Origin of Nutrients in Ground Water Discharging from The King's Bay Springs

Citrus County, Florida

Revised January 1998

Prepared by the
Ambient Ground-Water Quality Monitoring Program
Southwest Florida Water Management District

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 under the supervision of a Licensed Professional Geologist in the State of Florida.

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Date

License No. 1475

ORIGIN OF NUTRIENTS

IN GROUND WATER DISCHARGING

FROM THE KING'S BAY SPRINGS

Ambient Ground-Water
Quality Monitoring Program,

Southwest Florida Water Management District

July, 1994 (Revised January, 1998)

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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 cubic feet per second (630 mgd).

2. Approximately 335 tons of nitrogen (ammonium+nitrite+nitrate+organic nitrogen) is contained in ground water discharging from the King's Bay Springs every year. Approximately 205 tons of this is nitrate as N.

3. Approximately 38 tons of phosphorus are contained in the annual discharge of the King's Bay Springs. Relative to nitrogen, phosphorus concentrations in Floridan aquifer ground water are low because orthophosphate tends to precipitate as a calcium phosphate mineral (carbonate-hydroxylapatite) in the relatively alkaline water of the Floridan aquifer. In addition, the low total phosphorus concentrations indicate minimal orthophosphate and organic phosphorus which suggests that any sources of phosphorus, such as organic-rich surface water or animal wastes, are not presently affecting the springs.

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

5. Nitrate concentrations in samples collected between January 1991 and January 1998 from four of the most significant springs in the King's Bay Complex were statistically evaluated to determine whether nitrate levels in the springs were increasing. Of the four springs tested, one showed a statistically significant increasing trend.

6. One hundred and three wells were sampled for nitrate in the study area. Thirty-two percent had concentrations between 0.2 to 0.6 mg/l nitrate 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.

7. Historical nitrate data for study area spring water and ground water are extremely limited. Therefore, it is difficult to determine whether nitrate concentrations have increased significantly in recent years. However, three dedicated monitor wells sampled for this study in 1992 were 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 seven years. In addition, comparison of the median concentration of nitrate in Floridan aquifer ground water sampled from over 700 monitor wells statewide (0.01 mg/l) (Upchurch, 1992) to the current concentration of nitrate in ground water discharging from the springs (approximately 0.2 mg/l), indicates that the spring-water concentrations are 20 times higher than the natural ground-water concentrations in the Floridan aquifer statewide.

8. Ground water in the springs is largely derived from the drainage basin roughly 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.

9. 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.

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

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

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

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

14. A plume of what is probably naturally occurring nitrogen is moving toward the springs from Lake Rousseau. However, it has apparently not yet affected the springs.

15. There are small, localized sources of development-related nitrogen in the eastern portion of the City of Crystal River which are apparently residential and golf course turf fertilizers and septic tanks. This nitrogen along with naturally occurring nitrogen are probably the sources of the low levels of nitrogen in ground water discharging from the springs.

EXECUTIVE SUMMARY (continued)

16. 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.

17. Ten development-related sources of nitrogen in the study area were investigated. Of these, residential and golf-course turf fertilization, septic-tank effluent, and effluent disposal from sewage treatment are apparently contributing the majority of nitrogen that is present in ground water. Because the nitrate concentrations in the King's Bay Springs are low relative to those in other major springs in the District, it is not possible to determine which of these sources is most significant. However, an investigation of increasing nitrate levels in Homosassa, Chassahowitzka, and Weeki Wachee Springs just to the south of King's Bay, has shown that turf fertilization is the primary source of nitrate for these springs (Jones *et al.*, 1997). The four 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.

18. Stormwater runoff in the karst terrain may be partially responsible for conveying fertilizer-derived nitrogen into the ground-water system.

19. There is little that can be done to reduce present nitrogen loading from the springs to the coastal estuaries because that nitrogen has been applied to the study area for many years and is now entrained in the ground-water flow system. Any attempt to reduce nitrate loading in the recharge area may not result in reduced nitrate levels in the springs for a decade or longer.

20. An investigation of the application of inorganic nitrogen fertilizers in the coastal subdivisions in the study area should be initiated in the near future. The study should focus on identifying the specific areas of application, the amount applied, and the amount of nitrogen reaching ground water following application. The study should also attempt to reduce the use of fertilizers by developing best management practices and by promoting Xeriscaping$_{TM}$ - the replacement of turf with native species of plants that require less fertilizer and water.

EXECUTIVE SUMMARY (continued)

21. The importance of sources, such as residential and golf course turf/landscape fertilization, septic-tank effluent, and sewage effluent disposal will greatly increase as rapid residential and commercial development proceeds in the study area. It is therefore, extremely important that best management and alternative landscape practices be developed that reduce the use of fertilizer. Waste disposal practices that are compatible with the region's karst geology and its accompanying extreme vulnerability to ground-water contamination must also be implemented. These practices include:

    a. Avoidance of high-densities of septic systems.
    b. Planning for the development of centralized, advanced waste-water treatment (AWT) systems that denitrify effluent.
    c. More stringent design, construction, and monitoring of large-scale percolation or spray field systems. These systems should stay on line only until it is feasible to construct the centralized AWT systems.
    d. Proper storage and treatment of stormwater.

22. The springs should continue to be sampled quarterly for nutrients, major analytes, and trace organics and annually for nitrogen-isotopic ratios to determine the effects of changing land use and to determine the effectiveness of remedial efforts.

23. The District should work with Citrus County and other interested agencies to formulate land-use plans that will minimize additional nitrogen loadings to the study area.

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INTRODUCTION

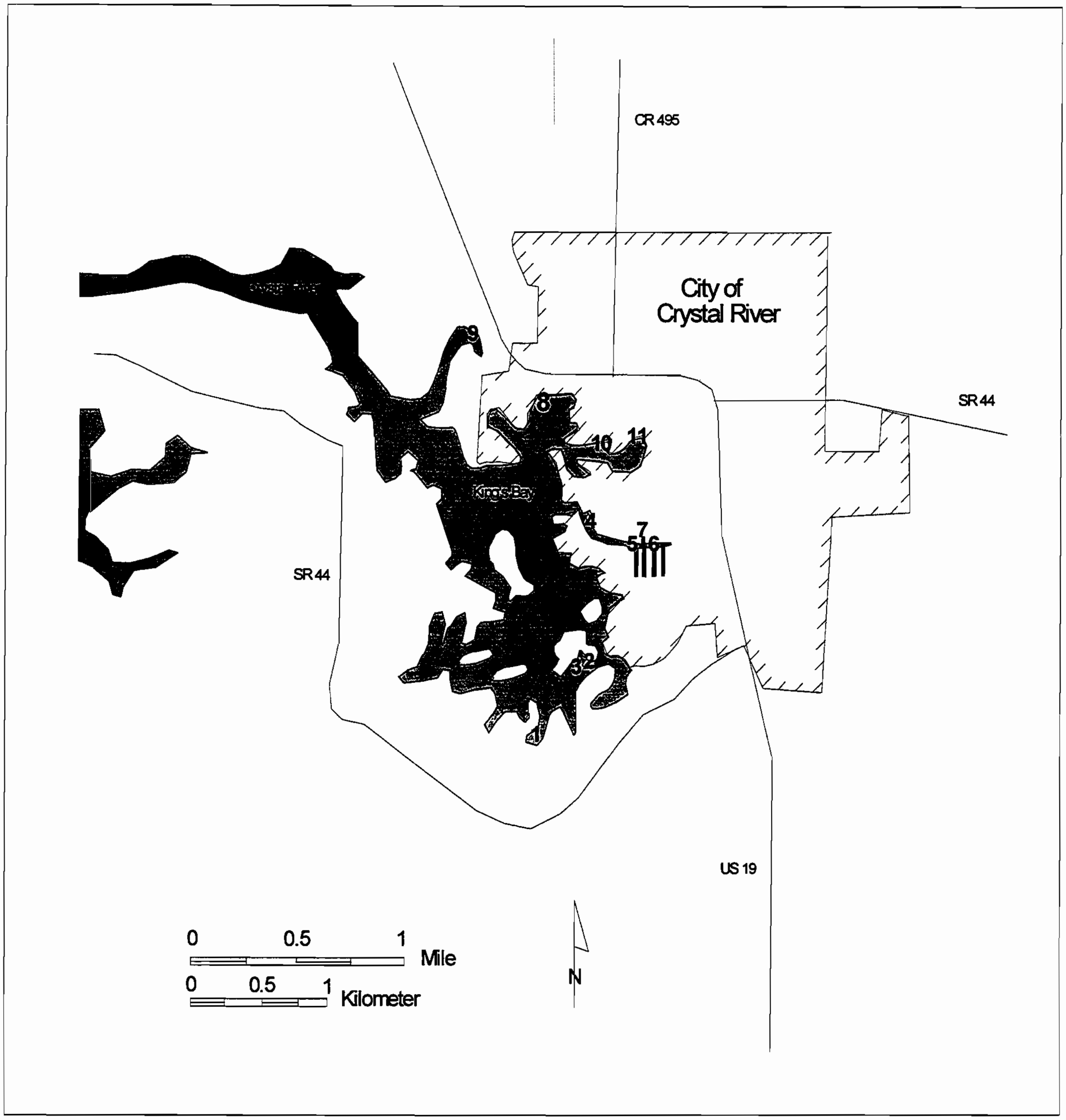
The numerous springs and seeps in King's Bay in Citrus County, Florida (Figure 1) discharge ground water at the rate of approximately 975 cubic feet per second (630 mgd). The concentration of total nitrogen (ammonium+nitrite+nitrate+organic nitrogen) and total phosphorus in water discharging from the springs is approximately 0.35 mg/l and 0.04 mg/l respectively. At these concentrations, approximately 335 tons of nitrogen and 38 tons of phosphorus are contained in ground water discharging from the King's Bay Springs every year. Approximately 205 tons (~ 61% of the 335 tons total) of the nitrogen is in the form of nitrate.

It has been determined by Romie (1990) that ground water discharging from numerous subaqueous springs in King's Bay is the source of 94 percent of the total nitrogen and 84 percent of the total phosphorus entering the bay. A possible effect of the increasing nutrient loading from spring discharge is the increased growth of Lyngbya majuscula, a filamentous blue-green algae (Romie, 1990) and other native and non-native species of aquatic vegetation. This vegetation can form large floating mats that remove oxygen from the water when they die and decay. Excess vegetation can also reduce the clarity of the water which can block sunlight from reaching sea grass and other beneficial bottom-dwelling vegetation. Finally, the mats are unsightly, their decay causes a foul odor, and they can impair navigation and other recreational uses of the water body.

Ground water discharging in the King's Bay Springs originates as rainfall in the recharge area inland of the springs. The rainfall infiltrates the Floridan aquifer and flows seaward toward the springs. The portion of the recharge area that is most likely causing nutrient enrichment in the springs (the study area) is depicted in Figure 2.

Because historical data on nitrate levels in ground water discharging from the King's Bay Springs and ground water in the study area are extremely limited, it is difficult to establish that nitrate concentrations have significantly increased prior to the beginning of regular water-quality monitoring in 1991. However, comparison of the median concentration of nitrate in Floridan aquifer ground water sampled from over 700 monitor wells statewide (0.01 mg/l) (Upchurch, 1992) to the current concentration of nitrate in ground water discharging from the springs (approximately 0.2 mg/l), indicates that the spring-water concentrations are 20 times higher than the natural ground-water concentrations. In addition, nitrate concentrations in samples collected between January 1991 and January 1998 from four of the most significant springs in the King's Bay Complex were statistically evaluated to determine whether nitrate levels in the springs were increasing. Of the four springs tested, one showed a statistically significant increasing trend.

While some of nitrogen in the spring water appears to be the result of natural processes, enrichment that is apparently occurring is human-induced (anthropogenic),



Legend

1 = Black Spring
2 = Tarpon Hole II
3 = Tarpon Hole
4 = Manatee Sanctuary
5 = Three Sisters II
6 = Idiots Delight
7 = Three Sisters
8 = Catfish Corner
9 = Millers Creek
10 = Hunters Spring
11 = House Spring

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

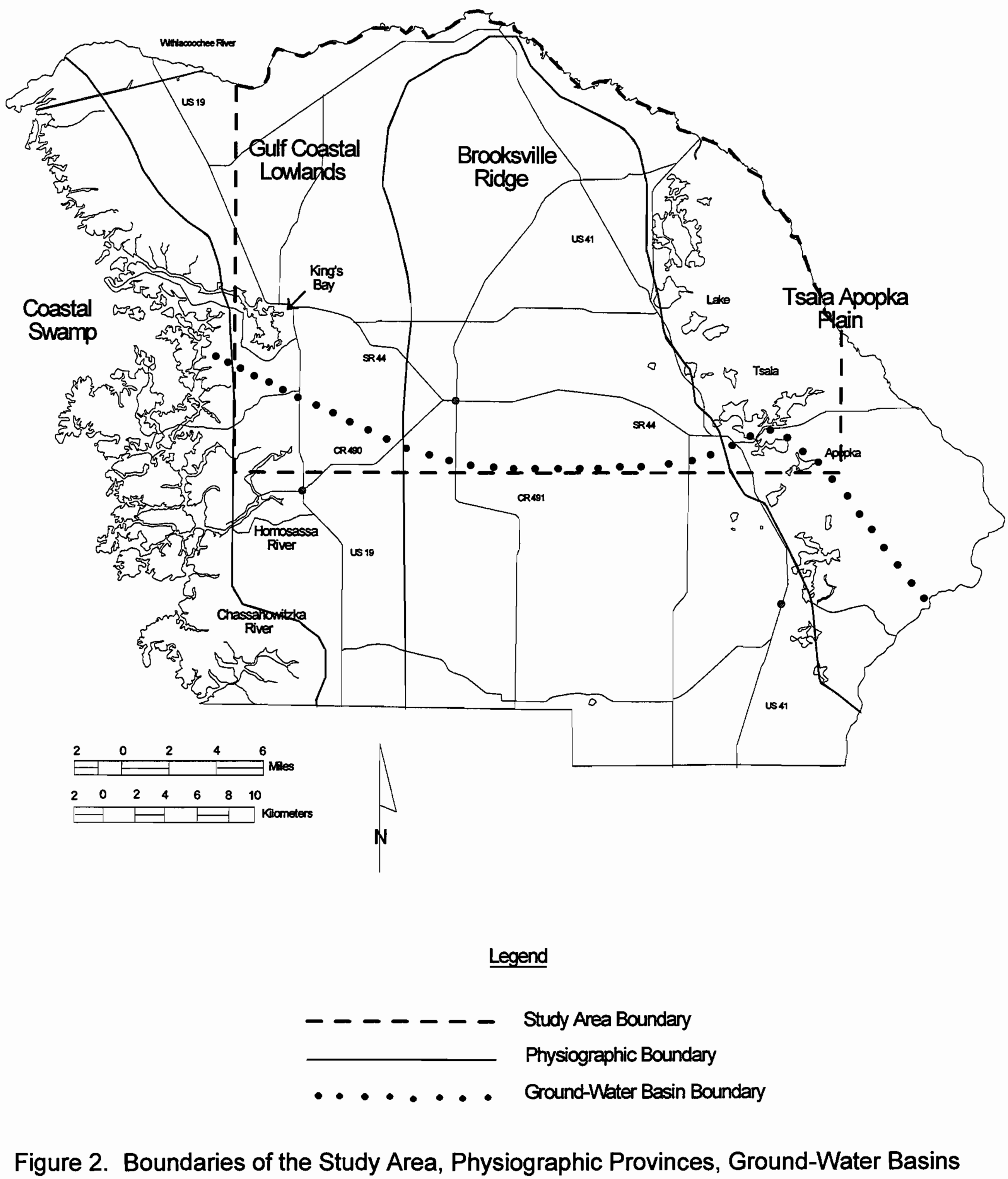


Figure 2. Boundaries of the Study Area, Physiographic Provinces, Ground-Water Basins and Location of Important Geologic, Hydrologic, and Cultural Features.

and contamination of ground water must be occurring within the recharge area of the King's Bay Springs.

Because the nutrient-rich ground water discharging from the springs may be 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 two years, was carried out by the Ambient Ground-Water Quality Monitoring Program (AGWQMP), also of the SWFWMD.

The SWFWMD continued to study other large spring complexes in the District (Jones *et al.*, 1996; Jones *et al.*, 1997) following the release of this report in 1994. Information obtained from those studies has prompted the authors to revise this report to include the more recent data and conclusions.

DESCRIPTION OF THE STUDY AREA

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 on the Brooksville Ridge 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 two to eight 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 two to eight miles in width. Elevations range from 10 to 100 feet above NGVD. The topography consists of relatively flat plains to rolling hills. Relief is a result 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 seventeen miles in width at the Hernando County line to about five 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 Brooksville Ridge is underlain by 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 fractures. The ridge has an irregular surface due to karst activity and elevations may vary by more than 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. Siliciclastic 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 near the town of Inglis forming Lake Rousseau, a relatively small lake which 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 six 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 Coastal Lowlands and 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 five and ten 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 five to ten miles inland.

The central portion of the study area, while still relatively rural, contains a number of rapidly expanding retirement communities. These communities are characterized by high-density residential development and golf courses. The central to northern regions of this area have entire square-mile sections 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 contains the Withlacoochee State Forest. The State Forest is regularly logged and is virtually uninhabited. Portions of the eastern flank of the

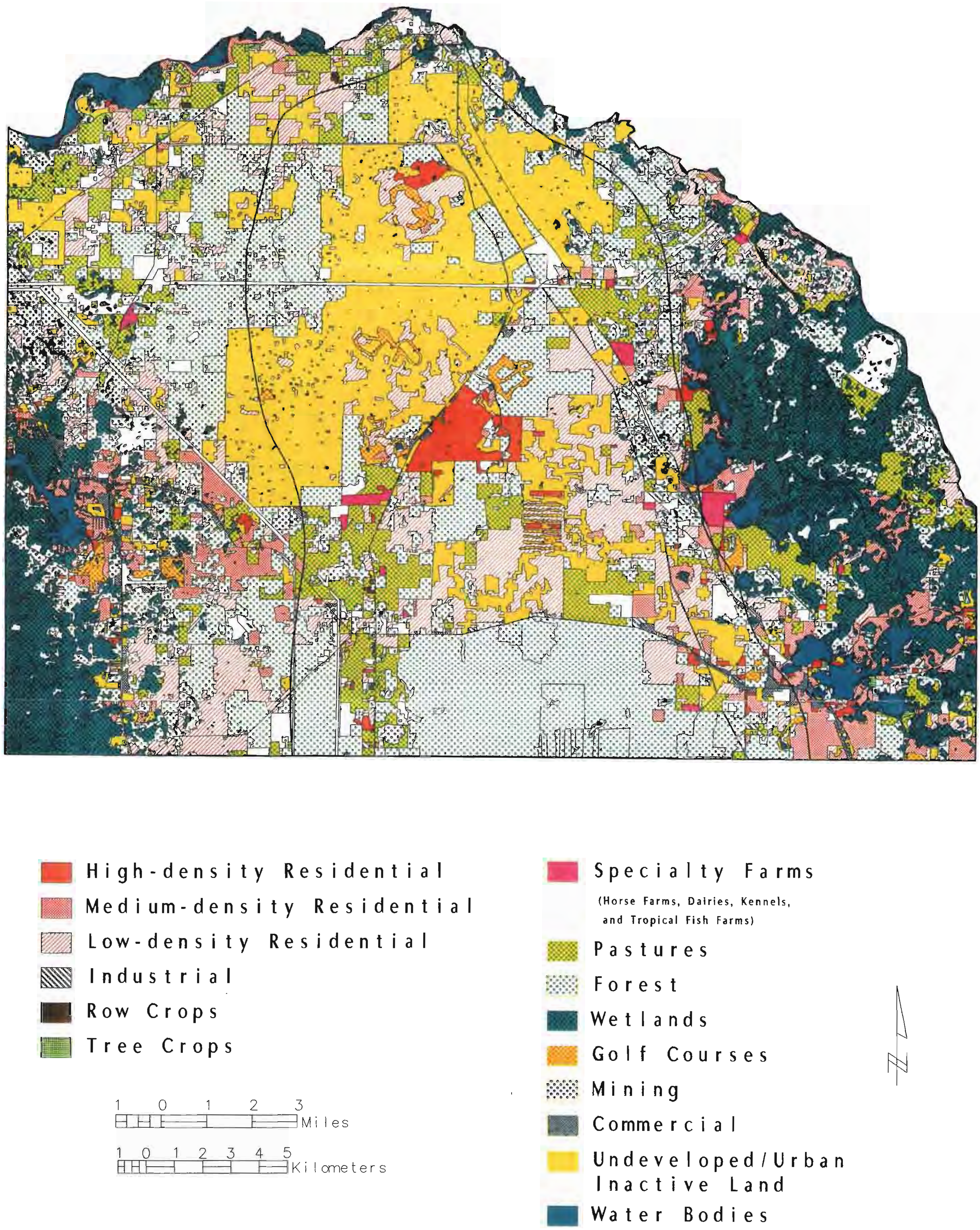


Figure 3. Land Use in the Study Area (1990).

Brooksville Ridge were mined for phosphate rock from the late 1800s to the 1960s. These small mine pits and quarries 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 on the western margin of Lake Tsala Apopka and is the largest town in the study area. In parts 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). The region consists of thick sequences of Tertiary age, marine carbonate rocks exposed at or very near (10 to 20 feet) land surface in the eastern and western study area, and covered with Brooksville Ridge sediments in the central area. Where rock is near land surface, a thin veneer of sediment covers the limestone that consists of Quaternary age unconsolidated to poorly-indurated siliciclastic deposits. These quartz sands are primarily marine terrace deposits and coastal dune trains. Dunes are prevalent in the Coastal Lowlands and along the western flank of the Brooksville Ridge.

Geologic formations present in the study area, in ascending order, are the Avon Park Formation and Ocala Limestone of middle to late Eocene age, the early Oligocene age Suwannee Limestone, and the late Oligocene to Pliocene undifferentiated Hawthorn Group sediments. Adjacent to and overlying the Hawthorn Group are surficial marine terrace deposits. The Hawthorn Group, and associated reworked Hawthorn sediments, along with the Quaternary Beach Ridge and Dune deposits (Scott, 1998), make up the Brooksville Ridge. The Suwannee Limestone is present only as erosional remnants along the Brooksville Ridge, and the Avon Park Formation underlies the entire study area, but is only exposed in a small area in northwestern Citrus County (Scott, 1998).

The Ocala Limestone also covers the entire study area, and is the dominant formation exposed at the surface in Citrus County (Scott, 1998). Both the Ocala Limestone and Avon Park Formation comprise the Floridan aquifer in the study area. Both units have been significantly fractured and modified by karst processes with well-developed solution channel and cavernous porosity (Ryder, 1985). This secondary porosity is responsible for high permeabilities and transmissivities observed in the Floridan aquifer, and also for the abundance of springs along the coastal margin.

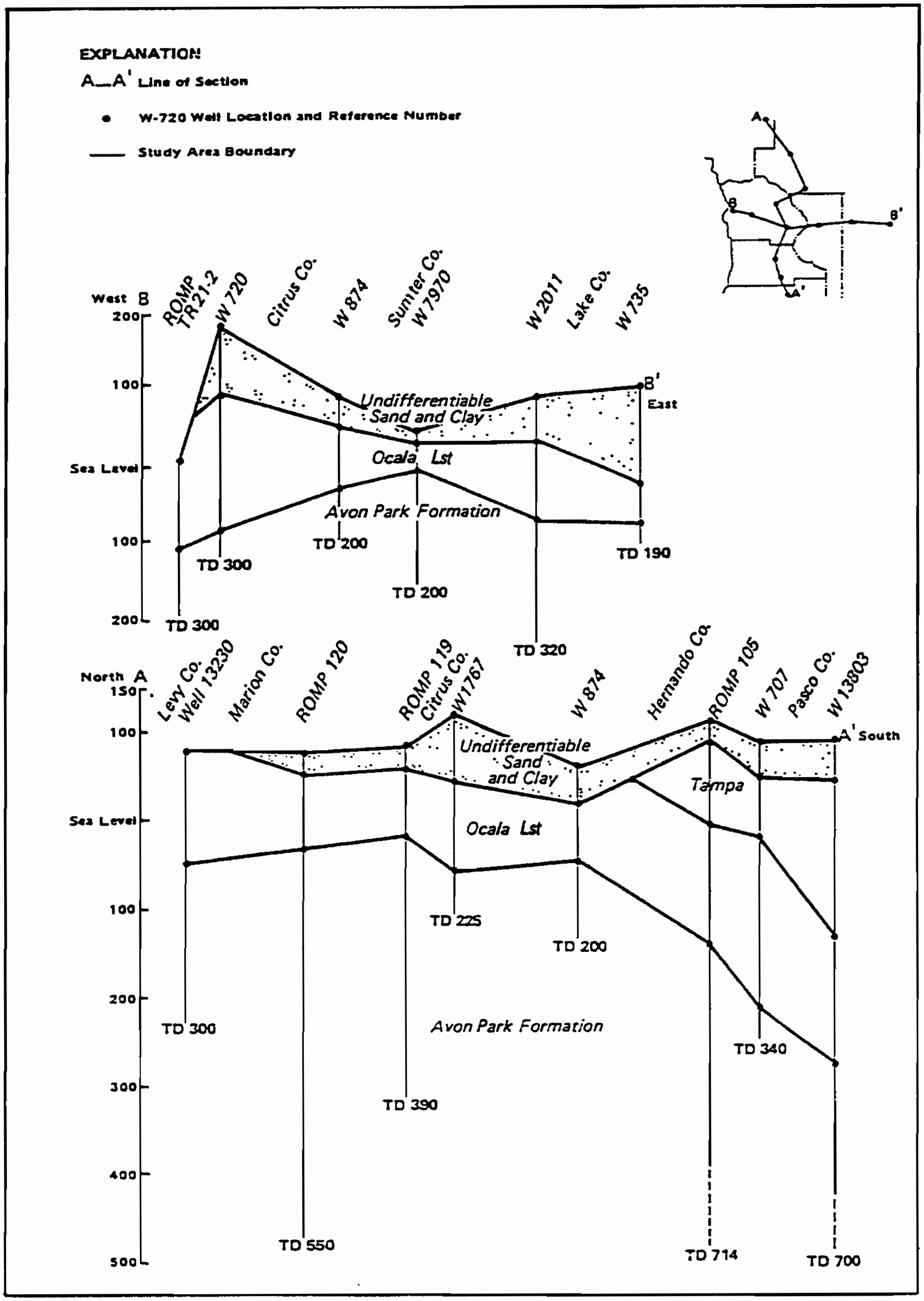


Figure 4. Generalized Geologic Cross Sections through the Northern SWFWMD area (modified from Gilboy, 1985).

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.

The Brooksville Ridge Quaternary terrace deposits and Hawthorn Group sediments overlie the Floridan aquifer in the central region of the study area. These sediments act as an upper semi-confining unit, but are typically breached by sinkholes. The sediments were deposited in shallow marine environments, with subsequent reworking through subaerial erosion and karst modification. Hawthorn sediments consist of clayey sand, silt, and reddish gray to green weathered clay. Phosphorite pebbles and fossils common to the Hawthorn are absent in the Brooksville Ridge section (Scott, 1998), and the highly weathered and reworked nature of the formation complicate recognition of the facies originally deposited there.

Weathering of the phosphorite from Hawthorn Group sediments has resulted in the dissolution of carbonate-fluorapatite and precipitation of carbonate-hydroxylapatite in localized crusts and nodules associated with the sinkholes on the east flank of the Brooksville Ridge (Upchurch, 1992). The deposits extended from northern Hernando County, through the study area in Citrus County, and up into Levy and Marion Counties (Upchurch, 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 cobbling 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 does not have an 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.

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 and the Ocala Limestone, in ascending order. The top of the aquifer is usually defined as the uppermost vertically persistent permeable limestone or dolostone. The lower part of the Avon Park Formation contains evaporites consisting of gypsum and anhydrite that reduce permeability of the rock and forms the lower confining unit 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

Several previous investigations, (Aucott 1988, Ryder 1985, Adams 1985, and Stewart 1980) provide recharge estimates for the Floridan aquifer for regions including Citrus County. These references are used in the following summary of recharge characteristics for physiographic regions described in the study area. Yobbi (1989)

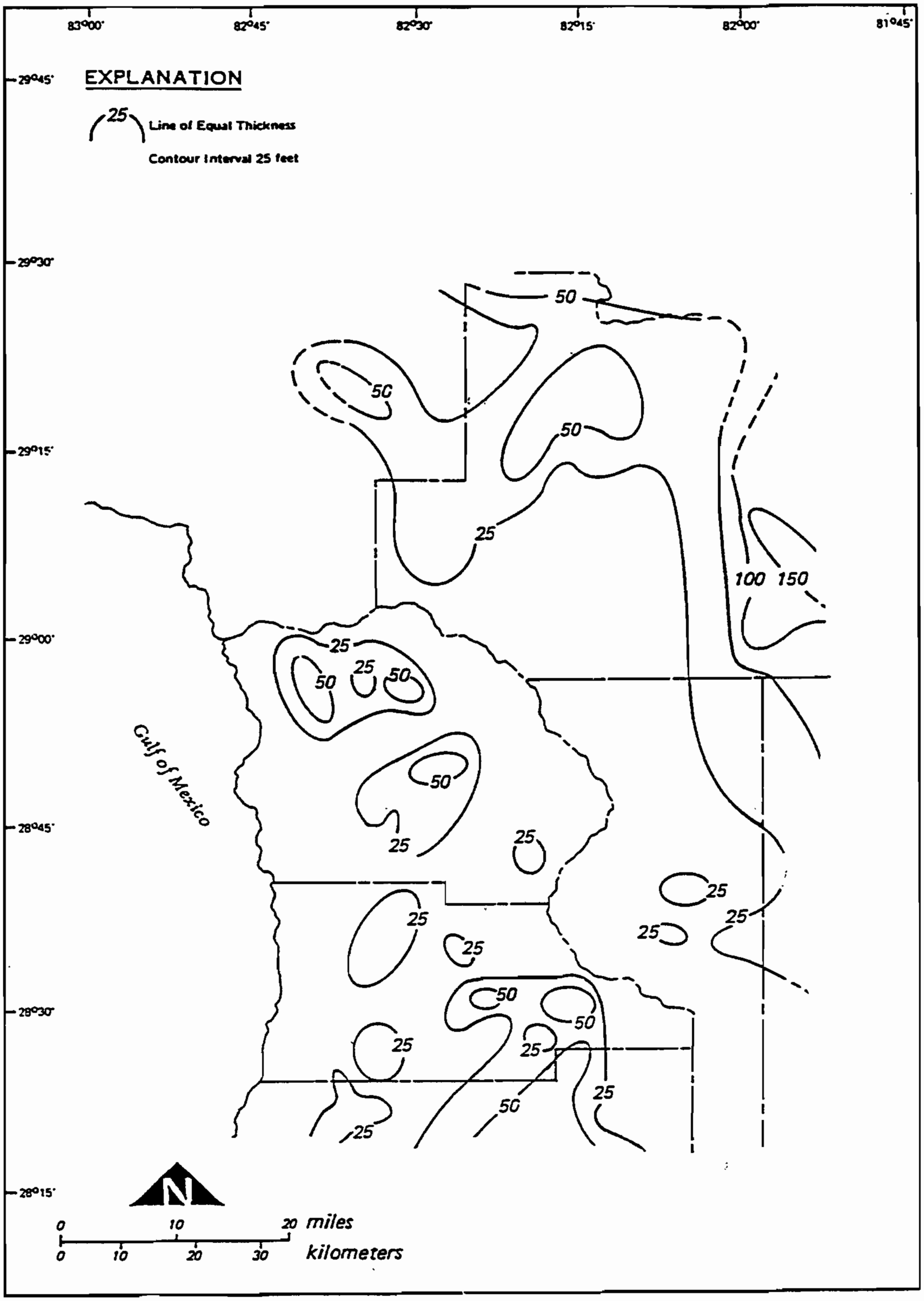


Figure 5. Thickness of the Confining Unit Above the Floridan Aquifer in the Northern District Area (from Faulkner, 1970 and Bouno *et al*, 1979).

gives more detailed, model derived Floridan aquifer recharge values across the study area. Composite recharge estimates applied to the physiography of Citrus County are given in Figure 6.

Recharge to the Floridan aquifer in the study area occurs by direct infiltration of rainfall through surficial sediments and by seepage of surface water from Lake Tsala Apopka (Rutledge 1978). Direct recharge may also occur through sections of the Withlacoochee River, including Lake Rousseau (Anderson and Laughlin 1982, German 1978). Estimated annual recharge is highest in the Brooksville Ridge region, (9 to 22 inches) and Coastal Lowlands Province, (3 to 16 inches), with a lower recharge (9 to 11 inches) or discharge conditions present in both the Coastal Swamp and Lake Tsala Apopka Areas. In general, high recharge rates occur where the top of the Floridan aquifer is near land surface and overlying sediments lack confining properties. Also, karst features with associated internal drainage induce higher recharge to the Floridan aquifer. Lower recharge rates occur where overlying confining materials retard recharge, or where an upward flow potential exists.

Recharge is highest on the Brooksville Ridge because it is a karst terrain with internal drainage through abundant sinkholes (Kimrey and Anderson 1987). The Ridge land surface is generally well drained with few surface water features, no permanent streams or extensive wetlands, and a relatively deep water table. These factors maximize recharge potential since infiltration of rainfall is rapid and surface runoff is not present. The high recharge rate in the Coastal Lowlands region is due to similar characteristics, although the water table is generally higher and surficial deposits overlying the Floridan aquifer are thinner.

Recharge within the Tsala Apopka Plain is generally low due to near coincident levels in surface waters or the surficial aquifer and the Floridan aquifer (Rutledge 1978). However, both Rutledge (1978) and Bradner (1988) seem to indicate that the potentiometric surface of the Floridan aquifer is consistently below the level of the lake which would result in downward leakage of lake water into the Floridan aquifer.

Estimates of recharge potential in the Coastal Swamp region of the study area are variably low to absent, with values of -9 inches (discharge), to 11 inches per year. The coastal margin is primarily an area of regional discharge, with possibly localized recharge only over very short distances proximal to the King's Bay Springs complex. The very low recharge and discharge characteristics are evidenced by the Floridan potentiometric surface positioned at or above land surface in the Coastal Swamp region.

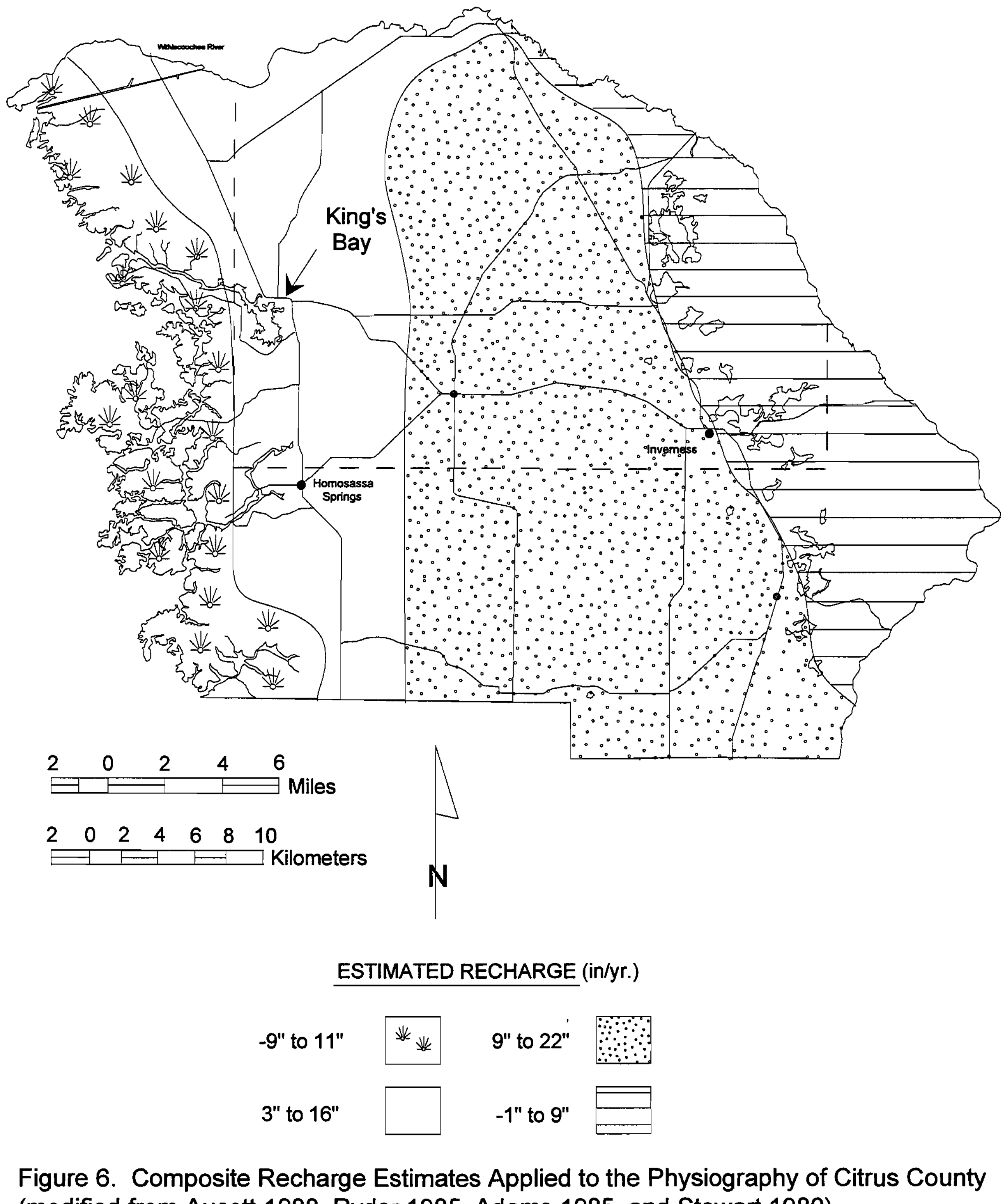


Figure 6. Composite Recharge Estimates Applied to the Physiography of Citrus County (modified from Aucott 1988, Ryder 1985, Adams 1985, and Stewart 1980).

Fresh-Water/Salt-Water Transition Zone

The King's Bay Springs lie in or near the fresh-water/salt-water transition zone; a brackish zone in the Floridan aquifer where seaward-moving fresh water meets landward-moving salt water. As a result of their proximity to the transition zone, many of the springs in the study area discharge brackish water. The high salt content of many brackish springs indicates that Gulf water has intruded through interconnected solution conduits gulfward of the springs (Yobbi, 1992). In general, springs located more inland and northward in King's Bay are further from the transition zone and, therefore, have fresher water.

The position of the transition zone results from the dispersive characteristics of the geologic strata, fresh-water flow, tidal effects, recharge, and pumping of wells (Wentworth, 1951). The transition zone is bounded on the seaward side by chloride concentrations that can be as high as 19,000 mg/l and on the landward side by chloride concentrations of 25 mg/l (Causseaux and Fretwell, 1979). A sharp boundary does not exist in coastal aquifers because of mechanical dispersion and tidal or water level fluctuations caused by changes in recharge or pumpage with time. Instead, a dynamic equilibrium has been established that causes fresh water and salt water to mix and form a transition zone between fresh water and salt water (Yobbi, 1992). Salt water is not static in the transition zone but flows from the sea floor into the zone of transition and back to the sea floor (Cooper et al., 1964).

The transition zone moves horizontally and vertically in the upper Floridan aquifer in response to changes in fresh-water head and tides in the gulf. As a result of the movements of the transition zone, the water quality and magnitude of discharge of the springs continuously change. Tidal fluctuations result in diurnal fluctuations in water quality and discharge. Salinity is generally lowest at low tide when the transition zone is further seaward. Discharge generally peaks at low tide and is a function of the difference in head between the aquifer and the spring pool.

Changes in fresh-water head are largely seasonal. The discharge of most springs peaks in late summer and early fall (which corresponds to the end of the peak rainfall season) and gradually declines toward winter and spring. However, spring flow during wet periods is not always proportional to the increase in rainfall as a result of storage in the aquifer. The increase in fresh-water flow in the wet season has the effect of pushing the transition zone seaward. This results in a decrease in salinity in the springs.

The AGWQMP has been investigating the position and thickness of the transition zone through its Coastal Ground-Water Quality Monitoring Network since 1992. Figures 7 is a west to east cross section through the transition zone near Homosassa Springs in Citrus County.

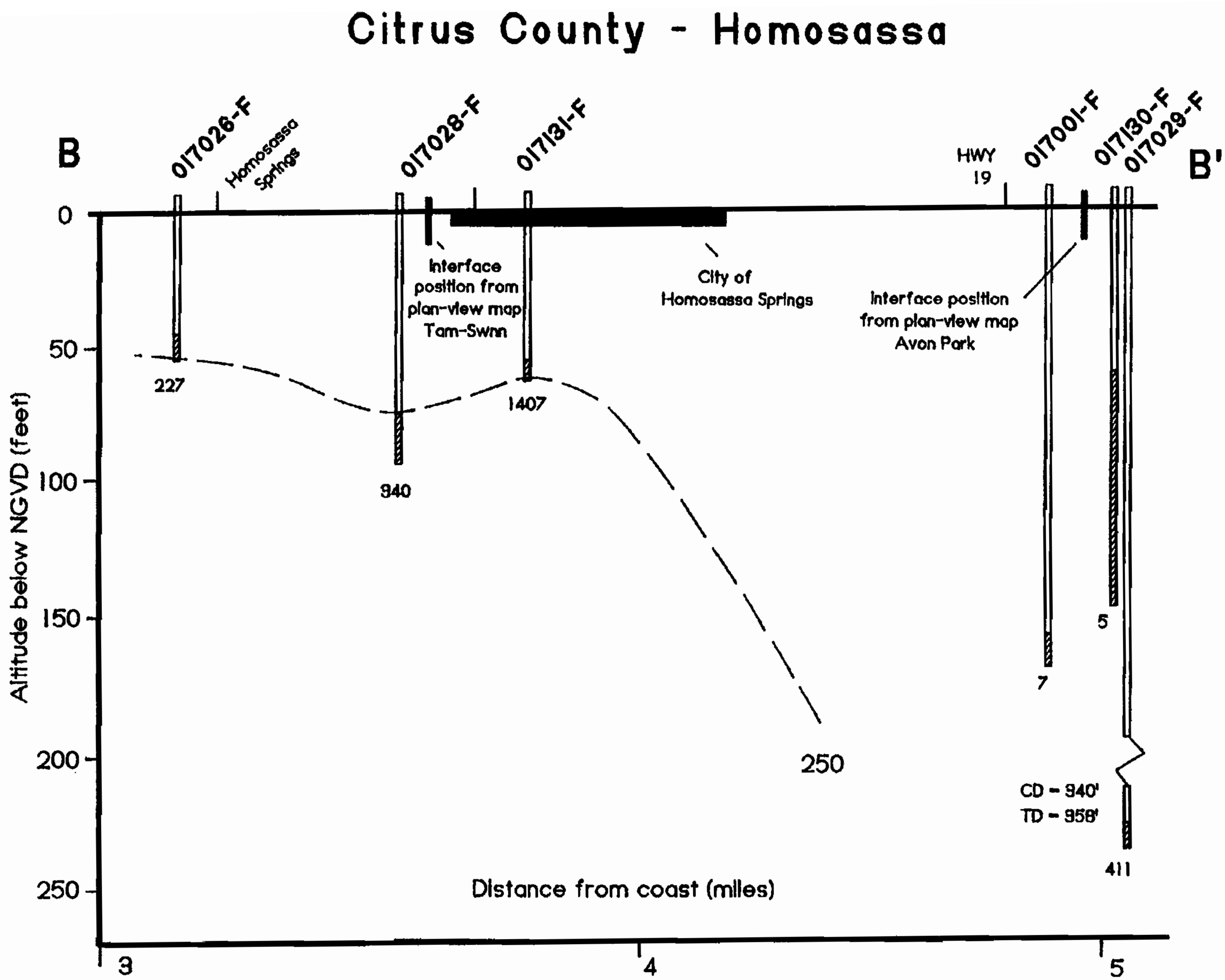


Figure 7. West to East Cross Section through the Salt-Water Fresh-Water Transition Zone Near Homosassa Springs (DeHaven, 1995).

Yobbi (1992) showed the approximate position of the 250 mg/l line of equal chloride concentration at a depth of 100 feet below sea level in the Upper Floridan aquifer based on samples collected from wells and springs (1964 through 1980) (Figure 8). Chloride concentrations in ground water exceeding 250 mg/l generally occur at a depth of less than 100 feet seaward of this line and greater than 100 feet inland of this line.

Data presented in Yobbi (1992), water quality data collected by the AGWQMP (DeHaven, 1995) from its coastal monitor well network, and surface geophysical surveys (Bisdorf and Zohdy, 1979; Stewart and Gay, 1983;) indicate very prominent landward reentrants of the transition zone in the vicinity of the major coastal springs. The reentrants result from the concentration of discharge at the major springs, which has the effect of reducing fresh-water head. This allows salt water to migrate inland in the vicinity of the springs.

Thickness of the Potable Water Zone

Figure 9 depicts a generalized thickness of potable ground-water in the Floridan aquifer across Citrus County. The potable thickness interpretation is based on historical hydrogeologic data spanning several years and includes water-quality data from monitor wells, test drilling data, and from geophysical logs (Appendix IV). Water quality criteria for determining the thickness of the potable-water zone are defined by ground-water conditions where chloride or sulfate concentrations exceed the 250 mg/l drinking water standards established by the FDEP (1993).

The depth to nonpotable ground water was determined from the casing depths of wells when sample data indicated that nonpotable conditions exist in the open wellbore intersecting the aquifer. Water-quality profiles obtained during test drilling at monitor sites or associated geophysical data were also used to verify water-quality changes with depth.

Thickness of the potable-water zone in the Floridan aquifer in Citrus County and the study area ranges from 300 feet in the southern and central regions, to less than 200 feet along the coastal margin and in the Tsala Apopka/Withlacoochee River area. The average thickness of potable ground water in Citrus County is 200 to 300 feet, although nonpotable conditions occur less than 100 feet deep near the coast where landward reentrants of the transition zone exist near the spring complexes.

Potable thickness in the central and eastern regions of the county is limited by the occurrence of sulfate-rich waters emanating from the dissolution of gypsum or anhydrite near the base of the Floridan aquifer (Sacks 1996, Hickey 1990). Depth to sulfate-rich ground water is controlled by the depth of sulfate minerals and the recharge potential, where a high degree of ground-water recharge in an active flow system tends

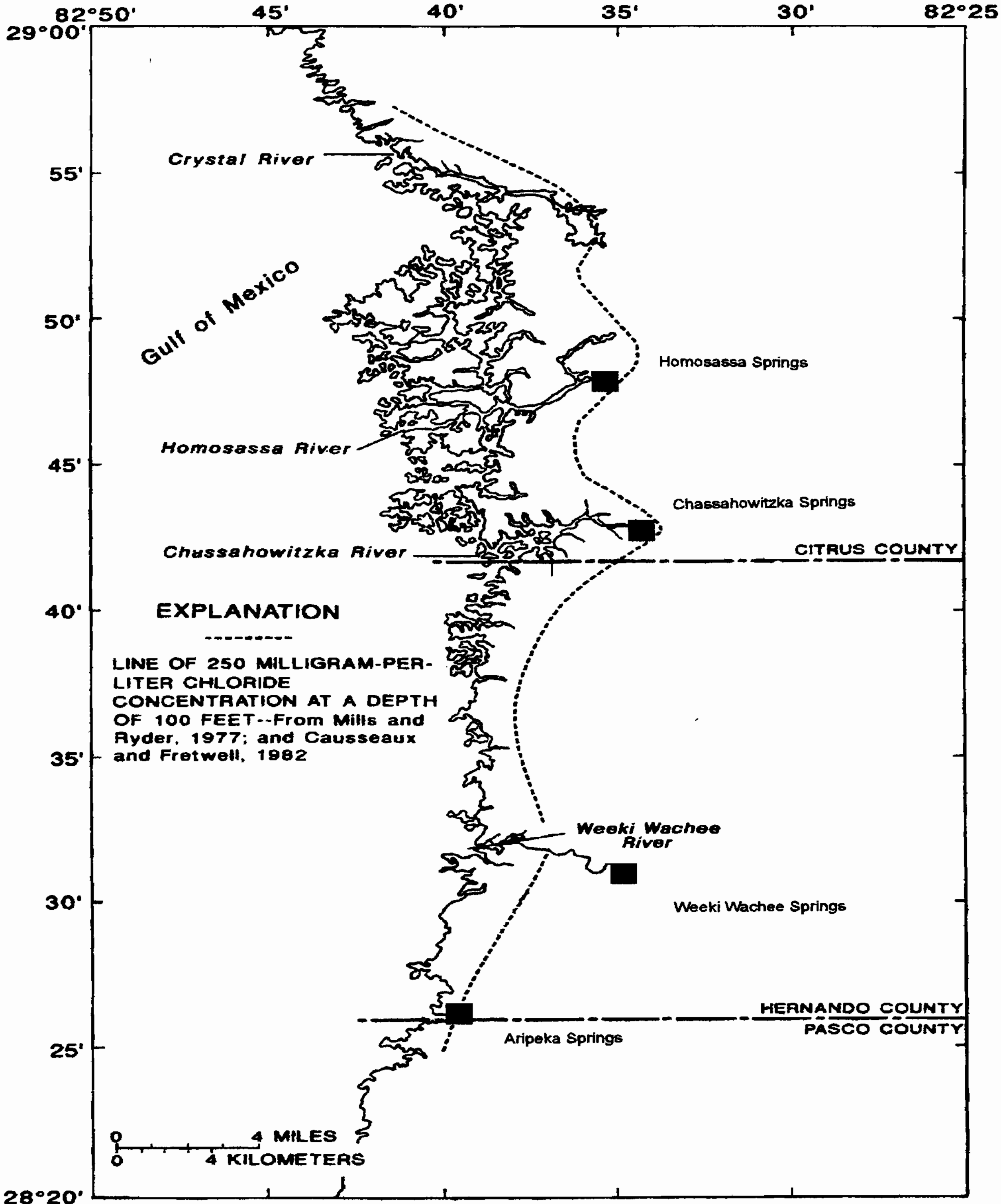


Figure 8. Approximate Position of the 250 mg/l Line of Equal Chloride Concentration at a Depth of 100 Feet Below Sea Level in the Upper Floridan Aquifer (Modified from Yobbi, 1992).

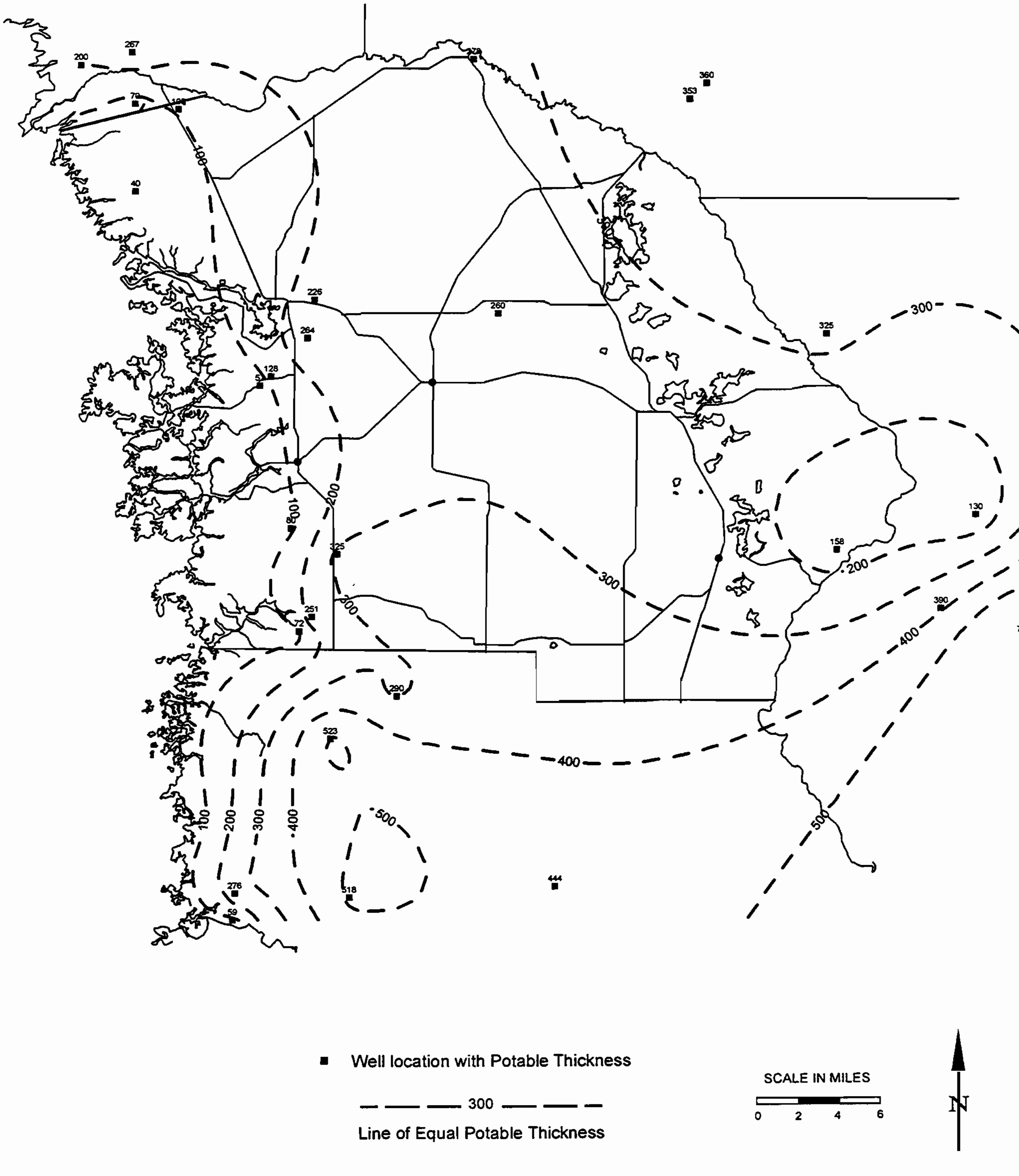


Figure 9. Generalized Thickness of the Potable Water Zone in the Floridan Aquifer across Citrus County.

to increase potable thickness. A thinner freshwater lens is found in regions where ground-water recharge rates are lower and where ground-water discharge is occurring, such as along the Withlacoochee River and the Gulf coast.

Although Causey and Leve (1976) determined the thickness of the potable-water zone in the northern portion of the SWFWMD to be considerably greater, the information presented above is based on recent data that provide a more accurate assessment of the potable-water thickness. The conclusion that the potable-water zone is considerably thinner than what was described by Causey and Leve is supported by Ryder (1985).

Description of the 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 approximately six miles west of the bay. Figure 1 depicts the locations of eleven 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 Hole (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 a large subaqueous vent approximately 200 feet in diameter and 50 feet deep.

The discharge of the springs in King's Bay is affected by tidal fluctuations (Rosenau et al. 1977). Conductivity readings taken before and after dead-low tide by AGWQMP staff indicate that the water quality of many coastal springs changes with tidal fluctuations. In addition, 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

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 traveled 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 King's Bay Springs from those that discharge to Homosassa Springs to 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 King's 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 Florida Geological Survey, the Florida Department of Environmental Protection (FDEP), and the SWFWMD.

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, seven dedicated monitor wells were located in the study area and included in the network. Figure 10 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 11 indicates the stratigraphic interval and aquifer from which each well is receiving water.

WATER-QUALITY SAMPLING OF MONITOR WELLS AND SPRINGS

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 monitor well and springs sampling are included in Appendices II and III, respectively. Methods used are current, U.S.E.P.A.-approved standard methods, where available.

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 were

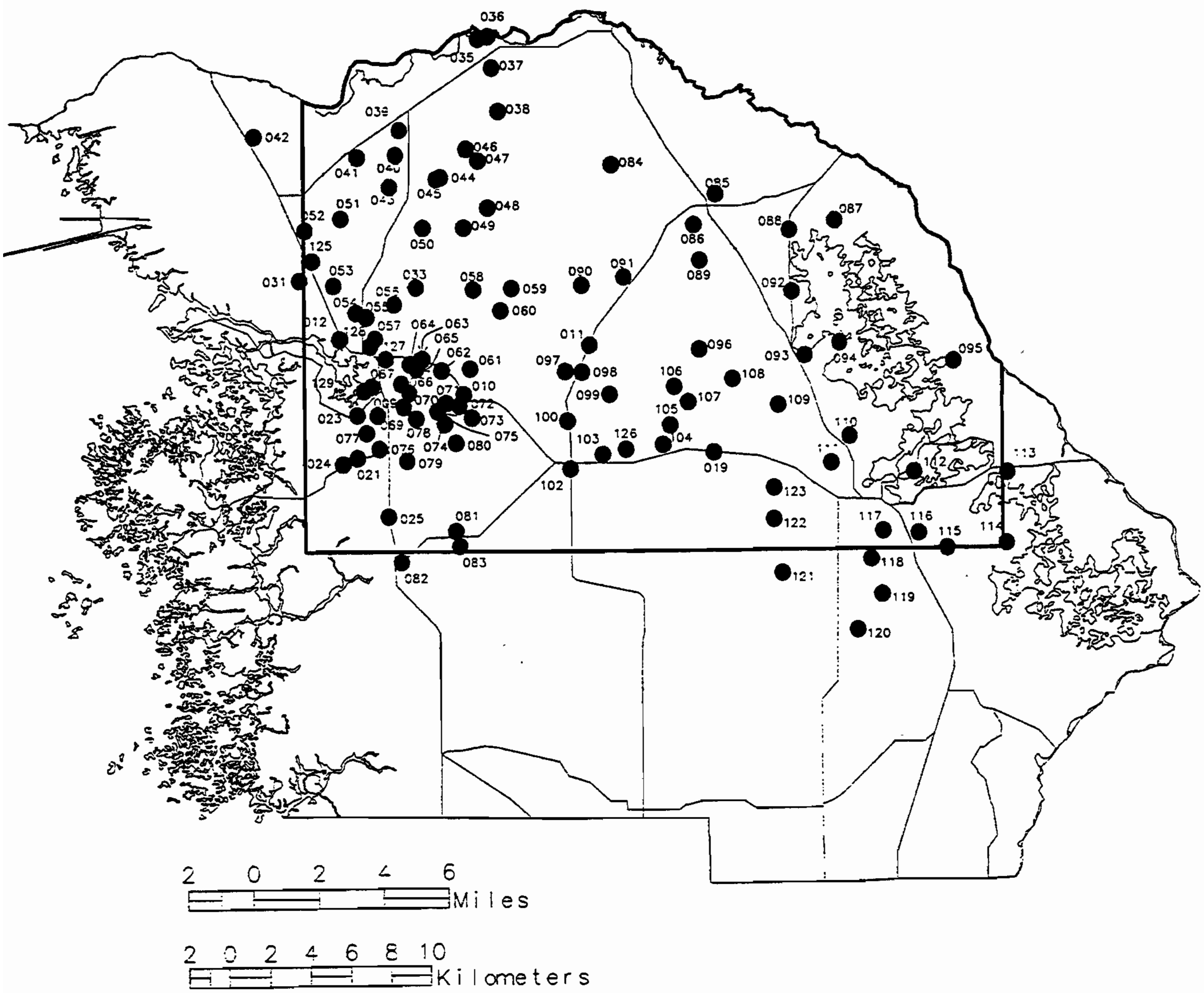


Figure 10. Location of Sampled Wells in the Study Area.

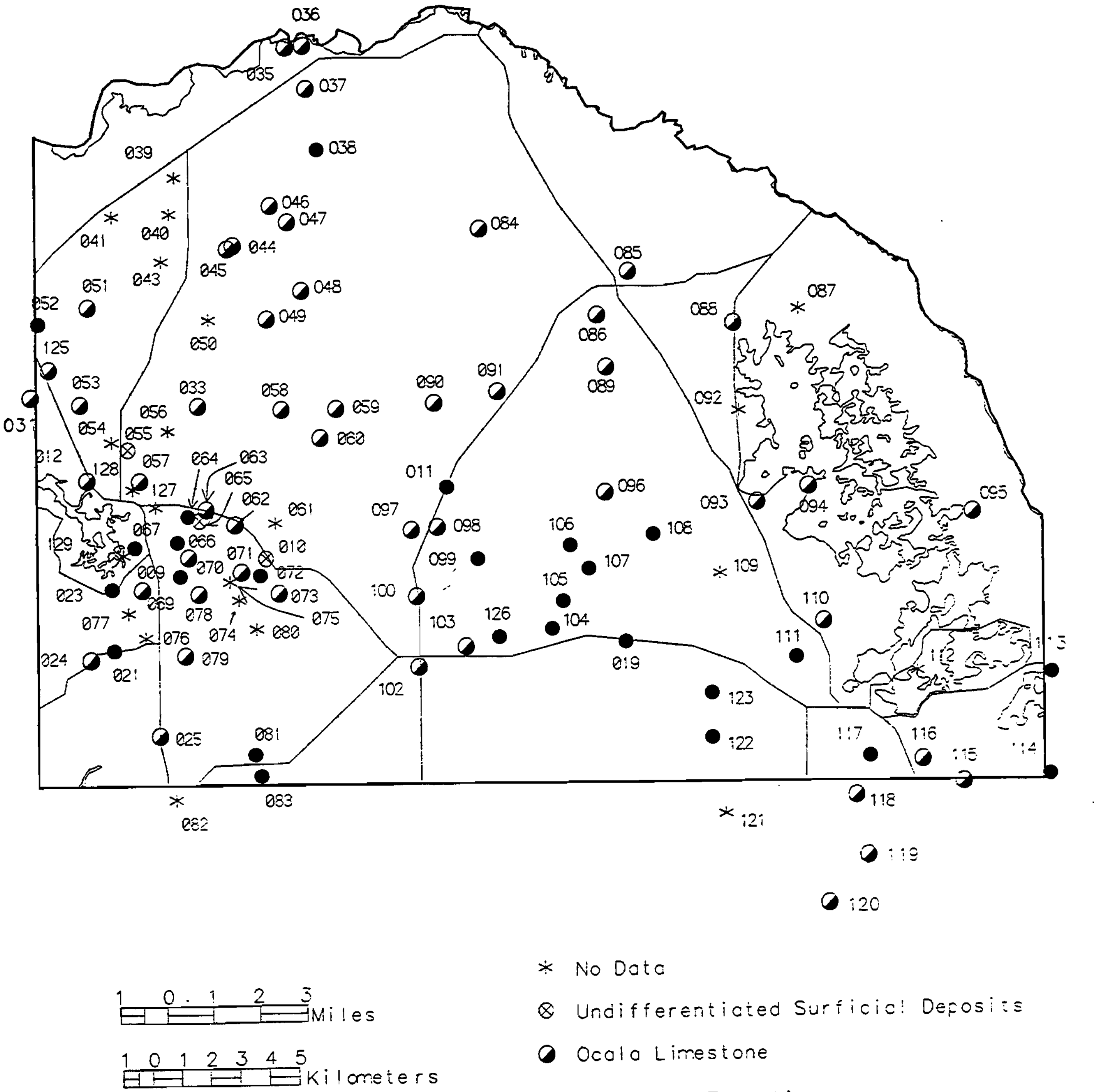


Figure 11. Stratigraphic Interval from Which Network Wells Obtain Water.

Table 2. - Chemical 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	

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.

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 ten major ions, six nutrients, total dissolved solids, total organic carbon, and iron. A total of 93 wells were sampled for these parameters. The second list included four 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. Fifteen wells were sampled for tritium, seven for $\delta^{15}N$, and 27 for uranium-234 and -235.

Springs Network

All springs were initially sampled in late April 1991 for eleven major ions, six nutrients, total dissolved solids, total organic carbon, and six 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 six 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 spring water quality with nutrient sources.

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 12. From the figure it is apparent that a large number of very extensive sinkholes, some measuring several square miles in extent, are located within the boundaries of the Brooksville Ridge. Littlefield *et al.* (1984) showed that sinkholes are often aligned along photolinear features[1], 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 13. 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.

Lines of equal potential of the potentiometric surface usually shift slightly gulfward between May and September, as the Floridan aquifer system is recharged by summer rains and pumping is reduced.

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[1] 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 west-central Florida, including Citrus County, 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.

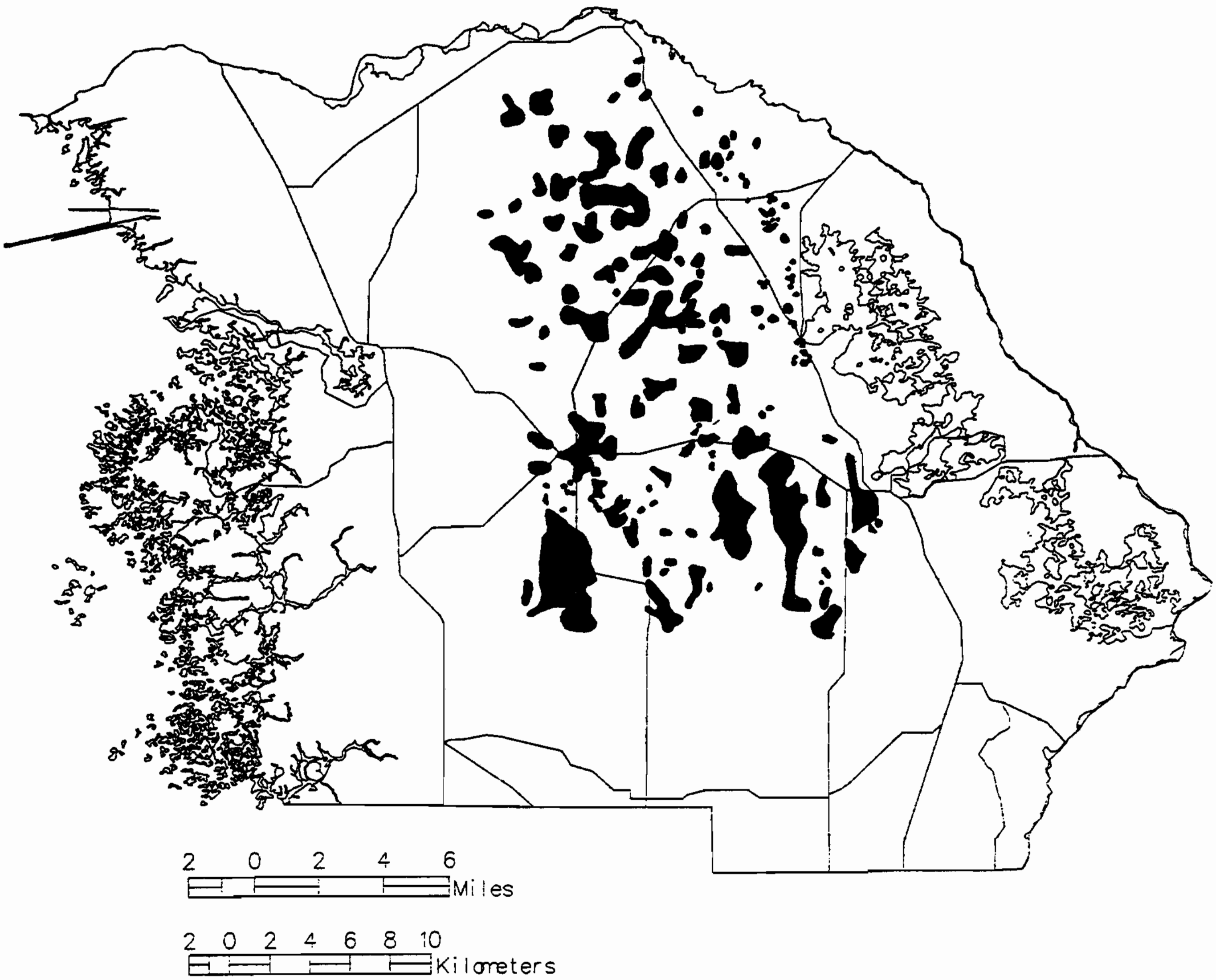

Figure 12. Location of Major Karst Features in the Study Area.

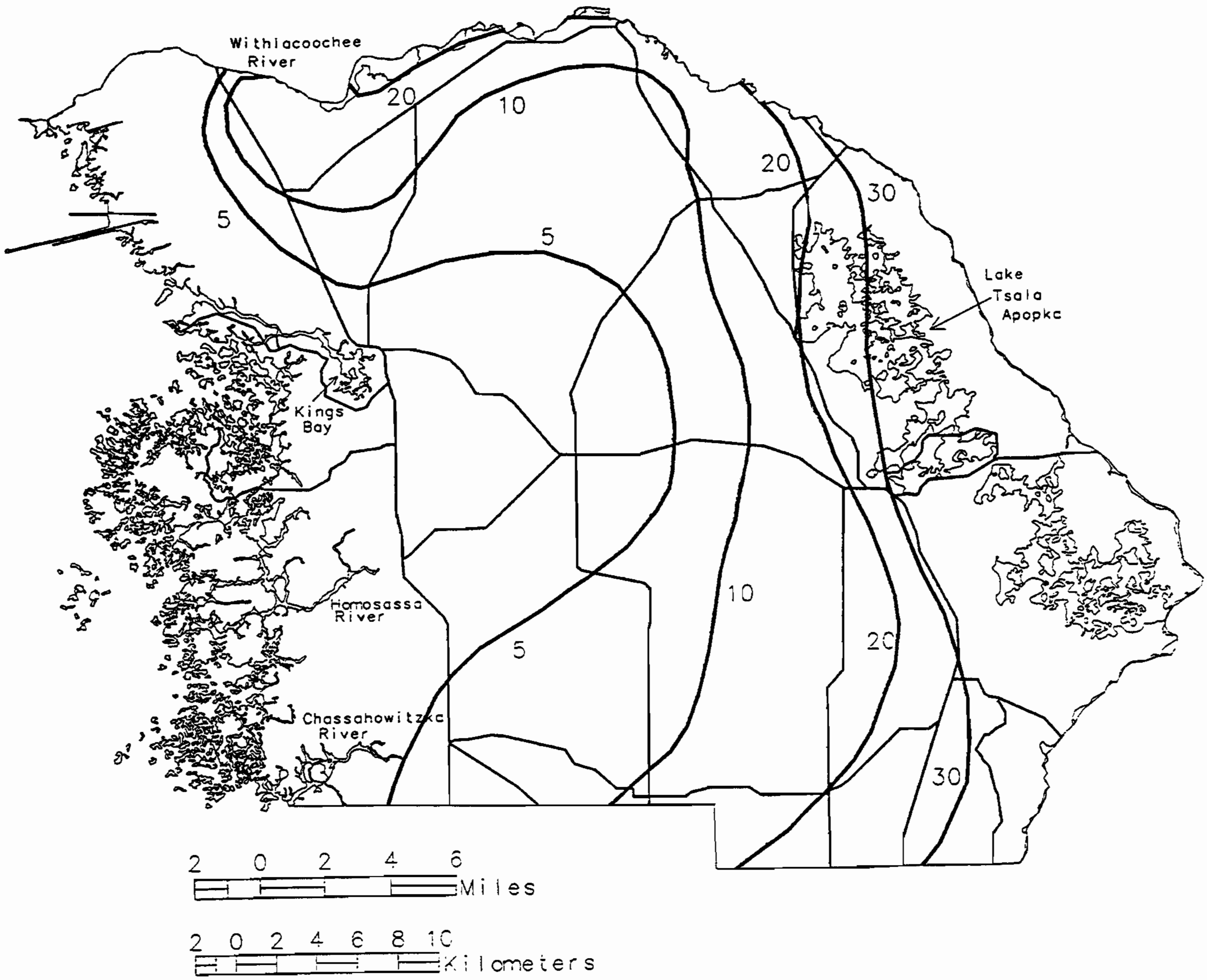

Figure 13. Potentiometric Surface of the Floridan Aquifer in Citrus County, May, 1991 (modified from Mularoni, 1992).

GROUND-WATER CHEMISTRY: RECHARGE AREA

This section presents an analysis of the chemistry of ground water in the recharge area of the King's Bay Springs. Samples used in this analysis were obtained from the 103 wells included in the monitor well network. The section begins with a hydrochemical facies characterization using Piper and Stiff diagrams. Next is an analysis of the major analyte content of ground water using concentration contour maps. This is followed by a discussion of nitrogen geochemistry and the distribution of the various nitrogen species in ground water. The section ends with a discussion of the distribution of additional nutrients and iron in recharge area ground 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 diagrams (Stiff, 1951), 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 plotted on a Piper diagram (Piper, 1944), which relates the changes in proportions, but not concentrations, between samples.

Chemical data from 89 wells sampled by the AGWQMP in the study area were used to construct a Stiff diagram for each well. Fourteen wells were deleted from the set of data used for hydrochemical facies analysis because four had passed through water filters prior to sampling and ten wells had nutrient data only. Figure 14 presents a Piper diagram and representative Stiff diagrams were added to demonstrate differences and similarities in the ratio of major ions in the Floridan aquifer.

Figure 14 shows that most water-quality samples in the study area are dominated by calcium and bicarbonate. Calcium-bicarbonate water types indicate that the chemistry of the ground water is dominated by simple dissolution of limestone. A small number of samples contain a significant presence of magnesium and sulfate, and to a lesser extent, the chloride ion. The low sulfate content reflects a shallow flow system. Higher sulfate content may indicate seawater mixing, deeper ground-water flow, or oxidation of organics/pyrite (FeS_2) in overlying sediments.

The higher proportions of magnesium, seen in some of the water-quality samples, may result from seawater mixing, or ground-water flow through dolostones of the Floridan aquifer. Because the magnesium-sulfate wells are completed into shallow portions of the aquifer and are located well away from the coast, ground-water flow through dolostones of the Floridan aquifer is the likely source of this water type. Finally,

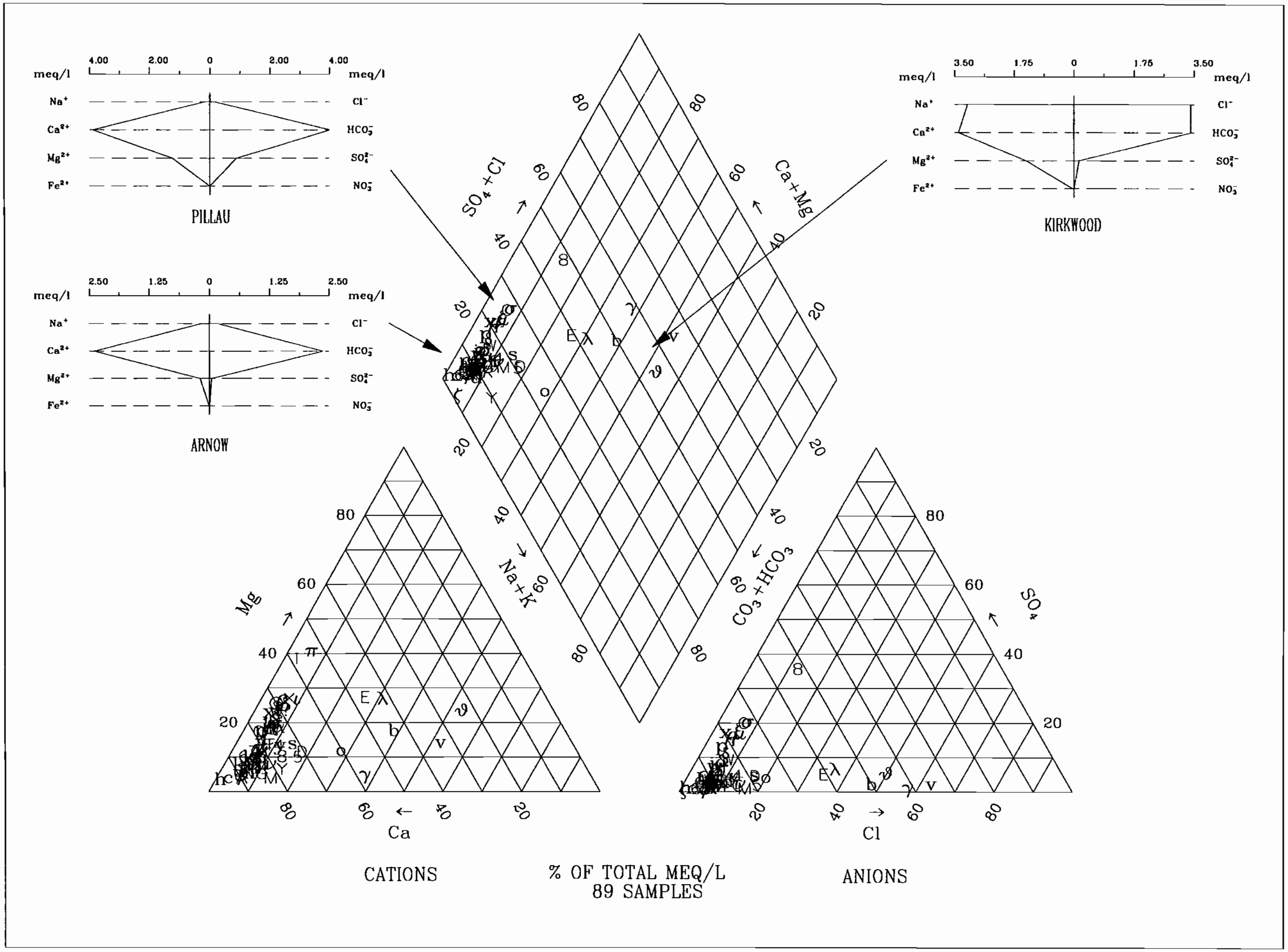

Figure 14. Characterization of Recharge Area Ground Water Using Piper and Stiff Diagrams. Arrows relate relative positions of water types on the Diagram.

elevated proportions of chloride in study area ground water may reflect seawater mixing or concentration by evapotranspiration.

MAJOR ANALYTES

In this part of the report the analytes that are discussed are considered to be the ones most indicative of the origin and fate of ground water. These analytes are: pH, bicarbonate, calcium, chloride, sulfate, and TDS. pH is included because it is intimately associated with bicarbonate and calcium and it controls chemical interaction with rock materials. TDS is also included because it is a measure of the total concentration of all the major and minor constituents. Other major ions, such as sodium, magnesium, potassium, and fluoride, occur in small but significant concentrations. Contour maps of these ions were not included because their utility was considered to be limited in characterizing ground-water quality in the study area. However, data for these parameters are included in Appendix II.

In Figures 15 through 28, the concentrations in milligrams per liter (mg/l), unless otherwise noted, of each indicator constituent is plotted next to the location of the well from which it was sampled. The SURFER® graphics package was used to machine contour the data. The machine-contoured maps were then edited to produce hydrogeologically reasonable maps. No changes were made to the contour patterns, only unsupported lines and inappropriate contours were changed. The maps, therefore, reflect an independent, quantitative interpretation of the data.

Three spatial domains are represented in the distributions of many of the analytes discussed below. The domains will henceforth be referred to as 1) the lake domain, 2) the ridge domain, and 3) the coastal domain. The lake domain apparently reflects leakage of surface water into the Floridan aquifer. This pattern is repeated in other analytes that are not discussed, and strongly suggests a local flow system with recharge near Lake Tsala Apopka, underflow of the Tsala Apopka water in central Citrus County, and up welling along the inner margin of the transition zone. The low concentrations in the ridge domain reflect recently recharged waters that have not reacted with the limestone and dolostone of the Floridan aquifer. These ridge domain waters lie above the Tsala Apopka and regional flow-system waters. Waters of the coastal domain are easily explained by salt-water mixing and up welling of the regional ground-water flow system at the inner margin of the transition zone.

Bicarbonate, Calcium, and pH

As rainfall passes through the soil layer it becomes increasingly acidic (low pH) as a result of its reaction with carbon dioxide (CO_2) to form carbonic acid (H_2CO_3) and by addition of natural organic acids (humic acid, etc.). These acids react with limestone ($CaCO_3$) to produce dissolved calcium (Ca^{2+}) and bicarbonate (HCO_3^-). As limestone is dissolved by acid, pH increases because acidity is consumed and calcium and bicarbonate are produced. Figures 15a and 15b,16a and 16b, and 17a and 17b show the distribution of bicarbonate, calcium, and pH, respectively, in study area ground water.

Figures 15a and 15b and 16a and 16b show that bicarbonate and calcium concentrations occur in three north-south domains: 1) moderately high concentrations in the lake domain, 2) low concentrations in the ridge domain, and 3) high concentrations in the coastal domain.

Several wells near the springs show high bicarbonate and calcium concentrations as a result of deeper sampling depths and/or upwelling of regional ground-water flow. However, the overall trend in the data suggests that lower concentrations of bicarbonate and calcium are displaced towards the King's Bay Springs and that convergent ground-water flow is occurring in the vicinity of the City of Crystal River. pH levels near the springs are typically near neutrality[2] (7.0-7.9), and reflect a conduit-dominated flow system where ground-water residence time is short.

In comparing the pH to concentrations of calcium and bicarbonate, an apparent anomaly exists in the ridge domain of the study area. In this area, low calcium and bicarbonate concentrations should result in a relatively low pH. However, pH regularly exceeds 8.0 in this area. This anomaly was observed in western Marion County near Rainbow Springs, and likely results from another process acting independently of carbonate-rock dissolution to raise pH to such high levels (Jones *et al*, 1996).

Chloride

Chloride is a chemically conservative[3] element, so it is usually used as a tracer of physical water flow. Figures 18a and 18b show the distribution of chloride in study area ground water. 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 discussed previously are represented in the patterns of the chloride data. The lake domain has several highs that suggest slightly deeper wells or water that has been concentrated through evapotranspiration prior to recharging the Floridan aquifer. The ridge domain reflects recently recharged waters that are shallow and have not been in contact with the

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[2] pH ranges from acid (pH =1 to approximately 7) to alkaline (pH = about 7 to 14). At a pH of 7 the water is said to have a neutral pH.

[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.

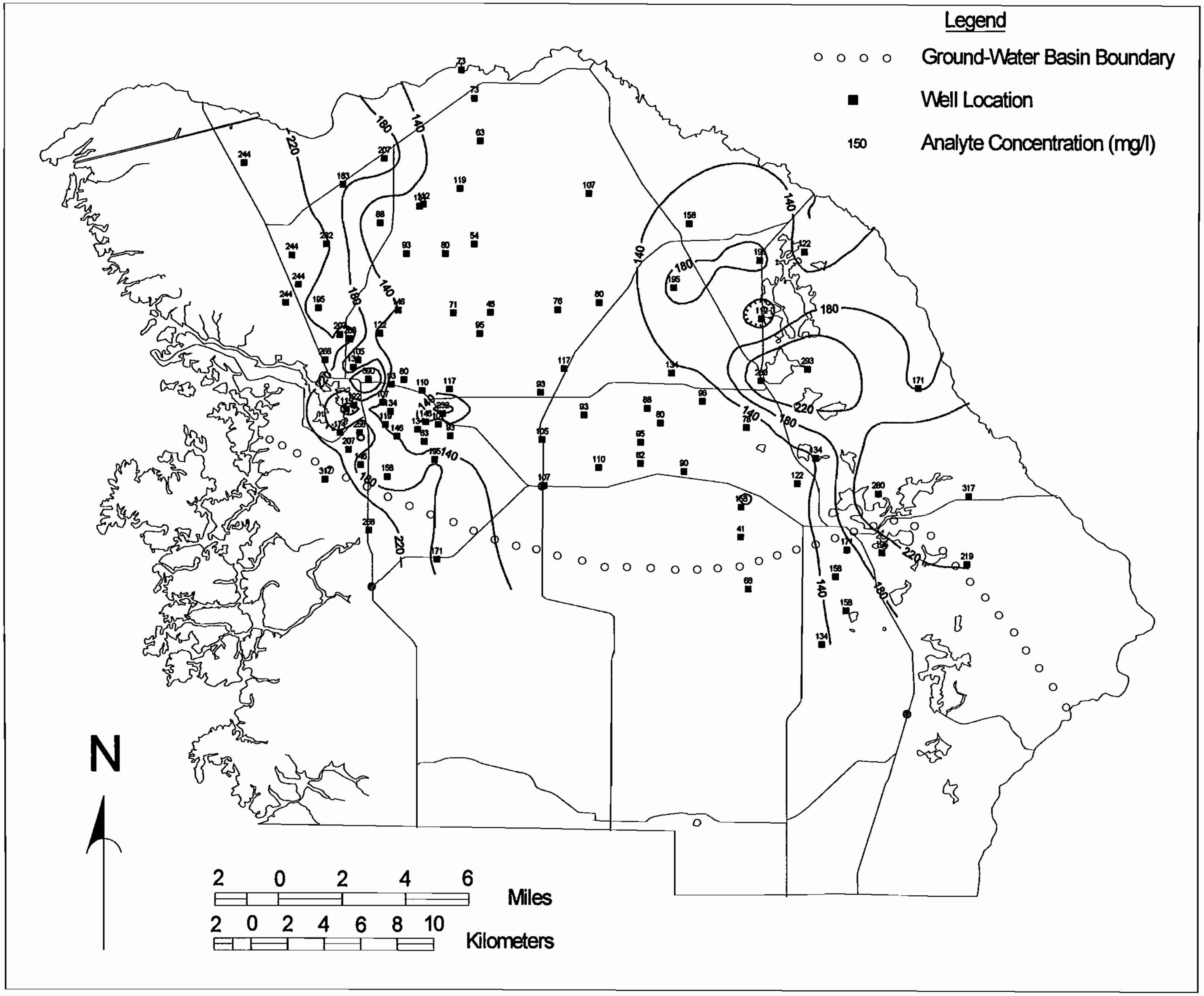

Figure 15a. Bicarbonate Concentrations in Study Area Ground Water.

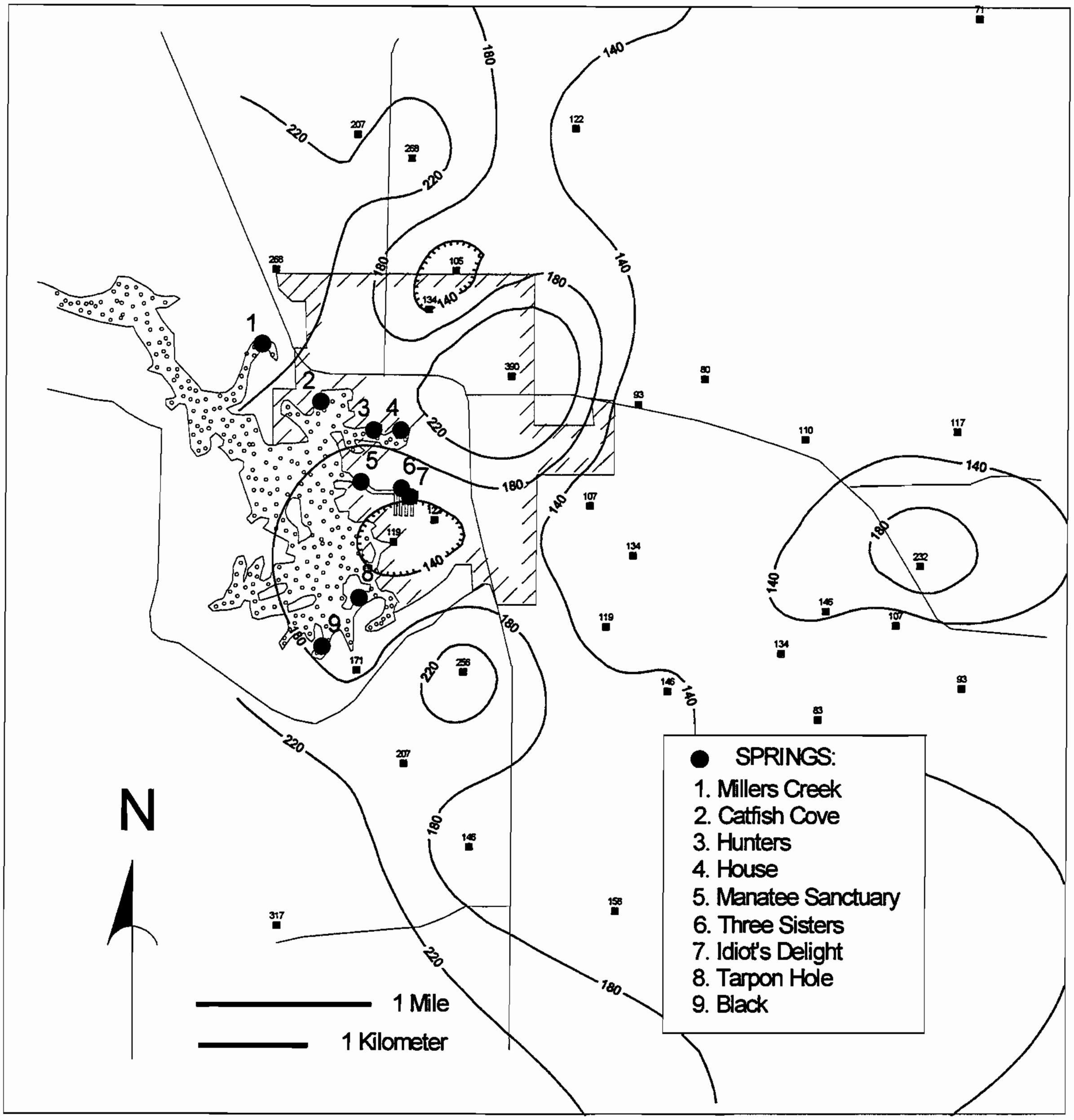

Figure 15b. Bicarbonate Concentrations in Ground Water in the Vicinity of the City of Crystal River.

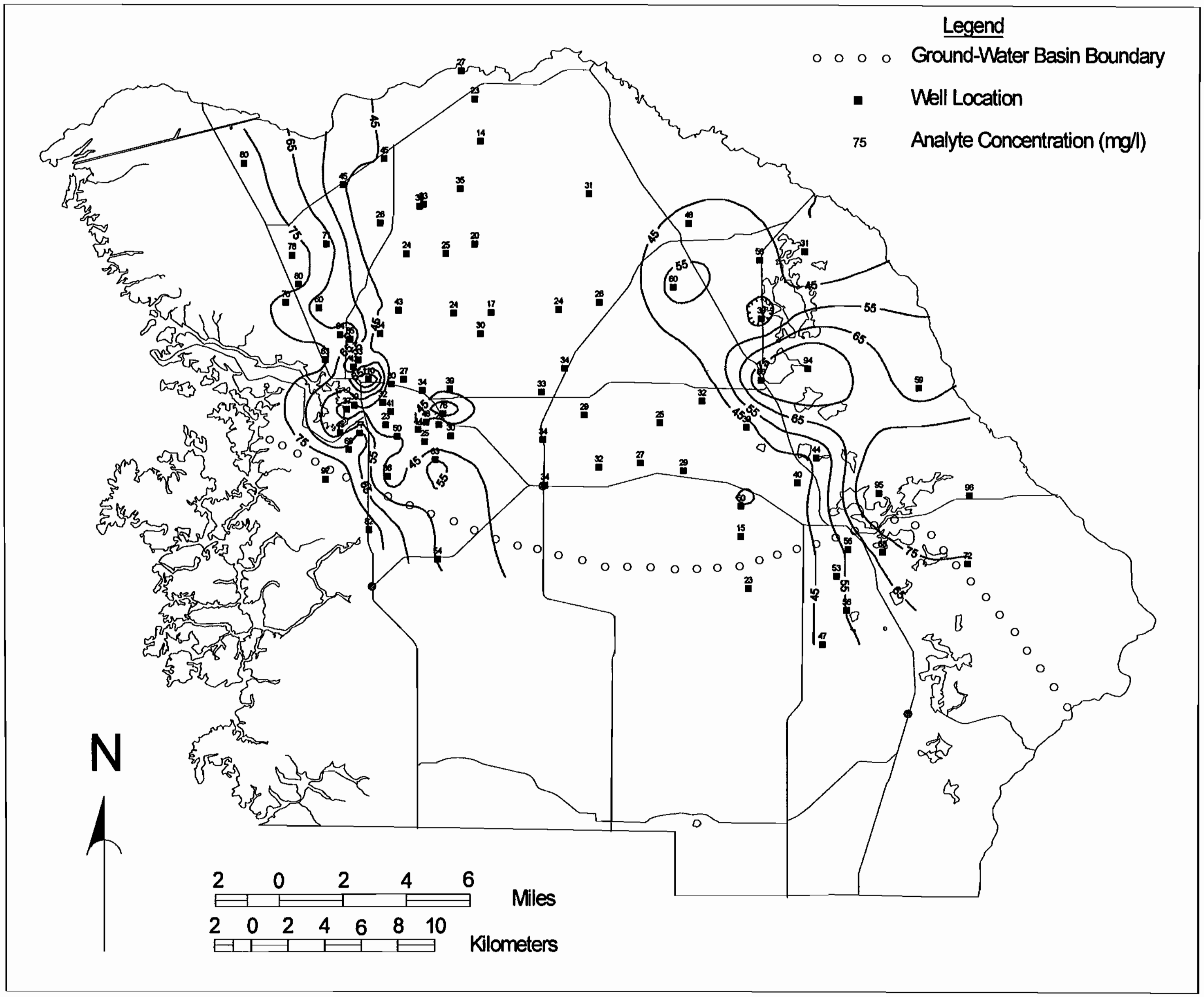

Figure 16a. Calcium Concentrations in Study Area Ground Water.

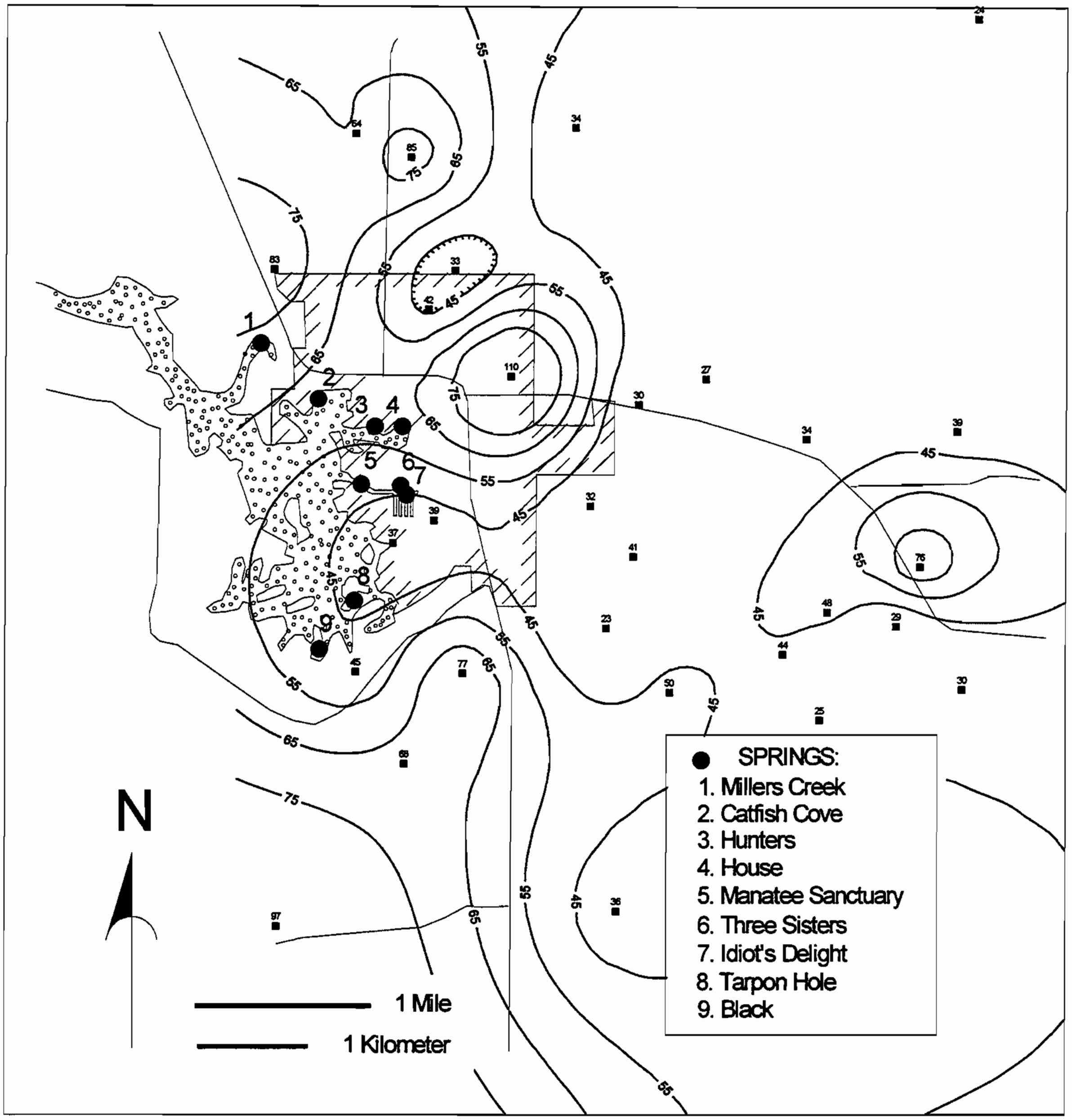

Figure 16b. Calcium Concentrations in Ground Water in the Vicinity of the City of Crystal River.

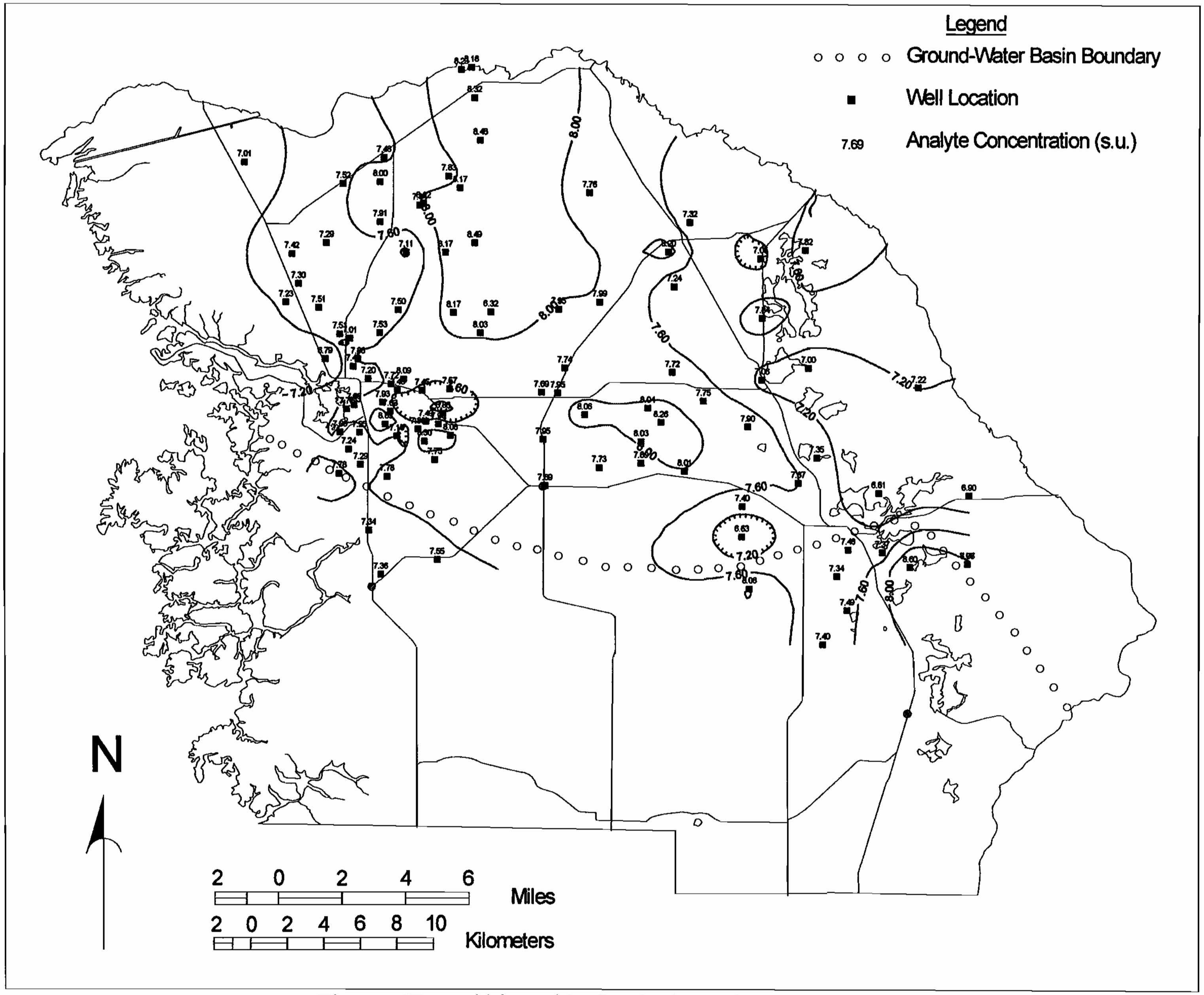

Figure 17a. pH Level in Study Area Ground Water.

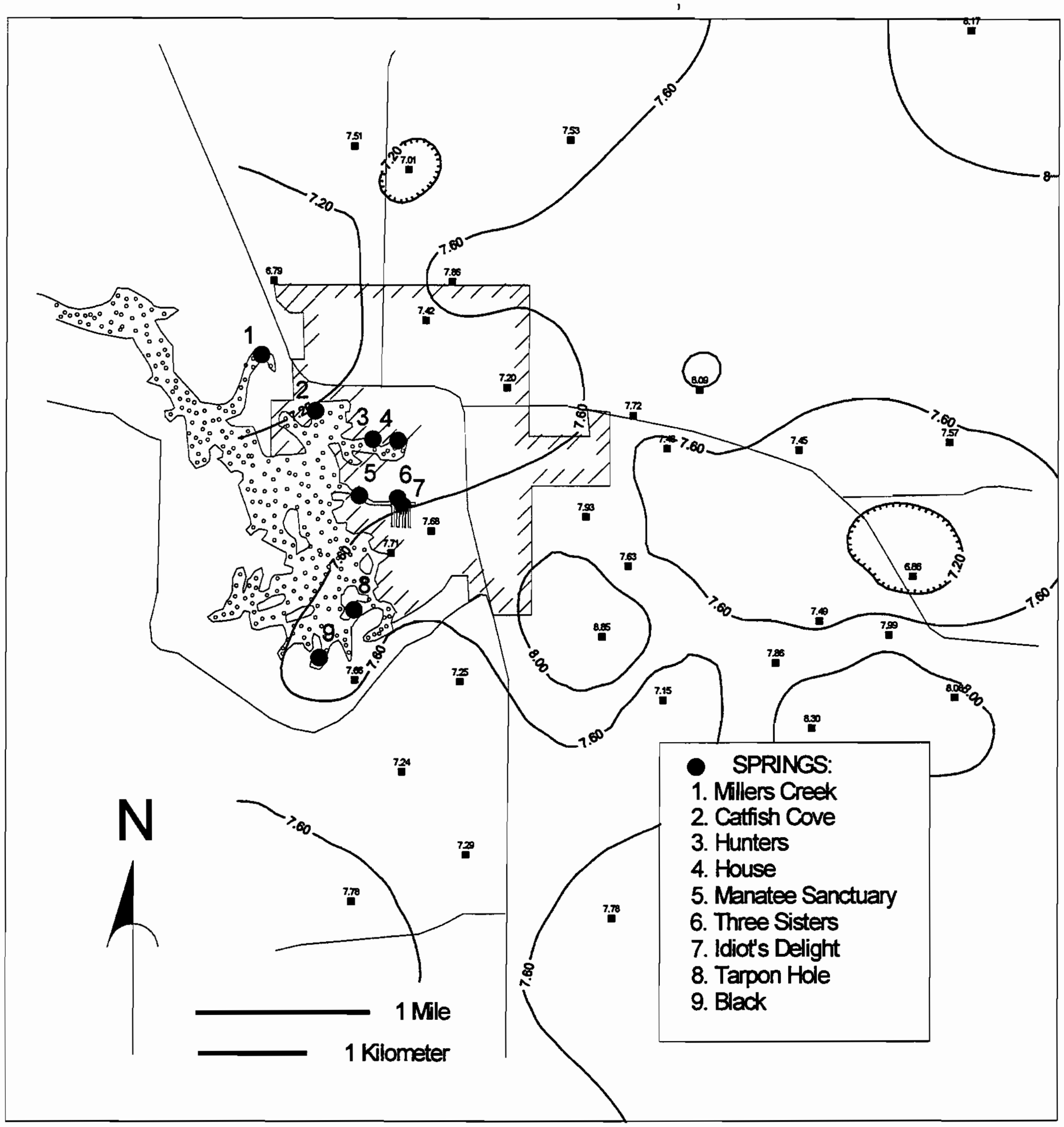

Figure 17b. pH Level in Ground Water in the Vicinity of the City of Crystal River.

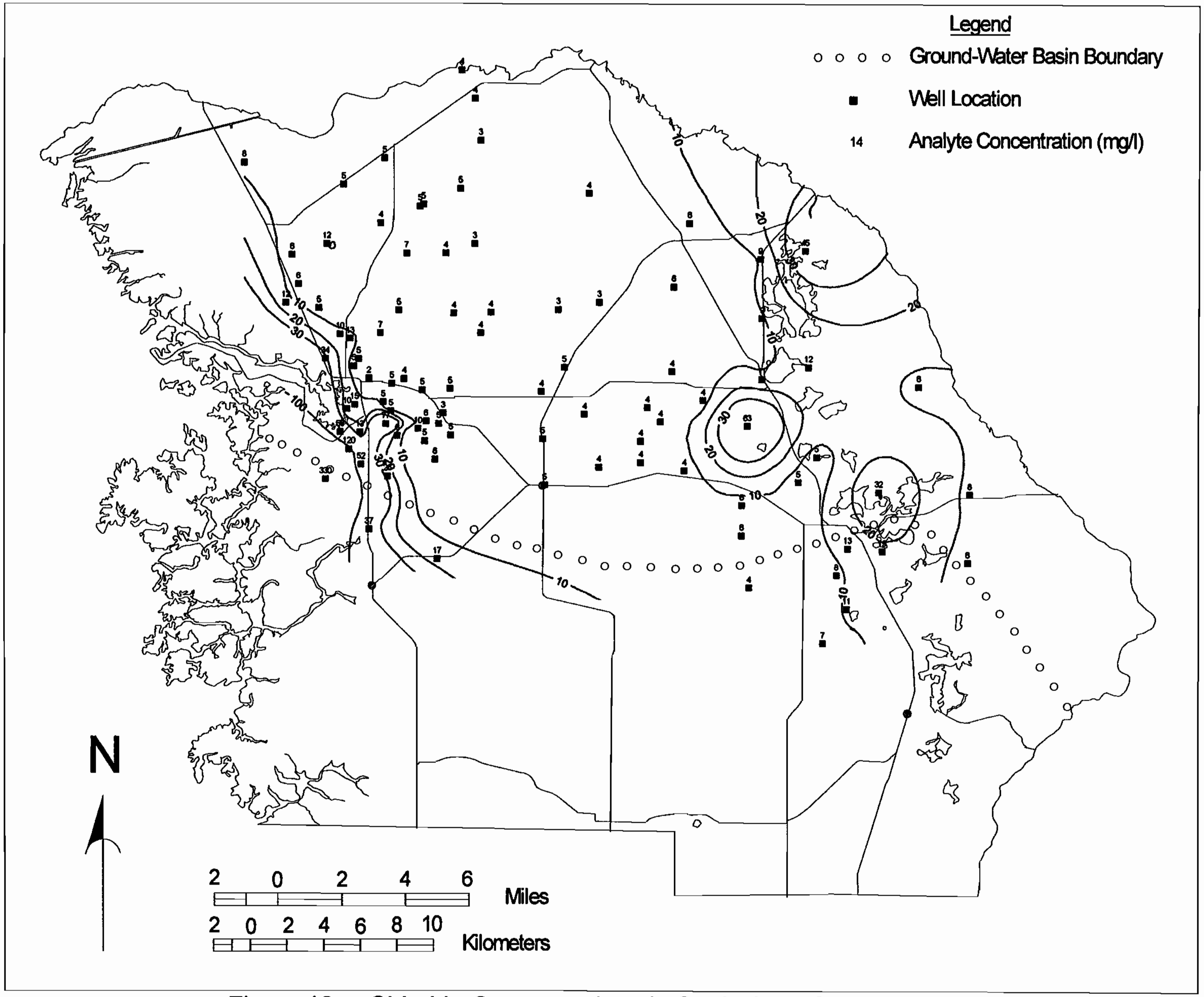

Figure 18a. Chloride Concentrations in Study Area Ground Water.

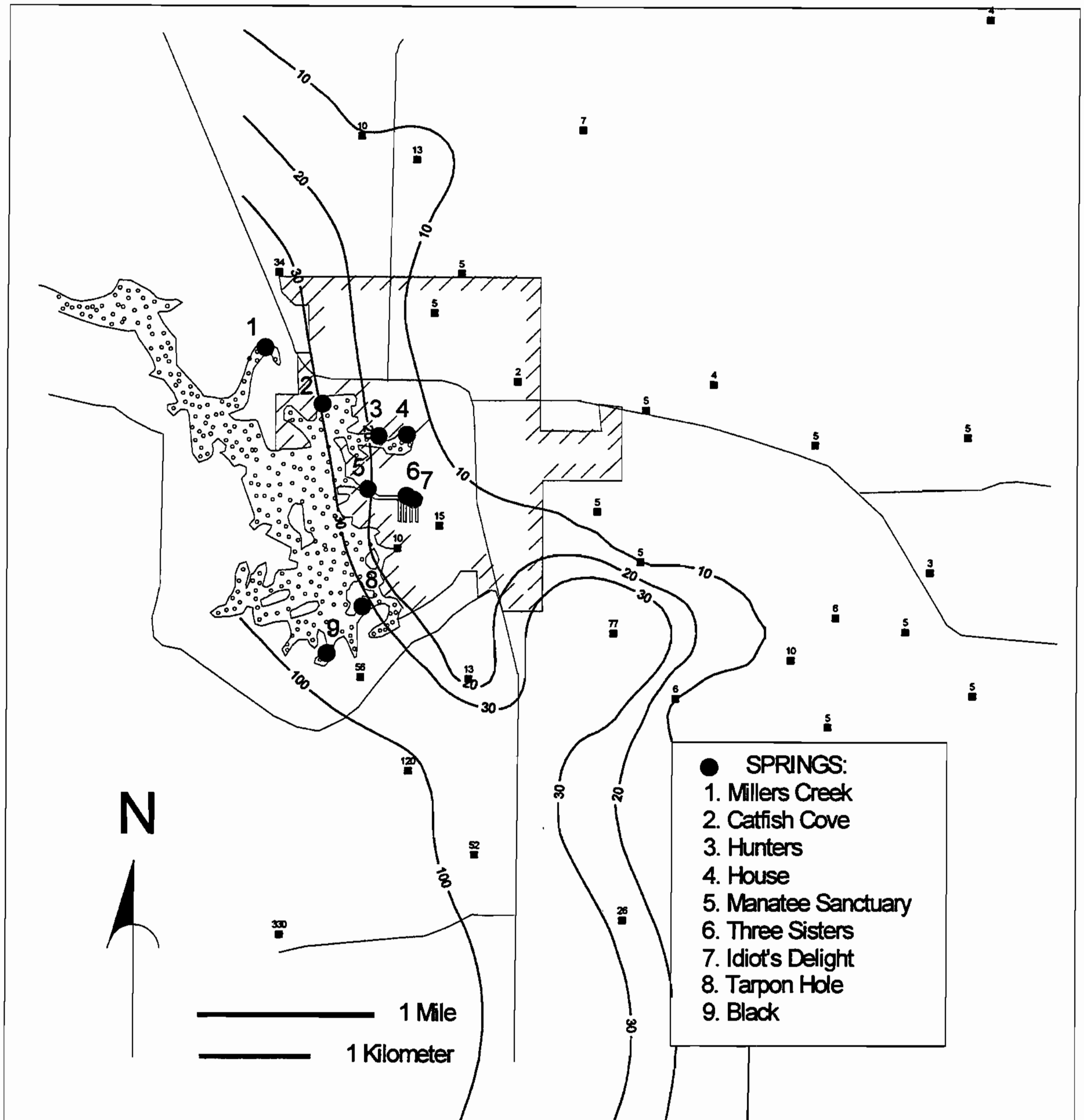

Figure 18b. Chloride Concentrations in Ground Water in the Vicinity of the City of Crystal River.

transition zone. Finally, water in the coastal domain is strongly affected by seawater mixing. Chloride concentrations in the springs indicate that at low tide the 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 was not possible to document inland migration of the transition zone at high tide. 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 likely that the transition zone moves 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 18b). This is either reflective of slightly deeper wells or 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 ($CaSO_4 \cdot 2H_2O$) or anhydrite ($CaSO_4$). Upchurch (1992) provides examples 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 important. There is minimal gypsum and/or anhydrite in near surface sediments, but the base of the upper Floridan aquifer is characterized by these minerals. Gypsum has also been found locally in the Hawthorn Group in several areas of west-central Florida (Upchurch, 1992). Sulfate is also abundant in seawater. 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.

Figures 19a and 19b show the distribution of sulfate in ground waters of the study area. Sulfate concentrations are low in the ridge domain, and there is a complex pattern near the coast. The pattern in the coastal domain suggests two components. The inner margin of the transitions zone is characterized by concentrations that gradually increases 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 convergent component of the regional flow system that does not contact the base of the aquifer. Seaward of the springs, sulfate increases rapidly, which reflects mixing with seawater and possible upwelling of deeper flow-system water.

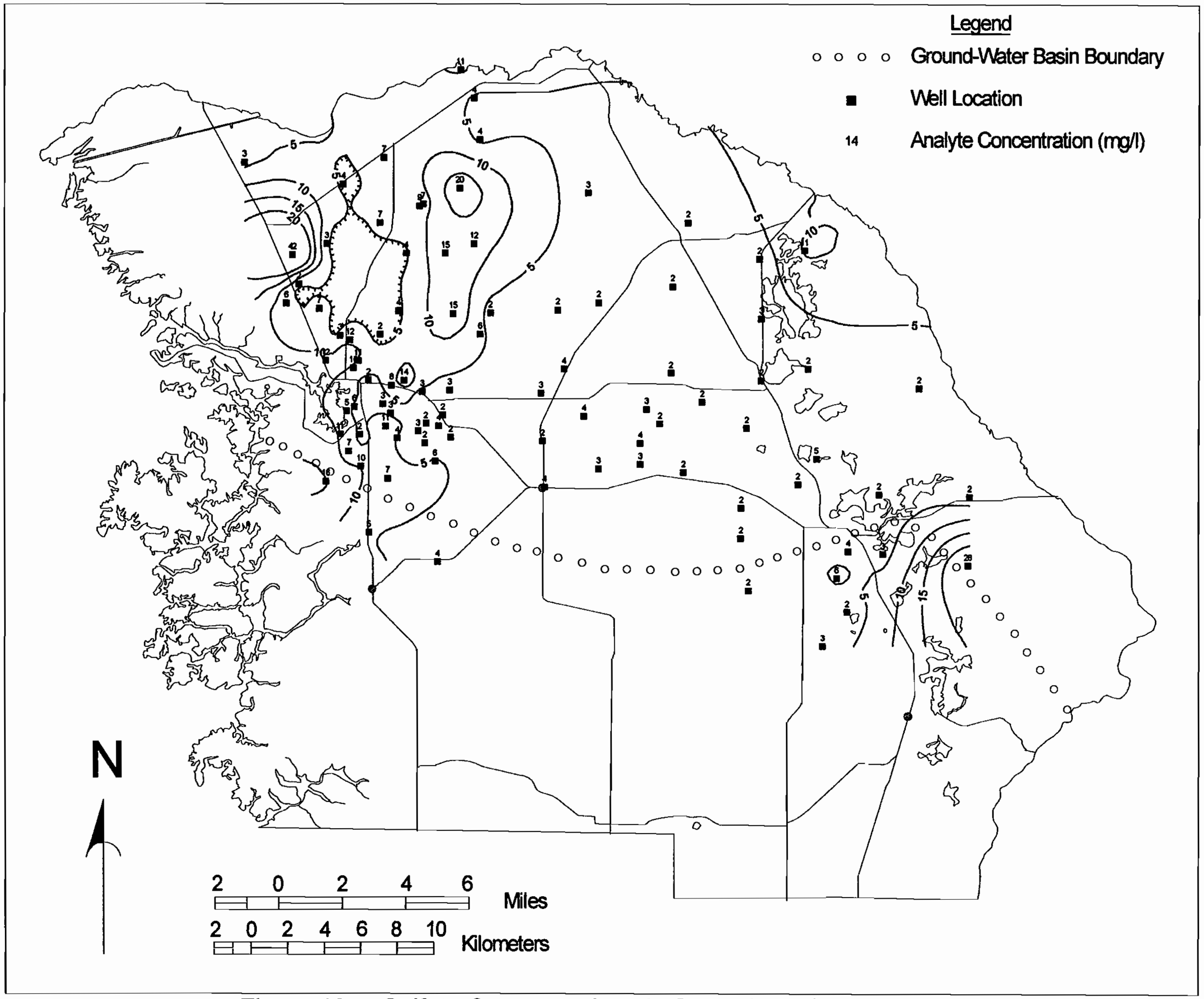

Figure 19a. Sulfate Concentrations in Study Area Ground Water.

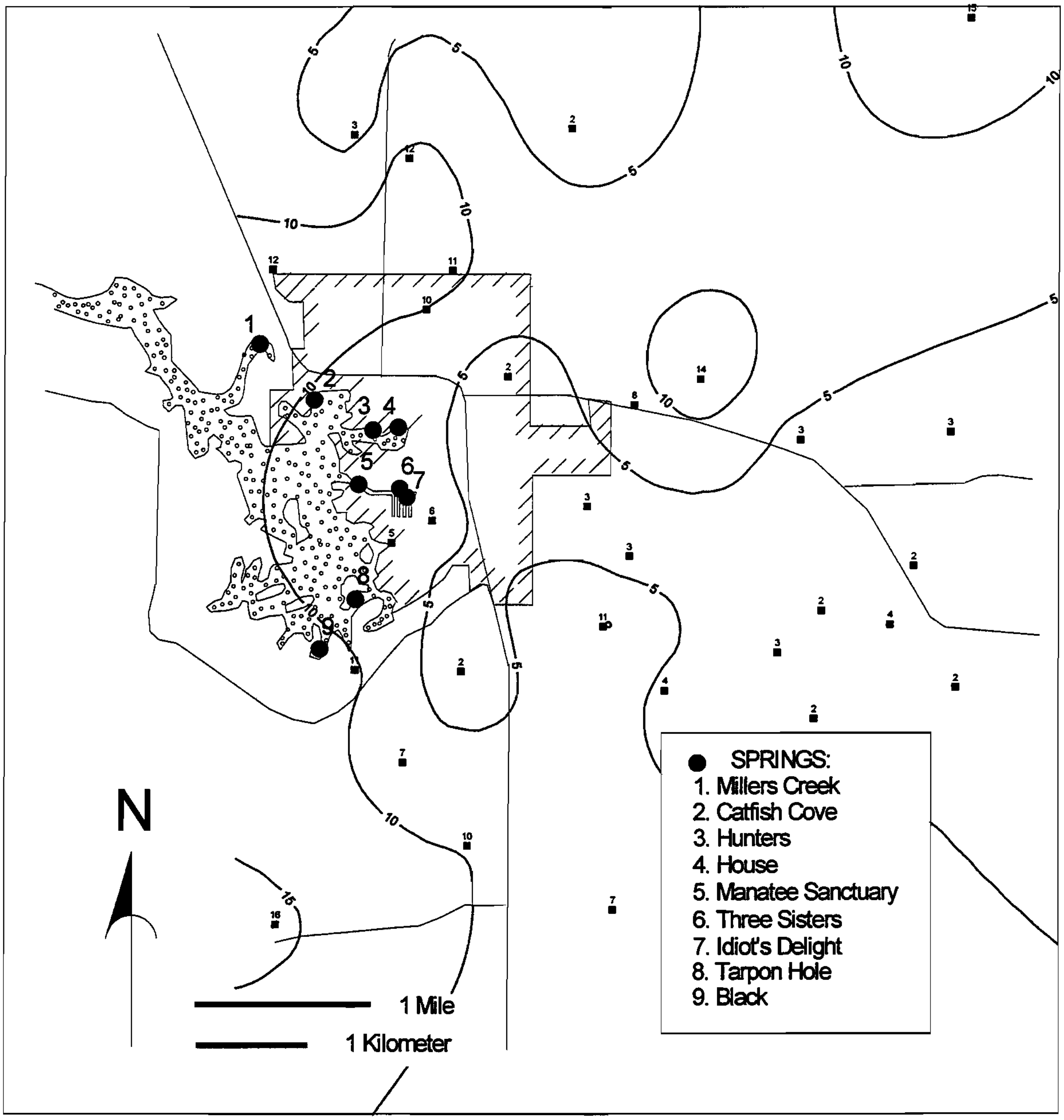

Figure 19b. Sulfate Concentrations in Ground Water in the Vicinity of the City of Crystal Riiver.

Total Dissolved Solids

The distribution of total dissolved solids (TDS) in study area ground water is shown in Figures 20a and 20b. The data reflect concentrations of calcium, magnesium, sodium, potassium, bicarbonate, sulfate, chloride, and other constituents in the ground water (Appendix II). 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 seawater, 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 seawater produces high TDS concentrations.

As expected, TDS concentrations closely mimic the patterns of water quality shown in previous analytes. Moderately high concentrations of TDS in the lake domain indicate recharge of surface waters from Lake Tsala Apopka to the Floridan aquifer. Low concentrations in the ridge domain reflect recently recharged waters that are shallow and have not come to chemical equilibrium with limestones and dolostones of the Floridan aquifer. Finally, high concentrations in the coastal domain are the result of seawater mixing/upwelling along the transition zone.

There are several TDS highs located within the City of Crystal River near the springs. These highs most likely reflect deeper wells open to higher TDS waters in the inner transition zone. Similar to sulfate, there is a corridor of low TDS concentrations oriented east-west in the vicinity of the springs that may represent a convergent, regional flow system.

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 Springs, 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 deep ground water as the ammonium

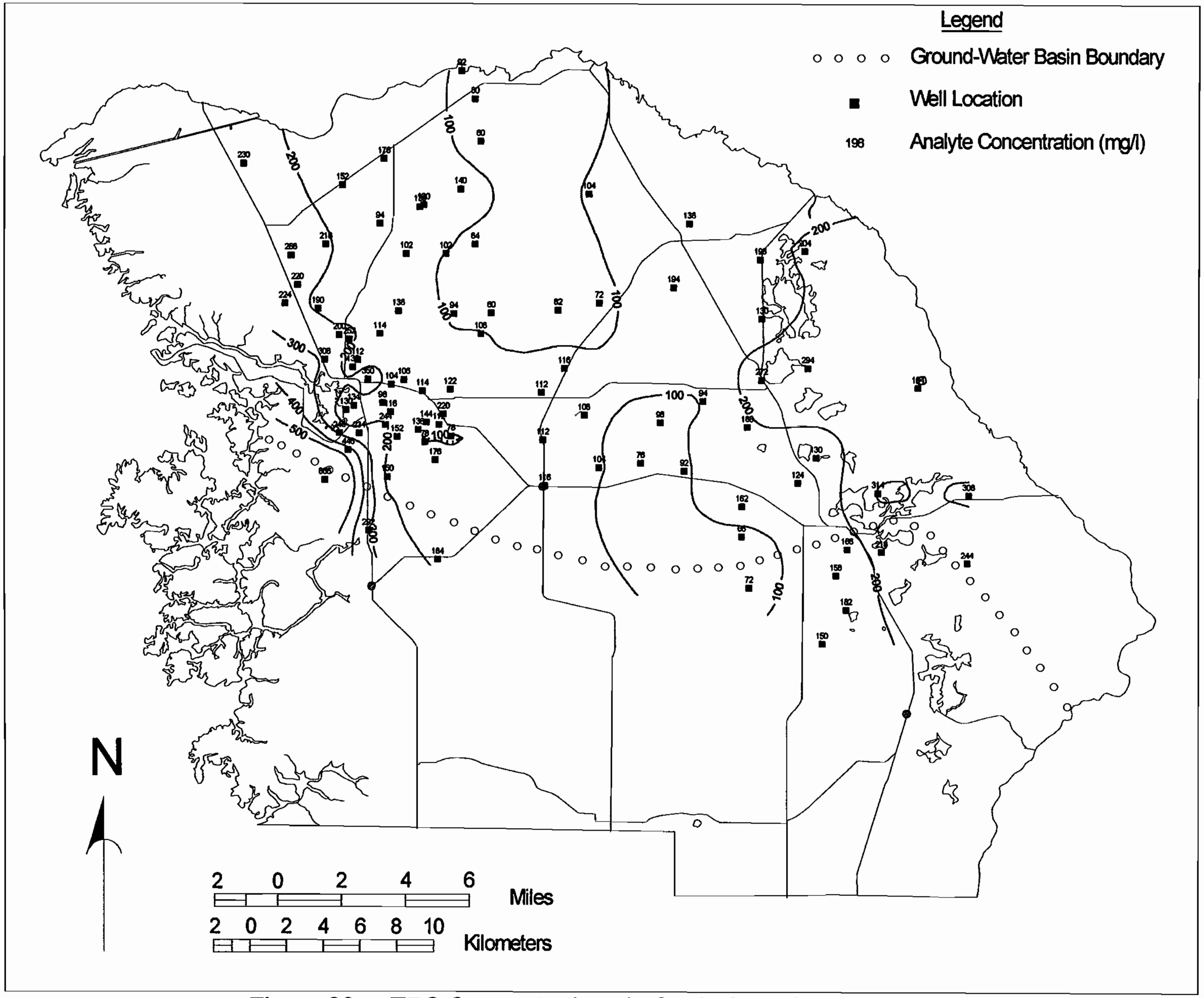

Figure 20a. TDS Concentrations in Study Area Ground Water.

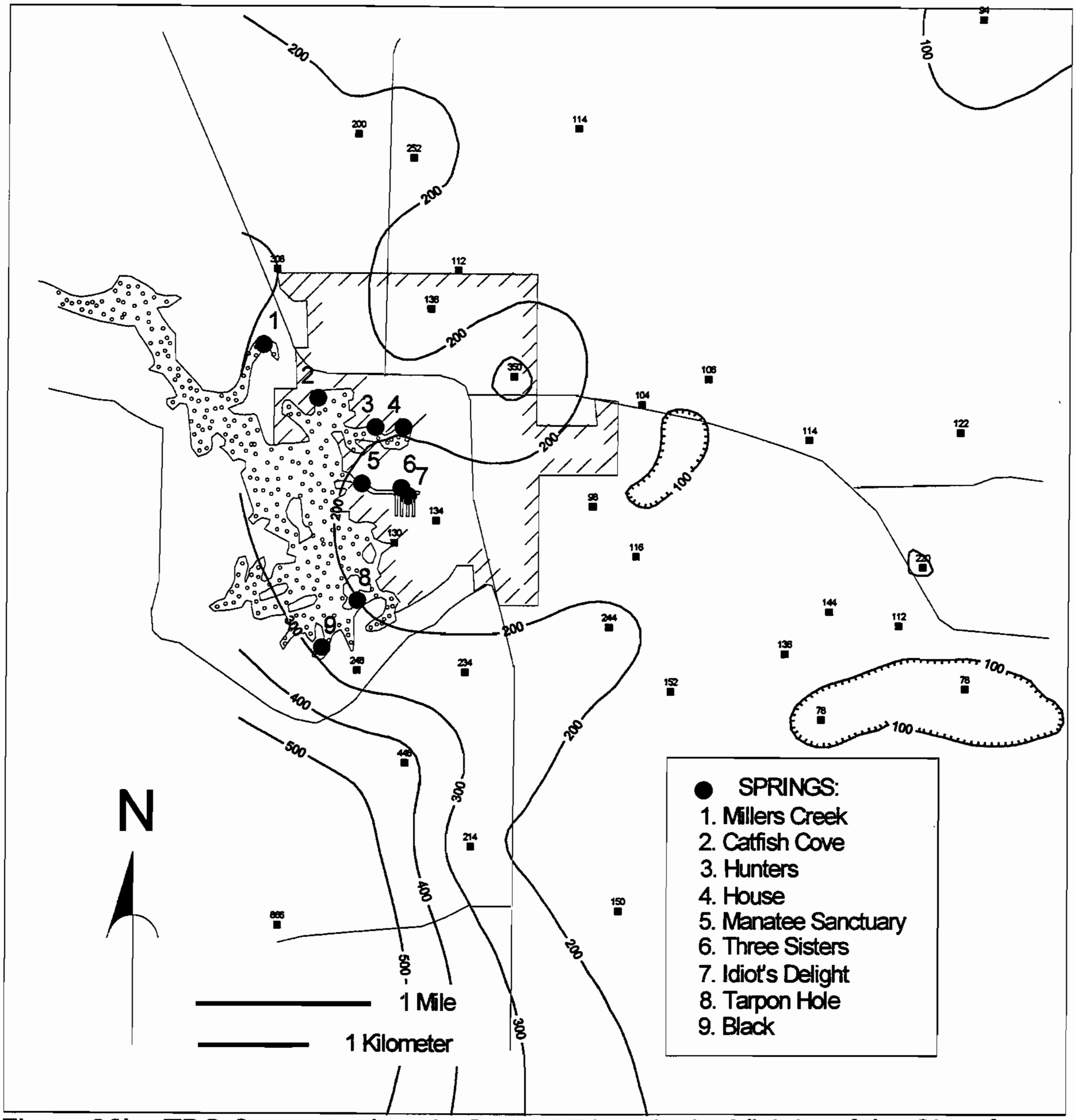

Figure 20b. TDS Concentrations in Ground Water in the Vicinity of the City of Crystal River.

ion (NH_4^+) because of prevalent pH and reduction-oxidation potentials and the potential for volitization of ammonia gas. The complex, organic compounds can occur as soluble organic molecules and as particles. 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

$$\text{Organic Nitrogen} \rightarrow NH_4^+ \rightarrow NO_2^- \rightarrow NO_3^-. \qquad (1)$$
$$\text{Oxidation} \rightarrow$$
$$\leftarrow \text{Reduction}$$

The reduction/oxidation reactions indicated in reaction series 1above 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. Ammonia and nitrate 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 nitrate. Consequently, precipitation is a source of nitrate and ammonium, derived from both natural and anthropogenic causes. Nitrate in precipitation in Florida ranges from below detection limits to over 10 mg/l, and the statewide mean in precipitation is approximately 1 mg/l (Upchurch, 1992). Ammonium ion in precipitation ranges from below detection limits to over 17 mg/l (Upchurch, 1992) and the mean concentration is about 0.2 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 and dry fallout events supplies nitrogen to the plant cover, which apparently results in little excess nitrogen to pass into the ground-water system. Direct recharge of storm-water 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 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 somewhat onto clays and soil particles, so some soil and aquifer materials may 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.

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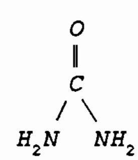
[4] Urea is a principal nitrogen product in urine. It has the formula 

. Urea is a by-product of the liver.

Oxidizing conditions occur in oxygenated soils, vadose environments and shallow, oxygenated portions of aquifers. Oxidizing conditions are necessary for microbes to produce the complex reactions required to make the nitrogen useable for plants. Under oxidizing conditions 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.

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. Contamination of ground water occurs if 1) nitrate production from ammonium and more complex nitrogen compounds is not completed within the root zone, 2) the nitrate is unavailable to plants and denitrifying microbes, or 3) nitrate is produced in quantities too great for biological agents to fix. 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 soils. 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 in the water or soil. 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 typically 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^-. 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).

Each of the nitrogen species in ground water can cause problems where present in excess. If nitrification of ammonia is not limited by oxygen availability, nitrate can form deep within the aquifer. If ammonium persists in ground water, nitrification can occur upon discharge at a spring. In either case, human health and environmental quality may be jeopordized. 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 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 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 organic-waste sources. Organic nitrogen is likely to be highest near waste-disposal facilities, animal feedlots, and areas where septic tanks are close together. Extensive wetlands, swamps, and water bodies rich in humic substances and other naturally occurring organisms can also serve as sources of elevated organic nitrogen concentrations.

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[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.

Figures 21a and 21b show the distribution of organic nitrogen in study area ground water. High organic nitrogen concentrations occur in the lake domain, and the presence of organic nitrogen beneath the lake strongly suggests that surface water is recharging the Floridan aquifer. There is a second, minor high in the swamps of the coastal domain. Elsewhere, organic nitrogen concentrations are low or below detection limits due to their absence or rapid oxidation in the soils and shallow portions of the aquifer.

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.

Figures 22a and 22b show the distribution of ammonium in study area ground water. While small amounts of ammonium are scattered throughout the area, ammonium is concentrated in the study area in two regions. 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 content and reflects organic-rich recharge to the Floridan aquifer. The second high is within the City of Crystal River and is based on one sample that may be affected by a point source, such as a septic tank.

Nitrite

Nitrite (NO_2^-) is less stable in ground water than either nitrate or ammonium. It is primarily 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 usually only persist near a source.

Nitrite concentrations are below the detection limit in all but one well. Because the concentration in this well was only slightly above the detection limit, nitrite concentrations were not plotted or contoured. Similar to the low ammonium concentrations, the low nitrite concentrations are indicative of a shallow, well oxygenated flow system that allows rapid conversion of nitrite to nitrate.

Nitrate

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.

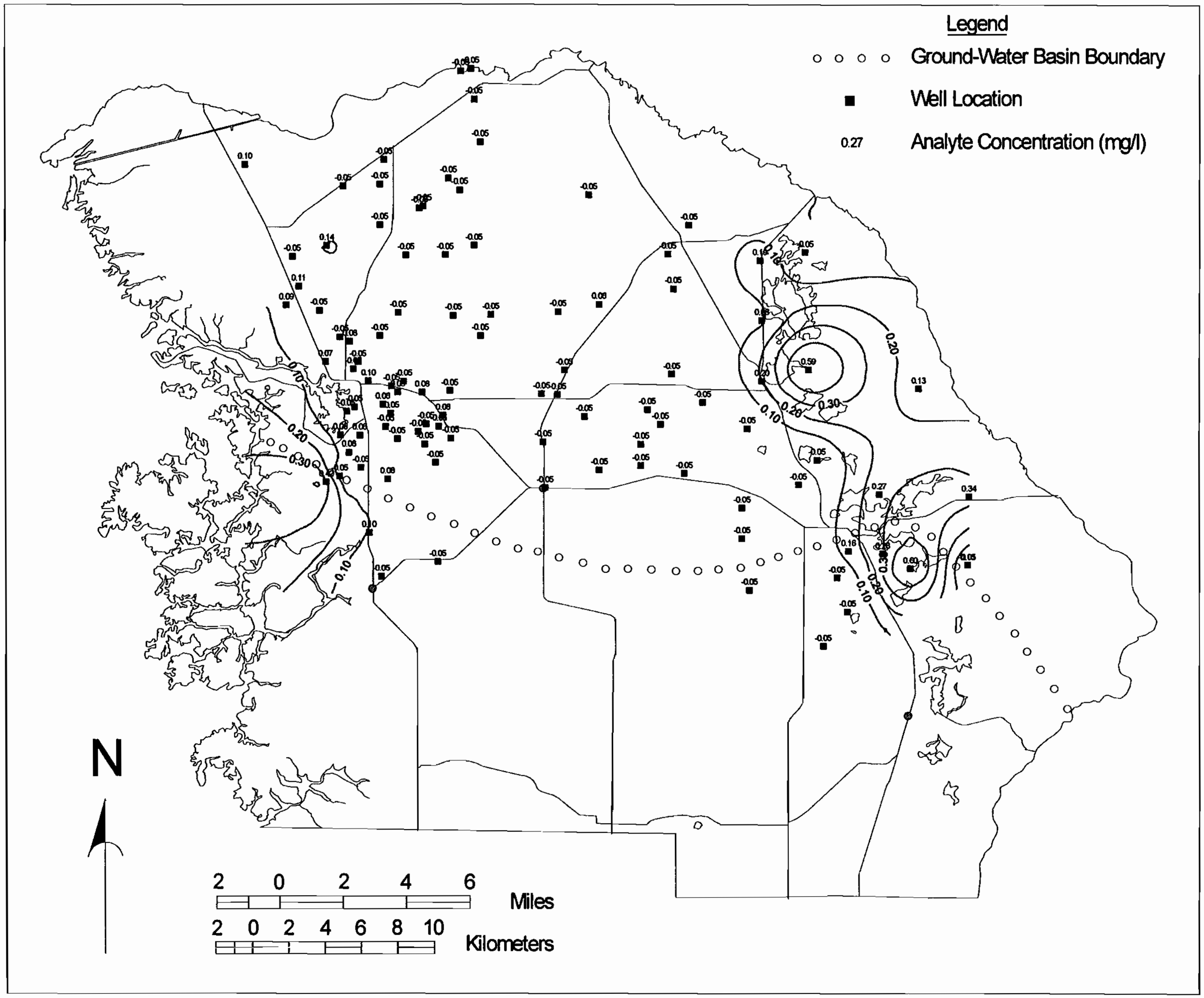

Figure 21a. Organic Nitrogen Concentrations in Study Area Ground Water.

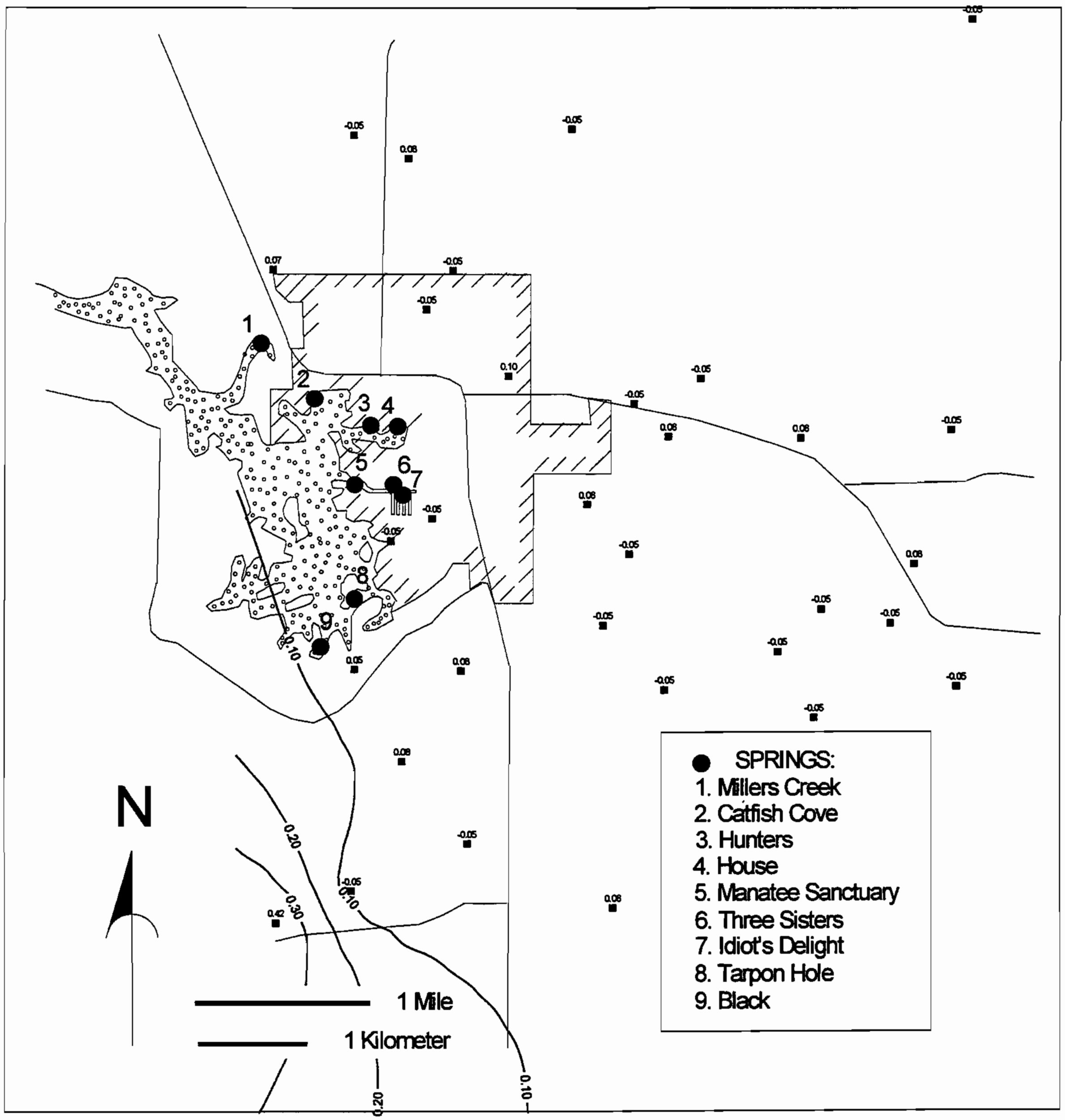

Figure 21b. Organic Nitrogen Concentrations in Ground Water in the Vicinity of the City of Crystal River.

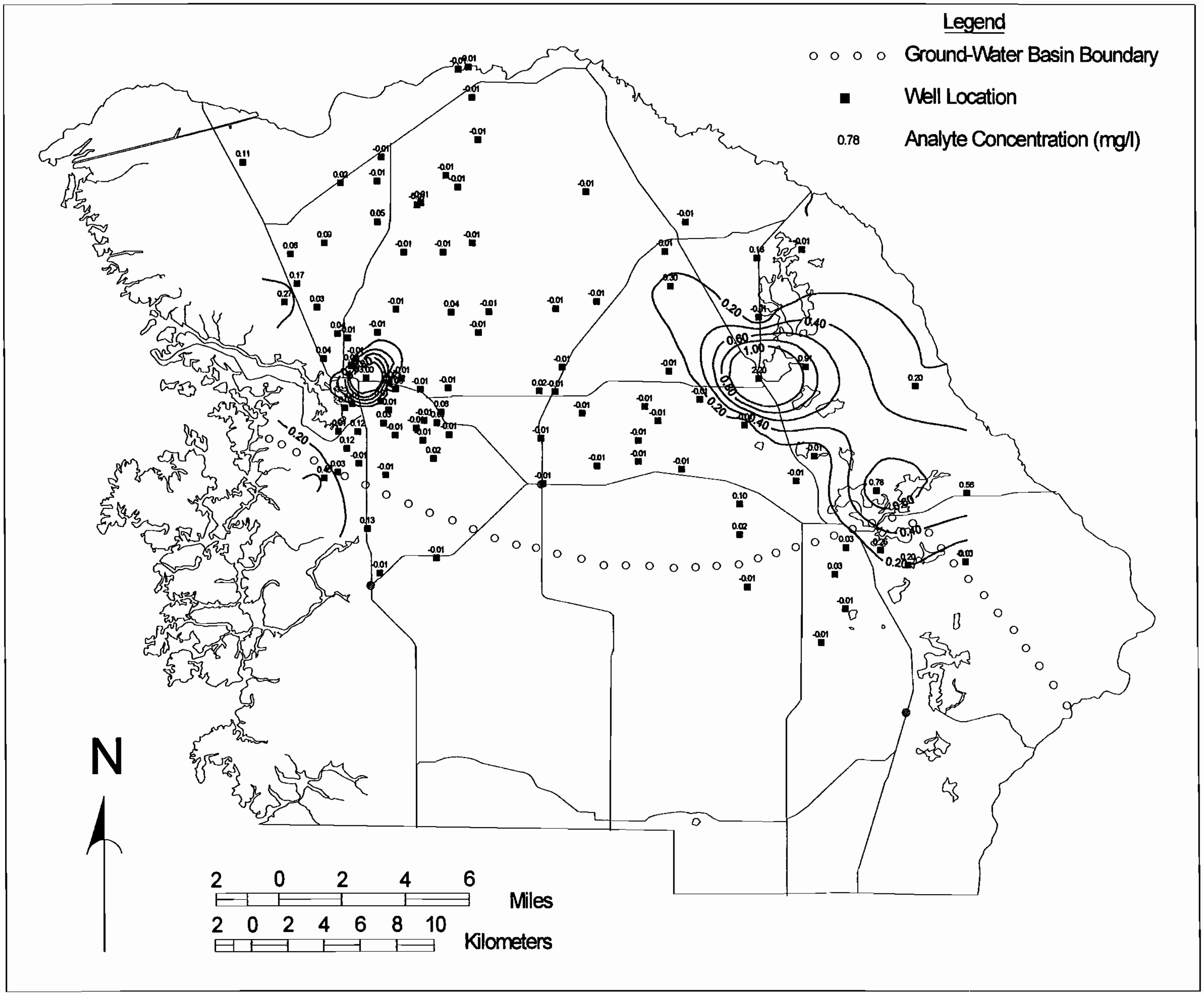

Figure 22a. Ammonium Concentrations in Study Area Ground Water.

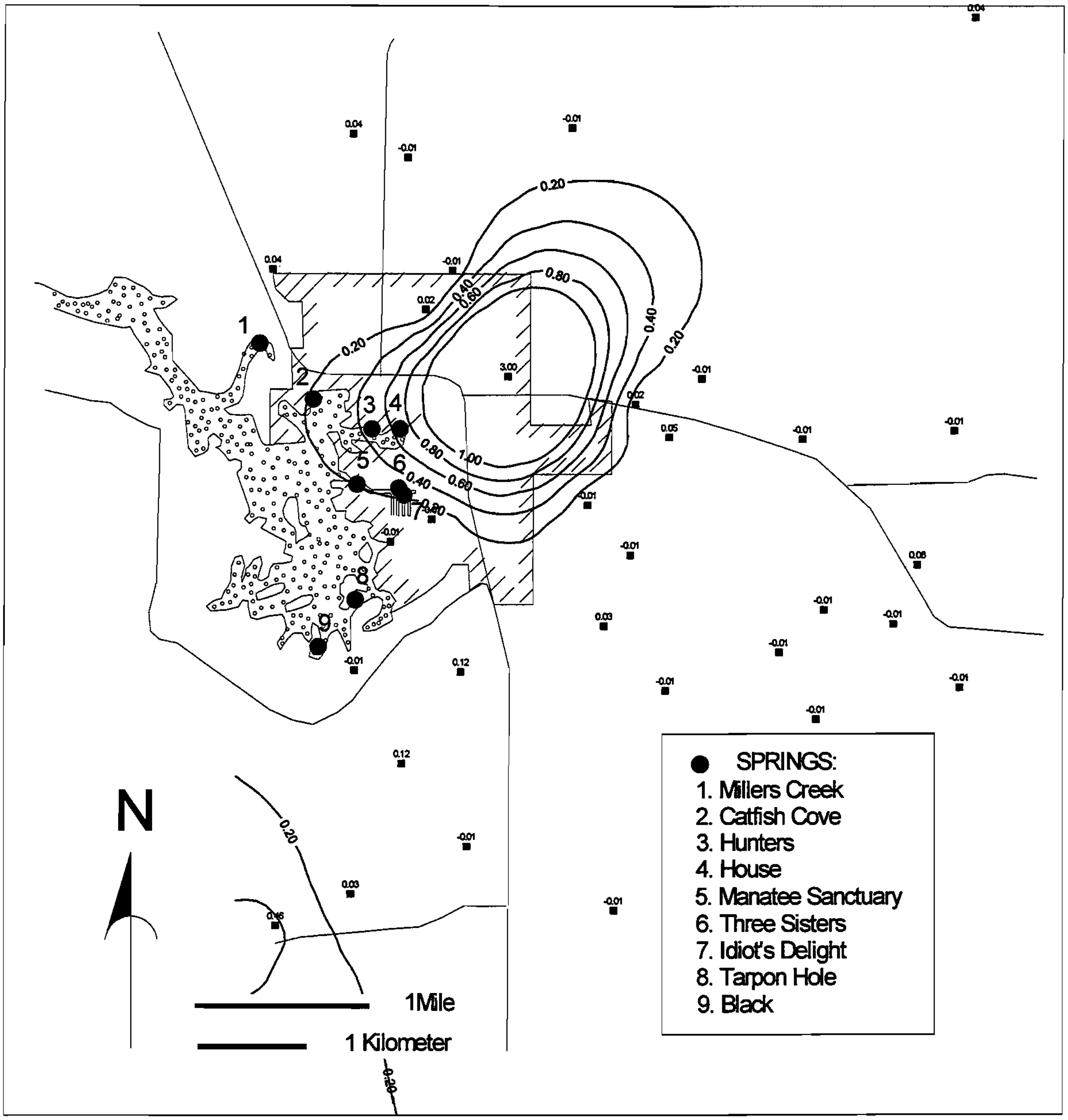

Figure 22b. Ammonium Concentrations in Ground Water in the Vicinity of the City of Crystal River.

Figures 23a and 23b show the distribution of nitrate in study area ground water. Ground water in the study area is widely enriched in nitrate. Nitrate concentrations of the eleven largest springs in King's Bay average 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) as stated in the introduction of this report, it is considerably elevated over nitrate concentrations in ground water in the undeveloped portions of the state.

One hundred and three well samples were analyzed for nitrate/nitrite in the study area. Thirty-five percent had concentrations between 0.2 to 0.6 mg/l (NO_3 as N) and eight 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 exist in the lake domain near Lake Tsala Apopka where recharge of nitrogen-rich water is widespread. Comparison with Figures 21a and 22a shows that this high nitrate reflects oxidation of reduced nitrogen species leaking from the lake or surrounding sites.

There is a broad, linear area of elevated 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 apparent linear plume extends northeast-southwest from the vicinity of Holder, just south of Dunnellon. This plume, however, is based on one sample and may be spurious. There is a third plume 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 23b shows the nitrate distribution in the vicinity of the City of Crystal River. Note that there is a minor high just east of the springs, and somewhat higher concentrations outside the city limits. There is little evidence for a nitrate source immediately adjacent to the springs.

Total Nitrogen

Since transformations between nitrogen species are rapid and complex, it is often best to consider total nitrogen content of the water. Total nitrogen concentrations represent the summation of all of the previously discussed nitrogen species. The distribution of total nitrogen (Figures 24a and 24b) ties several of the pathways previously discussed together. The elevated nitrogen concentrations that are a result of leakage from Lake Tsala Apopka are well represented. The east-west, northeast-southwest, and north-south corridors of nutrient enrichment are also strengthened. These corridors correspond with principal directions of fractures and lineaments and suggest that there is a long-term supply of nitrogen moving in the direction of the springs.

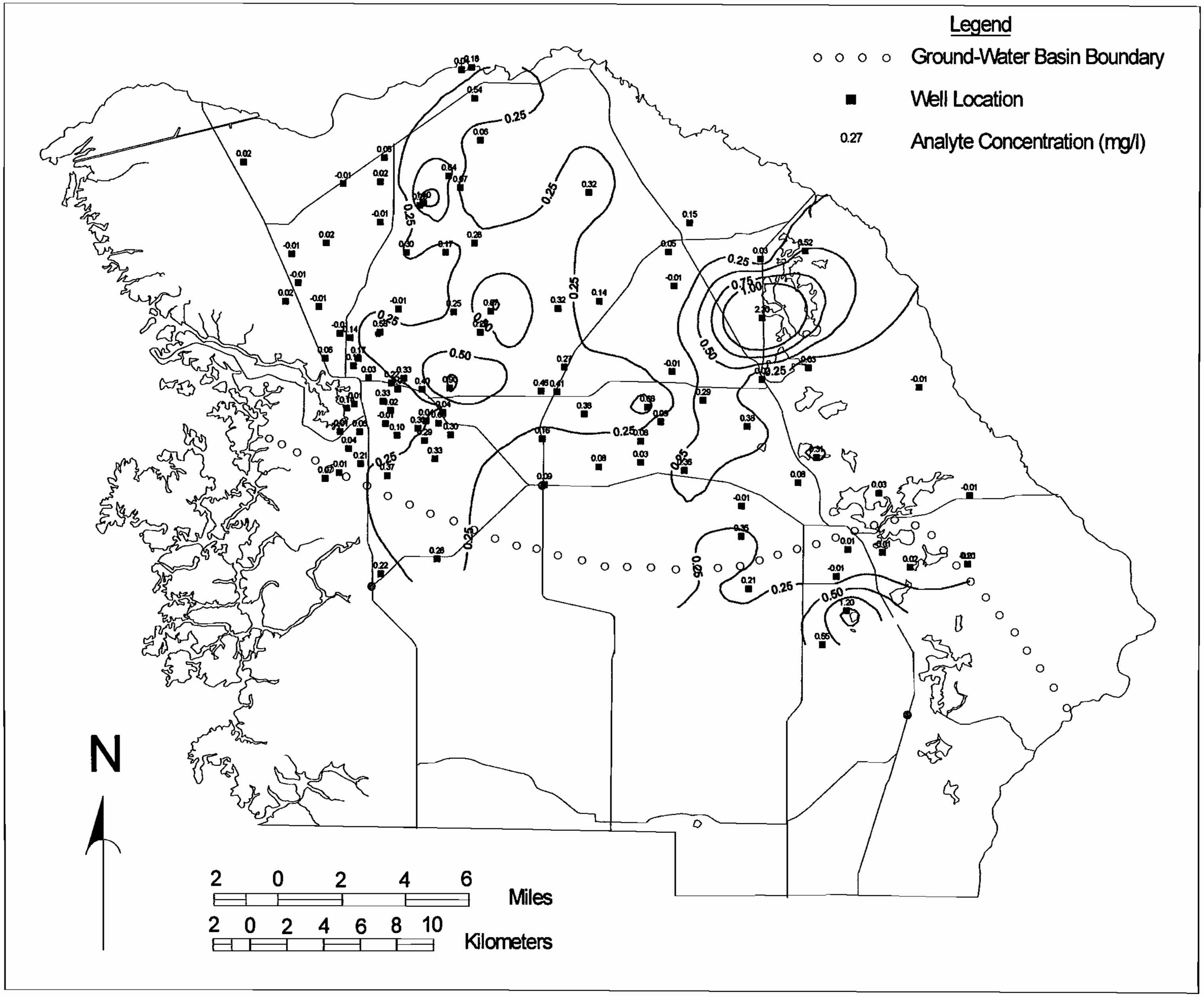

Figure 23a. Nitrate Concentrations in Study Area Ground Water.

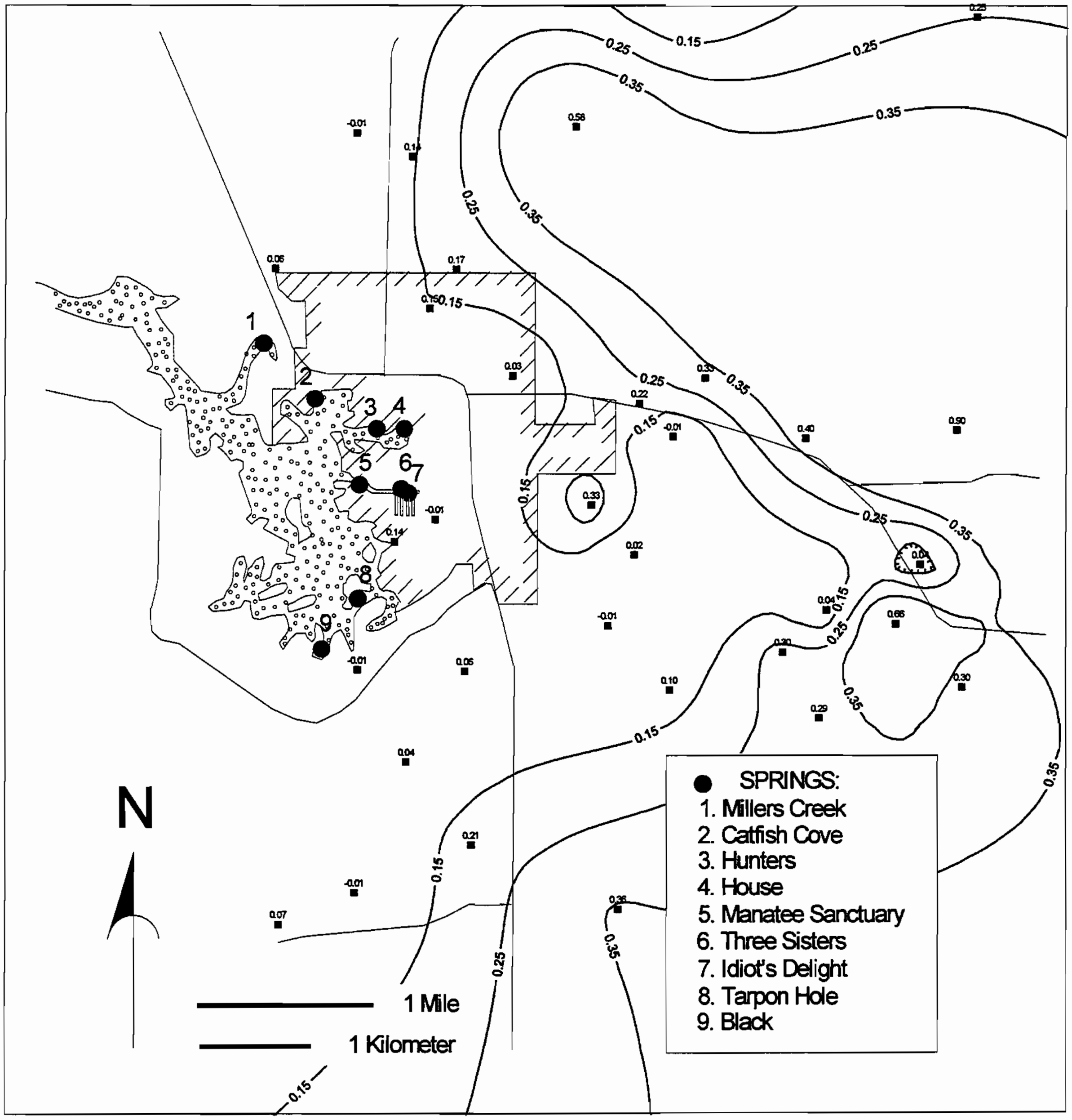

Figure 23b. Nitrate Concentrations in Ground Water in the Vicinity of the City of Crystal River.

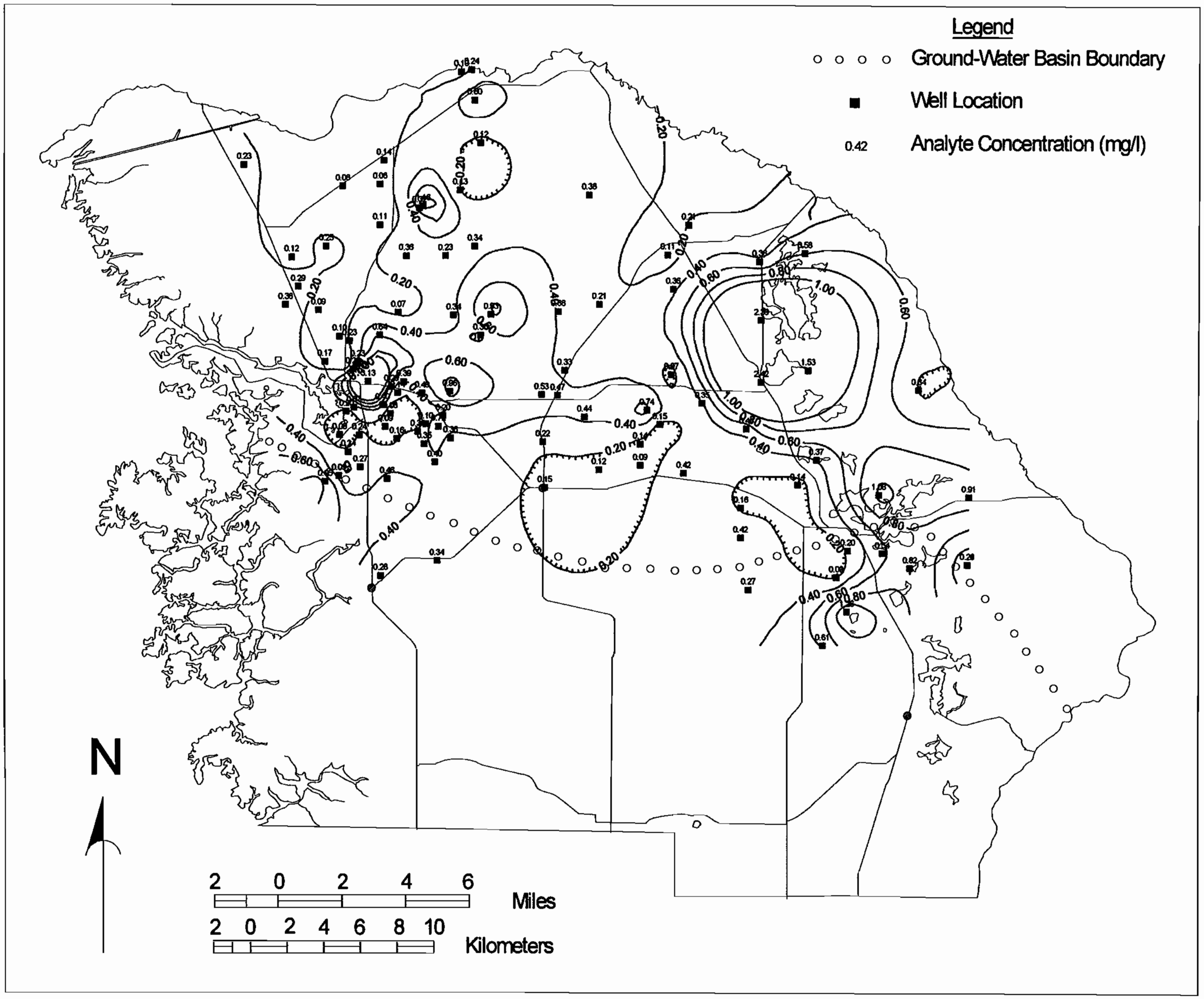

Figure 24a. Total Nitrogen Concentrations in Study Area Ground Water.

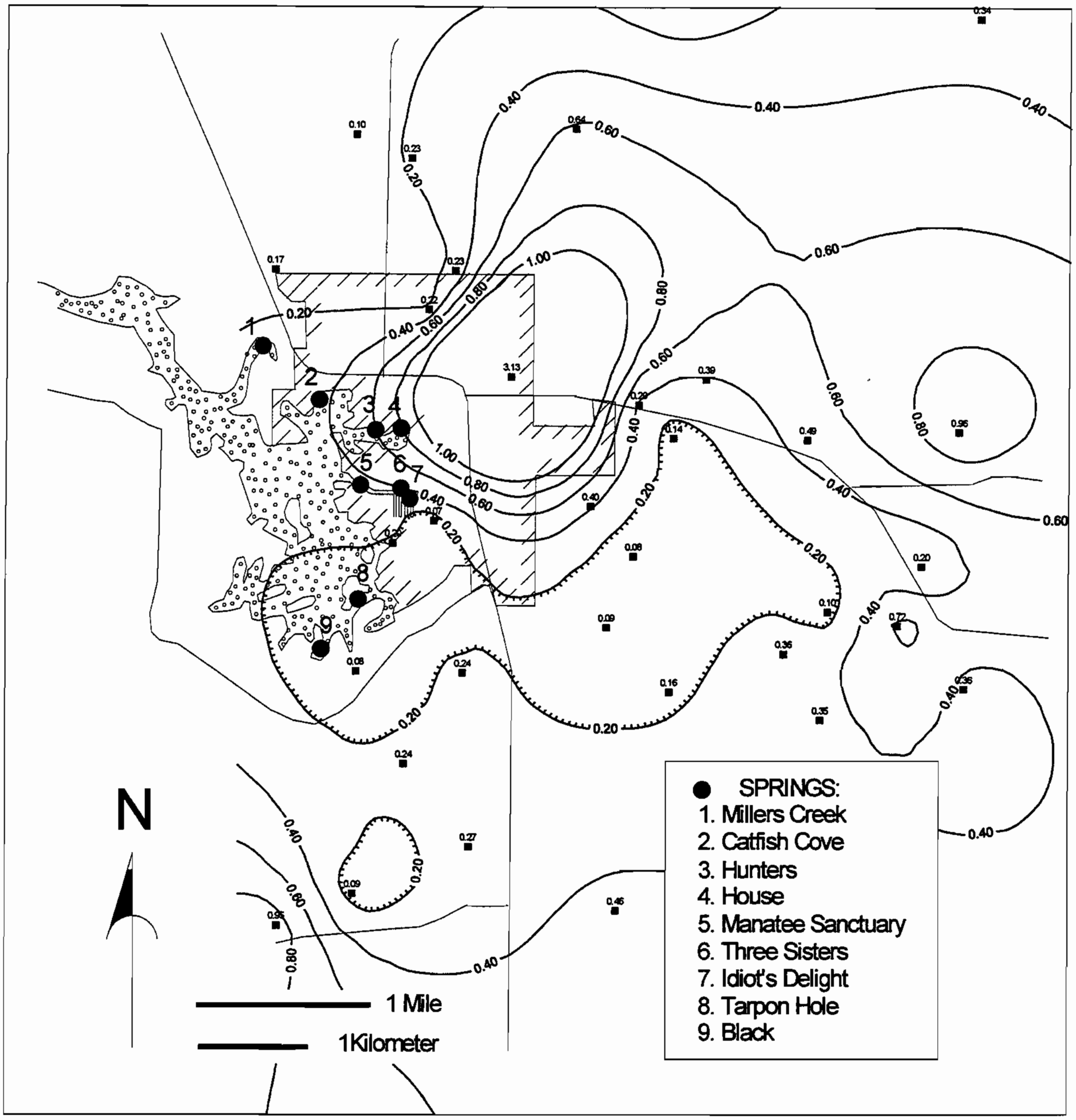

Figure 24b. Total Nitrogen Concentrations in Ground Water in the Vicinity of the City of Crystal River.

ADDITIONAL NUTRIENTS AND IRON

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.

Figures 25a and 25b show the distribution of TOC in study area ground water. The elevated nitrogen (especially organic nitrogen and ammonium) water under Lake Tsala Apopka in the lake domain is also characterized by high TOC. Water in the ridge domain contains minimal TOC, and there is a concentration 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. There is also a high within the City of Crystal River. This sample was obtained from the same well that exhibited high ammonium concentrations, and may be affected by a point source.

Total Phosphorus and Orthophosphate

The analyte total phosphorus includes complex organic compounds as well as simple, inorganic phosphorus compounds. It is an indicator of localized contamination by organic sources, such as animal wastes. Organic phosphorus compounds are destroyed by the microbial reactions discussed previously. 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-hydroxylapatite 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). 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.

Orthophosphate (Figures 26a and 26b) and total phosphorus (Figures 27a and 27b) are present in low concentrations in ground water in the eastern half of the area where the hard-rock phosphate mines once existed. However, highs below Lake Tsala Apopka are likely due to leakage of surface waters into the Floridan aquifer There are also several minor highs in the coastal domain. Of special importance is the high total

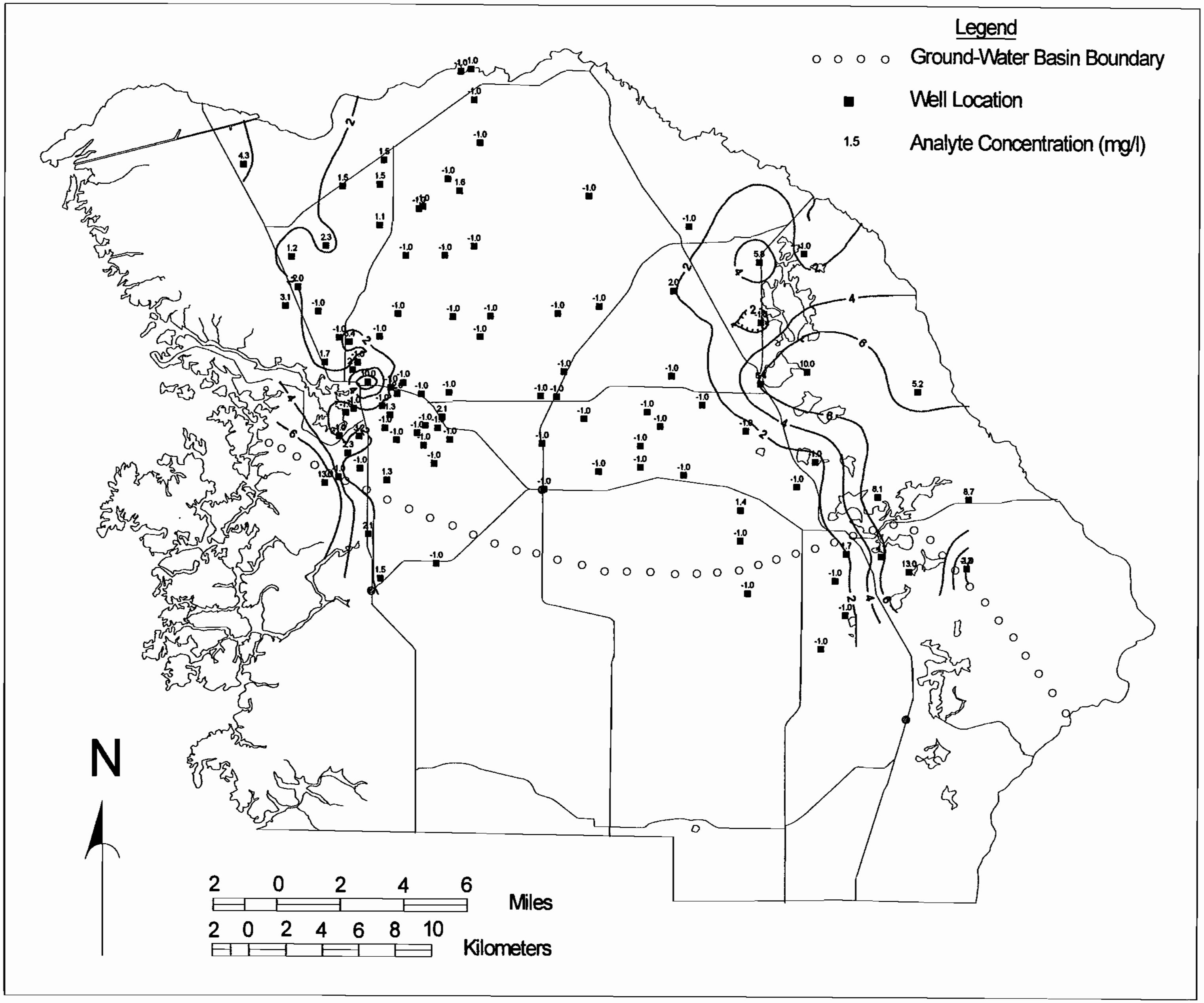

Figure 25a. TOC Concentrations in Study Area Ground Water.

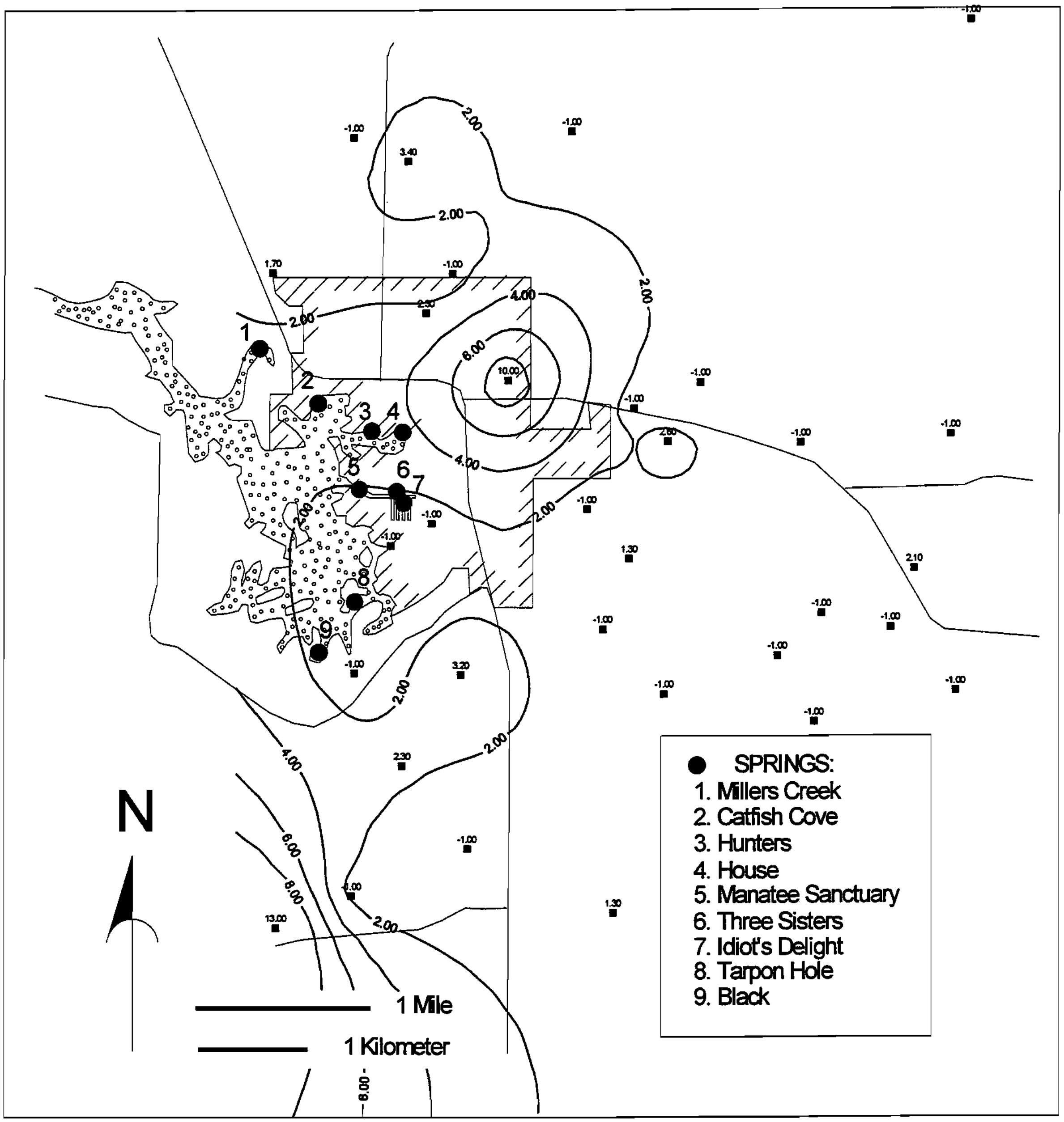

Figure 25b. TOC Concentrations in Ground Water in the Vicinity of the City of Crystal River.

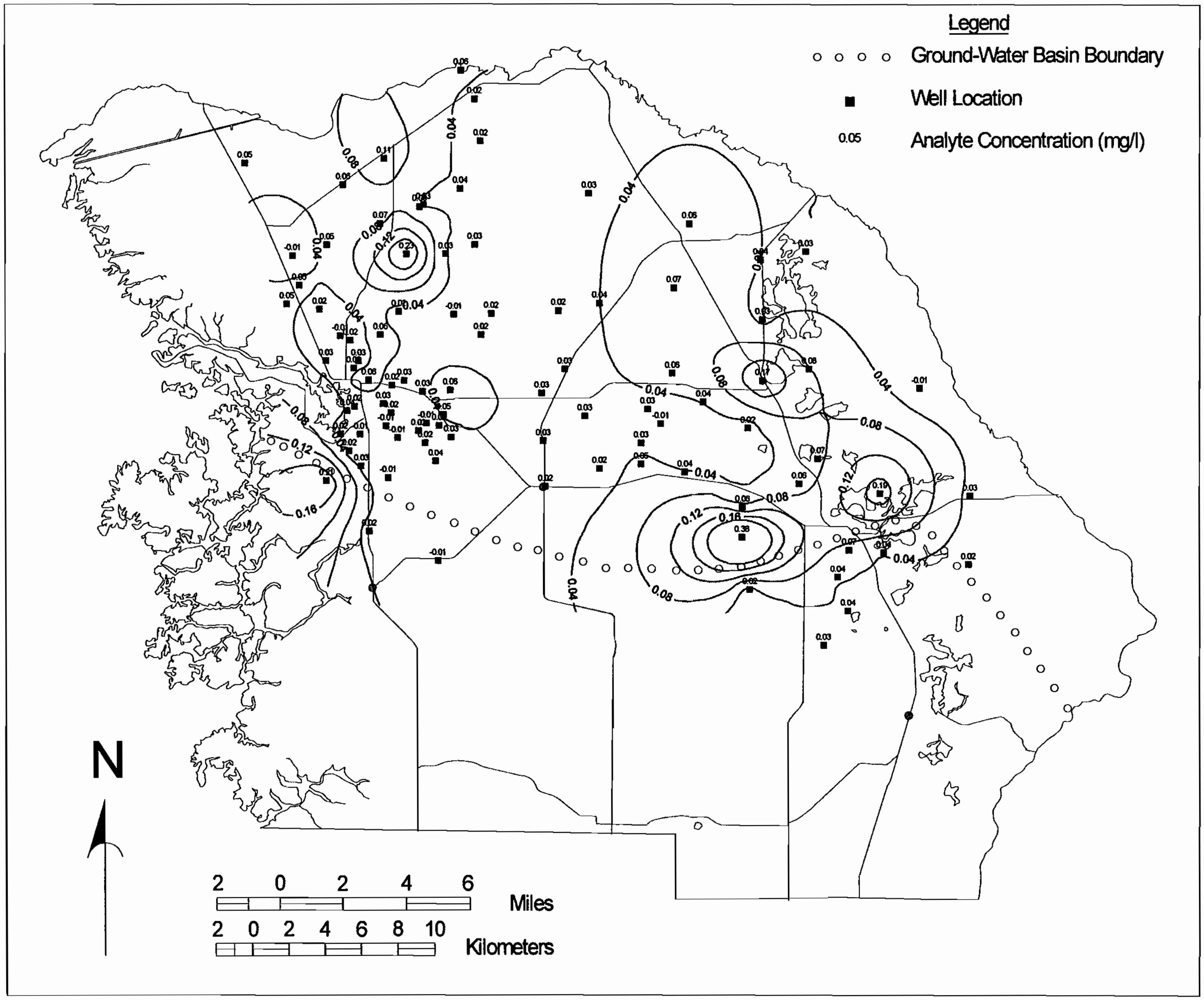

Figure 26a. Ortho Phosphate Concentrations in Study Area Ground Water.

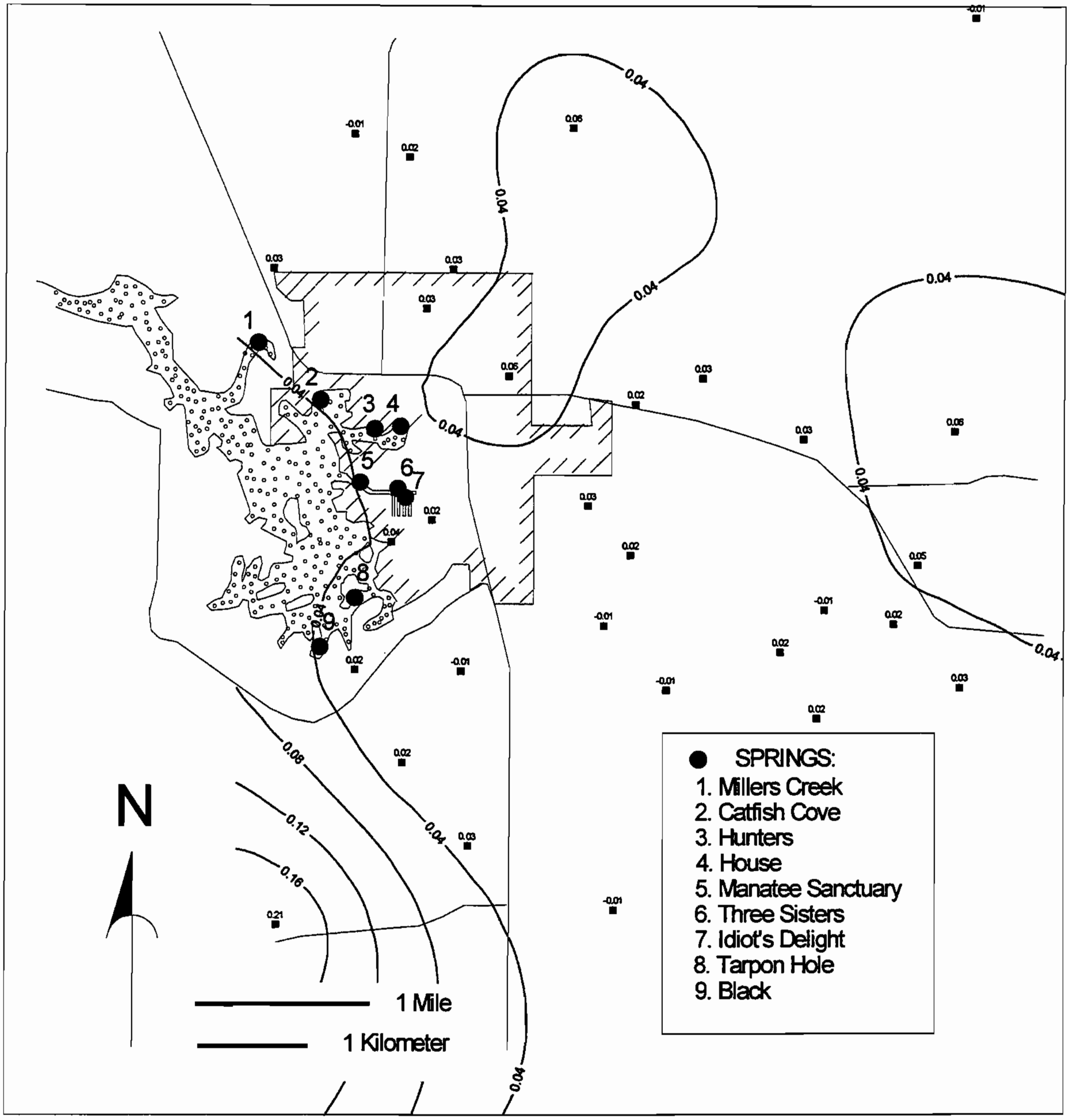

Figure 26b. Ortho Phosphate Concentrations in Ground Water in the Vicinity of the City of Crystal River.

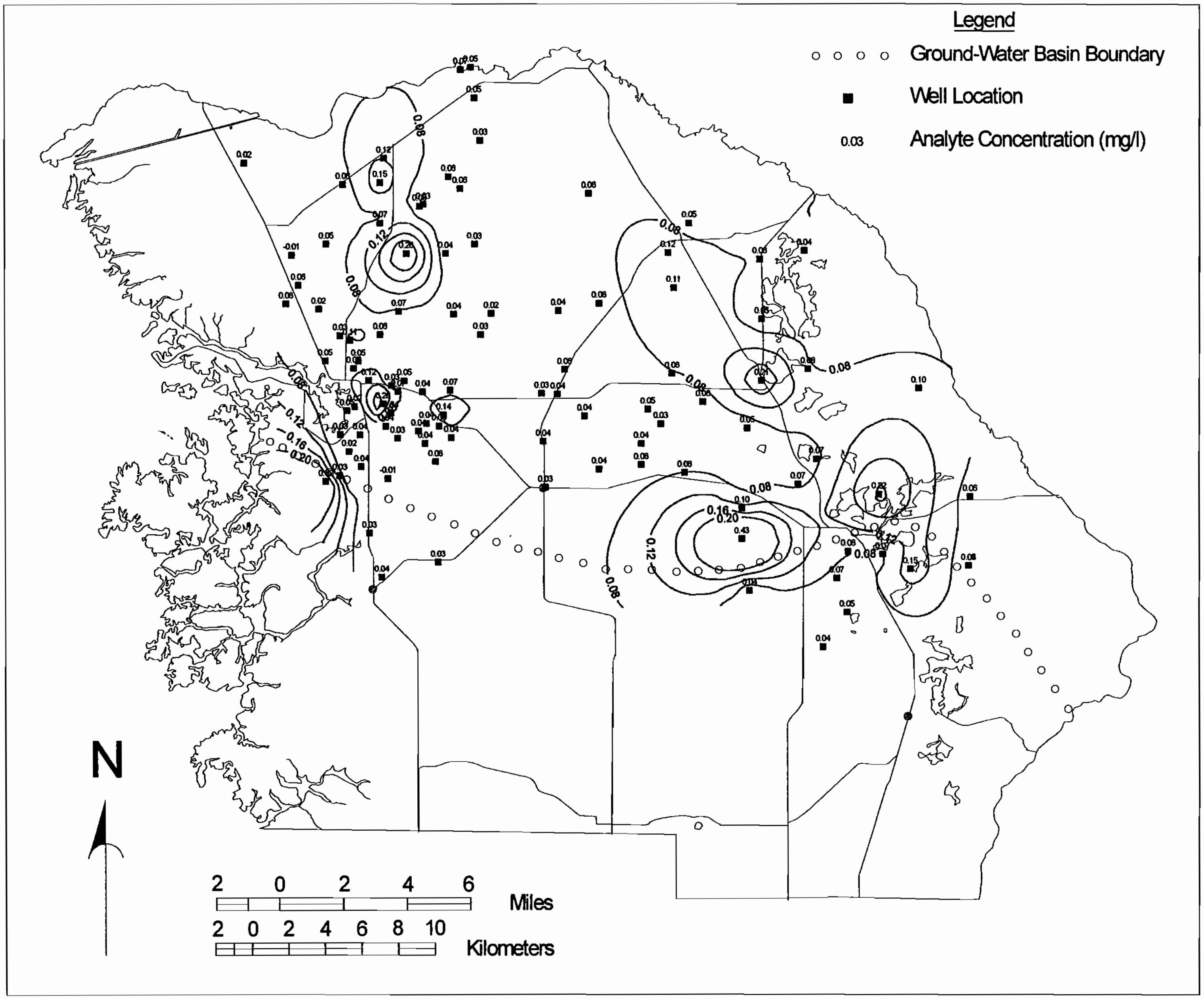

Figure 27a. Total Phosphorus Concentrations in Study Area Ground Water.

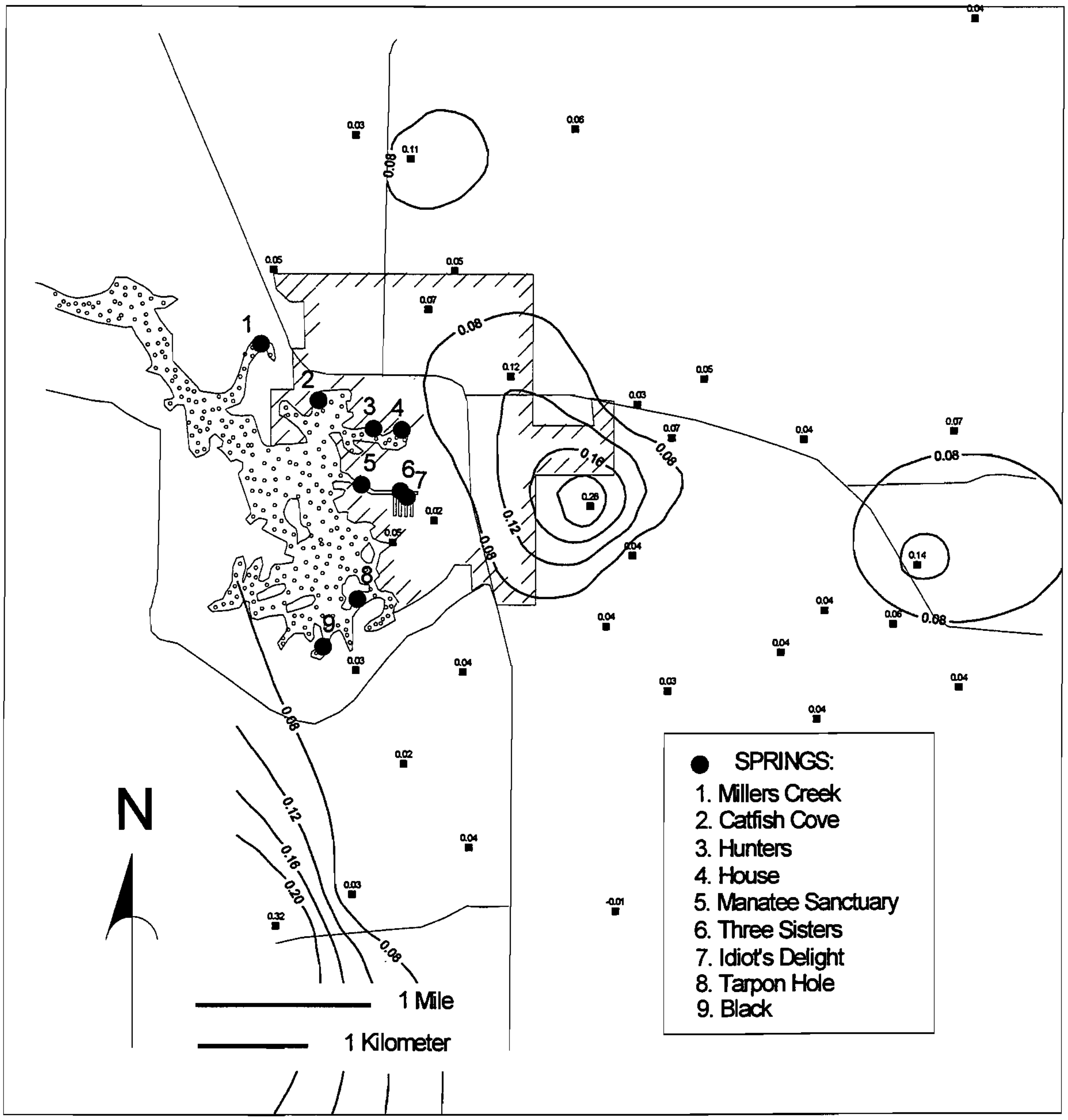

Figure 27b. Total Phosphorus Concentrations in Ground Water in the Vicinity of the City of Crystal River.

phosphorus and orthophosphate water that extends southward from Lake Rousseau. There is also a minor high in the eastern portion of the City of Crystal River.

Iron

The sources of iron in ground water in the study area include 1) oxidation of pyrite (FeS_2), 2) oxidation of organic compounds, and 3) dissolution of iron oxide minerals. Iron has two valence states, Fe^{2+} and Fe^{3+}. Fe^{2+} is generally the stable form of iron in chemically-reducing ground water. In oxidizing ground water, bacteria induce colloidal ferric hydroxide ($Fe(OH)_3$) to precipitate. These iron colloids and the associated bacteria cause clogging of well screens and aquifer pore throats. They also cause color and turbidity to violate the Secondary Drinking Water Standard. Ferric hydroxide is the reddish to yellowish scale or stain that is so commonly found where iron-rich waters are utilized.

The distribution of iron in study area ground water is shown in Figures 28a and 28b. Iron concentrations are highest in the lake and coastal domains and lowest in the ridge domain. High iron concentrations in the lake domain reflect the recharge of iron-rich surface water to the Floridan aquifer. High iron in the coastal domain reflects the abundance of coastal swamps in and near the King's Bay Springs. The low iron content of the ridge domain shows that recharge to the aquifer in the area is rapid, and lacks a significant surface water component.

Near the springs there is a small area of higher iron concentration represented in two wells in the southern portion of the City of Crystal River. This is either reflective of deeper wells or a small upconing due to pumpage in the area. The high in the eastern portion of the City of Crystal River is seen in other water-quality data (especially ammonium and TOC concentrations), and indicates that ground water is likely influenced by a nearby source, such as a septic tank.

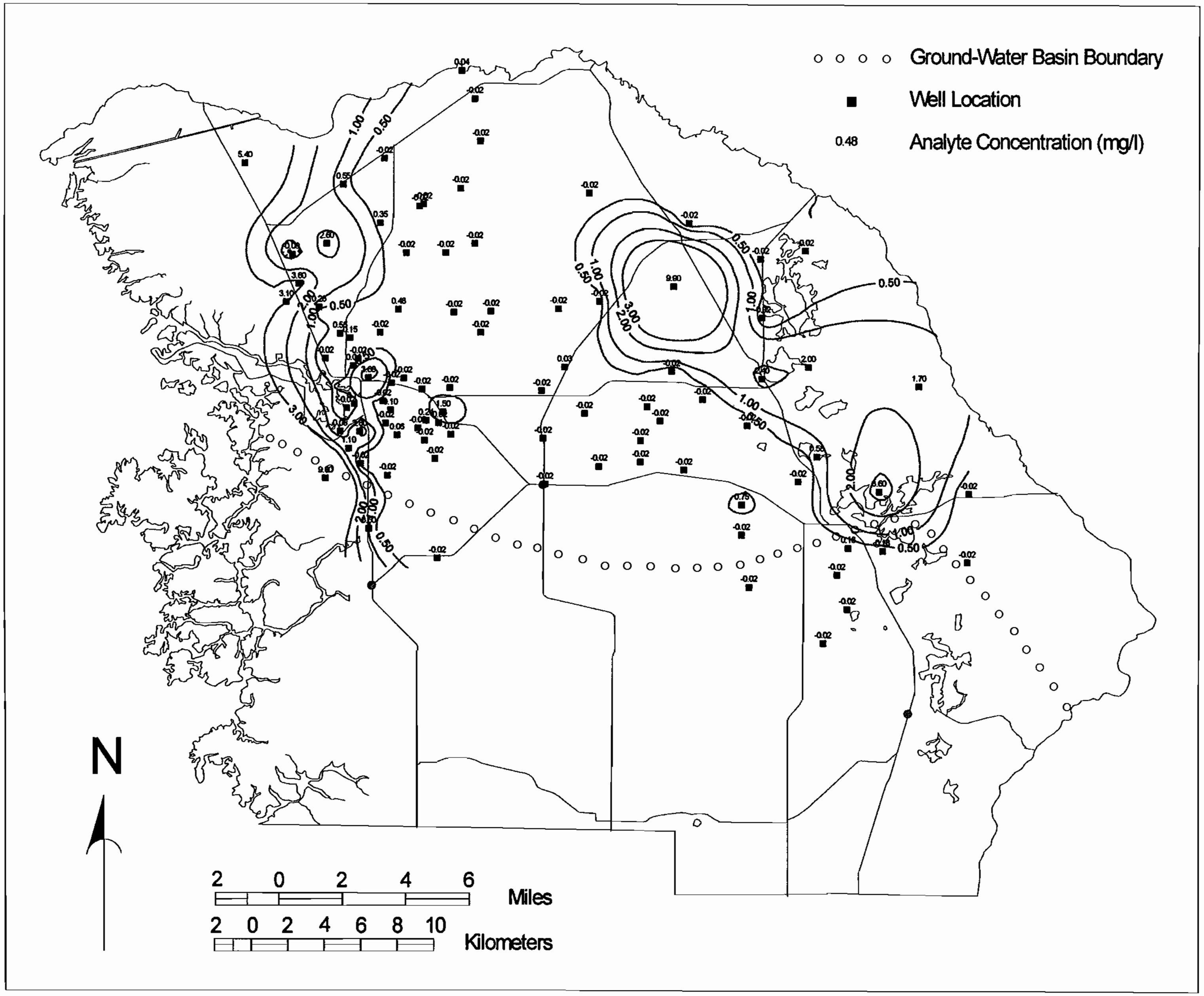

Figure 28a. Iron Concentrations in Study Area Ground Water.

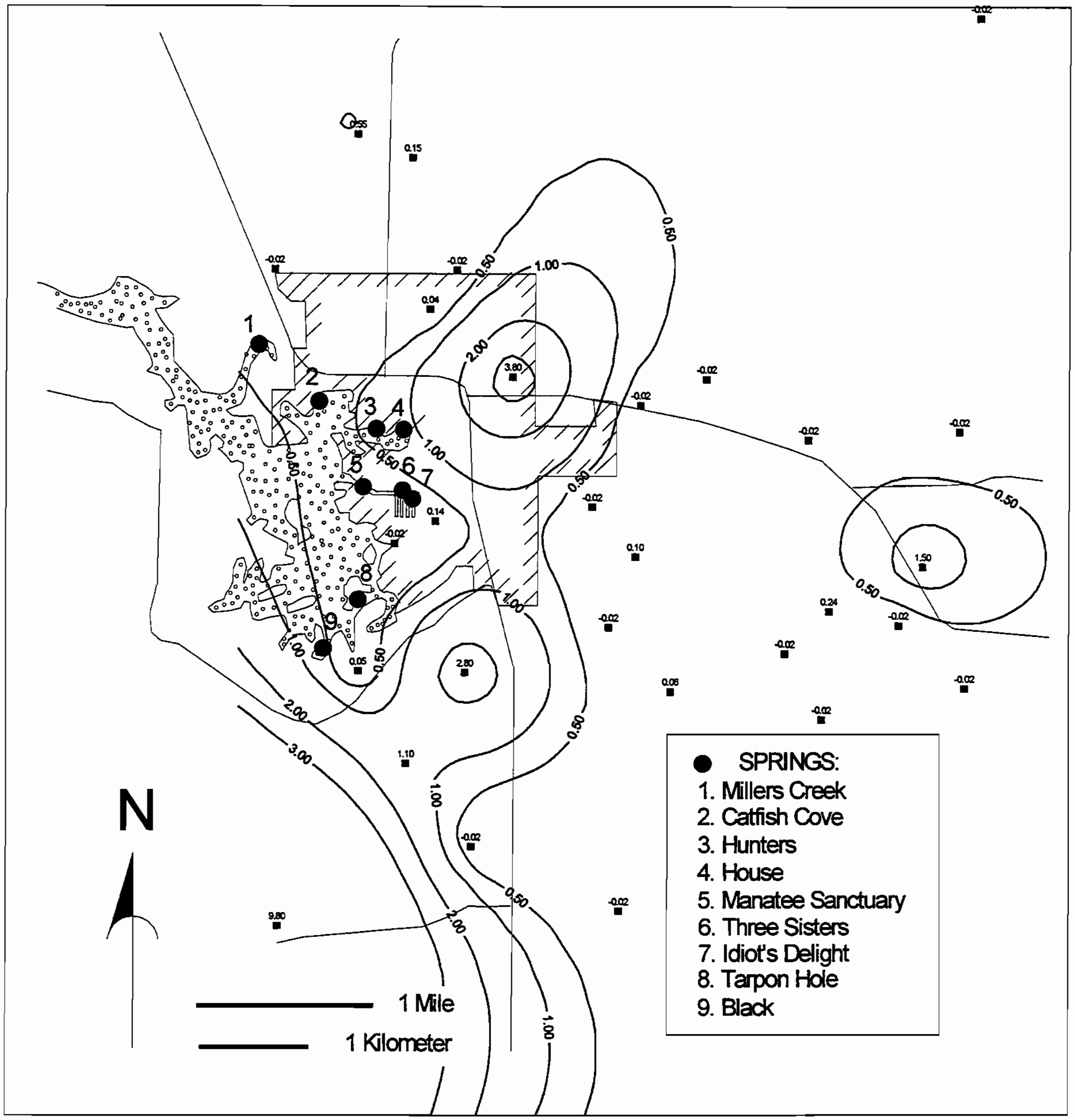

Figure 28b. Iron Concentrations in Ground Water in the Vicinity of the City of Crystal River.

GROUND-WATER CHEMISTRY: SPRINGS

This section presents an analysis of the chemistry of water discharging from eleven springs in the King's Bay complex. Although there are many more springs in the complex, the springs chosen for sampling were considered to be representative of the water quality in different areas of King's Bay. Table 3 shows the means of the concentrations of a number of chemical analytes for each of the sampled springs, the number of times each spring was sampled, and the hydrochemical facies group of water from each spring. A complete list of the chemical data for all the samples for each spring is included in Appendix III.

HYDROCHEMICAL FACIES

The hydrochemical facies technique is used here to provide a preliminary appraisal of the chemistry of the springs. The means of chemical analytes in samples collected from the eleven springs during the sampling events were used to construct a Stiff diagram for each spring. For a comparison of the chemistry of the individual springs, the eleven analyses were plotted on a Piper diagram. Examination of the Piper diagram (Figure 29) reveals three distinct groups of samples. Figure 29 also displays three Stiff diagrams that are representative of the different water-quality groups delineated from the spring samples.

Group A is represented by only one spring, House Spring. The location of the group A spring in the center-left area of the Piper Diagram indicates that this spring is dominated by calcium-bicarbonate-type water. Calcium-bicarbonate-type water results from simple dissolution of limestone in the shallow Floridan aquifer flow system. Group A springs are located furthest inland of all the springs in the study area and, therefore, water quality is probably not significantly influenced by tides (water quality does not change in response to tidal fluctuations). Chloride concentrations are low because they are not affected by mixing with sea water.

The group B and C springs are located close enough to the coast for significant water-quality changes to occur in response to tidal fluctuations. Because the water discharging from the springs is freshest at low tide, every attempt was made to consistently collect samples at low tide. This proved very difficult because the lag between low tide at Cedar Key, the nearest tide station in the Gulf of Mexico, and the corresponding low water level in the Floridan aquifer in the study area can be highly variable for each spring.

The location of the group B springs in the center of the Piper Diagram (Figure 29) indicates that the water quality of these springs, at low tide, is transitional between the calcium-bicarbonate dominated water of the group A springs and the sodium-chloride dominated water of the group C springs. If samples were collected from the group B springs at high tide, the concentration of the major ions, especially sodium and

Table 3. Analyte Concentration Means at Low Tide for Springs in the King's Bay Complex (mg/l unless otherwise noted).

Hydro-chemical Facies Group	Spring Name	Times Sampled 02/91-08/92	Field pH (std. units)	Field Cond. (umhos)	*Dis Ca	HCO_3	Dis Mg	Dis Na	Dis F	Dis Cl	Dis K	Dis SO_4	Dis NO_3 as N	Dis ON	Dis NH_4	Dis TP	TOC	Dis Fe^{+2}	TDS
A	House	4	7.76	183	27	71	4.9	2.6	0.07	3.7	0.27	13	0.27	-0.05	-0.01	0.03	-0.50	-0.02	99
B	Idiot's Delight	5	7.90	271	31	88	5.1	16	0.07	29	0.63	6.0	0.16	-0.05	0.01	0.04	0.76	-0.02	154
	Three Sisters	4	8.02	310	31	85	5.8	22	0.07	36	0.81	7.0	0.16	-0.05	0.01	0.04	-0.50	-0.02	167
	Manatee Sanct.	4	7.88	380	32	84	7.3	34	0.06	60	1.25	11	0.27	-0.05	0.02	0.04	-0.50	-0.02	204
	Hunters	4	7.98	335	30	77	7.2	28	0.06	48	1.00	14	0.25	-0.05	0.01	0.04	-0.50	-0.02	178
	Catfish Corner	5	8.04	272	27	78	7.0	17	0.07	29	0.66	17	0.22	0.05	0.01	0.04	0.66	-0.02	158
	Three Sisters #2	4	7.76	343	30	86	6.7	30	0.06	53	1.07	9.0	0.20	0.05	0.02	0.04	-0.50	-0.02	190
C	Black	4	7.74	4,038	67	111	78	685	0.11	1,133	22	179	0.26	-0.05	0.01	0.04	3.30	0.02	2,315
	Tarpon Hole	5	7.70	1,470	49	108	30	236	0.09	402	8.1	61	0.16	-0.05	-0.01	0.05	2.83	0.02	884
	Millers Creek	4	7.37	1,513	52	117	30	227	0.29	385	7.3	60	0.10	0.06	0.01	0.05	1.13	0.06	825
	Tarpon Hole #2	4	7.71	1,125	46	104	21	155	0.09	265	5.3	40	0.15	-0.05	0.01	0.04	4.63	0.02	627

* Dis = Dissolved

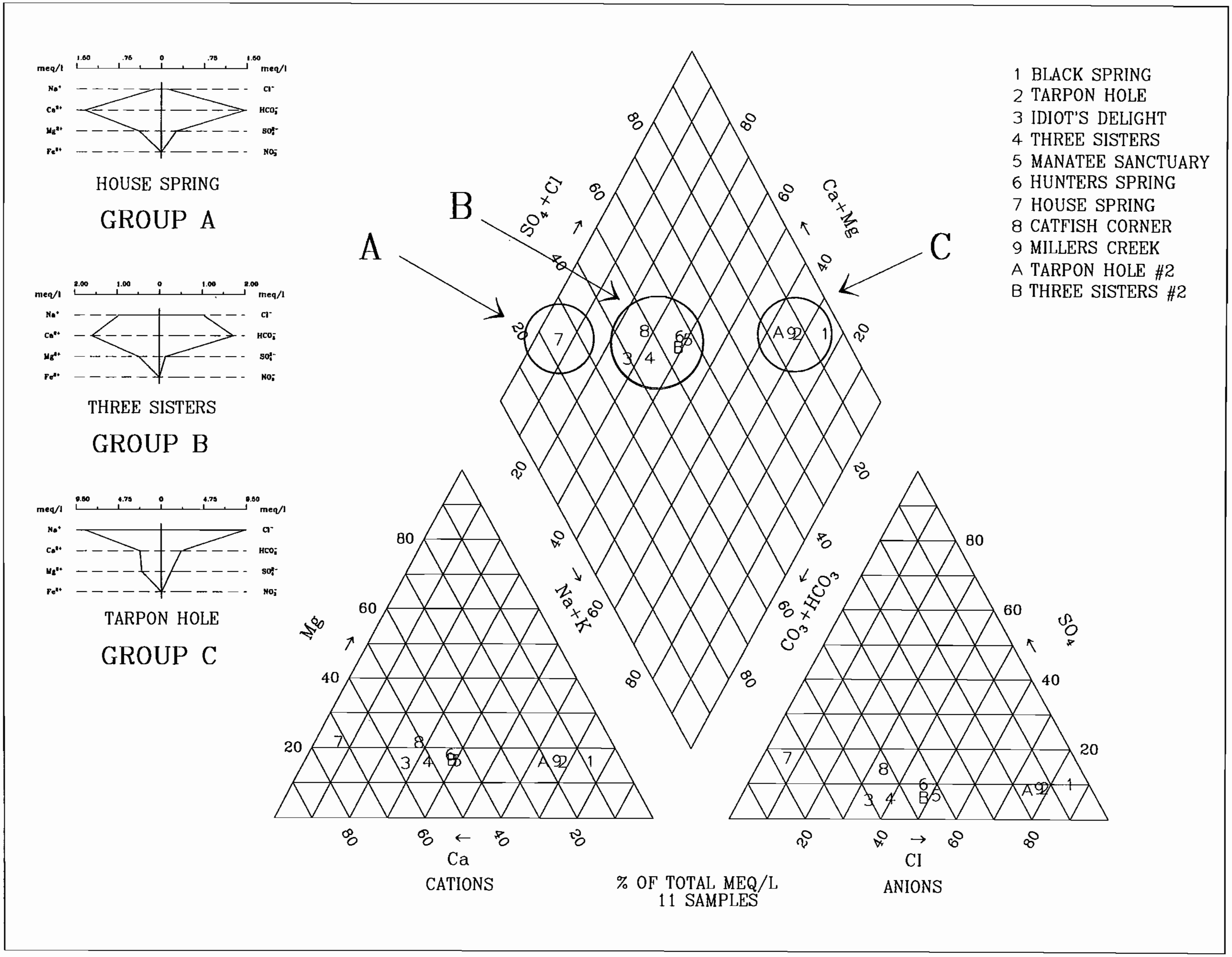

Figure 29. Characterization of Ground Water Discharging from King's Bay Springs using Piper and Stiff Diagrams.

chloride, would be higher, but not necessarily high enough to place them into group C. The group B springs include Idiot's Delight, Catfish Corner, Three Sisters, Hunters, Three Sisters #2, and Manatee Sanctuary.

The location of the group C springs in the center-right area of the Piper Diagram indicates that these springs are dominated by sodium-chloride type water that results from minimal mixing of fresh water from the recharge area with sea water from the Gulf. The group C springs include, Tarpon Hole #2, Tarpon Hole, Millers Creek, and Black.

MAJOR ANALYTES, NITROGEN SPECIES, AND IRON

As explained previously, the major analytes were considered to be pH, bicarbonate, calcium, chloride, sulfate, and TDS. pH was included because it is intimately associated with bicarbonate and calcium. TDS was included because it is a measure of the concentration of all the major and minor analytes. In analyzing the water quality of the springs, magnesium, sodium, and potassium were also included with the major analytes. This is because the concentration of these parameters is low in ground water and much higher in sea water. Therefore, these parameters are very useful when identifying springs with a significant sea-water influence. Nitrate is the only nitrogen species included in this discussion because the concentrations of nitrite and ammonium in the springs were almost always near or below the detection limit. Total organic carbon was the only additional nutrient included because phosphorus concentrations were always near or below the detection limit. Finally, iron was included because it occurs in significant concentrations in some of the springs.

Figure 1 depicts the locations of the individual springs in the King's Bay complex. Table 3 contains the means of the concentrations of each major analyte (mg/l unless otherwise noted) for each spring in the complex. The springs are separated into groups in the table according to the hydrochemical facies classification discussed previously (group A, B, or C). This is to insure that comparisons are not made between springs that are influenced by the transition zone and those that are not.

Table 3 indicates that there is one group A spring (calcium/bicarbonate dominated water), six group B springs (significant sodium/chloride dominated water), and four group C springs (sodium/chloride dominated water).

All of the group B springs in the King's Bay Complex are located along the eastern shore of the bay. It is apparent from the table that at low tide, the means of the concentrations of all the analytes are well within the Florida Department of Environmental Protection's (FDEP) Drinking Water Standards.

The group C springs in the King's Bay complex discharge non-potable water at low tide because they exceed the FDEP Drinking Water Standards for chloride, sodium, and TDS. Iron values for Tarpon Hole, Tarpon Hole #2, and Millers Creek are considerably higher than those of any other spring in the complex, and may indicate mixing with organic- rich water from the coastal swamps.

The mean total phosphorus concentration for all springs in the complex ranges from 0.030 mg/l (Catfish Corner) to 0.079 mg/l (Black). Using a mean concentration of 0.04 mg/l and a discharge of 630 mgd for all springs in the complex, approximately 38 tons of phosphorus is discharged annually. Relative to nitrogen, phosphorus concentrations in Floridan aquifer ground water are low because orthophosphate tends to precipitate as a calcium phosphate mineral (carbonate-hydroxylapatite) in the relatively alkaline water of the Floridan aquifer. In addition, the low total phosphorus concentrations indicate minimal orthophosphate and organic phosphorus which suggests that significant sources of phosphorus, such as organic-rich surface water or animal wastes, are not in close proximity to the springs.

TOC concentrations were below the detection limit of 0.5 mg/l for most springs in the complex with the exception of Black, Tarpon Hole, Tarpon Hole #2, and Millers Creek. These springs are the most strongly influenced by the transition zone and the elevated TOC levels may indicate that seawater has a higher background TOC level than ground water.

The mean total nitrogen concentration (ammonium+nitrite+nitrate+organic nitrogen) for all springs in the King's Bay complex ranges from 0.21 mg/l (Tarpon Hole #2) to 0.54 mg/l (Catfish Corner). Using a mean concentration of 0.35 mg/l and a discharge of 630 mgd for all springs in the complex, approximately 335 tons of nitrogen are discharged annually.

The mean nitrate concentration for all springs in the King's Bay complex ranges from 0.10 mg/l (Millers Creek) to 0.27 mg/l (House). Using a mean concentration of 0.20 mg/l and a discharge of 630 mgd for all springs in the complex, approximately 205 tons of nitrate are discharged annually.

Nitrite concentrations are not listed in the table because they are all near or below their detection limits. Because ammonium and nitrite concentrations in the springs are low and nitrate concentrations are high, ammonium in ground water appears to have been oxidized to nitrate before reaching the springs. The fact that this process occurs rapidly in shallow karst flow systems indicates the major contributors of nitrogen in the recharge area are not within the immediate vicinity (several thousand feet) of the springs.

NITRATE TRENDS IN THE KING'S BAY SPRINGS

Nitrate concentrations in samples collected from four of the King's Bay Springs between January 1991 and January 1998 were statistically evaluated to determine whether nitrate levels in the springs were increasing. The four springs were Hunter's, Idiot's Delight, Catfish Corner, and Tarpon Hole. Nitrate data for the springs are plotted in Figure 30. Trends were evaluated using regression analysis and significance was determined using a *t*-test. Of the four springs tested, only Hunter's showed a statistically significant increasing trend at $\alpha=0.05$.

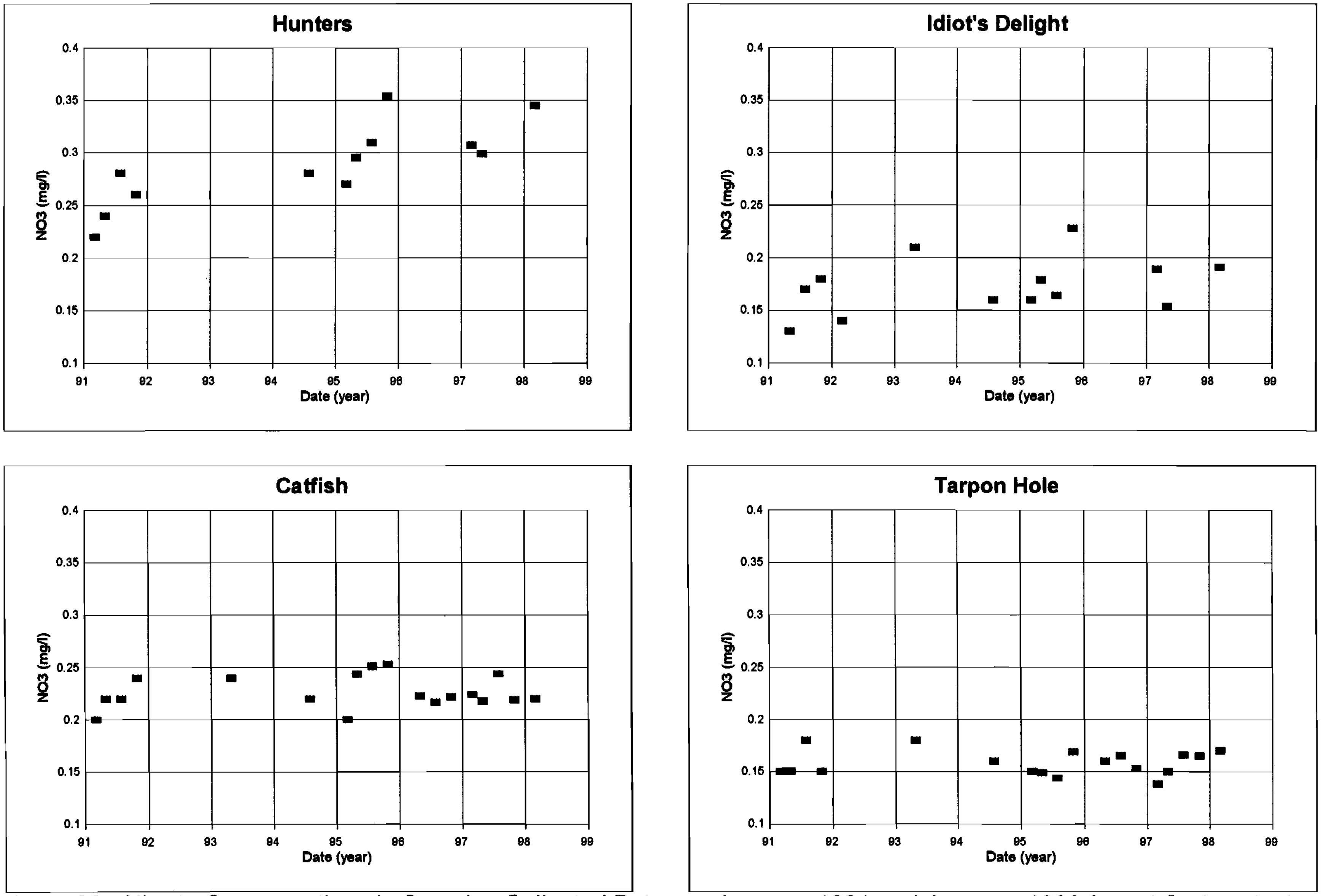

Figure 30. Nitrate Concentrations in Samples Collected Between January, 1991 and January, 1998 from 4 Springs in the King's Bay Complex.

GROUND-WATER CHEMISTRY: ISOTOPIC CONTENT

Uranium

The naturally occurring concentrations of uranium and the activity ratio of ^{234}U to ^{238}U in well and spring-water samples has been successfully utilized by J.K. Osmond and J.B. Cowart (*i.e.*, Osmond and Cowart, 1976; Cowart , 1978) of Florida State University to trace ground-water flow systems, determine relative ages of ground-water masses, and determine provenance of water masses. Cowart's analysis of the uranium isotopic content of ground-water samples collected for a study of Lithia and Buckhorn Spring complexes (Jones and Upchurch, 1993) and the Rainbow Springs Complex (Jones *et al.*, 1996) was instrumental in determining the source areas of those springs. The following three paragraphs, modified from Cowart and Osmond (1992), explain the chemical basis for the technique.

Ground water in the deep, slow-moving portions of the Floridan aquifer flow system is characterized by low concentrations of uranium (< 0.1 µg/l) associated with relatively high $^{234}U/^{238}U$ 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 alpha-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 character that is distinctly different from deeper Floridan aquifer systems. These shallow waters exhibit higher concentrations of uranium with much lower $^{234}U/^{238}U$ activity ratios (sometimes with less than the equilibrium value of 1). This results from: 1) the oxidizing nature of rapidly recharging water which mobilizes uranium as a complex of the U^{6+} ion (uranyl, UO_2^{+2}), 2) the resulting high leach component of uranium which completely masks the recoil component of ^{234}U, and 3), assuming that the leaching process has just begun on a time scale "short" relative to the half-life of ^{234}U (250,000 years) the uranium leached from host-rock surfaces is depleted in ^{234}U because of previous recoil mobilization.

Because uranium is most soluble in oxidizing environments where it forms uranyl (UO_2^{+2}) ions, 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.

Twenty seven wells and six springs were sampled for uranium isotopes. Results of the sampling are listed in Table 4 and the distribution of $^{234}U/^{238}U$ activity ratio and uranium concentration data for the wells and springs are shown in Figure 31. Analysis of the samples was completed by Dr. James Cowart at Florida State University. Cowart was also contracted to determine relationships between the ground-water and spring samples, if possible. The map reference number relates the spring or well to its location on Figures 1 or 7.

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 six 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 31 indicate that only the extreme southern portion of the study area may not be a recharge area for the springs.

NITROGEN

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 difficult to determine the relative contributions of these sources to nitrate in study area ground water. The isotopic ratio of $^{15}N/^{14}N$ (expressed as $\delta^{15}N$) can provide a direct indication of the importance of certain nitrate sources. It is especially useful for characterization of animal waste (organic) sources as opposed to inorganic sources. The ratio of nitrogen isotopes in dissolved nitrate is expressed in parts per thousand (ppt) and is calculated using the following equation:

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

Where

α = the activity of the specified isotope

Three $\delta^{15}N$ ranges have been defined for nitrate from different sources (Wolterink *et al.,*1979). The $\delta^{15}N$ values for nitrate from unfertilized, cultivated fields

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

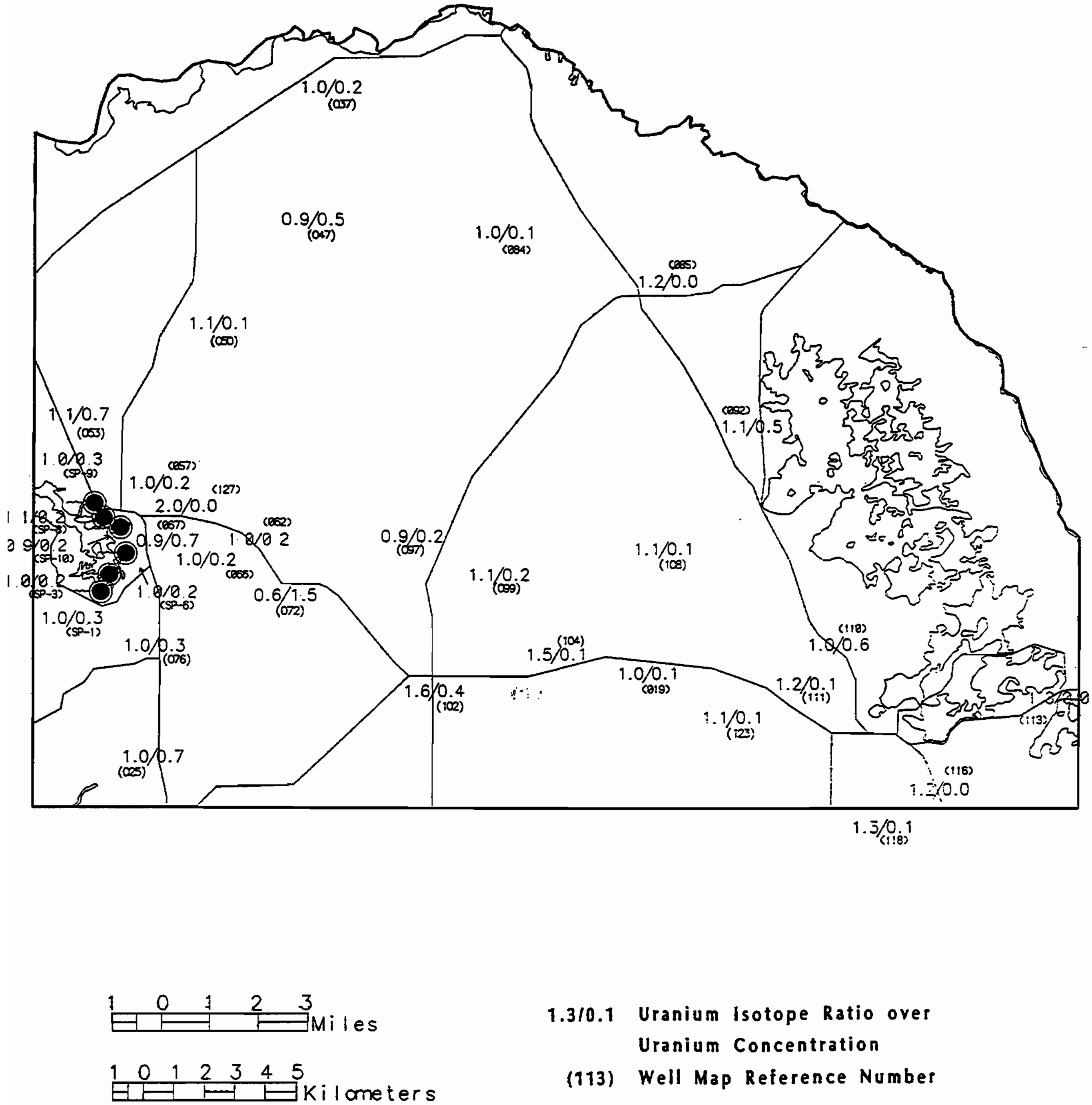

Figure 31. Uranium Isotopic Activity Ratios and Concentrations (ug/l) in Study Area Ground Water.

(nitrate resulting from the oxidation of part of the organic nitrogen in the soil from crop plowing) range from +2 to +8 ppt (Kreitler, 1975). In the warm, humid environment of west-central Florida, only a minimal amount of nitrate should leach from undisturbed soils (Andrews, 1994). Isotopic ratios in water affected by animal waste (organic nitrogen) sources, such as septic tanks, feedlots, and barnyards, range from +10 to +20 ppt. However, these sources cannot be distinguished from each other. Nitrate leached from synthetic, ammonium nitrate 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 ppt, with 90 percent of the samples ranging from -3 to +2 ppt (Kreitler, 1975; Kreitler and Jones, 1975).

Seven wells and four 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 32 shows the spatial distribution of $\delta^{15}N$.

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-defined areas in the aquifer, indicating that nitrogen loading and transport is occurring in specific areas.

Overall, the low nitrate concentrations and the difficulty in sorting out overlapping sources (i.e. residential and golf course turf fertilization, agricultural fertilization, livestock, septic tank, and sewage waste sources) makes it very difficult to draw meaningful conclusions from the nitrogen isotope data. It is probable, however, that the water receives nitrogen from multiple sources, which results in isotopic ratios that are not extreme and that reflect the mixed origins.

TRITIUM

Tritium (^{3}H) is an isotope of hydrogen that is formed by cosmic-ray activation of nitrogen and by atmospheric testing of nuclear weapons. Determining the tritium content of aquifer water helps to determine whether the aquifer is being recharged locally or from a more distant source. Because of the dramatic increase in tritium in 1952 as a result of the onset of atmospheric testing of hydrogen bombs, tritium provides a useful marker for relatively young water in the hydrologic cycle. Before

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
Romp 113	019	2.6
Kelly	037	3.2
Aubin	061	6.2
Clemens	066	3.5
Lyons	080	5.0
Hunt	084	3.1
Kremnetz	092	8.8
Lisotta	099	2.8
Rhame	109	5.5
Case	110	5.8

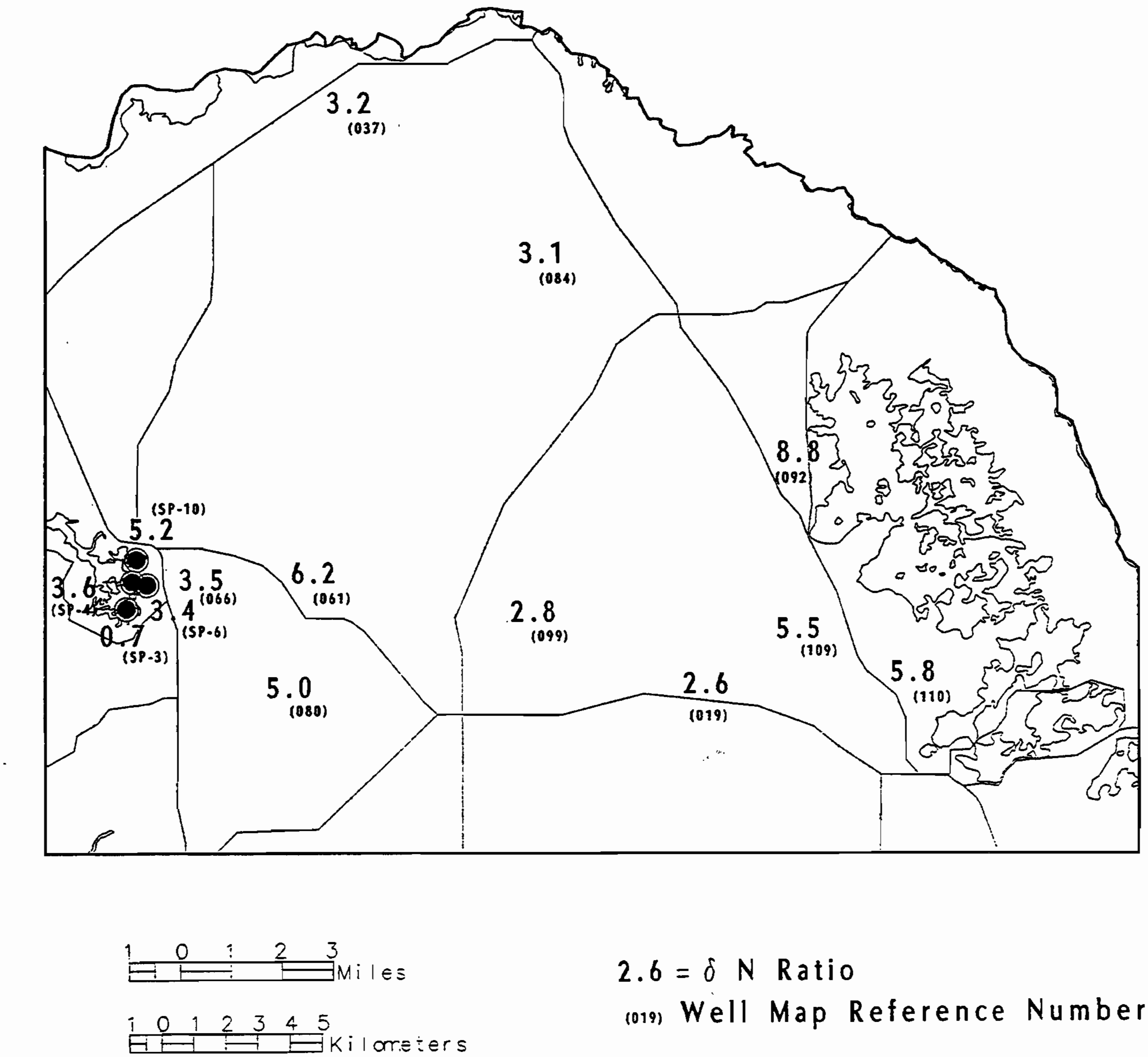

Figure 32. $\delta^{15}N$ Isotopic Ratios in Study Area Ground Water.

1952, the tritium content of meteoric water ranged from 1 to 10 tritium units[6] (TU) (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 to the hydrologic cycle in the mid-1940's, the major build-up of tritium began with increased atmospheric testing in the 1950's. This resulted in rainfall concentrations of tritium reaching 1,188 TU at Ocala, Florida, in 1963 (Yobbi, 1992). 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 pre-1950 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 20 years.

Studies in the northern portion of the SWFWMD (Faulkner, 1970; Swancar and Hutchinson, 1992) determined that ground water in the shallow portion of the Floridan aquifer has entered the aquifer very recently. Faulkner (1970) investigated the tritium content of ground water in the Rainbow Springs study area and found tritium activities in wells and springs 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. This indicates that a large percentage of the water discharging from Rainbow and Silver Springs in 1966-68 could not have been in the flow system for more than 16 years.

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) because of 1) relatively long periods required for recharge and 2) mixing with older waters in the Floridan aquifer. Their data for wells in the ground-water basins of the springs described in this report strongly implicate rapid recharge and flow toward the coastal springs.

Samples obtained from fifteen wells in the study area and Tarpon Hole, Catfish Corner, and Idiots Delight Springs were analyzed for tritium. Results of the analyses

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

are included in Table 6. The map reference number relates the well or spring to its location on Figures 1 or 7. Figure 33 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 34, the distribution of tritium in precipitation over time, 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 seawater and freshwater in varying proportions, so the moderately high tritium contents suggest relatively young water, but do not indicate whether the tritium is in the seawater or freshwater component. Comparison of the bulk water composition and tritium contents of freshwater inland, suggest that the tritium in the springs is from the freshwater 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).

Table 6. 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
Kelly Well	037	25.0
Aubin	061	5.9
Sheffield	063	4.1
Needleman	067	6.6
Verona	070	5.6
Arnow	071	6.6
Hunt	084	5.3
Beohl	094	17.5
Lisotta	099	7.2
Townsend	102	4.7
Rhame	109	4.7
Case	110	5.6
Frenzel	112	6.2
Cutrone	116	5.0
Houston	123	6.6

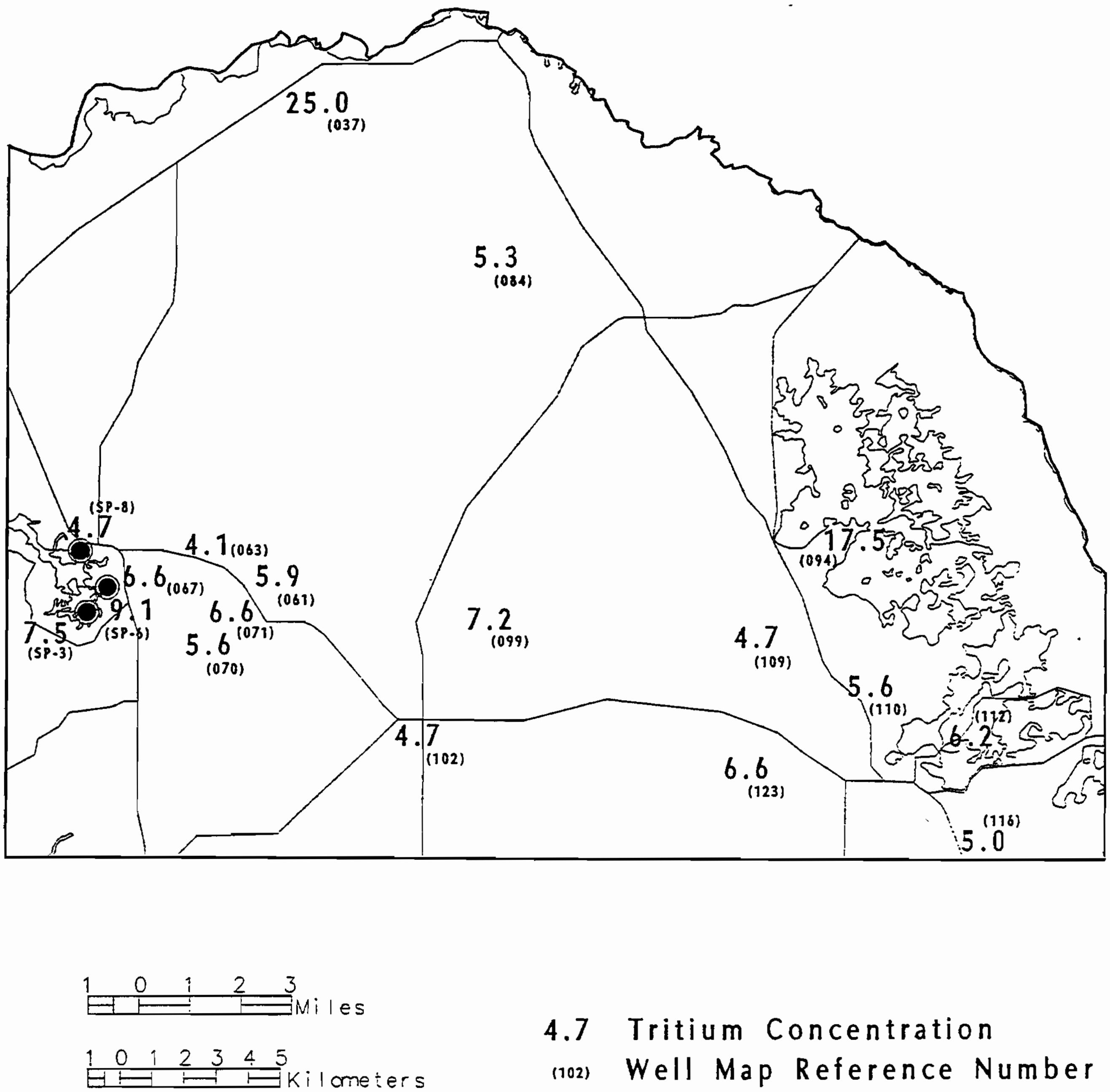

Figure 33. Tritium Activities (TU) in Study Area Ground Water.

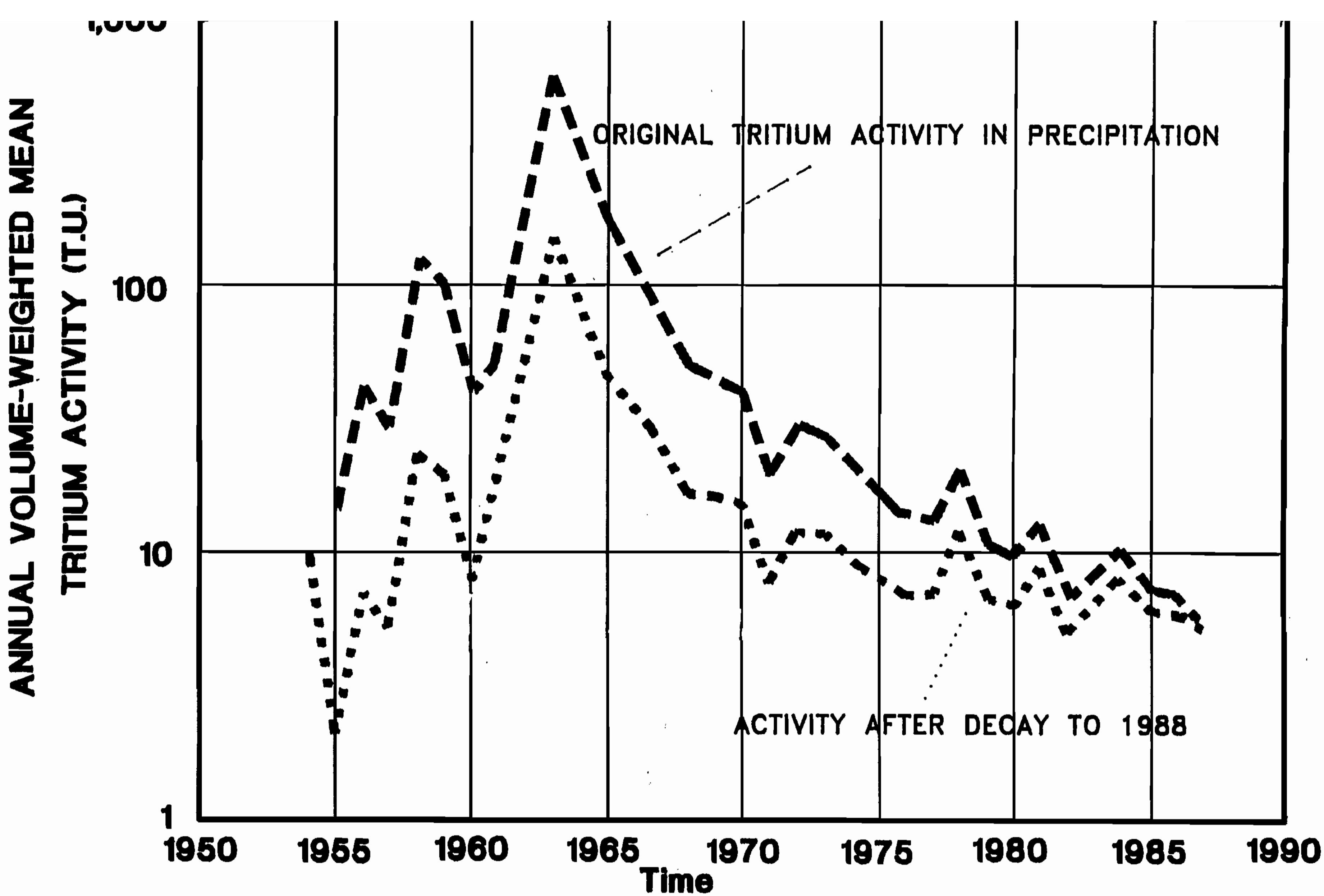

Figure 34. Distribution of Tritium in Precipitation Over Time (modified from Swancar and Hutchinson, 1992)

CONCEPTUAL FLOW MODEL

The following is discussion of a number of aspects of ground water flow in the study area including delineation of the flow system, dynamics of the flow system, and ground water velocity and travel time.

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 along the Brooksville Ridge, under Lake Tsala Apopka, and possibly Lake Rousseau, with a more dispersed recharge prevalent throughout the remainder of the area. The Beach Ridge and Dune deposits covering much of the Gulf Coastal Lowlands physiographic province and the western flank of the Brooksville Ridge may provide a significant shallow-flow contribution to spring discharge, due to the unconfined conditions of the Floridan aquifer in the region and its close proximity to the coast. 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.

Ground water moves through the Floridan aquifer partially as diffuse flow and partly through fracture conduits, solution channels and caverns. Diffuse flow occurs as water percolates in from the surface, enters the aquifer system, and moves through the pore spaces between grains of sand and limestone. As ground water flow continues through the limestone matrix, intergranular or diffuse flow becomes less important and conduit flow increases in importance in terms of aquifer permeability. Ultimately, the smaller fractures are enlarged by solution of the matrix and intersect other fracture conduits or solution channels that transport water to the springs. These major fractures, which concentrate in rectilinear patterns, are also connected to the surface by sinkholes located along their length, allowing more direct recharge to the aquifer. The developed conduit flow imparts a pattern of corridors or pathways of slightly poorer water quality in the Floridan aquifer. Several of these pathways point toward the springs at King's Bay. The most significant water quality trends are seen in the east-west corridor that extends from Lake Tsala Apopka to the springs and the north-south corridor that appear to be developing from Lake Rousseau.

This conduit flow is focused at the spring discharge in King's Bay. The spring flows consist of recently recharged waters that, from the isotopic data, appear only to have been in the ground water flow system a few tens of years. Also, the apparent transition from a steep gradient beneath Lake Tsala Apopka to a nearly flat potentiometric surface in the central and coastal areas 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 ground water movement from high recharge areas to the coast.

GROUND WATER TRAVEL TIME

Ground water travel times for the central flow corridor from Lake Tsala Apopka to the King's Bay Springs were estimated using the equation given below for average linear velocity (Freeze and Cherry, 1979):

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

where:

V = average linear velocity (ft/day);

K = hydraulic conductivity (ft/day); with K = T/b; T = transmissivity (ft^2/day) and b = aquifer thickness (ft)

ΔH = change in head (ft.);

L = length of flow path (ft.);

n = porosity (0.15 for karst aquifers)

To determine hydraulic conductivity for the equation it was first necessary to obtain transmissivity values for the Floridan aquifer across the central corridor of the study area. Transmissivity data were obtained from aquifer pumping tests conducted in the study area (Atlanta Testing and Engineering, 1989; SWFWMD, 1987, 1994), and also from ground water flow models developed by Ryder (1985) and later refined by Yobbi (1989). Results of four aquifer pumping tests in the central and western study area yielded transmissivities ranging from 1,500,000 gal/day/ft to 20,000,000 gal/day/ft, with an average value of 8,050,000 gal/day/ft. This closely agrees with the model-derived value reported by Ryder (1985) for the study area.

Aquifer pumping test data is nonexistent in the east-central portion of the study area, although tests on the Floridan aquifer in surrounding areas give transmissivities ranging from 213,000 gal/day/ft in northeastern Hernando County, (SWFWMD, 1987) to 500,000 gal/day/ft in southwest Marion County (SWFWMD, 1994). Specific capacity data from a well located in the town of Inverness (well # 90 in Anderson and Laughlin, 1982) was used to estimate a Floridan aquifer transmissivity of 570,000 gal/day/ft in eastern Citrus County. A transmissivity estimate of 500,000 gal/day/ft for the eastern portion of the central corridor is supported by the referenced test data, although modeled values provided by both Ryder (1985) and Yobbi (1989) are higher by at least an order of magnitude.

Hydraulic conductivity estimates for the Floridan Aquifer were determined for the transmissivity value (converted to ft^2/day) divided by an aquifer thickness (b) of 250 feet. This is the average thickness of the potable-water zone in the upper Floridan aquifer across the central flow corridor, based on the geologic and water quality data presented in Figure 9 (see page 21). 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 or at the base of the area of active ground water circulation.

The hydraulic gradient $\Delta H/L$, for the central corridor was determined from the May 1991 potentiometric surface map of the Upper Floridan aquifer (Mularoni, 1992). The average linear velocity of ground water flow was calculated for an 8-mile segment from the approximate center of the study area to King's Bay (Figure 35). A hydraulic gradient of 1.2×10^{-4} was calculated for the 5-foot change in head across the segment.

Porosity values (n) for carbonate aquifers range from five to 20 percent, with porosity estimates as high as 50% for karst limestone (Domenico and Schwartz, 1990; Freeze and Cherry, 1979). A porosity of 15 percent for the Upper Floridan aquifer was used for a well head protection model for major public supply wells in Hernando County (SWFWMD, 1993). This porosity value is also used to estimate the average linear velocity across the study area, since it conservatively approximates the wide range of porosities that may occur over large areas in a fractured karst aquifer.

The average linear velocity equation was used to estimate the time required in years for ground water to flow from the central Citrus County flow corridor to the King's Bay Springs (Figure 35). It is apparent that nitrate entering ground water in the central portion of the study area requires approximately 34 years to travel the eight miles between the Brooksville Ridge and the King's Bay Springs. However, the accuracy of this application is limited because the average linear velocity equation is generally not appropriate for areas where conduit flow is prevalent. Additionally, the diffuse recharge component contributing to flow along major fractures is ignored, and estimates of aquifer thickness, transmissivity, and the exact gradient across the study area may also be inaccurate.

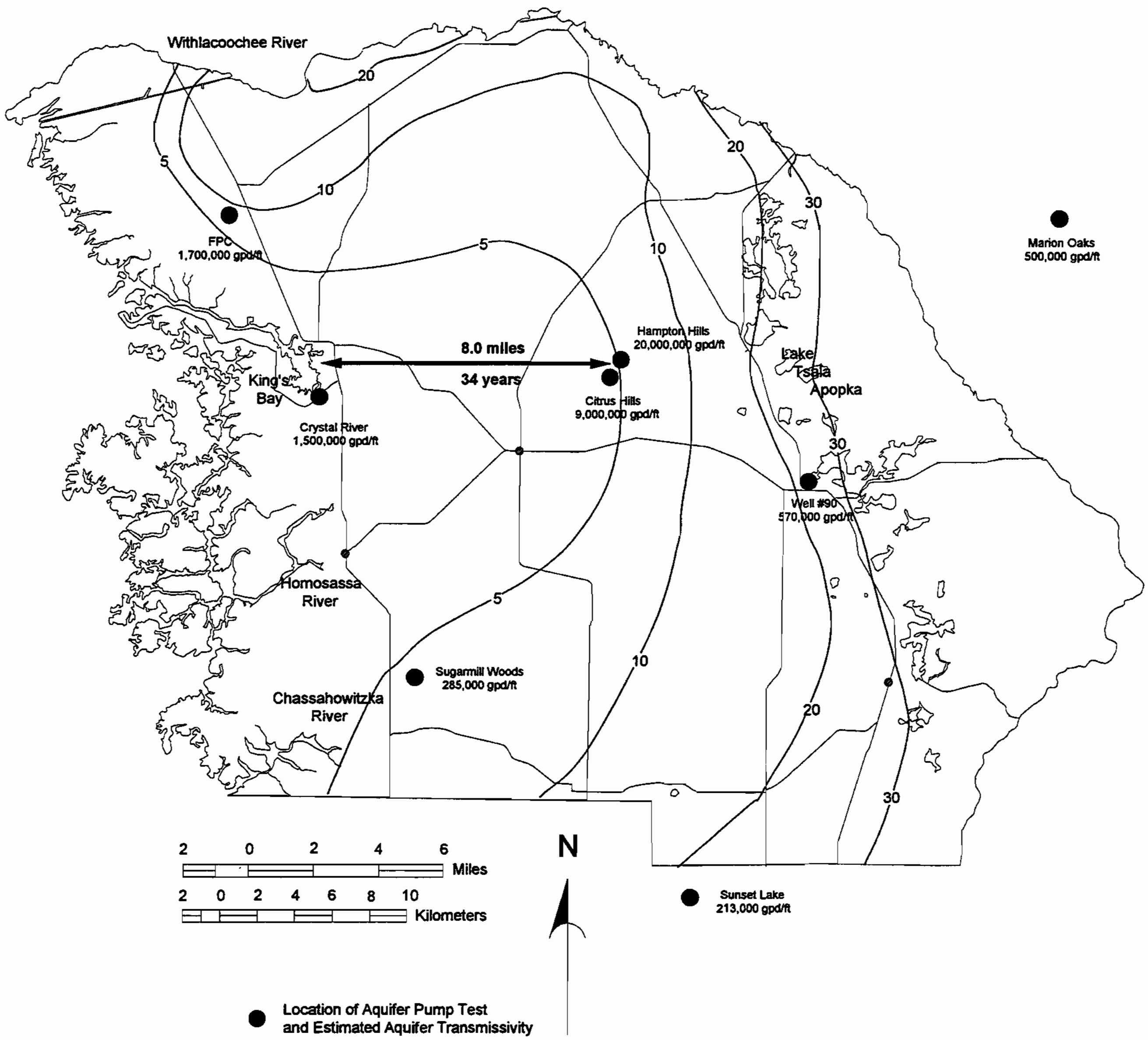

Figure 35. Potentiometric Surface and Travel Time Along the Central Ground-Water Flow Corridor Between the Brooksville Ridge and the King's Bay Springs.

NITROGEN LOADING OF THE GROUND-WATER SYSTEM

The following section begins with a discussion of the portions of the recharge area where the nitrogen discharging from the springs is most likely to enter the Floridan aquifer. Next is a nitrogen loading estimate for each of the following sources in the study area: 1) naturally occurring nitrogen from organic decay, 2) rainfall, 3) residential and commercial development serviced by septic tanks, 4) fertilization of residential turf, 5) fertilization of golf course turf, 6) sewage effluent disposal, 7) land disposal of sewage sludge, 8) land disposal of septage sludge, 9) row crop fertilization, citrus fertilization, 10) pasture fertilization, 11) dairies, and 12) cattle.

It is important for the reader to remember that discussions of land use and land-use acreage in this section refer to the conditions that existed in the study area in 1990 as depicted in Figure 3.

NITROGEN SOURCE AREAS

Nutrient and isotopic data indicate two potential nitrate sources for the springs. There are local sources within the City of Crystal River and in the immediate vicinity that may be a cause of nitrate enrichment of the springs. These sources include residential and golf course turf fertilizers, residential septic tanks, and small sewage treatment facilities. There is an even greater problem, however, in that the ground waters distal to the springs are also enriched in nitrate 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 aquifer. 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. Although the lakes are a long-term, low-level source of nitrogen to ground water in the Floridan aquifer in the study area, the relatively low levels of nitrogen may be diluted to background levels before reaching he springs.

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 low density, there is a significant potential for accelerated degradation if waste disposal practices are not reevaluated and altered.

NITROGEN LOADING ESTIMATES

Naturally Occurring Organic Decay

Nitrogen can be released into the ground-water system environment through the microbial decomposition of surface biomass, which is largely plant material. However, the actual amount of nitrogen 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 low-level 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 one 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

Aerial photograph analysis and delineation of the extent of sewer systems indicated that there were approximately 17,000 septic tanks in the study area in 1990.

The density of septic tanks is delineated in Figure 36. 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). 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 three people. The annual nitrogen contribution per septic tank would then be approximately 53 lbs (Walker *et al.* 1973a). Using this figure, the total nitrogen contribution from septic tanks in the study area is approximately 458 tons/yr. When broken out by physiographic province the loadings are as follows:

Province		Nitrogen Loading (tons/yr)
Tsala Apopka Plain	=	125
Brooksville Ridge	=	166
Gulf Coastal Lowlands	=	167
Total	=	458

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 37 lbs/yr of nitrogen to ground water, which, according to Hantzsche and Finnemore (1992), is fully converted to nitrate. Using this figure, the total amount of nitrogen that reaches ground water from septic tanks in the study area is approximately 320 tons/yr.

Turf Fertilization

Approximately 35,000 acres in the study area were occupied by low, medium, and high density residential land uses in 1990. A large percentage of this land use has associated turf and it can be assumed that a significant portion of the turf is fertilized. Jones *et al.*, (1997) have shown that fertilization of turf in the recharge areas of Homosassa, Chassahowitzka, and Weeki Wachee Springs to the south of the King's Bay Springs is the dominant factor responsible for rapidly increasing nitrate levels in these springs.

Accurately quantifying the nitrogen contribution from the fertilization of landscaping is highly problematic. This is because it is extremely difficult to determine the percentage of landscaping that is maintained with fertilizers, how much fertilizer is

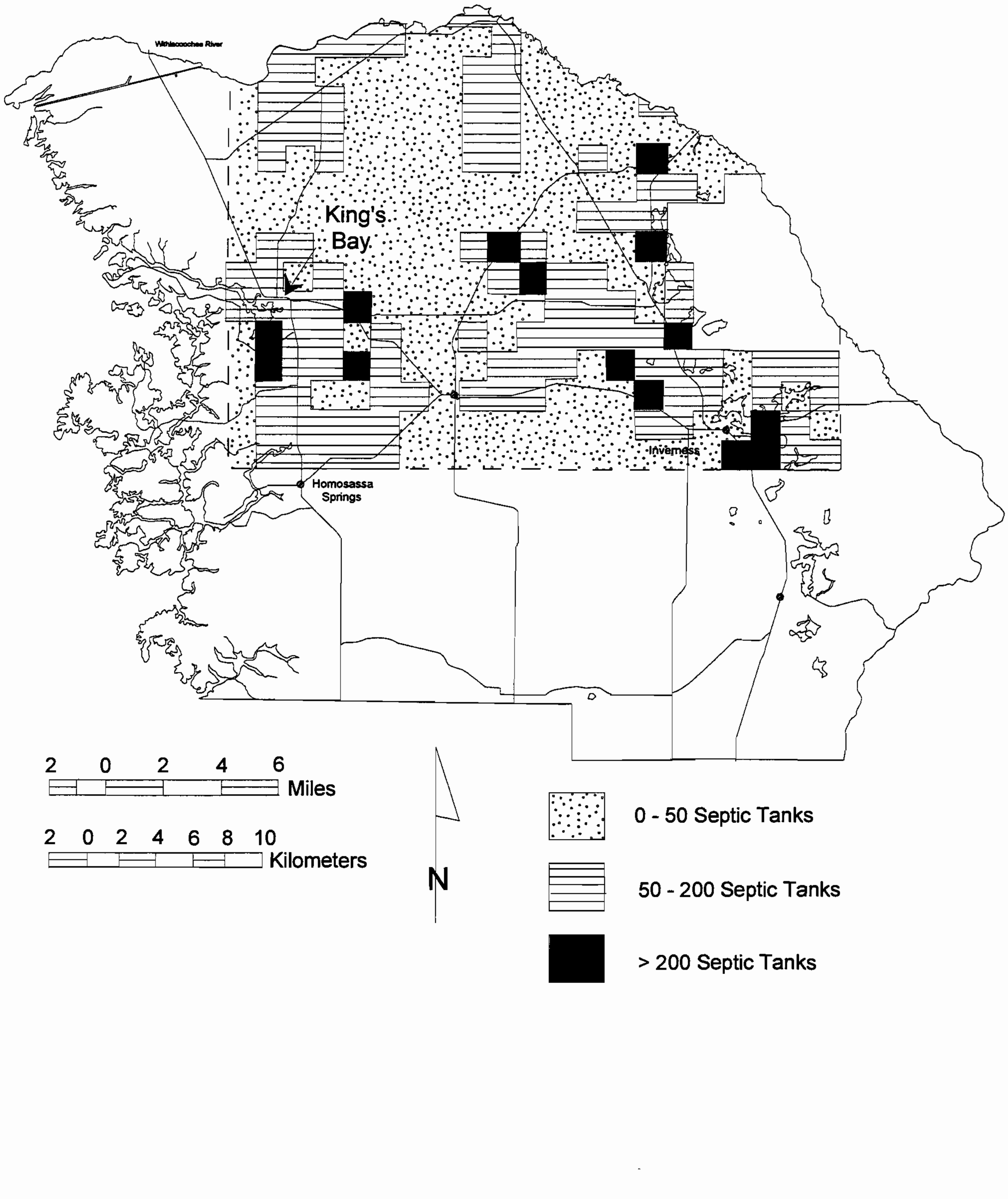

Figure 36. Density of Septic Tanks per square mile in the Study Area in 1990.

applied, and how much of the fertilizer directly percolates to ground water. However, the authors have calculated a nitrogen loading estimate for turf fertilization that can be considered a starting point for those interested in pursuing a more accurate number. It is left to the reader to judge the validity of the assumptions and recalculate the loading estimate if more accurate data are available.

It is first assumed that the structure, patio, pool, driveway, sidewalk, unfertilized planters, wooded areas, and other areas without turf take up to 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 (CES) recommends two lbs per year of nitrogen per 1000 square feet (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. Broken out by physiographic province the application rates would be as follows:

Province		Nitrogen Loading (tons/yr)
Tsala Apopka Plain	=	64
Brooksville Ridge	=	150
Gulf Coastal Lowlands	=	105
Total	=	319

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.

Nitrate levels in ground water underlying 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 study and the study of nitrate loading to the large, coastal springs to the south of King's Bay make it reasonable to assume that turf fertilization is significantly 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 122), 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 this value is considered a fair approximation, then only a small amount of nitrogen from turf fertilization is removed by stormwater.

Golf Courses

There were eleven golf courses in the study area in 1990 (Figure 37) covering approximately 1,865 acres. Determining the amount of nitrogen applied to golf courses as fertilizer is highly problematic. 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

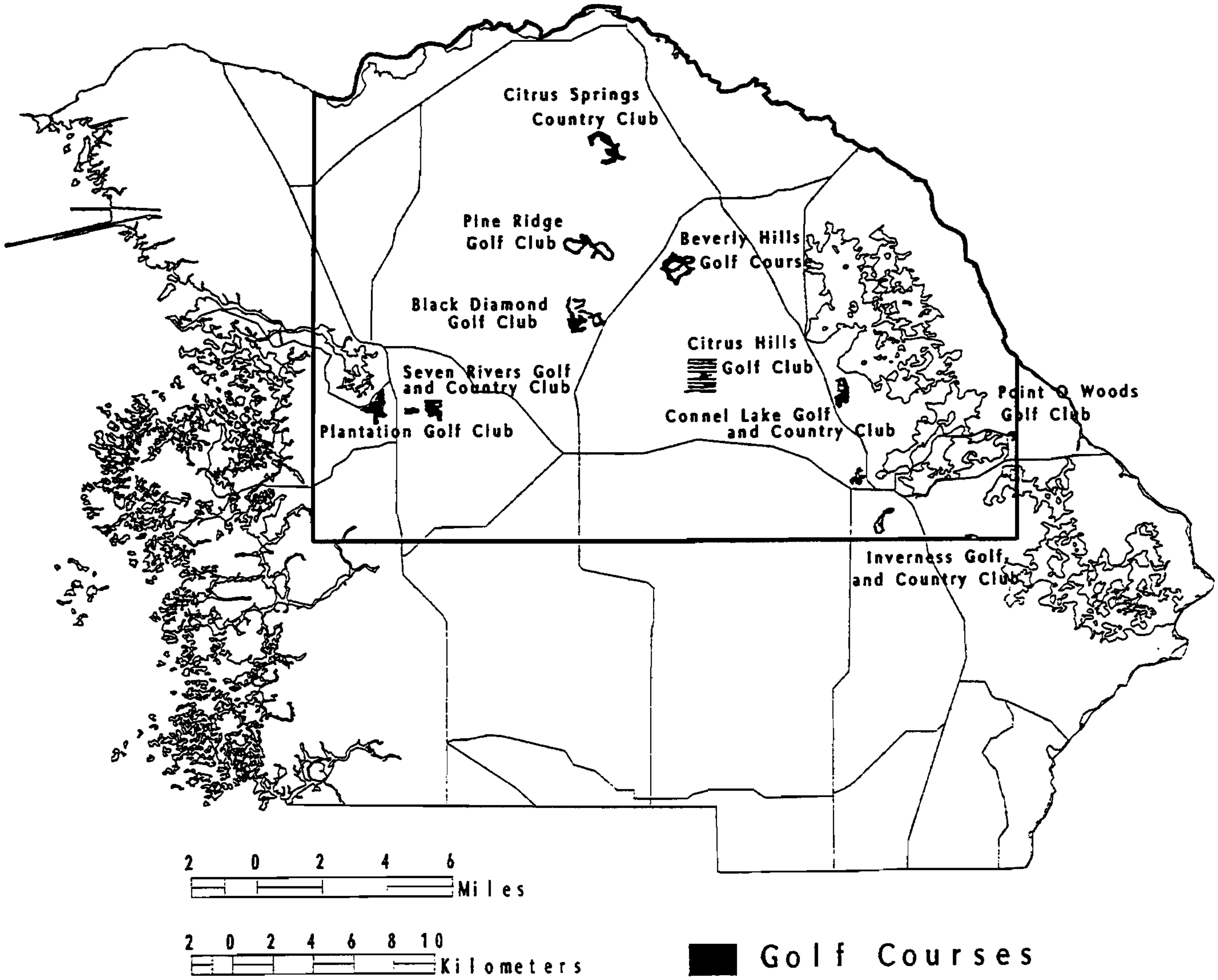

Figure 37. Location of Golf Course in the Study Area in 1990.

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

In 1992 there were 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 38 is a location map of these wastewater facilities. Table 7 contains the 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 g.p.d. to the City of Inverness Wastewater Treatment Plant with a permitted capacity of 1.5 million g.p.d..

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 in 1992 was approximately 874 million gallons. Total nitrogen concentrations in municipal wastewater range from 20 to 85 mg/l (USEPA, 1981). A value of 40 mg/l, which the (USEPA, 1981) refers to as the median concentration, was chosen for the total nitrogen content of wastewater. Using 40 mg/l, the total amount of nitrogen in 874 million gallons is 146 tons. All 42 of the wastewater treatment plants treated wastes to the secondary level in 1992. Secondary treatment typically removes approximately 10 to 40 percent of the total nitrogen from domestic wastewater (Akers and Associates, 1991). Using an average of 25 percent removal, 36 tons is 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.

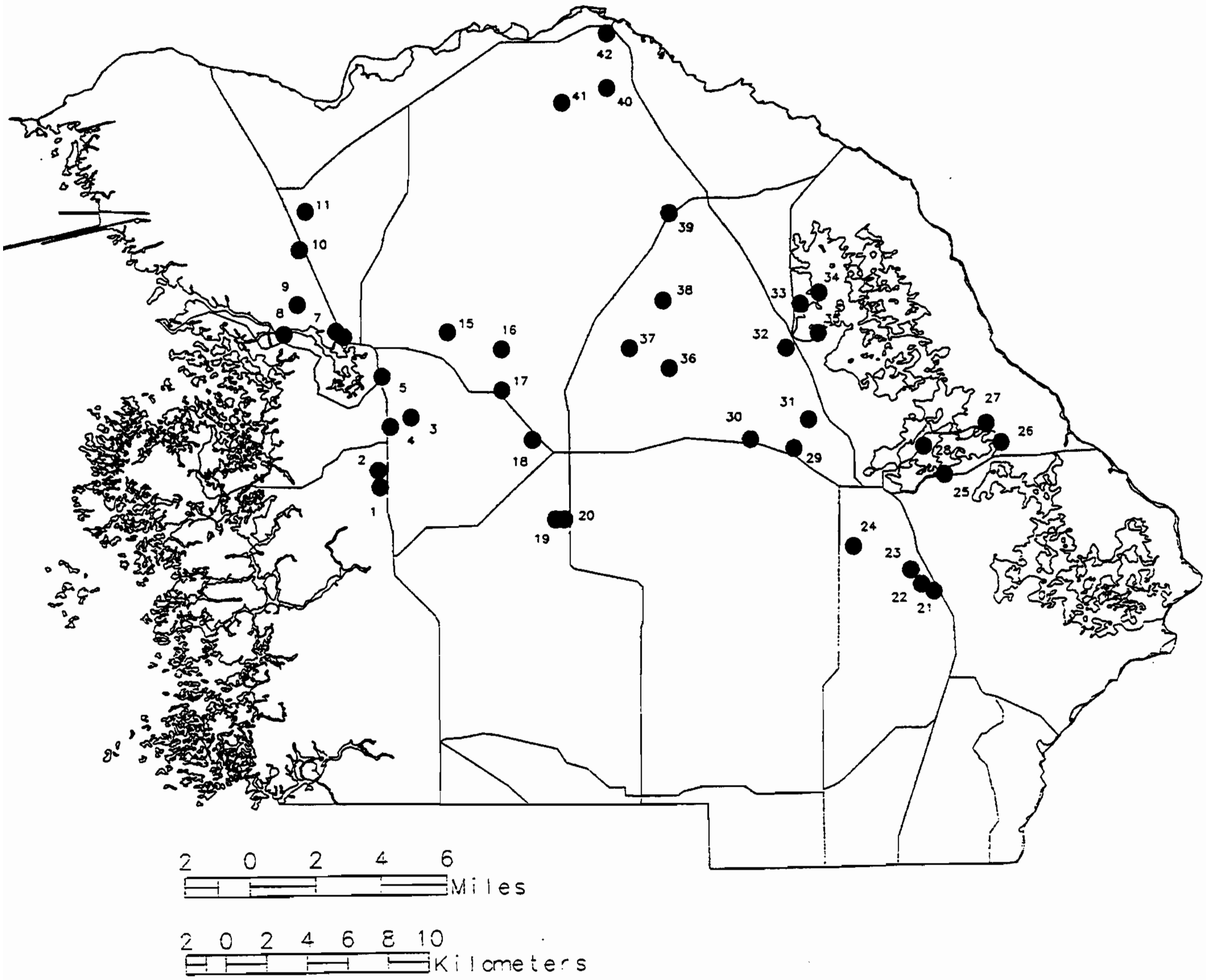

Figure 38. Location of Wastewater Treatment Facilities in the Study Area in 1992.

Table 7. Active Wastewater Treatment Facilities in the Study Area in 1992.

FACILITY	MAP INDEX	WASTEWATER TREATED IN 1992 (GALLONS)	EFFLUENT DISPOSAL METHOD
IMP. GARDENS M.P.	1	790,000	PP
FOREST VIEW M.P.	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 M.P.	6	1,025,000	PP
CITY OF CRYSTAL RIVER	7	273,689,167	SF
CRYSTAL RIVER M.P.	8	1,065,000	PP
INDIAN SPRINGS	9	5,475,000	PP
COMFORT INN	10	1,551,000	PP
SEVEN RIVERS COME. 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 M.P.	15	1,095,000	SF
MEADOW CREST	16	28,257,083	PP
KEY PINE VILLAGE	17	1,003,750	PP
LECANTO HILLS M.P.	18	1,003,750	PP
LECANTO SCHOOL COMPLEX	19	12,835,833	PP
PALM TERRACE M.P.	20	5,292,500	SF
ENSIGNS OASIS	21	1,125,416	PP

Table 7. Active Wastewater Treatment Facilities in the Study Area in 1992 (continued).

FACILITY	MAP INDEX	WASTEWATER TREATED IN 1992 (GALLONS)	EFFLUENT DISPOSAL METHOD
FORT COOPER M.P.	22	2,701,000	PP
CITY OF INVERNESS	23	237,493,333	PP
ROYAL OAKS	24	3,577,000	PP
OAK POND M.P.	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 M.P.	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

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, seven use spray fields, and one uses a drain field. 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.

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 three 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 12, the Ridge is characterized by numerous sinkhole features some of which encompass 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 7), and because it is permitted to treat in excess of 100,000 g.p.d., 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 (FDEP, 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 varies considerably in elevation over short distances, which 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 in depth from 280 to 405 feet, 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. While well below the drinking water standard for nitrate (10 mg/l), these concentrations are high for ground water in Citrus County and could indicate contamination from the nearby spray field. It could also be argued that flow of nitrate-rich ground water under the Brooksville Ridge from Lake Tsala Apopka 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 in 1992 was disposed of at four sites in the study area and one site several miles to the south (Figure 39). The Domestic Waste Section of the FDEP is responsible for overseeing sludge disposal. The calculations

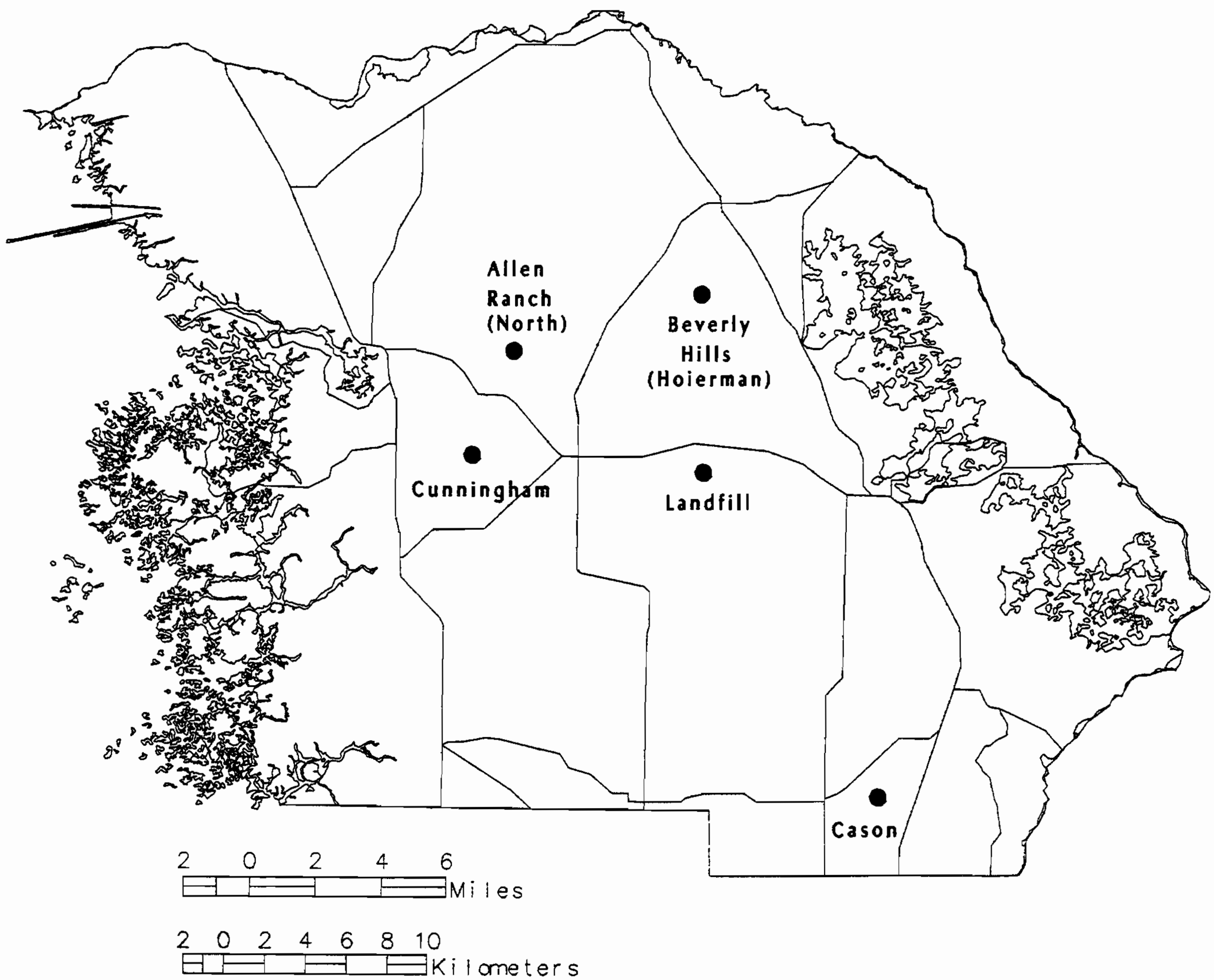

Figure 39. Location of Sewage Sludge Disposal Sites in the Study Area in 1992.

discussed previously indicate that sludge generated in the study area may contain approximately 36 tons of nitrogen. According to the FDEP, most of the sludge is disposed of at the Allen Ranch in the Brooksville Ridge province. Beverly Hills disposes sludge exclusively at the Hoierman site. A small amount of sludge is disposed of at the County Landfill and the Cunningham Ranch. The City of Crystal River disposes 11 tons at the Cason property outside the study area in the southern portion of Citrus County. With the exception of the county landfill site, Sludge spreading sites in the study area are privately owned agricultural lands . 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.

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 physiographic province from sludge disposal can be estimated.

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

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 62-640 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 FDEP. 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

Septage spreading 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. 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 in 1992 are plotted in Figure 40. There are three active and nine inactive sites in the study area. Information concerning acreage and status of each site is listed in Table 8 (Citrus County Public Health unit, 1993).

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 records were not 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 fair 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.

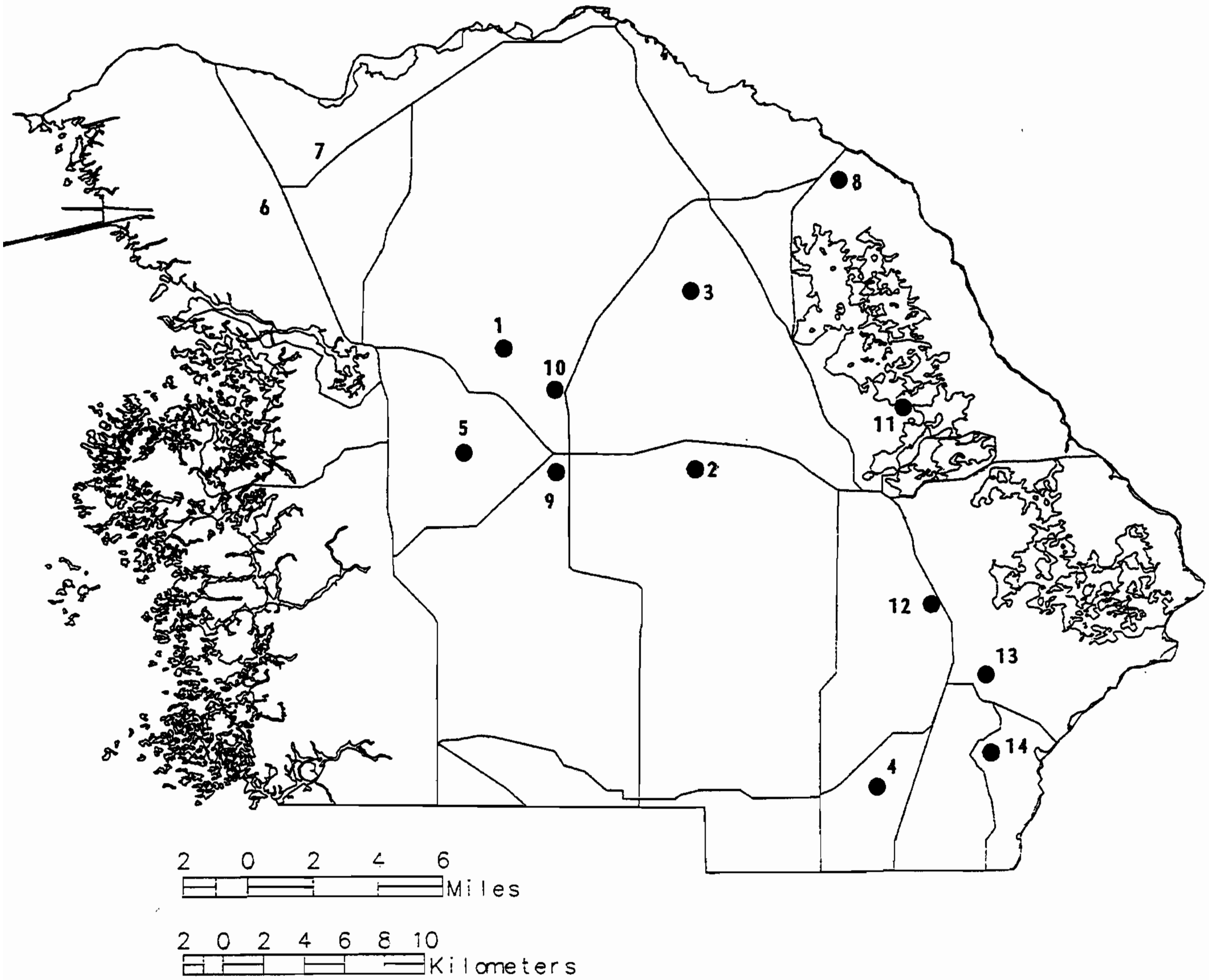

Figure 40. Location of Septage Sludge Disposal Sites in the Study Area in 1992.

Table 8. Active and Inactive Septage Spreading Sites in the Study Area in 1992.

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 DeanRanch	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

Agriculture

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

Row Crops

According to the County Extension Service (CES), row crops are a relatively minor land use in Citrus County covering only about 624 acres in 1993 (Andy Rose, 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 CES, 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/FDEP,1990). Interpretation of historical aerial photographs indicates that citrus in the study area covered approximately 2,600 acres in 1965. According to the CES, 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 1985, severe freezes killed most of the trees. According to the CES, replanting of citrus between 1985 and 1992 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 2.3 tons of nitrogen to the study area.

In 1992, nitrogen loading from citrus production was insignificant in the study area due to the small amount of acreage that remained 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, sewage effluent disposal, and inputs from Lake Tsala Apopka.

Pasture Fertilization

Pasture fertilization has been determined to be a significant source of nitrate to Rainbow Springs in Marion County (Jones *et al.,* 1996). Pasture occupied approximately 16,450 acres in the study area in 1990. Nitrogen fertilizers are applied to pastures to promote the growth of pasture grasses. Bahia Grass, a common pasture grass, is a warm-season perennial grown for livestock grazing and hay. It can withstand heavy grazing stress, and produces good quality hay if well fertilized. Bahia Grass readily takes up mineral nutrients in the soil and recycles them within the upper soil zone. If harvested, however, the mineral nutrients contained within the hay are not recycled into the soil and must be supplemented by fertilization (Dr. Carrol Chambliss, University of Florida, personal communication, 1995).

Accurately quantifying the nitrogen contribution from the fertilization of pasture in the study area is problematic. In an investigation of nitrogen loading in the recharge area of Rainbow Springs in the SWFWMD, conducted by Jones *et al.,* (1996), nitrogen loading from pasture fertilization was determined by assuming that all pasture acreage in the study area was fertilized at the rate of 50 lbs N/ac/yr.

For this report, the authors developed an alternative method that estimates loading using the Florida Department of Agriculture and Consumer Services (FDACS) Annual Summary of the Consumption of Fertilizer Materials and Mixtures in Florida Counties (FDACS, 1993). Because this method uses numerous assumptions and calculations, it is fully detailed in Appendix V.

According to FDACS (1993), the tonnage of nitrogen in fertilizer utilized in farming in the study area from July, 1992 to June, 1993 was 178 tons. Fertilizers containing this amount of nitrogen were applied to row crops, citrus and pasture; the dominant crops in the study area. To determine the total amount of nitrogen applied only to pasture, the 29 tons of nitrogen applied to row crops and citrus, calculated on page 117, were subtracted from the 178 tons of nitrogen used in farming, leaving 149 tons. Broken out by physiographic province the estimated loadings are as follows:

Province		Nitrogen Loading (tons/yr)
Tsala Apopka Plain	=	34
Brooksville Ridge	=	69
Gulf Coastal Lowlands	=	46
Total	=	149

This amount of nitrogen is relatively small and, while it may elevate nitrate concentrations in ground water locally, it probably has no effect on the springs.

Dairies

Dairies have been determined to be a significant source of nitrate to some springs in Hillsborough County (Jones and Upchurch, 1993). However, analysis of aerial photographs and discussions with the Soil Conservation Service (SCS) and the CES indicate that cattle dairies do not exist and have not existed in Citrus County. 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 dairies are insignificant.

Cattle

In 1990, areas where beef cattle were pastured in Citrus County occupied a significant portion of the study area (Figure 3, pasture acreage). According to the FDACS (1990), there were approximately 6,000 beef cattle in Citrus County in 1990. According to the SCS (pers. come, 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.

There are several factors that reduce the actual amount of nitrogen that reaches ground water. First, the number of cattle reported by the FDACS 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. There were approximately 15,000 acres of unimproved and improved pasture in the study area (SWFWMD, 1990). Dividing 180 tons 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 beef cattle are usually widely dispersed and not concentrated into small feedlot areas. As a result, the nitrogen in their waste is more likely to be removed by the many uptake mechanisms discussed previously. When these factors are taken into account, the amount of nitrogen contributed by beef cattle in the study area 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 9 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 9. 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:

$$N = r \cdot EMC \cdot A \cdot R, \tag{4}$$

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 10 lists some of the land uses that contribute significant amounts of nitrogen to stormwater and an estimate of the amount of nitrogen contributed in 1990 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 10. Stormwater Nitrogen Contribution from Four Important Land Uses in the Study Area in 1990.

LAND USE	PHYSIOGRAPHIC PROVINCE T.A.P	B.R.	G.C.L.	TOTAL NITROGEN (tons/yr)
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 11 is a summary of the nitrogen contributions of the various sources in the study area in the early 1990s. It must be stressed that there is a high uncertainty involved in calculating these . It must also be stressed that what is being estimated for each of the sources 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 give no indication of the degree to which a specific source is enriching the nitrogen content of ground water. The utility of these estimates lies in the information they provide as to the relative nitrogen contributions of the sources. This allows regulatory agencies to concentrate their efforts on sources that produce significant quantities.

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 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 must be considered 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 and Lake Rousseau appears to be moving toward the King's Bay Springs. Although this water could be contributing low levels of nitrogen to the springs, the distance of the lakes from the springs probably insures that most nitrogen from the lakes is diluted to background levels before reaching the springs.

Table 11. Nitrogen Loading Sources and Nitrogen Loaded By Physiographic Province (tons/yr) in the Early 1990s.

LAND USE	REGIONAL NITROGEN LOADING PHYS. PROVINCE T.A.P.	B.R.	G.C.L.	TOTAL	SIGNIFICANCE OF NITROGEN SOURCES TO NITROGEN CONCENTRATIONS IN THE SPRINGS
Naturally Occurring	?	?	?	?	Probably insignificant - ground-water N in background areas is low - organic decay in Lake Tsala Apopka may contribute significant N to ground water locally but it is probably diluted to background levels before reaching the springs
Rainfall	254	544	348	1,146	Probably insignificant - ground-water N in background areas is low, most rainfall N probably removed by vegetative uptake or immobilized in soil layer
Septic Tanks	125	166	167	548	Significant - N loading is high and is occurring near the springs
Residential Turf Fertilizer	64	150	105	319	Significant - extensive residential areas are within seven miles of the springs
Golf Courses Fertilizer	25	169	49	243	Significant - six golf courses are located within seven miles of the springs
Sewage Effluent Disposal	33	34	43	110	Minor significance - N contamination of ground-water has been documented at sites in the study area
Land Disposal of Sewage Sludge	0	25	0	25	Insignificant - quantity of N from sewage sludge spread at sites in study area is low
Land Disposal of Septage Sludge	0	4.7	3.3	8	Insignificant - quantity of N spread at sites in study area is very low
Row Crops	low	27	low	27	Insignificant - row crops are a minor land use in the study area
Citrus	low	2	low	2	Insignificant - citrus industry in study area greatly reduced by freezes in mid 1980s, however, past citrus production may contribute to elevated N levels in the Lake Rousseau and Inverness areas
Fertilized Pasture	34	69	46	149	Minor significance - the calculated N loading is relatively low and most N is probably utilized by pasture grass and attenuated in the soil
Beef Cattle	36	86	58	180	Minor significance - cattle widely dispersed, most N in waste is probably used by pasture grass and attenuated in soil

The most significant contributors of nitrogen to ground water in the study area, from most important to least, are residential and golf course turf fertilizers, septic-tank effluent, and sewage effluent disposal. 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 distribution map 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, five to seven 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.

The fertilization of turf from 35,000 acres of residential development and eleven golf courses in the study area contributes approximately 562 tons/yr of nitrogen to the land surface in the study area. This nitrogen is loaded over a relatively small area and, therefore, could overload the vegetative and soil removal mechanisms and nitrogen could reach ground water in significant quantities. In addition, much of the residential development and many of the golf courses are located close enough to the springs to allow a significant amount of the fertilizer nitrogen to reach the springs before the nitrogen can be diluted to background levels. To determine the actual amount of nitrate reaching ground water from the fertilization of residential and golf course turf, studies should be initiated that intensely monitor the actual loading rates and schedules and quality of ground water beneath sewered subdivisions and in the vicinity of golf courses. The amount of nitrate reaching the springs from turf fertilizers can be reduced if an effort is under taken to adopt Xeriscaping$_{TM}$: the replacement of turf with native vegetation that requires little or no water or fertilizer.

The 17,000 septic-tanks in the study area contribute approximately 458 tons/yr of nitrogen to shallow soils near the land surface. Septic tanks in the City of Crystal River are probably contributing a significant amount of nitrogen to the springs. This is because densities of septic tanks are high, the high water table may reduce the effectiveness of treatment, and the tanks are close enough to the springs so that dilution of nitrogen in the effluent is minimal. Septic tanks in Beverly Hills may also contribute nitrogen to the springs because densities are high and the subdivision is relatively close to the springs. Areas where septic tanks exist under similar conditions to those in the Cities of Crystal River and Beverly Hills should be sewered. However, septic tanks are not a problem in areas where they are not concentrated, water tables are not near the land surface, and where they are not in the immediate vicinity of the springs.

Sewage treatment plants in the study area annually produce effluent that contains approximately 110 tons of nitrogen. The effluent is often disposed of in unlined percolation ponds or spray fields and the sandy, sinkhole-prone terrain insures that it will rapidly infiltrate into the Floridan aquifer. Because the amount of nitrogen is relatively low and the effluent is distributed between 42 facilities across the study area, the effect of the nitrogen on the King's Bay Springs is probably minimal. However, the fact that levels of nitrate above the drinking water standard have been documented in ground water beneath the Beverly Hills effluent spray field indicates that the potential for local nitrate contamination from the disposal of sewage effluent is very high. Because the rapid growth of the county insures that the amount of effluent will rapidly increase in the coming years, it is important that large, regional advanced wastewater treatment facilities be constructed in the study area that incorporate a denitrification step prior to land disposal of effluent.

Pasture fertilization probably has a minimal impact on nitrogen concentrations in ground water. This is because the amount of nitrogen from pasture fertilization is relatively low, pasture acreage is widely dispersed across the study area, and is not concentrated in the vicinity of the springs.

The estimate of nitrogen derived from beef cattle waste, although significant, may have little effect on ground-water quality because the cattle are widely dispersed in the study area 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 vegetative and soil uptake mechanisms discussed previously.

Nitrogen sources that are insignificant because they produce very small amounts of nitrogen are land disposal of sewage and septage sludge, dairies, row crops, and citrus.

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 cubic feet per second (630 mgd).

2. Approximately 335 tons of nitrogen (ammonium+nitrite+nitrate+organic nitrogen) is contained in ground water discharging from the King's Bay Springs every year. Approximately 205 tons of this is nitrate as N.

3. Approximately 38 tons of phosphorus are contained in the annual discharge of the King's Bay Springs. Relative to nitrogen, phosphorus concentrations in Floridan aquifer ground water are low because orthophosphate tends to precipitate as a calcium phosphate mineral (carbonate-hydroxylapatite) in the relatively alkaline water of the Floridan aquifer. In addition, the low total phosphorus concentrations indicate minimal orthophosphate and organic phosphorus which suggests that any sources of phosphorus, such as organic-rich surface water or animal wastes, are not presently affecting the springs.

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

5. Nitrate concentrations in samples collected between January 1991 and January 1998 from four of the most significant springs in the King's Bay Complex were statistically evaluated to determine whether nitrate levels in the springs were increasing. Of the four springs tested, one showed a statistically significant increasing trend.

6. 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 nitrate 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.

7. Historical nitrate data for study area spring water and ground water are extremely limited. Therefore, it is difficult to determine whether nitrate concentrations have increased significantly in recent years. However, three dedicated monitor wells sampled for this study in 1992 were 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 seven years. In addition, comparison of the median concentration of nitrate in Floridan aquifer ground water sampled from over 700 monitor wells statewide (0.01 mg/l) (Upchurch, 1992) to the current concentration of nitrate in ground water discharging from the springs (approximately 0.2 mg/l), indicates that the spring-water concentrations are 20 times higher than the natural ground-water concentrations in the Floridan aquifer statewide.

8. Ground water in the springs is largely derived from the drainage basin roughly 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.

9. 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.

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

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

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

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

14. A plume of what is probably naturally occurring nitrogen is moving toward the springs from Lake Rousseau. However, it has apparently not yet affected the springs.

15. There are small, localized sources of development-related nitrogen in the eastern portion of the City of Crystal River which are apparently residential and golf course turf fertilizers and septic tanks. This nitrogen along with naturally occurring nitrogen are probably the sources of the low levels of nitrogen in ground water discharging from the springs.

CONCLUSIONS (continued)

16. 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.

17. Ten development-related sources of nitrogen in the study area were investigated. Of these, residential and golf-course turf fertilization, septic-tank effluent, and effluent disposal from sewage treatment are apparently contributing the majority of nitrogen that is present in ground water. Because the nitrate concentrations in the King's Bay Springs are low relative to those in other major springs in the District, it is not possible to determine which of these sources is most significant. However, an investigation of increasing nitrate levels in Homosassa, Chassahowitzka, and Weeki Wachee Springs just to the south of King's Bay, has shown that turf fertilization is the primary source of nitrate for these springs (Jones *et al.*, 1997). The four 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.

18. Stormwater runoff in the karst terrain may be partially responsible for conveying fertilizer-derived nitrogen into the ground-water system.

RECOMMENDATIONS

1. There is little that can be done to reduce present nitrogen loading from the springs to the coastal estuaries because that nitrogen has been applied to the study area for many years and is now entrained in the ground-water flow system. Any attempt to reduce nitrate loading in the recharge area may not result in reduced nitrate levels in the springs for a decade or longer.

2. An investigation of the application of inorganic nitrogen fertilizers in the coastal subdivisions in the study area should be initiated in the near future. The study should focus on identifying the specific areas of application, the amount applied, and the amount of nitrogen reaching ground water following application. The study should also attempt to reduce the use of fertilizers by developing best management practices and by promoting Xeriscaping$_{TM}$ - the replacement of turf with native species of plants that require less fertilizer and water.

3. The importance of sources, such as residential and golf course turf/landscape fertilization, septic-tank effluent, and sewage effluent disposal will greatly increase as rapid residential and commercial development proceeds in the study area. It is therefore, extremely important that best management and alternative landscape practices be developed that reduce the use of fertilizer. Waste disposal practices that are compatible with the region's karst geology and its accompanying extreme vulnerability to ground-water contamination must also be implemented. These practices include:

   a. Avoidance of high-densities of septic systems.
   b. Planning for the development of centralized, advanced waste-water treatment (AWT) systems that denitrify effluent.
   c. More stringent design, construction, and monitoring of large-scale percolation or spray field systems. These systems should stay on line only until it is feasible to construct the centralized AWT systems.
   d. Proper storage and treatment of stormwater.

4. The springs should continue to be sampled quarterly for nutrients, major analytes, and trace organics and annually for nitrogen-isotopic ratios to determine the effects of changing land use and to determine the effectiveness of remedial efforts.

5. The District should work with Citrus County and other interested agencies to formulate land-use plans that will minimize additional nitrogen loadings to the study area.

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APPENDICES

APPENDIX I

Specifications of Monitor Wells

AP ID	WELL ID	LATITUDE	LONGITUDE	TD	CD	LSE
7009-F	ROMP TR 21-3 AVON PA	285235.329	823417.136	252	240	6.11
7010-F	LECANTO WELL # 7	285254	823230	30	20	8.00
7011-F	NORTH LECANTO DEEP	285413.299	822842.970	335	288	68.87
7012-F	CRYSTAL RIVER SH	285422.502	823613.714	53	3	8.11
7019-F	ROMP 113 OCALA	285124	822456	150	130	129.93
7021-F	ROMP TR 21-2 DP	285112	823544	111	105	3.42
7023-F	CRYSTAL SHORES	285220	823544	129	96	5.00
7024-F	OZELLO WL 4 NR CRYS	285102	823610	75	60	6.00
7025-F	BAPTIST CHURCH PAST	284939	823447	60		10.00
7031-F	HRS 15 COON	285554	823730	58	56	10.00
7033-F	VAVERCHEK	285544	823357	45	33	10.00
7035-F	THOMAS	290221	823205	45	30	45.00
7036-F	BREAUX	290225	823146	250		50.00
7037-F	KELLY	290135	823139	185		90.00
7038-F	STEFKE	290026	823127	300		140.00
7039-F	EATON	285955	823428			30.00
7040-F	AZZARATTI	285915	823435			25.00
7041-F	WITTY	285911	823545			30.00
7042-F	HUNDT	285944	823852			25.00
7043-F	ROBERTS	285824	823446			30.00
7044-F	WILKEY	285840	823313	90		30.00
7045-F	PARMENTER	285837	823320	62		30.00
7046-F	FORGET	285926	823226	86		90.00
7047-F	SWEEN	285907	823204	130		110.00
7048-F	THOMAS	285752	823146	126		120.00
7049-F	SMITH	285720	823230	125		70.00
7050-F	RUBIN	285719	823344			20.00
7051-F	JULIUS	285733	823615	65		17.00
7052-F	PILLAU	285714	823720	200		10.00
7053-F	HERBERT	285546	823628	81	60	10.00
7054-F	MUNN	285503	823547			10.00
7055-F	HAYES	285456	823528	12		10.00
7056-F	WHEELER	285517	823437			10.00
7057-F	WOOD	285422	823512	50	45	5.00
7058-F	HARTLE	285541	823213	134	88	50.00
7059-F	AUSTIN	285543	823103	170		90.00
7060-F	ELHEROT	285508	823122	200		110.00
7061-F	AUBIN	285335	823218			20.00
7062-F	EXLEY	285332	823310	60		10.00
7063-F	SHEFFIELD C	285350	823345	49		10.00
7064-F	JOYNER	285342	823408	116	91	5.00
7065-F	ELLIS	285332	823356	23		5.00
7066-F	CLEMENS	285311	823424	77	65	5.00
7067-F	NEEDLEMAN	285306	823518	80		5.00
7069-F	JULIAS	285220	823507	73	50	5.00
7070-F	VARONA	285256	823409	100		5.00
7071-F	ARNOW	285240	823302	60		10.00
7072-F	LADD	285236	823238	170		10.00
7073-F	REEDER	285217	823215	115	90	20.00
7074-F	RATHBUN	285207	823304			10.00
7075-F	CULPEPPER	285227	823317			10.00
7076-F	DYER	285127	823504			10.00

MAP ID	WELL ID	LATITUDE	LONGITUDE	TD	CD	LSE
017077-F	KIRKWOOD	285152	823527			5.00
017078-F	SAVINO	285215	823356	40		10.00
017079-F	MILLER T	285108	823413	40		10.00
017080-F	LYONS	285137	823244			10.00
017081-F	CAYLOR	284916	823244	65		10.00
017082-F	CANVAS EXPERTS	284826	823423			10.00
017083-F	SHELLERT	284852	823237	80	30	10.00
017084-F	HUNT	285902	822802	99	97	80.00
017085-F	KELLNER	285815	822453	112	92	70.00
017086-F	HOGAN	285726	822532	110		70.00
017087-F	SCHWINDT	285732	822115			50.00
017088-F	OPPERMAN	285717	822239	65		40.00
017089-F	CHASFIN	285629	822521	245	243	110.00
017090-F	ROBERTS T	285549	822857	123	120	90.00
017091-F	LOGHT	285602	822740	147	114	90.00
017092-F	KREMNETZ	285539	822234			60.00
017093-F	THOMAS	285358	822210	60	30	50.00
017094-F	BOEHL	285418	822106	41	40	45.00
017095-F	ANTONEN	285348	821738	50	40	50.00
017096-F	RECORD	285408	822522	380	220	70.00
017097-F	TOLLE	285332	822926	100	65	35.00
017098-F	MILLER	285331	822856	235	220	120.00
017099-F	LISOTTA	285255	822805	260	253	100.00
017100-F	RANKIN	285213	822922	115		65.00
017102-F	TOWNSEND	285057	822917	62		40.00
017103-F	MOORE	285120	822818	52		30.00
017104-F	KURTH	285136	822618	220	185	110.00
017105-F	ROBERTS	285207	822615	350	180	145.00
017106-F	OLDNETTLE	285308	822607	275		104.00
017107-F	DISPONZIO	285244	822542	270		120.00
017108-F	CALLUNDER	285321	822423	152		80.00
017109-F	RHAME	285239	822259			85.00
017110-F	CASE	285149	822048	40		50.00
017111-F	GOODWIN K	285107	822122	120	84	70.00
017112-F	FRENZEL	285052	821850			50.00
017113-F	BLACK	285050	821600	100		40.00
017114-F	MOORE	284857	821602	123		40.00
017115-F	TWITTY	284850	821750	28		40.00
017116-F	CUTRONE	284914	821842	64		50.00
017117-F	MILLER M	284918	821947	145		60.00
017118-F	MOTT	284833	822008	60		70.00
017119-F	MC GEE	284737	821948	90	65	75.00
017120-F	LAYTON	284640	822033	137		90.00
017121-F	HOLDER MINE	284811	822252			40.00
017122-F	BURNS	284937	822307	126	126	45.00
017123-F	HOUSTON	285027	822307	180	70	30.00
017125-F	KREGOSKI	285625	823707	86		10.00
017126-F	ENZ	285128	822736	240	233	120.00
017127-F	ROMERO	285350	823452			5.00
017128-F	LEWIS	285410	823521			5.00
017129-F	PORT PARADISE	285259	823532			5.00

APPENDIX II

Water-Quality Data for Sampled Monitor Wells

LAYTON	10/28/91	7.40	23.00	195.00	-0.01	0.55	0.55	0.04	0.03	-1.00	134.00	47.00	2.30	4.10	-0.10	6.90	3.00	0.06	-20.00
MC GEE	10/30/91	7.49	23.50	250.00	-0.01	1.20	1.20	0.05	0.04	-1.00	158.00	56.00	2.10	5.90	0.20	11.00	-2.00	0.06	-20.00
HOLDER MINE	10/30/91	8.06	23.00	120.00	-0.01	0.21	0.21	0.04	0.02	-1.00	68.00	23.00	1.10	3.30	0.20	4.20	-2.00	0.03	-20.00
CANVAS EXPERTS	11/12/91	7.36	23.00	300.00	-0.01		0.22	0.04		1.50									
MOTT	10/31/91	7.34	23.00	240.00	0.03	-0.01	-0.01	0.07	0.04	-1.00	158.00	53.00	3.00	5.00	0.30	8.30	6.00	0.07	-20.00
TWITTY	10/17/91	8.60	26.00	300.00	0.20		0.02	0.15		13.00									
SHELLERT	11/12/91	7.55	23.50	250.00	-0.01	0.28	0.28	0.03	-0.01	-1.00	171.00	54.00	3.30	6.90	0.20	17.00	4.00	0.03	-20.00
MOORE	10/17/91	8.07	24.50	400.00	-0.01	-0.01	-0.01	0.04	0.02	2.30	219.00	72.00	10.00	4.30	0.40	6.40	28.00	0.19	-20.00
CUTRONE	10/17/91	7.37	24.00	400.00	0.25	-0.01	-0.01	0.07	0.04	4.70	195.00	68.00	2.50	9.80	0.30	19.00	3.00	0.04	180.00
CAYLOR	11/12/91	7.92	23.00	190.00	-0.01	0.41	0.41	0.04	0.02	-1.00	122.00	40.00	3.50	4.00	0.20	6.30	7.00	0.05	-20.00
MILLER M	10/17/91	7.48	23.50	300.00	0.03	-0.01	-0.01	0.08	0.07	1.70	171.00	56.00	3.10	4.80	0.20	13.00	4.00	0.08	160.00
BURNS	10/28/91	6.63	24.00	90.00	0.02	0.35	0.35	0.43	0.36	-1.00	41.00	15.00	1.20	3.00	-0.10	5.70	-2.00	0.16	-20.00
BAPTIST CHURCH PAS	10/24/91	7.34	23.00	405.00	0.13			0.03	0.02	2.10	268.00	82.00	6.80	22.00	1.80	37.00	5.00	0.07	600.00
HOUSTON	10/28/91	7.40	23.00	225.00	0.10	-0.01	-0.01	0.10	0.06	1.40	158.00	50.00	2.20	3.40	0.20	5.70	-2.00	0.07	750.00
BLACK	10/31/91	6.90	23.50	2000.00	0.56	-0.01	-0.01	0.06	0.03	6.70	317.00	96.00	6.80	4.70	0.40	7.70	-2.00	0.09	-20.00
FRENZEL	10/17/91	6.81	23.50	500.00	0.76	0.03	0.03	0.22	0.19	6.10	280.00	95.00	2.60	18.00	0.60	32.00	-2.00	0.07	3600.00
TOWNSEND	10/22/91	7.69	24.00	170.00	-0.01	0.09	0.09	0.03	0.02	-1.00	107.00	34.00	3.20	3.20	0.20	5.20	4.00	0.06	-20.00
OZELLO WL 4 NR CRY	10/17/91		22.00	1300.00	0.46	0.07	0.07	0.32	0.21	13.00	317.00	97.00	25.00	170.00	6.10	330.00	16.00	0.09	9800.00
GOODWIN K	10/30/91	7.67	23.00	180.00	-0.01	0.08	0.06	0.07	0.06	-1.00	122.00	40.00	1.50	3.70	0.20	4.80	-2.00	0.07	-20.00
MILLER T	10/08/91	7.78	24.00	300.00	-0.01	0.36	0.37	-0.01	-0.01	1.30	158.00	36.00	4.40	20.00	0.50	26.00	7.00	0.06	-20.00
ROMP TR 21-2 DP	10/17/91	7.78	23.00	920.00	0.03		-0.01	0.03		-1.00									
MOORE	10/21/91	7.76	23.50	145.00	-0.01		0.20	0.05		-1.00									
ROMP 113 OCALA	10/08/91	8.01	24.00	140.00	-0.01	0.36	0.36	0.06	0.04	-1.00	90.00	29.00	1.50	2.50	1.30	4.00	-2.00	0.05	-20.00
DYER	10/08/91	7.29	24.00	400.00	-0.01	0.21	0.21	0.04	0.03	-1.00	146.00	-0.10	-0.10	96.00	-0.10	52.00	10.00	0.09	-20.00
ENZ	10/29/91	7.73	24.00	165.00	-0.01	0.06	0.06	0.04	0.02	-1.00	110.00	32.00	3.70	2.70	0.20	3.80	3.00	0.04	-20.00
KURTH	10/24/91	7.89	23.50	130.00	-0.01	0.03	0.03	0.06	0.05	-1.00	82.00	27.00	1.70	2.50	0.20	3.80	3.00	0.05	-20.00
LYONS	10/24/91	7.75	24.00	270.00	0.02	0.33	0.33	0.06	0.04	-1.00	195.00	63.00	3.40	3.20	0.20	5.60	6.00	0.04	-20.00
CASE	10/31/91	7.35	24.00	210.00	-0.01	0.31	0.31	0.07	0.07	-1.00	134.00	44.00	1.10	3.60	-0.10	5.30	5.00	0.05	580.00
KIRKWOOD	10/08/91	7.24	23.00	600.00	0.12	0.04	0.04	0.02	0.02	2.30	207.00	68.00	17.00	72.00	1.40	120.00	7.00	0.08	1100.00
ROBERTS	10/31/91	8.03	23.00	145.00	-0.01	0.08	0.08	0.04	0.03	-1.00	95.00	-0.10	-0.10	45.00	-0.10	3.80	4.00	0.06	-20.00
RATHBUN	10/16/91	8.30	24.00	155.00	-0.01	0.29	0.29	0.04	0.02	-1.00	83.00	25.00	3.90	3.20	0.20	4.90	-2.00	0.05	-20.00
RANKIN	10/16/91	7.95	23.50	185.00	-0.01	0.16	0.16	0.04	0.03	-1.00	105.00	34.00	3.20	3.20	-0.10	4.70	-2.00	0.05	-20.00
SAVINO	10/22/91	7.15	24.00	240.00	-0.01	0.10	0.10	0.03	-0.01	-1.00	146.00	50.00	3.30	3.70	0.20	6.20	4.00	0.07	60.00
REEDER	10/16/91	8.08	24.00	170.00	-0.01	0.30	0.30	0.04	0.03	-1.00	93.00	30.00	2.10	3.10	-0.10	4.70	-2.00	0.05	-20.00
JULIAS	10/08/91	7.25	23.00	500.00	0.12	0.06	0.06	0.04	-0.01	3.20	256.00	77.00	4.30	8.20	0.40	13.00	-2.00	0.07	2800.00

CULPEPPER	10/21/91	7.86	24.00	215.00	-0.01	0.30	0.30	0.04	0.02	-1.00	134.00	44.00	4.00	5.30	0.20	10.00	3.00	0.05	-20.00
ROMP TR 21-3 AVON PA	11/08/91	8.85	25.00	480.00	0.03	-0.01	-0.01	0.04	-0.01	-1.00	119.00	23.00	14.00	56.00	6.90	77.00	11.00	0.25	-20.00
LADD	10/22/91	7.99	24.00	170.00	-0.01	0.66	0.66	0.06	0.02	-1.00	107.00	29.00	6.40	3.10	0.20	4.90	4.00	0.08	-20.00
RHAME	10/30/91	7.90	23.50	280.00	-0.01	0.38	0.38	0.05	0.02	-1.00	78.00	39.00	2.10	29.00	0.20	63.00	-2.00	0.07	-20.00
ARNOW	10/21/91	7.49	24.00	225.00	-0.01	0.04	0.04	0.04	-0.01	-1.00	146.00	48.00	2.30	3.80	-0.10	6.10	-2.00	0.05	240.00
DISPONZIO	10/28/91	8.26	24.00	125.00	-0.01	0.09	0.09	0.03	-0.01	-1.00	80.00	25.00	2.10	2.70	0.20	3.50	-2.00	0.05	-20.00
LECANTO WELL # 7	10/08/91	6.86	24.00	370.00	0.08	0.04	0.04	0.14	0.05	2.10	232.00	76.00	1.70	2.00	0.40	3.30	-2.00	0.08	1500.00
LISOTTA	10/30/91	8.06	24.00	150.00	-0.01	0.38	0.38	0.04	0.03	-1.00	93.00	29.00	3.60	3.10	0.20	4.30	4.00	0.05	-20.00
VARONA	10/15/91	7.63	23.00	220.00	-0.01	0.02	0.02	0.04	0.02	1.30	134.00	41.00	3.70	3.60	-0.10	5.20	3.00	0.06	100.00
PORT PARADISE	11/12/91	7.71	23.50	190.00	-0.01	0.14	0.14	0.05	0.04	-1.00	119.00	37.00	4.00	6.30	0.30	9.70	5.00	0.07	-20.00
NEEDLEMAN	10/08/91	7.68	23.50	300.00	-0.01	-0.01	-0.01	0.02	0.02	-1.00	122.00	39.00	4.60	8.70	0.40	15.00	6.00	0.12	140.00
OLDNETTLE	10/30/91	8.04	24.00	145.00	-0.01	0.68	0.68	0.05	0.03	-1.00	88.00	-0.10	-0.10	43.00	-0.10	3.90	3.00	0.05	-20.00
CLEMENS	10/08/91	7.93	24.00	200.00	-0.01	0.33	0.33	0.26	0.03	-1.00	107.00	32.00	3.80	3.50	0.20	5.20	3.00	0.06	-20.00
CALLUNDER	10/30/91	7.75	23.50	155.00	-0.01	0.29	0.29	0.06	0.04	-1.00	98.00	32.00	2.20	2.80	0.20	4.10	-2.00	0.05	-20.00
MILLER	10/16/91	7.95	23.50	200.00	-0.01		0.41	0.04		-1.00		-99.90							
TOLLE	10/15/91	7.69	24.00	180.00	0.02	0.46	0.46	0.03	0.03	-1.00	93.00	33.00	2.40	3.20	-0.10	4.40	3.00	0.05	-20.00
EXLEY	10/15/91	7.45	24.00	200.00	-0.01	0.40	0.40	0.04	0.03	-1.00	110.00	34.00	3.70	3.70	0.30	4.90	3.00	0.05	-20.00
ELLIS	10/15/91	7.48	24.00	295.00	0.05		-0.01	0.07		2.60		-99.90							
AUBIN	10/15/91	7.57	24.50	210.00	-0.01	0.90	0.90	0.07	0.06	-1.00	117.00	39.00	2.70	3.70	0.20	4.90	3.00	0.04	-20.00
JOYNER	10/31/91	7.72	24.00	165.00	0.02	0.22	0.22	0.03	0.02	-1.00	93.00	30.00	4.40	3.30	0.20	5.20	8.00	0.06	-20.00
ANTONEN	10/29/91	7.22	23.00	240.00	0.20	-0.01	-0.01	0.10	-0.01	5.20	171.00	59.00	1.70	4.80	0.30	7.60	-2.00	0.05	1700.00
SHEFFIELD C	10/15/91	6.09	23.50	170.00	-0.01	0.33	0.33	0.05	0.03	-1.00	80.00	27.00	4.50	2.60	0.20	4.20	14.00	0.05	-20.00
ROMERO	10/15/91	7.20	25.00	600.00	3.00	0.03	0.03	0.12	0.06	10.00	390.00	110.00	7.30	7.90	2.30	2.10	-2.00	0.02	3600.00
THOMAS	10/29/91	7.06	22.50	365.00	2.20	0.02	0.02	0.21	0.17	6.40	280.00	86.00	2.70	6.30	0.40	11.00	-2.00	0.08	2400.00
RECORD	10/28/91	7.72	24.00	190.00	-0.01	-0.01	-0.01	0.08	0.06	-1.00	134.00	-0.10	-0.10	58.00	-0.10	4.20	-2.00	0.05	-20.00
LEWIS	10/14/91	7.42	23.00	245.00	0.02	0.15	0.15	0.07	0.03	2.30	134.00	42.00	6.50	3.50	0.40	5.10	10.00	0.07	40.00
NORTH LECANTO DP	10/15/91	7.74	24.00	190.00	-0.01	0.27	0.27	0.06	0.03	-1.00	117.00	34.00	5.00	3.90	0.30	4.90	4.00	0.06	30.00
BOEHL	10/31/91	7.00	21.00	370.00	0.91	0.03	0.03	0.08	0.08	10.00	293.00	94.00	3.70	7.20	0.40	12.00	-2.00	0.09	2000.00
CRYSTAL RIVER SH	10/08/91	6.79	23.00	500.00	0.04	0.06	0.06	0.05	0.03	1.70	268.00	83.00	8.10	24.00	0.80	34.00	12.00	0.06	-20.00
WOOD	10/14/91	7.86	23.00	210.00	-0.01	0.17	0.17	0.05	0.03	-1.00	105.00	33.00	6.20	3.10	-0.10	4.80	11.00	0.06	-20.00
HAYES	10/14/91	7.01	23.00	430.00	-0.01	0.14	0.14	0.11	0.02	3.40	268.00	85.00	4.10	8.80	0.50	13.00	12.00	0.05	150.00
MUNN	10/14/91	7.51	23.00	365.00	0.04	-0.01	-0.01	0.03	-0.01	-1.00	207.00	64.00	9.50	5.70	0.50	9.70	3.00	0.09	550.00
ELHEROT	10/15/91	8.03	24.50	175.00	-0.01	0.29	0.29	0.03	0.02	-1.00	95.00	30.00	4.40	2.70	-0.10	3.70	6.00	0.06	-20.00
WHEELER	10/07/91	7.53	23.00	300.00	-0.01	0.58	0.58	0.06	0.06	-1.00	122.00	34.00	7.10	4.40	-0.10	7.00	-2.00	0.09	-20.00
KREMNETZ	10/21/91	7.84	24.00	220.00	-0.01	2.30	2.30	0.05	0.03	-1.00	112.00	39.00	2.30	5.90	-0.10	9.40	3.00	0.03	-20.00

HARTLE	10/22/91	8.17	24.00	140.00	0.04	0.25	0.25	0.04	-0.01	-1.00	71.00	24.00	4.10	2.40	-0.10	3.70	15.00	0.06	-20.00
AUSTIN	10/15/91	8.32	23.50	100.00	-0.01	0.87	0.87	0.02	0.02	-1.00	46.00	17.00	1.80	2.90	-0.10	4.10	-2.00	0.03	-20.00
VAVERCHEK	10/14/91	7.50	23.00	250.00	-0.01	-0.01	-0.01	0.07	0.02	-1.00	146.00	43.00	6.90	2.90	-0.10	5.40	4.00	0.07	480.00
HERBERT	10/14/91	7.51	22.50	330.00	0.03	-0.01	-0.01	0.02	0.02	-1.00	195.00	60.00	8.00	3.40	0.20	5.40	7.00	0.09	280.00
ROBERTS T	10/21/91	7.95	24.00	120.00	-0.01	0.32	0.32	0.04	0.02	-1.00	76.00	24.00	1.80	2.30	-0.10	3.20	-2.00	0.04	-20.00
HRS 15 COON	10/10/91	7.23	22.50	390.00	0.27	0.02	0.02	0.08	0.05	3.10	244.00	70.00	7.30	8.50	0.80	12.00	6.00	0.10	3100.00
LOGHT	10/10/91	7.99	25.00	170.00	-0.01	0.14	0.14	0.06	0.04	-1.00	80.00	28.00	1.90	2.20	-0.10	3.40	-2.00	0.04	-20.00
KREGOSKI	10/10/91	7.30	23.00	390.00	0.17	-0.01	-0.01	0.06	0.05	2.00	244.00	80.00	2.10	4.00	0.20	6.20	-2.00	0.05	3600.00
CHASFIN	10/21/91	7.24	24.00	310.00	0.30	-0.01	-0.01	0.11	0.07	2.00	195.00	60.00	2.40	3.50	0.20	6.10	-2.00	0.07	9900.00
PILLAU	10/10/91	7.42	23.50	460.00	0.06	-0.01	-0.01	-0.01	-0.01	1.20	244.00	78.00	15.00	4.00	0.90	5.70	42.00	0.27	90.00
OPPERMAN	10/29/91	7.05	24.50	265.00	0.16	0.03	0.03	0.08	0.04	5.80	195.00	56.00	4.10	6.30	0.30	9.30	-2.00	0.06	-20.00
RUBIN	10/09/91	7.11	22.50	180.00	-0.01	0.30	0.30	0.28	0.23	-1.00	93.00	24.00	6.10	3.80	-0.10	7.10	4.00	0.23	-20.00
SMITH	10/09/91	8.17	24.00	175.00	-0.01	0.17	0.17	0.04	0.03	-1.00	80.00	25.00	5.20	2.50	-0.10	3.70	15.00	0.08	-20.00
HOGAN	10/10/91	8.20	24.50	160.00	-0.01		0.05	0.12											
SCHWINDT	10/30/91	7.82	23.00	290.00	-0.01	0.52	0.52	0.04	0.03	-1.00	122.00	31.00	12.00	26.00	0.60	45.00	11.00	0.07	-20.00
JULIUS	10/10/91	7.29	23.50	390.00	0.09	0.02	0.02	0.05	0.05	2.30	232.00	71.00	3.50	16.00	-0.10	12.00	3.00	0.06	2600.00
THOMAS	10/09/91	8.49	24.00	140.00	-0.01	0.28	0.28	0.03	0.03	-1.00	54.00	20.00	3.30	2.20	-0.10	3.20	12.00	0.06	-20.00
KELLNER	10/10/91	7.32	24.00	260.00	-0.01	0.15	0.15	0.06	0.06	-1.00	158.00	48.00	4.00	3.60	-0.10	5.90	-2.00	0.08	-20.00
ROBERTS	10/10/91	7.91	23.50	175.00	0.05	-0.01	-0.01	0.07	0.07	1.10	88.00	26.00	5.80	2.70	0.40	3.80	7.00	0.13	350.00
PARMENTER	10/09/91	7.84	23.00	240.00	-0.01	0.28	0.26	0.05	0.05	-1.00	134.00	38.00	7.60	3.30	-0.10	4.80	9.00	0.11	-20.00
WILKEY	10/07/91	8.12	23.00	250.00	-0.01	1.10	1.10	0.03	0.03	-1.00	112.00	33.00	8.20	3.90	0.20	4.60	7.00	0.10	-20.00
HUNT	10/21/91	7.76	24.00	190.00	-0.01	0.32	0.32	0.06	0.03	-1.00	107.00	31.00	3.80	2.60	-0.10	4.30	3.00	0.06	-20.00
SWEEN	10/09/91	8.17	23.00	240.00	-0.01	0.07	0.07	0.06	0.04	1.60	119.00	35.00	8.50	3.00	-0.10	4.60	20.00	0.11	-20.00
WITTY	10/09/91	7.52	23.50	295.00	0.02	-0.01	-0.01	0.06	0.06	1.50	183.00	45.00	9.90	3.20	0.20	5.10	4.00	0.15	550.00
AZZARATTI	10/11/91	8.00	23.50	185.00	-0.01		0.02	0.15		1.50									
FORGET	10/10/91	7.83	23.50	160.00	-0.01		0.64	0.06		-1.00									
HUNDT	10/09/91	7.01	23.00	395.00	0.11	0.02	0.02	0.02	0.05	4.30	244.00	80.00	3.10	5.10	-0.10	7.60	3.00	0.06	5400.00
EATON	10/07/91	7.48	23.00	400.00	-0.01	0.08	0.08	0.12	0.11	1.50	207.00	45.00	18.00	2.70	0.20	4.60	7.00	0.12	-20.00
STEFKE	10/07/91	8.48	24.00	150.00	-0.01	0.08	0.06	0.03	0.02	-1.00	63.00	14.00	6.50	1.70	-0.10	3.20	4.00	0.07	-20.00
KELLY	10/21/91	8.32	24.00	130.00	-0.01	0.54	0.54	0.05	0.02	-1.00	73.00	23.00	3.80	2.60	-0.10	4.20	4.00	0.05	-20.00
THOMAS	10/07/91	8.23	24.00	200.00	-0.01	0.04	0.04	0.07	0.08	-1.00	73.00	27.00	2.60	2.30	0.20	3.50	11.00	0.06	40.00
BREAUX	10/21/91	8.18	24.00	130.00	-0.01		0.18	0.05		-1.00									

APPENDIX III

Water-Quality Data for Sampled Springs

STATION	SAMP_DATE	FIELD_PH std pH units	FIELD_TEMP degrees C	FIELD_COND umhos	DIS_NH3(N) mg/l	DIS_NO3(N) mg/l	NO2+NO3 (N) mg/l	TOT_PO4 mg/l	DIS_OPO4 mg/l	TOC mg/l	HCO3_HCO3 mg/l	DIS_CA mg/l	DIS_MG mg/l	DIS_NA mg/l	DIS_K mg/l	DIS_CL mg/l	DIS_SO4 mg/l	DIS_F mg/l	DIS_FE ug/l
BLACK	02/11/91	8.20	23.00	4200.00	-0.01	0.28	0.22	0.04	0.02	11.00	140.00	68.00	76.00	770.00	23.00	1300.00	190.00	0.11	-30.00
BLACK	04/30/91	7.52	23.00	5500.00	-0.01	0.28	0.15	0.03	0.03	1.20	158.00	82.00	110.00	940.00	28.00	1500.00	260.00	0.11	30.00
BLACK	07/29/91	7.73	23.50	3700.00	-0.01	0.28	0.28	0.04	0.02	-0.50	110.00	62.00	74.00	580.00	20.00	980.00	170.00	0.12	
BLACK	10/23/91	7.49	24.00	2750.00	0.01	0.25	0.25	0.04	0.02	-0.50	134.00	57.00	53.00	450.00	15.00	750.00	97.00	0.11	-30.00
BLACK	04/12/93	7.43	25.00	4180.00	0.02	0.27	0.27	0.02	0.02										
BLACK	07/20/94	7.57	23.90	4730.00	0.04	0.87	0.88	-0.01	0.08	-0.50		76.00	91.00	755.00	26.00	1350.00	195.00	0.14	-30.00
BLACK	01/23/95	7.65	23.20	3740.00	-0.01	0.21	0.21	0.05	0.04	-0.50		67.00	73.00	588.00	20.00	1035.00	151.00	0.10	-30.00
BLACK	02/06/96	7.72	22.50	3460.00	0.02	0.29	0.29	0.50	0.01	-0.50		71.00	71.00	546.00	21.00	969.00	146.00	0.10	48.00
BLACK	01/29/97	7.55	23.50	4430.00	-0.01	0.21	0.21	0.03	0.01	-0.50		73.00	87.00	543.00	25.00	1098.00	216.00	0.14	-30.00
BLACK	04/09/97	7.27	23.80	4940.00	-0.01	0.22	0.22	0.04	0.03	-0.50		72.00	96.00	770.00	28.00	1531.00	219.00	0.19	38.00
BLACK	08/21/97	7.42	23.90	8340.00	0.03	0.24	0.24		0.01	0.89		121.00	168.00	1360.00	49.00	2503.00	355.00	0.14	46.00
TARPON HOLE #2	02/11/91	7.81	23.00	1100.00	0.01	0.14	0.14	0.05	0.03	17.00	130.00	45.00	21.00	160.00	5.30	280.00	40.00	0.08	-30.00
TARPON HOLE #2	04/30/91	7.69	23.50	1250.00	-0.01	0.15	0.15	0.03	0.03	-0.50	134.00	45.00	22.00	170.00	5.90	280.00	49.00	0.08	-30.00
TARPON HOLE #2	07/29/91	7.81	24.00	650.00	-0.01	0.17	0.17	0.04	0.03	-0.50	110.00	43.00	18.00	100.00	3.70	180.00	32.00	0.09	
TARPON HOLE #2	10/23/91	7.54	24.00	1300.00	0.01	0.15	0.15	0.05	0.03	-0.50	134.00	50.00	24.00	190.00	6.30	320.00	39.00	0.09	-30.00
TARPON HOLE	02/11/91	7.75	23.00	1450.00	-0.01	0.15	0.15	0.05	0.03	11.00	140.00	47.00	27.00	210.00	7.30	370.00	51.00	0.11	-30.00
TARPON HOLE	04/30/91	7.66	23.50	1500.00	-0.01	0.15	0.15	0.04	0.03	-0.50	134.00	48.00	28.00	230.00	7.50	350.00	61.00	0.08	-30.00
TARPON HOLE	07/29/91	7.76	24.00	1200.00	-0.01	0.18	0.18	0.04	0.03	-0.50	110.00	46.00	26.00	170.00	5.80	300.00	51.00	0.09	
TARPON HOLE	10/23/91	7.49	24.00	1200.00	-0.01	0.15	0.15	0.06	0.03	-0.50	134.00	48.00	23.00	180.00	6.00	310.00	40.00	0.08	-30.00
TARPON HOLE	08/03/92	7.84	23.50	2000.00						1.67	142.70	56.00	45.00	390.00	14.00	680.00	100.00		
TARPON HOLE	04/12/93	7.66	25.40	1820.00		0.18	0.19		0.02										
TARPON HOLE	07/20/94	7.75	23.90	1416.00	0.06	0.16	0.17	0.02	0.02	0.57		50.00	27.00	188.00	6.50	355.00	51.00	0.11	-30.00
TARPON HOLE	01/23/95	7.74	23.10	1193.00	0.01	0.15	0.15	0.05	0.05	-0.50		47.00	22.00	157.00	5.10	284.00	42.00	0.08	40.00
TARPON HOLE	04/03/95	7.36	23.60	1552.00	0.01	0.15	0.15	0.04	0.03	-0.50		49.00	28.00	205.00	7.00	362.00	56.00	0.09	43.00
TARPON HOLE	07/27/95	7.56	24.00	1577.00	-0.01	0.14	0.14	0.07	0.04	-0.50		48.00	25.00	215.00	7.30	377.00	61.00	0.08	48.00
TARPON HOLE	10/25/95	7.63	24.10	1675.00	-0.01	0.17	0.17	0.03	0.02	0.52		53.00	32.00	228.00	9.10	430.00	64.00	0.10	36.00
TARPON HOLE	02/06/96	7.67	23.40	1450.00	0.03		0.19	0.03	0.03	-0.50		50.00	27.00	206.00	7.50	304.00	54.00	0.09	57.00
TARPON HOLE	04/18/96	7.75	23.50	1287.00	-0.01	0.16	0.16	0.03	0.03	-0.50		48.00	24.00	169.00	6.10	300.00	46.00	0.09	34.00
TARPON HOLE	07/17/96	7.71	24.00	1348.00	-0.01	0.17	0.17	0.02	0.01	-0.50		46.00	25.00	180.00	6.40	319.00	49.00	0.13	-30.00
TARPON HOLE	10/17/96	7.86	23.80	2110.00	-0.01	0.15	0.15	0.06	0.04	-0.50		52.00	39.00	297.00	11.00	544.00	75.00	0.09	-30.00
TARPON HOLE	01/29/97	7.67	23.80	1761.00	-0.01	0.14	0.14	0.04	0.03	0.65		48.00	32.00	243.00	8.50	458.00	71.00	0.12	31.00
TARPON HOLE	04/09/97	7.63	23.70	1957.00	-0.01	0.15	0.15	0.04	0.03	-0.50		48.00	36.00	271.00	9.90	500.00	78.00	0.20	33.00
TARPON HOLE	07/08/97	7.53	23.50	3010.00	0.01	0.17	0.17		0.02	-0.50		8.95	6.61	436.00	2.01	706.00	115.00	0.11	-30.00
TARPON HOLE	10/07/97	7.57	23.70	2970.00	0.02	0.17	0.17		0.02	0.84		65.60	56.80	454.00	16.10	764.00	112.00	0.11	86.50
IDIOTS DELIGHT	04/29/91	7.85	24.00	295.00	-0.01	0.13	0.13	0.03	0.03	1.20	112.00	32.00	5.20	21.00	0.75	36.00	8.00	0.06	-30.00
IDIOTS DELIGHT	07/30/91	8.00	23.50	270.00	-0.01	0.17	0.17	0.04	0.03	-0.50	88.00	25.00	5.50	14.00	0.50	22.00	6.00	0.07	
IDIOTS DELIGHT	10/24/91	7.74	24.00	250.00	0.01	0.18	0.18	0.04	0.03	-0.50	110.00	34.00	4.70	12.00	0.50	20.00	4.00	0.07	-30.00
IDIOTS DELIGHT	02/10/92	8.00	23.50	270.00	-0.01	0.14	0.14	0.05	0.03	-0.50	110.00	32.00	4.80	14.00	0.70	26.00	5.00	0.06	-30.00
IDIOTS DELIGHT	08/03/92	7.91	24.00	270.00						1.11	113.40	32.00	5.10	21.00	0.70	39.00	7.00		
IDIOTS DELIGHT	04/12/93	7.53	27.30	563.00		0.21	0.21	0.03	0.03										
IDIOTS DELIGHT	07/20/94	8.40	25.00	301.00	0.02	0.16	0.16	-0.01	0.02	0.60		36.00	5.60	19.00	0.60	29.00	7.80	0.10	-30.00
IDIOTS DELIGHT	01/23/95	7.94	23.20	256.00	-0.01	0.16	0.16	0.05	0.05	-0.50		35.00	4.80	11.00	0.40	19.00	5.00	0.06	-30.00
IDIOTS DELIGHT	04/03/95	7.63	23.90	279.00	0.01	0.18	0.18	0.03	0.02	-0.50		36.00	5.20	15.00	0.40	26.00	6.40	0.07	30.00
IDIOTS DELIGHT	07/27/95	7.81	24.40	293.00	-0.01	0.16	0.16	0.03	0.03	-0.50		33.00	4.90	17.00	0.50	30.00	6.30	0.06	51.00
IDIOTS DELIGHT	10/25/95	7.87	24.50	266.00	0.04	0.23	0.23	0.03	0.02	-0.50		35.00	4.90	13.00	0.50	24.00	5.50	0.08	-30.00
IDIOTS DELIGHT	02/06/96	8.19	22.40	283.00	0.03		0.24	0.01	0.02	-0.50		33.00	4.70	15.00	0.50	27.00	6.50	0.07	-30.00
IDIOTS DELIGHT	01/29/97	7.90	24.30	271.00	-0.01	0.19	0.19	0.03	0.01	-0.50		31.00	4.70	13.00	0.30	26.00	5.70	0.08	-30.00
IDIOTS DELIGHT	04/09/97	7.87	24.30	312.00	-0.01	0.15	0.15	0.03	0.04	-0.50		31.00	5.20	18.00	0.50	35.00	7.30	0.10	-30.00
THREE SISTERS RUN	04/29/91	8.06	24.00	330.00	0.01	0.11	0.11	0.03	0.03	-0.50	112.00	32.00	5.90	29.00	1.00	47.00	9.00	0.06	-30.00
THREE SISTERS RUN	07/30/91	7.92	24.00	300.00	0.01	0.17	0.17	0.04	0.03	-0.50	90.00	25.00	6.20	22.00	0.64	29.00	6.00	0.07	
THREE SISTERS RUN	10/24/91	8.00	24.00	280.00	0.01	0.20	0.20	0.04	0.02	-0.50	102.00	34.00	5.20	16.00	0.60	24.00	6.00	0.07	-30.00
THREE SISTERS RUN	02/10/92	8.10	24.00	330.00	0.01	0.16	0.16	0.04	0.03	-0.50	110.00	32.00	5.80	22.00	1.00	44.00	7.00	0.06	-30.00
THREE SISTERS #2	04/29/91	7.84	24.00	380.00	0.01	0.17	0.17	0.03	0.03	-0.50	112.00	28.00	6.40	35.00	1.20	59.00	11.00	0.06	-30.00
THREE SISTERS #2	07/30/91	8.01	24.00	330.00	0.01	0.19	0.19	0.03	0.03	-0.50	90.00	23.00	6.70	23.00	0.78	37.00	8.00	0.07	
THREE SISTERS #2	10/24/91	7.78	24.00	300.00	0.01	0.23	0.23	0.05	0.03	-0.50	107.00	35.00	5.80	20.00	0.70	34.00	6.00	0.07	-30.00
THREE SISTERS #2	02/10/92	7.41	24.00	360.00	0.03	0.21	0.21	0.04	0.03	-0.50	110.00	33.00	7.90	40.00	1.60	83.00	11.00	0.05	-30.00
MANATEE SANCTUARY	04/29/91	7.89	24.00	400.00	-0.01	0.26	0.26	0.03	0.02	-0.50	110.00	31.00	7.70	42.00	1.50	70.00	13.00	0.05	-30.00
MANATEE SANCTUARY	07/30/91	7.99	24.00	353.00	-0.01	0.28	0.28	0.04	0.03	-0.50	88.00	32.00	7.50	28.00	0.99	45.00	10.00	0.07	

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
HUNTERS	01/23/95	8.05	23.10	316.00	-0.01	0.27	0.28	0.04	0.04	-0.50		32.00	7.00	22.00	0.80	39.00	13.00	0.06	-30.00
HUNTERS	04/03/95	8.01	23.70	361.00	0.01	0.30	0.30	0.03	0.02	-0.50		33.00	7.70	28.00	0.80	50.00	14.00	0.07	30.00
HUNTERS	07/27/95	8.02	24.50	344.00	-0.01	0.31	0.31	0.05	0.03	-0.50		30.00	6.60	26.00	0.60	46.00	13.00	0.06	-30.00
HUNTERS	10/25/95	8.06	25.00	298.00	0.02	0.35	0.35	0.02	0.01	-0.50		31.00	6.60	20.00	0.80	36.00	12.00	0.07	-30.00
HUNTERS	02/06/98	8.02	22.30	304.00	0.05		0.33	0.01	0.02	-0.50		30.00	8.10	20.00	0.70	35.00	12.00	0.06	37.00
HUNTERS	01/29/97	8.06	23.80	331.00	-0.01	0.31	0.31	0.03	0.01	-0.50		28.00	6.80	25.00	0.70	41.00	13.00	0.08	-30.00
HUNTERS	04/09/97	7.95	24.10	442.00	-0.01	0.30	0.30	0.04	0.03	-0.50		28.00	8.60	40.00	1.30	79.00	18.00	0.10	-30.00
HOUSE	02/11/91	7.66	24.00	180.00	-0.01	0.24	0.24	0.04	0.02	-0.50	98.00	27.00	4.50	2.10	0.50	4.40	12.00	0.06	-30.00
HOUSE	04/30/91	8.02	25.00	180.00	-0.01	0.27	0.27	0.03	0.02	-0.50	90.00	26.00	4.50	2.60	0.21	3.00	13.00	0.06	-30.00
HOUSE	07/29/91	7.95	24.00	190.00	-0.01	0.28	0.28	0.03	0.02	-0.50	72.00	27.00	5.60	2.70	0.16	3.00	14.00	0.07	
HOUSE	10/24/91	7.42	24.00	180.00	-0.01	0.30	0.30	0.03	0.02	-0.50	88.00	29.00	5.00	2.90	0.20	4.30	12.00	0.07	-30.00
CATFISH	02/11/91	8.23	24.00	280.00	-0.01	0.20	0.20	0.04	0.02	-0.50	95.00	28.00	6.90	17.00	1.00	29.00	18.00	0.07	-30.00
CATFISH	04/29/91	7.92	24.00	290.00	-0.01	0.22	0.22	0.03	0.03	-0.50	119.00	27.00	7.20	21.00	0.69	34.00	18.00	0.07	-30.00
CATFISH	07/29/91	8.10	24.00	290.00	-0.01	0.22	0.22	0.03	0.02	-0.50	78.00	28.00	8.10	16.00	0.61	26.00	18.00	0.08	
CATFISH	10/23/91	7.83	25.00	280.00	0.01	0.24	0.24	0.05	0.03	-0.50	88.00	28.00	6.70	17.00	0.60	29.00	16.00	0.07	-30.00
CATFISH	08/03/92	8.10	26.00	220.00						1.29	92.70	26.00	6.10	13.00	0.40	28.00	15.00		
CATFISH	04/12/93	7.70	27.10	778.00		0.24	0.24	0.03	0.03										
CATFISH	07/20/94	8.01	25.20	307.00	0.08	0.22	0.22	0.02	0.02	1.96		32.00	7.70	20.00	0.60	32.00	18.00	0.09	-30.00
CATFISH	01/23/95	7.97	23.00	323.00	0.05	0.20	0.20	0.04	0.04	-0.50		33.00	8.20	21.00	0.60	37.00	17.00	0.06	-30.00
CATFISH	04/03/95	8.02	23.60	305.00	0.01	0.24	0.24	0.03	0.02	-0.50		31.00	7.60	19.00	0.60	34.00	18.00	0.08	-30.00
CATFISH	07/27/95	7.99	24.10	325.00	-0.01	0.25	0.25	0.05	0.03	-0.50		28.00	7.10	22.00	0.70	40.00	19.00	0.06	30.00
CATFISH	10/25/95	8.01	26.20	371.00	0.04	0.25	0.25	0.02	0.01	-0.50		32.00	8.90	29.00	1.00	53.00	20.00	0.08	-30.00
CATFISH	02/06/96	8.03	21.80	333.00	0.30		0.25	0.01	0.01	-0.50		31.00	7.80	23.00	0.80	42.00	19.00	0.07	-30.00
CATFISH	04/18/96	8.31	23.60	310.00	-0.01	0.22	0.22	0.03	0.03	-0.50		31.00	7.80	19.00	0.80	33.00	17.00	0.08	294.00
CATFISH	07/18/98	7.93	24.00	305.00	0.01	0.22	0.22	-0.01	0.01	-0.50		33.60	7.86	16.20	0.60	32.00	17.00	0.11	-30.00
CATFISH	10/17/98	7.97	23.60	928.00	-0.01	0.22	0.22	0.05	0.03	-0.50		38.00	18.00	113.00	4.00	208.00	39.00	0.08	-30.00
CATFISH	01/29/97	7.94	24.10	321.00	-0.01	0.22	0.23	0.02	0.01	-0.50		29.00	7.70	21.00	0.60	38.00	17.00	0.09	-30.00
CATFISH	04/09/97	7.97	23.80	308.00	-0.01	0.22	0.22	0.02	0.03	-0.50		27.00	7.40	19.00	0.70	37.00	18.00	0.22	-30.00
CATFISH	07/09/97	7.70	23.80	299.00	-0.01	0.24	0.24		0.02	-0.50		29.40	7.30	17.40	0.63	32.00	17.70	0.09	-30.00
CATFISH	10/07/97	7.94	24.00	338.00	-0.01	0.22	0.22		0.02	0.42		30.60	7.76	21.60	0.64	37.10	18.40	0.09	-30.00
MILLERS CREEK	04/30/91	7.36	23.50	1700.00	-0.01	0.07	0.07	0.04	0.03	1.90	158.00	55.00	30.00	240.00	7.40	360.00	66.00	0.07	110.00
MILLERS CREEK	07/30/91	7.69	23.00	1100.00	-0.01	0.16	0.16	0.05	0.03	-0.50	110.00	45.00	26.00	160.00	5.20	260.00	50.00	0.08	
MILLERS CREEK	10/24/91	7.31	23.00	800.00	0.01	0.09	0.09	0.06	0.02	1.00	134.00	44.00	16.00	98.00	3.50	170.00	29.00	0.08	-30.00
MILLERS CREEK	01/10/92	7.13	22.00	2450.00	0.02	0.09	0.09	0.05	0.04	1.10	170.00	65.00	47.00	410.00	13.00	750.00	93.00	0.94	40.00

APPENDIX IV

Data Table for Figure 9; Generalized Thickness of the Potable Water Zone in the Floridan Aquifer across Citrus County

SITE	LON	LAT	WATER LEVEL (~ ft. bls)	POTABLE DEPTH (ft. bls)	POTABLE THICKNESS (ft)	REFERENCE
ROMP 119	821910	290106	27	380	353	SWFWMD / ROMP drilling and geophysical data, 1982.
Spruce Creek 10" Well	821830	290140	20	380	360	SWFWMD / ROMP geophysical data, 1996.
TR 124	824125	290230	0	200 *	200	SWFWMD, 1996 Citrus Co. qw data; SWFWMD, 1995 CGWQMP report.
TR 125	824131	290229	3	270 *	267	SWFWMD, 1996 Citrus Co. qw data; SWFWMD, 1995 CGWQMP report.
S. Dunnellon Wtr. Assoc. 8" Well	822749	290228	8	286 *	278	SWFWMD / ROMP geophysical data, 1995
Citrus Rec. Marina TMW-1	823930	290035	12	120	108	SWFWMD / ROMP geophysical data, 1996.
IAC-52	824121	290034	n/a	60 *	60	SWFWMD, 1996 Citrus Co. qw data; SWFWMD, 1995 CGWQMP report.
IAC-54	824114	290034	n/a	60 *	60	SWFWMD, 1996 Citrus Co. qw data; SWFWMD, 1995 CGWQMP report.
IAC-S Deep	824113	290046	12	82	70	SWFWMD / ROMP geophysical data, 1985.
Fl. Power Corp. #2	824110	285733	2	42 *	40	SWFWMD, 1996 Citrus Co. qw data; SWFWMD, 1995 CGWQMP report.
ROMP 114	823403	285355	3	229	226	SWFWMD / ROMP corehole data, 1977.
WRWSA Citrus Hills WF. MTW	822645	285330	130	390	260	Atlanta Testing and Engineering, 1989.
ROMP 112	821341	285250	14	339	325	SWFWMD / ROMP qw data, 1989.
ROMP LP-4	820743	284628	10	140	130	SWFWMD / ROMP geophysical data, 1983.
Altman #2	820740	284623	9	200	191	SWFWMD / ROMP geophysical data, 1984.
Jumper Creek JC3	820904	284309	n/a	390 *	390	USGS WRI-OFR 82-331.
Jumper Creek JC19	820546	284208	5	721	716	USGS WRI-OFR 82-331.
ROMP TR 21-2	823544	285112	2	130	128	SWFWMD / ROMP corehole data, 1978.
ROMP TR 21-3	823419	285234	6	270	264	SWFWMD / ROMP corehole data, 1978.
ROMP 110	821312	284513	10	168	158	SWFWMD / ROMP corehole data, 1989.
Ozello #4	823610	285102	3	60 *	57	SWFWMD, 1996 AGWQMP Citrus Co. report.
Homosassa #3	823453	284551	1	81	80	SWFWMD, 1996 AGWQMP Citrus Co. report.
Sugarmill Woods MZ1-Deep	823303	284457	5	330	325	Geraghty and Miller, 1979.
ROMP TR 20-1	823402	284244	31	282	251	SWFWMD / ROMP corehole data, 1982.
ROMP TR 20-3	823315	283828	11	534	523	SWFWMD / ROMP corehole data, 1997.
HRS 19A Zolinger	823432	284243	n/a	72 *	72	SWFWMD, 1996 Citrus Co. qw data; SWFWMD, 1995 CGWQMP report.
ROMP 107X 16" well	823038	283959	78	368	290	SWFWMD / ROMP geophysical data, 1983; Geraghty & Miller, 1979.
ROMP TR 19-2	823657	283243	1	277 *	276	SWFWMD / ROMP geophysical data, 1983.
Presb. Youth Camp\ Weeki Wachee	823702	283203	7	66 *	59	SWFWMD, 1996 AGWQMP Hernando Co. report.
WHCWS MW-1 Deep	823227	283253	12	530	518	USGS geophysical data, 1983.
ROMP 105	822416	283321	65	509	444	SWFWMD / ROMP drilling data, 1983.

* well casing depth
n/a data not available

Data Table for Figure 9, Generalized Thickness of the Potable Water Zone in the Floridan Aquifer across Citrus County.

APPENDIX V

Assumptions and Calculations Used in the Determination of Nitrogen Loading from Pasture Fertilization

Assumptions and Calculations Used in the Determination of Nitrogen Loading from Pasture Fertilization.

Nitrogen loading from pasture fertilization was determined using the Florida Department of Agriculture and Consumer Services (FDACS) Annual Summary of the Consumption of Fertilizer Materials and Mixtures in Florida Counties (FDACS, 1993). An analysis of data contained in the report indicated that from July, 1992, to June, 1993, farm uses in the study area consumed an estimated 178 tons of fertilizer nitrogen. Because the level of detail for fertilizer information in the report was given at the county level, numerous assumptions were required to arrive at a value of fertilizer nitrogen for the study area. These assumptions and calculations are explained below.

In Citrus County, 470 tons of single-nutrient fertilizer were sold between July, 1992 and June, 1993. Because the composition of the fertilizer was not specified, a nitrogen content of 28% was assumed for 75% of this tonnage (75% of the single-nutrient fertilizers listed on page 7 of FDACS (1993) are nitrogen bearing, and of those nitrogen fertilizers the average nitrogen composition is 28%). Also during this time period, 5,880 tons of multi-nutrient fertilizer were sold. The composition of the 5,880 tons was not specified and a nitrogen composition of 11% was assumed (11% nitrogen is the average nitrogen composition of the 280 multi-nutrient fertilizers listed on pages 8-13, FDACS (1993).

Having calculated the nitrogen tonnage for single and multi-nutrient fertilizers, the nitrogen tonnage values were combined to obtain a county-wide nitrogen tonnage. Using GIS land-use data and interpretation of land-use maps, the percentage of farm use in the study area was determined. Assuming a uniform distribution of nitrogen over the land use, the percentage of farm use in the study area was multiplied by the county-wide nitrogen tonnage to get the tonnage of N in the study area.

Because the calculated value of nitrogen (178 tons) was that which was contained in all fertilizers dedicated to farm use, not just pasture, the calculated amount of nitrogen contained in fertilizers applied to citrus and row crops (29 tons) had to be subtracted from the total. This resulted in approximately 149 tons of nitrogen in fertilizer applied to pasture.