/823345	10/15/91	8.09	23.5	170.0	65.6	80.00	-2.00	4.2	14.00	0.05	-0.01
N.Lecanto Well	017YF011	288	335	285414/822842	10/15/91	7.74	24.0	190.0	95.9	117.00	-2.00	4.9	4.00	0.06	-0.01
Romero	017PF127	UNK	UNK	285350/823452	10/15/91	7.20	25.0	600.0	319.8	390.00	-2.00	2.1	-2.00	0.02	0.06
Exley	017PF062	UNK	55-60	285332/823310	10/15/91	7.45	24.0	200.0	90.2	110.00	-2.00	4.9	3.00	0.05	-0.01
Varona	017PF070	UNK	100	285256/823409	10/15/91	7.63	23.0	220.0	109.9	134.00	-2.00	5.2	3.00	0.06	-0.01
Aubin	017PF061	UNK	UNK	285335/823218	10/15/91	7.57	24.5	210.0	95.9	117.00	-2.00	4.9	3.00	0.04	-0.01
Tolle	017PF097	65	100	285332/822926	10/15/91	7.69	24.0	180.0	76.3	93.00	-2.00	4.4	3.00	0.05	-0.01
Miller	017PF098	220	235	285331/822856	10/16/91	7.95	23.5	200.0							
Rankin	017PF100	UNK	115	285213/822922	10/16/91	7.95	23.5	185.0	86.1	105.00	-2.00	4.7	2.00	0.05	-0.01
Reeder	017PF073	90	115	285217/823215	10/16/91	8.08	24.0	170.0	76.3	93.00	-2.00	4.7	2.00	0.05	-0.01
Rathbun	017PF074	UNK	UNK	285207/823304	10/16/91	8.30	24.0	155.0	68.1	83.00	-2.00	4.9	2.00	0.05	-0.01
Crystal Shores	017FF023	96	129	285220/823544	10/16/91	7.66	22.5	450.0	140.2	171.00	-2.00	56.0	11.00	0.16	0.01
Cutrone	017PF116	UNK	64	284914/821842	10/17/91	7.37	24.0	400.0	159.9	195.00	-2.00	19.0	3.00	0.04	0.10
Miller	017PF117	UNK	145	284918/821947	10/17/91	7.48	23.5	300.0	140.2	171.00	-2.00	13.0	4.00	0.08	-0.01
Romp TR 21-2	017XF021	105	111	285112/823544	10/17/91	7.78	23.0	920.0							
Fenzel	017PF112	UNK	UNK	285052/821850	10/17/91	6.81	23.5	500.0	229.6	280.00	-2.00	.32.0	-2.00	0.07	
Moore	017PF114	UNK	123?	284857/821602	10/17/91	8.07	24.5	400.0	179.6	219.00	-2.00	6.4	28.00	0.19	0.10
Twitty	017PF115	UNK	28	284850/821750	10/17/91	8.60	26.0	300.0							
Ozello #4	017FF024	60	75	285102/823610	10/17/91		22.0	1300.0	259.9	317.00	-2.00	330.0	16.00	0.09	0.03
Breaux	017PF036	UNK	250	290225/823146	10/21/91	8.18	24.0	130.0							
Kremnetz	017PF092	UNK	UNK	285539/822234	10/21/91	7.84	24.0	220.0	91.8	112.00	-2.00	9.4	3.00	0.03	-0.01
Kelly	017PF037	UNK	185	290135/823139	10/21/91	8.32	24.0	130.0	59.9	73.00	-2.00	4.2	4.00	0.05	-0.01

Wells - Water-Quality Data

Well Name	AGWQMP ID	Ca	Mg	K	NA	(N) NH3	(N) NO3	(N) NO2+NO3	(N) ORG N	(P) PO4	(P) P	TDS	TOC	Fe
Thomas	017PF035	27.0	2.6	0.20	2.3	-0.01	0.04	0.04	-0.05	0.06	0.07	92.0	-1.00	0.04
Stefke	017PF038	14.0	6.5	0.10	1.7	-0.01	0.06	0.06	-0.05	0.02	0.03	60.0	-1.00	-0.02
Eaton	017PF039	45.0	18.0	0.20	2.7	-0.01	0.08	0.08	-0.05	0.11	0.12	176.0	1.50	-0.02
Wilkey	017PF044	33.0	8.2	0.20	3.9	-0.01	1.10	1.10	-0.05	0.03	0.03	120.0	-1.00	-0.02
Wheeler	017PF056	34.0	7.1	0.10	4.4	-0.01	0.58	0.58	-0.05	0.06	0.06	114.0	-1.00	-0.02
Needleman	017PF067	39.0	4.6	0.40	8.7	0.01	-0.01	-0.01	-0.05	0.02	0.02	134.0	-1.00	0.14
Julias	017PF069	77.0	4.3	0.40	8.2	0.12	0.06	0.06	0.06	-0.01	0.04	234.0	3.20	2.80
Clemens	017PF066	32.0	3.8	0.20	3.5	-0.01	0.33	0.33	0.06	0.03	0.26	98.0	-1.00	-0.02
Dyer	017PF076	-0.1	-0.1	-0.10	96.0	-0.01	0.21	0.21	-0.05	0.03	0.04	214.0	-1.00	-0.02
Kirkwood	017PF077	68.0	17.0	1.40	72.0	0.12	0.04	0.04	0.08	0.02	0.02	446.0	2.30	1.10
Miller	017PF079	36.0	4.4	0.50	20.0	-0.01	0.36	0.37	0.08	-0.01	0.01	150.0	1.30	-0.02
Lecanto #7	017YF010	76.0	1.7	0.40	2.0	0.08	0.04	0.04	0.08	0.05	0.14	220.0	2.10	1.50
Crystal Riv Sh	017XF012	83.0	8.1	0.80	24.0	0.04	0.06	0.06	0.07	0.03	0.05	308.0	1.70	0.02
ROMP 113	017YF019	29.0	1.5	1.30	2.5	0.01	0.36	0.36	-0.05	0.04	0.08	92.0	-1.00	-0.02
Parmenter	017PF045	38.0	7.6	0.10	3.3	-0.01	0.26	0.26	-0.05	0.05	0.05	136.0	-1.00	-0.02
Sween	017PF047	35.0	8.5	0.10	3.0	-0.01	0.07	0.07	-0.05	0.04	0.06	140.0	1.60	-0.02
Thomas	017PF048	20.0	3.3	-0.10	2.2	-0.01	0.28	0.28	-0.05	0.03	0.03	84.0	-1.00	-0.02
Rubin	017PF050	24.0	6.1	-0.10	3.8	-0.01	0.30	0.30	-0.05	0.23	0.28	102.0	-1.00	-0.02
Smith	017PF049	25.0	5.2	-0.10	2.5	-0.01	0.17	0.17	-0.05	0.03	0.04	102.0	-1.00	-0.02
Witty	017PF041	45.0	9.9	0.20	3.2	0.02	-0.01	-0.01	-0.05	0.06	0.06	152.0	1.50	0.55
Hundt	017PF042	80.0	3.1	0.10	5.1	0.11	0.02	0.02	0.10	-0.05	0.02	230.0	4.30	5.40
Roberts	017PF043	26.0	5.8	0.40	2.7	0.05	-0.01	-0.01	-0.05	0.07	0.07	94.0	1.10	0.35
Julius	017PF051	71.0	3.5	0.10	16.0	0.09	0.02	0.02	0.14	-0.05	0.05	218.0	2.30	2.60
Pillau	017PF052	78.0	15.0	0.90	4.0	0.06	-0.01	-0.01	-0.05	0.01	0.01	268.0	1.20	0.09
Kregoski	017PF125	80.0	2.1	0.20	4.0	0.17	-0.01	-0.01	0.11	-0.05	0.06	220.0	2.00	3.60
Coon	017DF031	70.0	7.3	0.80	8.5	0.27	0.02	0.02	0.09	-0.05	0.08	224.0	3.10	3.10
Kellner	017PF085	48.0	4.0	-0.10	3.6	-0.01	0.15	0.15	-0.05	0.06	0.06	138.0	-1.00	-0.02
Hogan	017PF086					-0.01		0.05	-0.05		0.12			
Light	017PF091	26.0	1.9	-0.10	2.2	-0.01	0.14	0.14	0.06	0.04	0.06	72.0	-1.00	-0.02
Forget	017PF046					0.01		0.64	-0.05		0.06		-1.00	
Azzarati	017PF040					-0.01		0.02	-0.05		0.15		1.50	
Lewis	017PF128	42.0	6.5	0.40	3.5	0.02	0.15	0.15	0.05	0.03	0.07	136.0	2.30	0.04
Wood	017PF057	33.0	6.2	0.10	3.1	0.01	0.17	0.17	-0.05	0.03	0.05	112.0	-1.00	-0.02
Hayes	017PF055	85.0	4.1	0.50	8.8	0.01	0.14	0.14	0.08	0.02	0.11	252.0	3.40	0.15
Herbert	017PF053	60.0	8.0	0.20	3.4	0.03	-0.01	-0.01	-0.05	0.02	0.02	190.0	1.00	0.28
Munn	017PF054	64.0	9.5	0.50	5.7	0.04	-0.01	-0.01	-0.05	-0.01	0.03	200.0	1.00	0.55
Vaverchak	017PF033	43.0	6.9	-0.10	2.9	0.01	-0.01	-0.01	0.05	0.02	0.07	138.0	1.00	0.48
Austin	017PF059	17.0	1.8	0.10	2.9	-0.01	0.87	0.87	-0.05	0.02	0.02	60.0	-1.00	-0.02
Elherot	017PF060	30.0	4.4	0.10	2.7	-0.01	0.29	0.29	-0.05	0.02	0.03	108.0	-1.00	-0.02
Ellis	017PF065					0.05		-0.01	0.08		0.07		2.60	
Sheffield	017PF063	27.0	4.5	0.20	2.6	-0.01	0.33	0.33	-0.05	0.03	0.05	106.0	-1.00	-0.02
N.Lecanto Well	017YF011	34.0	5.0	0.30	3.9	-0.01	0.27	0.27	-0.05	0.03	0.06	116.0	-1.00	0.03
Romero	017PF127	110.0	7.3	2.30	7.9	3.00	0.03	0.03	0.10	0.06	0.12	350.0	10.00	3.80
Exley	017PF062	34.0	3.7	0.30	3.7	-0.01	0.40	0.40	0.08	0.03	0.04	114.0	-1.00	-0.02
Varona	017PF070	41.0	3.7	0.10	3.6	-0.01	0.02	0.02	0.05	0.02	0.04	116.0	1.30	0.10
Aubin	017PF061	39.0	2.7	0.20	3.7	-0.01	0.90	0.90	0.05	0.06	0.07	122.0	-1.00	-0.02
Tolle	017PF097	33.0	2.4	0.10	3.2	0.02	0.46	0.46	-0.05	0.03	0.03	112.0	-1.00	-0.02
Miller	017PF098					-0.01		0.41	-0.05		0.04		-1.00	
Rankin	017PF100	34.0	3.2	0.10	3.2	-0.01	0.16	0.16	-0.05	0.03	0.04	112.0	-1.00	-0.02
Reeder	017PF073	30.0	2.1	0.10	3.1	-0.01	0.30	0.30	-0.05	0.03	0.04	78.0	-1.00	-1.00
Rathbun	017PF074	25.0	3.9	0.20	3.2	-0.01	0.29	0.29	-0.05	0.02	0.04	78.0	-1.00	-1.00
Crystal Shores	017PF023	45.0	16.0	1.10	29.0	0.01	-0.01	-0.01	0.06	0.02	0.03	248.0	-1.00	0.05
Cutrone	017PF116	68.0	2.5	0.30	9.8	0.25	0.01	0.01	0.28	0.04	0.07	218.0	4.70	0.18
Miller	017PF117	56.0	3.1	0.20	4.8	0.03	0.01	0.01	0.16	0.07	0.08	166.0	1.70	0.16
Romp TR 21-2	017XF021					0.03		-0.01	0.05		0.03		-1.00	
Fenzel	017PF112	95.0	2.6	0.60	18.0	0.78	0.03	0.03	0.27	0.19	0.22	314.0	8.10	3.60
Moore	017PF114	72.0	10.0	0.40	4.3	0.10	-0.01	-0.01	0.10	0.02	0.04	244.0	2.30	-0.02
Twitty	017PF115					0.20		-0.02	0.60		0.15		13.00	
Ozello #4	017PF024	97.0	25.0	6.10	170.0	0.46	0.07	0.07	0.42	0.21	0.32	866.0	13.00	9.80
Breaux	017PF036					0.01		0.18	-0.05		0.05		-1.00	
Kremnetz	017PF092	39.0	2.3	-0.10	5.9	-0.01	2.30	2.30	0.08	0.03	0.05	130.0	-1.00	-0.02
Kelly	017PF037	23.0	3.8	0.10	2.6	-0.01	0.54	0.54	-0.05	0.02	0.05	80.0	-1.00	-0.02

Wells - Water-Quality Data

Well Name	AGWQMP ID	Cased Depth	Total Depth	Lat\Long	Date Sampled	Field pH	Field Temp	Field Cond	HCO3 as CaCO3	HCO3 as HCO3	CO3 as CaCO3	Cl	SO4	F	S
Roberts	017PF090	120	123	285549/822857	10/21/91	7.95	24.0	120.0	62.3	76.00	-2.00	3.2	2.00	0.04	-0.01
Chasfin	017PF089	243	245	285629/822521	10/21/91	7.24	24.0	310.0	159.9	195.00	-2.00	6.1	2.00	0.07	0.02
Moore	017PF103	UNK	52	285120/822818	10/21/91	7.76	23.5	145.0							
Hunt	017PF084	97	99	285902/822802	10/21/91	7.76	24.0	190.0	87.7	107.00	-2.00	4.3	3.00	0.06	-0.01
Arnow	017PF071	UNK	60	285240/823302	10/21/91	7.49	24.0	225.0	119.7	146.00	-2.00	6.1	2.00	0.05	-0.01
Hartle	017PF058	88	134	285541/823213	10/22/91	8.17	24.0	140.0	58.2	71.00	-2.00	3.7	15.00	0.06	-0.01
Townsend	017PF102	UNK	62	285057/822917	10/22/91	7.69	24.0	170.0	87.7	107.00	-2.00	5.2	4.00	0.06	-0.01
Ladd	017PF072	UNK	170	285236/823238	10/22/91	7.99	24.0	170.0	87.7	107.00	-2.00	4.9	4.00	0.08	-0.01
Savino	017PF078	UNK	40	285215/823356	10/22/91	7.15	24.0	240.0	119.7	146.00	-2.00	6.2	4.00	0.07	-0.01
Culpepper	017PF075	UNK	UNK	285227/823317	10/21/91	7.86	24.0	215.0	109.9	134.00	-2.00	10.0	3.00	0.05	-0.01
Kurth	017PF104	185	220	285136/822618	10/24/91	7.89	23.5	130.0	67.2	82.00	-2.00	3.8	3.00	0.05	-0.01
Lyons	017PF080	UNK	UNK	285137/823244	10/24/91	7.75	24.0	270.0	159.9	195.00	-2.00	5.6	6.00	0.04	-0.01
Baptist Ch Pas	017PF025	UNK	60	284939/823447	10/24/91	7.34	23.0	405.0	219.8	268.00	-2.00	37.0	5.00	0.07	-0.01
Record	017PF096	UNK	220	285408/822522	10/28/91	7.72	24.0	190.0	109.9	134.00	-2.00	4.2	-2.00	0.05	-0.01
Disponzio	017PF107	UNK	270	285244/822542	10/28/91	8.26	24.0	125.0	65.6	80.00	-2.00	3.5	-2.00	0.05	-0.01
Layton	017PF120	UNK	137	284640/822033	10/28/91	7.40	23.0	195.0	109.9	134.00	-2.00	6.9	3.00	0.06	-0.01
Burns	017PF122	126	126	284937/822307	10/28/91	6.63	24.0	90.0	33.6	41.00	-2.00	5.7	-2.00	0.16	-0.01
Houston	017PF123	70	180	285027/822307	10/28/91	7.40	23.0	225.0	129.6	158.00	-2.00	5.7	-2.00	0.07	0.04
Thomas	017PF093	30	60	285358/822210	10/29/91	7.06	22.5	365.0	229.6	280.00	-2.00	11.0	-2.00	0.08	0.04
Antonen	017PF095	40	50	285348/821738	10/29/91	7.22	23.0	240.0	140.2	171.00	-2.00	7.6	-2.00	0.05	0.06
Opperman	017PF088	UNK	65	285717/822239	10/29/91	7.05	24.5	265.0	159.9	195.00	-2.00	9.3	-2.00	0.06	-0.01
Enz	017DF126	233	240	285128/822736	10/29/91	7.73	24.0	165.0	90.2	110.00	-2.00	3.8	3.00	0.04	-0.01
Lisotta	017PF099	253?	260	285255/822805	10/30/91	8.06	24.0	150.0	76.3	93.00	-2.00	4.3	4.00	0.05	-0.01
Oldnettle	017PF106	UNK	275	285308/822607	10/30/91	8.04	24.0	145.0	72.2	88.00	-2.00	3.9	3.00	0.05	-0.01
Holder Mine	017PF121	UNK	UNK	284811/822252	10/30/91	8.06	23.0	120.0	55.8	68.00	-2.00	4.2	-2.00	0.03	-0.01
Rhame	017PF109	UNK	UNK	285239/822259	10/30/91	7.90	23.5	280.0	64.0	78.00	-2.00	63.0	-2.00	0.07	-0.01
McGee	017PF119	65	90	284737/821948	10/30/91	7.49	23.5	250.0	129.6	158.00	-2.00	11.0	-2.00	0.06	-0.01
Callunder	017PF108	UNK	152	285321/822423	10/30/91	7.75	23.5	155.0	80.4	98.00	-2.00	4.1	-2.00	0.05	-0.01
Schwindt	017PF087	UNK	UNK	285732/822115	10/30/91	7.82	23.0	290.0	100.0	122.00	-2.00	45.0	11.00	0.07	-0.01
Goodwin	017PF111	84	120	285107/822122	10/30/91	7.67	23.0	180.0	100.0	122.00	-2.00	4.8	-2.00	0.07	-0.01
Boehl	017PF094	40	41	285418/822106	10/31/91	7.00	21.0	370.0	240.3	293.00	-2.00	12.0	-2.00	0.09	0.03
Roberts	017PF105	180	350	285207/822615	10/31/91	8.03	23.0	145.0	77.9	95.00	-2.00	3.8	4.00	0.06	-0.01
Case	017PF110	UNK	40	285149/822048	10/31/91	7.35	24.0	210.0	109.9	134.00	-2.00	5.3	5.00	0.05	-0.01
Black	017PF113	UNK	100	285050/821600	10/31/91	6.90	23.5	2000.0	259.9	317.00	-2.00	7.7	-2.00	0.09	0.07
Mott	017PF118	UNK	60	284833/822008	10/31/91	7.34	23.0	240.0	129.6	158.00	-2.00	8.3	6.00	0.07	0.02
Joyner	017PF064	91	116	285342/823408	10/31/91	7.72	24.0	165.0	76.3	93.00	-2.00	5.2	8.00	0.06	-0.01
Romp TR21-3 DP	017XP009	240	252	285234/823419	11/08/91	8.85	25.0	480.0	97.6	119.00	12.00	77.0	11.00	0.25	0.09
Caylor	017PF081	UNK	65	284916/823244	11/12/91	7.92	23.0	190.0	100.0	122.00	-2.00	6.3	7.00	0.05	-0.01
Canvas Experts	017PF082	UNK	UNK	284826/823423	11/12/91	7.36	23.0	300.0							
Port Paradise	017PF129	UNK	UNK	285259/823532	11/12/91	7.71	23.5	190.0	97.6	119.00	-2.00	9.7	5.00	0.07	-0.01
Shellert	017PF083	30	80	284852/823237	11/12/91	7.55	23.5	250.0	140.2	171.00	-2.00	17.0	4.00	0.03	-0.01

Wells - Water-Quality Data

Well Name	AGWQMP ID	Ca	Mg	K	NA	(N) NH3	(N) NO3	(N) NO2+NO3	(N) ORG N	(P) PO4	(P) P	TDS	TOC	Fe
Roberts	017PF090	24.0	1.8	0.10	2.3	-0.01	0.32	0.32	-0.05	0.02	0.04	82.0	-1.00	-0.02
Chasfin	017PF089	60.0	2.4	0.20	3.5	0.30	0.01	0.01	-0.05	0.07	0.11	194.0	2.00	0.99
Moore	017PF103					-0.01		0.20	-0.05		0.05		-1.00	
Hunt	017PF084	31.0	3.8	0.10	2.6	-0.01	0.32	0.32	0.05	0.03	0.06	104.0	-1.00	-0.02
Arnow	017PF071	48.0	2.3	0.10	3.8	0.01	0.04	0.04	-0.05	-0.01	0.04	144.0	1.00	0.24
Hartle	017PF058	24.0	4.1	0.10	2.4	0.04	0.25	0.25	-0.05	0.01	0.04	94.0	-1.00	-0.02
Townsend	017PF102	34.0	3.2	0.20	3.2	-0.01	0.09	0.09	-0.05	0.02	0.03	116.0	-1.00	-0.02
Ladd	017PF072	29.0	6.4	0.20	3.1	-0.01	0.66	0.66	-0.05	0.02	0.06	112.0	-1.00	-0.02
Savino	017PF078	50.0	3.3	0.20	3.7	-0.01	0.10	0.10	-0.05	-0.01	0.03	152.0	-1.00	0.06
Culpepper	017PF075	44.0	4.0	0.20	5.3	-0.01	0.30	0.30	-0.05	0.02	0.04	138.0	-1.00	-0.02
Kurth	017PF104	27.0	1.7	0.20	2.5	-0.01	0.03	0.03	-0.05	0.05	0.06	76.0	-1.00	-0.02
Lyons	017PF080	63.0	3.4	0.20	3.2	0.02	0.33	0.33	-0.05	0.04	0.06	178.0	-1.00	-0.02
Baptist Ch Pas	017PF025	82.0	6.8	1.80	22.0	0.13	0.57	0.57	0.10	0.02	0.03	292.0	2.10	0.02
Record	017PF096	-0.1	-0.1	-0.10	58.0	0.01	-0.01	-0.01	-0.05	0.06	0.08	148.0	-1.00	-0.02
Disponzio	017PF107	25.0	2.1	0.20	2.7	0.01	0.09	0.09	-0.05	-0.01	0.03	96.0	-1.00	-0.02
Layton	017PF120	47.0	2.3	0.10	4.1	0.01	0.55	0.55	-0.05	0.03	0.04	150.0	-1.00	-0.02
Burns	017PF122	15.0	1.2	0.10	3.0	0.02	0.35	0.35	-0.05	0.38	0.43	66.0	-1.00	0.02
Houston	017PF123	50.0	2.2	0.20	3.4	0.10	0.01	0.01	-0.05	0.06	0.10	162.0	1.40	0.75
Thomas	017PF093	86.0	2.7	0.40	6.3	2.20	0.02	0.02	0.20	0.17	0.21	272.0	6.40	2.40
Antonen	017PF095	59.0	1.7	0.30	4.8	0.20	-0.01	-0.01	0.13	0.01	0.10	194.0	5.20	1.70
Opperman	017PF088	56.0	4.1	0.30	6.3	0.16	0.03	0.03	0.19	0.04	0.08	198.0	5.80	-0.02
Enz	017DP126	32.0	3.7	0.20	2.7	-0.01	0.06	0.06	-0.05	0.02	0.04	104.0	-1.00	-0.02
Lisotta	017PF099	29.0	3.6	0.20	3.1	-0.01	0.38	0.38	-0.05	0.03	0.04	108.0	-1.00	-0.02
Oldnettle	017PF106	-0.1	-0.1	-0.10	43.0	0.01	0.68	0.68	-0.05	0.03	0.05	90.0	-1.00	-0.02
Holder Mine	017PF121	23.0	1.1	0.20	3.3	-0.01	0.21	0.21	-0.05	0.02	0.04	72.0	-1.00	-0.02
Rhame	017PF109	39.0	2.1	0.20	29.0	-0.01	0.38	0.38	-0.05	0.02	0.05	188.0	-1.00	-0.02
McGee	017PF119	56.0	2.1	0.20	5.9	-0.01	1.20	1.20	-0.05	0.04	0.05	182.0	-1.00	-0.02
Callunder	017PF108	32.0	2.2	0.20	2.8	0.01	0.29	0.29	-0.05	0.04	0.06	94.0	-1.00	-0.02
Schwindt	017PF087	31.0	12.0	0.60	26.0	0.01	0.52	0.52	0.05	0.03	0.04	204.0	-1.00	-0.02
Goodwin	017PF111	40.0	1.5	0.20	3.7	0.01	0.08	0.08	-0.05	0.06	0.07	124.0	-1.00	-0.02
Boehl	017PF094	94.0	3.7	0.40	7.2	0.91	0.03	0.03	0.59	0.08	0.08	294.0	10.00	2.00
Roberts	017PF105	0.1	-0.1	-0.10	45.0	0.01	0.08	0.08	-0.05	0.03	0.04	94.0	-1.00	-0.02
Case	017PF110	44.0	1.1	0.10	3.6	-0.01	0.31	0.31	-0.05	0.07	0.07	130.0	-1.00	0.58
Black	017PF113	96.0	6.8	0.40	4.7	0.56	-0.01	-0.01	0.34	0.03	0.06	308.0	8.70	-0.02
Mott	017PF118	53.0	3.0	0.30	5.0	0.03	-0.01	-0.01	-0.05	0.04	0.07	158.0	1.00	-0.02
Joyner	017PF064	30.0	4.4	0.20	3.3	0.02	0.22	0.22	-0.05	0.02	0.03	104.0	-1.00	-0.02
Romp TR21-3 DP	017XF009	23.0	14.0	6.90	56.0	0.03	-0.01	-0.01	-0.05	-0.01	0.04	244.0	-1.00	-0.02
Caylor	017PF081	40.0	3.5	0.20	4.0	0.01	0.41	0.41	-0.05	0.02	0.04	122.0	-1.00	-0.02
Canvas Experts	017PF082					0.01		0.22	-0.05		0.04		1.50	
Port Paradise	017PF129	37.0	4.0	0.30	6.3	0.01	0.14	0.14	-0.05	0.04	0.05	130.0	-1.00	-0.02
Shellert	017PF083	54.0	3.3	0.20	8.9	0.01	0.28	0.28	-0.05	0.01	0.03	184.0	-1.00	-0.02

Springs and Wells - Isotopic Sampling Results

Uranium Isotope Data

Well Name	AQWQMP ID	U234/U238 Activity Ratio	Uranium Concentration (ug/l)	NO2+NO3 Concentration as N (mg/l)	UK Factor	NK Factor
Baptist Church	017PF025	1.0	0.7	0.6	U	N
Kelly	017PF037	1.0	0.2	0.5	U	N
Sween	017PF047	0.9	0.5	0.1	U	
Rubin	017PF050	1.1	0.1	0.3	U	N
Pillao	017PF052		0.0	0.0		
Herbert	017PF053	1.1	0.7	0.0	U	
Wood	017PF057	1.0	0.2	0.2	U	N
Exley	017PF062	1.0	0.2	0.4	U	N
Joiner	017PF064		0.0	0.2		N
Clemens	017PF066	1.0	0.2	0.3	U	N
Needleman	017PF067	0.9	0.7	0.0	U	
Ladd	017PF072	0.6	1.5	0.7	U	N
Dyer	017PF076	1.0	0.3	0.2	U	N
Hunt	017PF084	1.0	0.1	0.3	U	N
Kellner	017PF085	1.2	0.0	0.2		N
Kremnitz	017PF092	1.1	0.5	1.0	U	N
Boehl	017PF094			0.0		
Tolle	017PF097	0.9	0.2	0.5	U	N
Lisotta	017PF099	1.1	0.2	0.4	U	N
Townsend	017PF102	1.6	0.4	0.1		
Kurth	017PF104	1.5	0.1	0.0		
Callunder	017PF108	1.1	0.1	0.3	U	N
Case	017PF110	1.0	0.6	0.3	U	N
Goodwin	017PF111	1.2	0.1	0.1		
Black	017PF113	1.3	0.0	0.0		
Black	017PF113					
Cutrone	017PF116	1.2	0.0	0.0		
Mott	017PF118	1.3	0.1	0.0		
Mott	017PF118					
Houston	017PF123	1.1	0.1	0.0		
Romero	017PF127	2.0	0.0	0.0		
Romp 113	017YF019	1.0	0.1	0.4	U	N
Tarpon Hole	SP009	1.0	0.2	0.2	U	N
Black Spg	SP011	1.0	0.3	0.1	U	N
Catfish Spg	SP012	1.1	0.2	0.3	U	N
Miller Spg	SP013	1.0	0.2	0.2	U	N
Hunters Spg	SP014	0.9	0.2	0.2	U	N
Idiots Delight	SP017	1.0	0.2	0.2	U	N

UK: U = Activity Ratio < 1.2 and Uranium Concentration > 0.1 ug/l
NK: N = NO2+NO3 > 1.0 mg/l

Tritium Data

Well Name	AGWQMP ID	Tritium Activity (PCI/Liter)*
Beohl	017PF094	5.6 +-0.5 E01
Hunt	017PF084	1.7 +-0.2 E01
Townsend	017PF102	1.5 +-0.3 E01
Needleman	017PF067	2.1 +-0.3 E01
Sheffield	017PF063	1.3 +-0.1 E01
Kelly Well	017PF037	8.1 +-1.4 E00
Rhame	017PF109	1.5 +-0.2 E01
Cutrone	017PF116	1.6 +-0.3 E01
Frenzel	017PF112	2.0 +-0.3 E01
Case	017PF110	1.8 +-0.3 E01
Houston	017PF123	2.1 +-0.3 E01
Aubin	017PF061	1.9 +-0.4 E01
Arnow	017PF071	2.1 +-0.3 E01
Lisotta	017PF099	2.3 +-0.2 E01
Verona	017PF070	1.8 +-0.2 E01
Catfish Corner	SP-001	1.5 +-0.4 E01
Idiots Delight	SP-002	2.9 +-0.3 E01
Tarpon Hole Spg	SP-003	2.4 +-0.4 E01

Nitorgen Isotope Data

Well Name	AGWQMP ID	NO2+NO3 Concentration as N (mg/l)	N15/N14 Ratio (0/00)
Manatee Sanc	SP-008	0.21	+3.6
Hunters Spg	SP-006	0.22	+5.2
Idiots Delight		0.212	+3.4
Tarpon Hole		0.815	+0.7
Lyons	017PF080	0.33	+5.0
Romp 113	017YF019	0.36	+2.6
Clemens	017PF066	0.33	+3.5
Case	017PF110	0.31	+5.8
Rhame	017PF109	0.38	+5.5
Hunt	017PF084	0.32	+3.1
Lissota	017PF099	0.38	+2.8

* To convert pico curies/liter (PCI/Liter) to tritium units (TU), multiply the tritium concentration in PCI/Liter by 3.2.

01914

REPORT NAME:
ORIGIN OF NUTRIENTS IN GROUND

AUTHOR & REPORT DATE:
AGWQMP 7/94

KEY WORD:
KINGS BAY

CART #/PG #:
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