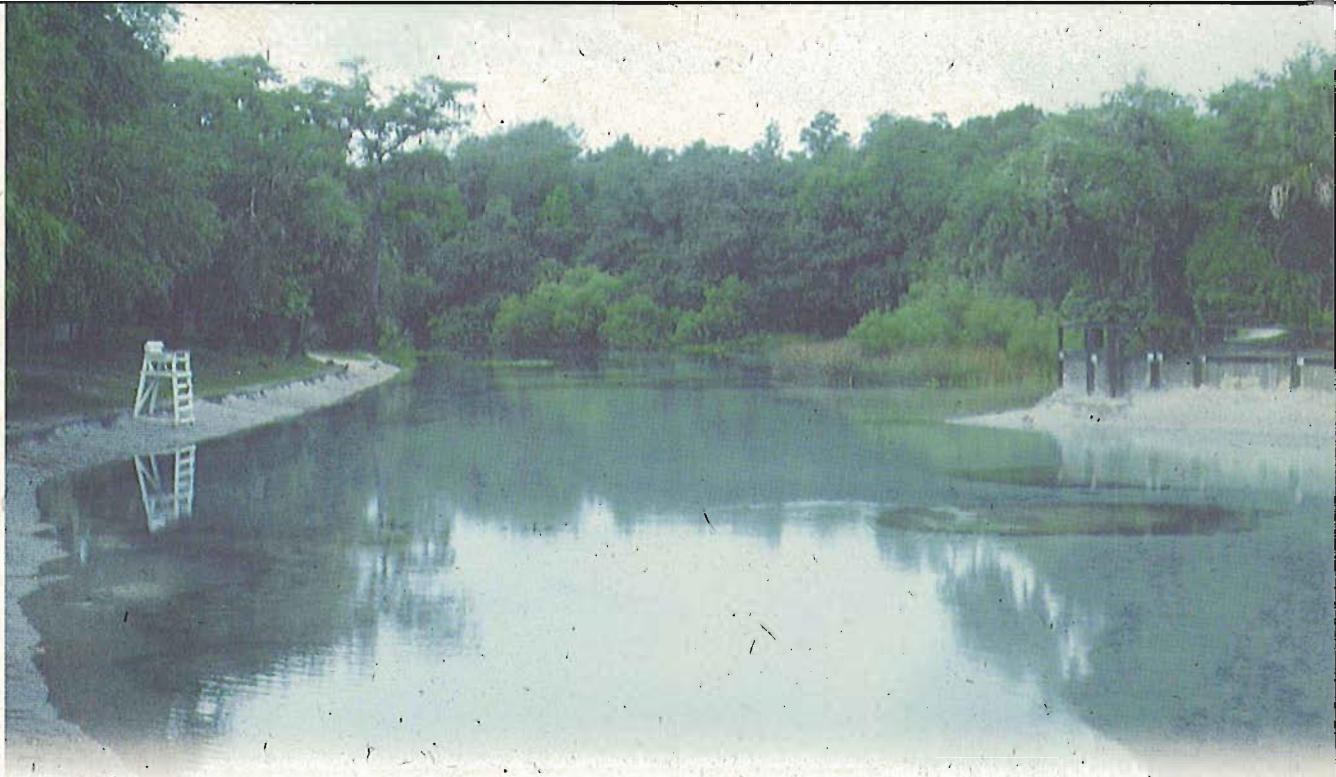

Origin of Nutrients in Ground Water Discharging from Lithia and Buckhorn Springs

Hillsborough County, Florida

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 Lithia and Buckhorn Springs" were prepared by or reviewed by a Certified Professional Geologist in the State of Florida.

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

License No. 1475

ORIGIN OF NUTRIENTS

IN GROUND WATER DISCHARGING

FROM LITHIA AND BUCKHORN SPRINGS

Ambient Ground-Water
Quality Monitoring Program,

Southwest Florida Water Management District

September, 1993

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EXECUTIVE SUMMARY

1. Buckhorn and Lithia Springs are discharging nitrate-rich waters into the Alafia River and Tampa Bay. The average nitrate concentrations of Lithia and Buckhorn Springs are 3.1 and 2.1 mg/l NO_3 as N, respectively. The total amount of nitrate the springs contribute annually to the river is approximately 157 tons. This is 22 percent of the total nitrogen contributed to Tampa Bay by the Alafia River.

2. Cargill Phosphate, the owners of Lithia and Buckhorn Springs, divert approximately 14 percent of the combined flow of the springs to their chemical complex at the mouth of the Alafia River. This diversion prevents approximately 26 tons of nitrate from entering the Alafia River yearly.

3. Although the nitrate content of Boyette Spring, 12 mg/l NO_3 as N, exceeds the Drinking Water Standard, the discharge magnitude of the spring is so small that the amount of nitrate it contributes to the Alafia River is negligible.

4. Boyette Springs is discharging Surficial Aquifer water. Lithia and Buckhorn Springs are discharging Floridan Aquifer water. These latter springs contain a small deep-flow component, but most of the water is derived from nearby recharge in the Brandon karst terrain.

5. The Tampa clay, which separates the Floridan and Intermediate Aquifers, pinches out at about the longitude of Lithia Springs. Therefore, east of the springs, there is an Intermediate Aquifer, while west, in the Brandon karst terrain, the Intermediate is technically absent and the Tampa Member strata are in hydrologic connection with older limestones of the Floridan Aquifer.

6. The Brandon karst terrain is a karst inlier surrounded by Hawthorn Group strata that partly confine the Floridan Aquifer. Drainage in the terrain is internal, through numerous sinkholes and karst conduits. The sinkholes are aligned along lineaments.

7. Within the terrain the Tampa clay is absent and recharge is directly to the Floridan Aquifer.

8. The potentiometric surface of the Floridan Aquifer indicates that transmissivities are high in the terrain, and that generally westward flow diverges into two components. Water in the northern half of the terrain (roughly, north of I-4) flows westward, while water in the southern half flows south and southeast, towards the springs and the Alafia River.

EXECUTIVE SUMMARY (continued)

9. Fracture-trace analysis indicates that karst conduiting is connected to the springs and provides pathways from the terrain to the spring complexes. Minimum travel time of ground water in the fracture is approximately 1 mile every 5 years.

10. Hydrochemical facies of study-area waters shows that spring waters are chemically similar to terrain waters. There is no chemical evidence of Alafia River water discharging from the springs. There is little evidence of very deep Floridan water discharging, as well.

11. Sodium to chloride ratios support the hydrochemical facies data and tie the spring water to the southern half of the terrain.

12. Uranium and uranium isotopic ratios also indicate a local, south-terrain source for the spring waters.

13. Tritium concentrations are ambivalent. Activities are moderately low and suggest water that recharged in the late 1950s or early 1960s.

14. Nitrogen isotopic ratios are very helpful in identifying nitrogen sources. Boyette Spring is clearly affected by animal wastes from a dairy south of the spring. A dairy west of Buckhorn Springs has affected local ground water, but dilution has prevented serious degradation of the springs. Water in the karst terrain and Lithia and Buckhorn Springs is largely affected by inorganic fertilizers applied to citrus, with minor animal-waste contributions.

15. Changes in land use within the last 10 to 15 years have caused a change in nitrogen sources in the Brandon karst terrain. It is unclear how much septic tanks will impact the springs, but the 11,000 septic tanks now present in the area will most likely adversely affect future concentrations of nitrogen in the springs.

16. There is little that can be done to reduce present nitrogen loading from the springs because that nitrogen is an artifact of past land-use practices. Spring discharge augmentation will not reduce loading, but would reduce concentrations. Use of aquatic plants to control nitrogen is possible, but would require significant changes in the spring environments. Interception of the water through wells is possible, but would reduce spring discharge and negatively impact the estuary.

17. Several measures should be taken in the near future to increase our understanding of the nitrate problem in the Brandon area and to assess the role of septic tanks. These are listed below.

    a) All wells in the monitor network utilized in this report should be sampled for nitrogen isotopes in order to optimally site a dedicated network of monitor wells.

b) This dedicated network would consist of approximately 10 to 20 strategically placed and carefully constructed monitor wells in the Brandon karst terrain. Construction standards for these wells would strictly adhere to Florida Administrative Code 17-761 requirements. These wells could provide detailed information on the presence, depth, and thickness of aquifers and confining layers. The strategic locations would insure that the areas where nitrate concentrations are highest would be thoroughly delineated and monitored, and strict adherence to proper well construction standards would insure that the accuracy of water quality information obtained from these wells would be beyond question.

c) The monitor well network should be sampled annually for nutrients, major analytes, and trace organics for an indefinite period. Nitrogen isotopic ratios should be determined each time. If the ratios start to increase, a shift in nitrogen sources from past agricultural land uses such as citrus and dairies to present land uses such as residential development served by septic tanks would be indicated. If the decision was made to sewer the septic tank areas, the annual sampling would determine the effect of the reduction of septic tanks on ground-water quality.

d) For the reasons discussed above, the springs should also be sampled annually for nutrients, major analytes, and trace organics. Nitrogen isotopic ratios should also be determined each time.

18. Future nitrogen loading as the septic-tank-derived water approaches the springs is a concern. It is not possible to determine the effect of the arrival of the septic-tank derived water on the water quality of the springs. However, the potential for this water to enrich the nitrate concentration of spring water exists. If it is concluded from the additional monitoring discussed above that septic tank effluent will degrade the water quality of the springs, a program of conversion of residential areas served by septic tanks either to sewers or alternative on-site systems that more effectively remove nitrogen should be undertaken. The regional nitrogen isotope data will allow prioritization of those areas that would need sewering or installation of alternative on-site systems.

19) The District should work with Hillsborough County and other interested agencies to formulate land-use plans that would prevent additional nitrogen loadings to the Brandon karst terrain.

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INTRODUCTION

Nutrients are a serious detriment to Tampa Bay water quality. Tributaries have proven to be a significant source of these nutrients, and it has been determined that the Alafia River delivers approximately 705 tons/yr of nitrate (NO_3^-) to Tampa Bay, significantly more than any other major tributary (Flannery, 1989). Lithia and Buckhorn Springs[1] are two of the major sources of nitrate in the Alafia River (Figure 1), contributing approximately 22 percent (157 tons/yr) of the total. In addition, data collected by the U.S. Geological survey (1985) indicate that Lithia and Buckhorn Springs are among the most nitrate-rich springs in Florida.

The complexities of the Lithia and Buckhorn Springs systems have made it difficult to determine the sources of spring waters. However, the springs seem to have two components of flow; a deep, Floridan aquifer component that possibly originates in the Green Swamp and a shallow flow component made up of recharge that occurs locally in the Brandon area of central Hillsborough County.

Nitrate concentrations in ground water in undeveloped areas of Polk and Hillsborough Counties have been obtained by the Ambient Ground-Water Quality Monitoring Program (AGWQMP) (Jones *et al.*, 1990). Comparison of these data with nitrate data in ground water discharging from the springs clearly indicates that the spring-water concentrations greatly exceed natural background ground-water concentrations. In addition, historical water-quality data from Lithia and Buckhorn Springs (Florida State Board of Conservation, 1951; Florida Bureau of Geology, 1977; and the U.S. Geological Survey, 1985), indicate that Lithia Springs Major experienced a 17 fold increase in nitrate concentrations from 1923 to 1991 while concentrations in Buckhorn Springs Main increased 9-fold from 1966 to 1991.

Since enrichment of nitrate to the level that occurs in the spring water does not appear to be a result of natural processes, human-induced contamination of the ground water must be occurring somewhere within the recharge area of the springs. Because nitrate-rich ground water discharging from the springs is degrading the quality of the Alafia River and Tampa Bay, the Surface Water Improvement and Management (SWIM) Program of the Southwest Florida Water Management District (SWFWMD) authorized an investigation of the problem. The investigation, which began in March of 1991 and lasted 18 months, was carried out by the Ambient Ground-Water Quality Monitoring Program (AGWQMP) also of the SWFWMD. The

[1] While both Lithia and Buckhorn Springs are named as if they are simple systems, both consist of several vents. This study has shown that the two vents of Lithia Springs (herein named Lithia Major and Lithia Minor) discharge similar waters and can be considered as one spring. Buckhorn Springs, however, consists of at least four vents (termed Buckhorn Main, East, West, and South in this report), several of which are chemically dissimilar.

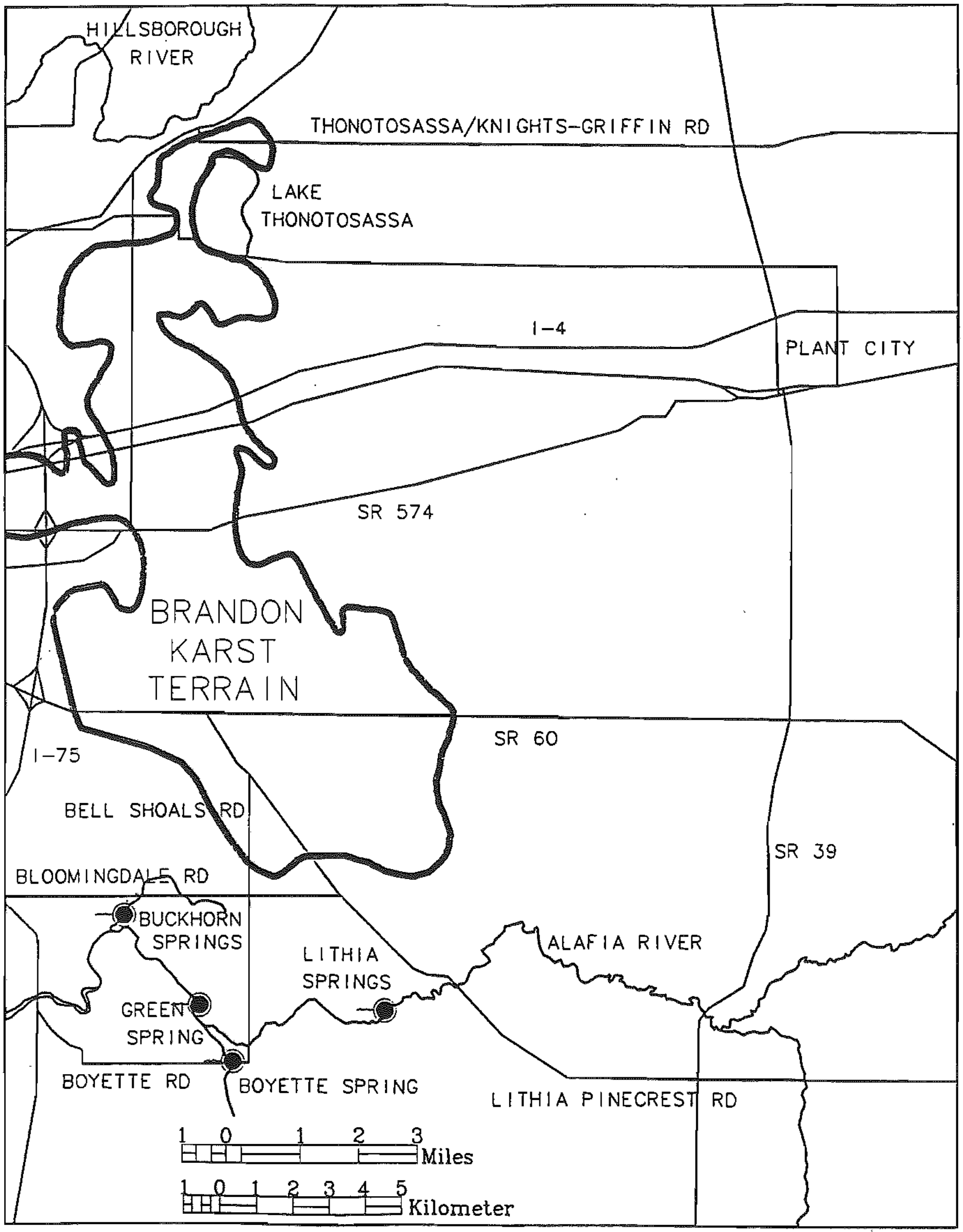

Figure 1. Study Area and Location of Important Geologic, Hydrologic, and Cultural Features.

scope of the investigation involved delineating the areas where nitrates were entering the aquifer system, identifying the land uses that were contributing the nitrates, and determining what could be done to slow or reverse the nitrification of ground water in the area.

DESCRIPTION OF THE STUDY AREA

INTRODUCTION

The project study area (Figure 1) encompasses approximately 125 square miles in the vicinity of the Alafia River in central Hillsborough County. The northern boundary of the study area is Interstate 4 and the southern boundary is Balm-Boyette and Lithia Roads. The western and eastern boundaries are Interstate 75 and Highway 39 respectively. The following sections explain the geographic setting, topography, and drainage; land use; the geology and hydrogeology; karst hydrogeology; and the Lithia and Buckhorn Spring systems.

Geographic Setting, Topography, and Drainage

The Tampa area is located in sandy, poorly drained coastal lowlands. From Tampa Bay, a relatively flat plain slopes eastward across the study area. This plain is the former bottom of an estuary that, during the Pleistocene Epoch (10,000 to 1 million years ago), occupied an area much larger than the present Tampa Bay. Because of deposition of clayey and shelly sands in this estuary, earlier sinkholes and other karst features were largely buried. Near the coast and in low areas, such as Harney Flats on the western side of the study area, the landscape is, therefore, relatively flat and featureless. In the central part of the study area the pre-Pleistocene and early Pleistocene sinkholes are now being reactivated, and a karst terrain (the "Brandon karst terrain" of Upchurch and Littlefield, 1987; Trommer, 1987) with internal drainage has resulted (Figure 1).

In the western third of the study area, the coastal lowlands are bordered by a scarp that roughly coincides with the Pamlico Shoreline (SWFWMD, 1988). The Pamlico Shoreline resulted from a retreat of the sea to an elevation of approximately 35 feet during the on-set of the last glaciation. This escarpment is characterized by rolling hills that originate from sinkhole development and deposition of coastal dune and beach ridges. Drainage is typically internal and controlled by karst depressions.

East of the scarp are upland areas which consist of low rolling hills, sinkholes, ponds, and swamps. Land surface elevations range from near sea level in the vicinity of the Alafia River to greater than 140 feet above the National Geodetic Vertical Datum (NGVD) in the eastern portion of the area.

The Alafia River is the major surface-water feature in the study area. The Alafia River begins on the Polk Upland in Polk County and flows west to the Hillsborough Bay section of Tampa Bay near Gibsonton. The flood plains of the Alafia are low, wetland strands. The average annual flow rate of the Alafia River at Lithia Springs is 362 ft^3/s (SWFWMD, 1988). The drainage area at the Lithia Springs stream gage is 335 square miles. Because of phosphate mining and processing, agriculture, and other land uses upstream, the quality of water in the Alafia River in the study area is generally poor. High concentrations of sulfates, fluorides, and total dissolved solids have been measured.

Land Use

Figure 2 illustrates the current land uses prevalent in the study area. Land use for this figure was determined through analysis of infrared aerial photography flown in 1989 and 1990. Interpretations were made for the entire SWFWMD area by a private consultant.

It is apparent from Figure 2 that the study area can be conveniently divided into a western and eastern area based on two distinct types of land use that dominate each area. The western area, which contains the city of Brandon, is dominated by rapidly expanding urban and suburban land uses, such as high-density residential and commercial properties. A much smaller portion of the western area contains agricultural land uses, such as citrus, row crops, pasture, and dairies, and natural land uses, such as forested uplands and wetlands. However, areas dominated by these land uses are being converted to urban land uses at a rapid pace.

The eastern portion of the study area is much more rural in character. It mainly contains citrus and row crops interspersed with small areas of forested uplands and wetlands. A large portion of the eastern area is dominated by a northwest-trending band of lakes and wetlands that were created when the area was mined for phosphate. Densities of residential and commercial land uses in the eastern portion of the study area are low except for relatively minor concentrations in the Plant City area.

Figures 3 and 4 depict the land use that existed in 1965 and 1989-1990, respectively, in the portion of the Brandon karst terrain deemed to be most directly related to nutrient loading in the springs. Land use was determined from a detailed analysis of aerial photographs. The analysis was conducted by AGWQMP staff who were very familiar with the study area. These individuals often verified their interpretations in the field to insure accuracy. These land-use maps are considered to be somewhat more detailed and accurate than the Figure 2 land-use map. In addition, because the maps were constructed by different groups, different symbology is used to depict land uses.

Examination of Figures 3 and 4 indicates that there has been a significant transition from rural, agricultural land uses in the first half of the century to suburban and urban uses in the 1970's and 80's. Because of the relatively slow velocities of ground water flow, past land uses are important sources of contemporary contamination. It is especially important to note that in 1965 much of the southern half of the karst terrain was dedicated to citrus, while in 1990 the same areas are residential. Note also, that there has been a significant increase in both on-site

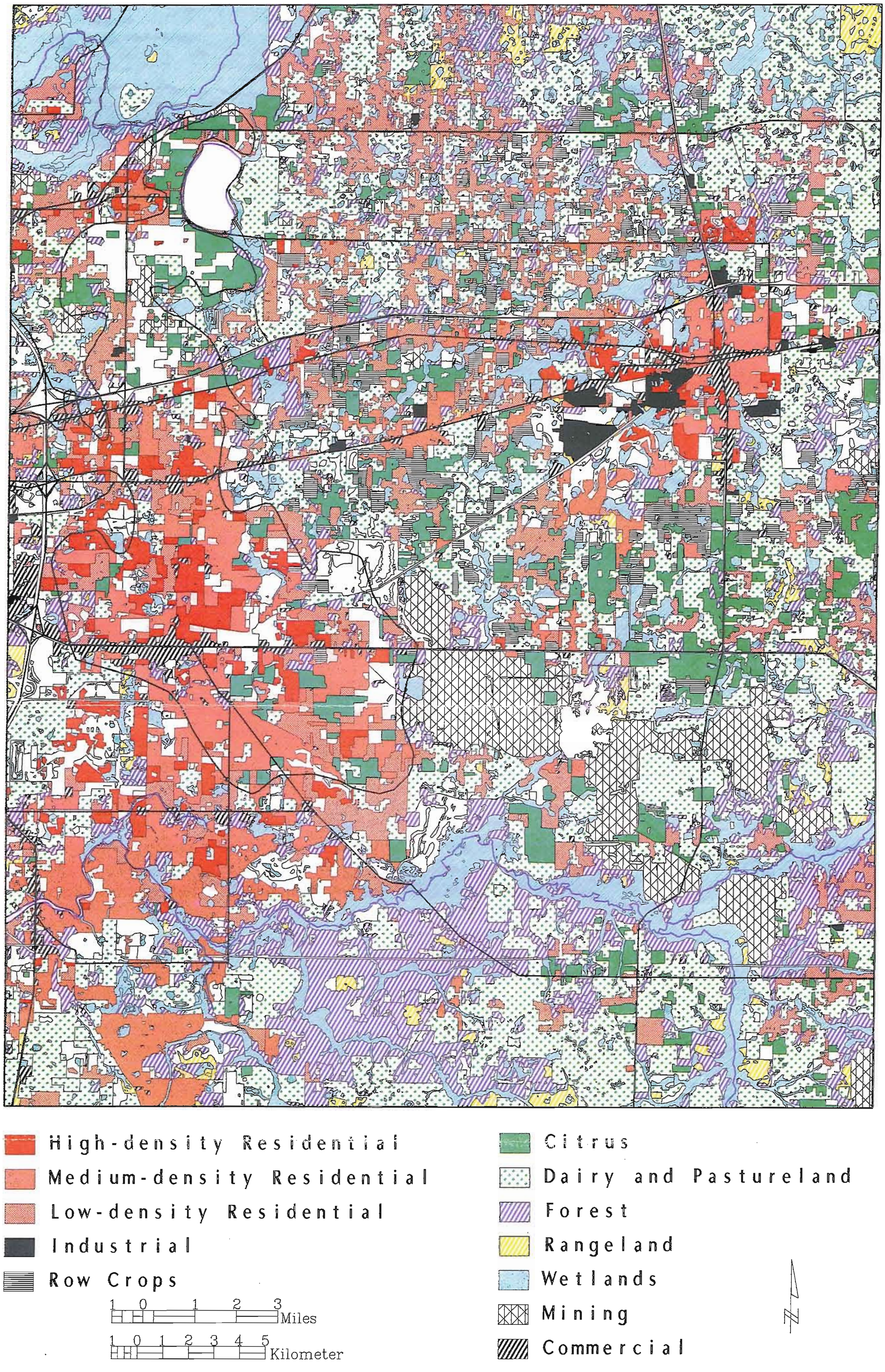

Figure 2. Land Use in the Study Area (1990).

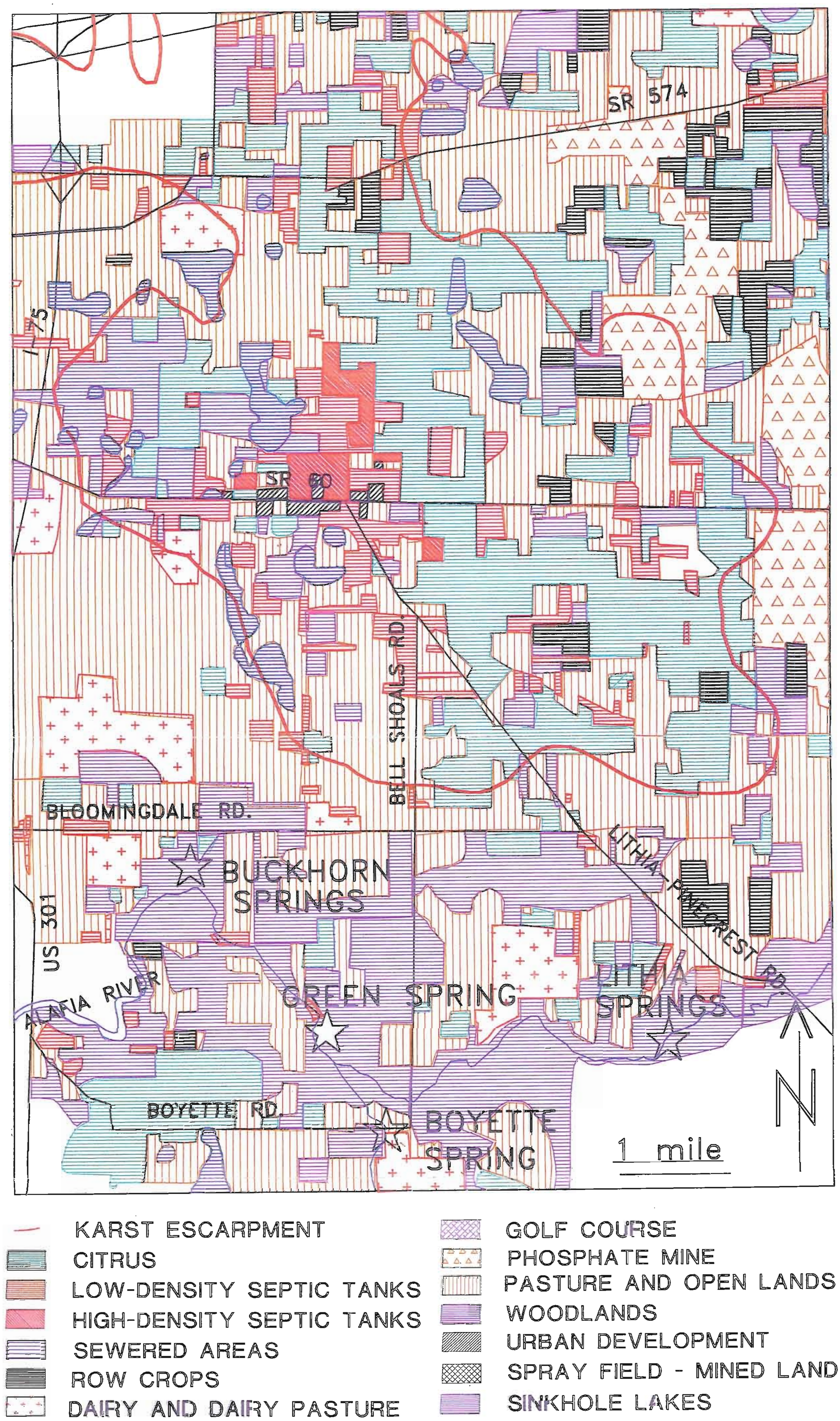

Figure 3. Land Use in the Brandon Karst Terrain (1965).

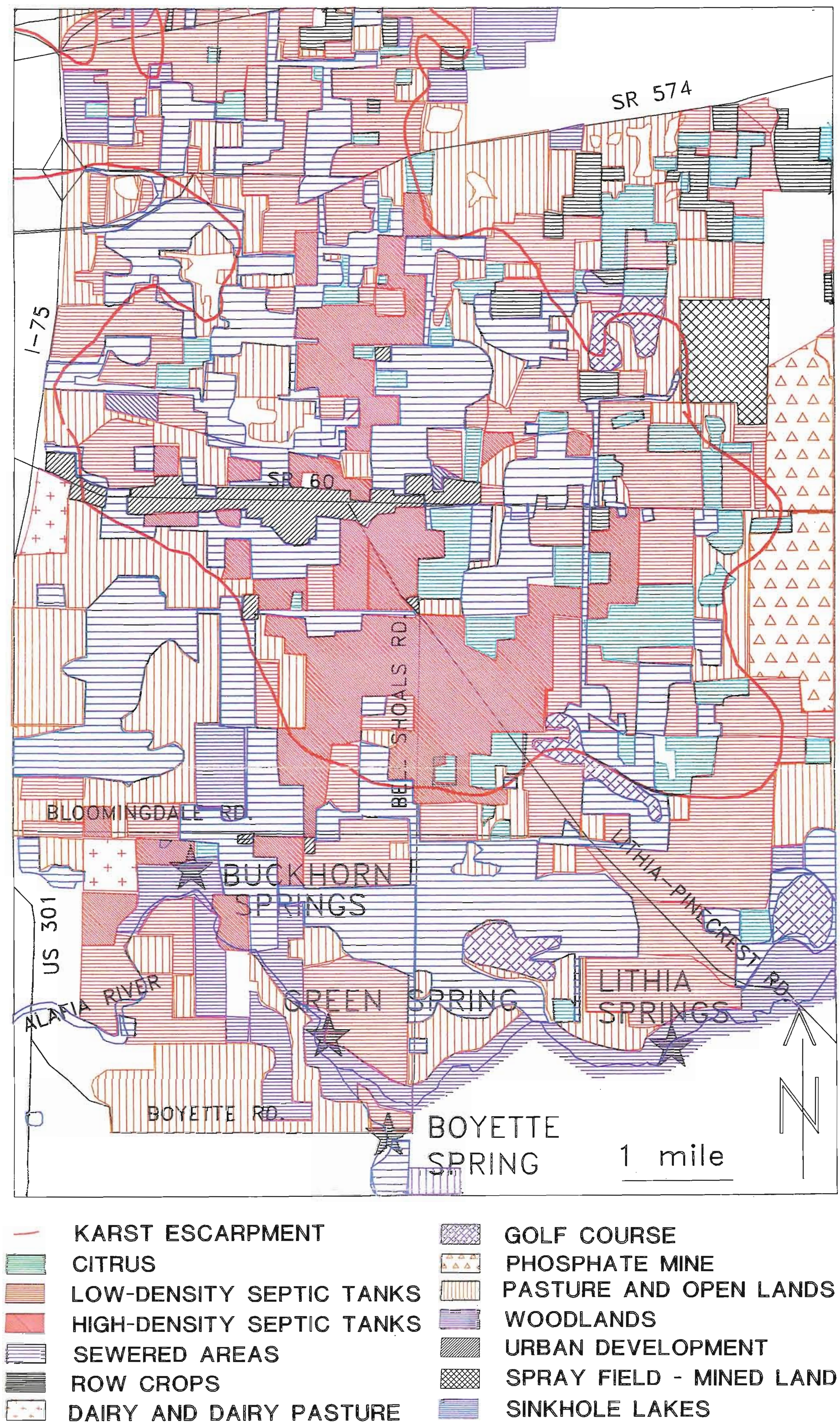

Figure 4. Land Use in the Brandon Karst Terrain (1990).

sewage treatment (septic tank/drain field facilities) and of sewered communities. In many areas the density of homes per unit area has increased to the maximum allowable.[2] Where these homes are served by septic-tank systems, a separate symbol for high-density septic tanks is utilized.

Geology/Hydrogeology

The study area is dominated by a sequence of Tertiary carbonate rocks several thousand feet thick, which collectively make up the Floridan Aquifer. These are overlain by a much thinner, wedge-shaped sequence of late Tertiary and Quaternary interbedded carbonate and clastic deposits that comprise the Intermediate and Surficial Aquifer Systems. Stratigraphic and hydrostratigraphic units in the study area are listed and described in Table 1.

The hydrogeology of the study area is complex because it is located in a zone of geologic transition. Here, the Floridan Aquifer changes from being confined in the southern and eastern portions of the study area to semi-confined in the west-central portion to unconfined in the northwestern portions of the study area. This results from the south to north and east to west thinning, or pinching out, of the Miocene Hawthorn Group. The Hawthorn Group contains the permeable units that comprise the Intermediate aquifer and the confining beds which separate the aquifer system from the overlying Surficial and underlying Floridan Aquifer System. The zone of thinning and/or pinch out of the Hawthorn Group coincides with the Pamlico scarp and constitutes a major hydrologic boundary as well as a topographic feature (Figure 5).

Figure 6 is a location map of six geologic cross sections through the study area. Figures 7, 8, and 9 show the cross sections. Geologic descriptions of the sediments in the wells used in the cross sections are included in Appendix I.

It is apparent from the cross sections that the Peace River and Arcadia Formations of the Hawthorn Group are thinnest in the portion of the study area north of the Alafia River and west of Lithia Springs. East of Lithia Springs, the lower portion of the Tampa Member contains clays (the "Tampa clay") that hydraulically separate the Tampa Member from the underlying Suwannee Limestone of the Floridan Aquifer. In this area the Tampa is considered to be part of the Intermediate Aquifer (Geraghty and Miller, 1984). West of Lithia Springs, this clay layer is not present in any of the well logs that make up the cross sections. Therefore, west of Lithia Springs, the Tampa Member of the Arcadia Formation is hydraulically connected to the Floridan

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[2]Allowable septic-tank densities in Hillsborough County are based on flow volume to the septic system and lot size. A maximum of 2500 gpd/ac is permitted in areas served by public water and 1500 gpd/ac in areas served by wells. In conjunction with the flow volume restrictions, 1 septic tank per 1/3 acre is permitted in areas served by public water and 1 per 1/2 acre is permitted in areas served by wells.

Table 1. Geology and Hydrogeology of the Study Area.

<table>
<tr><th rowspan="2">System</th><th rowspan="2">Series</th><th rowspan="2" colspan="2">Stratigraphic unit</th><th colspan="3">Hydrogeologic unit</th></tr>
<tr><th>System</th><th>West of Lithia Springs</th><th>East of Lithia Springs</th></tr>
<tr><td>Quaternary</td><td>Holocene and Pleistocene</td><td colspan="2">Terrace deposits</td><td>Surficial aquifer system</td><td>Surficial aquifer</td><td>Surficial aquifer</td></tr>
<tr><td rowspan="10">Tertiary</td><td rowspan="4">Miocene</td><td rowspan="4">Hawthorn Group</td><td>Bone Valley Member</td><td rowspan="4">Intermediate aquifer system or intermediate confining unit</td><td rowspan="2">Semi-confining unit</td><td>Semi-confining unit</td></tr>
<tr><td>Peace River Formation</td><td rowspan="2">Intermediate aquifer</td></tr>
<tr><td>Arcadia Formation</td><td rowspan="5">Upper Floridan aquifer</td></tr>
<tr><td>Tampa Member</td><td>Lower Tampa semi-confining unit</td></tr>
<tr><td>Oligocene</td><td colspan="2">Suwannee Limestone</td><td rowspan="6">Floridan aquifer system</td><td rowspan="3">Upper Floridan aquifer</td></tr>
<tr><td rowspan="4">Eocene</td><td colspan="2">Ocala Limestone</td></tr>
<tr><td colspan="2" rowspan="2">Avon Park Formation</td></tr>
<tr><td>Middle confining unit</td><td>Middle confining unit</td></tr>
<tr><td colspan="2" rowspan="2">Oldsmar and Cedar Keys Formations</td><td rowspan="2">Lower Floridan aquifer</td><td rowspan="2">Lower Floridan aquifer</td></tr>
<tr><td>Paleocene</td></tr>
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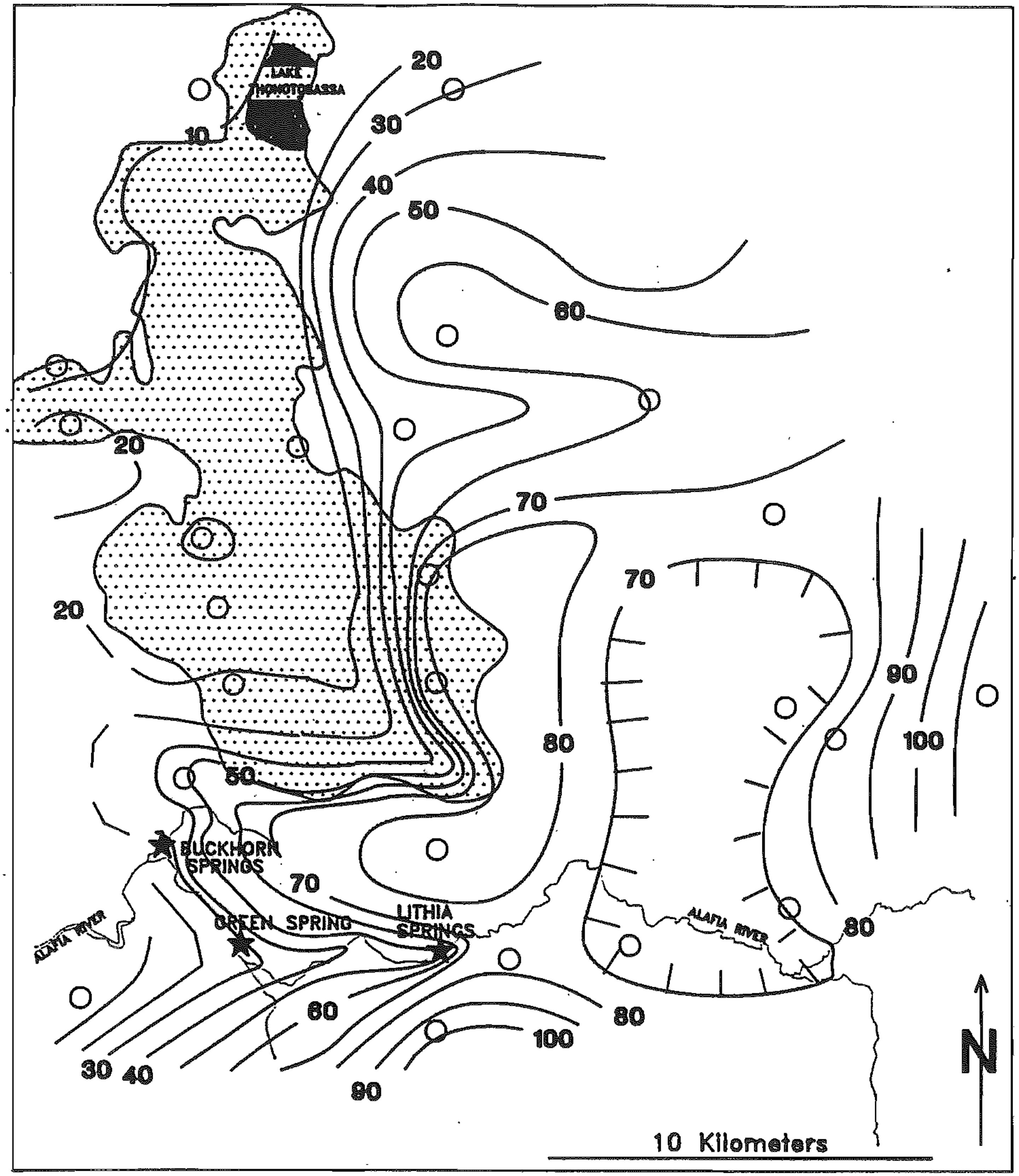


Figure 5. Thickness of Clays confining the Floridan Aquifer in the Study Area.

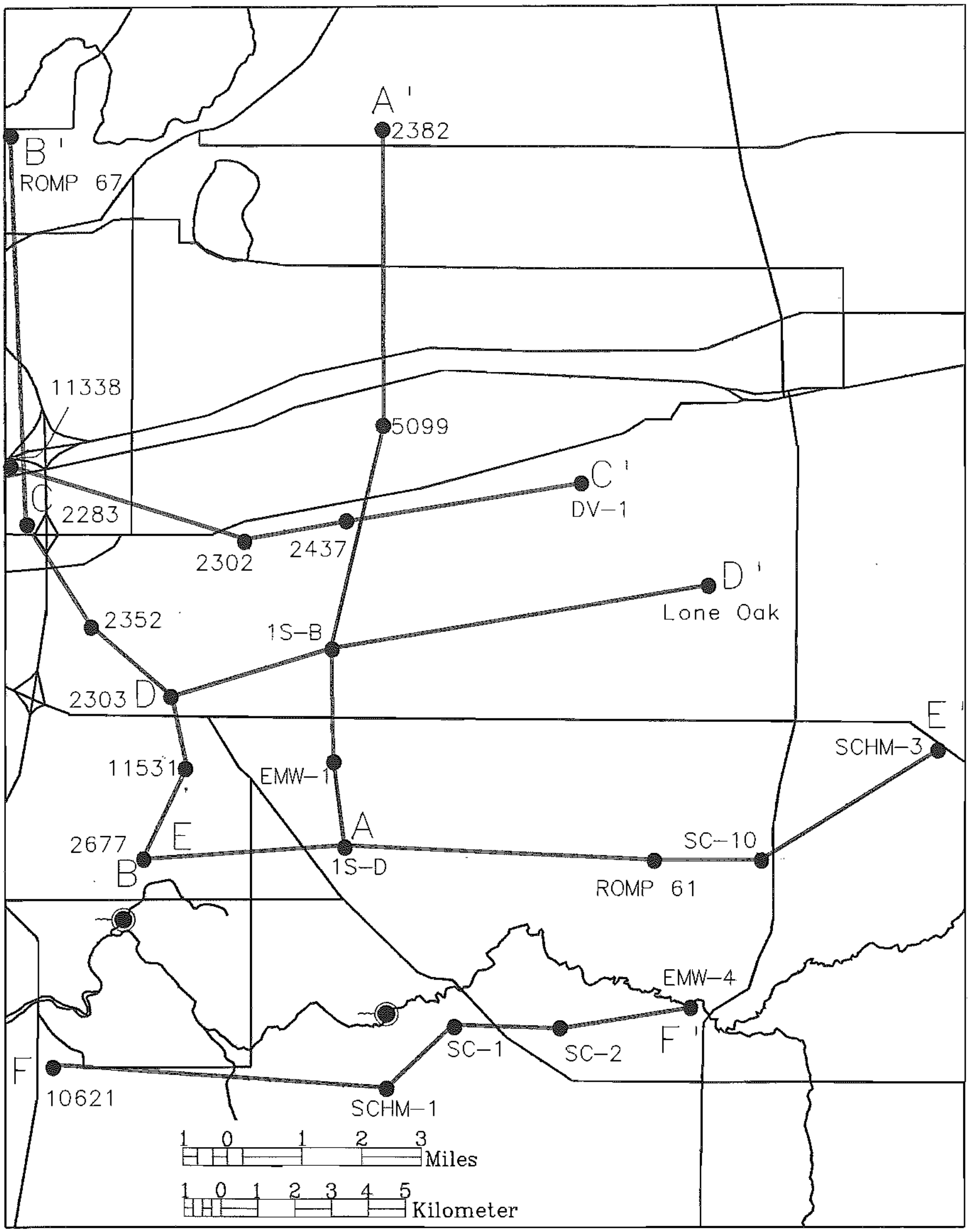
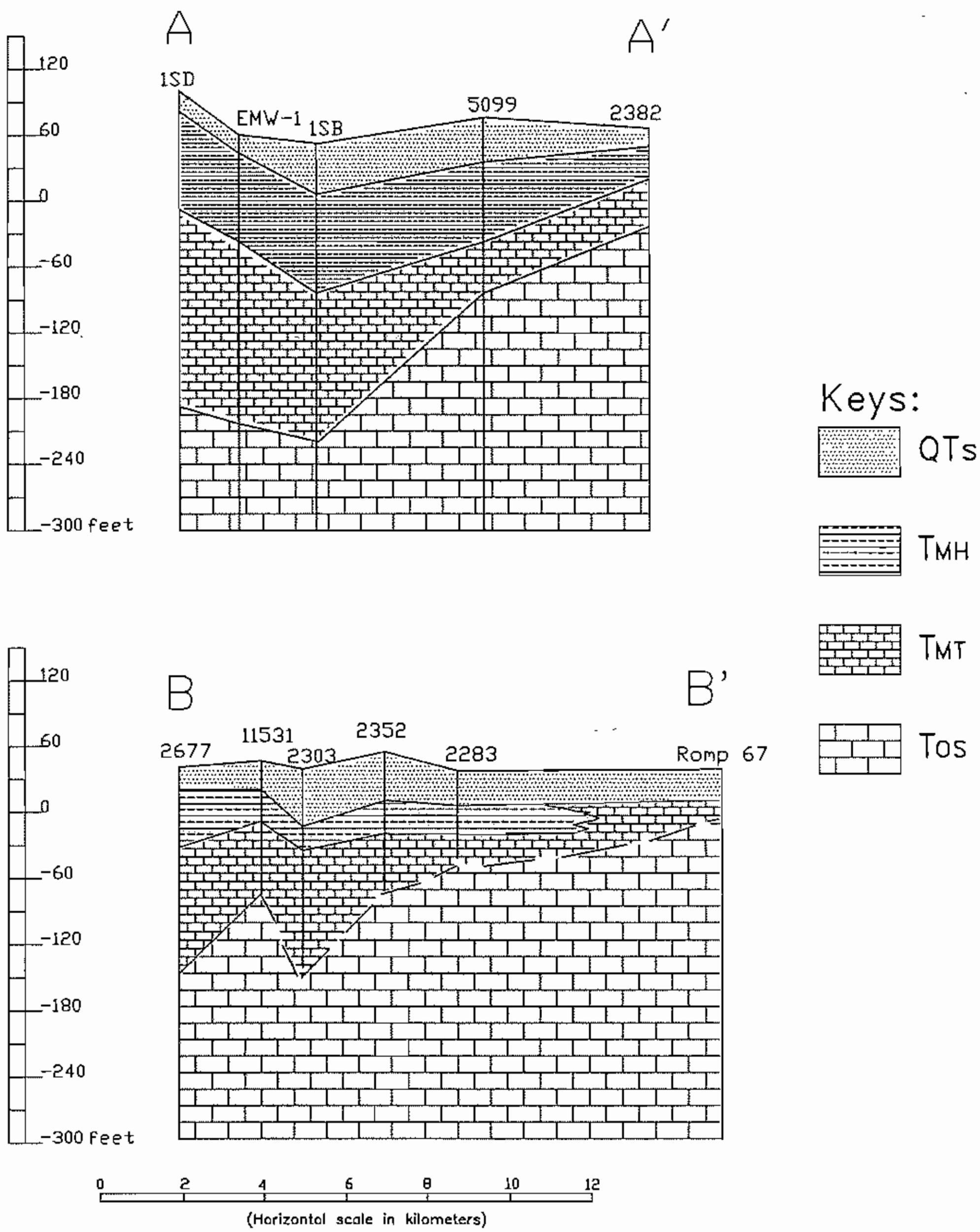
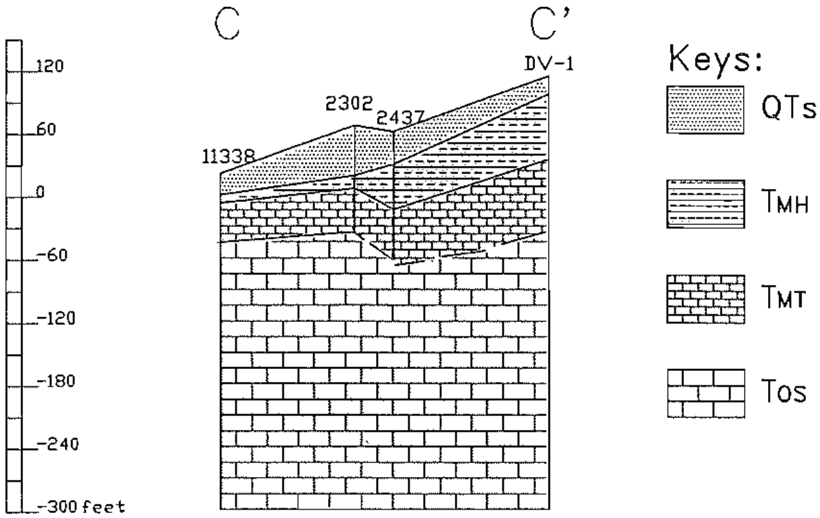


Figure 6. Locations of Geologic Cross Sections through the Study Area.

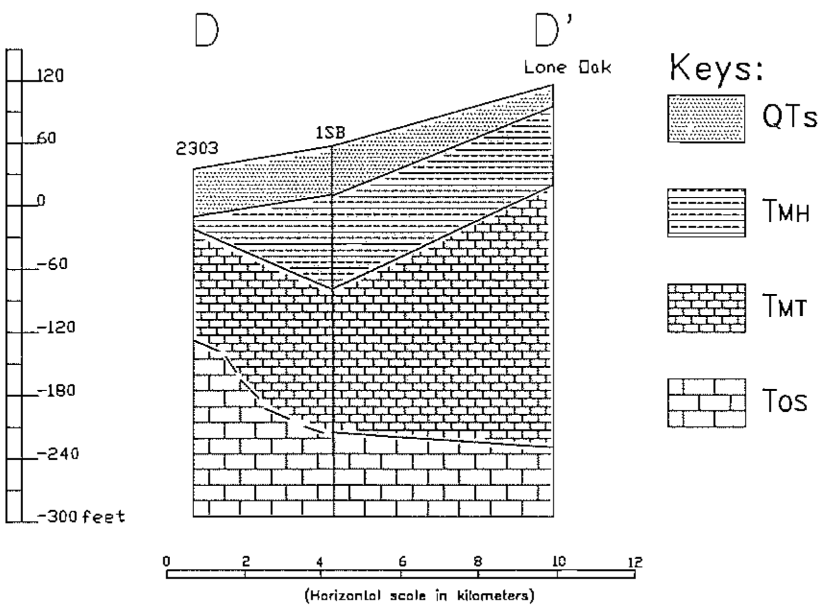


The Suwannee L. S. was not reached in logs 2303, 2352, and 2283. Therefore, clay content at the Tampa/Suwannee contact could not be evaluated

Figure 7. Cross Sections A to A' and B to B'.



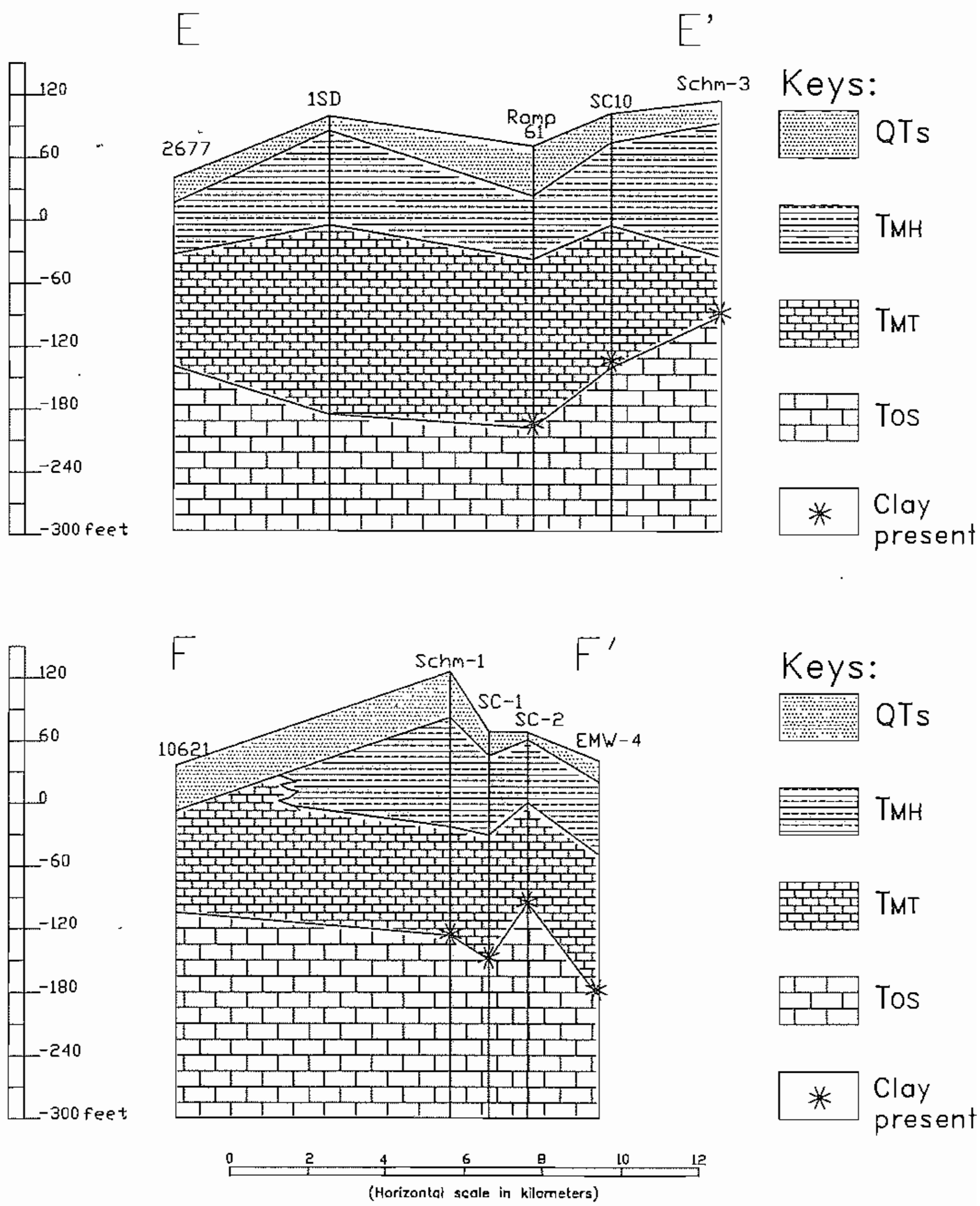
The Suwannee L. S. was not reached in logs 2302 and 2437. Therefore, clay content at the Tampa/Suwannee contact could not be evaluated.



The Suwannee L. S. was not reached in log 2303. Therefore, clay cotent at the Tampa/Suwannee contact could not be evaluated.

Lone Oak formation picks were made with a gamma log. Attempts to evaluate clay content at the Tampa/Suwannee contact using the gamma log were inconclusive.

Figure 8. Cross Sections C to C' and D to D'.



QTs: Quaternary – Tertiary sand

TMH: Tertiary Miocene Hawthorn Group

TMT: Tertiary Miocene Tampa limestone

TOS: Tertiary Oligocene Suwannee limestone

Figure 9. Cross Section E to E' and F to F'

Aquifer, and the Intermediate Aquifer, except for a few discontinuous permeable units within thin siliciclastic horizons, cannot be documented.

Karst Hydrogeology

The poorly confined area north of the Alafia River and west of Lithia Springs is a result of the development of karst topography which will be referred to throughout this report as the Brandon karst terrain (Upchurch and Littlefield, 1987) (Figure 10 , dotted area). The Brandon karst terrain is a 41 square mile, slightly elevated area characterized by internal drainage, numerous sinkholes, and significantly increased Floridan aquifer transmissivities. Upchurch and Littlefield (1987) studied sinkhole risk in the area. Table 2 summarizes their sinkhole distribution data by USGS quadrangle.

Covered karst (Table 2) refers to karst with over 100 feet of overburden (siliciclastic sediment) overlying the limestone. Bare karst exists where limestone is exposed at the land surface or exists beneath a thin soil cover. Much of the area is characterized by the development of modern sinkholes, with highest probabilities of occurrence in the Dover area (Table 2). The Dover sinkholes are largely a result of heavy pumpage to protect crops during periods of freezing temperatures (Metcalf and Hall, 1984; Bengtsson, 1987). The Brandon karst terrain is clearly illustrated in Table 2

Table 2. Summary of Sinkhole Distribution Data (from Upchurch and Littlefield, 1987).

Quadrangle	Karst Terrain Type	Number of Modern Sinkholes (1964-85)	Number of Modern Sinkholes per Square Mile	Percent of Area in Ancient Sinkholes
Brandon	Thin to thick cover; some bare	10	0.02	7
Dover	Covered	28	0.06	1
Riverview	Thickly covered	10	0.02	1
Lithia	Thickly covered	2	0.004	0

where the Brandon Quadrangle averages seven percent of the land surface in ancient sinkholes. Upchurch and Littlefield (1987) indicate that over 15 percent of the land surface consists of closed depressions in the heart of the Brandon karst terrain.

The Brandon karst terrain coincides with portions of the Pamlico escarpment and is analogous to the Cody Escarpment (White, 1970) of north and

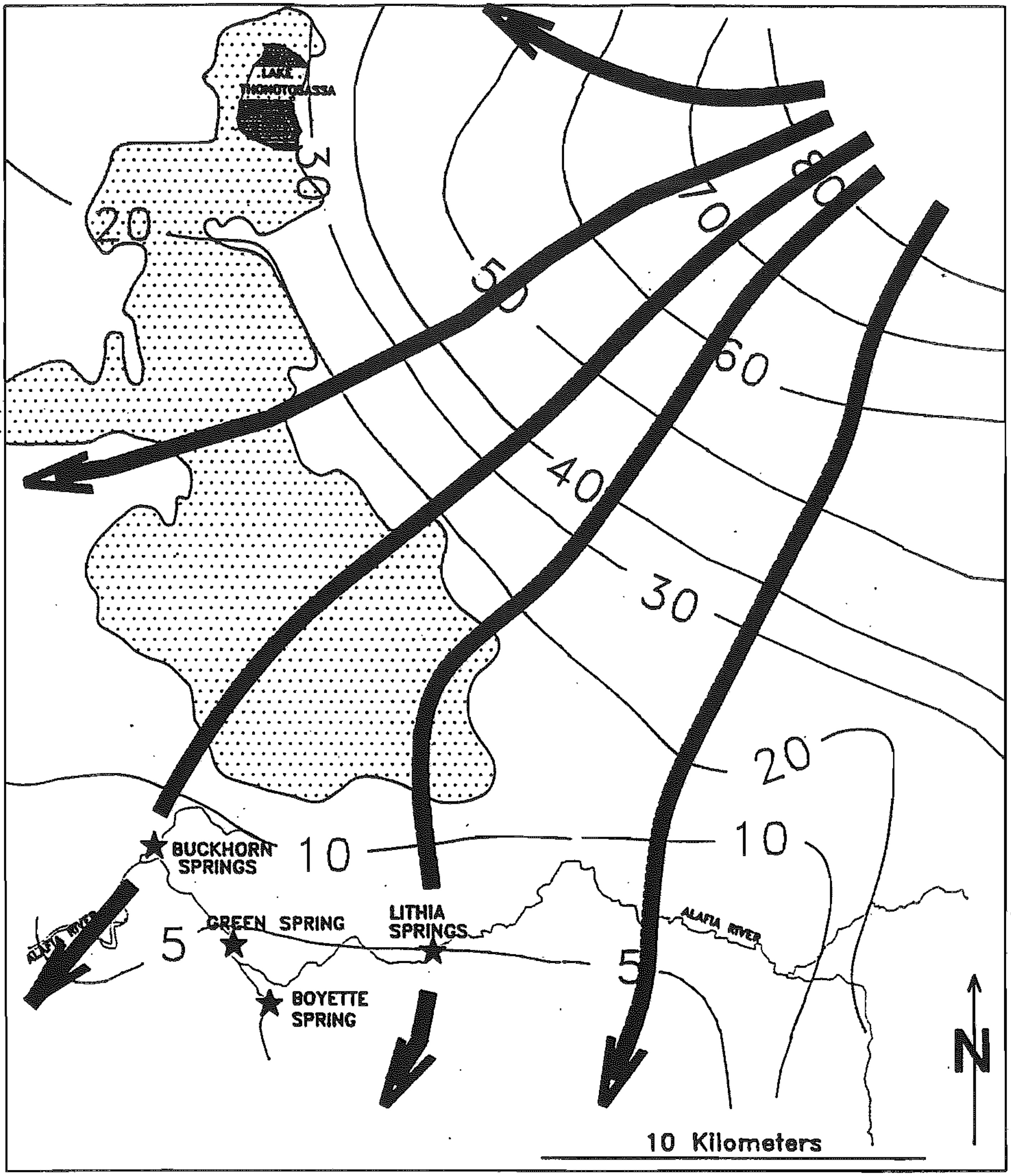


Figure 10. Generalized Potentiometry of the Floridan Aquifer Through the Study Area (modified from Barr, May, 1989).

central Florida. The hydrology of this escarpment has been described by Lawrence and Upchurch (1976, 1982) and Upchurch and Lawrence (1984). Such terrains form at the pinch out of the Hawthorn Group where recharge of highly aggressive water is concentrated.

The Brandon karst terrain was formed as acidic water, including organic-rich surface water, Surficial Aquifer water, and water from clastic horizons in the Intermediate Aquifer system leaked through the thin confining layer. Chemical erosion of the limestones of the Intermediate and Floridan Aquifer systems was, thus, focused at the pinch out. The sinkholes captured surface-water drainage and funneled it underground which promoted further dissolution of limestone. This led to progressive integration of voids beneath the surface allowing larger and larger amounts of water to be funneled into the underground drainage system. Eventually, the surface water drainage system in the area disappeared altogether, and today all drainage is internal. The underground drainage system consists of vertical and lateral conduits that lie below the present water table and greatly facilitate ground-water flow.

The residual clastic sediments and remnants of limestone remained as ridges between sinkholes. In many cases, the clastic sediments were washed into the karst conduiting beneath the sinkholes. Figure 11 illustrates a cross section of a sinkhole near the junction of Mulrennen Road and Brandon Boulevard (SR 60). This sinkhole is on the eastern edge of the Brandon karst terrain and clearly illustrates the fate of siliciclastics within the drainage basin of the sink. The test boring in the throat of the sinkhole was extended over 200 feet without encountering limestone. Thus, the sinkhole is connected with karst conduiting in both the Intermediate and Floridan Aquifer Systems.

It is uncertain when the sinkholes formed. Upchurch (1993, in press) has shown that karst formation in Florida began at least as early as late Miocene (the Messinian low sea stand, approximately 6.5 million years ago). The sinkholes in the study area are post-Hawthorn as indicated by superposition. At any rate, many of the sinkholes were formed prior to the Plio-Pleistocene marine transgressions (5 million years ago), and modern sinkhole topography has formed by reactivation of these older sinkholes. At present, the Brandon karst terrain is growing. The data of Upchurch and Littlefield (1987; Table 2) show that modern sinkholes are most probable in the Dover area, northeast of the Brandon karst terrain.

The portion of the study area south of the Alafia River and east of Lithia Springs lacks significant sinkhole development (Figure 1) and related underground drainage. This is because the thicker clay layers of the Hawthorn Group suppress downward migration of surface water and prevent dissolution of the limestone or reactivation of buried karst features. This area is influenced less by sinkhole development than surface erosion caused by rivers and transgression and regression of the sea.

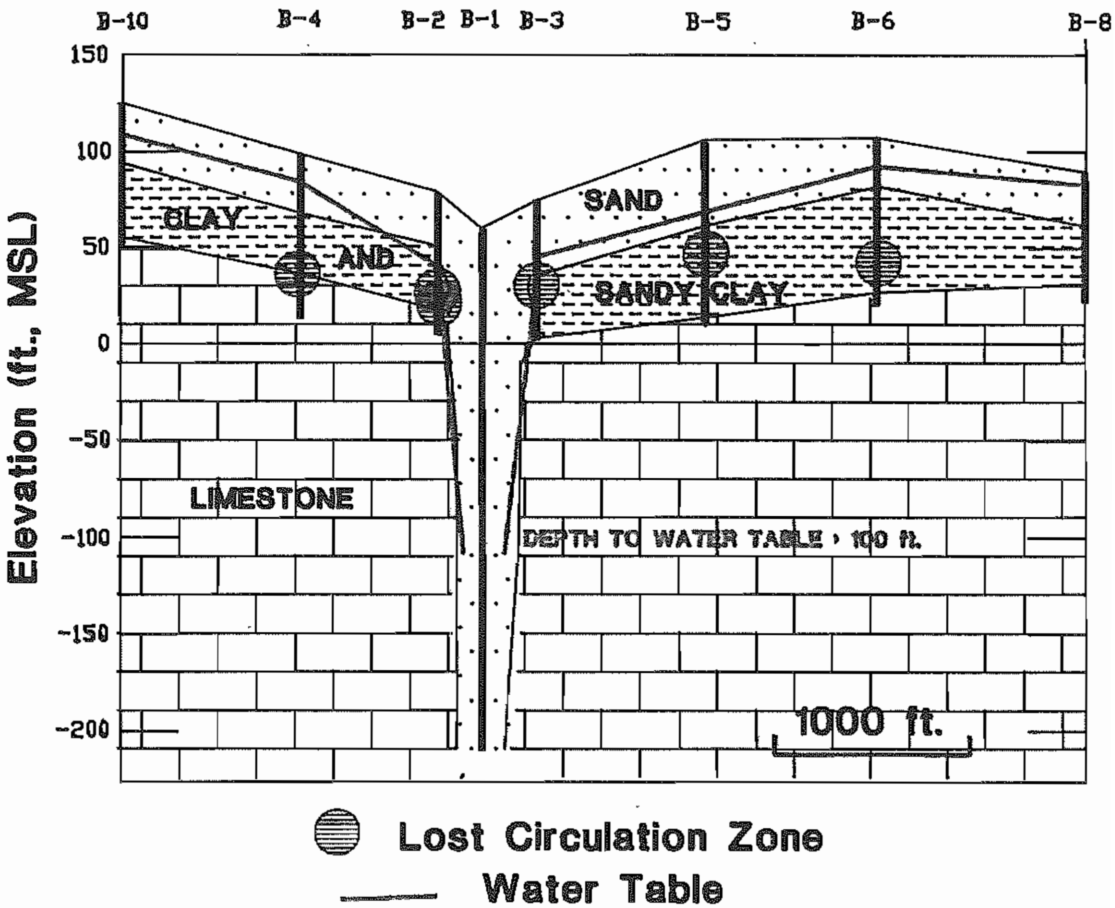


Figure 11. Cross Section through the Mulrennan Road Sinkhole.

Figure 10 shows the location of the Brandon karst terrain, as defined by the Pamlico scarp and large sinkholes; the general potentiometric surface of the Floridan Aquifer; and general ground-water flow patterns in the Floridan Aquifer, based on orthogonals to potential isolines. The potentiometric gradient flattens out in the Brandon karst terrain as indicated by an increase in the spacing of potentiometric contour lines. This results from a increase in the transmissivity of the Floridan Aquifer in the area as a result of the enhanced conduit flow system. The main inputs to the conduit system are the sinkholes. The flow lines indicate that ground water moving southwest through the Floridan Aquifer is intercepted by the increased transmissivities of the Brandon karst terrain and diverted southward towards Lithia and Buckhorn Springs.

Springs in the Study Area

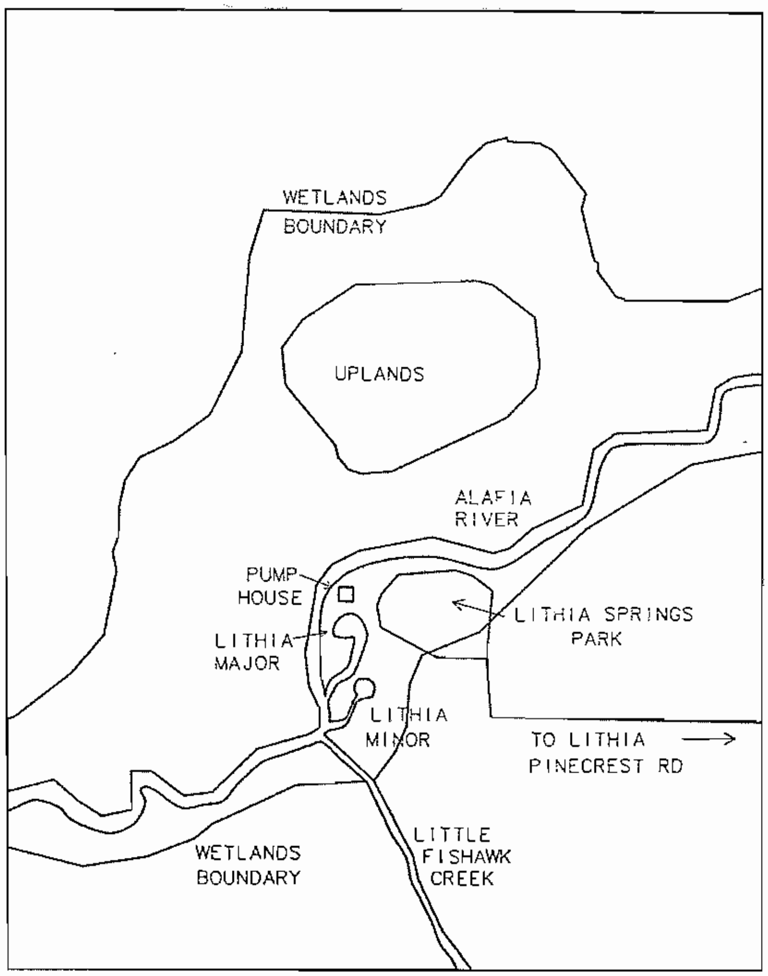
An extensive reconnaissance of the study area revealed a total of 8 terrestrial springs on or near the Alafia River. Two are located at Lithia Springs, 4 at Buckhorn Springs, 1 on Bell Creek (Boyette Spring), and Green Spring which occurs on the northeast side of the river between Buckhorn and Lithia Springs. Locations of the Springs are depicted in Figure 1. It is highly probable that subaqueous springs are located beneath the surface of the Alafia River. However, none were located during a reconnaissance of the river.

Lithia Springs

Lithia Springs is located on the north shore of the Alafia River, approximately 4 miles southeast of Buckhorn Springs (Figure 1). Lithia Springs consists of two springs, each with runs flowing a short distance to the Alafia River (Figure 12).

The larger spring is known as Lithia Springs Major. It forms an oval pool 75 to 100 ft. in diameter with 1 vent discharging from a nearly horizontal cavern. Limestone exposures surrounding the spring belong to the middle portion of the Arcadia Formation of the Hawthorn Group (Scott, Thomas, Florida Geological Survey, pers. comm. 1993). Average discharge of Lithia Spring Major is approximately 40.0 ft^3/s. This was calculated by adding the average of 36 flow measurements obtained over a 9-year period (West Coast Regional Water Supply Authority, 1992) to the average annual pumpage from the spring by Cargill Fertilizer (SWFWMD, 1992).

Lithia Springs Minor is located approximately 400 ft southeast of Lithia Springs Major. The spring discharges into a pool approximately 50 ft across, and the water travels down a 10 ft. wide run 100 ft. to the Alafia River. Discharge from Lithia Springs Minor averages 7ft^3/s. This also was calculated by averaging thirty six flow measurements obtained over a 9-year period (West Coast Regional Water Supply Authority, 1992). Lithia Springs Minor is not pumped.



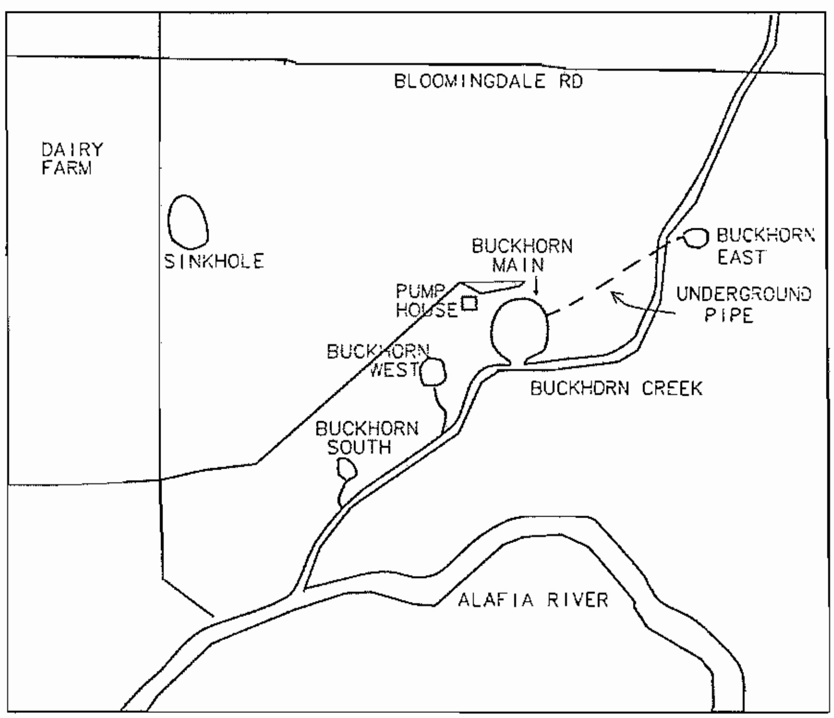


Figure 12. Immediate Vicinity of Lithia Springs (Top) and Buckhorn Springs (Bottom).

Buckhorn Springs

The Buckhorn Springs complex is located approximately 2.8 miles northeast of the Town of Riverview (Figure 1). The spring complex is composed of four principal springs and many smaller, less-significant vents located near Buckhorn Creek on the north shore of the Alafia River. The principal springs are: Buckhorn Springs Main, Buckhorn Springs East, Buckhorn Springs West, and Buckhorn Springs South (Figure 12). All of the springs, except Buckhorn Springs East, flow into Buckhorn Creek which enters the Alafia River approximately 0.4 miles downstream from Buckhorn Springs Main. The flow from Buckhorn Springs East has been diverted from Buckhorn Creek to the Buckhorn Springs Main Pool through an underground pipeline.

Buckhorn Springs Main discharges directly to its run from a nearly horizontal cavern. Limestone exposures surrounding the cavern have not been identified. However, Buckhorn Springs Main is at approximately the same elevation as Lithia Springs Main. Therefore, similar to the Lithia Springs outcrops, those at Buckhorn are probably from the middle portion of the Arcadia Formation of the Hawthorn Group.

Buckhorn Springs Main is by far the largest of the four springs. Average discharge of Buckhorn Springs Main is approximately 14 ft^3/s. This was calculated by adding the average of 126 flow measurements obtained over a 2-year period (West Coast Regional Water Supply Authority, 1992) to the average annual pumpage from the spring by Cargill Fertilizer (SWFWMD, 1992).

Buckhorn Springs East, based on limited measurements obtained from this study, discharges approximately 1 ft^3/s. Rosenau (1977) gives three discharge measurements for Buckhorn West (Rosenau's Buckhorn Tributary Spring #3) which average 1.6 ft^3/s. The discharge from Buckhorn South has not been measured but is estimated by SWFWMD staff to be 1 ft^3/s. Therefore, total discharge from the 4 main vents of Buckhorn Springs is approximately 17.6 ft^3/s.

Boyette Spring

Boyette Spring is located on the west bank of Bell Creek directly under the bridge on Boyette Road, 0.3 miles west of Bell Shoals Road. The spring discharge creates a small oval pool 4 ft. in diameter. The pool drains through a narrow run approximately 10 ft. long that ends in Bell Creek. Discharge has not been measured but probably averages less than 0.1 ft^3/s. No limestone is visible at the spring, and it appears that Boyette Spring is situated at the contact between the Surficial Aquifer and the underlying Hawthorn Group clays. Therefore, the spring is part of the Surficial System and is not related to the karst system.

Green Spring

Green Spring is located on the north shore of the Alafia River approximately 1 mile downstream from the Bell Shoals Road bridge over the Alafia River. The spring is surrounded by a levee that creates a small, circular pond approximately 20 ft. in diameter. The spring vent is not discernable in the pond but a small outflow indicates that spring discharge is probably less than 0.5 ft^3/s. Conditions indicate that this spring is also contained within the Surficial Aquifer and is not related to the karst system.

STUDY DESIGN, METHODS, AND DATA COLLECTION

INTRODUCTION

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

Delineation of the Study Area

Deductive reasoning leads one to conclude that the nitrates and other nutrients being released to the Alafia River 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. While it was assumed that some, if not most, of the water discharging from the springs was from the Floridan aquifer and had followed lengthy flow paths from the Green Swamp recharge area, it is unlikely that contamination from recharge in the Green Swamp recharge area could have travelled to the springs in the 100 to 150 years of intense human activity. Therefore, one or more local sources of nutrients must exist and they must be related to a local recharge area.

One of the most important aspects of the project was, therefore, to determine the extent of the local recharge areas for Lithia and Buckhorn Springs. Prior to any water-quality sampling, the assumption was made that the source aquifer for at least the two main springs at Lithia and Buckhorn is the Floridan Aquifer. Flow nets constructed using the U.S. Geological Survey's May 1989 potentiometric surface map indicate that at least a portion of the water in the Floridan aquifer that passes through the Lithia and Buckhorn area originates as rainfall near the Green Swamp potentiometric high in northern Polk County. Once in the Floridan Aquifer, water flows west to the Hillsborough County line then turns southwest and moves through the Plant City vicinity and finally turns south as it enters the Brandon karst terrain and the Lithia and Buckhorn Springs vicinity.

Recharge can occur at many points along this flow path where the Floridan Aquifer is either unconfined or poorly confined. Although the areas where recharge potentially occurs are very large, staff decided that the study area could be significantly reduced through use of two criteria. First, many areas can be eliminated because of a lack of development. These areas could not contain nitrate sources sufficient to contaminate ground water to the current levels. Land use maps of the area indicate that virtually all of the flow path north of the Plant City area falls into this category. Second, the potentiometric surface of the Floridan Aquifer suggests that water north of Interstate Highway 4 flows westward, towards the Hillsborough River, rather than south or southwest, toward the springs.

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.

Collection of Existing Data

Once the local recharge area had been identified, the ground-water data collection phase of the project began. An extensive literature search was conducted to locate ground-water quality data for the springs and wells in the study area. A number of different data sources were utilized including the defunct Florida State Board of Conservation (1951), environmental consulting firms, West Coast Regional Water Supply Authority, the Florida Bureau of Geology, the Department of Environmental Regulation, and the U.S. Geological Survey (1985). Appendix II contains historical data for both Lithia and Buckhorn Springs and a number of monitor wells in the study area.

Establishment of a Study-Area Monitor-Well Network

The most important tool in determining the source of nutrients in the springs was the water-quality data obtained from the monitor-well network in the study area. 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 89 home-owner wells were included in the network. In addition, 12 existing monitor wells were located in the study area and included in the network. Nineteen additional homeowner wells were added to the network at various stages in the project when data analysis indicated inconclusive results or gaps in well coverage. Figure 13 is a map of monitor-well locations. Well Specifications are listed in Appendix III.

Stratigraphic Evaluation of Open-Hole Intervals of Monitor Wells

Total depth and cased 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 their screened intervals are open. Figure 14 indicates the stratigraphic interval and aquifer from which each well is receiving water.

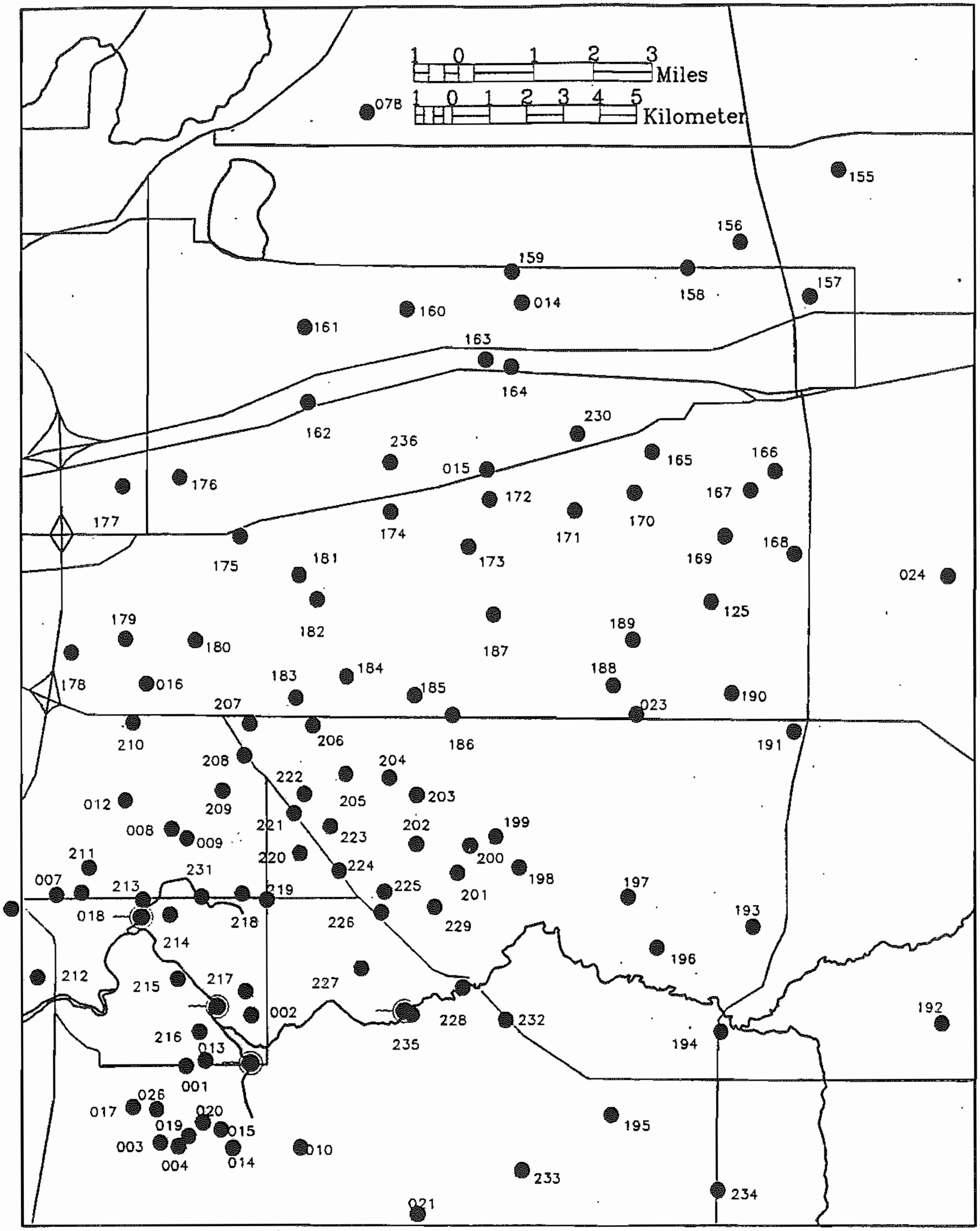
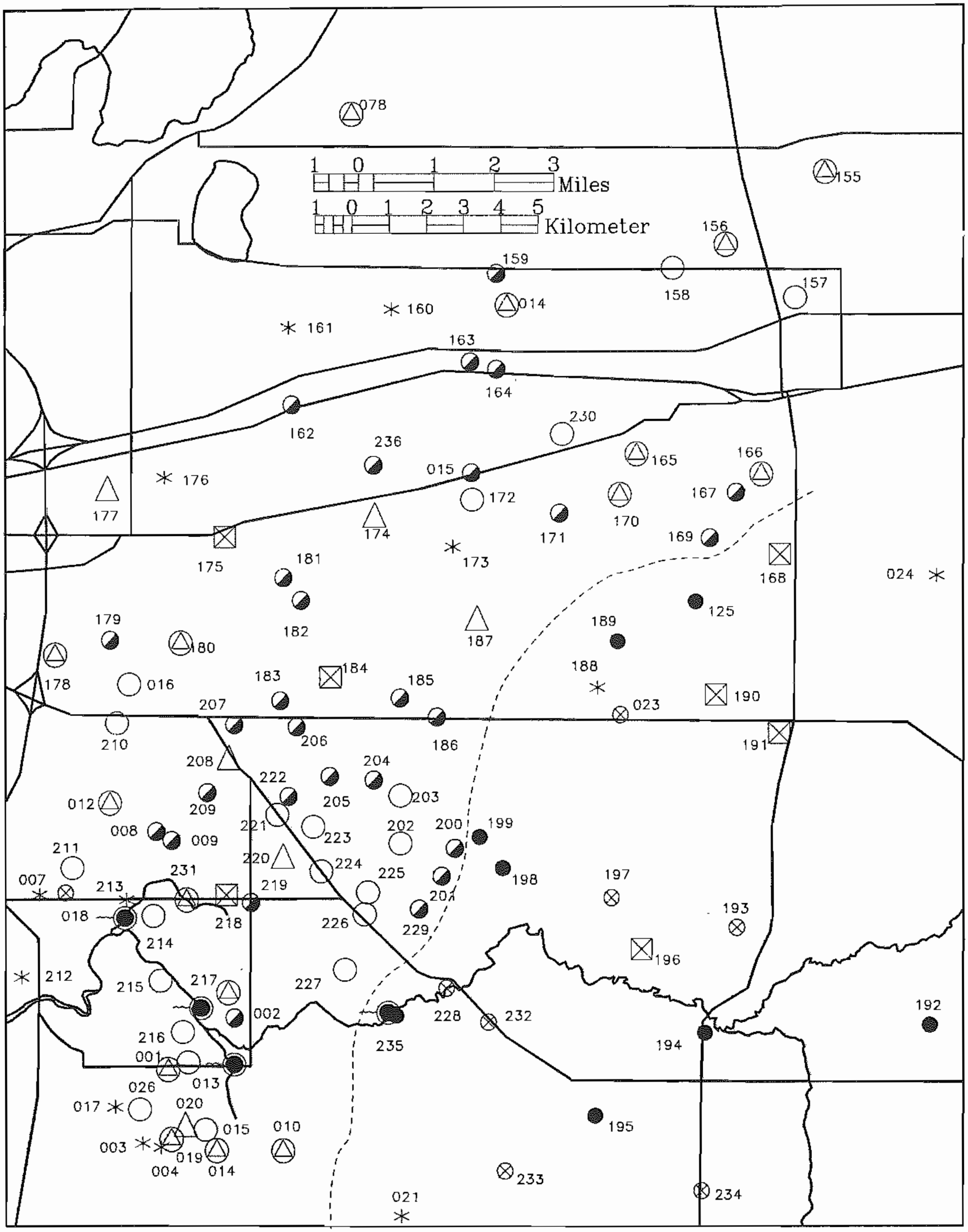


Figure 13. Location of Wells Sampled in the Study Area.



Dashed line separates general area of wells considered Floridan Aquifer from those considered intermediate Aquifer

Tampa Member - Floridan Aquifer

Hawthorn Group above Tampa Member - Intermediate Aquifer

Tampa Member Intermediate Aquifer

Tampa Member of Hawthorn Group and Suwannee L.S.

Hawhtorn Group Including Tampa Member - Intermediate Aquifer

Hawthorn Group Including Tampa Member Floridan Aquifer

Suwannee L.S.

No data

Figure 14. Stratigraphic Interval and Aquifer from Which Network Wells Obtain Water

Most of the wells in the eastern half of the study area, where the Hawthorn Group is relatively thick and the Tampa Clay is present, tap the limestones and dolostones of the Intermediate Aquifer System (Tampa Member, Arcadia Formation). Most wells in the western portion of the study area where the Brandon karst terrain is located are open to the Tampa Member where the Tampa Clay is absent. Since the Tampa Member of the Arcadia Formation is hydraulicly connected with the Floridan Aquifer, these wells are considered to be Floridan Aquifer wells. A large proportion of the wells in the Brandon karst terrain are also open to the Suwannee Limestone.

Water Quality Sampling of Springs, Monitor Wells, and Surface Water

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 and quality assurance data obtained from spring and monitor well sampling are included in Appendix IV. Methods used are current, U.S.E.P.A.-approved standard methods, where available.

Analytes

The list of analytes selected varied with the nature of the sample and its application to the study. Choices of analytes are discussed by sample type (below). Table 3 shows the analytes used in the study.

Table 3. - 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	

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

Tritium - Tritium (^3H) is a rare isotope of hydrogen that is formed by cosmic-ray activation of nitrogen. Before 1952, the tritium content of meteoric water (relatively recently recharged near-surface water) ranged from 1 to 10 TU[3].

Atmospheric nuclear-weapons testing has raised tritium activities as much as two orders of magnitude. While tritium began to be introduced in the mid-1940's, the major build-up of tritium began with cold-war testing in the 1950's (Figure 15). Tritium activities in meteoric waters increased until the mid-1960's when atmospheric test bans became effective. Tritium has a half life of 12.4 years, so decay and cessation of atmospheric testing have resulted in a decline of tritium in precipitation to activities similar to background. Thus, any ground waters that contain significant levels of tritium can be assumed to have been recharged in the period from 1950 to 1975. Ground waters with tritium activities less than 10 TU can be assumed to have been recharged before 1952 or within the last 10 years.

Tritium activities have been used successfully previously in several studies in the District. Faulkner (1973) found tritium activities in wells and springs near the Cross-Florida Barge Canal as high as 174 TU at the same time (1966-68) that rainfall contained activities as high as 158 TU. Activities in Rainbow and Silver Springs ranged from 38 to 85 TU and 25 to 150 TU, respectively. Swancar and Hutchinson (1992) used tritium to show that Floridan Aquifer waters in the northern half of the District are relatively young, with activities of 8 to over 10 TU common. The Lithia/Buckhorn study area is on the transition between these tritium-rich waters and water with activities of 0 to 2 TU south of the Alafia River. They also concluded that recent recharge water has relatively low tritium concentrations (on the order of 10 TU as opposed to higher activities) because of (1) relatively long periods required for recharge and (2) mixing with older waters in the Floridan Aquifer.

Uranium - The isotopic ratio $^{234}U/^{238}U$ has been successfully utilized by J.K. Osmond and J.B. Cowart (*i.e.*, Osmond and Cowart, 1976; Cowart *et al.*, 1978) of Florida State University to trace ground-water flow systems, determine relative ages of ground-water masses, and determine provenance of water masses. They were contracted to analyze 36 samples from the study area and determine similarities of the ground-water and spring samples, if possible. The discussions that follow are largely from their unpublished report (Cowart and Osmund, 1992).

Uranium concentration can be used to roughly determine age and history of ground water in Florida. Low concentrations (<0.1 µg/L) are typically associated with reducing conditions and deep, slow-moving waters. High concentrations (>0.1 µg/L) are found in oxidizing waters that are typically shallow and relatively young (recently

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[3] 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).

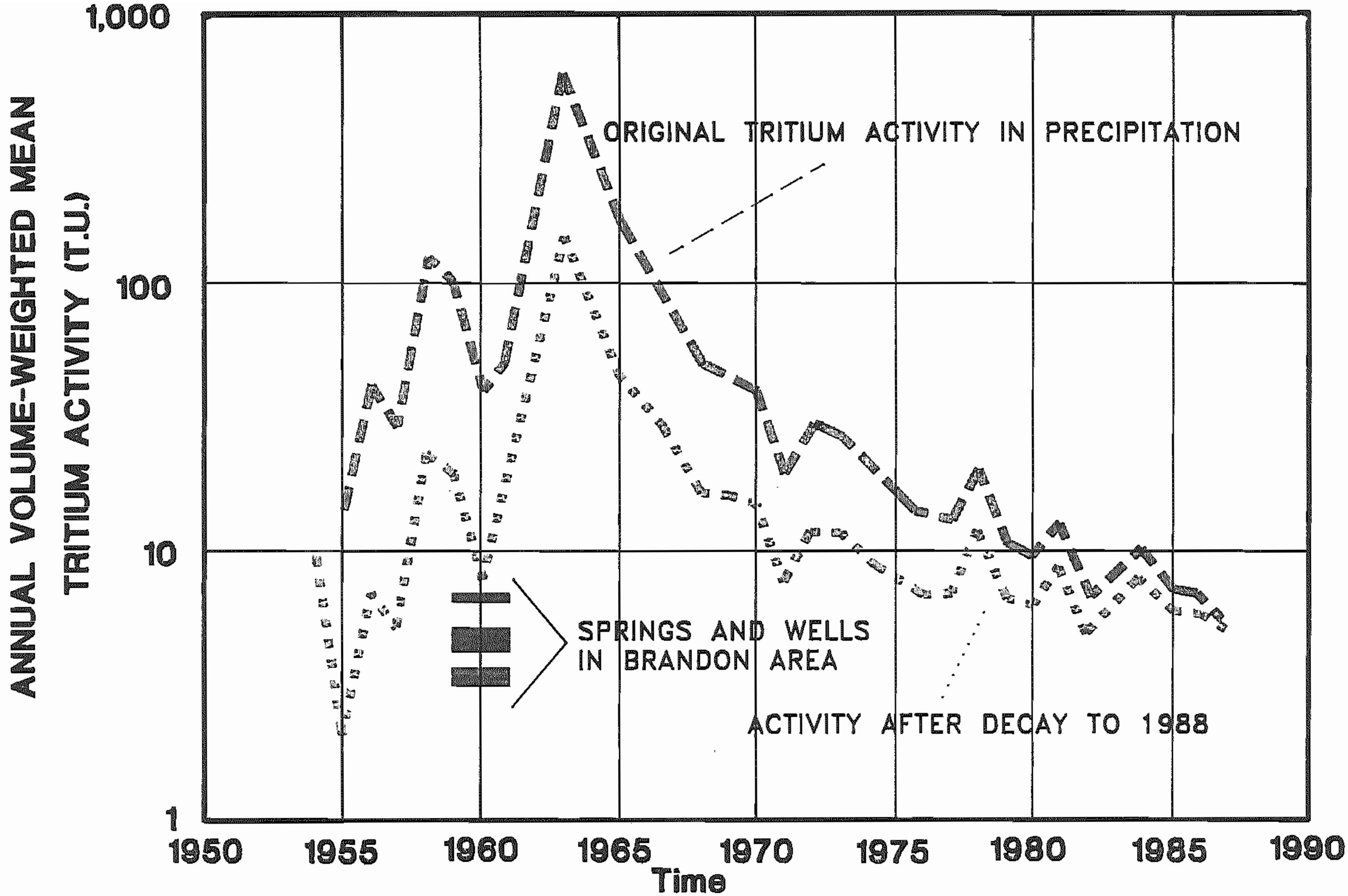


Figure 15. Distribution of Tritium in Precipitation Over Time.

recharged). The ratio of ^{234}U to ^{238}U is also sensitive to ground-water age. Alpha recoil (Osmond and Cowart, 1976) forces ^{234}U into ground water relative to ^{238}U. Thus, older waters tend to have higher $^{234}U/^{238}U$ than do younger waters.

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

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

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

Wolterink *et al.* (1979) studied two sites in the Tampa Bay area. One was a septic tank site first described by Rea and Upchurch (1980); the other a wastewater spray-irrigation site near the University of South Florida. Based on soil samples from the septic tank site, NO_3^- concentrations ranged from 5.7 to 56.0 mg/L, and the $\delta^{15}N$ ranged from -6.3 to +18.8. Raw data from the spray-irrigation facility were not reported.

Springs Network

The sampling schedule and list of parameters to sample from the 8 springs was complicated by the need to determine monthly and seasonal variability and the need to balance limited funds with the degree of importance of each spring (based on magnitude of discharge).

With the exception of Green Spring, all springs were initially sampled in late April 1991 for 11 major ions, 6 nutrients, total dissolved solids, total organic carbon, and 7 trace metals (Table 3). Green Spring was sampled in late April of 1992 for all of the above parameters except the metals. Following the initial sampling, Buckhorn Main, Buckhorn East, Boyette, and Lithia Major were sampled monthly for the nutrients and quarterly for the major ions through January 1992. From February through July 1992, these springs were sampled monthly for nutrients only. Buckhorn West, Buckhorn South, and Lithia Minor were sampled quarterly for nutrients and major ions through January of 1992. From February through July 1992, these springs were sampled quarterly for nutrients only.

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

Monitor-Well Network

Two separate parameter lists were formulated for the 101 wells in the study area that were to be sampled by the AGWQMP. The first list included 10 major ions, 6 nutrients, total dissolved solids, total organic carbon, and iron. A total of 95 wells were sampled for these parameters. The second list included 4 nutrients and total organic carbon. Fourteen wells were sampled for these parameters.

A small number of homeowner and monitor wells were also sampled for isotopes of hydrogen, nitrogen, and uranium. Seven wells were sampled for tritium, 8 for nitrogen-15, and 32 for uranium-234 and -235.

Surface-Water Network

Surface-water samples were taken from several locations on Bell Creek and Buckhorn Creek. Locations of creek samples are indicated in Figure 16. Sampling results from the creek samplings and from a 1986 sampling of 5 stations on the Alafia River are included in Appendix IV.

Characterization of the Flow System

As discussed previously, the presence of sinkholes, internal drainage, and springs in the Brandon karst terrain 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.

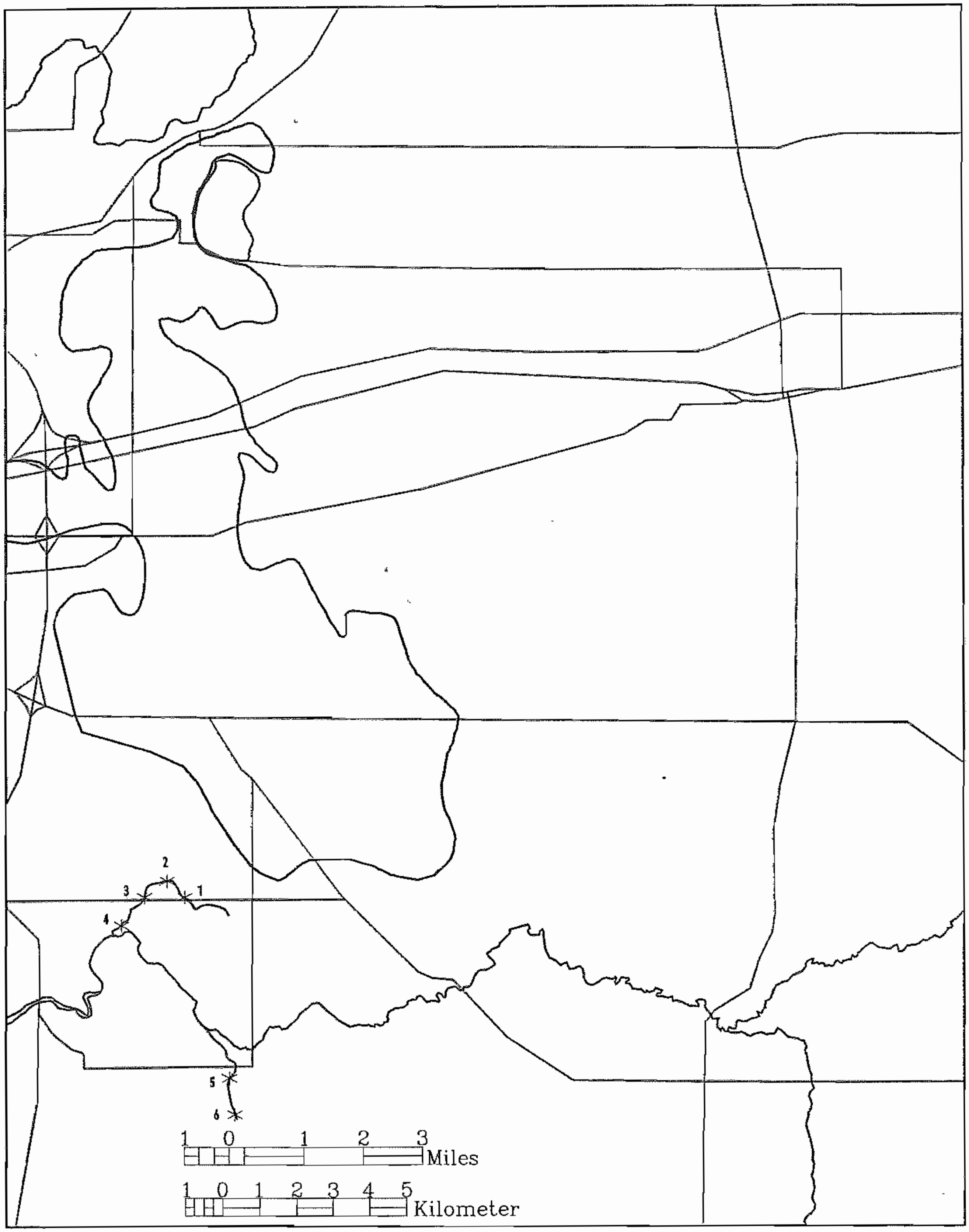


Figure 16. Creek Sample Locations.

Sinkhole Reconnaissance and Fracture-Trace Analysis

To characterize the extent of the Brandon karst terrain, USGS 7.5' topographic quadrangle maps of the study area were searched for closed-depression type features. These features were then field checked to determine if they were indeed sinkholes or some type of artificial depression, such as a borrow pit. Locations of the features are plotted in Figure 17 A. From the figure it is apparent that the majority of the sinkholes in the study area are located within the boundaries of the Brandon karst terrain.

Sinkholes in the Brandon karst terrain are often water filled. The elevation of the water surface in the sinkholes is considerably higher than the potentiometric surface of the Floridan Aquifer. Therefore, the sinkholes are probably plugged or partially plugged and the water level is representative of the Surficial Aquifer or a perched water table.

Figure 17 B depicts the location of wetlands in the study area. It is apparent in the figure that most of the wetlands occur outside of the Brandon karst terrain. The fact that water does not pond in low areas of the Brandon karst terrain, except within plugged sinkholes, is an indication of the efficiency of the underground drainage system.

Littlefield *et al.* (1984) showed that sinkholes in the area are aligned along photolinear features[4], or fracture traces. Identification of fracture traces in urbanized regions is difficult, so older photographs and satellite (LANDSAT) images were utilized in conjunction with the USGS topographic maps. Alignments were, thus, identified. Jian Chen, a graduate student and karst specialist at the University of South Florida conducted a second, independent analysis, which confirms the one reported here. Figure 17 C shows the locations of major fracture traces in the study area. Many smaller ones were identified, especially by Chen, but they are short and narrow and are, therefore, less likely to affect regional ground-water flow. Note that the springs are located along major fracture traces.

Two fracture traces are of primary significance to the following interpretations. One extends northwest from the Lithia Springs area and appears to serve as a conduit for flow southeastward from the Brandon karst terrain. The other extends north-

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

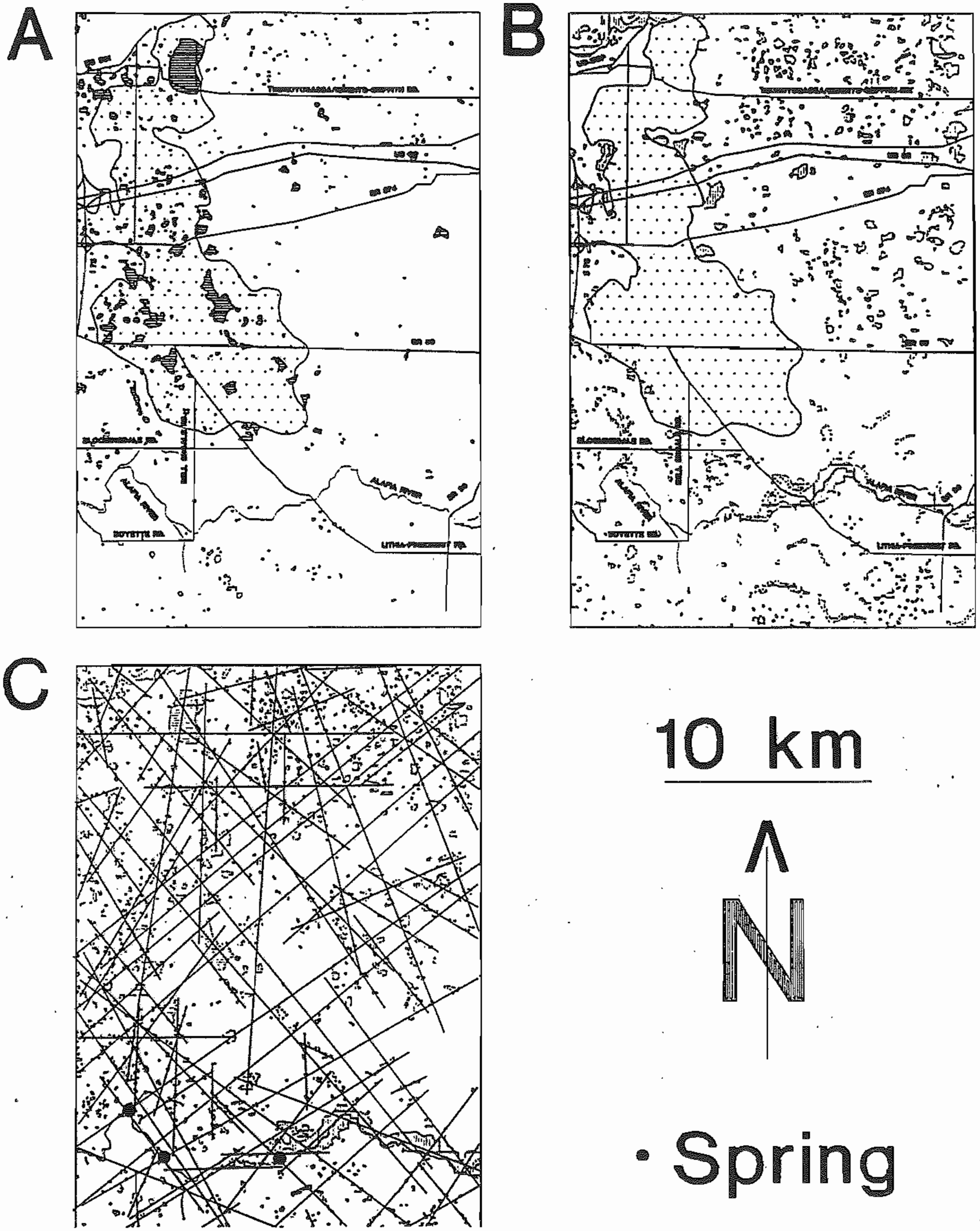


Figure 17. Locations of Major Sinkholes (A), Wetlands (B), and Fracture Traces (C) in the Study Area.

northwest, through Boyette Springs and Buckhorn Springs. This fracture trace seems to affect nitrate movement to both springs from adjacent sources.

Potentiometric Surface of the Floridan Aquifer

The potentiometric surface of the Floridan Aquifer in the study area is depicted in Figure 10. These data were taken from the May 1989 Floridan Aquifer potentiometric surface map (Barr, 1989). No local monitor wells exist for a more accurate map at this time.

Flow in the area is generally to the west and southwest. There was insufficient data for the authors of the potentiometric-surface map to place contours indicating discharge to the river and springs. Chemical data from this study indicate that there is a Floridan Aquifer component discharging through Lithia and Buckhorn Springs, however.

Note that the flow lines derived from the potentiometric surface suggest that water that passes through or is recharged in the southern half of the Brandon karst terrain flows towards the river and springs. Flow lines in the northern half of the Brandon karst terrain flow westward and suggest shallow discharge to the west, near the Tampa By-Pass Canal, Hillsborough River, and elsewhere. Therefore, the southern half of the karst terrain is most likely to contain sources of nutrients discharging through the springs.

From Figure 10 and previous discussions it is apparent that, from northeast to southwest across the study area, a significant flattening of the potentiometric gradient occurs in the Brandon karst terrain. This indicates that the transmissivity of the limestone in the Floridan Aquifer must increase dramatically in the area. This is further evidence that a well-developed karst flow system exists in the Brandon area.

Optical Brightener Tracing

To determine if subsurface connections exist between Lithia and Buckhorn Springs and sinkholes in the Brandon karst terrain, a colorless optical brightener (Blankophor BBH) was introduced into a sinkhole located one half mile from Buckhorn Springs and another located 3 miles from Lithia Springs. To detect the optical brightener, unbleached cotton balls were placed in the Lithia and Buckhorn Spring vents.

Although the cotton balls in the springs did not show any conclusive fluorescence after several introductions of optical brightener and several weeks of monitoring, one cannot conclude that there are no connections between the sinkholes and springs. There are three possible explanations for this apparent lack of connection. First, most of the sinkholes in the study area are heavily vegetated, filled with mud and debris, and show no indication of limestone. These factors could inhibit the movement of the optical brightener into the aquifer. Second, ground-water travel times between the sinkholes and the springs are much greater than the several weeks the springs were monitored. Finally, karst conduiting is a complex, pipe-like series of pathways. There is no guarantee that the sinkholes tested are directly connected to the springs. They may not be connected, or the connection is through such a tortuous route that the brightener was retarded or diluted too much for use.

Response of Spring Discharge to Rainfall

To determine how quickly the springs respond to rainfall events, an attempt was made to correlate spring discharge with rainfall in the study area. During the months of May and June, 1992, rainfall data were collected daily from 3 stations within 10 miles of both Lithia and Buckhorn Springs. Spring discharge data from Lithia Major and Buckhorn Main were collected every Monday, Wednesday, and Friday in May, Monday through Friday in June, and the last weekend in June. The majority of measurements were taken between 9:00 and 10:00 am. The correlation between rainfall and discharge for both springs is discussed in the results section on page 43.

Chemical Distributions

Chemical data were machine contoured using the SURFER graphic package. The plot files were written to a DXF file and imported into AUTOCAD and edited to produce hydrogeologically reasonable maps by Upchurch. No changes were made to the contour patterns, only unsupported lines and inappropriate contours were changed. The maps, therefore, reflect an independent, quantitative interpretation of the data.

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

Because of allegations that the Alafia River may be a source of water in Lithia Springs, analyses of river water from 5 stations, one downstream and 4 upstream of Lithia springs were included. These data were obtained from samples collected by SWFWMD staff in October of 1986. These data are presented in Appendix IV and are plotted on the Piper/Stiff diagrams for comparison.

RESULTS

RESPONSE OF SPRING DISCHARGE TO RAINFALL

Figure 18 shows the locations of the rainfall stations and Figure 19 shows the rainfall versus discharge correlations for Lithia and Buckhorn Springs. The rainfall versus discharge graph for Lithia Springs uses the rainfall data from the South Central Wellfield Station, the closest station. The graph of Lithia Springs data indicates that the discharge curve is composed of two components. Component 1 is a steady recession of flow through May, historically the last month of the dry season, and a steady increase in flow through June corresponding to the beginning of the rainy season around June 1. This component is interpreted to represent regional ground-water baseflow. Component 2 is represented by the numerous peaks in the discharge curve. These peaks correspond very closely to rainfall events, which indicates that the spring responds to nearby rainfall events in less than 24 hours. This is not to say that rainfall that falls within several miles of the springs discharges within 24 hours. In actuality, local rainfall pressurizes the flow system and it is this pressurization that increases the discharge at the springs.

An interesting anomaly is observed in the discharge curve at the end of June. From June 25 through June 28, discharge drops from approximately 26 ft^3/s to 0 ft^3/s, even though 3.5 inches of rain fell in the area between June 22 and June 29. This anomaly can be explained by the fact that the stage of the nearby Alafia River can control the discharge rate of Lithia Springs. Following the June 25 rainfall event, the Alafia River began to rise rapidly. As the river rose, it raised the level of the spring pool. This increased the pressure head over the spring vent which resulted in a decrease in flow from the spring. When the rising river caused the spring pool to reach a certain level, the flow gradient was reversed, the spring became a sink, and river water began to flow into the vent. This phenomenon has been verified by Lithia Park personnel who have reported seeing a debris swirl in the vicinity of the spring vent when much of the park was flooded by the Alafia River. Spring/sink systems are known as estavelles[5] (Sweeting, 1972, p. 214) and have been described in many karst areas, including Mammoth Cave National Park in Kentucky (Hess and White, 1989). The reversal of flow in Lithia Springs is strong evidence that the springs do not represent resurgence of flow lost upstream on the Alafia River through subaqueous swallow holes.

The rainfall versus discharge graph of Buckhorn Springs also uses the rainfall data from the South Central Wellfield Station because, although it is approximately 5 miles away, the rainfall correlates with discharge better than the data from the other

[5] An estavelle is a spring/sink system that, according to season, can be either a spring or a swallow hole.

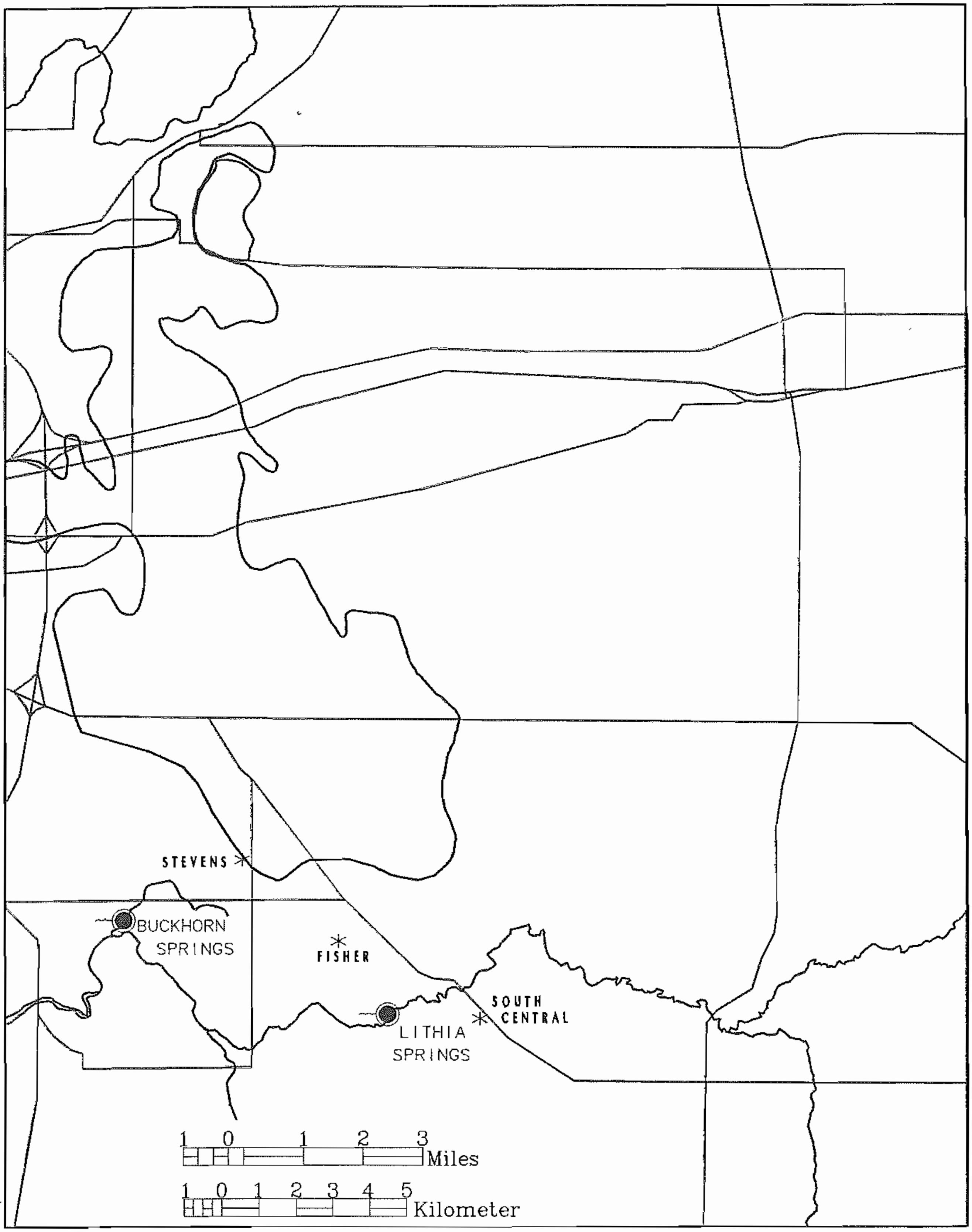
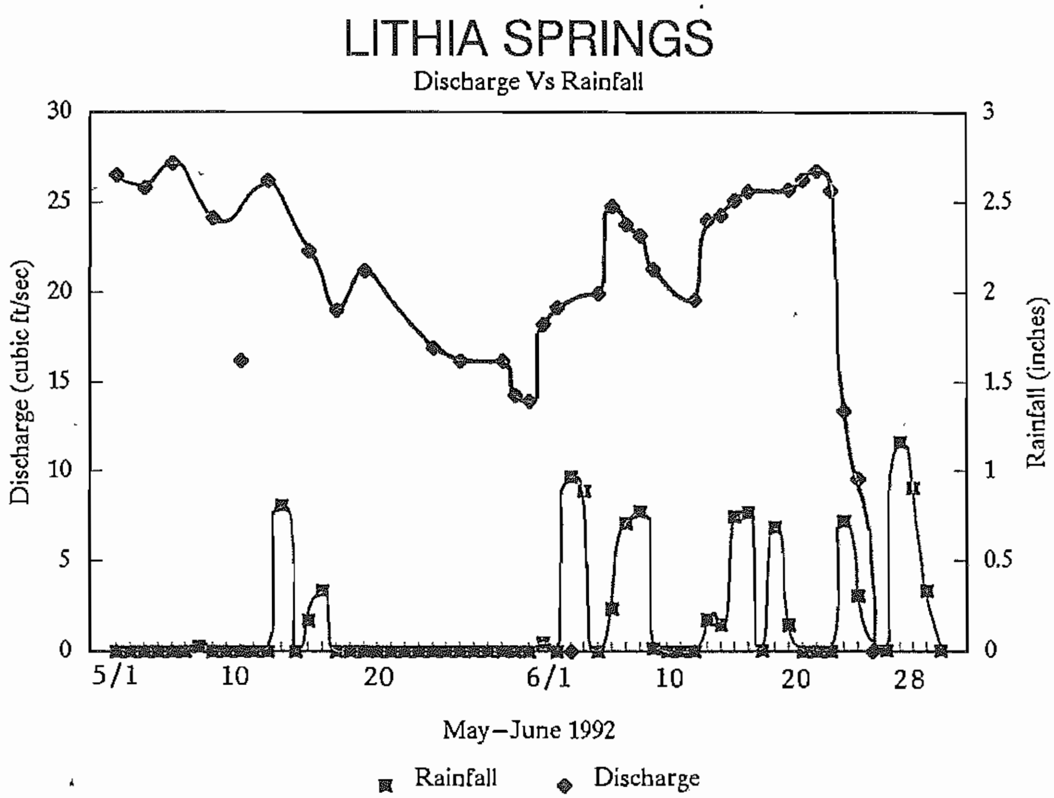


Figure 18. Rainfall Stations in the Study Area.



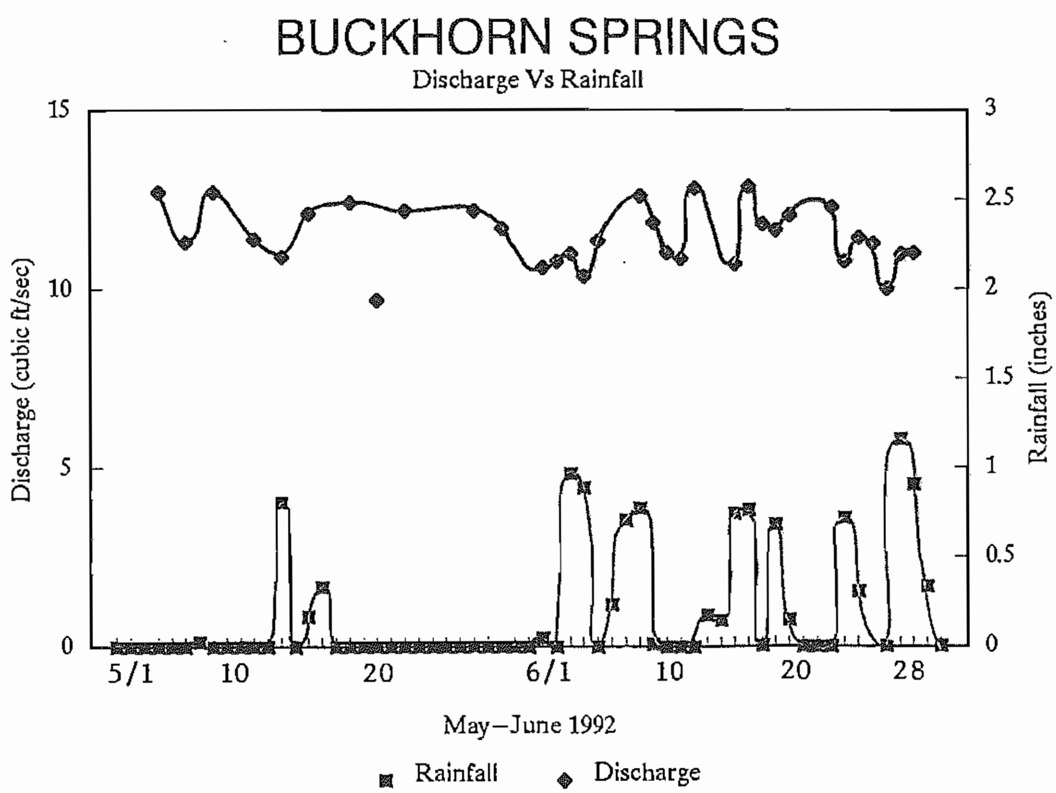


Figure 19. Rainfall/Discharge Correlations for Lithia and Buckhorn Springs.

stations. This may be because the South-Central station uses sophisticated measurement equipment while rainfall at the other stations is measured by volunteers using unsophisticated equipment.

The discharge curve displays an abundance of large amplitude peaks and troughs corresponding to rainfall events and an absence of a well-defined baseflow (dry season recession and wet-season increase in background discharge). This indicates that the spring may be more dependent on local recharge from sinkholes within the Brandon karst terrain rather than recharge from regional baseflow. The fact that the average annual Buckhorn discharge is only 37 percent that of Lithia may add weight to this conclusion.

The overall decrease in discharge toward the end of June illustrates that Buckhorn Springs discharge decreases as the stage of the Alafia River rises; a pattern that is similar to that of Lithia Springs. However, in the case of Buckhorn Springs the scenario is somewhat different because the Alafia River backs up Buckhorn Creek as it rises. The resulting buildup of slackwater in Buckhorn Creek raises the level in the Buckhorn Springs pool.

There is some question as to whether the Cargill withdrawals from Lithia and Buckhorn Springs are constant enough to eliminate the possibility of interference with the discharge curves. Repeated conversations with Cargill personnel have indicated that withdrawals do not fluctuate widely and only cease completely on rare occasions when pump maintenance is occurring. Therefore, it is reasonably certain that the curves do not reflect large fluctuations due to changes in the Cargill withdrawal rate.

CHEMICAL DISTRIBUTIONS

Tritium: An Indicator of Ground-Water Travel Time

Determining the tritium content of ground water in aquifer water helps to determine whether the aquifer is being recharged locally or from a more distant source. Tritium, a radioisotope of hydrogen, has a half life of approximately 12.4 years and is derived from both natural and artificial sources. Background tritium levels in rainfall prior to extensive atmospheric testing of hydrogen bombs between 1952 and 1963, were about 2 to 10 TU (6.4 to 32 pCi/L), depending on geographic location (Kaufman and Libby, 1954). With the advent of nuclear testing in 1952, large amounts of tritium were introduced into the atmosphere. This resulted in rainfall concentrations of tritium reaching 1188 TU (3,800 pCi/L) 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 averaged about 5 TU (16 pCi/L). Because of the dramatic increase in 1952, tritium provides a useful marker for relatively young water in the hydrologic cycle. Water recharge prior to 1952 should have a tritium concentration of less than 2 TU (6.4 pCi/L) (Yobbi, 1992).

Samples obtained from seven wells in the study area and from Lithia Springs Major, Buckhorn Springs Main, and Boyette Springs were analyzed for tritium. Results of the analyses are included in Table 4. The map reference number relates the well or spring to its location on Figure 20.

Table 4. Tritium Activities for Wells and Springs in the Study Area.

SITE NAME	MAP REFERENCE NUMBER	TRITIUM ACTIVITY (Pci/L)	(TU)
Boyette Spring	-	14	4.4
Lithia Spring Major	-	13	4.1
Buckhorn Spring Main	-	14	4.4
Ward	210	15	4.7
Howell	211	16	5.0
Cremeans	205	10	3.1
Thayer	026	11	3.4
Calloway	207	21	6.6
Meadows	190	16	5.0
Simmons Park	188	21	6.6

The tritium activities ranged from 3.1 TU to 6.6 TU (10 - 21 pCi/L) in monitor wells, while the springs ranged from 4.1 TU (13 pCi/L) in Lithia Major to 4.4 TU (14 pCi/L) in Buckhorn Main and Boyette Springs.

The tritium concentrations indicate that water in the 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 1960's. Comparison with Figure 15 suggests that activities in the 3 to 6 TU range are likely to have been recharged in the early 1950's, but not earlier, or in the 1990's. Alternative possibilities are (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]. All interpretations lead one to conclude that the water is young (<50 years since recharge). The rapid responses of the springs to rainfall events strongly suggests that flow to the springs is rapid and supports the conclusion that the water is young.

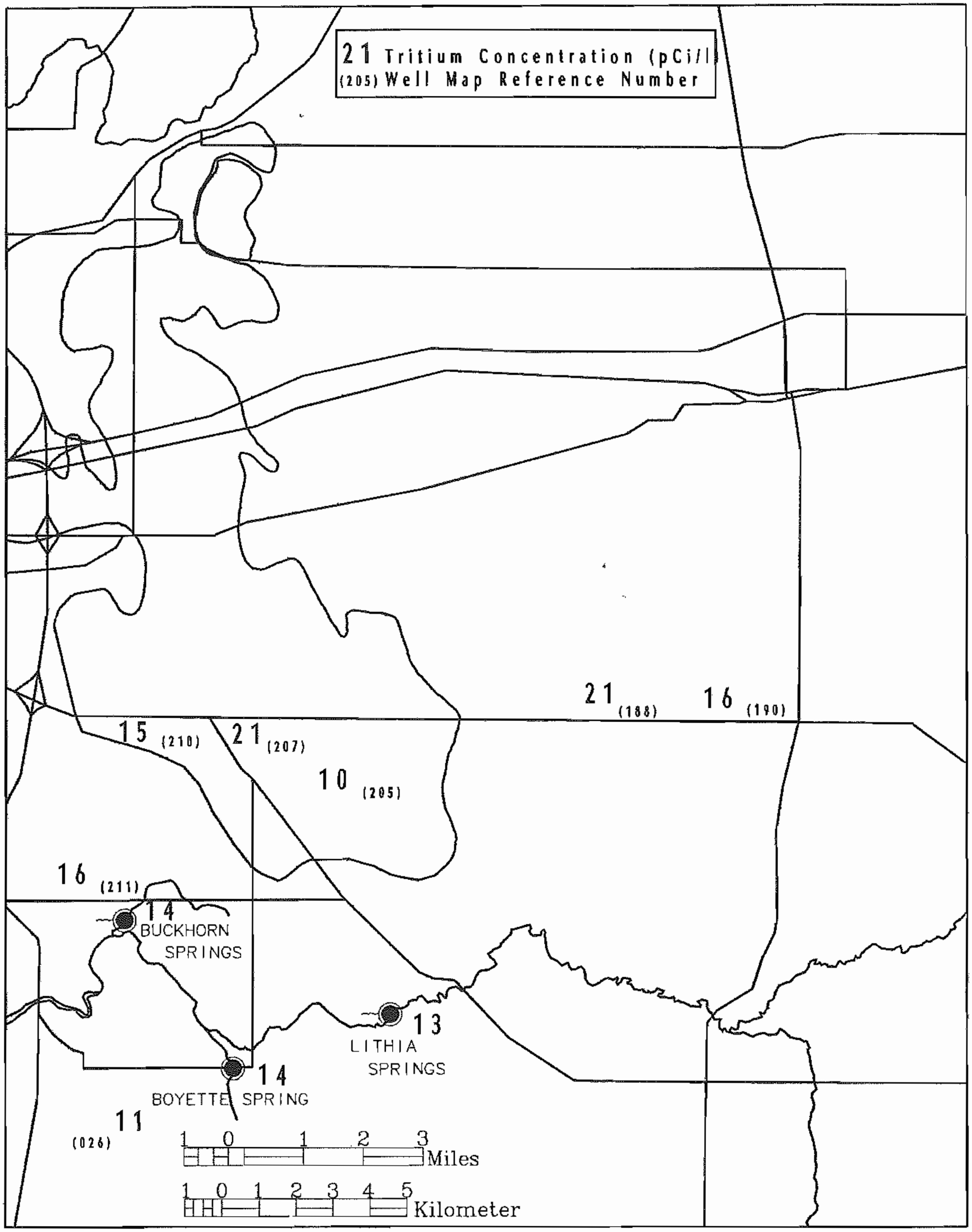


Figure 20. Tritium Concentrations (pCi/l) in Study Area Ground Water.

Uranium Isotopes: Indicators of Recharge Areas and Relative Water Ages

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

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

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

Twenty nine wells and four springs were sampled for uranium isotopes. The $^{234}U/^{238}U$ activity ratio and uranium concentration data are listed in Table 5. The map reference number relates the well or spring to its location on Figure 21.

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. Both Lithia Major and Buckhorn Main 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. This uranium isotope-derived recharge area is indicated in Figure 21. The area encompasses the southern portion of the Brandon karst terrain as well as extensions to the southeast and southwest of the terrain.

The Buckhorn Spring East uranium activity ratio and concentration, 1.2 and 0.5 respectively, are somewhat problematic. The activity ratio suggests flow in the

Table 5. 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
Lithia Major	-	0.7	1.0
Buckhorn Main	-	0.8	0.5
Buckhorn East	-	1.2	0.5
Boyette Spring	-	1.1	1.4
Davis	023	1.3	0.1
Hover	161	1.1	0.0
Sapp	167	0.9	0.1
Sheffield	177	0.5	4.1
Campo	179	1.0	0.1
Jones	180	1.1	0.0
Sydney Church	187	0.6	0.4
Albritten	193	1.9	1.0
Ernest	195	1.2	0.2
First Baptist	197	0.8	10.0
Pardo	199	1.4	0.0
Cremeans	205	1.1	0.1
Desrouchers	209	1.1	0.1
Howell	211	0.7	7.0
Carter	212	1.5	0.1
Bunch	213	1.1	0.7
Hernandez	214	1.1	0.1
Crellin	216	0.9	2.7

Table 5. Uranium Isotope Activity Ratios and Concentrations from Wells and Springs in the Study Area (continued).

SITE NAME	MAP REFERENCE NUMBER	$^{234}U/^{238}U$ ACTIVITY RATIO	U CONCENTRATION ug/l
Walter	217	1.5	0.1
Engle	220	0.8	4.8
Brandewien	225	0.7	0.6
Rector	227	1.3	0.0
Gleason	228	0.9	0.2
Cooper	229	0.6	0.9
Hills Cty Util	231	0.6	3.3
WCRWSA 1i	232	1.9	0.1
WCRWSA 7i	233	1.1	3.0
WCRWSA 6i	234	1.4	0.1

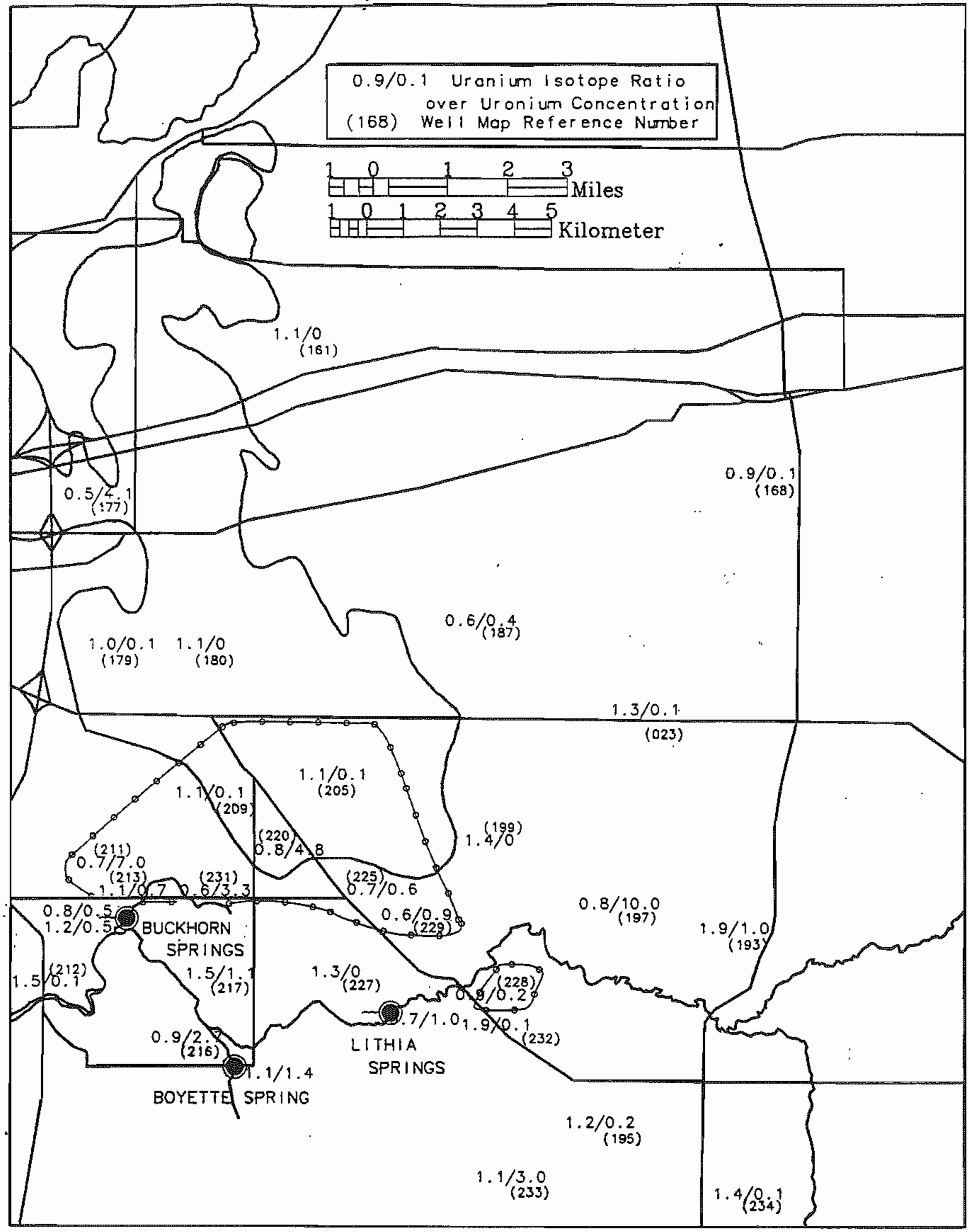


Figure 21. Uranium Isotopic Ratios and Concentrations in Study Area Ground Water. Dotted Line Encloses Wells that have Uranium Isotopic Ratios and Concentrations that are Similar to those of Lithia and Buckhorn Springs.

deep Floridan Aquifer System while the concentration suggests a rapidly recharging shallow karst flow system. It is difficult to determine what this indicates other than Buckhorn Main and Buckhorn East do not share a common source, which is supported by the water chemistry.

The Boyette Spring uranium activity ratio and concentration 1.1 and 1.4 µg/L respectively, is also problematic. The water chemistry of this spring indicates a Surficial Aquifer source. Although a Surficial source is supported by the high uranium concentration, the high uranium ratio indicates a deep Floridan aquifer source. The Hawthorn Group, which contains high uranium-daughter concentrations (Upchurch, Sam B., University of South Florida, personal communication, 1992) is near land surface at Boyette Springs (it is exposed in Bell Creek) and leaching by the acidic, organic-rich Surficial Aquifer water may account for the high activity ratio.

Nitrogen Isotopes: Differentiation of Nitrate Sources

Although many proven sources of nitrate, including septic-tank effluent, commercial and residential landscape fertilizers, land spreading of septic and sewage sludge, agricultural fertilizers, and dairy wastes are present in the study area, it is extremely difficult to determine the relative contributions of these sources to the nitrate problem at the springs. The $\delta^{15}N$ ratio in ground-water nitrate can provide a direct indication of the importance of certain nitrate sources. It is especially useful for characterization of animal-waste sources as opposed to inorganic sources. Three $\delta^{15}N$ ranges have been defined for nitrate from different sources (Wolterink *et al.*, 1979; Figure 22). The $\delta^{15}N$ values for nitrate from unfertilized, cultivated fields (nitrate resulting from the oxidation of part of the organic nitrogen in the soil from crop plowing) range from $+2^{o}/_{oo}$ to $+8^{o}/_{oo}$. Nitrate from animal-waste nitrogen ranges from $+10^{o}/_{oo}$ to $+20^{o}/_{oo}$. Fertilizers composed of inorganic nitrogen (the type most likely to be used on row crops, citrus, and landscaping) have associated $\delta^{15}N$ ratios of -8 to $+6.2^{o}/_{oo}$, with 90% of the samples ranging from -3 to $2^{o}/_{oo}$ (Krietler, 1975; Krietler and Jones, 1975). Figure 22 compares literature ranges of $\delta^{15}N$ with data from the study area.

Eight wells (four in the Brandon karst terrain and four elsewhere in the study area) and three springs were sampled for nitrogen isotopes. The results of the sampling are included in Table 6. The map reference number in Table 6 relates the $\delta^{15}N$ ratio data to the location of the well or spring the sample was obtained from in Figure 23.

From Table 6 it is apparent that the $\delta^{15}N$ ratios for Lithia and Buckhorn Springs are 6.3 and $6.0^{o}/_{oo}$, respectively. The four wells sampled for nitrogen isotopes in the Brandon karst terrain have $\delta^{15}N$ values that range from 3.2 to $4.8^{o}/_{oo}$. These $\delta^{15}N$ ratios are unlikely to be the result of natural decay in unfertilized soils because the nitrate concentrations in the wells are far to high to have originated from natural

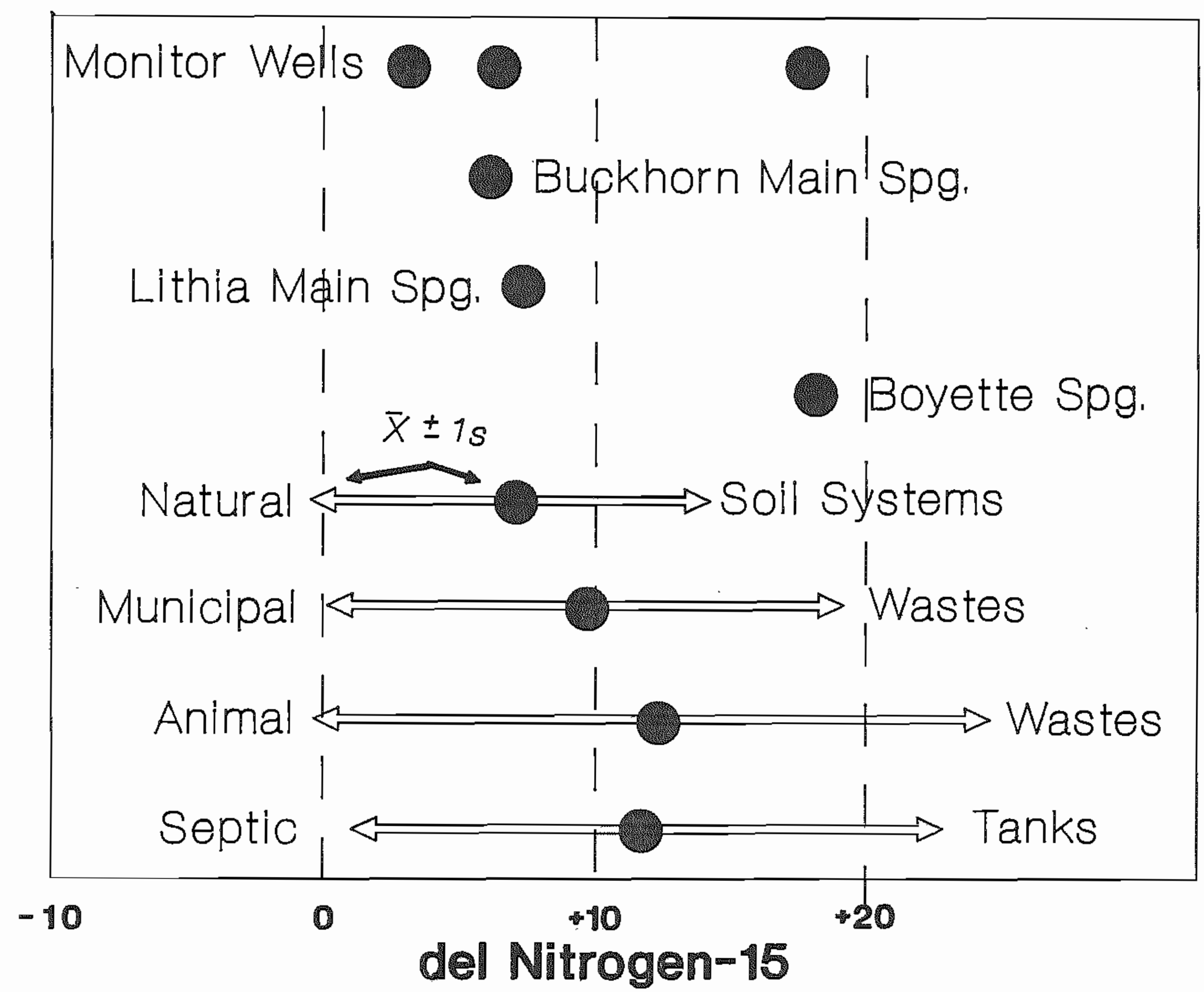


Figure 22. Graph Comparing Literature Ranges of $\delta^{15}N$ With Data From the Study Area.

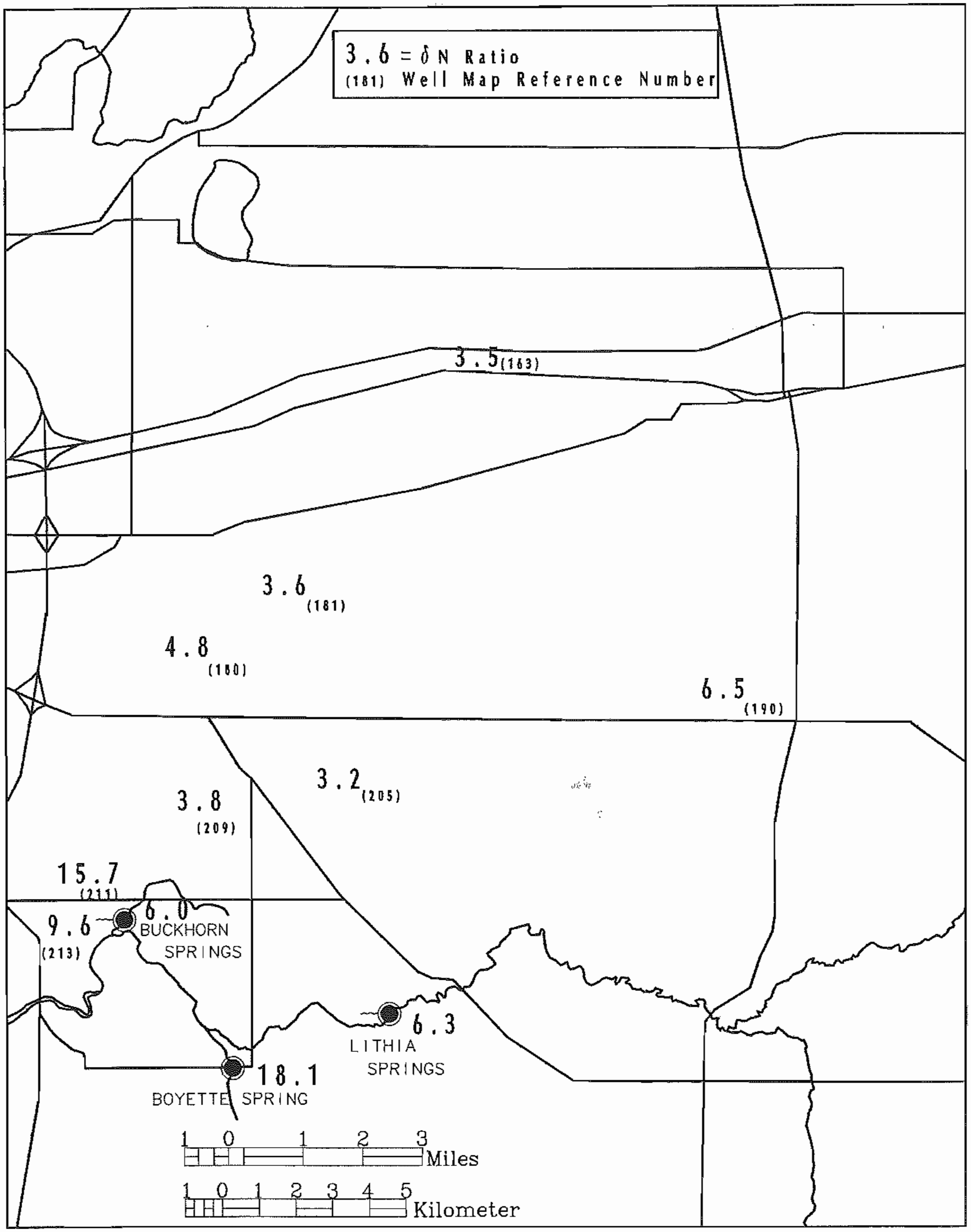


Figure 23. $\delta^{15}N$ Isotopic Ratios in Study Area Ground Water.

Table 6. $\delta^{15}N$ Ratios for Wells and Springs in the Study Area.

SITE NAME	MAP REFERENCE NUMBER	$\delta^{15}N$
Lithia Spring Major	008	6.3
Buckhorn Main	001	6.0
Boyette Spring	005	18.1
Jones	180	4.8
Wheeler	181	3.5
Harris	163	3.5
Howell	211	15.7
Bunch	213	9.6
Cremeans	205	3.2
Meadows	190	6.5
Desrochers	209	3.8

sources. The $\delta^{15}N$ ratios in the Brandon karst terrain monitor wells are at the upper end of the scale for inorganic nitrogen fertilizers, and may indicate that use of inorganic fertilizers by agriculture is the dominant source of nitrate in the Brandon karst terrain.

Outside of the Brandon karst terrain, a ratio of $3.5^{0}/_{00}$ was obtained from a well 3 miles west of Plant City, just south of I-4, and a value of $6.5^{0}/_{00}$ was obtained from a well located north of highway 60, approximately 1 mile west of highway 39. These values are also indicative of inorganic nitrogen fertilizers.

Water from a well in the Buckhorn Springs area, approximately 0.3 miles north of the spring, has a $\delta^{15}N$ value of $9.6^{0}/_{00}$. This ratio is at the minimum range of animal-waste nitrogen, and indicates that either septic tanks, dairies, or feedlots are the nitrogen source. Water from a well approximately 1.5 miles to the northwest of Buckhorn Springs has a $\delta^{15}N$ ratio of $15.7^{0}/_{00}$. This ratio, which is well within the animal-waste nitrogen range, may result from the area's long history of dairy and beef cattle pasturage. Septic tanks are not considered to be a source because relatively few are present in the area. As discussed above, the $\delta^{15}N$ ratio for water from Buckhorn Springs ($6.0^{0}/_{00}$) is significantly lower than the ratios for water from the two nearby wells that are dominated by animal-waste nitrogen. This indicates that Buckhorn Springs water is a mixture of waters, including water that has been influenced by the animal-waste nitrogen sources in the vicinity and water that has been affected by inorganic-nitrogen fertilizers derived from the Brandon karst terrain to the north.

The highest $\delta^{15}N$ ratio in the study area, 18.7‰, was from Boyette Spring. There is a high probability that this water is affected by animal wastes from a dairy to the southeast. Both the dairy and the spring lie along a lineament (fracture trace) that is defined by a number of aligned sinkholes and a sharp jog in the Alafia River to the northwest. Animal wastes appear to have drained into sinkholes on the dairy property, moved northwest along the fracture, and discharged into Bell Creek at Boyette Spring.

There is a weak positive correlation between $\delta^{15}N$ and nitrate concentration (Figure 24). Figure 24 may suggest that there are two trends in these data. One, characterized by low nitrate concentrations (0.7-<2 mg/L), the other by higher concentrations (3-11 mg/L). The springs fall between these two trends. There is not enough information available at this time to speculate on the reality of the trends or the relationship of the trends to the springs data. However, it is clear that higher $\delta^{15}N$ ratios correspond with higher nitrate concentrations.

Comparison of $\delta^{15}N$ and ^{3}H Data

Figure 25 shows $\delta^{15}N$ ratio data plotted against tritium activities for data from the study and from a similar study undertaken in Citrus County. Note that the low $\delta^{15}N$ ratios are associated with low tritium activities and high $\delta^{15}N$ ratios are associated with higher tritium activities. This relationship strongly supports the concept that the water is relatively young and that the nitrogen is a result of human activities rather than natural causes.

Total Dissolved Solids Concentrations

The distribution of total dissolved solids (TDS) in the study area is shown in Figure 26. Because Boyette Spring is thought to discharge Surficial Aquifer water, it was not included in the contouring. The data reflect concentrations of calcium, magnesium, sodium, sulfate and chloride in the ground water (Appendix III). The TDS content of ground water reflects three processes: (1) residence time in the aquifer, (2) chemical reactivity of the aquifer rock with the water, and (3) human influences (contamination). Limestones and dolostones are relatively reactive, so residence time is the dominant natural process that produces high TDS concentrations.

TDS concentrations are low in the eastern portions of the study area, where monitor wells are predominantly in the Intermediate Aquifer System. Here, the aquifer materials are less reactive dolostones, residence times are short, and local recharge may be important. Much of this area has been subject to phosphate mining, which

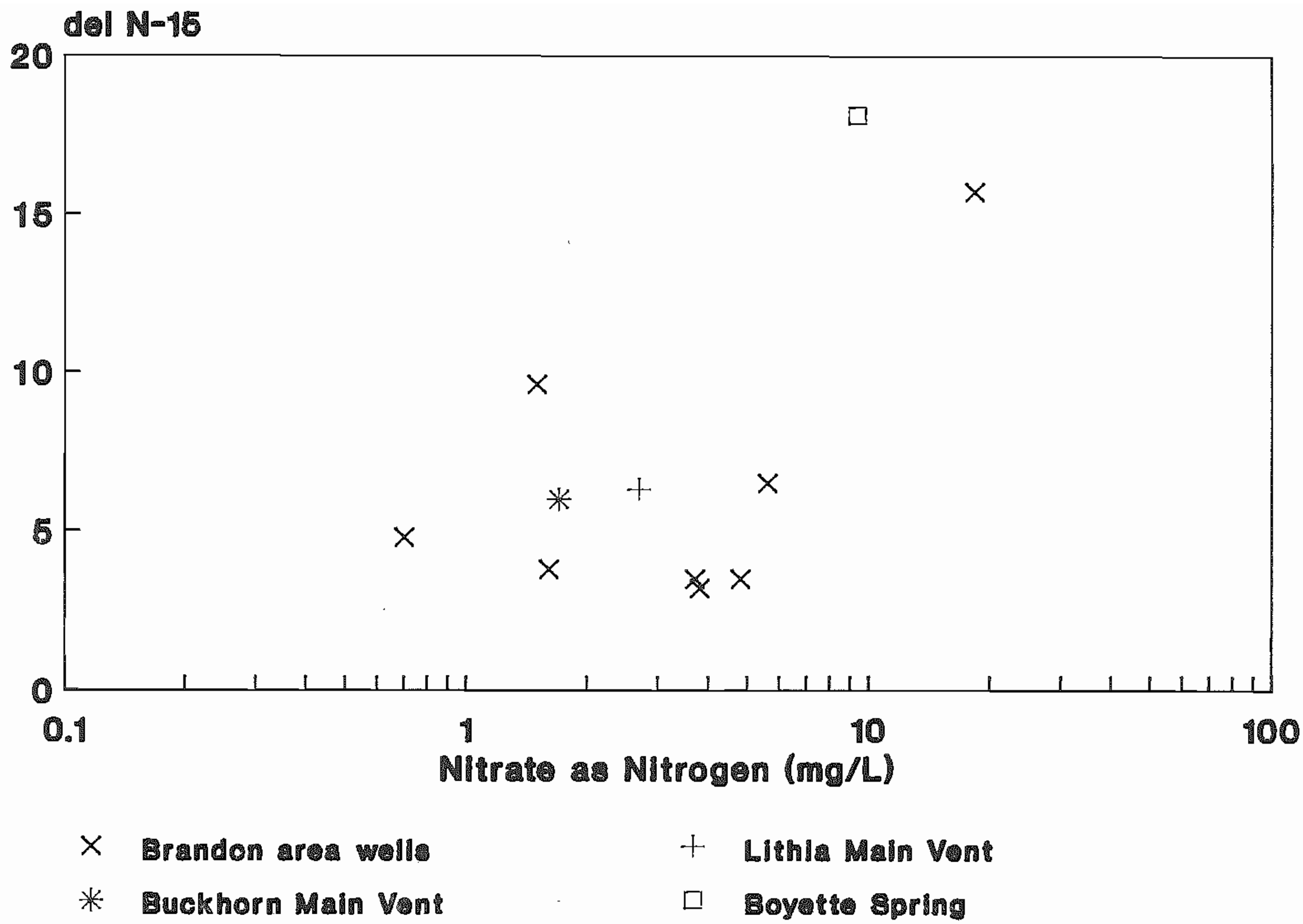


Figure 24. Graph Showing NO_3 Concentrations Plotted Against $\delta^{15}N$.

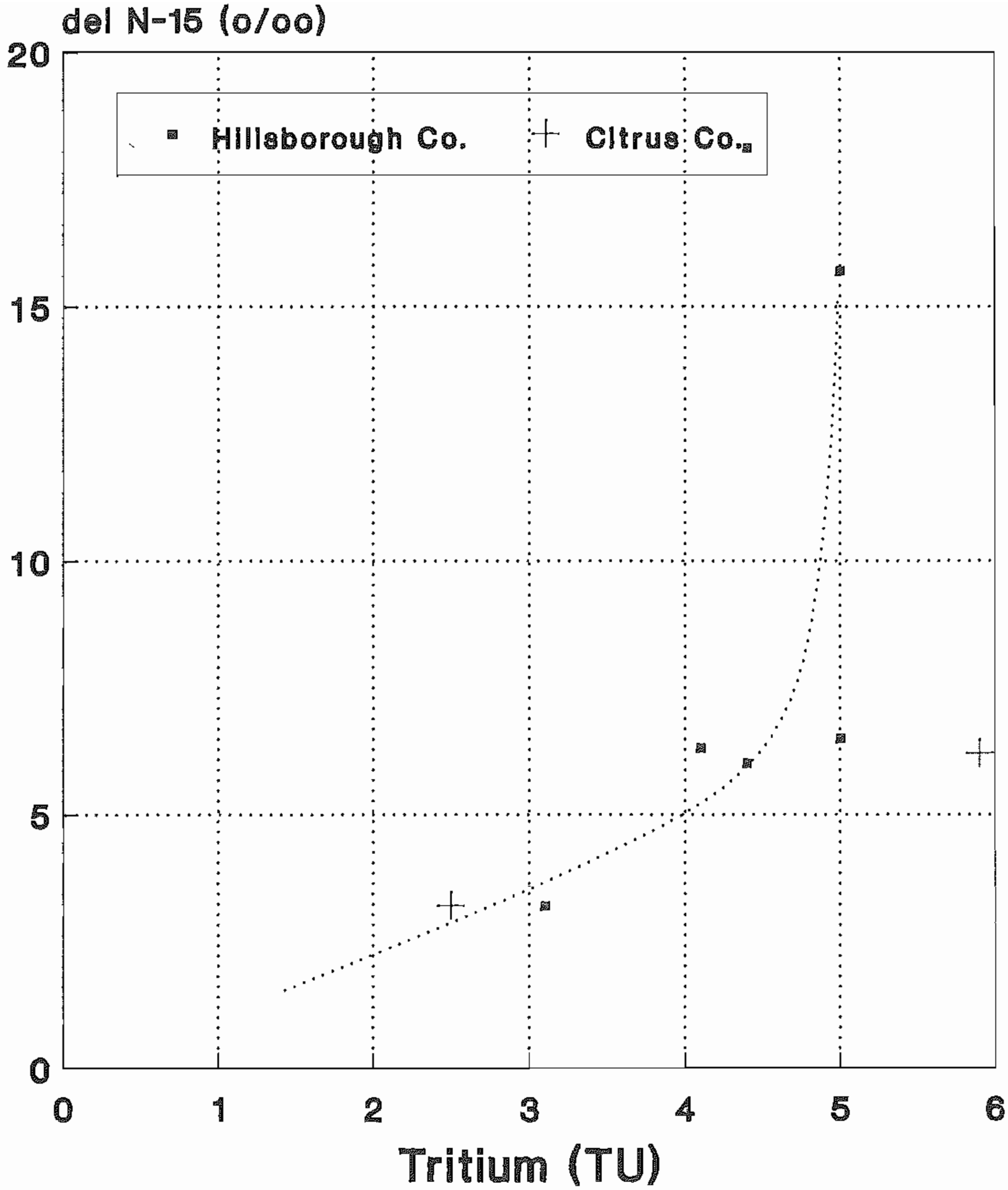


Figure 25. Graph Showing $\delta^{15}N$ Plotted Against Tritium Concentrations.

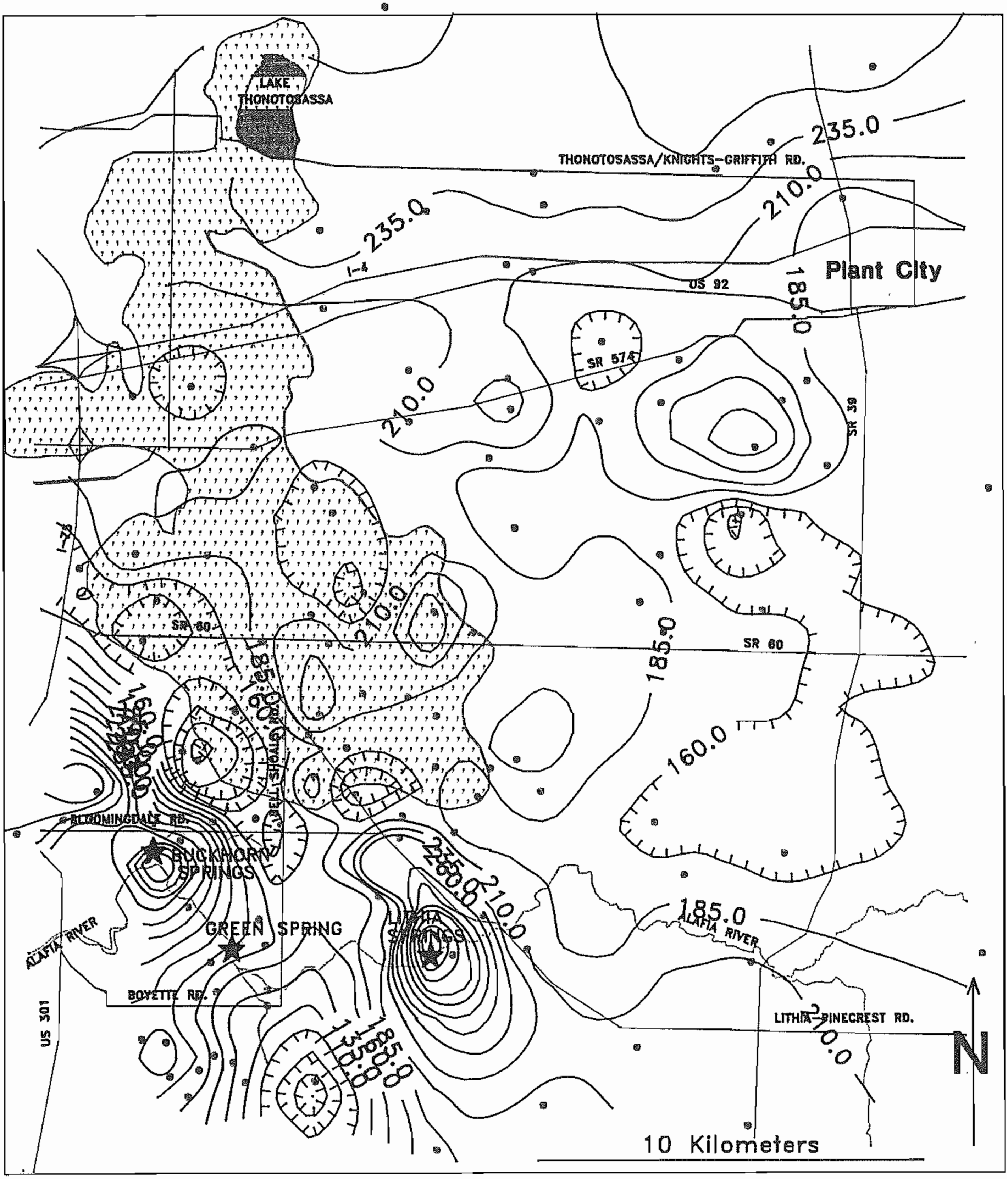


Figure 26. TDS Concentrations in Study Area Ground Water.

may enhance recharge and reduce residence times. The clays of the Intermediate Aquifer System are thin in this area as well (Figure 5).

TDS concentrations are also low in the Brandon karst terrain, where recharge is an important source of water. Closed contours in the Brandon karst terrain reflect areas of low TDS waters as a result of recent recharge. Note that the closed contour regions are aligned in a northwest-southeast pattern that coincides with Lithia Springs and one of the proposed lineaments (Figure 17). A secondary alignment extends northeast to southwest near Buckhorn Springs. This also coincides with a proposed lineament. Thus, there is support for the conclusion that the springs are "fed" by local recharge and flow through fractures or lineaments. While the Floridan Aquifer potentiometric surface (Figure 10) shows a general northeast to south or southwest direction, local flow is likely to follow these high-transmissivity paths of "least resistance", including divergences from the regional flow towards springs.

TDS concentrations are highest at Lithia and Buckhorn Springs, where the waters are mixtures of low TDS, recently recharged water and higher TDS waters from the deep flow system of the Floridan Aquifer. The low TDS southeast of Boyette Springs reflects recharge along the lineament of sinkholes previously mentioned.

Hydrochemical Facies

Plotting of the chemical data, including Alafia River data, on a Piper diagram (Piper, 1944) (Figure 27, triangles and diamonds in center of figure) indicates that there are three chemically distinct water masses represented in the area. These water masses are: (1) the Alafia River, (2) Buckhorn and Lithia Springs, and (3) the monitor wells. The river and springs water masses overlap the monitor well data, but not each other.

Water from the Alafia River has a calcium-sodium-sulfate-chloride composition. The high sodium-chloride content may result from evaporative concentration of maritime rainfall (Upchurch, 1992), or human sources. The calcium-sulfate may be derived from phosphochemical plants upstream or from discharge of deep Floridan aquifer waters.

Water from the two Lithia Springs vents is quite similar in composition and has a calcium-bicarbonate-sulfate composition. This composition is typical of Floridan aquifer waters, which contain increasing sulfate with depth. The similarity of waters from the two vents indicates that they have a common water source.

Unlike Lithia Springs, the Buckhorn Springs vents differ chemically. Buckhorn South and West are similar, with a calcium-sodium-chloride and to a lesser extent, sulfate composition. It can be concluded that these have a common source. The high sodium and chloride is of interest as it indicates an unusual source. Most shallow

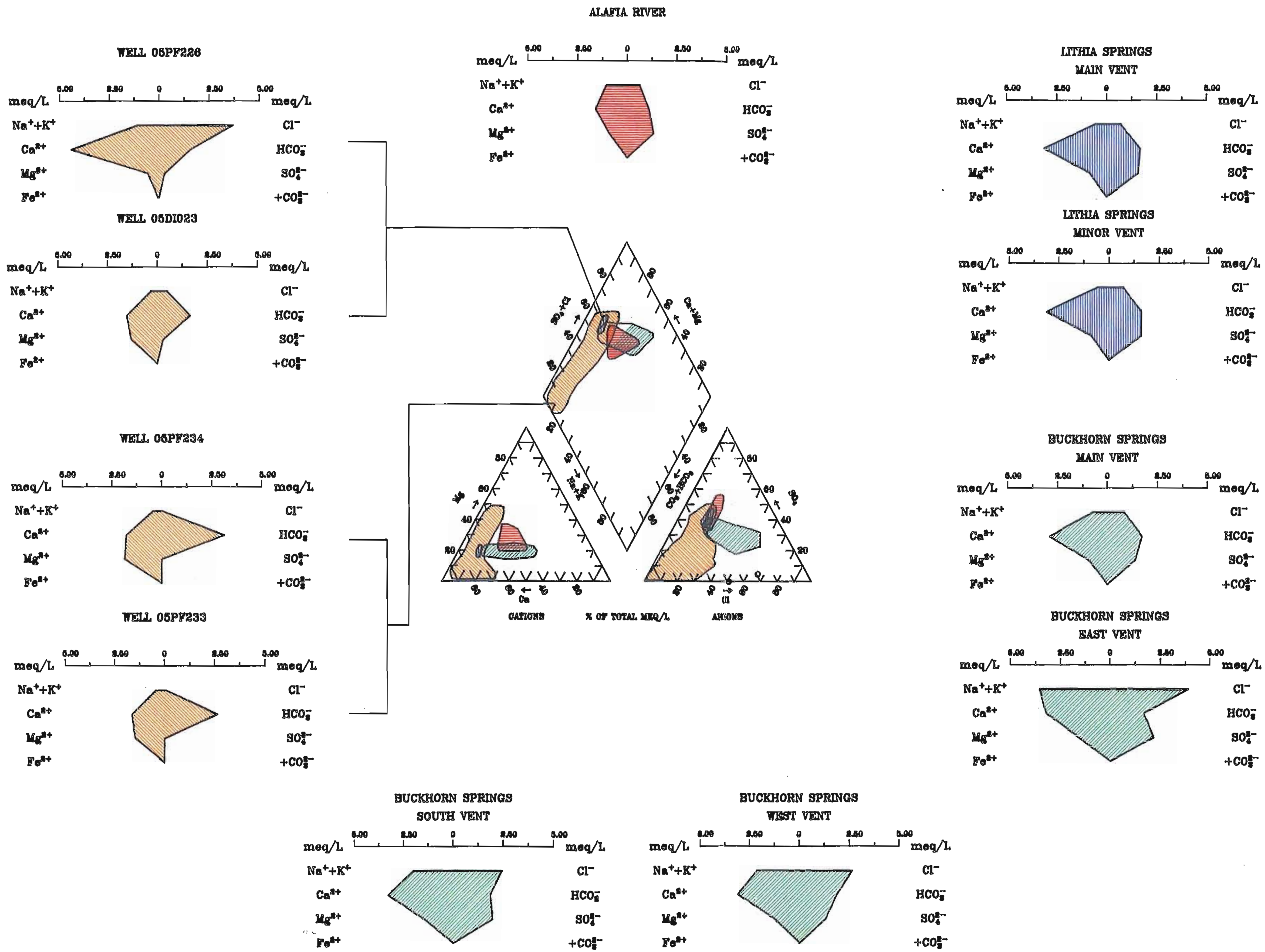


Figure 27. Characterization of Study Area Waters Using Piper and Stiff Diagrams.

aquifer water in Florida contains little sodium and chloride. This sodium and chloride is derived from precipitation that contains marine aerosols (Upchurch, 1992). Coastal ground water contains high sodium and chloride as a result of sea water. The water from Buckhorn South and West contain excess calcium, which suggests that these waters are not a result of salt-water intrusion. The other possible source is human activity, including animal and human wastes, food salts, and stock salting. If the sodium-chloride component is removed, the remaining compositional pattern is similar to Lithia Springs and Buckhorn Main.

The Buckhorn East vent is anomalous. The Stiff-diagram (Stiff, 1951) (Figure 27, the remaining figures on the page after excluding the Piper-diagram) pattern is very similar to sea water, however, unlike sea water it has excess calcium relative to magnesium. This composition is also sodium-chloride rich, but ionic strength is high and sulfate is high. Similar patterns occur near human waste sources, such as landfills, so one must conclude that Buckhorn East is highly affected by human activity.

The Buckhorn Main vent is chemically similar to Lithia Springs and reflects a similar source: Floridan Aquifer water. Composition is a calcium-bicarbonate-sulfate water.

The monitor well data range from calcium-magnesium-bicarbonate waters (Wells 05PF233 and 05PF234, Figure 27) to calcium-magnesium-bicarbonate-sulfate compositions (Wells 05PF228 and 05DI023, Figure 27). The data form a continuous mixing trend. The calcium-magnesium-bicarbonate waters are typical of deeper Intermediate Aquifer and of the Upper Floridan Aquifer, where dolostone and limestone are subject to dissolution. The more sulfate-rich water is more typical of deep Floridan Aquifer waters and of Intermediate Aquifer waters associated with oxidation of pyrite (FeS_2) in the Hawthorn clays. Note that the sulfate-rich end of the mixing trend overlaps the Alafia River and Lithia and Buckhorn Main samples. This overlap suggests that calcium-sulfate waters are sources for the river and springs. The well samples with the higher sulfate content are from Intermediate Aquifer wells south of the Alafia River. The calcium-magnesium-bicarbonate water samples are from an Intermediate-Aquifer well approximately 1 mile northeast of Lithia Springs and an Intermediate-Aquifer well near SR 60 north-northeast of Lithia Springs. The Brandon karst terrain well samples fall between the two end members compositionally and reflect similar sources of calcium, magnesium, bicarbonate, and sulfate, but with generally lower ionic strengths (lower TDS concentrations).

The Piper diagram clearly suggests that the river is not the source of waters in the springs, and it illustrates the complexity of possible sources. Compositionally, one cannot differentiate deeper Floridan Aquifer water and Intermediate Aquifer water. Either or both aquifers may constitute the sources of waters in the springs. Because the Piper and Stiff diagrams only show major element compositions, the roles of nutrients and isotopes as source indicators cannot be evaluated.

Sodium to Chloride Ratios

Upchurch (1992) has shown that the mole ratio of sodium to chloride can be utilized as an indicator of ground-water sources. Sea water has a mole ratio of approximately 0.8. Rainfall in Florida contains marine aerosols, so the rain water is a dilute sodium-chloride solution with a mole ratio of 0.8. Evaporation on the land surface and in the Surficial Aquifer does not change this ratio. As this water percolates through the clays of the Hawthorn Group, however, ion exchange occurs and the ratio changes. If sodium is released, the ratio increases. If sodium is exchanged for calcium, the ratio decreases. Human sources of sodium and chloride can also change the ratio.

Figure 28 shows the variation in the mole ratio of sodium to chloride as a function of chloride concentration. Note that the samples from the Alafia River show a linear trend with a positive slope. A few monitor-well samples follow this same trend, but the general pattern indicates that the composition of the river water is significantly different from the springs or regional ground water. This is a result of sodium and chloride sources upstream of the study area. The springs show a horizontal trend, which indicates that the sodium to chloride ratio does not change with chloride concentration. This pattern is typical of marine-aerosol dominated meteoric waters where evaporative concentration changes the concentrations, but not the ratio. Well water samples show considerable variability. The majority follow the springs trend, but many show relatively high sodium at low chloride concentrations. These high sodium waters probably represent ion exchange of calcium for sodium on clays or human sources of sodium.

Mapping of the sodium to chloride mole ratio (Figure 29) is particularly informative as to sources of water in the springs and causes of the high ratios in some wells. Recall that the springs uniformly have ratios near 0.5 (Figure 27). There are two regions of the study area where 0.5 ratio water occur. One is the Brandon karst terrain, the other is a region near the junction of SR 60 and SR 39 where the Hawthorn is thin (Figure 5) and recharge appears to occur. The region centered on the Brandon karst terrain is oriented along the lineaments previously identified, and it extends in the directions of both Lithia and Buckhorn Springs. This strongly supports the concept that the spring water includes a significant component of water from the karst terrain. The second region is less easily explained. It is a region of former phosphate mining, which may have enhanced recharge through the already thin clay beds to the Intermediate Aquifer.

The regions of sodium to chloride mole ratio greater than 1 generally coincide with regions where the Hawthorn Group is thick, and significant clays are present. This supports the concept that the higher sodium is a result of ion exchange. In this

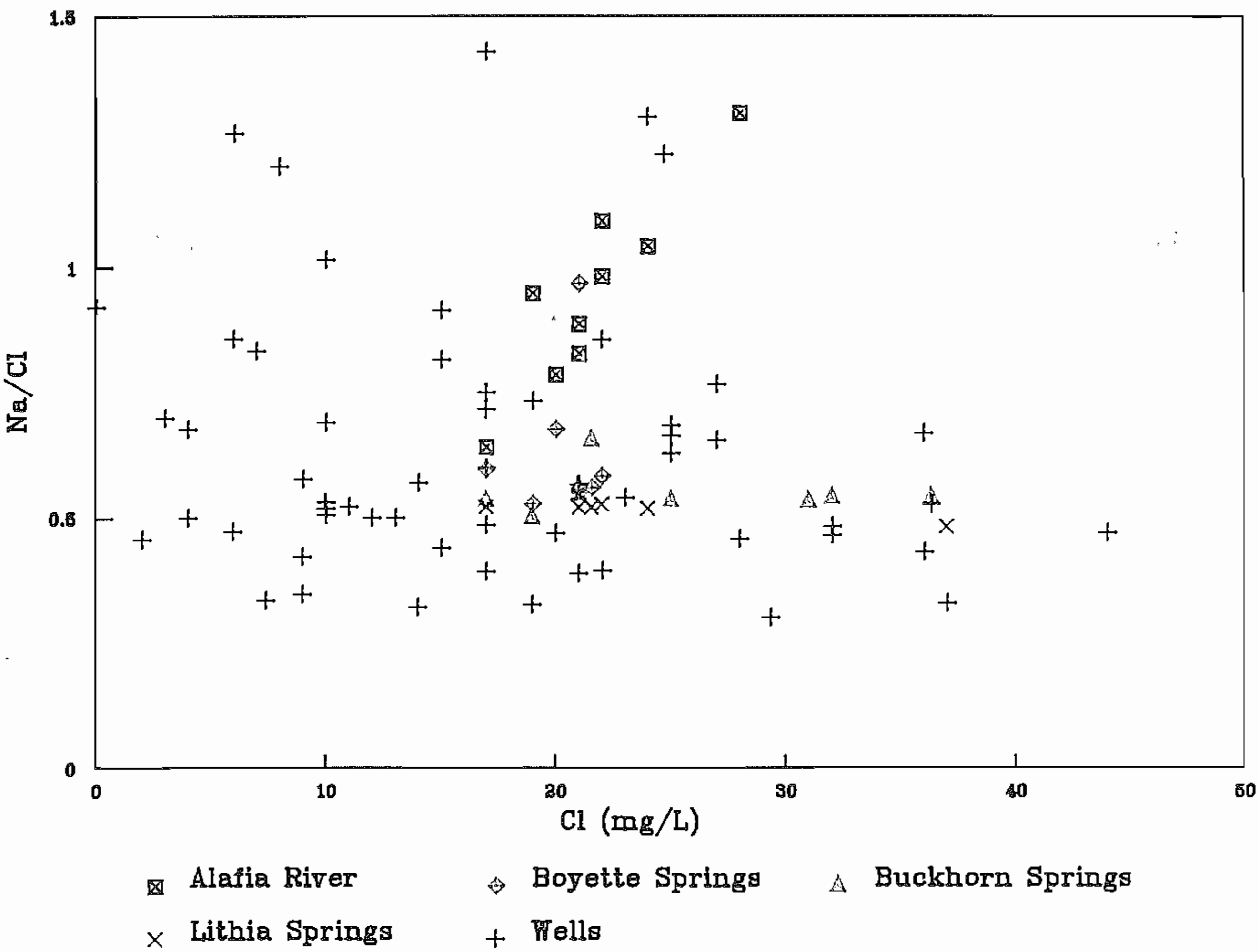


Figure 28. Sodium/Chloride Mole Ratio vs Chloride Concentration of Study Area Waters.

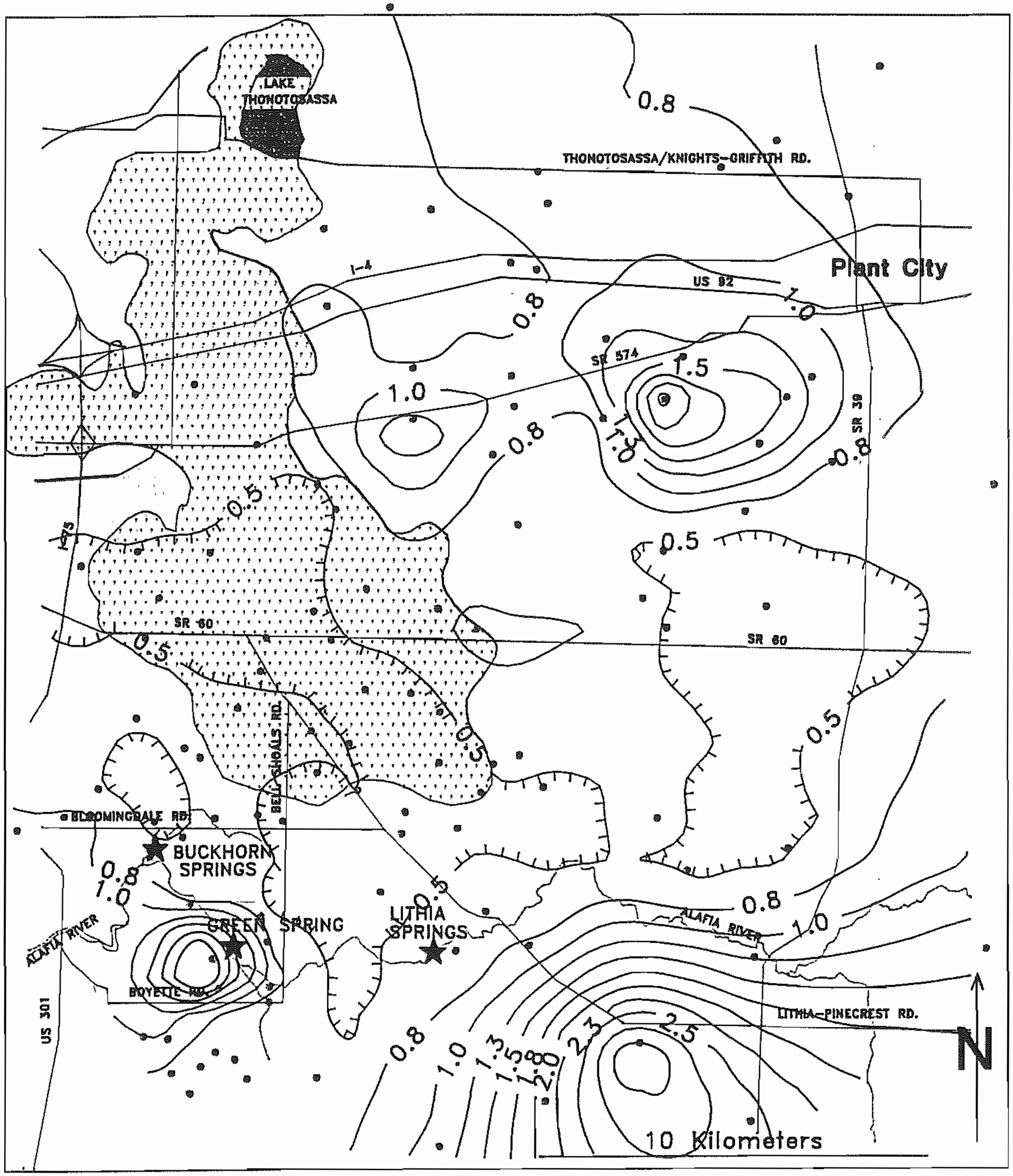


Figure 29. Sodium/Chloride Mole Ratio of Study Area Ground Water.

reaction, calcium or magnesium originally present in the ground water substitutes for sodium sorbed onto the smectitic clays of the Hawthorn according to the reaction

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

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

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

$$\begin{matrix}Organic\ Nitrogen \rightarrow NH_4^+ \rightarrow NO_2^- \rightarrow NO_3^-.\\ \text{---Oxidation--}\rightarrow\\ \leftarrow\text{--Reduction---}\end{matrix} \tag{3}$$

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

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

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

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

Animal wastes and decaying plant tissues release ammonia and ammonium, nitrite, nitrate, urea[6], 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 onto clays and soil particles, so some soil and aquifer materials mitigate ammonium migration. Septic-tank systems, land-application waste-treatment systems, and feed-lot wastes can, under circumstances of overloading or failure of sorption systems cause widespread ammonium contamination.

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

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

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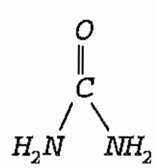
[6] Urea is a principal nitrogen product in urine. It has the formula 

. Urea is a by-product of the liver.

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

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

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

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

The only nitrogen compound for which there is a standard or guidance criterion in ground water in Florida is nitrate. Nitrate is subject to the Primary Drinking Water Standard (Florida Department of Environmental Regulation, 1989). The limit under the Primary standard is 10 mg/L as N, or 44 mg/L as NO_3^-. There is a health advisory for nitrate at 1 mg N/L (4.4 mg NO_3^-/L), as well. The major cause of concern is methemoglobinemia, an excess of methemoglobin[7], which causes oxygen deprivation. This condition is especially hazardous in infants and young children, where it produces a condition known as "blue baby syndrome" (Hersh, 1968; Hem, 1986). There are no standards for ammonium or other nitrogenous decay products in ground water (Florida Department of Environmental Regulation, 1989).

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[7] 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.

Each of the nitrogen species in ground water can cause problems where they occur in excess. If nitrification of ammonia does not deplete oxygen, it will form excess nitrate. Nitrate is very soluble and does not interact with soil components under aerobic conditions. It travels through the soil-water environment practically unimpeded. Unless conditions for denitrification exist, nitrate will not undergo further transformations once in the ground water (Preul and Schroepfer, 1968; Bouma, 1975a; Hall, 1975). Most studies report attenuation of nitrate concentration by dilution only. The concentration of nitrate in ground water decreases as the nitrate diffuses and is dispersed into surrounding waters of lower nitrate content (Walker *et al.*, 1973a,b; Hook *et al.*, 1978).

Organic Nitrogen

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

Figure 30 shows the distribution of organic nitrogen in the study area. High organic nitrogen concentrations occur in two areas: (1) near Boyette Springs and (2) just northwest of Buckhorn Springs. Both of these regions have dairies and/or feed lots nearby. It is important to note that organic nitrogen has been detected in low concentrations (<0.05 mg/L as N) throughout much of the area, especially the Brandon karst terrain. This is an important observation because it indicates a general loading of complex nitrogen molecules. This loading is most likely a result of use of septic tanks and of drainage of runoff through sinkholes.

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.

Ammonium is concentrated in the study area in three regions (Figure 31). There is a large area of ammonium-rich water north of SR 60, east of the Brandon karst terrain. It is unclear why ammonium concentrations are high here. The region is overlain by Hawthorn clays, so confinement is good and the waters are reducing, which would encourage stability of ammonium. The region is also characterized by phosphate mining, row crops, and some citrus (Figures 2-4), all of which may serve as ammonium sources. The second high is in carbonate rocks of the Intermediate Aquifer in the southeastern corner of the study area. The third area is west of Boyette Spring

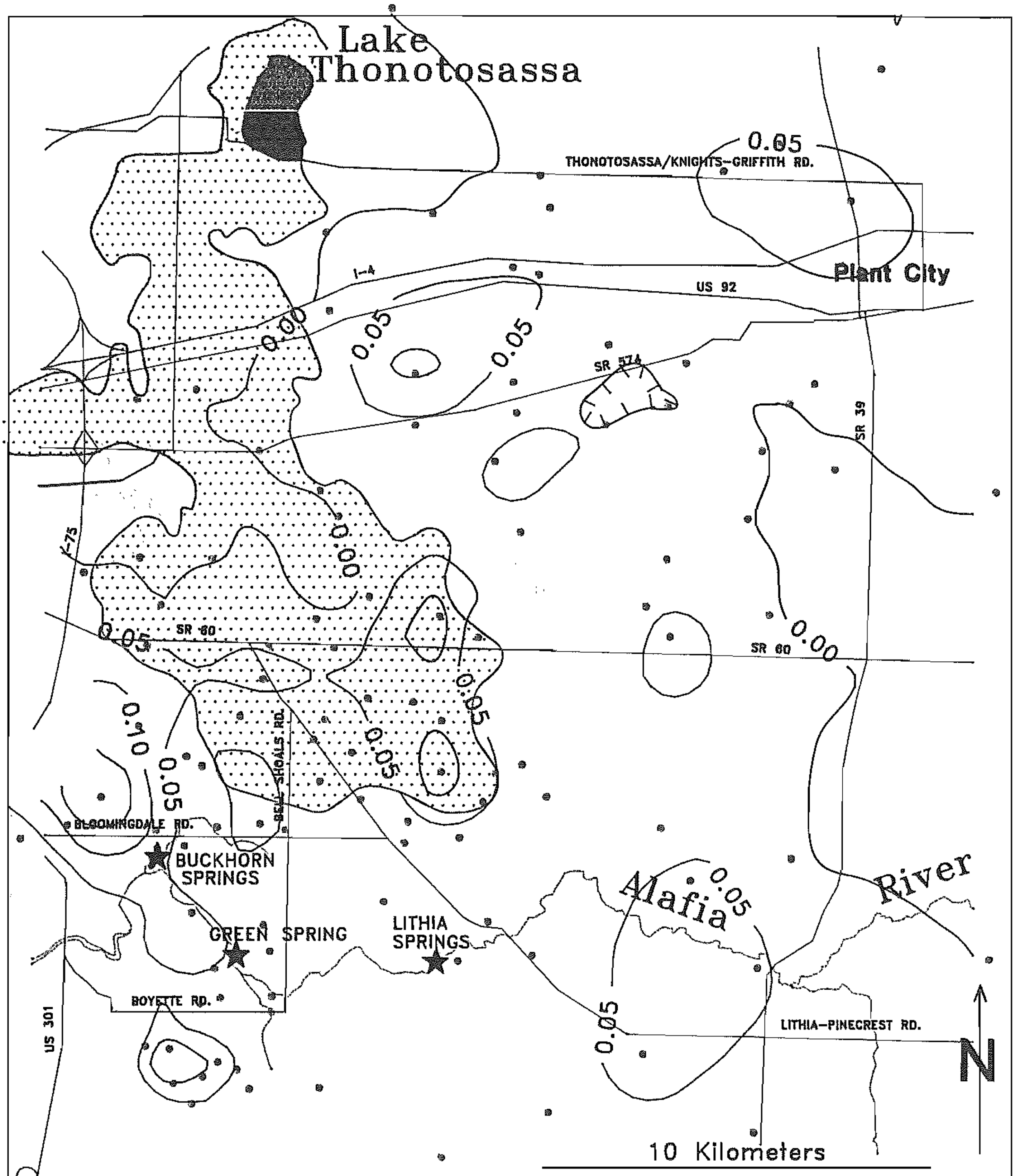

Figure 30. Organic Nitrogen Concentrations in Study Area Ground Water.

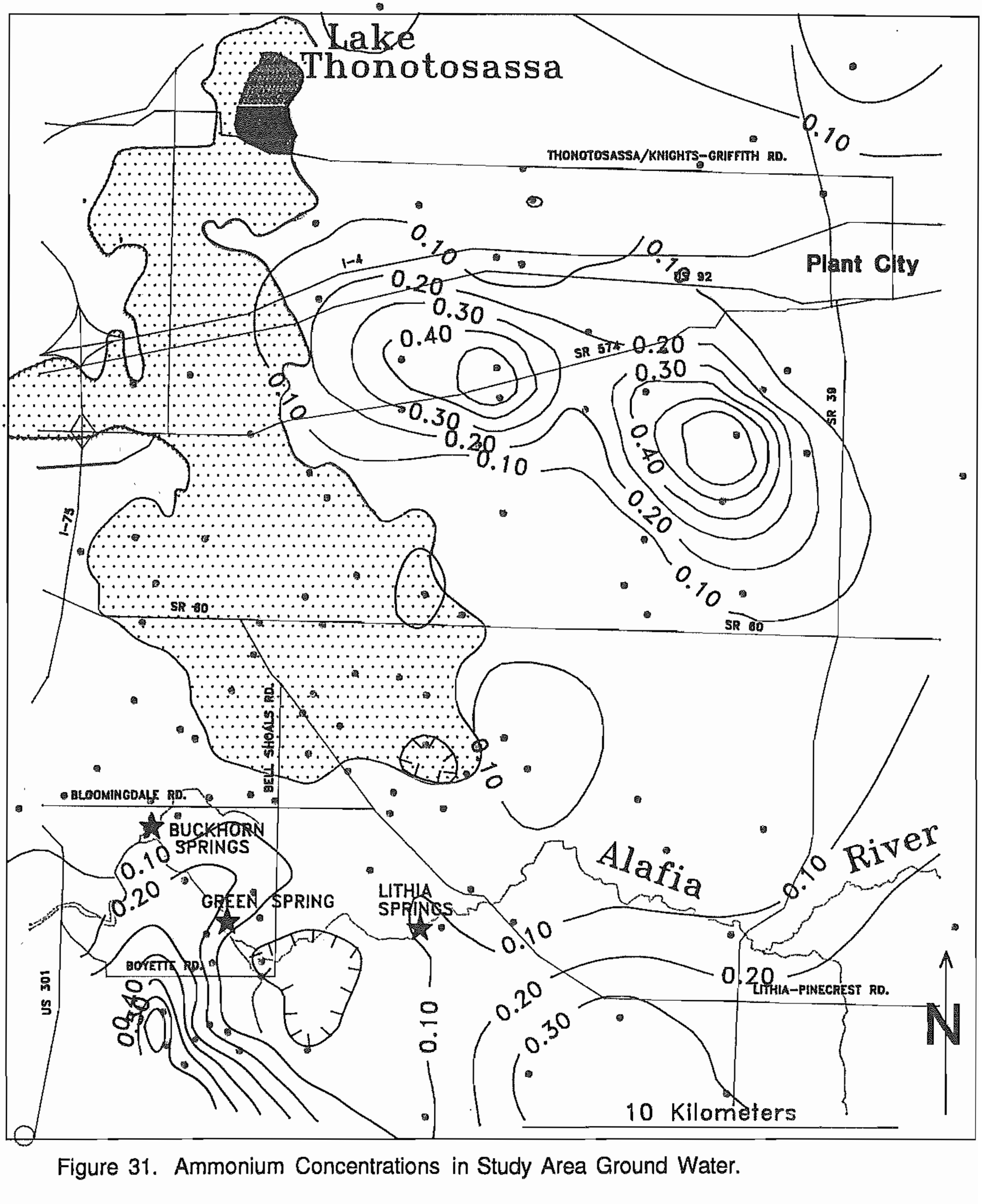

Figure 31. Ammonium Concentrations in Study Area Ground Water.

in the Floridan Aquifer System. Confinement is good in both of these areas. Sinkholes penetrate the Hawthorn in the Boyette Spring area. For example, sinkholes in Lake Grady, just south of Boyette Spring led to frequent drainage of the lake (Stewart, 1982), which may serve as a source of ammonium. The southeastern high is in a geologically similar setting, but ammonium sources are less obvious.

Nitrite

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

Figure 32 shows the distribution of nitrite in the study area. High nitrite was found in only one well, a well open to an unknown depth in the triangle between Bloomingdale, Bell Shoals, and Lithia-Pinecrest Roads. Elsewhere nitrite is either absent or present in trace quantities. Because of its low stability in a biologically active environment, one would not expect nitrite to be a significant component in the ground water of the Brandon area.

Nitrate

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

Ground water in the study area is widely enriched in nitrate. Highest concentrations are in the Brandon karst terrain (Figure 33), where recharge and oxidation are widespread. High nitrate concentrations occur near the junction of SR 60 and SR 39, between I-4 and US 92, near Boyette Spring, northwest of Buckhorn Springs, and near the junction of Lithia-Pinecrest Road and SR 60. The latter is in the heart of the Brandon karst terrain. The two highs near the springs are also regions of high organic nitrogen and ammonium and they are associated with feedlots and/or dairies. The highs north of US 92 and near the junction of SR 60 and 39 are less easily explained, and they are supported by data from one well each. The SR 60/SR 39 junction high coincides with a region of thinning of the Hawthorn Group (Figure 5).

Comparison of Figures 31 and 33 reveals an interesting pattern. Ammonium is most abundant where the aquifer system is confined and recharge is limited, while nitrate is most abundant in karstic areas, where recharge and oxidation can occur. There is very little overlap in the two analytes (Figure 34). This suggests a strong control on nitrogen speciation by relative confinement and rapidity of recharge. Figure 34 also demonstrates an important piece of evidence relative to the sources of water in the springs. The ammonia and nitrate concentrations in the Alafia River are plotted

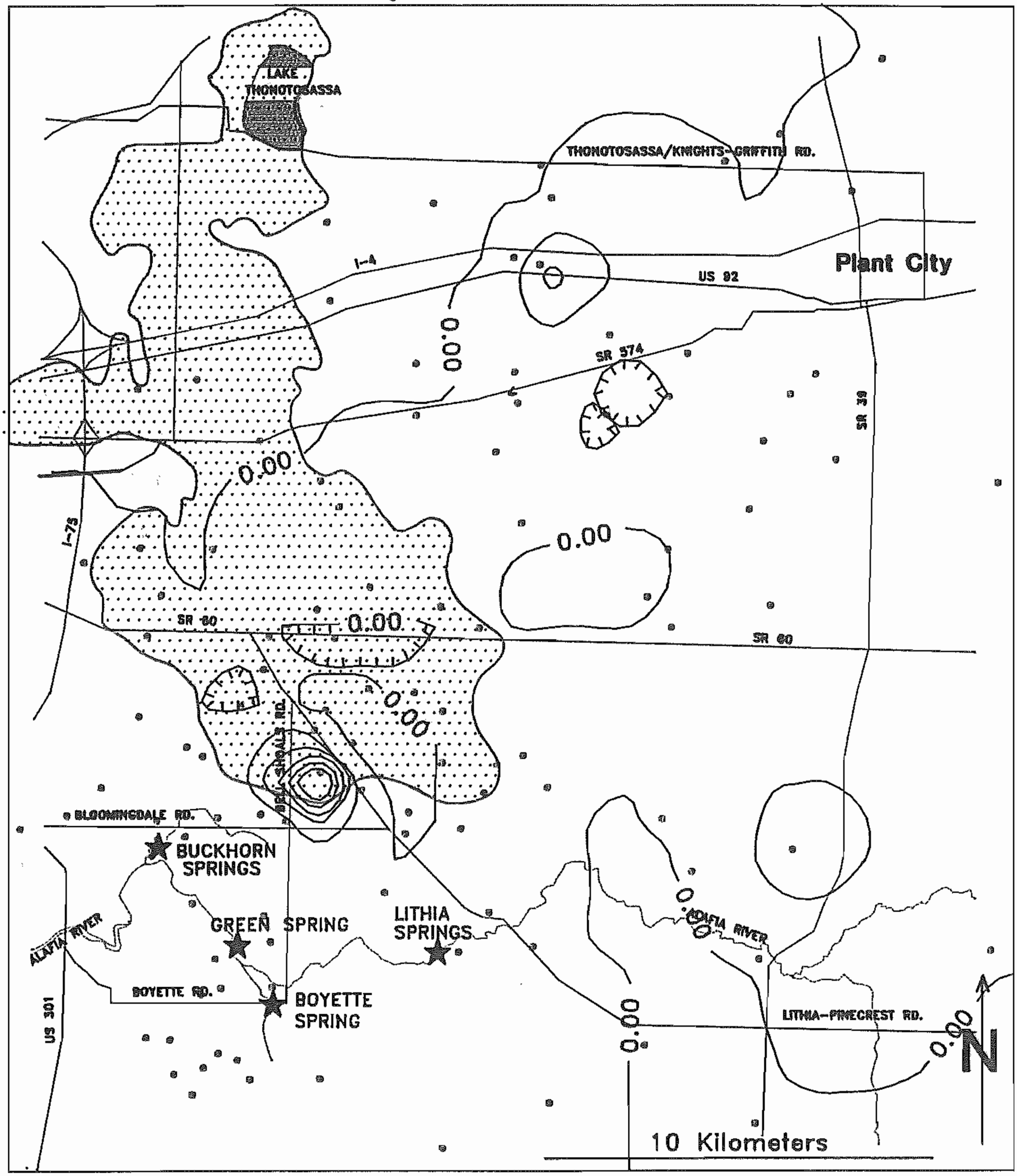

Figure 32. Nitrite Concentrations in Study Area Ground Water.

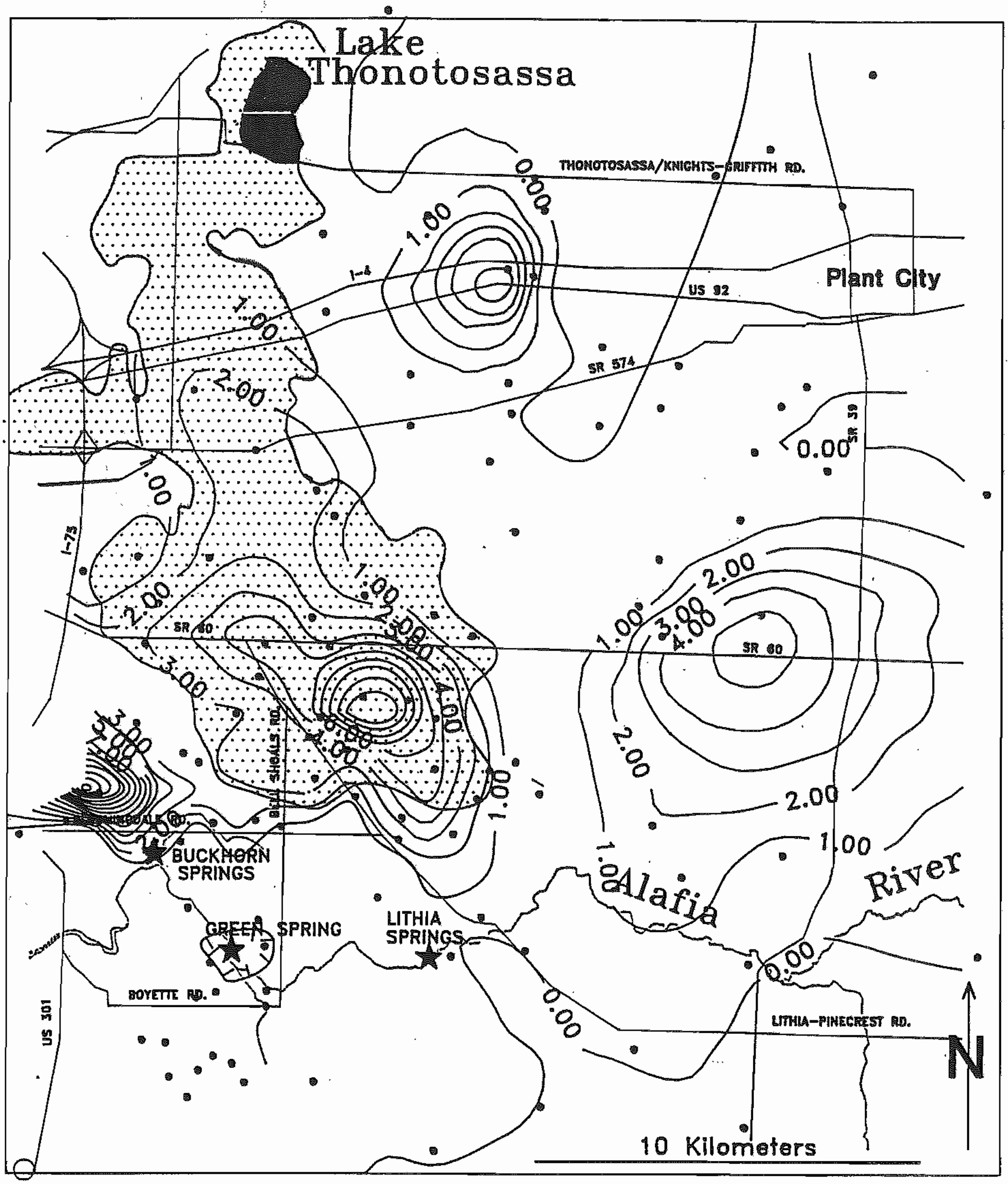

Figure 33. Nitrate Concentrations in Study Area Ground Water.

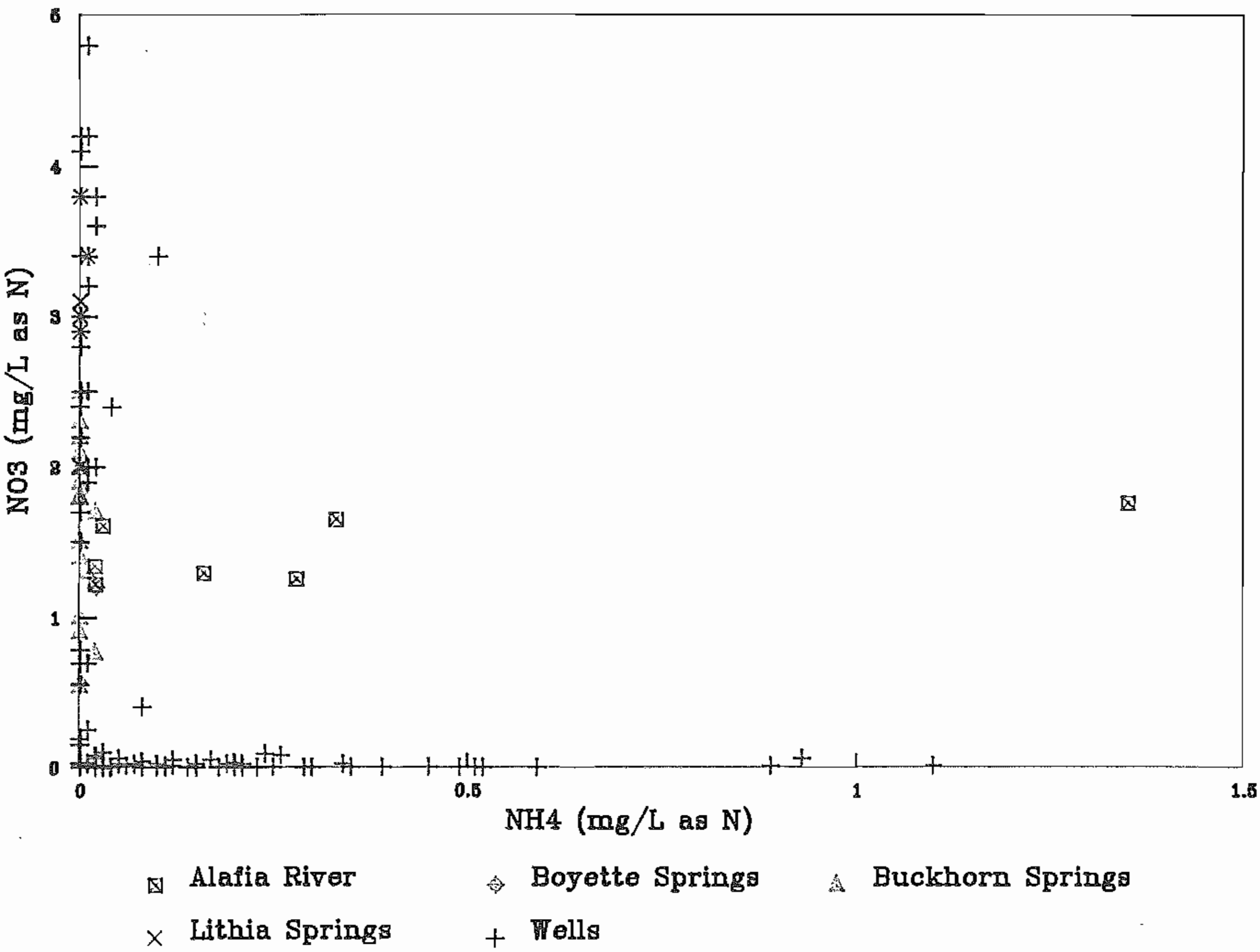

Figure 34. Ammonium Concentration vs Nitrate Concentration of Study Area Ground Water.

on the figure. Note that the river is enriched in both nitrogen species, while the springs are nitrate rich and ground water is either ammonium or nitrate rich. Finally, the nearest source of nitrate-rich ground water to the springs is the Brandon karst terrain.

ADDITIONAL NUTRIENTS

Total Organic Carbon

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

Figure 35 shows the distribution of TOC in the study area. The high ammonium region southwest of Plant City is also characterized by high TOC. There is also a high at the edge of the Pamlico scarp. The high TOC concentrations along the scarp were attributed by Lawrence and Upchurch (1982) to localized recharge where confinement by Hawthorn Group sediments ceases. Other highs occur west of Buckhorn Springs and southwest of Boyette Spring. TOC concentrations are above detection limits throughout the area.

Phosphorus Compounds

Total phosphorus and orthophosphate were determined throughout the study area. The analyte total phosphorus includes complex organic compounds as well as simple inorganics. It is an indicator of localized contamination by organic sources, such as animal wastes. Orthophosphate (PO_4^{3-}) is derived from certain detergents, oxidation, decomposition of complex organics, food additives, and weathering of phosphatic minerals in the Hawthorn Group (Upchurch, 1993). Orthophosphate is relatively insoluble in alkaline, carbonate-rich aquifers, and carbonate-fluorapatite is a typical precipitant. If orthophosphate is present in the limestone aquifers of the Intermediate or Floridan Aquifers, local recharge is often indicated (Upchurch and Lawrence, 1984).

Phosphorus compounds (Figures 36 and 37) are present in low concentrations in the eastern half of the area, where the carbonate aquifers are confined and alkaline. Highs occur in the Brandon karst terrain along the edge of the Pamlico scarp and locally in the interior of the terrain. Highest concentrations are near dairies in the southwest quadrant of the area (Compare Figures 36 and 37 with Figures 3 and 4).

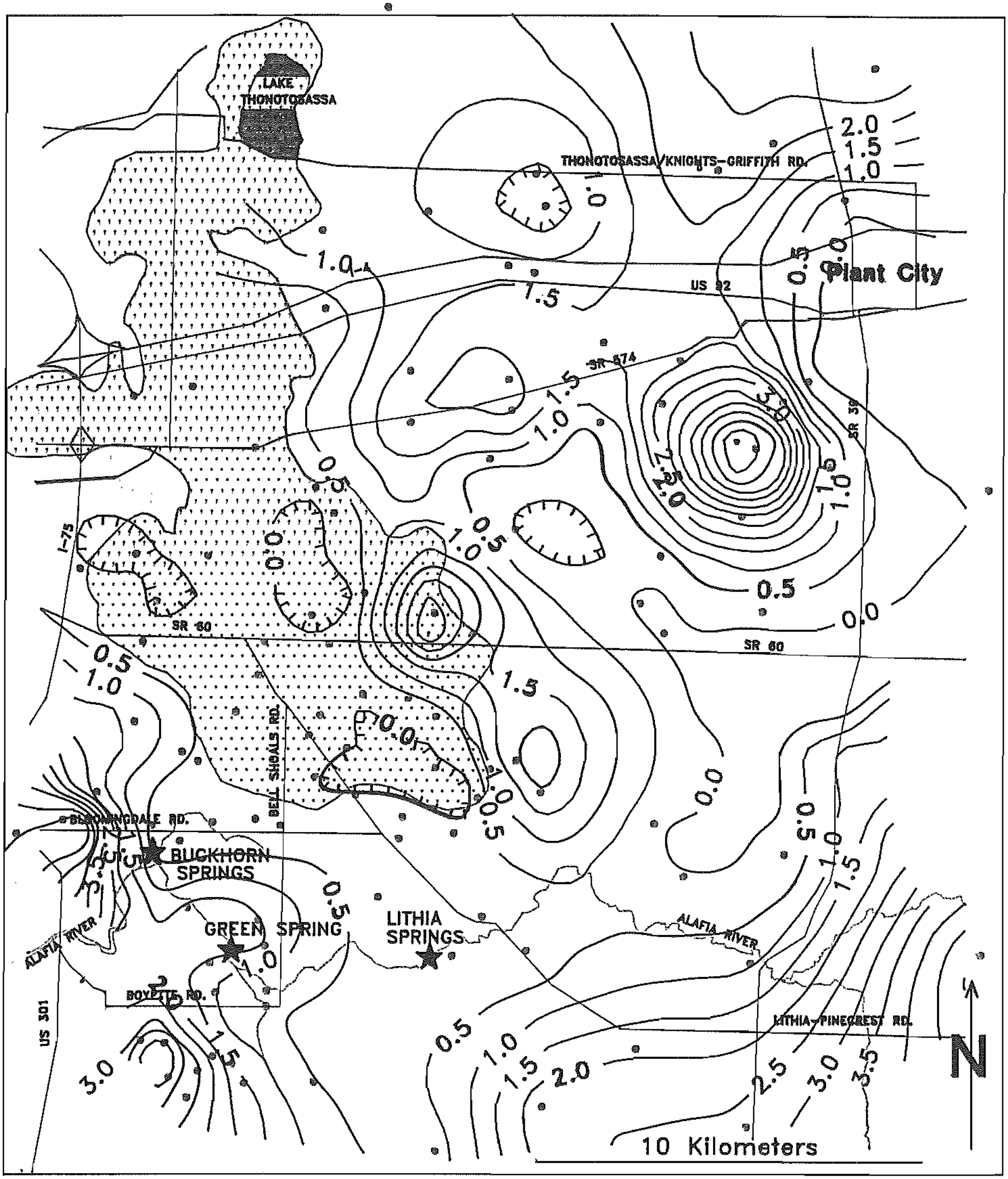

Figure 35. TOC Concentrations of Study Area Ground Water.

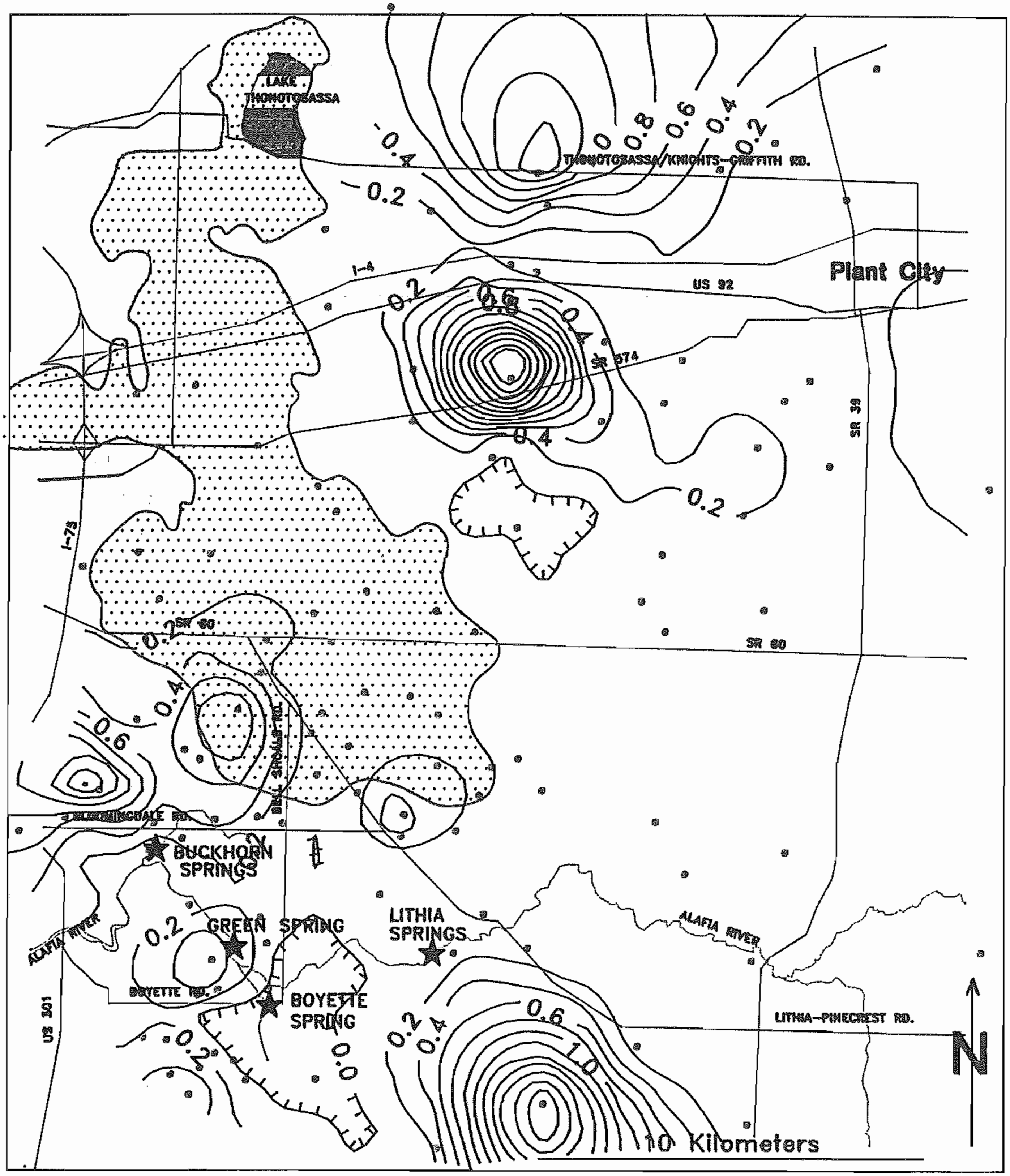

Figure 36. Total Phosphorus Concentrations of Study Area Ground Water.

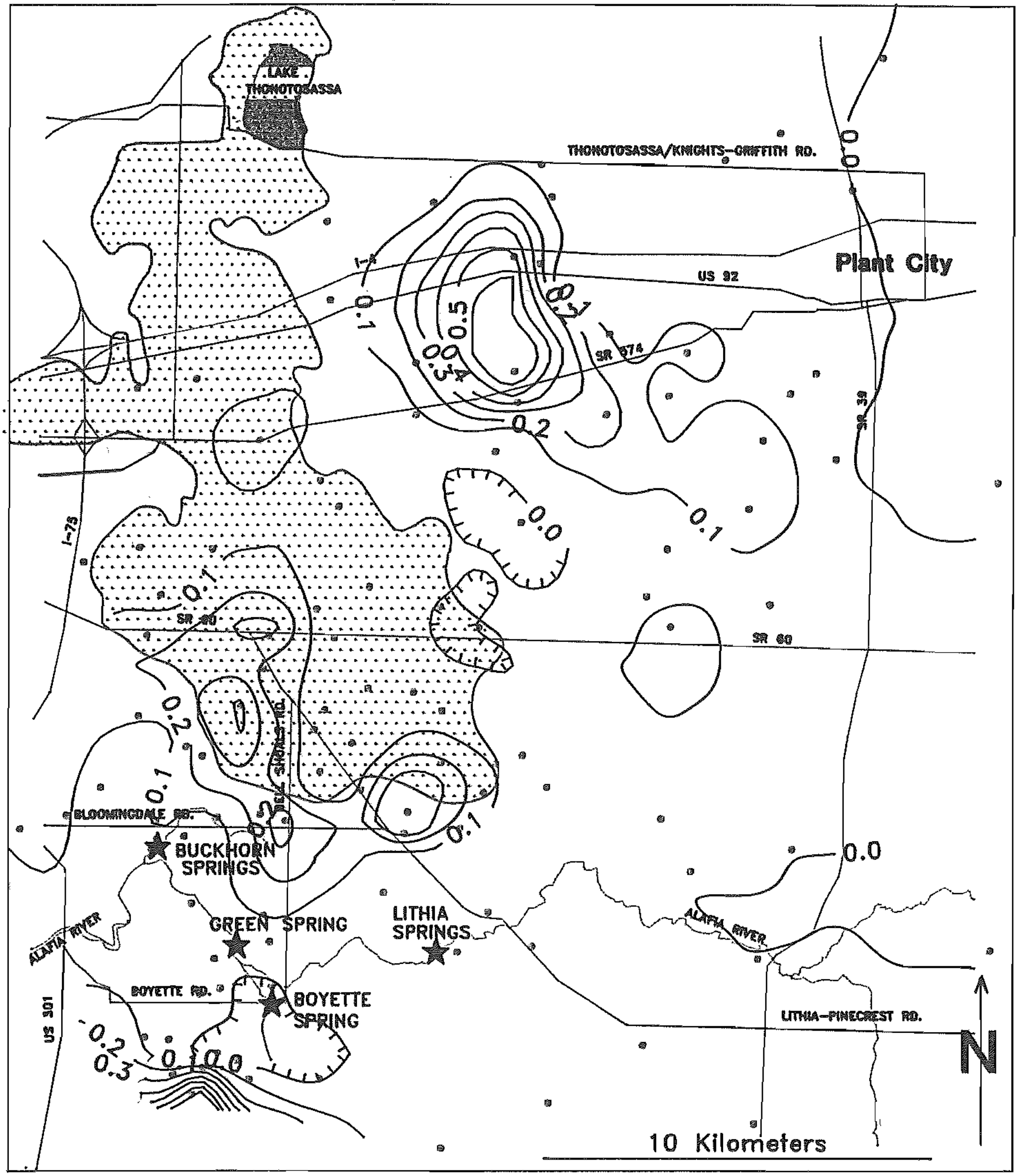

Figure 37. Phosphate Concentrations of Study Area Ground Water.

CONCEPTUAL FLOW MODEL AND NUTRIENT-SOURCE AREAS

Flow Model

The potentiometric surface of the Floridan Aquifer (Figure 10) reflects flow of waters in the Tampa Member of the Arcadia Formation (Hawthorn Group) and in the Suwannee Limestone within the karst terrain. Here, the Tampa clay, the clay that separates the Intermediate and Floridan Aquifers is absent and the Tampa is part of the Floridan Aquifer. To the east the two aquifers are separated by the clay horizons.

The potentiometric surface clearly reflects loss of the Tampa clay and increased transmissivities in the karst terrain. Here, the potential decreases and flow diverges to south and west (Figure 10). Fracture-trace analysis within the Terrain indicates potential conduiting that converges on the springs and provides down-gradient and lateral flow corridors from the karst terrain to the springs.

Nutrient Source Areas

There is ample physical and chemical evidence, therefore, that the southern half of the Brandon karst terrain can serve as a source of nutrients for the springs. Chemical and isotopic data indicate strong similarities between waters in the southern half of the terrain and Lithia and Buckhorn springs. Therefore, we conclude that the source(s) of nutrients in these springs are located within the southern half of the Brandon karst terrain and in pasturage and dairy facilities near the springs.

Cattle pasturage and dairies in the southwest portion of the study area, just south and southwest of the Brandon karst terrain, also affect ground water and some springs. Boyette Spring is a contact spring located on the Hawthorn Group clays. Here, nutrient-rich waters are derived from animal wastes (note high $\delta^{15}N$ and nitrate concentrations) introduced in pasturage just southeast of the springs. There is a string of sinkholes along a lineament that extends northwestward and flow appears to be localized along a "swale" in the clays along this linear feature. Pasturage northwest of Buckhorn Springs is also apparently contributing nitrogen (high $\delta^{15}N$ and nitrates) to the ground water. Wells near this pasturage show high levels of nutrients. Buckhorn Springs contains less nitrogen because of mixing with unaffected waters.

Ground-Water Travel Time

The discussion of the Brandon karst terrain conceptual flow model in the previous section hypothesized that ground water flow in the Floridan Aquifer is both diffuse and conduit dominated. Diffuse flow occurs as ground water percolates in from the surface, enters the aquifer systems, and moves between the grain to grain contacts of the sand and limestone. Upon entering limestone, intergranular (diffuse) flow becomes less important and conduit flow increases in importance. Ultimately, smaller fractures intersect the major fractures that transport water to one of the springs. These major fractures are also recharged directly by sinkholes located along their length.

Pumping tests of Floridan Aquifer wells in the Brandon karst terrain have yielded transmissivities that indicate both diffuse and conduit flow are important (Figure 38). These values were substituted into equation 4 to calculate average linear velocity.

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

where:

v = average linear velocity (ft/d);
K = hydraulic conductivity (g/d/ft^2), calculated from T = 2x10^6 g/d/ft and b = 400';
Δ H = change in head (ft.);
L = length of flow path (ft.);
n = porosity (0.05 for karst aquifers)

Aquifer thickness (b) was determined to be 400 ft. This is approximately the thickness of the upper Floridan Aquifer flow zone in the area which is thought to be composed of the Tampa member of the Arcadia Formation, the Suwannee Limestone, and the upper portion of the Ocala Limestone. A transmissivity (T) of 2x10^6 g/d/ft was used because this is the highest T value obtained from pumping tests in the area. This T value is used to simulate ground-water flow that might occur in long, continuous fractures that collect and funnel large amounts of water to the springs. A porosity value (n) of 5 percent was also used. This is the porosity value used for the Department of Environmental Regulation's methodology for delineating wellhead protection zones (Vecchioli et al., 1989). The average linear velocity obtained from the equation was used to estimate the time required in years for ground water to move from various points in the Brandon karst terrain to Lithia and Buckhorn Springs (Figure 39). This approximation indicates minimum travel times required for ground-water transport to the springs. In actuality, the calculated velocity is almost certainly over estimated because the fractures probably do not maintain a transmissivity of 2x10^6 g/d/ft for their entire length, paths of flow along the fractures are not as direct as those depicted in the figure and the diffuse component of flow that may recharge the major

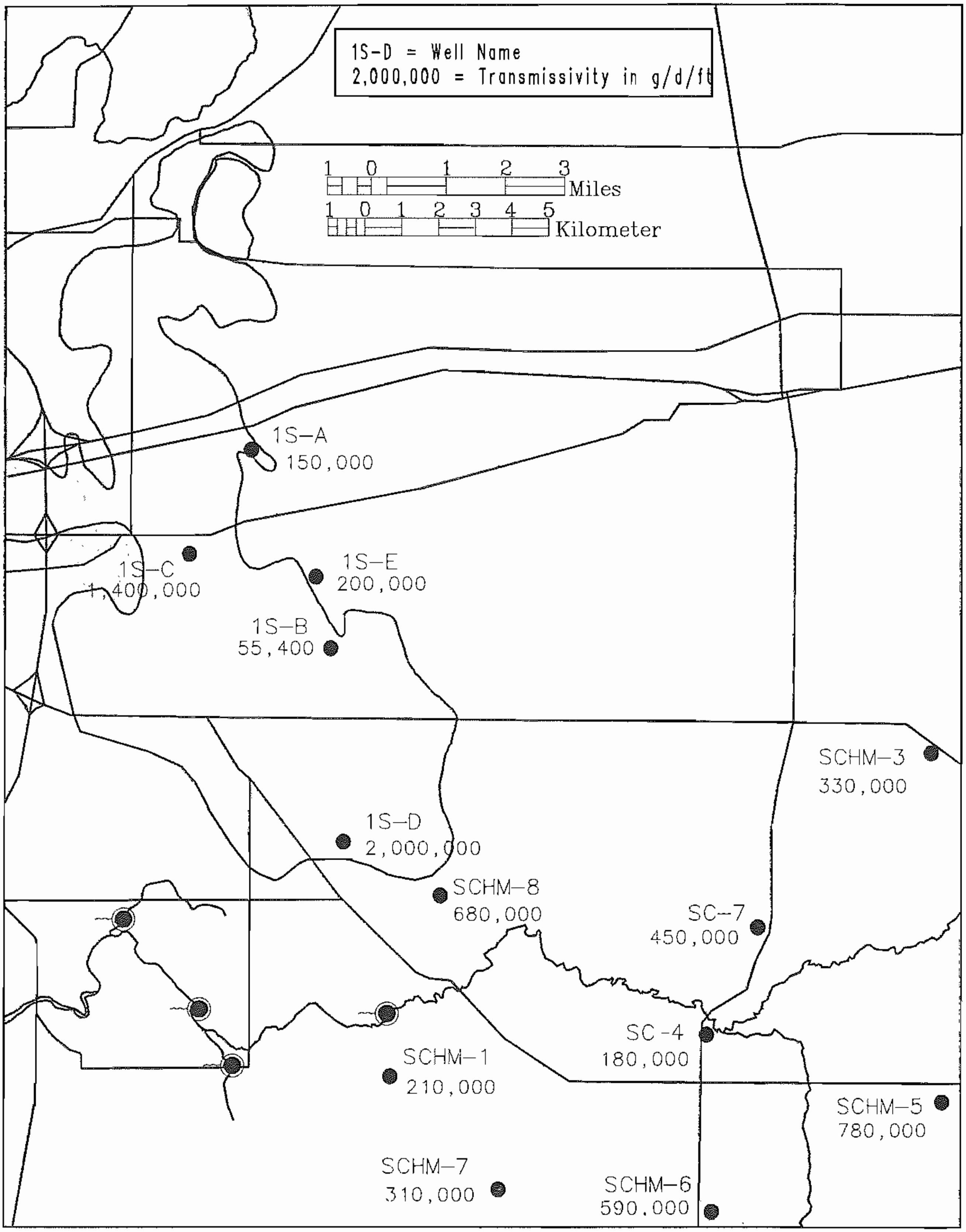

Figure 38. Pump Test-Derived Transmissivities from Floridan Aquifer Wells in the Study Area (Geraghty and Miller, 1988).

fractures is ignored. Other uncertainties exist, such as aquifer thickness and the exact gradient across the study area.

From Figure 39, it is apparent that ground water in the Brandon karst terrain north of highway 60 requires at least 20 years to reach Lithia or Buckhorn Springs. The time required is probably considerably longer since the travel time values are almost certainly overestimated.

Analysis of historical aerial photographs indicates that septic tanks, a major source of nitrogen in the study area, did not begin to reach high densities until the mid to late 1970s. Therefore, nitrates from the majority of septic tanks in the Brandon karst terrain probably have not yet reached the vicinity of the springs and the present nitrate concentrations in the spring water reflect earlier land uses, such as citrus. Although the time required for flow to reach the springs reduces the importance of septic tanks in terms of their current contribution to the nitrate problem in the springs, it indicates that they may become increasingly important in the future.

NUTRIENT LOADING OF THE GROUND-WATER SYSTEM

Introduction

Approximately 183 tons of nitrate is dissolved in the combined yearly discharge of Lithia and Buckhorn Springs. Freshwater from the springs containing approximately 26 tons of nitrate is diverted for industrial use by Cargill fertilizer. The remaining 157 tons flow into the Alafia River and ultimately reaches Tampa Bay. From previous discussions it is clear that the majority of nitrates in the waters of Lithia and Buckhorn springs enter the Floridan Aquifer system in the internally drained Brandon karst terrain south of the I-4 corridor. A number of sources that have the potential to contribute nitrates to ground water exist in this area. These include: 1) naturally occurring nitrates from organic decay and rainfall, 2) residential and commercial development serviced by septic tanks, 3) residential and commercial landscaping maintained with fertilizers, 4) golf courses, 5) ammonia pipelines, 6) agricultural contributions from citrus, row crops, dairy farms, and cattle production, 6) land spreading of septage and sewage sludge, 7) spray irrigation of treated waste water, and 8) storm-water runoff from residential, commercial and agricultural land uses. The following is a discussion and, where possible, a quantification of the contribution of nitrate from each of these sources to aquifer ground water.

Naturally Occurring Organic Decay

Nitrogen can be released into the environment through the microbial decomposition of surface biomass, which is largely plant material. However, the actual amount of nitrate contributed to ground water by this process is small because microbes and plants in the soil layer utilize and recycle the nitrogen as soon as it is

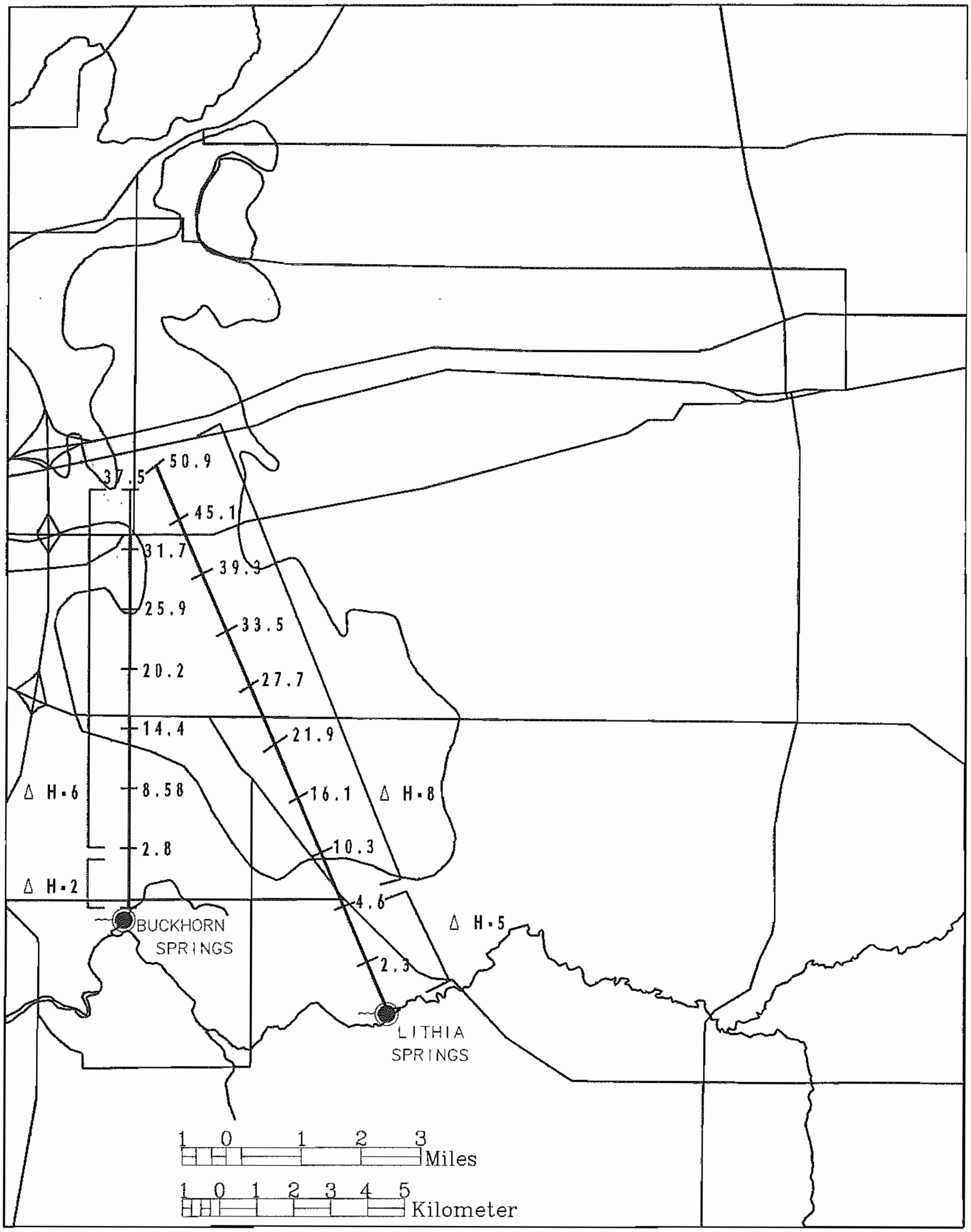

Figure 39. Time Required (years) for Ground Water in the Floridan Aquifer in the Brandon Karst Terrain to Reach Lithia and Buckhorn Springs.

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 northwest Hillsborough County where the only sources of nitrogen are organic decay and rainfall (Jones *et al.*, 1990)

Rainfall

The average nitrogen concentration in rainfall in the Tampa Bay area is 0.82 mg/L. This is based on monitoring data from the Tampa Bay National Urban Runoff Program (NURP) study conducted by Priede and Sedgwick, Inc. (1982). Using this figure, for the average rainfall year, the calculated rainfall load of N for the Brandon karst terrain south of the I-4 corridor is approximately 97 tons/yr. This amount of nitrogen, though large, may have little effect on ground water because it is applied during numerous rainfall events over the course of a year in small quantities to plant communities that utilize the nitrogen. 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 the study area have very low concentrations of nitrate. If rainfall was a significant source of nitrogen, ground water would probably have a uniformly elevated nitrate concentration across the entire study area.

Septic Tanks

Septic tanks are thought to be a significant source of nitrogen in the Brandon karst terrain. 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 mg/L to 100 mg/L with the average being in the range of 35 to 45 mg/L (U.S.E.P.A., 1980). Aerial photo analysis, ground reconnaissance, and analysis of the extent of the Hillsborough County sewer system, have indicated that there are approximately 11,000 septic tanks in the Brandon karst terrain. Relative densities of septic tanks are delineated in Figure 4. The Florida Statistical Abstract states that the average number of persons per household in the state is 2.5. In the Brandon area, 3 persons per household may be more accurate because the percentage of families in the area is probably higher than average. Using 3 persons per household, the annual nitrogen contribution per septic tank would be approximately 55 lb (Walker *et al.* 1973a). Research indicates that 20 to 40% of the nitrogen in effluent may be removed by mineralization, nitrification, denitrification, adsorption, biological uptake, fixation, or volatilization before the effluent reaches ground water (de Vries, 1972; Andreoli *et al.*, 1979; Harkin *et al.*, 1979; Peavy and Brawner, 1979; Laak, 1982). If 30% removal is achieved, and since it can be reasonably assumed that full conversion of nitrogen to nitrate occurs (Hantzsche and Finnemore, 1992), then approximately 211 tons/yr of nitrate could reach ground water. This is probably an under estimation of the actual value because the uncertainties of identifying structures served by septic tanks from aerial photographs required that estimates of septic tanks numbers be kept conservative.

Although the overall nitrate loading from septic tanks is low compared to other sources, septic tank nitrate takes on increased significance because the calculated value above is what is loaded directly to ground water. The calculated nitrogen loading value of the other sources is what is applied to the surface and what actually reaches ground water is probably significantly less because of the nitrogen removal mechanisms discussed previously.

Residential and Commercial Landscaping

Approximately 47 percent of the Brandon karst terrain south of the I-4 corridor is dominated by residential and commercial land uses. A large percentage of these land uses have associated landscaping such as lawns, shrubs, trees, and gardens. Quantifying the nitrogen contribution from the fertilization of landscaping was not considered possible. This is because it is extremely difficult to determine the percentage of landscaping that is maintained with fertilizers, how much fertilizer is applied, and how much of the fertilizer reaches ground water. However, an ongoing study (currently unpublished) conducted by the Ground-Water Quality Monitoring Program (GWQMP) of the Department of Environmental Protection (DEP), indicates that nitrogen contributions to ground water from landscape fertilization may be insignificant relative to other major sources. The study monitored ground-water quality in 22 areas across the state that were dominated by specific land uses. Three of the 22 areas were dominated by residential land uses where fertilization of landscaping was prevalent. Nitrate levels in ground-water samples obtained from numerous monitor wells in these areas were typically below 1 milligram per liter. These low levels may result from the following factors. First, many landscaped areas are not fertilized at all. Second, for those areas that are fertilized, quantities of fertilizer used can be less than that applied to agricultural lands, although the reverse may be true in certain affluent areas of limited extent where lawns are frequently and heavily fertilized. Finally, since the fertilizer is applied directly to landscaping, a large percentage of it would probably be utilized directly by the vegetation or removed by the mechanisms discussed previously.

Golf Courses

Buckhorn Springs and Diamond Hills golf courses are located within the boundaries of the Brandon karst terrain (Figure 40). Bloomingdale and River Hills golf courses are located approximately 1 to 1.5 miles south of the Brandon karst terrain. Together the courses cover approximately 600 acres.

Determining the amount of nitrogen applied to golf courses as fertilizer is highly problematical. However, a study commissioned by the Sarasota Bay National Estuary Program (1992) estimated that 28 tons/yr of nitrogen is applied to a golf course with

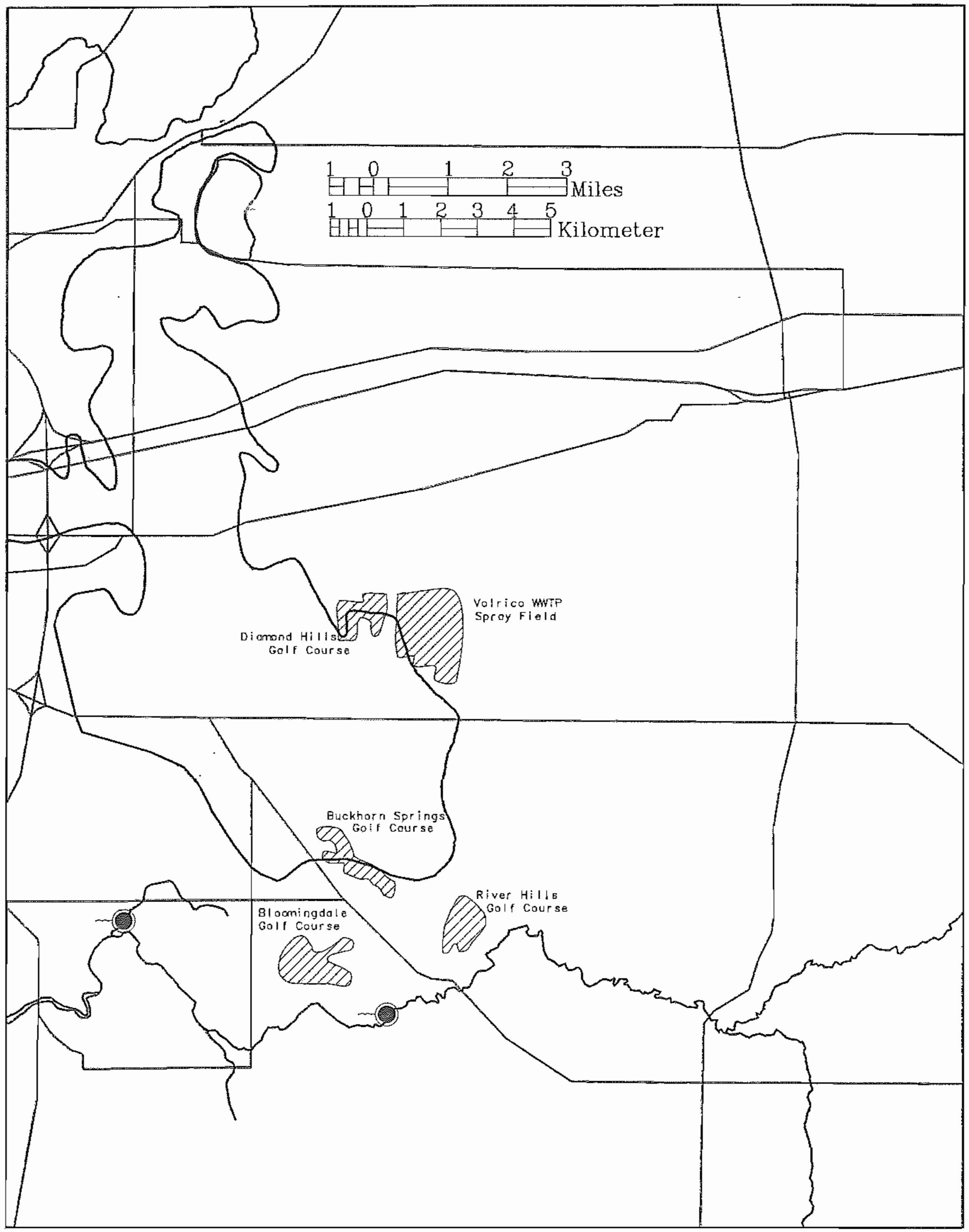

Figure 40. Golf Courses and Spray Fields in the Study Area.

15 acres of tees and greens and 200 acres of fairways. Therefore, the 600 acres of golf courses in or near the Brandon karst terrain may be receiving approximately 77 tons/yr of nitrogen. Although this is a significant amount of nitrogen, the previous discussion indicates that monitor wells around the golf courses are not indicating significant levels of nitrate in ground water.

Effluent Disposal From Sewage Treatment

There are approximately 49 permitted, active wastewater treatment facilities in the study area. Twenty are located in the Brandon karst terrain. Figure 41 is a location map of the wastewater facilities. Table 7 contains the map reference number, name, location, permitted capacity, and effluent disposal method for each facility. In addition to the active facilities, there are a total of 36 inactive facilities in the study area. Twenty are located in the Brandon karst terrain.

The facilities in the Brandon karst terrain range from small package plants for mobile home parks and businesses with permitted capacities of 4,500 gpd to the regional Valrico Wastewater Treatment Plant (VWTP) with a permitted capacity of 3 million gallons per day (Hillsborough County Planning and Zoning, 1992).

The VWTP is by far the largest wastewater treatment facility in the Brandon karst terrain, accounting for at least 80 to 90 percent of all permitted sewage treatment there (Hillsborough County Planning and Zoning, 1992). This facility discharged approximately 687 million gallons of tertiary-treated effluent for irrigation of golf courses and a spray field from January to December, 1991 (Hillsborough County Department of Water and Wastewater Utilities, 1992). The total nitrogen content of this volume of water was approximately 13,000 lbs. Fifty nine percent, or 407 million gallons/yr of effluent was sprayed on the Buckhorn and Bloomingdale Golf Courses. This volume contains approximately 7,700 lbs of nitrogen. The River Hills and Diamond Hills golf courses will be connecting with the system in the near future. The remaining 41 percent, or 279 million gallons/yr, of effluent was discharged at a spray field adjacent to the Valrico Waste-Water Treatment Plant (Hillsborough County Department of Water and Wastewater Utilities, 1992). This volume contains approximately 5,300 lbs of nitrogen.

A serious nitrate problem is indicated by data collected from 5 Surficial and Floridan Aquifer monitor wells at the Buckhorn Springs Golf Course (Hillsborough County Planning and Zoning, 1992). Concentrations averaged 6.9 mg/l from wells sampled quarterly between 1988 and 1992. Spray irrigation and/or golf course maintenance practices are probably not causing the elevated nitrate concentrations. The nitrates are present in the wells because the Buckhorn Springs Golf Course is near the regional nitrate high which probably has resulted from citrus cultivation that has existed for 50+ years in the area. The $\delta^{15}N$ data suggest that this high was caused by inorganic fertilizers, not effluent. The conclusion that spray irrigation is

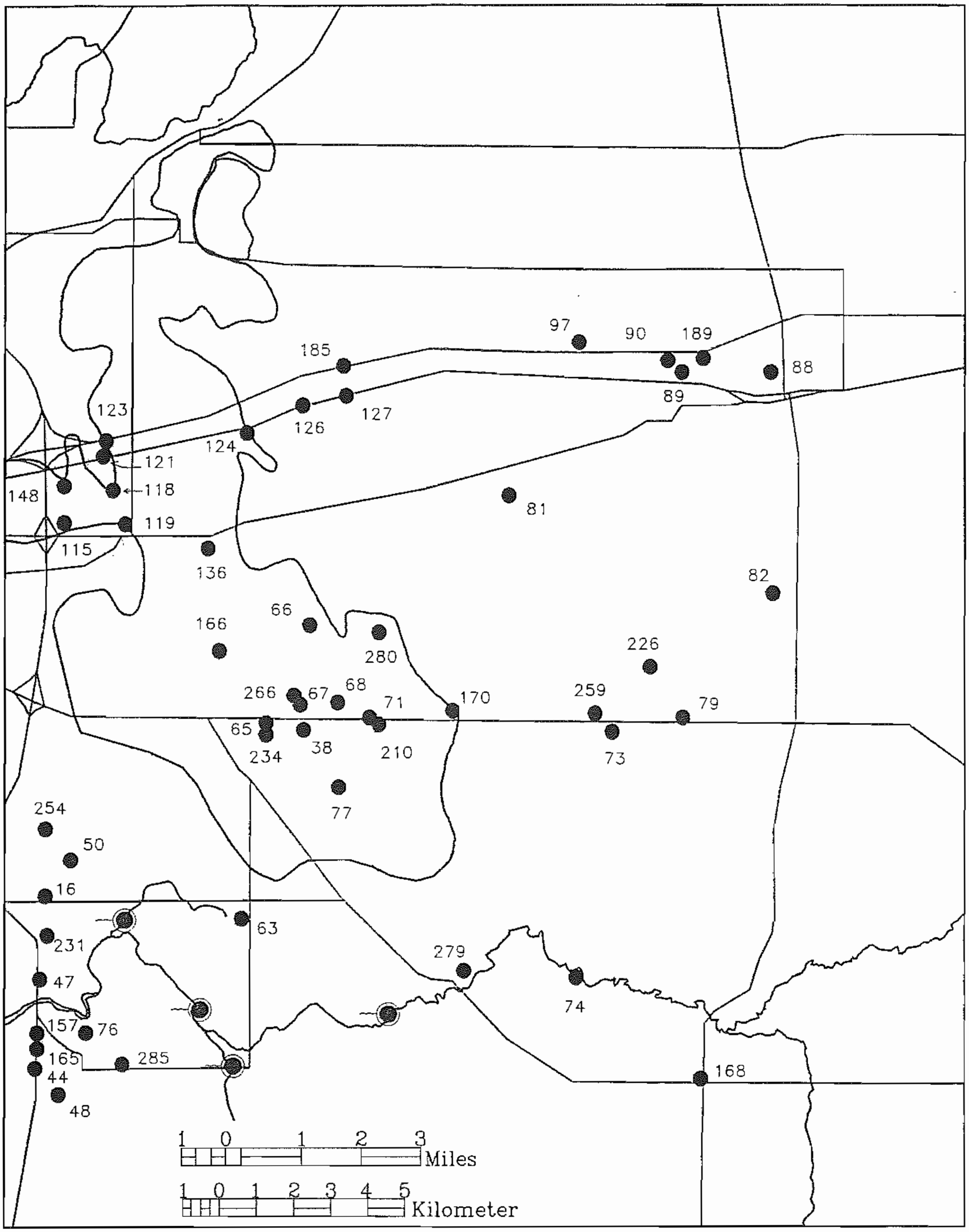

Figure 41. Active Wastewater Treatment Facilities in the Study Area.

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

FACILITY	MAP INDEX	DESIGN (TGD)	DISPOSAL TYPE
Bloomingdale Town Center Interim	16	5.40	DF
Brandon Brook Phase I	38	48.00	PP
Oakside MHP	44	18.00	PP/DF
Riverview Elem School	47	10.50	PP
Riverview Shopping Center	48	10.00	PP
Brookside Manor Apt	63	60.00	PP
Brandon Trlr Park	65	15.00	PP
Town & Country MHP	66	12.00	PP
Featherock	67	80.00	PP
Brandon Valrico Hills Estates	68	100.00	PP
Southern Pines MHP	71	4.50	PP
Citrus Hills RV Park	73	17.00	PP
Cedarkirk Camp	74	7.50	PP
Cristinia Interim (WW)	76	45.00	PP
Buckhorn Elem School	77	15.00	PP
Croft's MHP	79	17.00	PP
Crawford's 3 B's MHP	81	5.00	PP
Trappnell Elem School	82	17.70	PP
Plant City, City of	88	8000.00	SW
Robinson's Orange Park	89	11.40	PP
Strawberry Squares	90	27.00	PP
Speer MHP	97	20.00	SI
Davpam MHP	115	99.00	PP
Grandview MHP	118	20.00	PP
Mango Elem School	119	8.80	PP

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

FACILITY	MAP INDEX	DESIGN (TGD)	DISPOSAL TYPE
Prevatt MHP	121	5.00	PP
Days Inn of America	123	25.00	PP
Plantation Oaks MHP	124	11.20	PP
Green Acres Campground	126	45.00	PP
Tampa East KOA	127	15.00	PP
Kingsway Oaks	136	25.00	PP
Country Aire MHP	148	15.00	PP
Riverview Oaks Shopping Center	157	20.00	PP
Riverbay Plaza S/C	165	15.00	SW
Lakemont Hills	166	99.90	PP
Pinecrest School	168	12.00	PP
Valrico Hills MHP	170	8.50	PP
Rainbow Rock MHP	189	12.00	PP
Valrico Station	210	30.00	PP
Turkey Creek High Sch & Robins	226	21.00	PP
Bloomingdale Hills	231	131.00	SL
Brentwood Hills	234	16.00	PP
Purity Farms (Sterling Ranch)	254	230.00	SW
Starlite MHP	259	25.00	SI
Valrico Vista	266	24.80	PP
Riverhills Country Club IWWTP	279	300.00	PP
Valrico WWTP	280	3000.00	SW/SI
Riverglen	285	80.00	PP

probably not contributing to the nitrate problem at the springs is also supported by nitrate data from Bloomingdale golf course and the Valrico spray field monitor wells. These data indicate very low nitrate concentrations.

The other 19 wastewater treatment facilities in the Brandon karst terrain are permitted to treat approximately 662,500 gpd. The actual amount treated is considerably lower than the permitted maximum. This means that the VWTP may be treating 80 to 90 percent of all sewage in the Brandon karst terrain. These facilities dispose of effluent in several different ways. Percolation ponds followed by spray irrigation and drainfields are the most common disposal methods for facilities treating less than 100,000 gpd. Facilities permitted for volumes greater than 100,000 gpd generally use advanced wastewater treatment (AWT) and either discharge to surface water or use spray irrigation.

Overall, nitrogen loading of ground water from the discharge of treated effluent in the Brandon karst terrain is probably insignificant. This is because as much as 80 to 90 percent of all sewage treatment occurs at the VWTP. The total effluent discharged yearly from this plant, after undergoing tertiary treatment, contains a relatively minor amount of nitrogen (13,000 lbs) which is widely dispersed on spray fields and golf courses. Most of this nitrogen is probably utilized by vegetation or immobilized in the soil layer.

It is impossible to determine the nitrogen loading from the remaining percentage of sewage treatment occurring at the 19 smaller facilities in the Brandon karst terrain. This is because the actual volume (vs permitted) of sewage treated can not be determined and the amount of nitrogen in the sewage and the efficiency of nitrogen removal for each facility is not known. However, the actual volume of effluent treated is probably only 10 to 20 percent of the total treated in the Brandon karst terrain. In addition, 15 of the 19 facilities are small package plants permitted to treat 25,000 gpd or less. Even though none of the 19 facilities go beyond secondary treatment, the relatively small volume treated and the small size and wide dispersal of the sites probably results in an insignificant contribution of nitrogen to ground water. This contribution will be minimized even further as the small treatment facilities are phased out and their service areas are connected to the VWTP.

Septage and Sludge Spreading

The locations of active and inactive septage and sludge spreading sites in the study area are plotted in Figure 42. There are 13 sites in the study area. Three are located in the Brandon karst terrain. Information concerning acreage, land use, and status of each site is listed in table 8 (Hillsborough County Public Health unit, 1992; Hillsborough County Environmental Protection Commission, 1992). Septage/sludge spreading sites are usually privately owned agricultural lands. Because the waste has value as fertilizer, the owners of the land either pay to have the waste delivered or

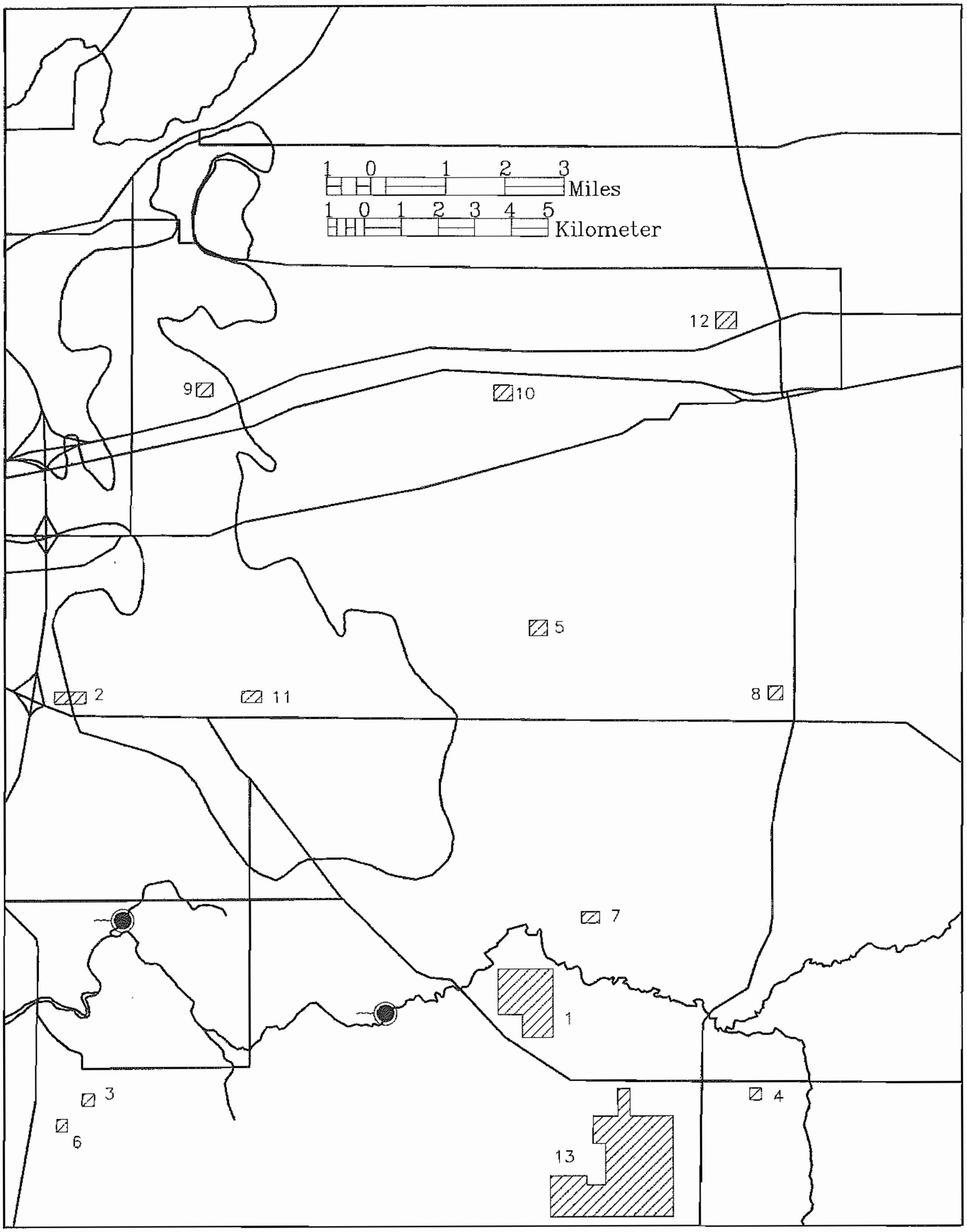

Figure 42. Active and Inactive Septage and Sludge Spreading Sites in the Study Area.

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

FACILITY	MAP INDEX	ACRES	LAND USE	SLUDGE/ SEPTAGE	STATUS
Capitano/Thompson Road Site	1	211.00	Pastureland/Grazing Only	Sludge	Active
Carlton/Woodberry Sludge Site	2	189.00	Pastureland	Sludge	Active
Martinez Dairy/ Ippolitto Site	3	110.00	Pastureland/Grazing	Slu/Sep	Active
Blitch/Osborne Ranch	4	148.00	Pastureland/Bahia/ Bermuda	Slu/Sep	Active
Sydney Farms	5	?	Pastureland	Septage	Active
Ballard Property	6	?	Pastureland/Grazing	Septage	Active
Turkey Creek Road Grove	7	?	Citrus	Septage	Active
Lawton Grove	8	?	Citrus	Septage	Active
Pruitt Road Grove	9	?	Pastureland	Septage	Active
Bethlehem Road Site	10	?	Citrus	Septage	Active
Crews Grove	11	?	Citrus	Septage	Inactive
Wallace Ranch Road Site	12	?	Pastureland	Septage	Active
Warren Allen Ranch Site	13	?	Pastureland/Silage/Sod	Sludge	Active

simply grant a disposal company permission to spread the waste on their land. Sources of the septage/sludge range from large scale wastewater treatment plants for major urban areas and small scale package plants for mobile home parks to disposal companies that revitalize septic tanks.

Land spreading of septage/sludge can contaminate ground water because the waste contains high concentrations of nutrients, trace metals, and organic compounds. If the application rate of the septage/sludge exceeds the capacity of the vegetation or soils to utilize or adsorb these compounds, they may percolate downward into ground water (Johnson, 1979).

The three land spreading sites in the Brandon karst terrain include one that only accepts sludge wastes (Carlton/Woodberry site, #2 on figure 42) and two that accept only septage wastes (Pruitt Road Grove and Crews Grove, #9 and #11 respectively on Figure 42). The Carlton/Woodberry site has not accepted sludge for the past year and is not likely to accept sludge in the future as the result of complaints from neighbors. The Pruitt Road site is open but records obtained from the Hillsborough County Health Unit pertaining to the volume of septage deposited at the site in 1992 and in previous years are apparently incomplete. Finally, the Crews site is closed.

It is obvious from the previous paragraph that the amount of nitrogen loaded to the karst terrain by septage/sludge spreading cannot be determined. However, the fact that two of the sites are not accepting waste is a good indication that the effects of land spreading on nitrate levels in ground water are not significant.

Leaks from Ammonia Pipelines

A number of investigators have speculated that undetected leaks from ammonia pipelines could supply large quantities of ammonia nitrogen to the study area. Ammonia pipelines carry liquid ammonia under high pressure and are buried within two to three feet of the surface. Two pipelines that supply ammonia to phosphochemical plants in Polk County pass through or are in close proximity to the study area. The first extends east from Highway 301 along Bloomingdale Road to Highway 640 which it follows past Highway 39 into Polk County. The second also extends east from Highway 301 south of the Alafia River along Boyette Road eventually reaching Highway 640 and merging with the first pipeline. Discussions with personnel from the Hillsborough County Environmental Protection Commission (EPC) and Tampa Pipeline (the company that maintains the pipelines) have indicated that significant leaks from these pipelines have occurred on only two occasions and were quickly contained. Minor leaks may not be detected quickly and could conceivably leak small quantities of ammonia into the near-surface environment. This ammonia would be rapidly converted to nitrate and could eventually reach ground water in the surficial and Floridan Aquifers. Although it is not possible to quantify the amount of nitrate in Floridan Aquifer ground water originating from ammonia pipeline leaks, there is no evidence to suggest that the pipelines are a significant source of nitrate north of the Alafia River. However, south of the river, an area of elevated ammonia concentrations (Figure 31) exists in the Floridan Aquifer in the vicinity of the Boyette ammonia pipeline. This ammonia probably has no effect on Lithia and Buckhorn Springs because the springs are up gradient. This ammonia is also not the source of the Boyette Spring nitrate because nitrogen isotope testing combined with land use mapping have clearly identified the source as animal waste.

Agriculture

Agricultural loadings of nitrogen in the Brandon karst terrain are subdivided into row crops, cattle pasturage, dairies, and citrus.

Row Crops

Row crops are prevalent in the northeast portion of the study area. However, both the 1965 and 1989 land use maps (Figures 3 and 4) indicate that row crops have never been prevalent in the Brandon karst terrain. It is thought that nitrogen from row crops in the northeast portion of the study area does not significantly contribute to the nitrate problem at the springs. This is because: 1) these areas are not located in an internally drained area, so the nitrogen may run off into streams, 2) nitrogen that reaches ground water in the Surficial Aquifer may be locally discharged to surface water, and 3) nitrogen that finally reaches the Floridan Aquifer would travel very slowly because the flow system in the northeast portion of the study area is not nearly as transmissive as that of the Brandon karst terrain.

Dairies and Cattle Pasturage

Dairy and beef cattle pasturage in or near the Brandon karst terrain, although historically a major land use, has been largely replaced by sewered residential subdivisions. Interpretation of historical aerial photography (Figure 3) indicates that there were at least 8 dairies in the study area in 1965 and many thousands of acres of associated pasturage. Although none of the dairies were located entirely within the Brandon karst terrain, six were located between the Alafia River and the southern boundary of the karst terrain. Today, only 1 of these 6 dairies remains.

No attempt was made to quantify historical and current nitrogen contributions from dairy and cattle pasturage. This is because the number of cattle in the area currently and historically and the amount of nitrogen supplied by each cow can not be determined. However, ground-water samples analyzed for nitrogen isotopes indicate that the nitrogen in ground water southwest of the Brandon karst terrain, where most of the dairies were located, originated from human or animal waste. Since the only major land use in this area prior to the development of sewered residential subdivisions in the 1980s, has been dairy and beef cattle pasturage, it can reasonably be assumed that this land use has contributed the nitrate.

Citrus

Aerial photographs indicate that citrus was a major land use in the Brandon karst terrain at least as early as the late 1940s. In 1965, 6900 acres or 33 percent of the Brandon karst terrain south of I-4 was dedicated to citrus cultivation. By 1989 encroachment of residential and commercial development had reduced citrus to only 2300 acres or 11 percent of the Brandon karst terrain south of I-4.

Approximately 180 to 200 lb/ac/yr and 150 to 200 lb/ac/yr of inorganic nitrogen fertilizer is applied to oranges and grapefruit, respectively (Bolcher, Jack, 1992, University of Florida Cooperative Extension Service, personal communication). If 175 lb/ac/yr is used as an average amount, approximately 600 tons of fertilizer was applied to citrus in 1965 and 201 tons were applied in 1989.

Ground-water samples obtained from wells in the Brandon karst terrain that were analyzed for nitrogen isotopes indicate that much of the nitrogen in ground water originated from inorganic nitrogen fertilizers, such as are utilized in commercial fertilizers. Comparison of the nitrogen-distribution maps (Figures 29-32) with the 1965 land-use data (Figure 3) suggests that the high nitrogen concentrations roughly coincide with the distribution of citrus in the 1960s. This coincidence combined with the low $\delta^{15}N$ ratios in ground water in these areas and the very high annual loadings of fertilizers that have been applied since at least the late 1940s, strongly point to past uses of fertilizers in citrus groves as a major source of nitrogen contamination.

Storm-Water Runoff

Stormwater is not an additional source of nitrogen over and above what has previously been calculated from the sources discussed above. The nitrogen in stormwater is simply what runs off from the other sources during rainfall events. Determining the amount of nitrogen in stormwater is necessary to illustrate the importance of proper storage and treatment of stormwater.

In karst areas, storm water is responsible for transporting a wide variety of highly concentrated pollutants directly into aquifer systems through sinkholes where little or no filtration occurs (Wallace, 1991). This problem is exacerbated by the fact that residential and commercial storm-water systems are often designed to funnel storm water directly to sinkholes because they are the lowest points in an area.

To calculate nitrogen contributions from 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 storm water for a number of land uses. It is generally accepted in the field of storm-water management that these values can be used in place of local monitoring programs to quantify nitrogen loading of storm water (Sarasota Bay National Estuary Program, 1992).

For total nitrogen, the EMC values are highest for cropland, citrus, and low- to medium-density, single-family residential land uses. This results from the fertilization of the croplands and citrus and the landscaping of residential areas. Industrial, commercial, and unimproved areas have the lowest EMC values because they are not

Table 9. Event Mean Concentration and Runoff Coefficient for Important Land Uses in the Brandon Karst Terrain.

LAND USE	RUNOFF COEF	EVENT MEAN CONCENTRATION TOTAL NITROGEN (mg/l)
Citrus	0.15	0.92
Residential *	0.15	1.76
Commercial	0.95	1.18
Golf Courses	0.15	2.70

* 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

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.

The only land uses that were included for the stormwater nitrogen calculations were golf courses, residential, commercial, and citrus. Other land uses such as industrial, cropland, 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 storm water 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:

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

where: N = total nitrogen (lbs/yr) in storm water 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 the land uses that contribute significant amounts of nitrogen to storm water, the total acreage of that land use within the Brandon karst terrain south of the I-4 corridor, and the amount of nitrogen estimated to be contributed annually to storm water using the above calculation.

According to Table 10 approximately 40,772 lb/yr (20 tons) of nitrogen is contained in storm water in the Brandon karst terrain. This value should be considered a very rough estimate for several reasons. First, the acreage of cattle pasturage was impossible to quantify because it could not be identified from aerial photographs. This could cause the total storm-water nitrogen load to be significantly underestimated because cattle pasturage may be a large contributor of nitrogen to storm water. Second, it is impossible to determine how much of the nitrogen in storm water may actually reach Floridan Aquifer ground water. Many factors such as partially blocked or plugged sinkholes, uptake of storm-water nitrogen by terrestrial and aquatic

TABLE 10. Acreage and Stormwater Nitrogen Contribution from Four Important Land Uses in the Brandon Karst Terrain.

LAND USE	ACREAGE	TOTAL NITROGEN (LBS/YR)
Citrus	2,300	3,800
Commercial	600	7,700
Residential	9,100	26,300
Golf Course	630	3,000
TOTAL	**12,630**	**40,800**

vegetation and uptake by soil bacteria could serve to lessen the impact of storm-water nitrogen on ground water.

Nitrogen Loading Summary

Table 11 is a summary of the nitrogen contributions of the non-agricultural land uses in the Brandon karst terrain. Tables 12A and 12B are summaries of the nitrogen contributions of recent and historical agricultural land uses in the Brandon karst terrain. Because of their long-term presence in the Brandon karst terrain (50+ years), nitrogen contributions from the agricultural land uses are broken down into historical and recent contributions. Historical loadings from other land uses are considered insignificant because these have reached significant densities in only the recent past (5-20 years).

There are several uncertainties in this analysis, but it is clear that agricultural practices were widespread in the karst terrain during the time interval of predicted recharge to the aquifer and that changes in land use have not necessarily created situations prone to natural improvement. The nitrogen isotopic data suggest localized animal waste sources, such as dairies, but ratios are generally low. The range of these ratios suggests that nitrogen in ground water was primarily derived from inorganic sources, such as inorganic fertilizers, with a minor overprint of animal wastes, such as from dairies, cattle pasturage, and septic tanks. Where loading estimates can be made, they support this conclusion.

Table 11. Non-Agricultural Nitrogen Loading Sources and Nitrogen Load.

SOURCE	N LOADING (TONS/YR)	SIGNIFICANCE
Naturally Occurring	Not possible to quantify	Insignificant because ground-water nitrogen in background areas is very low
Rainfall	97	Insignificant because ground-water nitrogen in background areas is very low
Septic Tanks	211	Very significant - the 211 tons is loaded directly to ground-water - however, septic tank nitrogen is not yet contributing to nitrate problems in the springs because of slow ground-water travel times
Effluent Disposal From Sewage Treatment	6.5 +	Insignificant - 80 to 90 percent of sewage treatment in Brandon karst terrain occurs at the Valrico AWT Plant - the 6.5 tons of nitrogen generated annually from this facility is widely disseminated on a spray field and 2 golf courses - the remaining sewage treatment occurs at 19 small, widely dispersed plants - volume of sewage treated by these facilities is relatively small
Residential and Commercial Landscaping	Not possible to quantify	Significance may not be great because overall loadings are probably low and uptake and fixation remove nitrogen prior to ground-water mixing

Table 11. Non-Agricultural Nitrogen Loading Sources and Nitrogen Load (continued).

SOURCE	N LOADING (TONS/YR)	SIGNIFICANCE
Golf Courses	82.5	Effects uncertain - nitrates in Buckhorn Golf Course wells are very high but are probably not caused by golf course fertilizers or treated effluent - nitrates in Bloomingdale Golf Course wells are low - no well data for other golf courses
Septage/Sludge Spreading	Not possible to quantify	Insignificant - only 3 small sites exist in Brandon karst terrain, two of which hve recently closed - much of the nitrogen in the waste is probably utilized by vegetation or immobilized in soil layer
Ammonia Pipelines	Not possible to quantify	Insignificant - no indications of ammonia in ground-water in vicinity of pipeline north of Alafia River - ammonia in ground-water south of river near a pipeline does not affect springs

Table 12A. Recent Agricultural Nitrogen Loading

SOURCE	N LOADING (TONS/YR)	SIGNIFICANCE
Row Crops	Not possible to quantify	Insignificant - acreage is far too small to contribute significant amounts of nitrogen to ground water
Citrus	200	Very significant - nitrogen isotopes indicate that citrus is a major contributor of nitrogen to the springs- however, significance is decreasing as citrus acreage is rapidly converted to residential land uses
Dairies and Cattle	Not possible to quantify	Significant - nitrogen isotopes indicate that nitrogen from cattle is a significant contributor of nitrogen to the springs - however, significance is decreasing as dairies and cattle pasturage are rapidly converted to residential land uses

Table 12B. Historical Agricultural Nitrogen Loading

SOURCE	N LOADING (TONS/YR)	SIGNIFICANCE
Row Crops	Not possible to quantify	Insignificant - acreage was far too small to contribute significant amounts of nitrogen to ground water
Citrus	600	Very significant - nitrogen isotopes indicate that citrus is a major contributor of nitrogen to the springs - this quantity of nitrogen was probably applied at least through the 1940's, 50's, and 60's
Dairies and Cattle Pasturage	Not possible to quantify	Significant - nitrogen isotopes indicate that nitrogen from cattle is a significant contributor of nitrogen to the springs - 6 dairies and thousands of acres of cattle pasturage existed in or near the Brandon karst terrain in the mid 1960's

CONCLUSIONS

1. Buckhorn, Boyette, and Lithia Springs are discharging nitrate-rich waters into the Alafia River and Tampa Bay. The total amount of nitrate the springs contribute annually to the river is approximately 157 tons. This is 22 percent of the total nitrogen contributed to Tampa Bay by the Alafia River.

2. Cargill Phosphate, the owners of Lithia and Buckhorn Springs, divert approximately 14 percent of the combined flow of the springs to their chemical complex at the mouth of the Alafia River. This diversion prevents approximately 26 tons of nitrate from entering the Alafia River yearly.

3. Boyette Springs is discharging Surficial Aquifer water, while Lithia and Buckhorn Springs are discharging Floridan Aquifer water. These latter springs contain a small deep-flow component, but most of the water is derived from nearby recharge in the Brandon karst terrain.

4. The Tampa clay, which separates the Floridan and Intermediate Aquifers, pinches out at about the longitude of Lithia Springs. Therefore, east of the springs, there is an Intermediate Aquifer, while west, in the Brandon karst terrain, the Intermediate is technically absent and the Tampa Member strata are in hydrologic connection with older limestones of the Floridan Aquifer.

5. The Brandon karst terrain is a karst inlier surrounded by Hawthorn Group strata that partly confine the Floridan Aquifer. Drainage in the terrain is internal, through numerous sinkholes and karst conduits. The sinkholes are aligned along lineaments.

6. Within the terrain the Tampa clay is absent and recharge is directly to the Floridan Aquifer.

7. The potentiometric surface of the Floridan Aquifer indicates that transmissivities are high in the terrain, and that generally westward flow diverges into two components. Water in the northern half of the terrain (roughly, north of I-4) flows westward, while water in the southern half flows south and southeast, towards the springs and the Alafia River.

8. Fracture trace analysis indicates that karst conduiting is connected to the springs and provides pathways from the terrain to the spring complexes. Minimum travel time of ground water in the fracture is approximately 1 mile every 5 years.

CONCLUSIONS (continued)

9. Hydrochemical facies of spring waters shows that spring waters are chemically similar to terrain waters. There is no chemical evidence of Alafia River water discharging from the springs. There is little evidence of very deep Floridan water discharging, as well.

10. Sodium to chloride ratios support the hydrochemical facies data and tie the spring water to the southern half of the terrain.

11. Uranium and uranium isotopic ratios also indicate a local, south terrain source for the spring waters.

12. Tritium concentrations are ambivalent. Activities are moderately low and suggest water that recharged in the late 1950s or early 1960s.

13. Nitrogen isotopic ratios are very helpful in identifying nitrogen sources. Boyette Spring is clearly affected by animal wastes from a dairy south of the spring. A dairy west of Buckhorn Springs has affected local ground water, but dilution has prevented serious degradation of the springs. Water in the karst terrain and Lithia and Buckhorn Springs is largely affected by inorganic fertilizers applied to citrus, with minor animal waste contributions.

14. Changes in land use within the last 10 to 15 years have caused a change in nitrogen sources in the Brandon karst terrain. It is unclear how much septic tanks will impact the springs, but the 11,000 septic tanks now present in the area will most likely adversely affect future concentrations of nitrogen in the springs.

RECOMMENDATIONS

1. There is little that can be done to reduce present nitrogen loading from the springs because that nitrogen is an artifact of past land-use practices. If there were no additional loadings, there should be a gradual reduction in nitrogen with time (10's of years). Spring discharge augmentation will not reduce loading, but would reduce concentrations. Use of aquatic plants to control nitrogen is possible, but would require significant changes in the spring environments. Interception of the water through wells is possible, but would reduce spring discharge and negatively impact the estuary.

2. Several measures should be taken in the near future to increase our understanding of the nitrate problem in the Brandon area and to assess the role of septic tanks. These are listed below.

   a) All wells in the monitor network utilized in this report should be sampled for nitrogen isotopes in order to optimally site a dedicated network of monitor wells.

   b) This dedicated network would consist of approximately 10 to 20 strategically placed and carefully constructed monitor wells in the Brandon karst terrain. Construction standards for these wells would strictly adhere to Florida Administrative Code 17-761 requirements. These wells could provide detailed information on the presence, depth, and thickness of aquifers and confining layers. The strategic locations would insure that the areas where nitrate concentrations are highest would be thoroughly delineated and monitored, and strict adherence to proper well construction standards would insure that the accuracy of water quality information obtained from these wells would be beyond question.

   c) The monitor well network should be sampled annually for nutrients, major analytes, and trace organics for an indefinite period. Nitrogen isotopic ratios should be determined each time. If the ratios start to increase, a shift in nitrogen sources from past agricultural land uses such as citrus and dairies to present land uses such as residential development served by septic tanks would be indicated. If the decision was made to sewer the septic tank areas, the annual sampling would determine the effect of the reduction of septic tanks on ground-water quality.

   d) for the reasons discussed above, the springs should also be sampled annually for nutrients, major analytes, and trace organics. Nitrogen isotopic ratios should also be determined each time.

3. Future nitrogen loading as the septic-tank-derived water approaches the springs is a concern. It is not possible to determine the effect of the arrival of the septic-tank derived water on the water quality of the springs. However, the potential for this water to enrich the nitrate concentration of spring water exists. If it is concluded from the additional monitoring discussed above that septic tank effluent will degrade the water quality of the springs, a program of conversion of residential areas served by septic tanks either to sewers or alternative on-site systems that more effectively remove nitrogen should be undertaken. The regional nitrogen isotope data will allow prioritization of those areas that would need sewering or installation of alternative on-site systems.

4. The District should work with Hillsborough County and all interested parties to formulate land-use plans that would prevent additional nitrogen loadings to the Brandon karst terrain.

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APPENDICES

APPENDIX I

Logs of Wells Used in the Geologic Cross Sections

APPENDIX I

Cross Section A to A'

WELL LOG NUMBER	IS-D
WELL LOG NAME	INTERIM SUPPLY WELL
COUNTY	HILLSBOROUGH
TOTAL DEPTH	201 FT
LOCATION	
ELEVATION	
COMPLETION DATE	

INTERVAL	DESCRIPTION	FORMATION
		UNDIFFERENTIATED SURFICIAL
0 - 5	Sand, fine-grained, silty, dark brown, organics	
5 - 15	Sand, fine-grained, tan to brown	
		HAWTHORN GROUP CLAYS
15 - 20	Clay, soft, slightly sandy, cream to tan; cemented sand, fine-grained, cream; minor decayed organics; medium-grained, quartz pebbles	
20 - 40	Clay, soft, slightly sandy, tan to orange; white, granular, soft limestone	
40 - 50	Clay, soft, silty, cream to tan; white, granular, soft limestone	
50 - 55	Clay, soft, sticky, cream to tan; minor white, granular, soft limestone	
55 - 60	Clay, soft, sticky, cream; white, angular, medium-hard limestone	
60 - 125	No samples	
125 - 130	Limestone, granular, hard, cream-colored; gray, hard, angular, chert	

APPENDIX I

Cross Section A to A'

	TAMPA MEMBER
130 - 140	Limestone, granular, soft to medium-hard, cream-colored; gray, hard, angular, chert
140 - 165	Limestone, granular, hard, cream-colored; minor fossil fragments
165 - 190	Limestone, granular, hard, cream-colored; fossil casts and molds
	SUWANNEE LIMESTONE
190 - 201	Limestone, granular, hard, cream-colored; fossil fragments

APPENDIX I

Cross Section A to A'

WELL LOG NUMBER	EMW-1
WELL LOG NAME	EXPLORATORY MONITOR WELL
COUNTY	HILLSBOROUGH
TOTAL DEPTH	820 FT
LOCATION	
ELEVATION	
COMPLETION DATE	

INTERVAL	DESCRIPTION	FORMATION
		UNDIFFERENTIATED SURFICIAL
0 - 5	Sand, quartz, fine-grained, tan; organics	
5 - 15	Sand, quartz, fine to medium-grained, tan; organics	
		HAWTHORN GROUP CLAYS
15 - 22	Clay, sandy, fine to medium-grained, soft, tan to orange; organics	
22 - 23	Clay, sandy, medium-grained, soft, orange; organics	
23 - 27	Clay, sandy, coarse-grained, soft, tan; interbedded with a white chalky substance; organics	
27 - 30	Clay, sandy, medium to coarse-grained, white to tan	
30 - 32	Clay, sandy, soft, tan to orange; interbedded with a white chalky substance	
32 - 36	Clay, sandy, tan to orange; iron stains throughout sample	
36 - 49	Clay, sandy, tan to brown; interbedded with a white chalky substance; iron stains throughout sample	
49 - 67	Limestone, clayey, angular to sub-angular, poorly indurated, crumbly, white	

APPENDIX I

Cross Section A to A'

67 - 70	Limestone, dolomitic, angular to sub-angular, poorly indurated, white
70 - 75	Limestone, clayey, sub-angular, poorly indurated, white; trace of iron stain
75 - 95	Limestone, clayey, sub-angular, poorly indurated, white to light gray
95 - 100	Limestone, dolomitic, angular to sub-angular, poorly indurated, white to light gray
	TAMPA MEMBER
100 - 115	Missing samples
115 - 125	Limestone, clayey, angular to sub-angular, poorly indurated, low porosity, white
125 - 145	Limestone, dolomitic, sub-angular, poorly indurated, low porosity, white; fossiliferous
145 - 170	Limestone, dolomitic, sub-angular, poorly indurated, low porosity, white to light gray
170 - 200	Limestone, dolomitic, angular to sub-angular, poorly indurated, low porosity, white
200 - 230	Limestone, dolomitic, sub-angular, poorly indurated, low porosity, white; fossiliferous
230 - 280	Limestone, dolomitic, angular to sub-angular, poorly indurated, pinpoint vugs, light gray; fossiliferous
	SUWANNEE LIMESTONE
280 - 295	Limestone, dolomitic, sub-angular, poorly indurated, pinpoint vugs, tan; fossiliferous
295 - 310	Dolostone, calcitic, microcrystalline, sub-angular, well indurated, tan; fossiliferous
310 - 320	Limestone, dolmitic, sub-angular, well indurated, low porosity, tan to brown; fossiliferous

APPENDIX I

Cross Section A to A'

WELL LOG NUMBER	IS-B
WELL LOG NAME	INTERIM SUPPLY WELL
COUNTY	HILLSBOROUGH
TOTAL DEPTH	650 FT
LOCATION	
ELEVATION	
COMPLETION DATE	

INTERVAL	DESCRIPTION	FORMATION
		UNDIFFERENTIATED SURFICIAL
0 - 10	Sand, silty, fine-grained, tan; organics	
10 - 20	Clay, stiff, yellow	
20 - 33	Sand, fine to medium-grained, tan; yellow, soft clay	
33 - 45	Sand, fine-grained, orange; orange, stiff clay	
		HAWTHORN GROUP CLAYS
45 - 55	Limestone, sandy, soft, white; orange stiff clay	
55 - 65	Limestone, sandy, soft, white	
65 - 71	Limestone, sandy, hard, white; white, soft, sandy, clay	
71 - 93	Limestone, sandy, medium-hard, white, chalky (gummy)	
93 - 100	Limestone, sandy, hard, brown	
100 - 105	Sand, fine-grained, white	
105 - 120	Limestone, sandy, medium-hard, white	
120 - 125	Clay, soft, cream	
125 - 128	Limestone, sandy, medium-hard, brown, porous	

APPENDIX I

Cross Section A to A'

128 - 130	Clay, soft, white
	TAMPA MEMBER
130 - 135	Limestone, soft, granular, fractured, brown, white; soft clay lense at 132 feet
135 - 153	Limestone, soft, granular, fractured, white
153 - 158	Limestone, soft, fractured, fossiliferous, brown; brown, soft clay
158 - 190	Limestone, sandy, soft, white
190 - 195	Limestone, granular, medium-hard, white
195 - 200	Limestone, sandy, soft, unconsolidated, white
200 - 220	Limestone, granular, medium-hard, white
220 - 260	Limestone, granular, soft, poorly indurated, white
	SUWANNEE LIMESTONE
260 - 270	Limestone, granular, soft, poorly indurated, tan
270 - 280	Limestone, granular, soft, poorly indurated, tan; gray, hard shale

APPENDIX I

Cross Section A to A'

WELL LOG NUMBER	5099
WELL LOG NAME	
COUNTY	HILLSBOROUGH
TOTAL DEPTH	560 FT
LOCATION	
ELEVATION	
COMPLETION DATE	

INTERVAL	DESCRIPTION	FORMATION
		UNDIFFERENTIATED SURFICIAL
0 - 20	Sand; white to dark, yellowish orange; 34% porosity, intergranular; grain size: fine; range: fine to coarse; roundness: sub-angular to rounded; medium sphericity; unconsolidated; accessory minerals: clay-02%, phosphatic sand-01%	
20 - 30	Sand; white; 34% porosity, intergranular; grain size: fine; range: fine to medium; roundness: angular to rounded; medium sphericity; unconsolidated; accessory minerals: phosphatic sand-02%	
30 - 40	Clay; white; 05% porosity, intergranular; moderate induration; cement types: clay matrix; accessory minerals: quartz sand-01%; other features: calcareous	
		HAWTHORN GROUP CLAYS
40 - 50	Limestone; white; 09% porosity, intergranular; grain type: calcilutite; grain size: cryptocrystalline; range: microcrystalline to microcrystalline; good induration; cement types: calcilutite matrix; accessory minerals: chert-15%; chert laminae present	

APPENDIX I

Cross Section A to A'

50 - 60	Sand; very light gray; 10% porosity, intergranular; grain size: fine; range: fine to medium; roundness: angular to sub-angular; medium sphericity; good induration; cement types: calcilutite matrix; accessory minerals: phosphatic grave-05%, chert-05%; fossils: sharks teeth
60 - 70	Limestone; white; 11% porosity, intergranular; grain type: calcilutite; grain size: cryptocrystalline; range: microcrystalline to microcrystalline; good induration; cement types: calcilutite matrix; accessory minerals: quartz sand 15%
70 - 80	Clay; white; 10% porosity, intergranular; moderate induration; cement types: clay matrix; accessory minerals; calcilutite-25%; accessory minerals: clay 05%, quartz sand-03%; other features: plastic
90 - 100	Same as above
100 - 110	Sand; white to light olive; 15% porosity, intergranular; grain size: medium; range: fine to course; roundness: sub-angular to rounded; medium sphericity; moderate induration; cement types: calcilutite matrix; accessory minerals: phosphatic sand-50%; other features: calcareous

TAMPA MEMBER

110 - 120	Limestone; white; 12% porosity, intergranular; grain type: calcilutite biegenic; 15% allochemical constituents; grain size: medium; range: fine to medium; good induration; cement types: calcilutite matrix; accessory minerals: quartz sand-07%
120 - 130	Limestone; white; 12% porosity, intergranular, pinpoint vugs, moldic; grain type: calcilutite; grain size: cryptocrystalline; range: microcrystalline to microcrystalline; good induration; cement types: calcilutite matrix; accessory minerals: dolomite-15%; other features: dolomitic
140 - 150	Limestone; very light gray; 15% porosity, intergranular, moldic, pinpoint vugs; grain type: calcilutite, biogenic, crystals; 35% allochemical constituents; grain size: medium; range: fine to coarse; good induration; cement types: calcilutite matrix; accessory minerals: quartz sand-05%

APPENDIX I

Cross Section A to A'

150 - 160 Limestone; white; 11% porosity, intergranular, pinpoint vugs; grain type: calcilutite; grain size: cryptocrystalline; range: microcrystalline to microcrystalline; good induration; cement types: calcilutite matrix; accessory minerals: quartz sand-01%

SUWANNEE LIMESTONE

160 - 170 Dolomite; moderate light gray; 18% porosity, moldic, vugular, intergranular; 50-90% altered; subhedral; grain size: very fine; range: very fine to fine; good induration; cement types: dolomite cement; other features: calcareous; fossils: fossil molds, mollusks, echinoid

APPENDIX I

Cross Section A to A'

WELL LOG NUMBER	2382
WELL LOG NAME	
COUNTY	HILLSBOROUGH
TOTAL DEPTH	144 FT
LOCATION	
ELEVATION	
COMPLETION DATE	

INTERVAL	DESCRIPTION	FORMATION
		UNDIFFERENTIATED SURFICIAL
0 - 15	Sand; white; 20% porosity, intergranular; grain size: medium; range: fine to coarse; roundness: sub-angular to rounded; high sphericity; poor induration; cement types: clay matrix; accessory minerals: clay-06%	
		HAWTHORN GROUP CLAYS
15 - 43	Clay; white; 05% porosity, intergranular; moderate induration; cement types: clay matrix; accessory minerals: quartz sand-05%	
43 - 46	Same as above	
		TAMPA MEMBER
46 - 85	Limestone; very light orange; 10% porosity, intergranular; grain type: calcilutite; grain size: cryptocrystalline; range: microcrystalline to microcrystalline; good induration; cement types: calcilutite matrix; accessory minerals: dolomite-15%, quartz sand-01%, chert-02%; other features: weathered, dolomitic	

APPENDIX I

Cross Section A to A'

SUWANNEE LIMESTONE

85 - 95	Calcarenite; very light orange; 13% porosity, intergranular, moldic; grain type: calcilutite, biogenic, skeletal; 90% allochemical constituents; grain size: medium; range: fine to medium; good induration; cement types: calcilutite matrix; accessory minerals: chert-02%; other features: low recrystallization

APPENDIX I

Cross Section B to B'

WELL LOG NUMBER	W-2677
WELL LOG NAME	
COUNTY	HILLSBOROUGH
TOTAL DEPTH	443 FT
LOCATION	
ELEVATION	
COMPLETION DATE	

INTERVAL	DESCRIPTION	FORMATION
		UNDIFFERENTIATED SURFICIAL
0 - 10	Sand; grayish orange; 35% porosity, intergranular, vugular; grain size: very fine; range: very fine to medium; roundness: angular; low sphericity; unconsolidated; accessory minerals: phosphatic sand-01%; limestone-01%; fossils: no fossils	
10 - 20	Sand; grayish orange to black; 35% porosity, intergranular, vugular; grain size: very fine; range: very fine to medium; roundness: angular; low sphericity; unconsolidated; accessory minerals: phosphatic gravel-01%, phophatic sand-01%, limestone-04%; fossils: no fossils	
		HAWTHORN GROUP CLAYS
20 - 35	Sand; grayish yellow to very light orange; 35% porosity, intergranular, vugular; grain size: fine; range: very fine to very coarse; roundness: angular; low sphericity; unconsolidated; accessory minerals: phophatic gravel-03%, phosphatic sand-03%, limestone-05%; fossils: sharks teeth	

APPENDIX I

Cross Section B to B'

35 - 50	Limestone; very light orange to grayish yellow; 21% porosity, intergranular, vugular; grain type: intraclasts, crystals; 40% allochemical constituents; grain size: microcrystalline; range: cryptocrystalline to microcrystalline; good induration; cement types: calcilutite matrix; accessory minerals; quartz sand-20%, phosphatic gravel-02%, phophatic sand 03%; fossils: mollusks
50 - 70	Dolomite; grayish orange pink to very light orange; 22% porosity, intergranular, vugular; 50-90% altered; anhedral; grain size: cryptocrystalline; range: microcrystalline to cryptocrystalline; good induration; cement types: dolomite cement; accessory minerals: quartz sand-30%, limestone-09%, phosphatic sand-01%; fossils: no fossils
	TAMPA MEMBER
70 - 80	Limestone; white; 22% porosity, intergranular, vugular; grain type: intraclasts, crystals; 60% allochemical constituents; grain size: microcrystalline; range: cryptocrystalline to microcrystalline; good induration; cement types: calcilutite matrix; accessory minerals: quartz sand-30%, phosphatic sand-01%, iron stain-01%; fossils: no fossils
80 - 90	Limestone; very light orange; 23% porosity, intergranular, vugular; grain type: intraclasts, crystals; 30% allochemical constituents; grain size: microcrystalline; range: cryptocrystalline to microcrystalline; good induration; cement types: calcilutite matrix, sparry calcite cement; accessory minerals: quartz sand-15%, spar-03%; fossils: echinoid
90 - 100	Limestone; very light orange; 23% porosity, intergranular, vugular; grain type: intraclasts, crystals; 30% allochemical constituents; grain size: microcrystalline; range: cryptocrystalline to microcrystalline; good induration; cement types: calcilutite matrix, sparry calcite cement; accessory minerals: quartz sand-12%, phosphatic sand-01%; fossisls: mollusks, worm traces, echinoid
100 - 110	Same as above

APPENDIX I

Cross Section B to B'

110 - 120	Limestone; light greenish yellow to light gray; 23% porosity, intregranular, vugular; grain type: intraclasts, crystals; 30% allochemical constituents; grain size: microcrystalline; range: cryptocrystalline to microcrystalline; good induration; cement types: calcilutite matrix, sparry calcite cement; accessory minerals: quartz sand-12%, phosphatic sand-01%; fossils: no fossils
120 - 130	Limestone; very light orange; 22% porosity, intergranular vugular; grain type: intraclasts, crystals; 30% allochemical constituents; grain size: microcrystalline; range: cryptocrystalline to microcrystalline; good induration; cement types: calcilutite matrix, sparry calcite cement; accessory minerals: quartz sand-15%, spar-03%, phosphatic sand-01%, pyrite-01%; fossils: no fossils
130 - 140	Limestone; very light orange; 23% porosity, intergranular, vugular; grain type: interclasts, crystals; 30% allochemical constituents; grain size: microcrystalline; range: cryptocrystalline to micro-crystalline; good induration; cement types: calcilutite matrix, sparry calcite cement; accessory minerals: quartz sand-08%, spar-01%, phophatic sand-01%, pyrite-01%; fossils: benthic foraminifera; with sorites
140 - 150	Limestone; very light orange; 22% porosity, intergranular, vugular; grain type: intraclasts, crystals; 30% allochemical constituents; grain size: microcrystalline; range: cryptocrystalline to micro-crystalline; good induration; cement types: calcilutite matrix, sparry calcite cement; accessory minerals: quartz sand-06%, pyrite-01%, spar-03%; fossils: no fossils
150 - 160	Limestone; very light orange; 22% porosity, intergranular, vugular; grain type: intraclasts, crystals; 30% allochemical constituents; grain size: microcrystalline; range: cryptocrystalline to micro-crystalline; good induration; cement types: calcilutite matrix, sparry calcite cement; accessory minerals: spar-04%; fossils: echinoid

APPENDIX I

Cross Section B to B'

160 - 170	Limestone; very light orange; 22% porosity, intergranular, vugular; grain type: intraclasts, crystals; 30% allochemical constituents; grain size: microcrystalline; range: cryptocrystalline to microcrystalline; good induration; cement types: calcilutite matrix, sparry calcite cement; accessory minerals: spar-05%; fossils: echinoid, worm traces, mollusks
170 - 180	Limestone; very light orange; 22% porosity, intergranular, vugular; grain type: intraclasts, crystals; 30% allochemical constituents; grain size: microcrystalline; range: cryptocrystalline to microcrystalline; good induration; cement types: calcilutite matrix, sparry calcite cement; accessory minerals: spar-05%; fossils: no fossils
180 - 190	Limestone; very light orange to white; 23% porosity, intergranular, vugular; grain type: intraclasts, crystals; 40% allochemical constituents; grain size: microcrystalline; range: cryptocrystalline to microcrystalline; poor induration; cement types: calcilutite matrix, sparry calcite cement; accessory minerals: quartz sand-03%, spar-03%; fossils: benthic foraminifera; with dictyconus cookei
	SUWANNEE LIMESTONE
190 - 200	As above with rotalia mexicana
200 - 210	No samples

APPENDIX I

Cross Section B to B'

WELL LOG NUMBER W-11531

WELL LOG NAME

COUNTY HILLSBOROUGH

TOTAL DEPTH 160 FT

LOCATION

ELEVATION

COMPLETION DATE

INTERVAL	DESCRIPTION	FORMATION
		UNDIFFERENTIATED SURFICIAL
0 - 1.7	Sand; brownish gray; 30% porosity, intergranular; grain size: medium; range: very fine to coarse; roundness: rounded; medium sphericity; unconsolidated; accessory minerals: limonite-01%, plant remains-01%	
1.7 - 3	Sand; moderate yellowish brown; 32% porosity, intergranular; grain size: medium; range: very fine to coarse; roundness: rounded; medium sphericity; unconsolidated; accessory minerals: clay-02%, limonite-01%, plant remains-01%	
3 - 4	Sand; dark gray; 35% porosity, intergranular, grain size: medium; range: very fine to coarse: roundness: rounded; medium sphericity; unconsolidated; accessory minerals: plant remains-03%; possible buried soil horizon with repeat of a-soil horizon	
4 - 5	Sand; brownish gray; 35% porosity, intergranular; grain size: medium; range: very fine to coarse; roundness: rounded; medium sphericity; unconsolidated; accessory minerals: limonite-01%, plant remains-01%	
5 - 10.3	Sand; moderate yellowish brown; 35% porosity, intergranular; grain size; medium; range: very fine to coarse; roundness: rounded; medium sphericity; unconsolidated; accessory minerals: limonite-01%, plant remains-01%	

APPENDIX I

Cross Section B to B'

10.3 - 12.5	Sand; very light gray to grayish brown; 25% porosity, intergranular; grain size: medium; range: very fine to coarse; roundness: rounded; medium sphericity; unconsolidated; sedimentary structures: bedded; accessory minerals: clay-02%
	HAWTHORN GROUP CLAYS
12.5 - 14.5	Sand; moderate gray; 20% porosity, intergranular; grain size: medium; range: very fine to coarse; roundness: rounded; medium sphericity; poor induration; cement types: clay matrix; sedimentary structures: bioturbated,; accessory minerals: clay-03%, limonite-02%, phosphatic sand-01%; clasts of clay balls in sand, more clay towards bottom, upper bone valley
14.5 - 18	Clay; very light gray; 05% porosity, not observed, low permeability; poor induration; cement types: clay matrix; accessory minerals: quartz sand-20%; dense clay with quartz grains supported by clay matrix
18 - 22.5	Clay; very light gray to dark yellowish orange; 05% porosity, not observed, low permeability; poor induration; cement types: clay matrix; sedimentary structures: mottled; accessory minerals: quartz sand -15%, limonite-01%, phosphatic sand-01%
22.5 - 25	Clay; light grayish green to dark yellowish orange; 05% porosity, not observed, low permiability; poor induration; cement types: clay matrix; sedimentary structures: mottled; accessory minerals: quartz sand-05%, limonite-02%, phosphatic sand-02%; other features: variegated; red and green clay
25 - 32.5	Sand; light brown to light grayish green; 07% porosity, not observed, low permeability, poor induration; cement types: clay matrix; sedimentary structures: mottled; accessory minerals: quartz sand-05%, limonite-02%, phosphatic sand-02%; other features: variegated; red and green clay

APPENDIX I

Cross Section B to B'

32.5 - 40	Sand; white to light olive; 07% porosity, not observed, low permeability; grain size: microcrystalline; range: cryptocrystalline to coarse; roundness: rounded; medium sphericity; poor induration; cement types: clay matrix; sedimentary structures: interbedded; accessory minerals: clay-20%, phosphatic sand-02%, chert-01% clasts of kaolin clay in sandy clay, 10 inch phosphatic green clay layer
40 - 42	Sand; dark yellowish orange; 20% porosity, intergranular; grain size: medium; range: microcrystalline to coarse; roundness: angular, medium sphericity; poor induration; cement types: clay matrix; sedimentary structures: mottled; accessory minerals: clay-45%, limonite-04%, plant remains-02%; other features: variegated; clay is deep red and perhaps oxidized by weathering during exposure
42 - 43	Clay; dark yellowish orange to white; 07% porosity, not observed, low permeability: poor induration; cement types: clay matrix; sedimentary structures: mottled; accessory minerals: quartz sand-20%, limonite-02%; other features: variegated
43 - 44	Sand; white, 12% porosity, intergranular; grain size: microcrystalline; range: cryptocrystalline to medium; roundness: angular, medium sphericity; poor induration; cement types: clay matrix; sedimentary structures: massive; accessory minerals: clay-50%; other features: granular
44 - 46	Sand; white to dark yellowish orange; 07% porosity, not observed, low permeability; grain size: microcrystalline; range: cryptocrystalline to medium; roundness: angular, medium sphericity; poor induration; cement types: clay matrix; sedimentary structures: mottled, brecciated; accessory minerals: quartz sand-50%; clasts of kaolin in mottled green and red clay eroded from below
46 - 50	Sand; white to dark yellowish orange; 12% porosity, intergranular; grain size: fine; range: cryptocrystalline to fine; roundness: angular, medium sphericity; poor induration; cement types: clay matrix; accessory minerals: clay-05%

APPENDIX I

Cross Section B to B'

50 - 51 Sand; very light orange; 05% porosity, intergranular; grain size: very fine; range: microcrystalline to very fine; poor induration; cement types: clay matrix; sedimentary structure: massive; accessory minerals: clay-04%; top of Tampa

TAMPA MEMBER

51 - 57 Calcilutite; very light orange; 15% porosity, intergranular, pinpoint vugs, moldic; grain type: calcilutite, skeletal; 15% allochemical constituents; grain size: fine; range: microcrystalline to coarse; good induration; cement types: calcilutite matrix; sedimentary structures: massive; accessory minerals: phosphatic sand-01%, spar-10%, quartz sand-15%, clay-02%, other features: granular; fossils: mollusks, benthic foraminifera; quartz grains are clear, not rounded with some reduction in angularity, some solution surfaces and vugs of clay and clay layers

57 - 82 Calcilutite; light grayish red to grayish yellow; 0% porosity, intergranular, low permeability; grain type: calcilutite, skeletal; 10% allochemical constituents; grain size: microcrystalline; range: cryptocrystalline to very fine; good induration; cement types: clay matrix; sedimentary structures: mottled, laminated; accessory minerals: quartz sand-30%; other features: platy, low recrystallization; fossils: mollusks, benthic foraminifera, coral; silicious coral frags and shelly ls. layers with clay layers

82 - 86 Calcilutite; very light orange; 15% porosity, intergranular, pinpoint vugs; grain type: calcilutite, skeletal; 05% allochemical constituents; grain size: microcrystalline; range: microcrystalline to coarse; good induration; cement types: calcilutite matrix; sedimentary structures: laminated; accessory minerals: phosphatic sand-01%, quartz sand-15%; other features: low recrystallization; fossils: mollusks

APPENDIX I

Cross Section B to B'

86 - 99	Calcilutite; very light orange; 15% porosity, intergranular, vugular, moldic; grain type: calcilutite, skeletal; 20% allochemical constituents; grain size: fine; range: microcrystalline to medium; good induration; cement types: calcilutite matrix; sedimentary structures: mottled; accessory minerals: phosphatic sand-02%, quartz sand-10%; other features: low recrystallization, granular; fossils: mollusks, benthic foraminifera, echinoid; mollusk frags (molds), 15 pct. of rock
99 - 114	Limestone; light brown; 20% porosity, moldic, intergranular; grain type: skeletal; 80% allochemical constituents; grain size: coarse; range: microcrystalline to coarse; good induration; cement types: calcilutite matrix; sedimentary structures: laminated; accessory minerals: quartz sand-20%; other features: low recrystallization, stromatal; fossils: mollusks, echnoid, benthic foraminfera; quartz as high as 30 pct. in some areas
	SUWANNEE LIMESTONE
114 - 116	Calcilutite; very light orange; 05% porosity, low permeability, pinpoint vugs; grain type: calcilutite; 10% allochemical constituents; grain size: microcrystalline; range: cryptocrystalline to very fine; good induration; cement types: calcilutite matrix; sedimentary structures: laminated; accessory minerals: spar-03%, quartz sand-02%; other features: low recrystallization, coquina; fossils: benthic foraminifera; top of suwannee, this zone has thin beds of shell hash
116 - 122	Limestone; very light orange; 25% porosity, moldic, possibly high permeability; grain type: skeletal, calcilutite; 60% allochemical constituents; grain size: very fine; range: cryptocrystalline to granule; good induration; cement types: calcilutite matrix; sedimentary structures: laminated; accessory minerals: spar-07%; other features: low recrystallization, coquina; fossils: mollusks, benthic foraminifera; porosity higher in some zones, collapse feature bringing material from above

APPENDIX I

Cross Section B to B'

122 - 139 Calcilutite; very light orange; 15% porosity, pinpoint vugs, moldic; grain type: calcilutite, skeletal; 25% allochemical constituents; grain size: microcrystalline; range: fine to cryptocrystalline; good induration; cement types: calcilutite matrix; accessory minerals: pyrite-01%; fossils: ostracods, benthic foraminifera, mollusks

APPENDIX I

Cross Section B to B'

WELL LOG NUMBER 2303

WELL LOG NAME

COUNTY HILLSBOROUGH

TOTAL DEPTH 126 FT

LOCATION

ELEVATION

COMPLETION DATE

INTERVAL	DESCRIPTION	FORMATION
		UNDIFFERENTIATED SURFICIAL
0 - 25	No samples	
25	Fine-grained sandstone; very loosely cemented by brown, weathered, limonitic clay; gypsiferous? quartz mostly angular and fairly clear (minute crystalline, opaque, black, and angular mineral accessory), no fossils, but small more of less regular rods present, probably of inorganic origin	
45	Same; fresh, not limonitic	
48 - 52	Same; mostly uncemented, fine, loose, gypsiferous, quartz-sand, very light clay (opaque mineral), with the previously mentioned rods fairly common; altered bryozoan and bivalve (rare); fragment of amphisorus or sorites (rare)	
		HAWTHORN GROUP CLAYS
60	Same fine, gypsiferous, quartz sand, increasingly more clayey; quartz, mainly angular and fairly clear; no rods, one poor fragment of bryzoan	

APPENDIX I

Cross Section B to B'

TAMPA MEMBER

70 - 75	Same, but calcareous and therefore well cemented and compact; white, very richly and finely sandy and somewhat clayey and gypsiferous limestone (or calcareous sandstone); stout spine of echinoid (rare); small, smooth ostracod sp. (fairly common); small elphidium sp. (rare)
80	Same white, sandy limestone with small rods of amorphous silica and botryoidal concretions of white chalcedony; siliceous fragments of thin-shelled bivalves (scarce); small smooth ostracod sp. (rare); tiny smooth narrow ostracod sp. (rare); minute discorinopsis qunteri cole? (rare); indistinct elphidium sp. (rare)
89	Same (not well washed, too coarse)
95	Same finely and very sandy, white limestone but conspicuously clayey; the fresh clay light-greenish tinge, the weathered clay rusty, brown; small smooth ostracod sp. (fairly common); minute elphidium sp. (fairly common)
104	Same; fragment of barnacle (rare); casts of bivalves (several); turreted gastropod sp. (rare), stout spines of echinoids (few), oogonium of chara (rare), small smooth ostracod sp. (common), minute elphidium sp. (fairly common); small spirolina sp. (few); minute quinqueloculina sp. (rare)
120	Same lithology, i.e., white, sandy, limestone with that characteristic light greenish tinged clay and the same very characteristic association of cast of bivalve, turreted gastropod, but especially: echinoid spines (few), small smooth ostracod (common), small elphidium sp. (fairly common), spirolina sp. (few), minute quinqueloculina sp. (scarce)

APPENDIX I

Cross Section B to B'

126 Lithogically, very much like Tampa limestone (finely arenaceous limestone) but with camparatively little clay and with quite an amount of limonite admixed; faunistically, also suggestive of Tampa limestone but not typical; mollusks (rare), a minute rod-like bryzoan sp. (frequent), spine of echinoid (rare), small smooth ostracod sp. (common), small elphidium sp. (frequent), no archaias floridanus, spirolina fragment? (rare and uncertain), other minute species of foraminifera present but not distinct; on the other hand, no discorinopsis qunteri cole, no coskinolina floridana cole, no dictyoconus, etc. Tampa limestone close to its bottom?

APPENDIX I

Cross Section B to B'

WELL LOG NUMBER 2352

WELL LOG NAME

COUNTY HILLSBOROUGH

TOTAL DEPTH 122 FT

LOCATION

ELEVATION

COMPLETION DATE

INTERVAL	DESCRIPTION	FORMATION
		UNDIFFENTIATED SURFICIAL
20	Yellowish fine sand with some clay	
28	Yellow, very sandy (fine) clay	
35	Light brown colored, very sandy clay, with fragments of light-colored sandstone	
42	Olive-brown, fine, clayey sand	
		HAWTHORN GROUP CLAYS
48	Mostly a calcareous sandstone, light-colored with some admixture of brown clay	
52	Fine, light tan sand, with some lumps of white, calcareous and sandy material	
55	Cream-colored, fairly hard limestone, possibly Hawthorn limestone	
66	Light, cream-colored, impure limestone, softer than above	
71	Tan, very fine sand, some clay, some light-cream, sandy, limestone	
82	Cream-colored, fairly dense limestone (sample finely crushed)	

APPENDIX I

Cross Section B to B'

TAMPA MEMBER

100	Light-cream, impure limestone; less dense than above
115	Cream-colored limestone and fine sand

APPENDIX I

Cross Section B to B'

WELL LOG NUMBER	2283
WELL LOG NAME	
COUNTY	HILLSBOROUGH
TOTAL DEPTH	90 FT
LOCATION	
ELEVATION	
COMPLETION DATE	

INTERVAL	DESCRIPTION	FORMATION
		UNDIFFERENTIATED SURFICIAL
20	Fine to medium grained quartz sand, chiefly fine; the larger grains subrounded and partly dimmed, the finest fraction angular and clear (opaque, black, rounded and polished mineral), spine of echinoid (rare)	
		HAWTHORN GROUP CLAYS
30	Chiefly fine-grained, quartz sand, slightly argillaceous, quartz angular to rounded, clear with (black, opaque, polished minerals) with small spherical nodules of aggregated minute quartz held together by a clayey matrix	
35	Same, more clayey; clay very light in color	
40	Same but fossiliferous	
42	Snow white, amophous or cryptocrystalline silica and fine quartz (minute siliceous concretions), same microfossils plus some silicified pelecypods and minute gastropods, ostracods (bryozoa fragments)	
46	Chiefly very fine quartz sand, but also some yellowish, slightly clayey, very loosely cemented soft sandstone	

APPENDIX I

Cross Section B to B'

55 Same

TAMPA MEMBER

63 Light-cream colored, very fine sandy, soft limestone, with much light-gray, glassy chalcedony admixed; (pyrite), very poorly fossiliferous (minute gastropod, small spines of echinoids, small smooth ostracod, oogon of chara) except for foraminifera of the smallest kind which, however, are not distinctly enough preserved to be of practical use; small spirolina sp. (rare)

65 Same, but with oogonia of chara fairly common, although mostly of rather poor

78 Same, somewhat more clayey; relatively stout spines of echinoids (scarce); fragments of gastropod (thick whorls) (scarce); small smooth ostracod (rare); minute miliolids (few); nonion cf. N chipolensis Cushman (scarce); 20-78' the occurance of oogonia of chara in Tampa limestone is rather exceptional

APPENDIX I

Cross Section B to B'

WELL LOG NUMBER	ROMP 67
WELL LOG NAME	
COUNTY	HILLSBOROUGH
TOTAL DEPTH	470 FT
LOCATION	
ELEVATION	
COMPLETION DATE	

INTERVAL	DESCRIPTION	FORMATION
		UNDIFFERENTIATED SURFICIAL
30 - 35	No samples	
35 - 40	Sand; accessory minerals: clay- %, calcilutite- %; clay and sand with abundant micrite particles	
		TAMPA MEMBER
40 - 45	Limestone; white; grain type: biogenic, calcilutite, skeletal; poor induration; other features: chalky; sparse biomicrite, friable	
45 - 50	As above	
50 - 55	As above	
55 - 60	Limestone; white to moderate gray; grain type: calcilutite; poor induration; accessory minerals: chert- %, clay- %; other features: chalky; micrite, friable, contains abundant lenses of gray; indurated clay and gray chert lenses	
60 - 65	Limestone; white; grain type: calcilutite; poor induration; accessory minerals: chert- %; other features: chalky; micrite contains abundant chert	
65 - 70	As above	

70 - 75	As above
	SUWANNEE LIMESTONE
75 - 80	Limestone; white to tan; grain type: biogenic, calcilutite, skeletal; accessory minerals: chert- %, clay- %; sparse biomicrite, contains abundant chert and lenses of indurated clay
80 - 85	Limestone; white; grain type: biogenic, calcilutite, skeletal; grain size: fine, poor induration; other features: chalky; sparse biomicrite, friable
85 - 90	As above
90 - 95	As above
95 - 100	As above

APPENDIX I

Cross Section C to C'

WELL LOG NUMBER	ROMP DV-1
WELL LOG NAME	
COUNTY	HILLSBOROUGH
TOTAL DEPTH	850 FT
LOCATION	
ELEVATION	
COMPLETION DATE	

INTERVAL	DESCRIPTION	FORMATION
		UNDIFFERENTIATED SURFICIAL
0 - 2.5	Sand; black to moderate light gray; 30% porosity, intergranular, possibly high permeability; grain size: fine; range: medium to fine; roundness: rounded to sub-angular; medium sphericity; unconsolidated; cement types: organic matrix; sedimentary structures: massive, accessory minerals: plant remains-02%; fossils: organics	
2.5 - 9	Sand; dark brown to dark reddish brown; 30% porosity, intergranular, possibly high permeability; grain size: fine; range: medium to fine; roundness: rounded to sub-angular; medium sphericity; unconsolidated; sedimentary structures: massive; accessory minerals: iron stain- %, quartz sand- %; fossils: organics, fossil fragments	
9 - 13.1	Sand; black to dark yellowish brown; 30% porosity, intergranular, possibly high permeability; grain size: fine; range: medium to fine; roundness: rounded to sub-angular; medium sphericity; unconsolidated; sedimentary structures: massive; fossils: mollusks, fossil fragments	

APPENDIX I

Cross Section C to C'

13.1 - 16.5	Sand; moderate brown to moderate yellowish brown; 10% porosity, intergranular; grain size: fine; range: very fine to fine; roundness: rounded to sub-angular; medium sphericity; moderate induration; cement types: clay matrix; sedimentary structures: massive; accessory minerals: clay-40%, iron stain %; fossils: mollusks, fossil fragments; clayey sand with 4 inch zone of shell frags in sand matrix
16.5 - 20	Sandstone; grayish brown to light grayish green; 15% porosity, intergranular; grain size: very fine; range: very fine to fine; good induration; cement types: silicic cement; no fossils
	HAWTHORN GROUP CLAYS
20 - 30	Clay; light olive gray to greenish gray; low permeability; poor induration; cement types: clay matrix; accessory minerals: quartz sand-05%, phosphatic sand- %; no fossils; very fine to coarse clear rounded quartz sand disseminated in above clay
30 - 37	Clay; light olive gray to greenish gray; poor induration; cement types: clay matrix; accessory minerals: phophatic sand- %; no fossils; very soft colloidal clay (30' - 37')
37 - 43.5	Clay; greenish gray to grayish green; poor induration; cement types: clay matrix; accessory minerals: quartz sand-02%, phosphatic sand-08%; other features: plastic; fossils: sharks teeth; yellowish-gray to black, rounded, coarse-grained phosphorite sand in above clay
43.5 - 46.5	Clay; yellowish gray to light olive; poor induration; accessory minerals: phosphatic sand-01%; fossils: none
46.5 - 47	Phosphate; moderate dark gray to dark gray; unconsolidated; accessory minerals: quartz sand-30%; fossils: none
47 - 53.5	Clay; yellowish gray to light olive gray; moderate induration; cement types: clay matrix; accessory minerals: quartz sand-05%, phosphatic sand-01%; fossils: none

APPENDIX I

Cross Section C to C'

53.5 - 58.5	Clay; light bluish gray to moderate bluish gray; moderate induration; cement types: clay matrix; accessory minerals: quartz sand-05%, phosphatic sand-02%; very fine-grained clear rounded quartz sand disseminated in stiff clay
58.5 - 63	Clay; yellowish gray; poor induration; cement types: clay matrix; accessory minerals: phosphatic sand-15%, quartz sand-01%
63 - 68	Clay; olive gray to moderate grayish green; good induration; cement types: clay matrix; accessory minerals: phosphatic sand-10%; very stiff clay
68 - 72	Clay; moderate grayish green to grayish green; poor induration; cement types: clay matrix; accessory minerals: phosphatic sand-10%, quartz sand-15%, chert- %; tan-black, very coarse to very fine phosphorite; very fine clear rounded quartz sand disseminated in clay; few fragments of fractured yellowish brown chert
74 - 80	Clay; grayish green to greenish gray; good induration; accessory minerals: phosphatic sand-20%, quartz sand-15%, silt-05%, chert- %; other features: plastic; very stiff sandy phosphatic clay; large chips of fractured yellowish-brown chert

TAMPA MEMBER

80 - 86	Calcilutite; yellowish gray to very light orange; moldic; good induration; cement types: calcilutite matrix, clay matrix; accessory minerals: quartz sand-05%, dolominte-03%; other features: dolomitic; fossils: fossil fragments, mollusks, coral; yellowish brown to clear quartz sand; tan-black phosphorite; dark yellowish brown to dark gray sandy dolomite

APPENDIX I

Cross Section C to C'

86 - 96	Calcilutite; dark greenish gray to dark greenish gray; grain type: calcilutite; good induration; cement types: calcilutite matrix, clay matrix; accessory minerals: quartz sand-35%, phosphatic sand-05%, dolomite-05%, chert- %; other features: dolomitic; fossils: fossil fragments, mollusks, barnacles; gray yellowish brown dolomite; very sandy greensih-gray clay; very coarse, medium to tan black phophorite; small vugs in ls.; phosphorite found mostly in clay; balanus
96 - 102.5	Calcilutite; yellowish gray; intergranular, pinpoint vugs; grain type: calcilutite; moderate induration; cement types: calcilutite matrix; sedimentary structures: mottled; accessory minerals: quartz sand-10%; other features: dolomitic, chalky, speckled; fossils: vertebrate
102.5 - 108	Calcilutite; very light orange to yellowish gray; 15% porosity; intergranular, pinpoint vugs, fracture; grain type: calcilutite, intraclasts; good induration; sedimentary structures: mottled, interbedded, laminated; accessory minerals: quartz sand-40%, clay-10%, pyrite-05%; other features: dolomitic, chalky; selective dolomitization of intraclasts and burrows; bright green very sandy clay infilling some burrows; large intraclasts
108 - 110	Same as above; poorer induration than above
110 - 118	Calcilutite; yellowish gray to very light orange; 20% porosity; intergranular, vugular, pinpoint vugs; grain type: intraclasts, calcilutite; good induration; cement types: calcilutite matrix, dolomite cement; sedimentary structures: mottled, laminated, bioturbated; accessory minerals: quartz sand-40%, dolomite-10%, clay-02%; other features: dolomitic, chalky; dolomitized burrows; scour surfaces; very large intraclasts, high degree of bioturbation
118 - 123	Calcilutite; very light orange to yellowish gray; 20% porosity, intergranular, pinpoint vugs, vugular; grain type: calcilutite; good induration; cement types: calcilutite matrix, dolomite cement; sedimentary structures: mottled, bioturbated; accessory minerals: quartz sand-35%, dolomite-20%; other features: dolomitic, chalky, variegated

APPENDIX I

Cross Section C to C'

123 - 130	Calcilutite; very light orange to yellowish gray; 15% porosity, intergranular, pinpoint vugs; grain type: calcilutite; good induration: cement types: calcilutite matrix, dolomite cement; sedimentary structures: mottled, bioturbated; accessory minerals: quartz sand-40%, dolomite-25%, chert-05%; other features: dolomitic, chalky, variegated; fossils: barnacles, mollusks, fossil fragments, fossil molds; botryoidal quartz infilling small vug; shell hash at bottom of section (mollusks) balanus
130 - 138	Calcilutite; very light orange to yellowish gray; 20% porosity, intergranular, vugular, pinpoint vugs; grain type: biogenic, calcilutite, skeletal; moderate induration; cement types: calcilutite matrix; sedimentary structures: mottled; accessory minerals: quartz sand-30%, dolomite-10%, clay-05%; other features: dolomitic, chalky; fossils: fossil fragments, mollusks, fossil molds
138 - 144	Calcilutite; very light orange to yellowish gray; 20% porosity, intergranular, vugular, pinpoint vugs; grain type: biogenic, skeletal, calcilutite; moderate induration; cement types: calcilutite matrix; sedimentary structures: mottled; accessory minerals: quartz sand-05%, dolomite-05%, clay-05%; other features: dolomitic, chalky; fossils: fossil fragments, mollusks, fossil molds, fossiliferous clayey biomicrite; pelecypods common
144 - 153	Clay; yellowish gray to moderate light gray; low permeability; moderate induration; cement types: clay matrix, dolomite cement; calcilutite matrix; sedimentary structures: massive; accessory minerals: calcilutite-20%, dolomite-05%, quartz sand-03%; other features: calcareous, greasy, splintery; fossils: none; some calcilutite fragments interbedded
153 - 159	Calcarenite; very light orange to yellowish gray; 20% porosity, moldic, intergranular, possibly high permeability; grain type: biogenic, calcilutite, skeletal cast; grain size: fine; range: medium to fine; moderate induration; cement types: calcilutite matrix; sedimentary structures: massive; accessory minerals: clay-02%, dolomite-05%, chert-03%; other features: chalky; fossils: mollusks, millolids, fossil fragments, fossil molds; nodular chert; pelecypods, gastropods

APPENDIX I

Cross Section C to C'

SUWANNEE LIMESTONE

159 - 169	Calcarenite; very light orange to yellowish gray; 30% porosity, moldic, intergranular, possilbly high permeability; grain type: biogenic, calcilutite, skeletal cast; grain size: medium; range: medium to fine; moderate induration; cement types: calcilutite matrix, sparry calcite cement; sedimentary structures: massive; accessory minerals: dolomite-01%, chert- %, spar-04%; other features: chalky, granular; fossils: mollusks, miliolids, fossil fragments, fossil molds, coral; dictyononus cookei
169 - 172	Calcarenite; grayish yellow to yellowish gray; 25% porosity, intergranular, moldic, possilbly high permeability; grain type: biogenic, calcilutite, skeletal cast; grain size: medium; range: medium to fine; good induration; cement types: calcilutite matrix, sparry calcite cement; sedimentary structures: massive; accessory minerals: spar-04%, dolomite-02%; other features: chalky, granular; fossils: miliolids, mollusks, coral, fossil fragments, fossil molds

APPENDIX I

Cross Section C to C'

WELL LOG NUMBER	2437
WELL LOG NAME	
COUNTY	HILLSBOROUGH
TOTAL DEPTH	120 FT
LOCATION	
ELEVATION	
COMPLETION DATE	

INTERVAL	DESCRIPTION	FORMATION
		UNDIFFERENTIATED SURFICIAL
5	Rusty colored, clear, fine to frosted medium grained quartz sand	
30	White to gray, sandy clay; some lumps of clay coated with rusty iron stain	
		HAWTHORN GROUP CLAYS
45	Brownish-gray, sandy clay; white, sandy clay with some iron stain	
55	White to light tan, sandy clay; rusty to red stained, fine to medium grained quartz sand	
60	Same as above with some tan calcareous, sandy clay	
		TAMPA MEMBER
75	White to cream, fairly porous, sandy limestone; limonite pebbles, sorites - rare	
85	Same as above	
95	Same as above; light pink tinted, fine to medium quartz sand echinoid spines common	
100	Same as above, plus echinoid plates	
110	Same - cones common - fragments of chalcedony	

APPENDIX I

Cross Section C to C'

120	Same as above

APPENDIX I

Cross Section C to C'

WELL LOG NUMBER	2302
WELL LOG NAME	
COUNTY	HILLSBOROUGH
TOTAL DEPTH	116 FT
LOCATION	
ELEVATION	
COMPLETION DATE	

INTERVAL	DESCRIPTION	FORMATION
		UNDIFFERENTIATED SURFICIAL
15	Fine to medium grained - on average fine - quartz sand, also fine-grained quartz embedded in dark, limonite matrix; the larger quartz grains well rounded and more or less dim, the finest fraction angular and clear	
22	Finely sandy clay, in parts very weathered; limonitic, partly fresh, light in color with a greenish tinge; with minute white broken siliceous rods, probably of inorganic origin	
35	Chiefly fine-grained quartz sand (minute shining opaque black mineral), the grains of quartz fairly rounded	
		HAWTHORN GROUP CLAYS
40	Same; with some light-greenish tinged clay	
45	Very fine-grained soft clayey light-colored sandstone	
48 - 50	Same, but with the clay snow-white	
		TAMPA MEMBER
50 - 54	Soft white finely sandy clayey limestone (or calcareous sandstone)	

APPENDIX I

Cross Section C to C'

68	Same, with minute microfossils obscured by the clay; small, smooth ostracod sp. (few); elphidium cf. E chipolensis (cushman) (scarce); spirolina? sp. (scarce)
85	Same with some amount of gray, glassy chalcedony, frequently rod-shaped or twig-shaped (branching); same ostracod and elphidium species
94	Same, very sparsely fossiliferous stout spine or echinoid (rare), fragments of massive gastropod - whorl (rare), oogonium of chara (rare), foraminifera, mostly minute and indistinct (few)
98	Very sandy, fine grained, white limestone (or calcareous sandstone) (chalcedony accessorial) with small mollusks, mainly casts (bivalves and gastropods), spines and small plates of echinoids, the spines fairly common; minute ophiurian remains (scarce), oogonium of chara, reworked? (scarce), minute, smooth ostrocod spp. (1 species conspicuously pitted) (rare each), rotalia of R. mexicana muttall mecatepecensis nutal (scarce), minute miliolid, mainly casts of quinqueloculinas, (rare), spirolina? sp. (rare)
110	Same, but with the calcium carbonate partially recrystallized (microcrystalline) and honey-colored; fauna similar, plus discorinopsis gunteri cole (rare), elphidium cf. E. rota ellis (scarce), tiny elphidium sp. (few)

APPENDIX I

Cross Section C to C'

WELL LOG NUMBER	11338
WELL LOG NAME	
COUNTY	HILLSBOROUGH
TOTAL DEPTH	332 FT
LOCATION	
ELEVATION	
COMPLETION DATE	

INTERVAL	DESCRIPTION	FORMATION
		UNDIFFERENTIATED SURFICIAL
0 - 4.5	Sand; very light orange to pinkish gray; grain size: fine; range: very fine to fine; roundness: sub-angular; medium sphericity; unconsolidated; accessory minerals: plant remains-40%, clay-20%, limestone-05%	
4.5 - 12	Sand; yellowish gray; grain size: fine; range: very fine to fine; roundness: rounded; medium sphericity; unconsolidated; accessory minerals; clay-10%, lime-stone-01%, heavy minerals- %	
12 - 13.5	As above	
13.5 - 15	Sand; yellowish gray; grain size: fine; range: very fine to fine; roundness: rounded; medium sphericity; unconsolidated; accessory minerals: clay-35%, lime-stone-01%, heavy minerals- %	
15 - 18	As above	
18 - 22.5	Sand; yellowish gray; grain size: fine; range: very fine to fine; roundness: rounded; medium sphericity; unconsolidated; accessory minerals: clay-10%, lime-stone-01%, heavy minerals- %	
		HAWTHORN GROUP CLAYS
22.5 - 28.5	Clay; greenish gray; accessory minerals: quartz sand 35%, iron stain-01%	

APPENDIX I

Cross Section C to C'

28.5 - 31	Clay; greenish gray to dark yellowish orange; accessory minerals: quartz sand-45%, iron stain-01%, limestone- %; a coral (questionable) frag
	TAMPA MEMBER
31 - 32	Chert; light brown to very light orange; accessory minerals: limestone-05%, iron stain-01%
32 - 36	Limestone; white; grain type: intraclasts; 15% allochemical constituents; moderate induration; cement types: calcilutite matrix; accessory minerals: quartz sand-15%
36 - 38	Limestone; white; grain type: intraclasts, skeletal; 20% allochemical constituents; grain size: fine; range: very fine to fine; moderate induration; cement types: calcilutite matrix; accessory minerals: quartz sand-15%; fossils: benthic foraminifera
38 - 42	Limestone; white; grain type: intraclasts, skeletal, calcilutite; 50% allochemical constituents; grain size: fine; range: very fine to medium; moderate induration; cement types: calcilutite matrix; accessory minerals: quartz sand-10%; other features: low recrystallization; fossils: benthic foraminifera, crustacea, plant remains
42 - 45.5	As above; more sandy
45.5 - 47.1	As above
47.1 - 50	As above; less allochems, slightly clayey
50 - 52.5	Limestone; white; grain type: intraclasts, skeletal; grain size: fine; range: very fine to fine: moderate induration; cement types: calcilutite matrix; accessory minerals: quartz sand-40%; fossils: benthic foraminifera
52.5 - 57.5	As above
57.5 - 62	As above, plus a few mollusk molds

APPENDIX I

Cross Section C to C'

62 - 65	Limestone; white; grain type: intraclasts, skeletal; 20% allochemical constituents; grain size: fine; range: very fine to fine; moderate induration; cement types: calcilutite matrix; accessory minerals: quartz sand-25%; fossils: benthic foraminifera; puteolinas
	SUWANNEE LIMESTONE
65 - 70	Limestone; very light orange; 5% porosity, vugular, pinpoint vugs, intergranular; grain types: intraclasts, skeletal; 35% allochemical constituents; grain size: fine; range: fine to coarse; good induration; cement types: calcilutite matrix, sparry calcite cement; accessory minerals: dolomite-%, quartz sand-05%; fossils: benthic foraminifera
70 - 74	As above; minor spar and dolo

APPENDIX I

Cross Section D to D'

WELL LOG NUMBER	
WELL LOG NAME	LONE OAK
COUNTY	HILLSBOROUGH
TOTAL DEPTH	650 FT
LOCATION	
ELEVATION	
COMPLETION DATE	

Lithologic log not available. Gamma Log Only.

APPENDIX I

Cross Section D to D'

WELL LOG NUMBER	IS-B
WELL LOG NAME	INTERIM SUPPLY WELL
COUNTY	HILLSBOROUGH
TOTAL DEPTH	650 FT
LOCATION	
ELEVATION	
COMPLETION DATE	

INTERVAL	DESCRIPTION	FORMATION
		UNDIFFERENTIATED SURFICIAL
0 - 10	Sand, silty, fine-grained, tan; organics	
10 - 20	Clay, stiff, yellow	
20 - 33	Sand, fine to medium-grained, tan; yellow, soft clay	
33 - 45	Sand, fine-grained, orange; orange, stiff clay	
		HAWTHORN GROUP CLAYS
45 - 55	Limestone, sandy, soft, white; orange stiff clay	
55 - 65	Limestone, sandy, soft, white	
65 - 71	Limestone, sandy, hard, white; white, soft, sandy, clay	
71 - 93	Limestone, sandy, medium-hard, white, chalky (gummy)	
93 - 100	Limestone, sandy, hard, brown	
100 - 105	Sand, fine-grained, white	
105 - 120	Limestone, sandy, medium-hard, white	
120 - 125	Clay, soft, cream	
125 - 128	Limestone, sandy, medium-hard, brown, porous	

APPENDIX I

Cross Section D to D'

128 - 130	Clay, soft, white
	TAMPA MEMBER
130 - 135	Limestone, soft, granular, fractured, brown, white; soft clay lense at 132 feet
135 - 153	Limestone, soft, granular, fractured, white
153 - 158	Limestone, soft, fractured, fossiliferous, brown; brown, soft clay
158 - 190	Limestone, sandy, soft, white
190 - 195	Limestone, granular, medium-hard, white
195 - 200	Limestone, sandy, soft, unconsolidated, white
200 - 220	Limestone, granular, medium-hard, white
220 - 260	Limestone, granular, soft, poorly indurated, white
	SUWANNEE LIMESTONE
260 - 270	Limestone, granular, soft, poorly indurated, tan
270 - 280	Limestone, granular, soft, poorly indurated, tan; gray, hard shale

APPENDIX I

Cross Section D to D'

WELL LOG NUMBER 2303

WELL LOG NAME

COUNTY HILLSBOROUGH

TOTAL DEPTH 126 FT

LOCATION

ELEVATION

COMPLETION DATE

INTERVAL	DESCRIPTION	FORMATION
		UNDIFFERENTIATED SURFICIAL
0 - 25	No samples	
25	Fine-grained sandstone; very loosely cemented by brown, weathered, limonitic clay; gypsiferous? quartz mostly angular and fairly clear (minute crystalline, opaque, black, and angular mineral accessory), no fossils, but small more of less regular rods present, probably of inorganic origin	
45	Same; fresh, not limonitic	
48 - 52	Same; mostly uncemented, fine, loose, gypsiferous, quartz-sand, very light clay (opaque mineral), with the previously mentioned rods fairly common; altered bryozoan and bivalve (rare); fragment of amphisorus or sorites (rare)	
		HAWTHORN GROUP CLAYS
60	Same fine, gypsiferous, quartz sand, increasingly more clayey; quartz, mainly angular and fairly clear; no rods, one poor fragment of bryzoan	

APPENDIX I

Cross Section D to D'

TAMPA MEMBER

70 - 75	Same, but calcareous and therefore well cemented and compact; white, very richly and finely sandy and somewhat clayey and gypsiferous limestone (or calcareous sandstone); stout spine of echinoid (rare); small, smooth ostracod sp. (fairly common); small elphidium sp. (rare)
80	Same white, sandy limestone with small rods of amorphous silica and botryoidal concretions of white chalcedony; siliceous fragments of thin-shelled bivalves (scarce); small smooth ostracod sp. (rare); tiny smooth narrow ostracod sp. (rare); minute discorinopsis qunteri cole? (rare); indistinct elphidium sp. (rare)
89	Same (not well washed, too coarse)
95	Same finely and very sandy, white limestone but conspicuously clayey; the fresh clay light-greenish tinge, the weathered clay rusty, brown; small smooth ostracod sp. (fairly common); minute elphidium sp. (fairly common)
104	Same; fragment of barnacle (rare); casts of bivalves (several); turreted gastropod sp. (rare), stout spines of echinoids (few), oogonium of chara (rare), small smooth ostracod sp. (common), minute elphidium sp. (fairly common); small spirolina sp. (few); minute quinqueloculina sp. (rare)
120	Same lithology, i.e., white, sandy, limestone with that characteristic light greenish tinged clay and the same very characteristic association of cast of bivalve, turreted gastropod, but especially: echinoid spines (few), small smooth ostracod (common), small elphidium sp. (fairly common), spirolina sp. (few), minute quinqueloculina sp. (scarce)

APPENDIX I

Cross Section D to D'

126 Lithogically, very much like Tampa limestone (finely arenaceous limestone) but with camparatively little clay and with quite an amount of limonite admixed; faunistically, also suggestive of Tampa limestone but not typical; mollusks (rare), a minute rod-like bryzoan sp. (frequent), spine of echinoid (rare), small smooth ostracod sp. (common), small elphidium sp. (frequent), no archaias floridanus, spirolina fragment? (rare and uncertain), other minute species of foraminifera present but not distinct; on the other hand, no discorinopsis qunteri cole, no coskinolina floridana cole, no dictyoconus, etc. Tampa limestone close to its bottom?

APPENDIX I

Cross Section E to E'

WELL LOG NUMBER SCHM-3

WELL LOG NAME

COUNTY HILLSBOROUGH

TOTAL DEPTH 880 FT

LOCATION

ELEVATION

COMPLETION DATE

INTERVAL	DESCRIPTION	FORMATION
		UNDIFFERENTIATED SURFICIAL
0 - 5	Sand, quartz, fine-grained, pale yellowish-orange	
5 - 10	Sand, quartz, fine-grained, dark yellowish-brown	
10 - 15	Sand, quartz, fine-grained, very pale orange	
		HAWTHORN GROUP CLAYS
15 - 30	Clay, very pale orange; sand, quartz, fine-grained, very pale orange	
30 - 55	Clay, dark yellowish orange to very light gray; phosphate	
55 - 80	Limestone, clayey, very light gray to light olive gray; phosphate	
80 - 120	Clay, pinkish gray to light greenish gray	
120 - 180	Limestone, granular, fine-grained, very pale orange; minor phosphate	
		TAMPA MEMBER
180 - 185	Clay, yellowish gray	
185 - 200	Limestone, granular, pinkish gray to yellowish gray	

APPENDIX I

Cross Section E to E'

200 - 210	Clay, greenish gray; limestone, granular, pinkish gray to yellowish gray
	SUWANNEE LIMESTONE
210 - 240	Limestone, granular, very pale orange to grayish orange
240 - 280	Limestone, granular, fossiliferous, very pale orange

APPENDIX I

Cross Section E to E'

WELL LOG NUMBER SC-10

WELL LOG NAME

COUNTY HILLSBOROUGH

TOTAL DEPTH 920 FT

LOCATION

ELEVATION

COMPLETION DATE

INTERVAL	DESCRIPTION	FORMATION
		UNDIFFERENTIATED SURFICIAL
0 - 25	Sand, quartz, fine-grained, yellowish-gray; clay, yellowish-gray	
25 - 30	Sand, quartz, fine-grained, yellowish-gray to dark yellowish-orange; clay	
		HAWTHORN GROUP CLAYS
30 - 40	Clay, yellowish-gray; snad, quartz, fine-grained; phosphate	
40 - 105	Limestone, clayey, very pale orange to olive gray; clay, light gray; phosphate	
		TAMPA MEMBER
105 - 160	Limestone, granular, fine-grained, clayey, white to greenish-gray	
160 - 180	Clay, calcareous, white to pinkish-gray; limestone, white to grayish-orange	
180 - 195	Limestone, granular, phosphatic, clayey, pinkish-gray to light gray; chert, light brownish-gray	
195 - 200	Limestone, granular, pinkish-gray	
200 - 245	Limestone, granular, clayey, pinkish-gray to dark gray	

APPENDIX I

Cross Section E to E'

SUWANNEE LIMESTONE

245 - 370	Limestone, granular, fossiliferous, pinkish-gray
370 - 390	Limestone, granular, fossiliferous, pale yellowish-brown

APPENDIX I

Cross Section E to E'

WELL LOG NUMBER ROMP 61

WELL LOG NAME

COUNTY HILLSBOROUGH

TOTAL DEPTH 1000 FT

LOCATION

ELEVATION

COMPLETION DATE

INTERVAL	DESCRIPTION	FORMATION
		UNDIFFERENTIATED SURFICIAL
0 - 5	Sand; light tan; grain size: medium; accessory minerals: clay-15%; some pebbles; clay is yellow-light yellow, soft, pliable	
5 - 20	Clay; light yellow to yellow; accessory minerals: quartz sand-15%, shell-05%; clay, light yellow-yellow 80%; sand: tan-yellow, medium-coarse, moderate sorting 15%; pebbles: 5-10mm, angular, with some shell fragments, mainly mollusks, 5%	
20 - 25	Clay; tan to brown; accessory minerals: limestone-%, quartz sand- %, iron stain- %; fossils: fossil fragments; clay, some iron stains, 50%; sand: brown-tan, quartz, medium to very coarse, poorly sorted, shell fragments and some limestone	
25 - 30	Sand; brown to moderate yellowish brown; accessory minerals: clay-15%, limestone-15%, phosphatic gravel-01%, organics-01%; quartz sand, poorly sorted 70%; clay: yellowish light brown, 15%; limestone: white to light tan, fossil fragments and rock fragments, 2-3mm, angular, 15%	
30 - 40	Sand; tan to yellow; range: coarse to very fine; accessory minerals: clay-20%, limestone- %; abundant pebbles 2-5mm, some purple phosphate pebbles; yellow clay-20%; white-tan limestone, fragmental 1-4mm; shell fragments not abundant	

APPENDIX I

Cross Section E to E'

40 - 45	Sand; yellow; grain size: fine; range: very coarse; poor induration; cement types: clay matrix; accessory minerals: iron stains- %, clay-30%, limestone-20%; some iron staining in sand; clay; yellow, iron stained 30%, acts as a cement; limestone: white to light tan, fragmental, angular, shell fragments
	HAWTHORN GROUP CLAYS
45 - 50	Limestone; yellow to light tan; grain type: calcilutite; poor induration; cement types: calcilutite matrix, clay matrix; accessory minerals: clay- %, quartz sand- %; poorly cemented, micritic limestone 85%; sand and clay: yellowish, poorly sorted, 15%
50 - 65	Limestone; white to moderate gray; grain type: calcilutite; range: coarse to very coarse; accessory minerals: phosphatic sand- %, organics- %, quartz sand-10%; limestone, poorly cemented, fossils not abundant, phosphate and organic material minor, 90%; sand: yellow, medium grained, poorly sorted, 10%
65 - 75	As above, phosphate more abundant
75 - 90	Limestone; white; grain type: calcilutite; range: medium to coarse; good induration; accessory minerals: quartz sand-01%; fossils: no fossils
90 - 120	Limestone; white to moderate gray; poor induration; accessory minerals: phosphatic sand-01%; fossils: no fossils; limestone: granular, very poorly cemented 13mm, traces of phos., micritic
	TAMPA MEMBER
120 - 130	Limestone; white to moderate gray; poor induration; grain type: calcilutite; accessory minerals: quartz sand- %, 50% limestone, white, micritic, granular, some sand, micritic, calcitic, cement, 50% gray limestone, crystalline, hard
130 - 165	Limestone; white; grain type: calcilutite; poor induration; granular

APPENDIX I

Cross Section E to E'

165 - 170	Limestone; white to light tan; grain type: calcilutite, crystals; sedimentary structures: bedded, sandy, some crystalline calcite, mostly micrite, less granular than above, appears bedded, some terrigenous fill material
170 - 175	Limestone; white; grain type: calcilutite; poor induration; accessory minerals: quartz sand- %
175 - 185	As above; limestone same as above; chert: brown, hard, conchoidal fracture, 5%
185 - 190	Limestone; light gray to tan; grain size: fine; poor induration; accessory minerals: quartz sand- %, 70% limestone, 20% dolomite: light brown, soft, microporous: chert: light brown to gray, hard, conshoidal fracture, 10%
190 - 200	Limestone; white to moderate gray; grain type: calcilutite; micritic limestone, calcareous sand, 50%; limestone, gray, crystalline, hard, fractured, 50%; traces of dolomite
200 - 215	No samples obtained from drillers 200-260', descriptions from drillers logs for 200-260' limestone hard to very hard
215 - 220	No samples; limestone; soft, calcareous clay
220 - 260	No samples; limestone; white with clay, soft
260 - 270	Limestone; white to light tan; poor induration; accessory minerals: chert-30%; other features: limestone, soft, 70%; gray, hard, chert
	SUWANNEE LIMESTONE
270 - 280	Limestone; white to light tan; grain type: biogenic, calcilutite, skeletal; poor induration; accessory minerals: chert-03%; fossils: fossil fragments, mollusks; biomicrite, pelecypod shell fragments common
280 - 300	As above; with some chert

APPENDIX I

Cross Section E to E'

WELL LOG NUMBER IS-D

WELL LOG NAME INTERIM SUPPLY WELL

COUNTY HILLSBOROUGH

TOTAL DEPTH 201 FT

LOCATION

ELEVATION

COMPLETION DATE

INTERVAL	DESCRIPTION	FORMATION
		UNDIFFERENTIATED SURFICIAL
0 - 5	Sand, fine-grained, silty, dark brown, organics	
5 - 15	Sand, fine-grained, tan to brown	
		HAWTHORN GROUP CLAYS
15 - 20	Clay, soft, slightly sandy, cream to tan; cemented sand, fine-grained, cream; minor decayed organics; medium-grained, quartz pebbles	
20 - 40	Clay, soft, slightly sandy, tan to orange; white, granular, soft limestone	
40 - 50	Clay, soft, silty, cream to tan; white, granular, soft limestone	
50 - 55	Clay, soft, sticky, cream to tan; minor white, granular, soft limestone	
55 - 60	Clay, soft, sticky, cream; white, angular, medium-hard limestone	
60 - 125	No samples	
125 - 130	Limestone, granular, hard, cream-colored; gray, hard, angular, chert	

APPENDIX I

Cross Section E to E'

TAMPA MEMBER

130 - 140	Limestone, granular, soft to medium-hard, cream-colored; gray, hard, angular, chert
140 - 165	Limestone, granular, hard, cream-colored; minor fossil fragments
165 - 190	Limestone, granular, hard, cream-colored; fossil casts and molds

SUWANNEE LIMESTONE

190 - 201	Limestone, granular, hard, cream-colored; fossil fragments

APPENDIX I

Cross Section E to E'

WELL LOG NUMBER W-2677

WELL LOG NAME

COUNTY HILLSBOROUGH

TOTAL DEPTH 443 FT

LOCATION

ELEVATION

COMPLETION DATE

INTERVAL	DESCRIPTION	FORMATION
		UNDIFFERENTIATED SURFICIAL
0 - 10	Sand; grayish orange; 35% porosity, intergranular, vugular; grain size: very fine; range: very fine to medium; roundness: angular; low sphericity; unconsolidated; accessory minerals: phosphatic sand-01%; limestone-01%; fossils: no fossils	
10 - 20	Sand; grayish orange to black; 35% porosity, intergranular, vugular; grain size: very fine; range: very fine to medium; roundness: angular; low sphericity; unconsolidated; accessory minerals: phosphatic gravel-01%, phophatic sand-01%, limestone-04%; fossils: no fossils	
		HAWTHORN GROUP CLAYS
20 - 35	Sand; grayish yellow to very light orange; 35% porosity, intergranular, vugular; grain size: fine; range: very fine to very coarse; roundness: angular; low sphericity; unconsolidated; accessory minerals: phophatic gravel-03%, phosphatic sand-03%, limestone-05%; fossils: sharks teeth	
35 - 50	Limestone; very light orange to grayish yellow; 21% porosity, intergranular, vugular; grain type: intraclasts, crystals; 40% allochemical constituents; grain size: microcrystalline; range: cryptocrystalline to microcrystalline; good induration; cement types: calcilutite matrix; accessory minerals; quartz sand-20%, phosphatic gravel-02%, phosphatic sand 03%; fossils: mollusks	

APPENDIX I

Cross Section E to E'

50 - 70	Dolomite; grayish orange pink to very light orange; 22% porosity, intergranular, vugular; 50-90% altered; anhedral; grain size: cryptocrystalline; range: microcrystalline to cryptocrystalline; good induration; cement types: dolomite cement; accessory minerals: quartz sand-30%, limestone-09%, phosphatic sand-01%; fossils: no fossils
	TAMPA MEMBER
70 - 80	Limestone; white; 22% porosity, intergranular, vugular; grain type: intraclasts, crystals; 60% allochemical constituents; grain size: microcrystalline; range: cryptocrystalline to microcrystalline; good induration; cement types: calcilutite matrix; accessory minerals: quartz sand-30%, phosphatic sand-01%, iron stain-01%; fossils: no fossils
80 - 90	Limestone; very light orange; 23% porosity, intergranular, vugular; grain type: intraclasts, crystals; 30% allochemical constituents; grain size: microcrystalline; range: cryptocrystalline to microcrystalline; good induration; cement types: calcilutite matrix, sparry calcite cement; accessory minerals: quartz sand-15%, spar-03%; fossils: echinoid
90 - 100	Limestone; very light orange; 23% porosity, intergranular, vugular; grain type: intraclasts, crystals; 30% allochemical constituents; grain size: microcrystalline; range: cryptocrystalline to microcrystalline; good induration; cement types: calcilutite matrix, sparry calcite cement; accessory minerals: quartz sand-12%, phosphatic sand-01%; fossisls: mollusks, worm traces, echinoid
100 - 110	Same as above
110 - 120	Limestone; light greenish yellow to light gray; 23% porosity, intregranular, vugular; grain type: intraclasts, crystals; 30% allochemical constituents; grain size: microcrystalline; range: cryptocrystalline to microcrystalline; good induration; cement types: calcilutite matrix, sparry calcite cement; accessory minerals: quartz sand-12%, phosphatic sand-01%; fossils: no fossils

APPENDIX I

Cross Section E to E'

120 - 130	Limestone; very light orange; 22% porosity, intergranular vugular; grain type: intraclasts, crystals; 30% allochemical constituents; grain size: microcrystalline; range: cryptocrystalline to microcrystalline; good induration; cement types: calcilutite matrix, sparry calcite cement; accessory minerals: quartz sand-15%, spar-03%, phosphatic sand-01%, pyrite-01%; fossils: no fossils
130 - 140	Limestone; very light orange; 23% porosity, intergranular, vugular; grain type: interclasts, crystals; 30% allochemical constituents; grain size: microcrystalline; range: cryptocrystalline to microcrystalline; good induration; cement types: calcilutite matrix, sparry calcite cement; accessory minerals: quartz sand-08%, spar-01%, phophatic sand-01%, pyrite-01%; fossils: benthic foraminifera; with sorites
140 - 150	Limestone; very light orange; 22% porosity, intergranular, vugular; grain type: intraclasts, crystals; 30% allochemical constituents; grain size: microcrystalline; range: cryptocrystalline to microcrystalline; good induration; cement types: calcilutite matrix, sparry calcite cement; accessory minerals: quartz sand-06%, pyrite-01%, spar-03%; fossils: no fossils
150 - 160	Limestone; very light orange; 22% porosity, intergranular, vugular; grain type: intraclasts, crystals; 30% allochemical constituents; grain size: microcrystalline; range: cryptocrystalline to microcrystalline; good induration; cement types: calcilutite matrix, sparry calcite cement; accessory minerals: spar-04%; fossils: echinoid
160 - 170	Limestone; very light orange; 22% porosity, intergranular, vugular; grain type: intraclasts, crystals; 30% allochemical constituents; grain size: microcrystalline; range: cryptocrystalline to microcrystalline; good induration; cement types: calcilutite matrix, sparry calcite cement; accessory minerals: spar-05%; fossils: echinoid, worm traces, mollusks

APPENDIX I

Cross Section E to E'

170 - 180	Limestone; very light orange; 22% porosity, intergranular, vugular; grain type: intraclasts, crystals; 30% allochemical constituents; grain size: microcrystalline; range: cryptocrystalline to microcrystalline; good induration; cement types: calcilutite matrix, sparry calcite cement; accessory minerals: spar-05%; fossils: no fossils
180 - 190	Limestone; very light orange to white; 23% porosity, intergranular, vugular; grain type: intraclasts, crystals; 40% allochemical constituents; grain size: microcrystalline; range: cryptocrystalline to microcrystalline; poor induration; cement types: calcilutite matrix, sparry calcite cement; accessory minerals: quartz sand-03%, spar-03%; fossils: benthic foraminifera; with dictyconus cookei
	SUWANNEE LIMESTONE
190 - 200	As above with rotalia mexicana
200 - 210	No samples

APPENDIX I

Cross Section F to F'

WELL LOG NUMBER	EMW - 4
WELL LOG NAME	
COUNTY	HILLSBOROUGH
TOTAL DEPTH	900 FT
LOCATION	
ELEVATION	
COMPLETION DATE	

INTERVAL	DESCRIPTION	FORMATION
		UNDIFFERENTIATED SURFICIAL
0 - 10	Sand, tan; tan to white clay; organic debris	
		HAWTHORN GROUP CLAYS
10 - 15	Clay, soft, tan to white; cream, soft to moderately hard limestone; trace sand; organic debris	
15 - 23	Clay, sandy, tan to white; cream, soft to moderately hard limestone	
23 - 40	Clay, sandy, soft, orange-brown; phosphorite; limestone lenses	
40 - 55	Limestone, granular, soft to hard, tan-gray; phosphorite	
55 - 77	Limestone, granular, phosphatic, gray, moderately hard to hard; some white granular limestone, gray clay and sandy clay, and phosphorite	
77 - 85	Clay, sandy, blue-gray; phosphorite	
85 - 100	Limestone, granular, gray; phosphorite; some blue clay	
100 - 123	Clay, sandy, gray; some phosphorite and limestone lenses	

123 - 137	Limestone, fine-grained, tan to gray; some sand and phosphorite
137 - 158	Clay, white to gray; some limestone, sand and phosphorite

TAMPA MEMBER

158 - 162	Limestone, fine grained, moderately hard, white to cream; some white clay and chert
162 - 185	Clay, white to gray; some hard, fine-grained, cream limestone; sand, chert, and phosphorite
185 - 204	Clay, white; some fine-grained, moderately hard, cream limestone
204 - 223	Limestone, fine-grained, moderately hard, cream to white; some chert and white clay

SUWANNEE LIMESTONE

223 - 361	Limestone, soft, granular, cream; trace of gray clay
361 - 500	Limestone, granular, hard, fossiliferous, tan; trace of clay

APPENDIX I

Cross Section F to F'

WELL LOG NUMBER	SC-2
WELL LOG NAME	
COUNTY	HILLSBOROUGH
TOTAL DEPTH	930 FT
LOCATION	
ELEVATION	
COMPLETION DATE	

INTERVAL	DESCRIPTION	FORMATION
		UNDIFFERENTIATED SURFICIAL
0 - 5	Sand, fine-grained, pale brown	
5 - 10	Sand, fine to medium-grained, slightly clayey, pale, yellowish-brown	
		HAWTHORN GROUP CLAYS
10 - 25	Clay, sandy, pale yellowish-brown	
25 - 40	Clay, sandy, slightly phosphatic, grayish-orange to dark yellow-orange	
40 - 45	Clay, sandy, phosphatic, grayish-orange to dark yellow-orange; limestone lenses, sandy, phosphatic	
45 - 60	Clay, sandy, phosphatic, greenish-gray	
60 - 70	Limestone, sandy, pale orange to light gray; clay, sandy, phosphatic, greenish-gray	
		TAMPA MEMBER
70 - 85	Limestone, dolomitic, slightly sandy, pale orange to light gray; clay, phosphatic, greenish-gray	
85 - 130	Limestone, slightly dolomitic and sandy, orange to light gray; clay, phosphatic, greenish-gray	

APPENDIX I

Cross Section F to F'

130 - 145	Clay, phosphatic, light gray to green-gray; limestone slightly dolomitic, sandy, light gray
145 - 165	Clay, pale orange; limestone, slightly sandy, light gray to pale brown
	SUWANNEE LIMESTONE
165 - 215	Limestone, slightly sandy, slightly dolomitic, pale yellowish-brown; trace clay, pale orange
215 - 245	Limestone, slightly sandy, pale orange to white; small amount of chert, gray to olive black; trace clay, white

APPENDIX I

Cross Section F to F'

WELL LOG NUMBER SC-1

WELL LOG NAME

COUNTY HILLSBOROUGH

TOTAL DEPTH 926 FT

LOCATION

ELEVATION

COMPLETION DATE

INTERVAL	DESCRIPTION	FORMATION
		UNDIFFERENTIATED SURFICIAL
0 - 20	Sand, quartz, fine to medium-grained, sub-angular to rounded, pale yellow to brown	
20 - 25	Sand, clayey, fine to medium-grained, sub-angular to rounded, pale yellow to brown; clay, sandy, green	
		HAWTHORN GROUP CLAYS
25 - 29	Clay, soft, brown to green; limestone, moderately hard, fien to medium-grained, yellowish brown	
29 - 50	Clay, sandy, soft, pale green to yellowish-brown; sand, quartzitic, angular to sub-rounded, poorly sorted, pale brown; some shell fragments	
50 - 65	Clay, firm, bluish-green; sand, fine to medium-grained, trace of pale yellowish brown	
65 - 70	Clay, soft, green-gray; trace of phosphatic sand	
70 - 85	Clay, firm, gray to tan; phosphatic sand in clay matrix	
85 - 100	Clay, firm, light to dark gray; some sandy clay	
		TAMPA MEMBER
100 - 110	Dolostone, finely crystalline, fractured, hard, light brown; chert, black	

APPENDIX I

Cross Section F to F'

110 - 115	Clay, soft, light gray; limestone fragments, sandy, dolomitic, tan
115 - 117	Limestone, fine-grained, sandy, soft to moderately hard, cream; trace of clay; chert fragments, gray to black
117 - 119	Clay, sandy, indurated, light gray
119 - 126	Limestone, granular, solution vugs, moderately well cemented, pale yellowish-brown; chert and shell fragments
126 - 127	Clay, soft, sandy, grayish-brown
127 - 130	Limestone, fine-grained, soft to moderately hard, fossiliferous, light gray; dolostone, finely crystalline, sandy, dense
130 - 135	Dolostone, finely crystalline, sandy, hard, light gray to tan; clay, soft, sandy, light green
135 - 142	Clay, soft, sandy, light green to gray; dolostone, sandy light brown
142 - 145	Limestone, sandy, fine-grained to microcrystalline, hard, bluish-gray
145 - 150	Chert, light gray to dark gray; clay, soft, blue-green; sandy dolostone and limestone
150 - 155	Limestone, fine-grained, hard, well cemented, light gray; clay, bluish-gray
155 - 164	Dolostone, sandy, finely crystalline, hard, gray to tan; clay, soft, sandy, plastic, off white
164 - 168	Clay, soft, off white to green; traces of dolostone and limestone
168 - 181	Clay, soft, white to blue-green; limestone, soft, fine-grained, tan to cream
181 - 191	Limestone, fine-grained, sandy, soft to moderately hard, tan; dolostone, finely crystalline, sandy, traces of clay
191 - 193	Sand, fine-grained, rounded, poorly cemented; clay, gray

APPENDIX I

Cross Section F to F'

193 - 197	Limestone, sandy, fine-grained, soft to moderately hard, light tan; dolostone, crystalline, hard, gray
197 - 200	Clay, sandy, soft, blue-green; limestone, granular, tan; chert, black
200 - 212	Limestone, granular, hard, tan, cream and gray; clay, calcareous, soft, white; dolostone, hard, gray
212 - 218	Limestone, granular, soft, off-white to tan
218 - 220	Clay, soft, off-white
	SUWANNEE LIMESTONE
220 - 228	Limestone, granular, moderately hard, some solution features, tan; chert, dark brown to black
228 - 233	Limestone, granular, fossiliferous, soft to moderately hard, tan

APPENDIX I

Cross Section F to F'

WELL LOG NUMBER SCHM-1

WELL LOG NAME

COUNTY HILLSBOROUGH

TOTAL DEPTH 940 FT

LOCATION

ELEVATION

COMPLETION DATE

INTERVAL	DESCRIPTION	FORMATION
		UNDIFFERENTIATED SURFICIAL
0 - 5	Sand, quartz, fine-grained, yellowish-gray	
5 - 15	Sand, quartz, fine-grained, dark moderate brown	
15 - 30	Sand, quartz, fine-grained, clayey, light brownish gray	
		HAWTHORN GROUP CLAYS
30 - 50	Clay, pinkish gray; phosphate	
50 - 60	Clay, light brownish gray; phosphate	
60 - 65	Clay, yellowish gray to light olive gray; phosphate	
65 - 80	Limestone, clayey, yellowish gray to light olive gray; clay, yellowish gray to light olive gray; phosphate	
80 - 100	Limestone, clayey, light olive gray to greenish gray; clay, light olive gray to greenish gray; phosphate	
100 - 145	Limestone, white to light gray; clay, white to light gray; phosphate	

APPENDIX I

Cross Section F to F'

TAMPA MEMBER

145 - 150	Limestone, granular, pinkish gray to light gray; phosphate
150 - 160	Chert, greenish gray; limestone, granular, pinkish gray to yellowish gray
160 - 170	Limestone, clayey, light olive gray; phosphate
170 - 180	Clay, yellowish gray
180 - 235	Limestone, granular, yellowish gray to pinkish gray; clay, yellowish gray

SUWANNEE LIMESTONE

235 - 265	Limestone, granular, pinkish gray
265 - 270	Limestone, granular, pinkish gray to light olive gray

APPENDIX I

Cross Section F to F'

WELL LOG NUMBER 10621

WELL LOG NAME

COUNTY HILLSBOROUGH

TOTAL DEPTH 694 FT

LOCATION

ELEVATION

COMPLETION DATE

INTERVAL	DESCRIPTION	FORMATION
		UNDIFFERENTIATED SURFICIAL
0 - 44	Sand; very light gray; grain size: fine: range: very fine to medium; roundness: sub-angular; medium sphericity; unconsolidated; accessory minerals: calcilutite-10%, phosphatic gravel-03%, phosphatic sand-07%, heavy minerals- %	
		TAMPA MEMBER
44 - 54	Limestone; very light gray; grain type: calcilutite, skeletal cast, skeletal; 3% allochemical constituents; grain size: medium; moderate induration; cement types: calcilutite matrix; accessory minerals: quartz sand-15%, phosphatic sand-01%, phosphatic gravel-03%, quartz- %; fossils: algae, crustacea, benthic foraminifera; sand is imbedded, phosphate sand embedded, quartz is chalcedony; sorites	
54 - 64	As above; echinoid spines, also	
64 - 74	As above	

APPENDIX I

Cross Section F to F'

74 - 94	Limestone; 03% porosity, intergranular; grain type: intraclasts, skeletal; 10% allochemical constituents; grain size: medium; moderate induration; cement types: calcilutite matrix; accessory minerals: quartz sand-15%, quartz-05%; other features: low recrystallization; fossils: crustacea, echinoid, benthic foraminifera; beekites common, sorites
94 - 104	As above; no beekites or sorites, minor chert, only 5% grains; a sandy micrite
104 - 114	As above, denser
114 - 124	As above, less than 3 pct. embedded sand; now 7 pct. brown and gray
124 - 134	Dolomite; light olive gray; 90-100% altered; grain size: very fine: good induration; cement types: dolomite cement; accessory minerals: quartz sand-15%; very fine sand, well sorted, evenly spread throughout
	SUWANNEE LIMESTONE
134 - 144	Limestone; very light orange; 10% porosity, intergranular; grain type: intraclasts, skeletal; 70% allochemical constituents; grain size: fine; range: very fine to medium; moderate induration; cement types: sparry calcite cement, calcilutite matrix; other features: low recrystallization; fossils: benthic foraminifera, echinoid, mollusks
144 - 154	As above, poor induration
154 - 164	As above, cavings
164 - 174	Limestone; 03% porosity, intergranular; grain type: intraclasts, skeletal; 10% allochemical constituents; grain size: medium; moderate induration; cement types: calcilutite matrix; accessory minerals: quartz sand-15%, quartz-05%; other features: low recrystallization; fossils: crustacea, echinoid, benthic foraminifera; like 104, must be all cavings

APPENDIX II

Historical Water-Quality Data for Lithia and Buckhorn Springs

APPENDIX II

Historical Water-Quality Data for Lithia and Buckhorn Springs

Spring Name	Date Sampled	Temp. Deg. C	Specific Cond	pH	Ca	Mg	Na	K	Cl	SO4	F	HCO3	Alk. as CaCO3	Ortho P	Total P	NO2 + NO3 as (N)	TDS
Lithia Springs	07/19/23				65	14			23	93		135				.172	331
	04/30/46			7.5	62	10			21	86	0.3	129				.16	285
	07/14/49			7.6	78	0.5			24	77		107					
	04/23/68		403	7.2	57	9.6	10	0.6	21	61	0.6	130				1.35	257
	10/10/72		468	7.7	58	11	12	0.6	22	79	0.4	130				2.4	284
	01/30/85		422	7.3	58	8.8	11	0.8	20	58	0.2			.05	.06	3.2	
Buckhorn Springs	06/02/66	23.5	424	7.3	56	11	16	0.8	29	67	0.2	130	110			.25	258
	10/16/72	23.5	416	8.0	50	12	14	0.8	26	64	0.3	130	100			1.11	250

APPENDIX III

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

APPENDIX III

Specifications of Sampled Wells and Water Quality Data

Well Name	AGWQMP ID	Cased Depth	Total Depth	Lat/Long	Date Sampled	Field pH	Field Temp	Field Cond	HCO3 as CaCO3	HCO3 as HCO3	CO3 as CaCO3	Cl	SO4
Heinz	057PF155	86	110	280417/820651	09/03/91	7.35	24.5	465.0	220.00	268.29	-2.00	13.0	-2.00
Daily	057PF160	UNK	UNK	280212/821356	09/03/91	7.48	24.0	395.0	190.00	231.71	-2.00	9.0	3.00
Arrington	057PF158	UNK	114	280250/820920	09/03/91	7.08	23.0	410.0	200.00	243.90	-2.00	9.0	3.00
Booth	057PF156	53	143	280313/820828	09/04/92	7.95	24.0	300.0					
Buti	057PF157	UNK	90	280226/820719	09/04/92	7.97	22.5	235.0	98.00	119.51	-2.00	10.0	4.00
Hinson	057PF159	84	115	280245/821214	09/04/92	7.34	23.0	400.0					
Harris	057PF163	60-80	184	280128/821239	09/04/92	6.92	24.0	220.0					
Heath	057PF164	UNK	168	280122/821214	09/04/92	7.39	23.0	335.0	120.00	146.34	-2.00	14.0	21.00
Fox	057PF162	53	153	280050/821533	09/05/91	7.40	23.0	330.0	160.00	195.12	-2.00	7.0	-2.00
Speer	057DF014	165	190	280218/821204	09/05/91	7.42	24.5	390.0	190.00	231.71	-2.00	7.0	-2.00
Hills Co Avia	057PF165	42	240	280009/820954	09/05/91	7.61	25.0	330.0	160.00	195.12	-2.00	4.0	-2.00
Sapp	057PF167	69	125	275936/820816	09/05/91	7.20	25.0	400.0	190.00	231.71	-2.00	7.0	-2.00
McDonald	057PF230	100	145	280024/821108	09/05/91	7.83	25.0	245.0	120.00	146.34	-2.00	3.0	-2.00
Cooper	057DF024	145	348	275823/820458	09/06/91	7.98	24.0	310.0	130.00	158.54	-2.00	15.0	8.00
Henry	057PF168	UNK	99	275841/820732	09/06/91	7.31	24.0	315.0	150.00	182.93	-2.00	9.0	-2.00
Grimette	057PF169	115	165	275856/820841	09/06/91	7.12	23.0	450.0	220.00	268.29	-2.00	10.0	-2.00
Plant Cty Pal	057PF170	78	190	275933/821011	09/09/91	7.57	25.0	375.0	190.00	231.71	-2.00	3.0	-2.00
Rabon	057PF171	68	120	275917/821110	09/09/91	7.49	24.0	235.0	96.00	117.07	-2.00	7.0	6.00
Romp DV-2	057YF125	108	130	275759/820854	09/09/91	5.20	26.0	120.0	6.00	7.32	-2.00	16.0	14.00
Romp DV-1	057PF172	90	140	275926/821234	09/10/91	7.65	24.5	380.0	180.00	219.51	-2.00	7.0	-2.00
Poli	057PF166	UNK	300	275953/820752	09/10/91	7.74	24.0	245.0	120.00	146.34	-2.00	5.0	-2.00
Simmons Park	057PF188	UNK	UNK	275645/821030	09/11/91	7.67	25.0	350.0	150.00	182.93	-2.00	12.0	10.00
Dover Park	057PF174	141	301	275915/821410	09/11/91	7.63	24.5	340.0	160.00	195.12	-2.00	4.0	-2.00
Guerrero	057DI015	96	135	275952/821237	09/11/91	6.49	26.0	900.0					
Romp 68-2	057YF078	120	221	280503/821437	09/11/91	7.03	24.0	330.0	180.00	219.51	-2.00	8.0	-2.00
Hover	057PF161	UNK	UNK	280155/821537	09/12/91	7.46	25.0	430.0	200.00	243.90	-2.00	11.0	-2.00
Sydney Church	057PF187	165	204	275746/821229	09/12/91	7.87	25.0	250.0	84.00	102.44	-2.00	10.0	18.00
Compton	057PF173	UNK	UNK	275845/821254	09/12/91	7.89	24.0	220.0	96.00	117.07	-2.00	8.0	-2.00
Boone	057PF175	UNK	65	275852/821638	09/12/91	7.29	26.0	400.0	150.00	182.93	-2.00	11.0	17.00
Kyle	057PF176	UNK	UNK	275943/821738	09/13/91	7.64	24.0	220.0	96.00	117.07	-2.00	10.0	6.00
Musgrave	057PF178	84	200	275710/821923	09/13/91	7.81	24.0	195.0	88.00	107.32	-2.00	5.0	-2.00
Sheffield	057PF177	280	475	275935/821834	09/13/91	7.48	24.0	340.0	140.00	170.73	-2.00	7.0	21.00
Campo	057PF179	UNK	165	275722/821830	09/16/91	7.42	24.0	370.0	130.00	158.54	-2.00	15.0	37.00
Jones	057PF180	110	230	275721/821721	09/16/91	7.70	24.5	310.0	130.00	158.54	-2.00	14.0	12.00
Wheeler	057PF181	UNK	130	275819/821540	09/16/91	7.65	24.5	250.0	88.00	107.32	-2.00	11.0	-2.00
Dunham	057PF182	84	185	275758/821522	09/16/91	7.82	25.0	295.0	110.00	134.15	-2.00	11.0	8.00
Marks	057PF183	60	205	275632/821542	09/17/91	7.38	23.5	350.0	130.00	158.54	-2.00	17.0	11.00
Rector	057PF227	UNK	250	275236/821435	09/17/91	7.91	24.5	170.0	78.00	95.12	-2.00	7.0	8.00
Emmanuel Chur,	057PF186	87	190	275618/821308	09/17/91	7.52	23.0	355.0	160.00	195.12	-2.00	12.0	-2.00
Brandiewie	057PF225	UNK	200	275343/821413	09/17/91	6.28	25.5	200.0	30.00	36.59	-2.00	24.0	17.00
Cerny	057PF185	200	200	275635/821345	09/17/91	8.09	25.0	250.0	62.00	75.61	-2.00	15.0	8.00
	HRS				01/14/92								
Taylor	HRS				01/14/92								
Childers	HRS				01/14/92								
Allen	057PF224	117	198	275401/821458	09/17/91	7.71	25.0	180.0	80.00	97.56	-2.00	6.0	10.00
Cooper	057PF229	60	158	275330/821324	09/17/91	7.44	25.0	270.0	82.00	100.00	-2.00	17.0	24.00
Griffin	057PF184	UNK	120	275651/821452	09/18/91	7.90	24.0	230.0	92.00	112.20	-2.00	6.0	-2.00
Watland	057PF223	UNK	200	275440/821507	09/18/91	7.58	25.0	270.0	94.00	114.63	-2.00	14.0	39.00
Engle	057PF220	UNK	400	275416/821537	09/18/91	7.83	25.0	400.0	78.00	95.12	-2.00	19.0	65.00
Davis	057DI023	84	175	275620/821007	09/18/91	6.71	24.5	320.0	100.00	121.95	-2.00	17.0	14.00
Saranko	057PF189	53	120	275725/821011	09/18/91	8.05	24.5	290.0	110.00	134.15	-2.00	22.0	-2.00
Ramsey	057PF192	UNK	205	275152/820501	09/18/91	7.85	24.5	295.0	140.00	170.73	-2.00	7.0	-2.00
Moseley	057PF218	UNK	80	275340/821633	09/19/91	7.35	25.0	140.0	50.00	60.98	-2.00	11.0	5.00
Woods	057PF191	50	115	275606/820731	09/19/91	7.91	24.5	330.0	120.00	146.34	-2.00	19.0	14.00
Meadows	057PF190	78	87	275639/820833	09/19/91	7.83	24.0	300.0	100.00	121.95	-2.00	16.0	-2.00
	HRS				01/14/92								
Resident	HRS				01/14/92								
Jarvis	HRS				01/14/92								
Walter	057PF217	UNK	200	275215/821629	09/19/91	7.24	23.5	270.0	160.00	195.12	-2.00	9.0	3.00
Albritton	057PF193	90	125	275315/820810	09/19/91	8.02	24.0	225.0	72.00	87.80	-2.00	10.0	20.00
McDermitt	057PF221	UNK	170	275451/821543	09/19/91	7.20	25.5	190.0	60.00	73.17	-2.00	12.0	10.00
Goodwin	057PF196	UNK	75	275256/820945	09/19/91	7.87	25.0	280.0	120.00	146.34	-2.00	10.0	-2.00
Cole	057PF219	UNK	100	275335/821609	09/19/91	6.64	5.0	220.0					
Lovegrove	057PF226	100	160	275325/821416	09/20/91	6.98	23.0	600.0	96.00	117.07	-2.00	130.0	13.00
Peifer	057PF194	UNK	285	275143/820841	09/20/91	7.72	23.5	350.0	140.00	170.73	-2.00	6.0	34.00
Crellin	057PF216	UNK	160	275139/821714	09/20/91	7.01	23.0	320.0	150.00	182.93	-2.00	2.0	20.00
Ernest	057PF195	UNK	170	275030/821029	09/20/91	7.61	25.0	400.0	150.00	182.93	-2.00	3.0	22.00
Thayer	057DI026	115	225	275031/821756	09/20/91	7.06	24.0	400.0	230.00	280.49	-2.00	5.0	-2.00
Hope	057PF215	UNK	138	275225/821736	09/23/91	7.15	24.0	340.0	180.00	219.51	-2.00	12.0	29.00
Bunch	057PF213	UNK	UNK	275334/821811	09/23/91	6.95	24.0	390.0	150.00	182.93	-2.00	44.0	37.00
Fuller	057PF208	165	335	275541/821632	09/24/91	7.74	24.5	220.0	66.00	80.49	-2.00	15.0	35.00

Well Name	F	S	Ca	Mg	K	NA	(N) NH3	(N) NO3	(N) NO2+NO3	(N) ORG N	(P) PO4	(P) P	TDS	TOC	Fe (ug)
Heinz	0.12	0.02	81.0	4.0	0.60	7.1	0.26	0.08	0.08	-0.05	-0.01	0.14	274.0	3.10	3.50
Daily	0.13	-0.01	70.0	3.2	0.38	6.6	0.08	0.04	0.04	-0.05	0.06	0.11	232.0	1.00	0.98
Arrington	0.25	-0.01	73.0	2.9	1.20	7.7	0.07	0.02	0.02	0.06	0.04	0.26	258.0	2.70	1.10
Booth							-0.01		0.02	0.06		0.01		-1.00	
Buti	0.73	-0.01	25.0	12.0	0.33	6.7	-0.01	0.55	0.55	0.08	-0.01	0.02	166.0	-1.00	-0.02
Hinson							0.04		0.02	0.09		0.07		1.80	
Harris							-0.01		8.40	0.06		0.74		-1.00	
Heath	0.21	-0.01	55.0	2.6	0.53	8.8	0.01	0.25	0.39	0.06	0.10	0.11	204.0	1.50	0.17
Fox	0.16	0.03	57.0	4.1	0.17	5.8	0.19	0.02	0.02	-0.05	0.07	0.07	198.0	-1.00	0.50
Speer	0.16	-0.01	70.0	2.6	0.60	6.4	0.12	0.01	0.01	-0.05	0.10	0.17	240.0	-1.00	0.10
Hills Co Avia	0.32	-0.01	51.0	7.8	0.56	4.9	0.21	0.02	0.02	-0.05	0.16	0.19	196.0	1.80	0.25
Sapp	0.59	0.02	46.0	17.0	0.95	11.0	0.20	0.03	0.03	-0.05	-0.01	0.07	246.0	3.40	1.20
McDonald	0.66	0.02	32.0	9.0	0.62	3.9	0.21	-0.01	-0.01	-0.05	0.05	0.06	166.0	1.60	0.30
Cooper	0.42	-0.01	29.0	17.0	0.33	10.0	0.02	-0.01	-0.01	-0.05	-0.01	-0.01	178.0	-1.00	-0.02
Henry	0.53	0.02	35.0	16.0	0.48	5.9	0.20	0.03	0.03	-0.05	-0.01	0.03	184.0	1.30	1.20
Grimette	0.43	-0.01	75.0	6.5	1.20	14.0	0.93	0.06	0.06	-0.05	0.21	0.37	308.0	7.50	1.20
Plant Cty Pal	0.37	-0.01	37.0	20.0	1.20	8.0	0.51	-0.01	-0.01	-0.05	-0.01	0.02	242.0	2.80	0.06
Rabon	0.60	0.04	29.0	8.1	0.85	3.5	0.10	0.02	0.02	-0.05	0.32	0.56	170.0	-1.00	1.10
Romp DV-2	0.15	0.50	4.4	2.6	1.20	8.0	0.45	-0.01	-0.01	-0.05	0.18	0.19	82.0	2.30	0.91
Romp DV-1	0.30	0.11	56.0	8.8	0.79	7.1	0.59	-0.01	-0.01	-0.05	0.06	0.07	266.0	2.50	0.09
Poli	0.76	-0.01	31.0	8.8	0.53	6.0	0.06	0.01	0.01	-0.05	0.03	0.04	184.0	-1.00	0.04
Simmons Park	0.44	-0.01	34.0	17.0	0.51	10.0	-0.01	0.02	0.02	-0.05	-0.01	0.02	224.0	-1.00	-0.02
Dover Park	0.45	-0.01	51.0	8.6	0.59	6.6	0.24	0.09	0.09	-0.05	0.06	0.09	230.0	2.20	0.55
Guerrero							0.65		0.08	-0.05		0.98		3.90	
Romp 68-2	0.12	-0.01	64.0	3.1	0.44	6.0	0.12	0.05	0.05	-0.05	0.04	0.58	226.0	1.50	1.30
Hover	0.15	-0.01	71.0	4.0	0.50	7.3	0.08	0.40	0.40	-0.05	-0.01	0.06	260.0	1.40	0.94
Sydney Church	0.49	0.01	29.0	9.3	0.42	5.3	0.03	0.01	0.01	-0.05	-0.01	0.03	164.0	-1.00	-0.02
Compton	0.55	-0.01	22.0	12.0	0.65	5.5	0.02	0.08	0.10	-0.05	-0.01	0.02	168.0	-1.00	-0.02
Boone	0.25	-0.01	67.0	2.7	0.28	6.6	-0.01	2.50	2.50	-0.05	0.16	0.18	234.0	-1.00	-0.02
Kyle	0.13	-0.01	42.0	1.9	0.29	5.7	0.01	2.50	2.50	-0.05	0.04	0.05	160.0	-1.00	-0.02
Musgrave	0.08	-0.01	33.0	1.9	0.65	2.2	0.01	0.02	0.02	-0.05	-0.01	0.02	126.0	-1.00	-0.02
Sheffield	0.16	-0.01	56.0	4.2	0.38	4.9	-0.01	0.78	0.78	-0.05	0.04	0.04	202.0	-1.00	-0.02
Campo	0.13	-0.01	55.0	6.7	0.41	7.4	0.04	-0.01	-0.01	-0.05	0.04	0.05	220.0	-1.00	-0.03
Jones	0.15	-0.01	51.0	3.2	0.49	6.6	0.04	2.40	2.40	-0.05	0.05	0.05	180.0	-1.00	-0.02
Wheeler	0.16	-0.01	39.0	2.3	0.39	4.3	0.02	3.60	3.60	-0.05	0.03	0.04	156.0	-1.00	-0.02
Dunham	0.21	-0.01	46.0	2.9	0.52	4.8	0.01	0.69	0.73	-0.05	0.04	0.06	170.0	-1.00	-0.02
Marks	0.14	0.01	58.0	3.4	0.47	6.4	0.01	3.40	3.40	-0.05	0.04	0.06	220.0	-1.00	-0.02
Rector	0.28	-0.01	24.0	9.2	0.51	3.2	0.03	-0.01	-0.01	-0.05	-0.01	0.02	122.0	-1.00	0.02
Emmanuel Chur.	0.39	-0.01	43.0	14.0	0.52	10.0	0.03	0.10	0.10	-0.05	-0.01	0.03	202.0	1.80	-0.02
Brandiewie	0.19	0.01	28.0	2.3	0.42	7.5	-0.01	3.80	3.80	-0.05	0.65	0.73	146.0	-1.00	-0.02
Cerny	0.12	-0.01	39.0	2.6	0.52	4.8	0.04	6.20	6.20	-0.05	-0.01	0.02	162.0	-1.00	-0.02
								5.90							
Taylor								0.12							
Childers								2.60							
Allen	0.15	-0.01	36.0	1.5	0.77	3.4	0.05	0.06	0.06	-0.05	0.09	0.11	114.0	-1.00	-0.02
Cooper	0.16	-0.01	43.0	5.5	0.49	7.9	0.02	3.80	3.80	-0.05	0.04	0.05	172.0	-1.00	-0.02
Griffin	0.24	-0.01	35.0	4.9	0.29	4.0	0.02	2.00	2.00	-0.05	0.01	0.03	128.0	-1.00	-0.02
Watland	0.22	-0.01	49.0	7.2	0.38	7.0	-0.01	2.40	2.40	-0.05	-0.01	0.02	192.0	-1.00	-0.02
Engle	0.36	-0.01	44.0	16.0	1.00	5.7	0.02	3.60	4.00	-0.05	-0.01	0.02	236.0	-1.00	-0.02
Davis	0.31	-0.01	31.0	16.0	0.24	7.5	0.01	4.20	4.20	0.09	0.21	0.23	184.0	-1.00	-0.02
Saranko	0.60	-0.01	30.0	15.0	0.28	7.2	0.01	0.03	0.03	0.05	-0.01	0.05	182.0	-1.00	-0.02
Ramsey	0.57	0.17	33.0	14.0	0.71	10.0	0.29	-0.01	-0.01	-0.05	-0.01	0.06	180.0	5.30	-0.02
Moseley	0.21	-0.01	28.0	1.0	0.36	5.7	0.10	3.40	3.40	-0.05	0.20	0.28	98.0	-1.00	-0.02
Woods	0.38	-0.01	36.0	18.0	0.33	7.9	0.10	-0.01	-0.01	-0.05	-0.01	0.14	196.0	-1.00	0.25
Meadows	0.43	-0.01	30.0	17.0	0.17	7.5	0.12	6.20	6.20	-0.05	-0.01	0.02	172.0	-1.00	-0.02
								5.90							
Resident								-0.05							
Jarvis								1.00							
Walter	0.47	0.22	41.0	20.0	0.36	4.4	0.23	-0.01	-0.01	-0.05	0.11	0.18	208.0	1.90	0.25
Albritton	0.59	-0.01	26.0	11.0	0.59	4.7	-0.01	0.19	0.27	-0.05	-0.01	0.04	146.0	-1.00	-0.02
McDermitt	0.10	-0.01	32.0	1.8	0.26	8.6	0.01	2.00	2.00	-0.05	0.04	0.07	152.0	-1.00	-0.02
Goodwin	0.32	-0.01	29.0	17.0	0.34	3.7	-0.01	1.70	1.70	0.09	-0.01	0.02	178.0	-1.00	-0.02
Cole							0.02		-0.01	0.12		0.42		-1.00	
Lovegrove	0.23	-0.01	89.0	6.9	0.40	25.0	0.11	0.01	0.01	0.10	0.04	0.04	522.0	1.20	1.50
Peifer	0.53	0.54	41.0	18.0	0.93	7.6	0.14	-0.01	-0.01	0.06	-0.01	0.08	220.0	1.00	-0.02
Crellin	0.31	2.50	48.0	14.0	0.59	7.1	0.20	-0.01	-0.01	0.07	0.01	0.99	218.0	1.60	-0.02
Ernest	0.70	0.41	42.0	18.0	0.68	10.0	0.39	-0.01	-0.01	0.08	-0.01	0.02	222.0	2.00	-0.02
Thayer	0.33	0.28	63.0	23.0	1.00	4.6	[illegible]	0.01	0.01	0.20	0.08	0.32	282.0	5.40	0.59
Hope	0.38	2.20	59.0	19.0	0.88	9.2	0.29	-0.01	-0.01	0.08	0.01	0.03	282.0	1.90	-0.02
Bunch	0.22	-0.01	71.0	13.0	0.76	19.0	-0.01	2.20	2.20	0.10	0.14	0.15	300.0	-1.00	-0.02
Fuller	0.22	-0.01	39.0	6.9	0.31	6.2	-0.01	3.00	3.00	0.08	-0.01	0.02	174.0	-1.00	-0.02

Well Name	AGWQMP ID	Cased Depth	Total Depth	Lat/Long	Date Sampled	Field pH	Field Temp	Field Cond	HCO3 as CaCO3	HCO3 as HCO3	CO3 as CaCO3	Cl	SO4
Hernandez	057PF214	25	142	275321/821744	09/24/91	7.41	25.0	700.0	130.00	158.54	-2.00	36.0	130.00
Carter	057PF212	UNK	UNK	275226/821954	09/24/91	6.96	24.5	600.0	200.00	243.90	-2.00	54.0	24.00
Howell	057PF211	84	165	275402/821904	09/24/91	7.01	24.0	800.0	200.00	243.90	-2.00	66.0	40.00
	SAL				04/30/92	7.11	24.0	700.0					
	HRS				01/14/92								
Soloman	HRS				01/14/92								
Calloway	057PF207	106	225	275609/821627	09/24/91	6.40	25.0	260.0	50.00	60.98	-2.00	32.0	16.00
	SAL				04/30/92	6.22	25.0	350.0					
	HRS				01/14/92								
Coggins	HRS				01/14/92								
Ch of Nat	HRS				01/14/92								
Ward	057PF210	78	156	275609/821822	09/24/91	7.24	28.0	220.0	58.00	70.73	-2.00	13.0	10.00
Cremeans	057PF205	UNK	137	275526/821452	09/25/91	7.46	25.0	230.0	64.00	78.05	-2.00	17.0	5.00
	SAL				04/29/92	7.22	25.0	270.0					
	HRS				01/14/92								
Quinn	HRS				01/14/92								
Adams	057PF204	80	120	275523/821409	09/24/91	7.39	24.0	240.0	44.00	53.66	-2.00	17.0	6.00
	HRS				01/14/92								
Fleiss	HRS				01/14/92								
Desrochers	057PF209	UNK	206	275510/821653	09/25/91	6.55	25.5	190.0	56.00	68.29	-2.00	10.0	5.00
Moulin	057PF206	90	150	275608/821525	09/25/91	7.50	24.5	390.0	110.00	134.15	-2.00	17.0	42.00
O'Shey-Perry	057PF202	115	170	275425/821342	09/26/91	7.11	24.5	475.0	80.00	97.56	-2.00	30.0	31.00
	HRS				01/14/92								
Stratton	HRS				01/14/92								
Resident	HRS				01/14/92								
Borregard	057PF201	UNK	160	275400/821302	09/26/91	6.69	24.0	280.0	130.00	158.54	-2.00	17.0	3.00
Shoffstall	057PF203	UNK	180	275508/821342	09/26/91	7.87	25.0	270.0	82.00	100.00	-2.00	14.0	10.00
Gleason	057PF228	40	140	275220/821256	09/30/91	7.59	23.0	400.0	120.00	146.34	-2.00	9.0	76.00
Hills Cty Util	057PF231	119	380	275337/821713	09/30/91	7.02	25.0	450.0	120.00	146.34	-2.00	17.0	84.00
Cook	057PF198	120	180	275405/821202	10/01/91	7.50	24.0	250.0	150.00	182.93	-2.00	12.0	-2.00
WCRWSA-SCO-11	057PF232	85	122	275152/821214	10/01/91	7.73	23.0	370.0	190.00	231.71	-2.00	9.0	-2.00
First Baptist	057PF197	73	180	275340/821014	10/01/91	8.00	24.5	200.0	94.00	114.63	-2.00	9.0	[illegible]
WCRWSA-SCHM-7	057PF233	98	125	274941/821157	10/01/91	7.45	24.5	320.0	160.00	195.12	-2.00	2.0	[illegible]
Bardowski	057PF200	UNK	138	275424/821250	10/01/91	7.74	24.0	240.0	110.00	134.15	-2.00	14.0	8.00
WCRWSA-SCHM-6	057PF234	85	115	274925/820843	10/01/91	7.45	24.0	770.0	190.00	231.71	-2.00	-1.0	-2.00
Rorabacher	057PF222	UNK	180	275508/821533	10/02/91	7.17	24.5	440.0	130.00	158.54	-2.00	23.0	22.00
	HRS				01/14/92								
Harrold	HRS				01/14/92								
Pardo	057PF199	189	247	275432/821225	10/02/91	7.20	25.0	390.0	170.00	207.32	-2.00	8.0	33.00
Roche	057PF236	UNK	165	275958/821411	11/12/91	7.36	24.0	310.0	183.00	223.17	-2.00	7.2	-2.00
WCRWSA Lithia	057PF235	UNK	114	275156/821345	11/13/91	7.63	26.0	500.0	122.00	148.78	-2.00	26.0	120.00

The following wells were sampled in June, 1992 to supplement the original data collected

Well Name	AGWQMP ID	Cased Depth	Total Depth	Lat/Long	Date Sampled	Field pH	Field Temp	Field Cond	HCO3 as CaCO3	HCO3 as HCO3	CO3 as CaCO3	Cl	SO4
Mandt	SP-001	100	197	275109/821727	06/22/92	6.97	24.5	350.0					
Arvel	SP-002	50	200	275154/821623	06/22/92	7.01	24.0	250.0					
Davis	SP-003	Unk	Unk	275002/821752	06/22/92	-	25.5	430.0					
Merrit	SP-004	Unk	Unk	274959/821734	06/22/92	-	25.0	1100.0					
Vanni	SP-005	Unk	Unk	275326/822020	06/22/92	-	25.5	255.0					
Roberts	SP-007	Unk	Unk	275338/821936	06/22/92	-	25.0	380.0					
Blanco	SP-008	80	150	275436/821743	06/22/92	-	26.5	230.0					
Larson	SP-014	70	140	274958/821640	06/23/92	7.27	24.0	450.0					
Stamper	SP-015	125	225	275014/821652	06/23/92	7.82	25.0	300.0					
Hensel	SP-019	Unk	225	275008/821724	06/25/92	6.77	25.5	360.0					
Hamilton	SP-009	Unk	155	275428/821728	06/25/92	-	25.5	170.0	30.34	37.0	-2.0	18.0	-2.0
Burket	SP-010	Unk	190	274959/821534	06/25/92	-	24.5	250.0	114.80	140.0	-2.0	9.2	10.0
H.M. Elem	SP-012	Unk	160	275501/821829	06/23/92	7.21	25.0	400.0	172.20	210.0	-2.0	18.0	-2.0
Strickland	SP-013	Unk	100	275114/821708	06/23/92	7.97	24.0	250.0	106.60	130.0	-2.0	4.5	-2.0
Kinsey	SP-016	63	170	275643/821809	06/24/92	8.10	25.0	210.0	68.88	84.0	-2.0	13.0	4.0
Reagan	SP-017	Unk	Unk	275033/821819	06/24/92	7.28	25.0	340.0	180.40	220.0	-2.0	5.4	-2.0
Summerall	SP-018	Unk	50	275340/821911	06/25/92	7.16	24.5	550.0	213.20	260.0	-2.0	42.0	-2.0
Carrathers	SP-020	168	280	275020/821710	06/25/92	7.32	24.0	330.0	172.20	210.0	-2.0	7.4	-2.0
Christian	SP-021	Unk	Unk	274902/821338	06/25/92	7.44	24.5	305.0	164.00	200.0	-2.0	6.0	-2.0

Well Name	F	S	Ca	Mg	K	NA	(N) NH3	(N) NO3	(N) NO2+NO3	(N) ORG N	(P) PO4	(P) P	TDS	TOC	Fe (ug)
Hernandez	0.41	0.35	85.0	19.0	0.30	19.0	0.03	-0.01	-0.01	-0.05	-0.01	0.03	400.0	-1.00	0.40
Carter	0.34	0.06	53.0	25.0	0.55	37.0	0.18	-0.01	-0.01	0.17	-0.01	0.11	326.0	4.40	2.10
Howell	0.12	-0.01	120.0	10.0	3.20	32.0	-0.01	21.00	21.00	0.24	0.06	2.00	524.0	1.40	-0.02
								16.00							
								17.00							
Soloman								14.00							
Calloway	0.17	-0.01	42.0	3.1	0.48	14.0	-0.01	7.40	7.40	0.06	0.48	0.50	198.0	-1.00	-0.02
								6.30							
								11.00							
Coggins								3.80							
Ch of Nat								3.90							
Ward	0.08	-0.01	32.0	1.5	0.86	7.4	-0.01	3.40	3.40	0.08	0.26	0.27	120.0	-1.00	-0.02
Cremeans	0.13	-0.01	48.0	3.4	0.49	5.1	-0.01	13.00	13.00	0.06	0.06	0.05	198.0	-1.00	-0.02
								3.80							
								4.40							
Quinn								4.10							
Adams	0.07	-0.01	39.0	2.8	0.37	6.6	-0.01	11.00	11.00	0.08	0.01	0.01	218.0	-1.00	-0.02
								12.00							
Fleiss								1.60							
Desrochers	0.13	-0.01	29.0	1.5	0.38	6.0	-0.01	2.90	2.90	-0.05	0.54	1.30	112.0	-1.00	-0.02
Moulin	0.18	-0.01	61.0	5.2	0.49	8.2	-0.01	4.10	4.10	0.05	0.05	0.06	242.0	-1.00	-0.02
O'Shey-Perry	0.16	-0.01	53.0	4.9	0.55	10.0	-0.01	6.80	6.80	0.15	0.28	0.29	226.0	-1.00	-0.02
								6.30							
Stratton								4.50							
Resident								4.60							
Borregard	0.12	-0.01	47.0	3.0	0.37	5.6	-0.01	0.69	0.69	0.07	0.18	0.19	164.0	-1.00	-0.02
Shoffstall	0.19	-0.01	38.0	5.7	0.41	5.9	0.01	4.80	4.80	0.10	0.03	0.04	174.0	-1.00	-0.02
Gleason	0.45	0.03	49.0	19.0	0.70	6.5	0.04	-0.01	-0.01	0.07	0.01	0.02	260.0	-1.00	0.06
Hills Cty Util	0.27	0.04	63.0	13.0	0.55	9.2	0.02	0.06	0.06	-0.05	0.03	0.53	276.0	-1.00	0.05
Cook	0.12	-0.01	50.0	9.9	0.67	3.9	0.20	0.02	0.02	-0.05	-0.01	0.01	190.0	1.90	1.20
WCRWSA-SCO-1i	0.23	0.01	39.0	23.0	0.48	6.1	0.04	-0.01	-0.01	-0.05	0.02	0.03	200.0	-1.00	0.12
First Baptist	0.35	-0.01	28.0	12.0	0.66	5.3	0.01	1.90	1.90	-0.05	0.01	0.03	140.0	-1.00	0.02
WCRWSA-SCHM-7i	0.68	0.18	33.0	18.0	0.88	9.8	0.35	-0.01	-0.01	-0.05	-0.02	2.80	196.0	2.50	0.18
Bardowski	0.17	-0.01	46.0	6.0	0.38	6.4	0.01	3.20	3.20	0.06	0.08	0.09	160.0	-1.00	-0.02
WCRWSA-SCHM-6i	0.71	0.60	36.0	23.0	0.88	10.0	0.30	-0.01	-0.01	-0.05	0.01	0.02	224.0	2.70	0.02
Rorabacher	0.21	-0.01	63.0	5.9	0.28	12.0	0.03	6.00	0.06	-0.05	0.06	0.11	278.0	-1.00	-0.02
								6.20							
Harrold								3.70							
Pardo	0.16	0.01	59.0	14.0	0.70	5.8	0.25	-0.01	-0.01	-0.05	0.05	0.07	246.0	2.50	0.58
Roche	0.21	0.06	55.0	3.5	0.80	4.8	0.49	-0.01	-0.01	0.14	0.12	0.12	184.0	1.70	-0.02
WCRWSA Lithia	0.35	0.50	65.0	20.0	1.00	15.0	0.17	0.05	0.05	-0.05	0.01	0.10	558.0	-1.00	1.10

The following wells were sampled in June, 1992 to supplement the original data collected

Well Name	F	S	Ca	Mg	K	NA	(N) NH3	(N) NO3	(N) NO2+NO3	(N) ORG N	(P) PO4	(P) P	TDS	TOC	Fe (ug)
Mandl							0.34	0.02	0.02	-0.05	0.02	0.04			
Arvel							-0.01	-0.01	-0.01	0.05	-0.01	-0.01			
Davis							0.52	-0.01	-0.01	0.07	-0.01	-0.01			
Merrit							0.89	0.01	0.01	-0.05	1.30	1.30			
Vanni							0.08	-0.01	-0.01	-0.05	0.06	0.10			
Roberts							0.11	-0.01	-0.01	0.08	0.14	0.21			
Blanco							-0.01	1.50	1.50	-0.05	-0.01	-0.01			
Larson							0.30	-0.01	-0.01	-0.05	0.03	0.03			
Stamper							0.15	-0.01	-0.01	0.06	0.03	0.05			
Hensel							0.15	0.02	0.02	0.15	0.09	0.69			
Hamilton	0.15	-0.01	23.0	1.1	0.31	7.1	-0.01	4.20	4.20	-0.05	0.32	0.32	120.0	-1.00	0.04
Burket	0.30	-0.01	33.0	12.0	0.57	5.4	-0.01	0.15	0.15	-0.05	-0.01	-0.01	150.0	-1.00	0.03
H.M. Elem	0.16	0.02	69.0	3.1	0.63	9.1	0.10	-0.01	-0.01	0.11	0.09	0.09	224.0	1.80	0.66
Strickland	0.31	-0.01	24.0	13.0	0.30	3.1	0.04	-0.01	-0.01	-0.05	-0.01	-0.01	124.0	-1.00	0.03
Kinsey	0.12	-0.01	26.0	7.8	0.44	4.5	-0.01	2.80	2.80	-0.05	-0.01	-0.01	102.0	-1.00	-0.02
Reagan	0.47	0.05	50.0	15.0	0.53	4.4	0.29	-0.01	-0.01	-0.05	0.12	0.15	200.0	3.00	0.38
Summerall	0.14	-0.01	80.0	3.1	0.69	36.0	-0.01	0.03	0.03	0.15	0.02	0.40	304.0	6.00	-0.02
Carrathers	0.34	0.04	41.0	19.0	0.59	3.9	0.07	0.02	0.02	0.07	-0.01	-0.01	190.0	2.30	0.06
Christian	0.37	0.01	38.0	17.0	0.73	6.3	0.05	0.02	0.02	0.05	-0.01	-0.01	186.0	-1.00	-0.02

Water Quality Data for Sampled Springs

HILLSBOROUGH COUNTY SPRINGS

Buckhorn Main Spring

Date	Field pH	Field Temp	Field Cond	HCO3 as CaCO3	HCO3 as HCO3	CO3 as CaCO3	Cl	SO4	F	S	Ca	Mg	K	Na	(N) NH3	(N) NO3
04/25/91	7.26	24.0	500.0	110.0	134.1	-2.00	25.0	68.0	0.19	0.20	56.0	11.0	0.66	14.0	-0.01	2.30
07/01/91	7.45	24.0	500.0												-0.01	2.10
07/24/91	7.43	24.5	500.0	98.4	120.0	-2.00	31.0	76.0	0.21	-0.20	58.0	12.0	0.75	17.0	-0.01	2.20
08/29/91	7.55	24.0	460.0												-0.01	2.50
09/23/91	7.35	26.0	365.0												0.02	
10/22/91	7.31	24.0	450.0	109.9	134.0	-2.00	32.0	58.0	0.20	-0.01	62.0	11.0	0.50	16.0	-0.01	2.00
12/02/91	7.59	25.0	450.0												-0.01	1.80
12/30/91	7.50	24.0	420.0												-0.01	1.90
01/28/92	7.49	24.0	420.0	114.8	140.0	-2.00	72.0	92.0	0.2	-0.01	59.0	12.0	0.7	14.0	-0.01	1.90
02/19/92	7.51	24.5	450.0												-0.01	1.50
03/26/92	7.57	24.0	435.0												0.02	1.90
04/28/92	7.28	23.5	400.0												0.01	1.80
05/25/92	7.42	24.5	440.0												-0.01	1.80
06/25/92	7.25	25.0	430.0												-0.01	1.80
07/29/92	7.44	25.0	440.0												-0.01	1.70

Buckhorn Springs East (sandbags)

Date	Field pH	Field Temp	Field Cond	HCO3 as CaCO3	HCO3 as HCO3	CO3 as CaCO3	Cl	SO4	F	S	Ca	Mg	K	Na	(N) NH3	(N) NO3
04/25/91	7.34	24.0	600.0	100.0	122.0	-2.00	64.0	74.0	0.24	0.40	44.0	11.0	2.30	42.0	-0.01	1.00
07/01/91	7.52	25.5	550.0												0.02	0.76
07/24/91	7.51	25.0	1100.0	98.4	120.0	-2.00	180.0	140.0	0.27	-0.20	73.0	25.0	3.70	100.0	-0.01	0.90
09/23/91	7.12	25.0	950.0												-0.01	
10/22/91	7.38	24.5	1000.0	109.9	134.0	-2.00	170.0	100.0	0.25	-0.01	76.0	22.0	2.80	98.0	0.01	1.3[illegible]
12/02/91	7.51	25.0	800.0												0.02	1.70
12/30/91	7.47	24.0	700.0												-0.01	1.40
01/28/92	7.25	24.0	600.0	114.8	140.0	-2.00	72.0	92.0	0.21	-0.01	66.0	16.0	1.80	42.0	-0.01	1.40
02/19/92	7.50	24.5	750.0												-0.01	1.30
03/26/92	7.60	24.0	700.0												-0.01	1.30
04/28/92	7.24	23.5	700.0												-0.01	1.20
05/26/92	7.50	25.0	550.0												-0.01	1.40
06/25/92	6.95	25.0	800.0												-0.01	1.10
07/29/92	7.46	24.0	880.0												0.01	1.10

Buckhorn Springs West (Tower)

Date	Field pH	Field Temp	Field Cond	HCO3 as CaCO3	HCO3 as HCO3	CO3 as CaCO3	Cl	SO4	F	S	Ca	Mg	K	Na	(N) NH3	(N) NO3
04/25/91	7.34	24.0	700.0	120.0	146.0	-2.00	94.0	68.0	0.17	-0.20	50.0	15.0	1.00	47.0	-0.01	1.80
07/24/91	7.38	24.5	750.0	106.6	130.0	-2.00	100.0	68.0	0.18	-0.20	67.0	16.0	1.00	50.0	-0.01	1.50
10/22/91	6.97	24.5	700.0	119.7	146.0	-2.00	87.0	54.0	0.17	-0.01	69.0	15.0	1.10	47.0	-0.01	1.80
01/28/92	7.36	24.0	700.0	123.0	150.0	-0.20	91.0	64.0	0.18	-0.01	66.0	15.0	1.10	49.0	-0.01	1.80
04/28/92	7.09	24.0	650.0												-0.01	1.60
07/29/92	8.02	25.0	700.0												-0.01	1.70

Buckhorn Springs South (Walking Trail)

Date	Field pH	Field Temp	Field Cond	HCO3 as CaCO3	HCO3 as HCO3	CO3 as CaCO3	Cl	SO4	F	S	Ca	Mg	K	Na	(N) NH3	(N) NO3
04/26/91	7.38	24.5	700.0	120.0	146.0	-2.00	85.0	98.0	0.18	0.40	62.0	17.0	1.20	46.0	-0.01	0.54
07/24/91	7.53	25.0	700.0	98.4	120.0	-2.00	86.0	100.0	0.20	-0.20	66.0	19.0	1.20	46.0	-0.01	0.60
10/22/91	7.13	25.0	700.0	119.7	146.0	-2.00	86.0	86.0	0.18	-0.01	71.0	18.0	1.30	45.0	-0.01	2.00
01/28/92	7.54	24.5	700.0	123.0	150.0	-2.00	82.0	100.0	0.17	-0.01	67.0	18.0	1.20	46.0	-0.01	0.79
04/28/92	7.42	24.0	650.0												-0.01	0.66
07/29/92	6.82	24.5	700.0												-0.01	0.62

HILLSBOROUGH COUNTY SPRINGS

Buckhorn Main Spring

Date	(N) NO2+NO3	(N) ORG N	(P) PO4	(P) P	TDS	TOC	Fe	Mn	Zn	Cd	Cr	Cu	Pb
04/25/91	2.30	0.05	0.04	0.05	418.0	-1.0	-0.02	-0.01	-0.01	-0.005	-0.005	-0.01	-0.005
07/01/91	2.10	0.05	0.04	0.07									
07/24/91	2.20	0.06	0.05	0.05	270.0	-1.0							
08/29/91	2.50	-0.05	0.05	0.05									
09/23/91	2.30	-0.05		0.05		-1.0							
10/22/91	2.00	0.06	0.04	0.06	264.0	-1.0	-0.02						
12/02/91	1.80	0.05	0.04	0.05									
12/30/91	1.90	0.10	0.04	0.06									
01/28/92	1.90	0.06	0.04	0.11	258.0	-1.0	-0.02						
02/19/92	1.50	0.09	0.05	0.05									
03/26/92	1.90	0.05	0.04	0.04									
04/28/92	1.80	0.11	0.04	0.06									
05/26/92	1.80	0.07	0.05	0.10									
06/25/92	1.80	-0.05	0.05	0.12									
07/29/92	1.70	0.07	0.04	0.05									

Buckhorn Springs East (sandbags)

Date	(N) NO2+NO3	(N) ORG N	(P) PO4	(P) P	TDS	TOC	Fe	Mn	Zn	Cd	Cr	Cu	Pb
04/25/91	1.00	0.28	0.05	0.07	336.0	3.2	0.04	-0.01	-0.01	-0.005	-0.005	-0.01	-0.005
07/01/91	0.76	0.28	0.07	0.16				-0.01	-0.01				
07/24/91	0.90	0.06	0.03	0.04	604.0	-1.0							
09/23/91	1.30	-0.05		0.03		-1.0							
10/22/91	1.30	0.05	0.02	0.05	592.0	-1.0	-0.02						
12/02/91	1.70	-0.05	0.04	0.04									
12/30/91	1.40	0.05	0.04	0.04									
01/28/92	1.40	0.06	0.03	0.05	372.0	1.80	-0.02						
02/19/92	1.30	0.05	0.03	0.06									
03/26/92	1.30	0.07	0.03	0.05									
04/28/92	1.20	0.11	0.03	0.05									
05/26/92	1.40	0.06	0.04	0.06									
06/25/92	1.10	-0.05	0.04	0.04									
07/29/92	1.10	0.06	0.03	0.04									

Buckhorn Springs West (Tower)

Date	(N) NO2+NO3	(N) ORG N	(P) PO4	(P) P	TDS	TOC	Fe	Mn	Zn	Cd	Cr	Cu	Pb
04/25/91	1.80	0.06	0.04	0.04	418.0	-1.0	-0.02	-0.01	-0.01	-0.005	-0.005	-0.01	-0.005
07/24/91	1.50	0.08	0.04	0.05	384.0	-1.0							
10/22/91	1.80	0.05	0.03	0.06	386.0	-1.0	-0.02						
01/28/92	1.80	0.07	0.03	0.06	402.0	1.60	-0.02						
04/28/92	1.60	0.07	0.04	0.12									
07/29/92	1.70	0.06	0.04	0.04									

Buckhorn Springs South (Walking Trail)

Date	(N) NO2+NO3	(N) ORG N	(P) PO4	(P) P	TDS	TOC	Fe	Mn	Zn	Cd	Cr	Cu	Pb
04/26/91	0.54	0.05	0.01	0.03	414.0	1.1	-0.02	-0.01	-0.01	-0.005	-0.005	-0.01	-0.005
07/24/91	0.60	-0.05	0.02	0.03	410.0	-1.0							
10/22/91	2.00	-0.05	-0.01	0.04	414.0	-1.0	-0.02						
01/28/92	0.79	0.06	0.02	0.06	398.0	1.5	-0.02						
04/28/92	0.66	0.09	0.01	0.05									
07/29/92	0.62	-0.05	0.02	0.03									

HILLSBOROUGH COUNTY SPRINGS

Boyette Spring

Date	Field pH	Field Temp	Field Cond	HCO3 as CaCO3	HCO3 as HCO3	CO3 as CaCO3	Cl	SO4	F	S	Ca	Mg	K	Na	(N) NH3	(N) NO3
04/26/91	6.28	23.5	600.0	150.0	183.0	-2.00	37.0	62.0	0.27	-0.02	51.0	20.0	23.00	25.0	-0.01	10.00
07/01/91	6.59	24.0	600.0												0.01	13.00
07/24/91	6.53	25.0	600.0	123.0	150.0	-2.00	36.0	61.0	0.28	-0.20	54.0	23.0	22.00	21.0	-0.01	12.00
09/23/91	6.14	25.0	2050.0												-0.01	
10/22/91	6.52	25.0	600.0	140.2	171.0	-2.00	36.0	50.0	0.27	-0.01	55.0	20.0	24.00	19.0	0.02	11.00
12/02/91	6.53	24.0	600.0												-0.01	14.00
12/30/91	6.48	23.0	600.0												0.02	11.00
01/28/92	6.41	24.0	600.0	139.4	170.0	-2.00	36.0	57.0	0.24	-0.01	54.0	21.0	23.0	21.0	-0.01	11.00
02/19/92	6.42	24.5	600.0												-0.01	11.00
03/26/92	6.56	24.0	550.0												-0.01	12.00
04/28/92	6.38	23.0	550.0												-0.01	11.00
05/26/92	6.49	24.5	550.0												-0.01	12.00
06/25/92	6.40	24.5	600.0												-0.01	13.00
07/29/92	6.45	24.0	600.0												-0.01	12.00

Green Sink

Date	Field pH	Field Temp	Field Cond	HCO3 as CaCO3	HCO3 as HCO3	CO3 as CaCO3	Cl	SO4	F	S	Ca	Mg	K	Na	(N) NH3	(N) NO3
04/28/92	6.87	22.0	390.0		170.0	-2.00	32.0	30.0	0.29	-0.01	47.0	23.0	0.69	15.0	0.02	2.00

Lithia Main

Date	Field pH	Field Temp	Field Cond	HCO3 as CaCO3	HCO3 as HCO3	CO3 as CaCO3	Cl	SO4	F	S	Ca	Mg	K	Na	(N) NH3	(N) NO3
04/25/91	7.36	24.5	410.0	110.0	134.0	-2.09	22.0	71.0	0.23	-0.20	59.0	8.9	0.67	12.0	-0.01	3.00
07/01/91	6.95	24.5	500.0												-0.01	3.10
07/24/91	7.80	25.0	500.0	90.2	110.0	-2.00	25.0	85.0	0.26	-0.20	63.0	12.0	0.75	13.0	-0.01	2.00
09/23/91	7.19	25.0	410.0												-0.01	
10/22/91	7.28	25.0	470.0	109.9	134.0	-2.00	27.0	73.0	0.26	-0.01	67.0	10.0	0.80	14.0	-0.01	3.80
12/02/91	7.55	25.0	450.0												-0.01	3.00
12/30/91	7.55	24.5	410.0												-0.01	3.10
01/28/92	7.47	24.5	445.0	106.6	130.0	-2.00	23.0	57.0	0.20	-0.01	63.0	9.5	0.7	13.0	-0.01	3.40
02/19/92	7.52	25.0	500.0												-0.01	3.30
03/26/92	7.55	26.0	435.0												-0.01	3.10
04/28/92	7.43	24.0	400.0												0.03	2.80
05/26/92	7.45	26.0	430.0												-0.01	3.10
06/25/92	7.31	24.5	420.0												-0.01	2.70
07/29/92	7.61	25.0	430.0												-0.01	2.70

Lithia Minor

Date	Field pH	Field Temp	Field Cond	HCO3 as CaCO3	HCO3 as HCO3	CO3 as CaCO3	Cl	SO4	F	S	Ca	Mg	K	Na	(N) NH3	(N) NO3
04/25/91	7.49	24.0	450.0	110.0	134.0	-2.00	23.0	74.0	0.23	-0.20	58.0	9.1	0.66	12.0	-0.01	2.90
07/24/91	7.39	25.0	500.0	90.2	110.0	-2.00	25.0	82.0	0.28	-0.20	64.0	12.0	0.73	13.0	-0.01	2.00
10/22/91	7.19	25.0	500.0	100.0	122.0	-2.00	27.0	77.0	0.26	-0.01	67.0	11.0	0.70	13.0	0.01	3.40
01/28/92	7.46	24.5	460.0	106.6	130.0	-2.00	24.0	56.0	0.21	-0.01	61.0	9.2	0.70	13.0	-0.01	3.10
04/28/92	7.40	24.0	400.0												-0.01	2.80
07/29/92	7.49	24.0	410.0												-0.01	2.60

HILLSBOROUGH COUNTY SPRINGS

Boyette Spring

Date	(N) NO2+NO3	(N) ORG N	(P) PO4	(P) P	TDS	TOC	Fe	Mn	Zn	Cd	Cr	Cu	Pb
04/26/91	10.00	0.23	0.09	0.09	364.0	5.2	-0.02	0.02	-0.01	0.008	-0.005	-0.01	-0.005
07/01/91	13.00	0.24	0.11	0.14									
07/24/91	12.00	0.24	0.13	0.23	364.0	2.8							
09/23/91	11.00	0.22		0.16		2.0							
10/22/91	11.00	0.24	0.13	0.15	348.0	1.7	-0.02						
12/02/91	14.00	0.25	0.12	0.12									
12/30/91	11.00	0.21	0.11	0.11									
01/28/92	11.00	0.22	0.12	0.42	360.0	4.4	-0.02						
02/19/92	11.00	0.30	0.11	0.20									
03/26/92	12.00	0.27	0.11	0.14									
04/28/92	11.00	0.27	0.10	0.12									
05/26/92	12.00	0.26	0.11	0.16									
06/25/92	13.00	0.14	0.10	0.66									
07/29/92	12.00	0.24	0.10	0.17									

Green Sink

Date	(N) NO2+NO3	(N) ORG N	(P) PO4	(P) P	TDS	TOC	Fe	Mn	Zn	Cd	Cr	Cu	Pb
04/28/92	2.00	0.10	0.28	0.32	266.0	1.0	-0.02						

Lithia Main

Date	(N) NO2+NO3	(N) ORG N	(P) PO4	(P) P	TDS	TOC	Fe	Mn	Zn	Cd	Cr	Cu	Pb
04/25/91	3.00	0.07	0.05	0.06	270.0	1.6	-0.02	-0.01	-0.01	-0.005	-0.005	-0.01	-0.005
07/01/91	3.10	0.06	0.05	0.07									
07/24/91	2.90	0.08	0.07	0.08	290.0	-1.0							
09/23/91	3.10	0.07		0.07		-1.0							
10/22/91	3.80	-0.05	0.05	0.07	298.0	-1.0	-0.02						
12/02/91	3.00	-0.05	0.06	0.06									
12/30/91	3.10	0.08	0.05	0.07									
01/28/92	3.40	0.06	0.05	0.21	256.0	1.1							
02/19/92	3.30	0.09	0.06	0.15									
03/26/92	3.10	0.08	0.05	0.08									
04/28/92	2.80	0.07	0.05	0.05									
05/26/92	3.10	0.06	0.07	0.07									
06/25/92	2.70	0.17	0.07	0.07									
07/29/92	2.70	-0.05	0.05	0.06									

Lithia Minor

Date	(N) NO2+NO3	(N) ORG N	(P) PO4	(P) P	TDS	TOC	Fe	Mn	Zn	Cd	Cr	Cu	Pb
04/25/91	2.90	0.07	0.05	0.06	276.0	-1.0	0.02	0.02	-0.01	-0.005	-0.005	-0.01	-0.005
07/24/91	2.00	0.07	0.07	0.10	280.0	-1.0							
10/22/91	3.40	-0.05	0.05	0.08	284.0	-1.0	-0.02						
01/28/92	3.10	0.08	0.06	0.18	250.0	1.7	-0.02						
04/28/92	2.80	0.08	0.05	0.05									
07/29/92	2.60	0.06	0.06	0.07									

APPENDIX III (Continued)

Environmental Isotopic Data for Sampled Wells

Lithia/Buckhorn Springs Project

Uranium Isotope Data

Well Name	AQWQMP ID	U234/U238 Activity Ratio	Uranium Concentration (ug/l)	NO2+NO3 Concentration as N (mg/l)	UK Factor	NK Factor
Davis	057DI023	1.3	0.1	4.2		N
Hover	057PF161	1.1	0.0	0.4		
Sapp	057PF167	0.9	0.1	0.0		
Sheffield	057PF177	0.5	4.1	0.8	U	
Campo	057PF179	1.0	0.1	0.0		
Jones	057PF180	1.1	0.0	2.4		N
Sydney Church	057PF187	0.6	0.4	0.0	U	
Albritten	057PF193	1.9	1.0	0.3		
Ernest	057PF195	1.2	0.2	0.0	U	
1st Baptist Chr	057PF197	0.8	10.0	1.9	U	N
Pardo	057PF199	1.4	0.0	0.0		
Cremeans	057PF205	1.1	0.1	13.0	U	N
Desrouchers	057PF209	1.1	0.1	2.9	U	N
Howell	057PF211	0.7	7.0	21.0	U	N
Carter	057PF212	1.5	0.1	0.0		
Bunch	057PF213	1.1	0.7	2.2	U	N
Hernandez	057PF214	1.1	0.0	0.0		
Crellin	057PF216	0.9	2.7	0.0	U	
Walter	057PF217	1.5	0.1	0.0		
Engle	057PF220	0.8	4.8	4.0	U	N
Brandewie	057PF225	0.7	0.6	3.8	U	N
Rector	057PF227	1.3	0.0	0.0		
Gleason	057PF228	0.9	0.2	0.0	U	
Cooper	057PF229	0.6	0.9	3.8	U	N
Hills Cnty Util	057PF231	0.6	3.3	0.1	U	
WCRWSA 1i	057PF232	1.9	0.1	0.0		
WCRWSA 7i	057PF233	1.1	3.0	0.0	U	
WCRWSA 6i	057PF234	1.4	0.1	0.0		
Buckhorn Main	SP-001	0.8	0.5	2.2	U	N
Buckhorn East	SP-002	1.2	0.5	1.8	U	N
Boyette	SP-005	1.1	1.4	12.0	U	N
Lithia Main	SP-007	0.7	1.0	7.0	U	N

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

Tritium Data

Well Name	AGWQMP ID	Tritium Activity (PCI/Liter)
Ward	057PF210	1.5 +-0.2 E01
Howell	057PF211	1.6 +-0.3 E01
Cremeans	057PF205	1.0 +-0.2 E01
Thayer	057DI026	1.1 +-0.2 E01
Calloway	057PF207	2.1 +-0.3 E01
Meadows	057PF190	1.6 +-0.2 E01
Simmons Park	057PF188	2.1 +-0.4 E01
Boyette	SP-003	1.4 +-0.3 E01
Lithia Main	SP-002	1.3 +-0.3 E01
Buckhorn Main	SP-001	1.4 +-0.4 E01

Nitorgen Isotope Data

Well Name	AGWQMP ID	NO2+NO3 Concentration as N (mg/l)	N15/N14 Ratio (0/00)
Lithia Main	SP-008	2.7	+6.3
Buckhorn Main	SP-001	1.7	+6.0
Boyette	SP-005	9.4	+18.1
Jones	057PF180	0.7	+4.8
Wheeler	057PF181	3.7	+3.5
Harris	057PF163	4.8	+3.5
Howell	057PF211	18.3	+15.7
Bunch	057PF213	1.5	+9.6
Cremeans	057PF205	3.8	+3.2
Meadows	057PF190	5.6	+6.5
Desrochers	057PF209	1.6	+3.8

APPENDIX IV

Surface-Water Sampling Results

APPENDIX IV

Surface-Water Sampling Results - Buckhorn and Bell Creeks

Buckhorn Creek Above Spring

Date	(N) NH3	(N) NO3	(N) NO2+NO3	(N) ORG N	(P) PO4	(P) P	(N) TKN	Turbidity
8/16/91	0.01	0.3	0.3	0.3	0.2	0.2	0.4	2.8
8/21/91	0.01	0.3	0.3	0.5	0.2	0.3	0.6	6.8

Bell Creek at Boyette Road

Date	(N) NH3	(N) NO3	(N) NO2+NO3	(N) ORG N	(P) PO4	(P) P
5/4/92	0.07	0.33	0.33	0.77	0.36	0.36

Bell Creek at Lake Grady

Date	(N) NH3	(N) NO3	(N) NO2+NO3	(N) ORG N	(P) PO4	(P) P
5/4/92	0.11	0.02	0.02	0.66	0.27	0.30

Buckhorn Creek at Bloomingdale

Date	(N) NH3	(N) NO3	(N) NO2+NO3	(N) ORG N	(P) PO4	(P) P
5/19/92	0.02	0.05	0.05	0.46	0.05	0.09

Buckhorn Creek at John Moore Rd.

Date	(N) NH3	(N) NO3	(N) NO2+NO3	(N) ORG N	(P) PO4	(P) P
5/19/92	-0.01	-0.01	-0.01	0.51	0.03	0.08

Buckhorn Creek at Campsite

Date	(N) NH3	(N) NO3	(N) NO2+NO3	(N) ORG N	(P) PO4	(P) P
5/19/92	-0.01	1.90	1.90	0.12	0.04	0.06

APPENDIX IV

Surface-Water Sampling Results - Alafia River

STATION #	DATE	TEMP	Sp COND	DO (mg/l)	pH	TDS (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Na (mg/l)	Alk HCO3 as CaCO3 (mg/l)	Cl (mg/l)	SO4 (mg/l)	NH3-N (mg/l)	NO3+NO2 (mg/l)	Ortho P (mg/l)	Total P (mg/l)
Alafia #1	10/22/86	22.0	379	6.60	7.15	238.5	40.8	10.0	4.7	17.35	80.0	21.0	58.7	0.01	1.84	1.611	2.555
Alafia #2	10/22/86	20.0	325	7.85	6.80	240.0	34.4	10.0	6.8	21.6	69.0	22.0	62.5	0.02	1.22	2.810	3.680
Alafia #3	10/22/86	21.5	448	8.60	6.65	262.0	33.3	12.0	5.8	25.0	61.0	24.0	70.0	0.02	1.34	4.030	4.595
Alafia #4	10/22/86	21.0	471	6.85	6.75	323.0	39.0	12.0	7.3	36.6	73.0	28.0	106.4	0.33	1.65	5.805	-----
Alafia #5	10/22/86	21.0	301	9.40	6.45	188.0	26.3	12.0	4.2	10.9	53.0	17.0	46.7	0.02	1.20	0.877	1.350