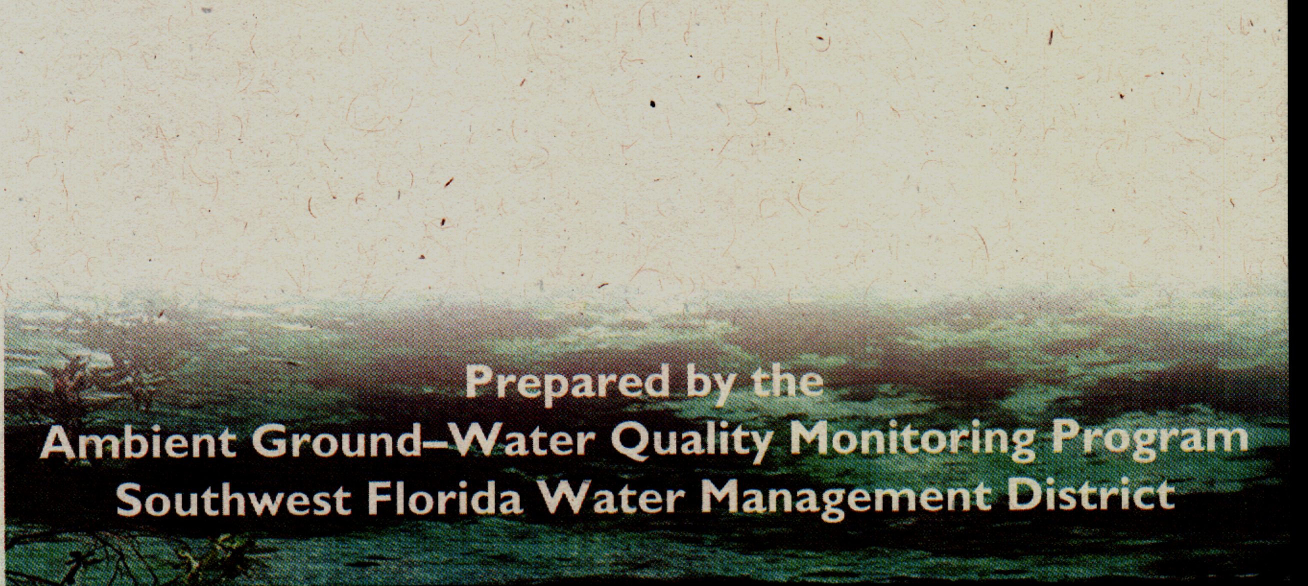
Origin of Nitrate in Ground Water Discharging from Rainbow Springs

Marion 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 Nitrate in Ground-Water Discharging from Rainbow Springs" were prepared by or under the supervision of a Licensed Professional Geologist in the State of Florida.

Gregg W. Jones 6/4/96

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ORIGIN OF NITRATE IN GROUND WATER DISCHARGING FROM RAINBOW SPRINGS, MARION COUNTY, FLORIDA

Ambient Ground-Water
Quality Monitoring Program,

Southwest Florida Water Management District

June, 1996
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EXECUTIVE SUMMARY

1. Between 1965 and 1993, the numerous springs and seeps of the Rainbow Springs Complex discharged ground water at an average rate of approximately 450 mgd.

2. Approximately 684 tons of nitrate as N are discharged each year in ground water emanating from the Rainbow Springs Complex.

3. The concentration of nitrate-nitrogen in ground water discharging from the largest springs in the Rainbow Complex is approximately 1.0 mg/l. This is elevated considerably over the concentration of nitrate in ground water in undeveloped portions of the study area (<0.1 mg/l).

4. Historic nitrate concentration data from springs in the Rainbow Complex is very limited. However, the quantity of data is sufficient to indicate that a 20-fold increase in nitrate concentrations during the past 40 years in the largest springs is not unreasonable.

5. Water discharging from the springs originates in the Rainbow Springs Ground-Water Basin. The basin ranges in size from approximately 645 square miles at the end of the dry season in May to approximately 770 square miles at the end of the wet season in September. The basin extends from near Gainesville at its northern extremity, to Ocala on the eastern side, to east-central Levy County on the western side, to Dunnellon on the southern side.

6. Fifty two percent of the Rainbow River discharge measured at the County Road 484 bridge near Dunnellon, discharges from the head spring area; the first 1500 feet of the Rainbow River. Eighty nine percent of the discharge enters the river in the first 1.5 miles.

7. Sixty six wells were sampled for nitrate in or near the Rainbow Springs Ground-Water Basin. Six percent had concentrations between 3.0 and 5.2 mg/l, 23 percent had concentrations between 1.0 and 3.0 mg/l, 24 percent had concentrations between 0.5 and 1.0 mg/l, 30 percent had concentrations between 0.1 and 0.5 mg/l, 3 percent had concentrations between 0.01 and 0.1 mg/l, and 14 percent had concentrations below the detection limit (0.01 mg/l). These figures indicate that the portion of the study area where nitrate is significantly elevated above naturally occurring levels (<0.1 mg/l) is extensive.

EXECUTIVE SUMMARY (continued)

8. The chemistry of water discharging from the springs in the Rainbow Complex indicates that the water has moved through a short, shallow flow system. That is, the water has probably not been in the aquifer for more than a few decades.

9. Much of the water discharging from the springs may have traveled rapidly through two major fractures in limestone of the Floridan aquifer. The fractures are conduits for the transport of large amounts of ground water to the springs. One fracture trends northwest from the springs along the Marion/Levy County line and the other trends northeast from the springs toward Ocala.

10. Two areas were identified in the study area where nitrate concentrations are uniformly high; these are northwest of the springs, just south of the Levy County line, and northeast of the springs, several miles west of Ocala.

11. The two major fracture systems discussed above pass through the areas of high nitrate.

12. Nitrogen isotopic data suggest that the main source of nitrate in the study area is inorganic fertilizer.

13. Ten anthropogenic sources of nitrate were identified in the study area. The amount of nitrogen each source contributes to the study area in tons/yr was estimated. The 3 highest sources were pasture fertilization (3,963 tons/yr), horses (1,501 tons/yr), and cattle (1,256 tons per yr).

14. Pasture fertilization was identified as the principal source of nitrate in the springs of the Rainbow Complex. Supporting data include: 1) identification of inorganic fertilizers as the source of nitrate in the study area using nitrogen isotopes, 2) nitrogen loading calculations showing that pasture fertilization contributes the largest amount of nitrogen to the study area, and 3) the highest nitrate concentrations in the Floridan aquifer in the study area coincide with pasture lands.

15. The development-related nitrogen sources, such as septic tanks, sewage, and residential turf and golf course fertilizers, are currently only minor contributors of nitrogen to the study area. However, the contributions of these sources will greatly increase as the density of these sources increases.

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

EXECUTIVE SUMMARY (continued)

17. An investigation of the application of inorganic nitrogen fertilizers in the Rainbow Spring Ground-Water Basin should be initiated in the near future. The study should focus on identifying the specific areas of application, the amount applied, and the amount of nitrogen reaching ground water following application. The study should also attempt to reduce the affect of fertilizers on ground-water quality by developing best management practices.

18. Best management practices should also be developed for preventing waste from horses and cattle in the study area from reaching ground water.

19. Sources, such as residential and golf course turf fertilization, septic tank effluent, and sewage effluent disposal, are regionally insignificant at present. However, their importance will greatly increase as rapid residential and commercial development proceeds in the study area. It is therefore, extremely important that waste disposal practices that are compatible with the region's karst geology and its accompanying extreme vulnerability to ground-water contamination be implemented prior to the onset of the extensive development projected for the near future. These practices include:

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

20. The springs should be sampled annually for nutrients, major analytes, trace organics and nitrogen-isotopic ratios to determine the effects of changing land use and to determine the effectiveness of remedial efforts, such as the implementation of best management practices for agricultural fertilizers.

21. The District should work with Marion County and other interested agencies to formulate land-use plans that would prevent additional nitrogen loadings to the study area.

22. A detailed map of the upper head spring area containing surveyed locations of all the spring vents and detailed drawings of the spring bottom should be prepared in the near future. This would insure the integrity of long-term data collection by making it easier for future samplers to determine the locations of historic sampling points.

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INTRODUCTION

Rainbow Springs, a first magnitude complex of springs located in southwestern Marion County (Figure 1), rises in wooded, rolling uplands to form the headwaters of the Rainbow River, alternatively referred to as Blue Run. The river flows south from the springs for 5.9 miles where it meets the Withlacoochee River near the town of Dunnellon.

To protect the Rainbow River's near-pristine water quality and the unique riverine ecosystem, the Florida Department of Environmental Protection (FDEP) has designated the river an Outstanding Florida Water (OFW). In addition, the Surface Water Improvement and Management (SWIM) program at the Southwest Florida Water Management District (SWFWMD) has designated the river its number two priority water body.

In spite of the high level of protection now afforded the river, there are indications that the quality of water in the river is declining. High levels of coliform bacteria have been detected and nuisance levels of *Lyngbya*, a filamentous blue green algae and *Hydrilla*, a macrophyte, occur in the lower portions of the river (Water and Air Resources, 1991). The recent increased growth of *Lyngbya* and *Hydrilla* may be related to an increase in the concentration of nitrate in ground-water discharging from the springs.

Figure 2 shows the location of the 18 springs in the Rainbow Complex that were selected for water quality and flow testing. Figure 3 shows historical nitrate concentrations at two of these springs in the upper head-spring area. Bridge Seep North, one of the smaller, less significant springs in terms of discharge in the Rainbow Complex, is the only spring that has a good historical record.[1] Although a regression analysis of the data indicates a statistically significant trend that has increased 5 fold over 38 years, the authors believe the actual increase could be much higher .

Rainbow Spring #4, much larger than Bridge Seep North in terms of discharge, has a nitrate concentration of approximately 1.0 mg/l. This concentration is typical of the larger springs in the Rainbow Complex which supply the vast majority of water to the Rainbow River. Because the sampling period of record for this spring is short, it is not possible to determine whether nitrate concentrations at this spring increased at the same rate as those in Bridge Seep North.[2] However, if, as the authors suspect, nitrate concentrations in the main springs have increased from the low 1950s level of Bridge Seep North to their current level of 1.0 mg/l, then the increase in the main springs has been in excess of 20-fold .

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[1] There is some ambiguity as to the exact location of the U.S. Geological Survey (USGS) sampling sites in the upper head spring area. After considerable research, the authors are reasonably certain that the USGS samples, collected from 1956-1987, were collected in the vicinity of the spring the Southwest Florida Water Management District has designated Bridge Seep North.

[2] The USGS moved their sampling location in the upper head spring area from the vicinity of Bridge Seep North to the vicinity of Rainbow Spring #4 in 1987 (personal communication, USGS, Altamonte Springs, Florida).

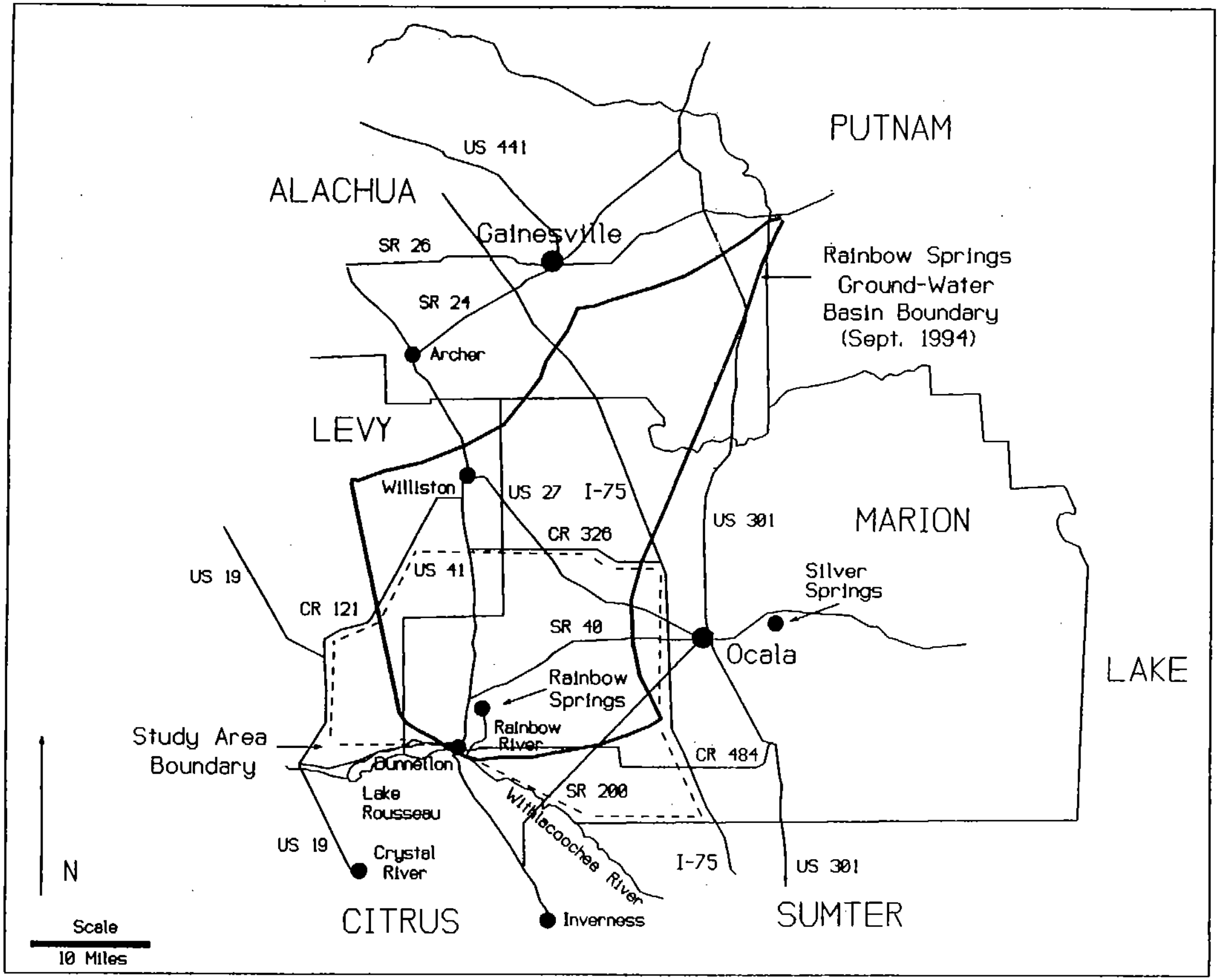


Figure 1. Location of Rainbow Springs, the Rainbow Springs Study Area, and the Rainbow Springs Ground-Water Basin.

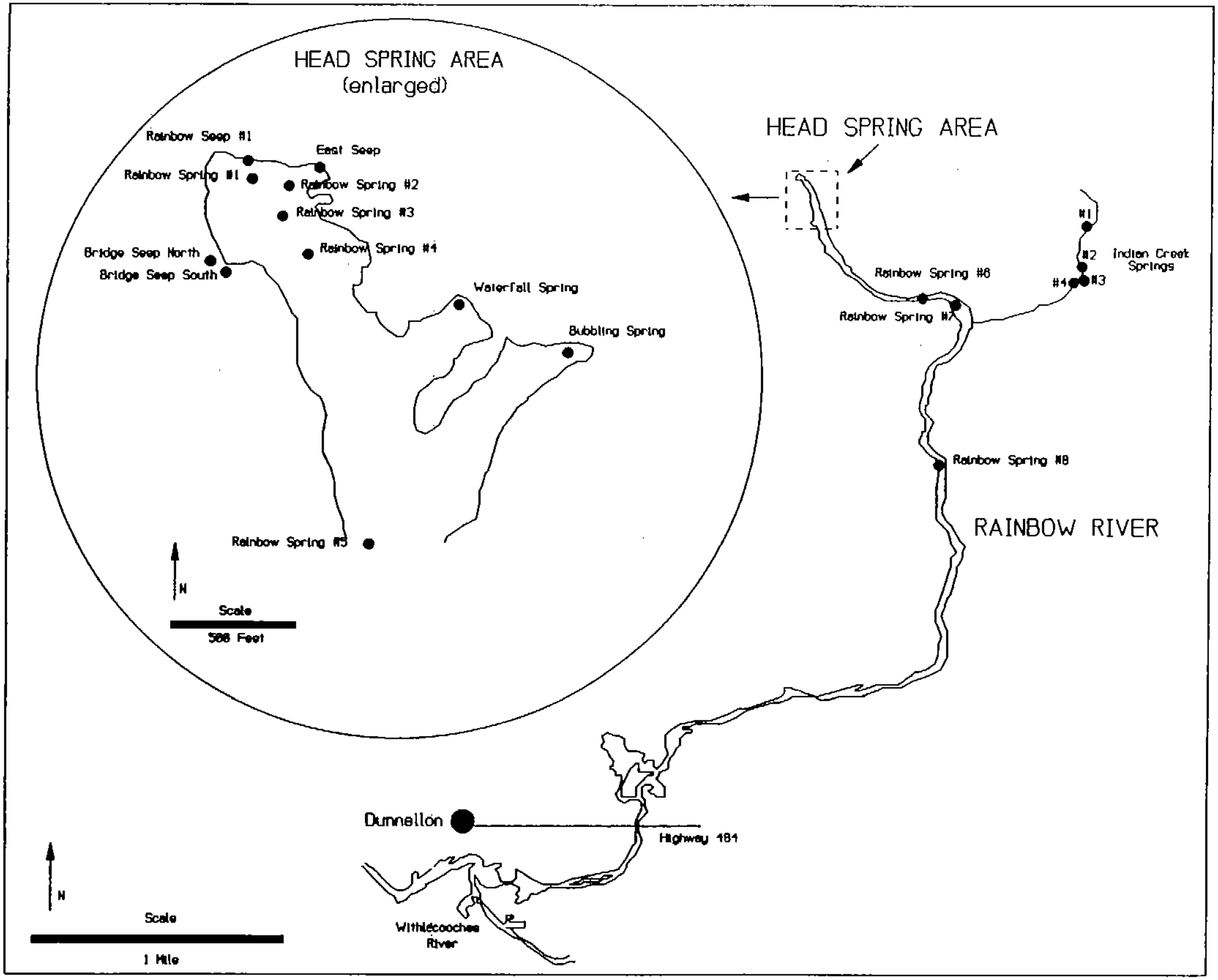
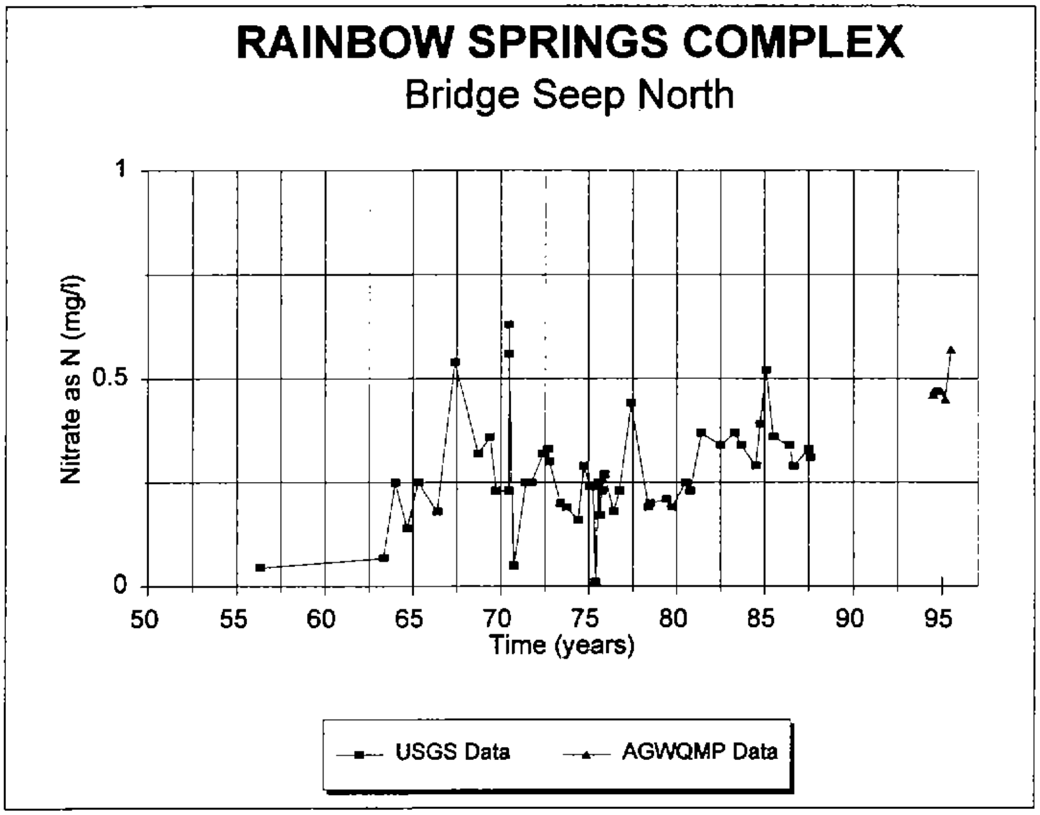


Figure 2. Location of the 18 Springs Selected for Water-Quality Sampling and Flow Testing.



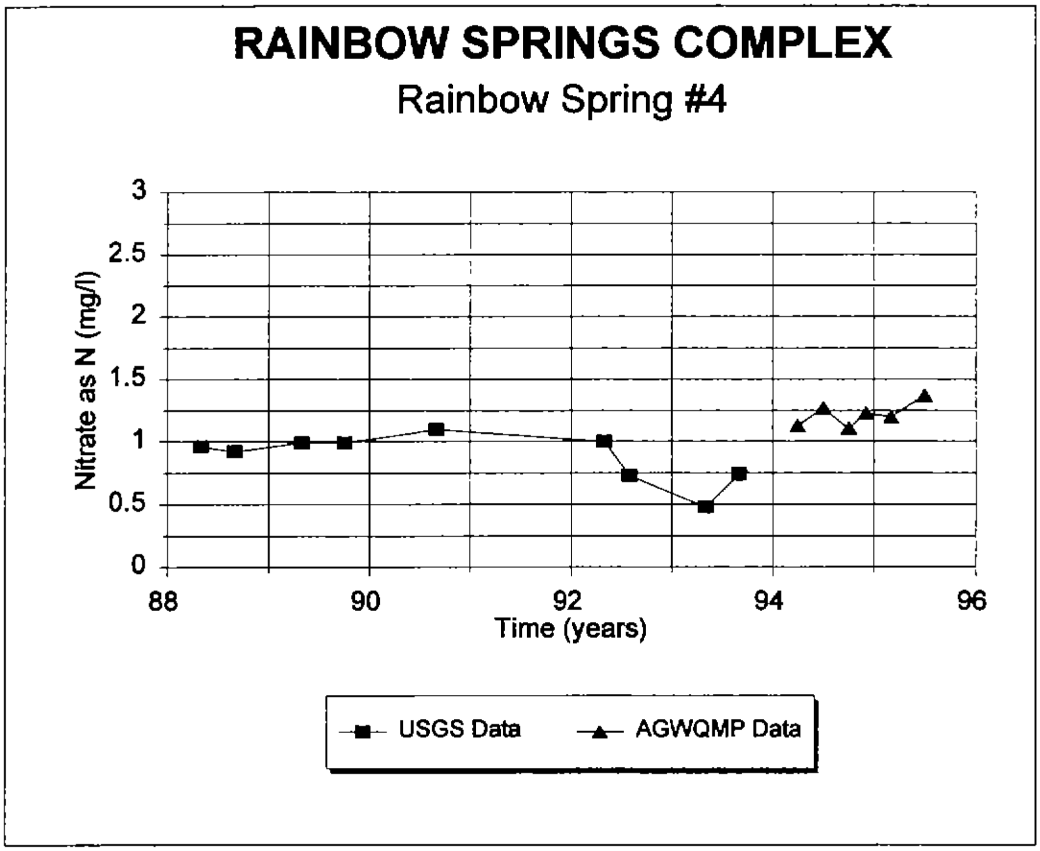


Figure 3. Historical Nitrate Concentrations from Bridge Seep North and Rainbow Spring #4.

Based on the average flow rate between 1965 and 1993 of 697 cfs (450 mgd), a concentration of 1 mg/l discharging from the main springs results in approximately 684 tons of nitrate contributed to the Rainbow River annually. This quantity of nitrate may significantly promote the increased growth of nuisance aquatic vegetation in the river.

Nitrate concentrations in ground water in undeveloped areas of Marion and Levy Counties have been compared with nitrate concentrations in ground water discharging from the springs. These data clearly indicate that the spring-water concentrations exceed natural background ground-water concentrations. Since enrichment of nitrate to the level that occurs in the spring water is not a result of natural processes, human induced contamination of the ground water must be occurring somewhere within the recharge area of the springs.

With the goal of preventing further deterioration of the water quality of the Rainbow River, the SWIM Program at the SWFWMD authorized an investigation to determine the sources of the increasing nitrate. The investigation, which began in August of 1993 and lasted 20 months, was carried out by the Ambient Ground-Water Quality Monitoring Program (AGWQMP), also of the SWFWMD. The scope of the investigation involved delineating the areas where nitrate is entering the aquifer system, identifying the land uses that are contributing the nitrate, and determining what can be done to slow or reverse the nitrification of ground water in the area.

DESCRIPTION OF THE STUDY AREA

Introduction

The Rainbow Springs study area encompasses all of southwestern Marion County west of I-75 and south of C.R. 326, and a small portion of southeastern Levy County east of U.S. 19 and C.R. 121, and south of C.R. 326 (Figure 1). The southern boundary of the study area includes the Withlacoochee River, and the Marion-Sumter County line. This 500 sq. mile region includes much of the Rainbow Springs Ground-Water Basin and a small portion of the Silver Springs Ground-Water Basin. The following sections discuss the geographic setting, topography, and drainage; the geology and hydrogeology; and karst topography and recharge.

Geographic Setting, Topography, and Drainage

The Rainbow Springs study area contains two small centers of population: Morriston and Dunnellon. The study area also abuts the City of Ocala which is a rapidly urbanizing area. Western Marion County lies in an area of gently rolling hills and karst plains. Land surface elevations range from 50 feet above NGVD near Dunnellon, to greater than 200 feet in the Fairfield Hills area northwest of Ocala (SWFWMD, 1987). White (1970) separated Marion County into eleven physiographic provinces, eight of which lie within the study area. These provinces include the Fairfield and Martel Hills, the Brooksville and Cotton Plant Ridges, the Western Valley, the Sumter Upland, the Tsala Apopka-Plain, and the Dunnellon Gap (Figure 4).

West of Ocala the topography is dominated by gently rolling hills, ranging in elevation from 100 to 215 feet above NGVD. These highland divisions include the Fairfield and Martel Hills, and the Brooksville and Cotton Plant Ridges. Surrounding the highlands are comparatively low, broad, nearly flat to gently rolling terrains, which include the Western Valley and Sumter Uplands (SWFWMD, 1987). West of Dunnellon and the Brooksville Ridge, the Coastal Lowlands slope gently to the west toward the Coastal Swamps of Levy County.

Levy County lies in an area of flat coastal swamps, karst plains, and gently rolling highlands. Land surface elevations range from sea level along the coast to over 125 feet NGVD in the Brooksville Ridge area. White (1970) separated Levy County into four physiographic provinces, two of which lie within the study area. These provinces include the Gulf Coastal Lowlands and the Brooksville Ridge.

The only major surface drainage features in the study area are the Withlacoochee and Rainbow Rivers. About 25 percent of the rainfall in Marion County contributes to surface drainage which supplies the rivers, lakes, and ponds in the county (Rohrer, 1984). The

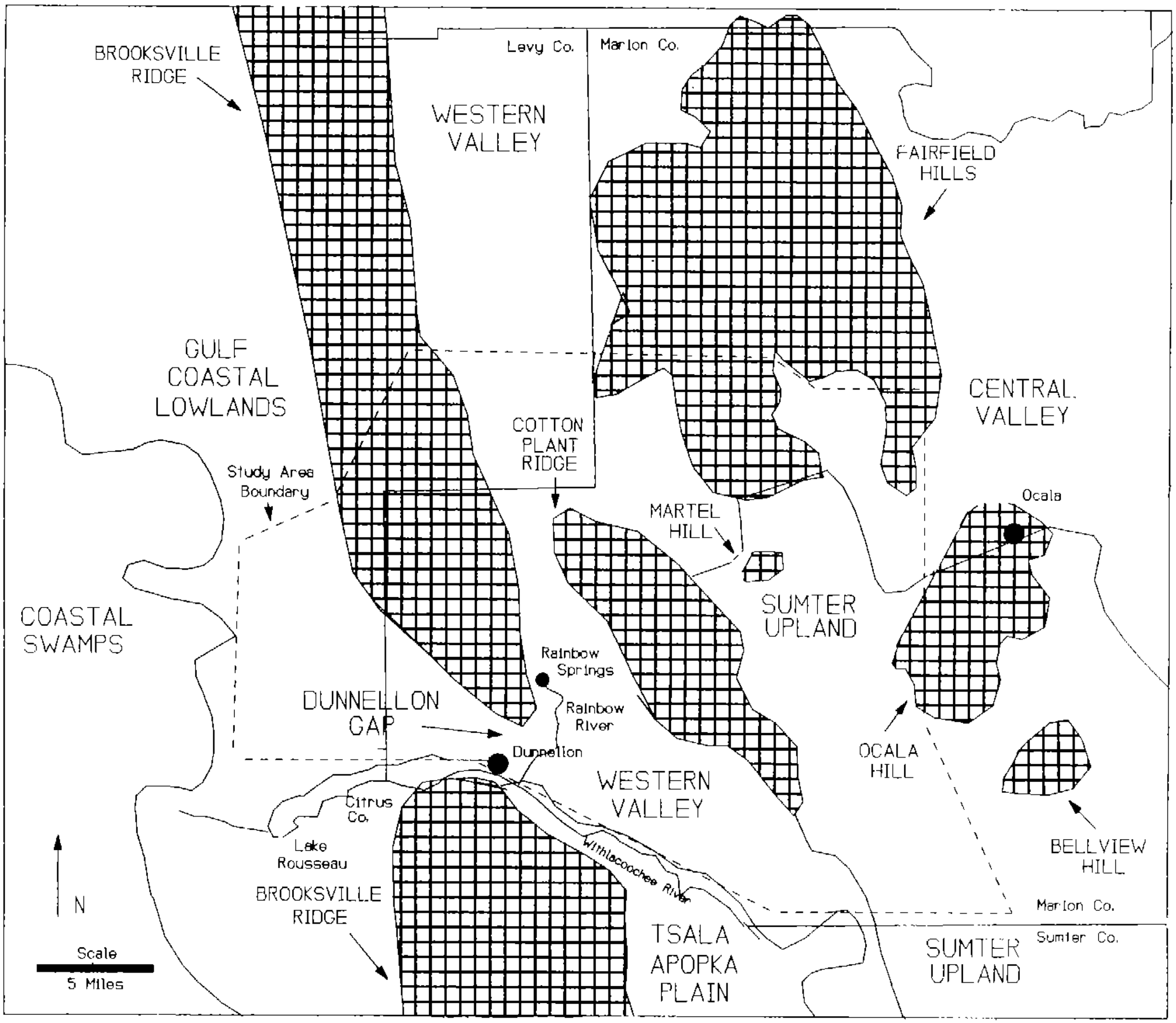


Figure 4. Physiographic Provinces in or Near the Study Area (modified from Puri and Vernon, 1964).

remainder, excluding evapotranspiration, drains internally into the Floridan aquifer or becomes temporarily perched over thin, discontinuous clay layers. Much of the water percolated into the Floridan aquifer in western Marion County reappears as surface flow at Rainbow Springs.

The Withlacoochee River flows along the southwestern boundary of Marion County having traveled from its headwaters in the Green Swamp southeast of the county. East of Inglis, the Withlacoochee River has been dammed, and Lake Rousseau, a relatively small lake, occupies much of the reach of the river between Citrus and Levy Counties. Prior to entering the lake, the Withlacoochee River receives discharge from Rainbow Springs by way of the Rainbow River at Dunnellon.

Land Use

Land use in the study area was determined from detailed analysis of aerial photography obtained in 1989-90 (Figure 5).

Although the eastern third of the study area is dominated by cropland, pasture, forest, and horse farms, it is rapidly losing its rural character. This is because a great deal of development in the form of retirement communities with associated commercial areas (stores, businesses, restaurants, etc) is occurring along the major highways leading to Ocala. At least 6 golf courses are present in this area, and numerous others are planned.

The center third of the study area is also dominated by cropland, pasture, forest, and horse farms, but it contains considerably less residential and commercial development. In the center of this area, at least 12 square miles have been sub-divided into dense networks of streets and platted lots. However, very few homes have been built in these areas.

The western third of the study area is the most rural in character, although significant residential and commercial development is occurring in the vicinity of Dunnellon. Similar to the eastern portions of the study area, the western portion is dominated by cropland, pasture, and forest. However, very few horse farms are present. Approximately 20 square miles of this area have been sub-divided into dense networks of streets and platted lots and, although there are very few existing homes, the potential density of residential development is high.

The far western portion of this area, mainly in Levy County, is almost completely covered by forest and is very sparsely populated. In the Dunnellon/Rainbow River/ Rainbow Springs portion of this area, the eastern flank of the Brooksville Ridge was mined in many places for phosphate rock. These small mines, which were worked from the late 1800s to the 1960s, are now abandoned and few have been reclaimed.

Marion and Levy Counties Land Use/Land Cover

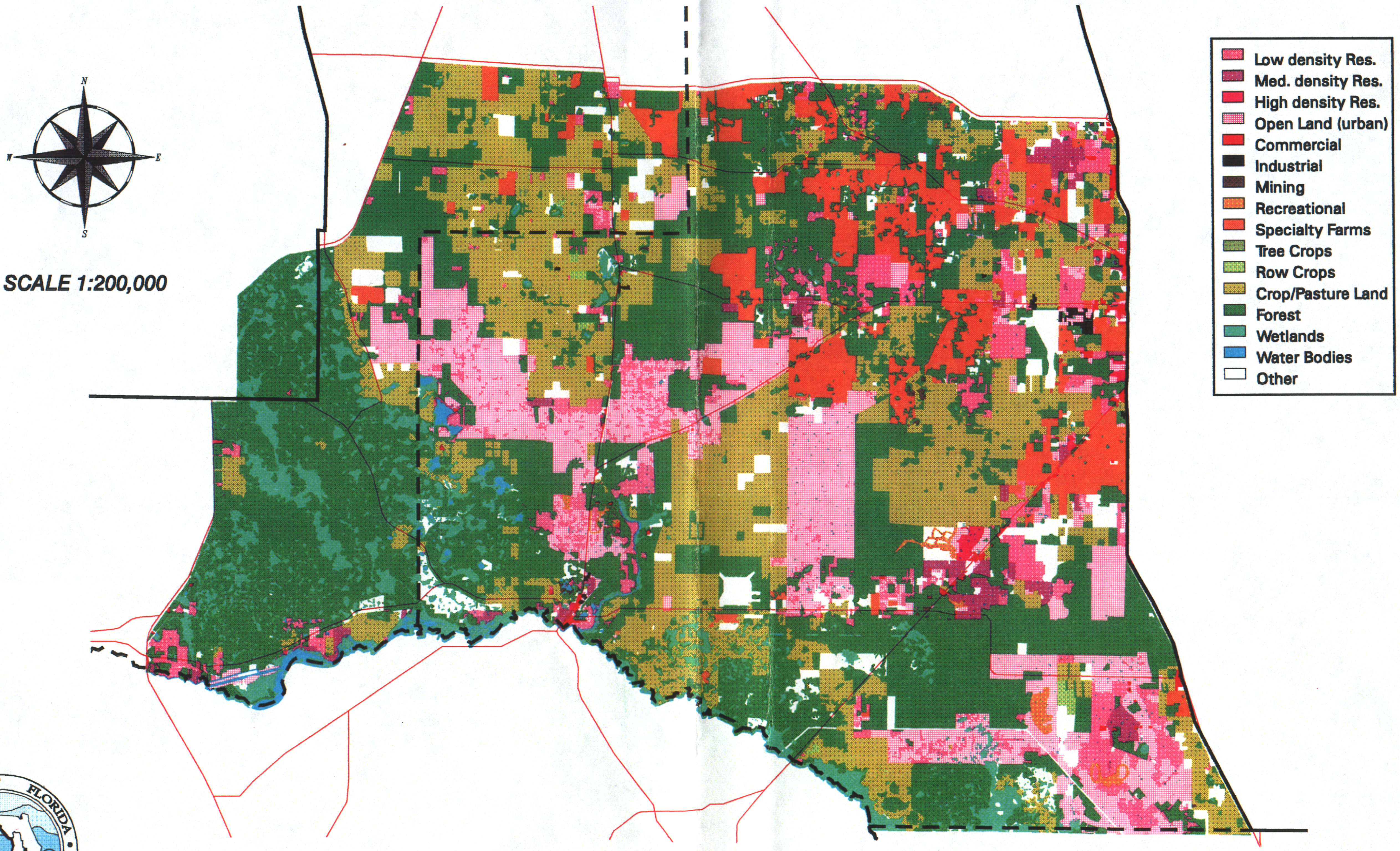


Figure 5. Land Use in the Rainbow Springs Study Area (1990).

Geology

Most of the following discussion of the geology, structure, geomorphology, groundwater hydrology, and karst of the study area was paraphrased from Faulkner (1970). Updated information from more recent work has been incorporated. Stratigraphic and hydrostratigraphic units in the study area are listed and described in Table 1.

Stratigraphy

Approximately 2,000 to 2,500 feet of early to middle Tertiary marine carbonates (limestones, dolostones, and some evaporites) are overlain by a much thinner section of late Tertiary and Quaternary marine, transitional, and terrestrial deposits which are predominantly siliciclastic in nature. The Tertiary and Quaternary-age sediments were deposited over a thick sequence of Cretaceous-age carbonates.

The oldest stratigraphic unit pertinent to this investigation is the Avon Park Formation of middle Eocene age. The Avon Park is present at or near the land surface on the crest of the Ocala Platform in southwestern Marion County and southeastern Levy County (Figure 6). The Avon Park in the study area consists of 200 to 400 feet of brown, finely fragmental, highly fossiliferous limestone and dolostone with low to high porosity. Gypsum is present in small amounts. The Avon Park is separated from the overlying Ocala Limestone by an erosional unconformity (Vernon, 1951).

The Ocala Limestone of late Eocene age overlies the Avon Park Formation of middle Eocene age throughout the study area, except where the Avon Park occurs at or near the land surface (Figure 6). There is evidence that the Ocala may also be missing beneath the Brooksville Ridge directly to the east of the Avon Park outcrop area. The absence of the Ocala in these places is probably due to removal from the crest of the Ocala Platform by erosion. Where the Ocala Limestone is present, it is generally at or near land surface. The lower portion of the Ocala in the study area consists of granular, highly fossiliferous to coquinal, tan and brown limestone. The lowermost portion of this segment frequently consists of gray and brown dolostone. The upper portion of the Ocala consists of soft, granular, very fossiliferous, cream to white limestone. In places, both the upper and lower portions are coquinas consisting almost entirely of the tests of foraminifers. In places the Ocala is cherty. Chert is usually found near the top of the section but cherty zones may occur at any depth in the unit. Differential erosion of the limestone surface has caused the formation of pinnacles and a wide variation in the altitude of the limestone surface. The presence of limestone at or near land surface has resulted in a mature karst terrain, including rolling hills, numerous sinkhole depressions, and lack of surface drainage (Phelps, 1994).

Table 1. Stratigraphic and Hydrostratigraphic Units in the Study Area (Sacks, 1996).

System	Series	Stratigraphic Unit	General Lithology	Hydrogeologic Unit	
Quaternary	Holocene and Pleistocene	Alluvium and terrace deposits	Sands and clays	Surficial aquifer system	
Tertiary	Pliocene	Alachua Formation	Phosphatic sands and clays	(Of limited areal extent in study area)	
	Miocene	Hawthorn Group	Phosphatic sands and clays		
	Eocene	Ocala Limestone	Limestone, fossiliferous to micritic	Floridan aquifer system	Upper Floridan Aquifer
		Avon Park Formation	Upper part, limestone and dolostone. Lower part, dolostone with intergranular gypsum; some bedded gypsum, peat and chert		Middle confining unit
		Oldsmar Formation	Limestone and dolostone, some evaporites and chert		Lower Floridan aquifer
	Paleocene	Cedar Keys Formation	Dolostone with evaporites		

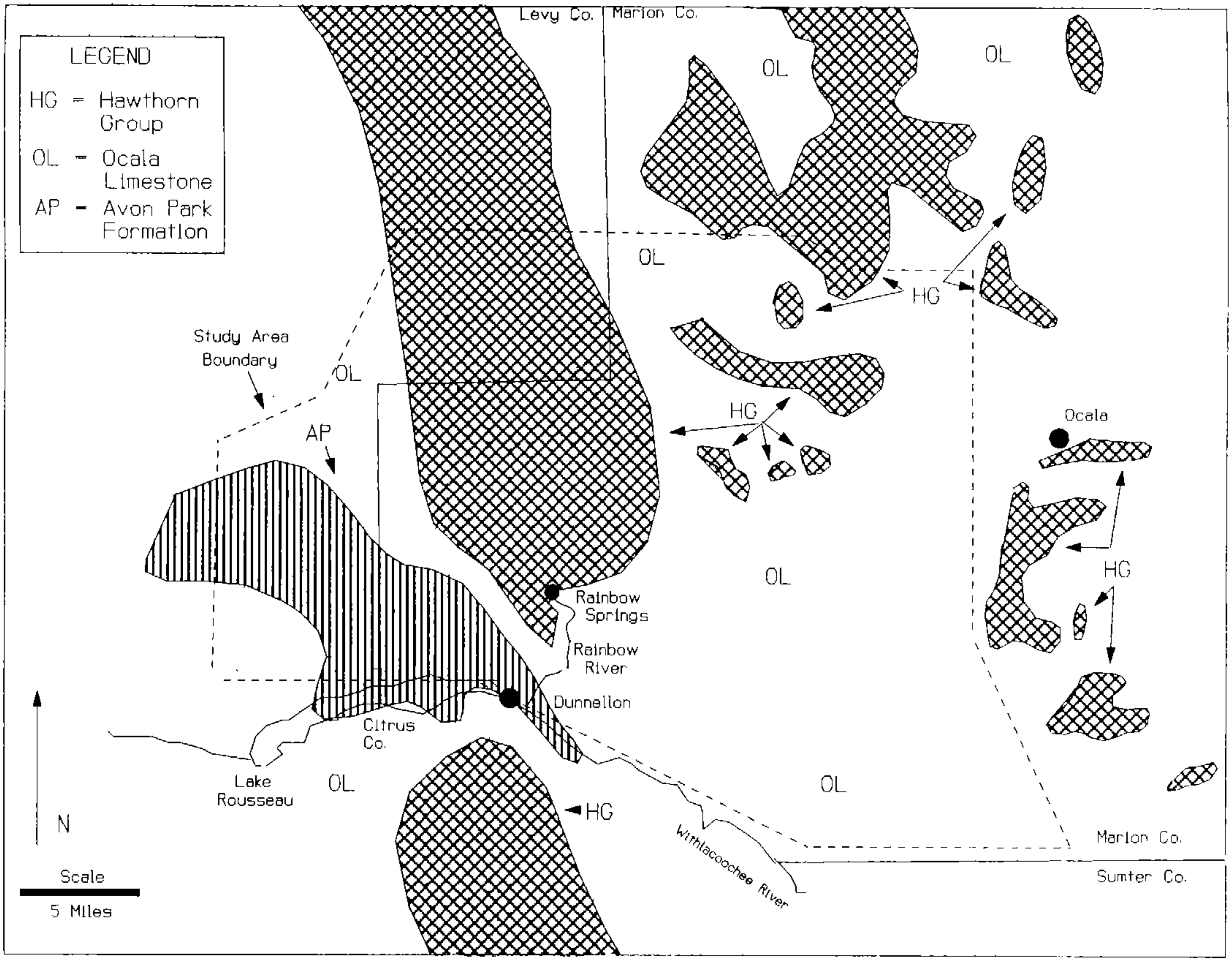


Figure 6. Geologic Map Showing Stratigraphic Units at or Near Land Surface (Modified from Faulkner, 1970).

Sediments of Oligocene age are absent in the study area. The oldest post-Eocene stratigraphic unit to occur is the Miocene Hawthorn Group, which unconformably overlies the Ocala Limestone. Hawthorn sediments have been eroded away in much of the study area (Faulkner, 1970). Where present, they occur as discontinuous outliers capping hills, such as the Brooksville Ridge, Fairfield Hills, and Ocala Hill (Figure 6). Hawthorn Group sediments were deposited in a variety of environments including lacustrine, fluvial and marine settings. Consisting of sand, silty sand, and waxy green clay, the Hawthorn sediments are variably phosphatic with phosphorite pebbles common. Much of the Hawthorn in the Brooksville Ridge area has been highly weathered, complicating recognition of the original depositional facies.

Weathering of the phosphorite has resulted in dissolution of carbonate-fluorapatite and re-precipitation of carbonate-hydroxylapatite in localized crusts and nodules that are associated with the sinkholes on the east side of the Brooksville ridge (Upchurch, 1993). These deposits of re-precipitated phosphate, which were locally termed "hard-rock phosphate," were extensively mined from the late 1880's through 1966 (Dinkins, 1969). Located along U.S. 41 at the foot and flank of the Brooksville Ridge, the mines were generally small due to the localized nature of the deposits in karst features (Jones and Upchurch, 1994).

Overlying much of the study area are Pliocene to Holocene-age clastic sediments ranging in thickness from 0 to 100 feet. These sediments are composed of nonmarine clayey sands, marine and lacustrine sand, shell marl, and sandy clay, and phosphatic limestone (Phelps, 1994).

Structure

The Cretaceous and early Tertiary sediments were deformed by the southeastward plunging Peninsular Arch. The axis of the arch trends northwest to southeast through eastern Marion County. In the early Tertiary, an arch-like structure known as the Ocala Platform affected rocks of middle Eocene age and younger. It was formerly believed to be an anticlinal arch folded by compressional forces, but is now thought to have originated either from an anomalous buildup of middle Eocene carbonate sediments (Winston, 1976) or differential compaction of middle Eocene carbonate material shortly after deposition (Miller, 1986). The axis of the Ocala Platform is parallel to the earlier Peninsular Arch, but it has been shifted 30 to 35 miles to the west. The area of the Ocala Platform has been subjected to increased erosion. This has resulted in the absence or thinning of the Ocala Limestone and the exposure of the underlying Avon Park Formation in southwest Marion County. Figure 7, a northeast-southwest geologic cross section through the study area, illustrates general stratigraphic and structural relationships.

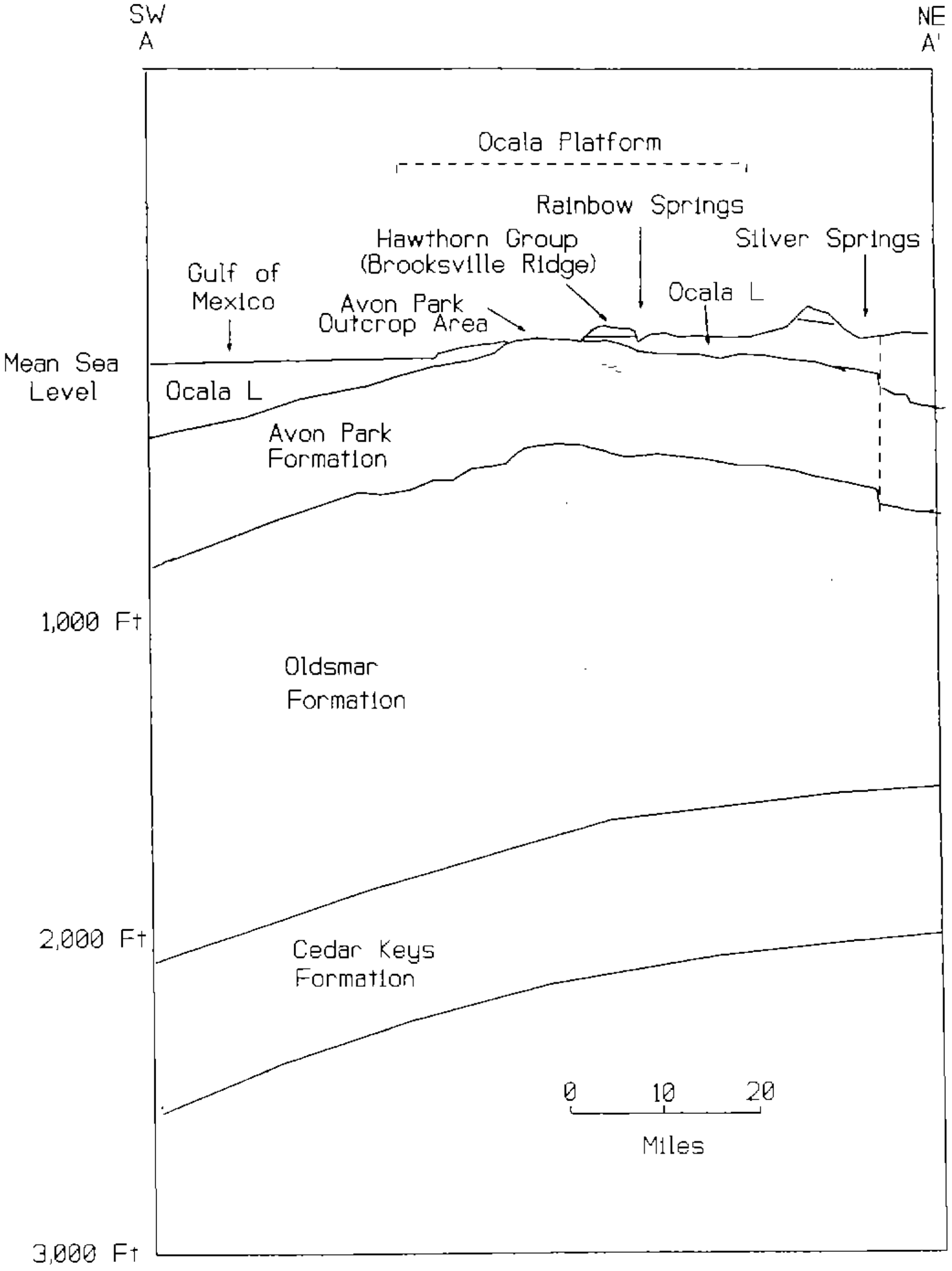


Figure 7. Southwest-Northeast Geologic Cross Section through the Study Area. Vertical Exaggeration of the Figure is Extreme (Modified from Faulkner, 1970).

According to Faulkner (1970), the existence and position of Rainbow Springs is at least partially controlled by the presence of the Ocala Platform and the low permeability of the Avon Park Formation relative to the Ocala Limestone. The Ocala Limestone wedges out on the northeast flank of the Ocala Platform because it was eroded off the crest of the structure (Figure 7). As the large volume of ground water moving south and southwestward through the highly permeable Ocala Limestone approaches the Ocala/Avon Park contact, it can not readily pass into the less permeable Avon Park. This causes the water to discharge at the surface in the vicinity of the contact.

Although this explanation may be correct for water moving toward the spring from the northeast, it is not correct for the large volume of water that is moving toward the spring from the northwest. This is because the Ocala is thin or absent well to the northwest of the springs. The low-permeability Avon Park may be capable of transmitting the large quantities of water to the springs from the northwest because the formation is apparently highly fractured in the area.

Tensional stresses resulting from the formation of the Ocala Platform and earth tides, have fractured and possibly faulted the rock strata. Faults and fractures are often expressed at the surface in the form of photo-lineaments which, are identified by aligned lakes and sinkholes, linear vegetative or soil patterns, and straight segments of streams and rivers. Lineaments can be recognized through the analysis of aerial photography or satellite imagery. Mapping of photolinears by Vernon (1951) revealed two sets of fractures; a primary set with a northwest-southeast trend and a secondary set with a northeast-southwest trend. The two sets intersect at nearly right angles. The primary set is parallel to the axis of the Ocala Platform and the secondary set trends in the direction of the dip of the flanks of the platform. The fractures and faults should not be thought of as discrete, narrow breaks in the rock. A more accurate conceptualization may be a linear zone of fractured and disrupted strata ranging in length from less than a mile to tens of miles and in width from tens to thousands of feet (Jones and Upchurch, 1991).

Fracture zones readily transmit ground water because permeability in the fractures is higher than in the surrounding rock. Therefore, mapping the fracture traces in the study area can facilitate the delineation of the principal routes of ground-water flow in the Floridan aquifer. A discussion of fracture zones in the study area, their control on the location and water quality of the spring, and their control on ground-water flow in the study area is presented on page 40.

Geomorphology

Low stands of the sea during the late Miocene and Pliocene Epochs resulted in development of a surface drainage system in the study area. Streams readily cut down into the soft Miocene sediments and eventually stripped much of these sediments off the underlying permeable limestone. Thus, the Miocene sediments were removed in the lowlands but remained in topographically higher areas. The higher areas in the western portion of the study area include the crest and flanks of the Ocala Platform. This is where the long, narrow, north-trending belt of the Hawthorn Group known as the Brooksville Ridge is located (Figures 4 and 6). Land surface altitudes in the Brooksville Ridge average over 100 feet and exceed 150 feet in places. The area is a rolling to broadly hummocky, karst terrain with numerous sinkholes that do not retain water.

In the central and eastern portions of the study area, the higher areas are the last vestiges of former surface drainage divides. These areas include the Fairfield Hills, Ocala Hills, and Martel Hills, all of which are capped with Hawthorn sediments (Figures 4 and 6). Elevations in these areas average about 150 feet but can be as high as 215 feet in places. Numerous sinkhole depressions have developed as the result of the collapse of limestone caverns. This has produced a hilly, karst topography. Many sinkholes retain water because they have clay bottoms while others are connected with the limestone aquifer and drain directly into it. Limestone caverns are oriented along the principal fracture directions, frequently occur well above the water table in the Hawthorn outcrop area, and are sometimes open to the surface.

Surrounding the highlands are comparatively low, broad, nearly flat to gently rolling, thinly covered Eocene limestone terrains - the Western Valley and Sumter Upland physiographic subdivisions (Figure 4). Average elevation of these areas is about 75 feet with elevations in the bottoms of sinkholes as low as 50 feet. The limestone is generally overlain by 25 to 50 feet of sand and clayey sand which allows direct recharge to the aquifer.

Ground Water Hydrology

Surficial Aquifer

The surficial aquifer consists of Miocene to Holocene age siliciclastic deposits that, where present, are contiguous with the land surface. The clastic sediments include sand, silty sand, and kaolinitic clay. The lower limit of the surficial aquifer coincides with the top of the low permeability beds of the Hawthorn Group or its residuum. Since a large portion of Marion and Levy Counties does not have an extensive confining layer, most of the study area does not have a surficial aquifer.

Floridan Aquifer

The Floridan aquifer is the principal source of water for the springs and domestic, agricultural, and industrial supplies in the study area. The freshwater-bearing part of the Floridan is known as the upper Floridan aquifer. The upper Floridan aquifer is composed of the Ocala Limestone and Avon Park Formation, in descending stratigraphic order (Table 1). The lower Floridan aquifer contains poor-quality water and is not used in the study area. The top of the upper Floridan aquifer is usually defined as the uppermost vertically persistent permeable limestone or dolostone. Where the confining beds that separate the surficial and upper Floridan aquifers are present, the top of the upper Floridan coincides with the base of the confining beds. The middle to lower portions of the Avon Park Formation contain gypsiferous dolostone and dolomitic limestone. The permeability of this portion of the aquifer is generally low and it is considered to be the middle confining unit of the Floridan aquifer. The middle confining unit occurs at an elevation of 500 to 800 feet below sea level in the study area (Miller, 1986).

In general, the upper Floridan aquifer is unconfined in the study area. However, discontinuous clay layers in the Brooksville Ridge and Fairfield Hills areas may be sufficiently thick to cause local, semi-confining conditions to exist. As a result, a limited surficial aquifer may occur in these areas, but there are enough breeches in the clay layer to allow percolation of water from the sand into the underlying limestone. In areas where saturated sand lies directly above limestone, water in the sand is hydraulically connected to the upper Floridan aquifer. Since the lower Floridan aquifer is not relevant to this report, the upper Floridan aquifer will be referred to simply as the Floridan aquifer.

Karst

A prerequisite to comprehending the ground-water hydrology of the study area is an understanding of the dominant role karst processes play in moving ground-water through the Floridan aquifer. The region of Marion and Levy counties, encompassed by the study area, has been extensively modified by karst processes. These areas are characterized by numerous sinkholes, lack of surface drainage, and undulating topography. In karst areas, the dissolution of limestone by ground water has created and enlarged cavities within the limestone which eventually collapse and form sinkholes. Sinkholes capture surface-water drainage and funnel it underground which further promotes dissolution of the limestone. This leads to progressive integration of voids beneath the surface, and allows larger and larger amounts of water to be funneled into the underground drainage system. Dissolution is most active at the water table or in the zone of water table fluctuation where carbonic acid, contained in atmospheric precipitation and generated by reaction with soil carbon dioxide, reacts with limestone and dolostone (Carroll, 1970).

The development of the underground drainage system in the study area has been greatly facilitated by the existence of fracture zones. As discussed previously, in late Miocene to Pliocene time, streams removed the less permeable Hawthorn sediments from the stream valleys and uncovered the underlying, highly fractured and permeable limestone. This allowed surface runoff to begin infiltrating into the limestone with increasing ease. When the infiltrating water reached the water-table surface, it moved along the fractures in the direction of the slope of the water table. As the infiltrating water dissolved the limestone, solution channel systems were produced. These were oriented parallel to the old drainage valleys, which were oriented with the fracture zones.

The thickness of the active karst flow system in the study area is related to the cyclic rise and fall of sea level over the last several million years. During periods when sea level was lower than present, there was a corresponding drop in the potentiometric surface of the Floridan aquifer. Since dissolution is most active at the water table or in the zone of water-table fluctuation, the portion of the Floridan aquifer where the most significant fracture enlargement was occurring would be considerably deeper than today. Since sea level was lower by as much as 300 feet during a portion of the Pleistocene, the greatest level of dissolution may have occurred at depths of 100 to 150 feet below present sea level (Geotrans, 1987). Karst that had formed at higher elevations during higher sea level stands would have been in the vadose zone and would only have transmitted water vertically from the surface to the water table rather than laterally as part of the flow system. When sea level rose to the present level, karst development was reactivated at higher levels and again became part of the lateral flow system. Karst has also formed along the fresh-water/salt-water transition zone (Randazzo and Bloom, 1985; Randazzo and Cook, 1987). Therefore, karst is present throughout much of the upper Floridan aquifer.

According to Faulkner (1970) most of the flow to Rainbow Springs is probably concentrated in the Ocala Limestone in the upper 100 feet of the Floridan aquifer. This portion of the flow system is characterized by rapid flow and short residence times which results in low total dissolved solids concentrations.

The lower portion of the Floridan aquifer is in the dolostone of the Avon Park Formation. The Avon Park dolostone is much less soluble than the overlying, undolomitized Ocala Limestone. Therefore, the development of solution-channel porosity is reduced. Permeability is also thought to be reduced by sand filling of solution cavities. Conversely, fractures may greatly enhance the permeability of the Avon Park in places, especially in the lower Avon Park.

Because permeability is lower in the Avon Park in the study area, this portion of the flow system is much less vigorous than the overlying flow system in the Ocala Limestone. Ground-water movement is relatively slow and residence time is typically much longer, which results in higher dissolved solids concentrations. Most of the ground water in this flow system probably bypasses the springs and moves toward coastal and offshore discharge areas. (Faulkner,1970).

Recharge

The Floridan aquifer in the study area is recharged from local rainfall. Recharge is high (> 10 inches/yr.) over most of the study area because the area is an internally drained, karst terrain (Faulkner, 1970). The greatest amount of recharge occurs on the flanks of the Ocala Platform where the Ocala Limestone is at or near land surface (Figure 6). Where the low-permeability Hawthorn sediments cover the limestone, significant recharge is concentrated at sinkholes. Faulkner (1970) and Anderson and Laughlin (1982) identified areas of poor recharge northwest and southeast of Dunnellon. Direct recharge of the aquifer is limited in these areas because the Avon Park Formation is at or near the land surface on the crest of the Ocala Platform (Figures 6 and 7). The comparatively low permeability of the upper part of the Avon Park, resulting from dolomitization and the presence of sand and clay fill in solution cavities, has caused local potentiometric highs, water levels near land surface, and rejection of recharge during wet periods.

Faulkner (1970) used the size of the dry-season Rainbow Springs Ground-Water Basin (645 sq. miles), and a discharge for the springs of 468 mgd to calculate an average recharge value for the basin of 15.2 inches/yr. In his model of the Floridan aquifer flow system in west central Florida, Ryder (1985), used high recharge values (> 10 inches/ yr.) for much of the study area. Stewart (1980) delineated high recharge areas over Marion and northeastern Levy Counties and low to moderate recharge (2 to 10 inches/yr.) in the Rainbow and Withlacoochee River vicinities and the area west of the Brooksville Ridge. Recharge is low to moderate along the Rainbow and Withlacoochee Rivers because the potentiometric surface of the Floridan aquifer is close to land surface.

SPRINGS IN THE RAINBOW COMPLEX

Introduction

The Rainbow Springs Complex is one of the largest spring systems in Florida. Between 1965 and 1993, average discharge was approximately 697 cfs (450 mgd) (USGS, 1994). Unlike a number of major springs in Florida, Rainbow Springs is composed of numerous vents distributed over a large area, rather than a single, very large discharge point. In addition to the springs at the head of the river, numerous springs discharge into the bed of the river through most of its length. A number of small springs also feed Indian Creek, a tributary that flows southwest and intersects the Rainbow River about a mile south of the head spring area.

An extensive reconnaissance of the head spring area, the Rainbow River, and Indian Creek area revealed dozens of springs and seeps. Eighteen of these were selected for extensive water quality and flow testing. Figure 2 depicts the locations of the 18 major springs.

Description/Discharge

Although Rainbow Springs is generally considered to be the group of springs in the head spring area, the total discharge of Rainbow Springs is computed by combining the discharge of the springs in the head spring area, the river springs, and the springs along Indian Creek. Discharge of the Rainbow River is regularly measured by the USGS approximately 5 miles down stream from the head-spring area at the C.R. 484 bridge, about 0.7 miles above the confluence of the Rainbow and Withlacoochee Rivers.

Figure 8 is a graph of mean monthly discharge between 1965 and 1993 at the C.R. 484 bridge. Discharge exhibits significant seasonality, reaching a minimum at the end of the dry season in June and peaking in October, after the end of the summer wet season. This pattern indicates that the lag time between seasonal changes in rainfall and the response of the spring system is minimal. This is an indication that the system is very open and vigorous and is mainly recharged by precipitation falling in close proximity (5 to 10 mile radius) of the springs.

For the purposes of this investigation, it was necessary to obtain the discharge of individual springs. This was attempted first by measuring the cross section of the spring vent, computing the area, and measuring flow velocities at points across the vent. It was quickly determined that this was not feasible as the cross sections of the vents are highly irregular. Open channel flow measurements down stream of each vent were then attempted. Because of the depth and width of the Rainbow River, a consultant with considerable expertise in open-channel flow measurements was contracted to undertake the project. Although the open-channel measurement method met with considerable

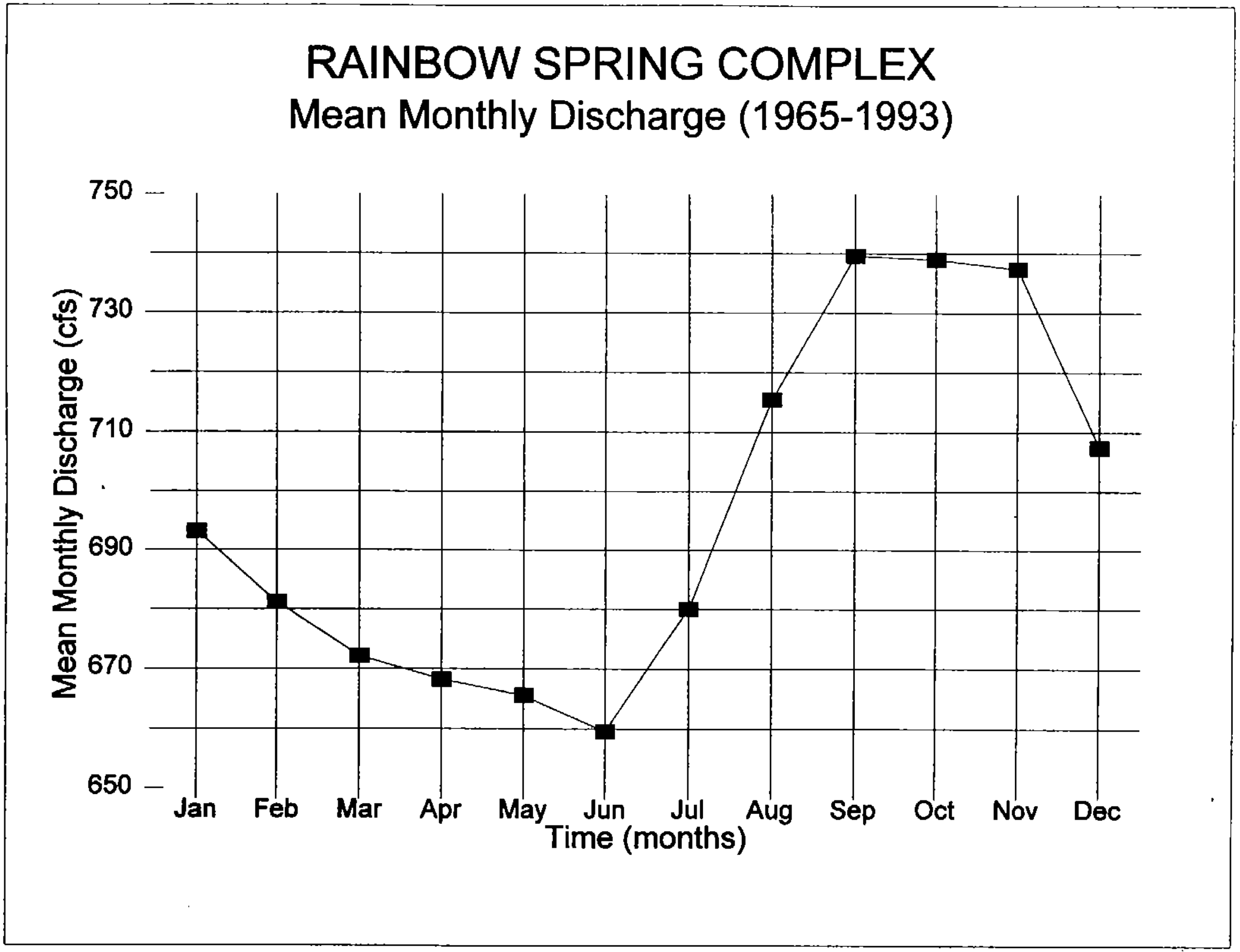


Figure 8. Graph of Mean Monthly Discharge at the C.R. 484 Bridge on the Rainbow River (USGS, 1994).

success, getting measurements between some of the large, closely-spaced springs in the head-spring area proved impossible. This necessitated the measurement of discharge from groups of springs in some cases.

Ten transects were established at various points in the head-spring area and the upper Rainbow River. Discharge was measured at the stations in late June and late August of 1995. Figure 9 shows the location of the 10 transects and the two discharge measurements at each transect. The transect location number is plotted next to each transect line. The two discharge measurements are displayed in columns near each transect line. The top measurement was recorded in late June and the bottom measurement in late August.

The two discharge measurements at each transect were averaged and are displayed as a percentage of the average Rainbow River discharge measured at the C.R. 484 bridge in late June and late August. For example, the average discharge at transect #7 in late June and late August was 329 cfs. The average discharge for the same period at the C.R. 484 bridge was 635 cfs. Therefore, the late June and late August average discharge at transect #7 was approximately 52 percent of the discharge for the same period measured at the C.R. 484 bridge.

The results of the discharge measurements showed that most of the discharge is occurring in the upper portion of the Rainbow River. This was determined using the following methodology. Average discharge for late June and late August at the C.R. 484 bridge was 635 cfs. Discharge for the same period at transect #10, approximately 4 miles above the C.R. 484 bridge, was 568 cfs. This is 89 percent of the late June and late August average discharge at the C.R. 484 bridge. Three hundred twenty nine cfs discharged from the head-spring area (the portion of the river upstream of transect #7) while 239 cfs discharged from the 1.5 mile segment of the Rainbow River from just below transect #7 to transect #10. Of this amount, 172 cfs discharged between transects #8 and #10. The majority of this flow discharged from Rainbow Spring #6 and #7, the two large springs in close proximity to one another in the bed of the river.

The following is a description of the 18 individual springs in the Rainbow Springs Complex that were selected for extensive testing. If it was possible to determine the discharge of the individual spring, the average of the late June and late August 1995 discharge measurements is specified.

Head Spring Area

The head spring area encompasses all springs that discharge into the first 1,500 feet of the Rainbow River. Of the dozens of springs and lateral seeps in the head spring area,

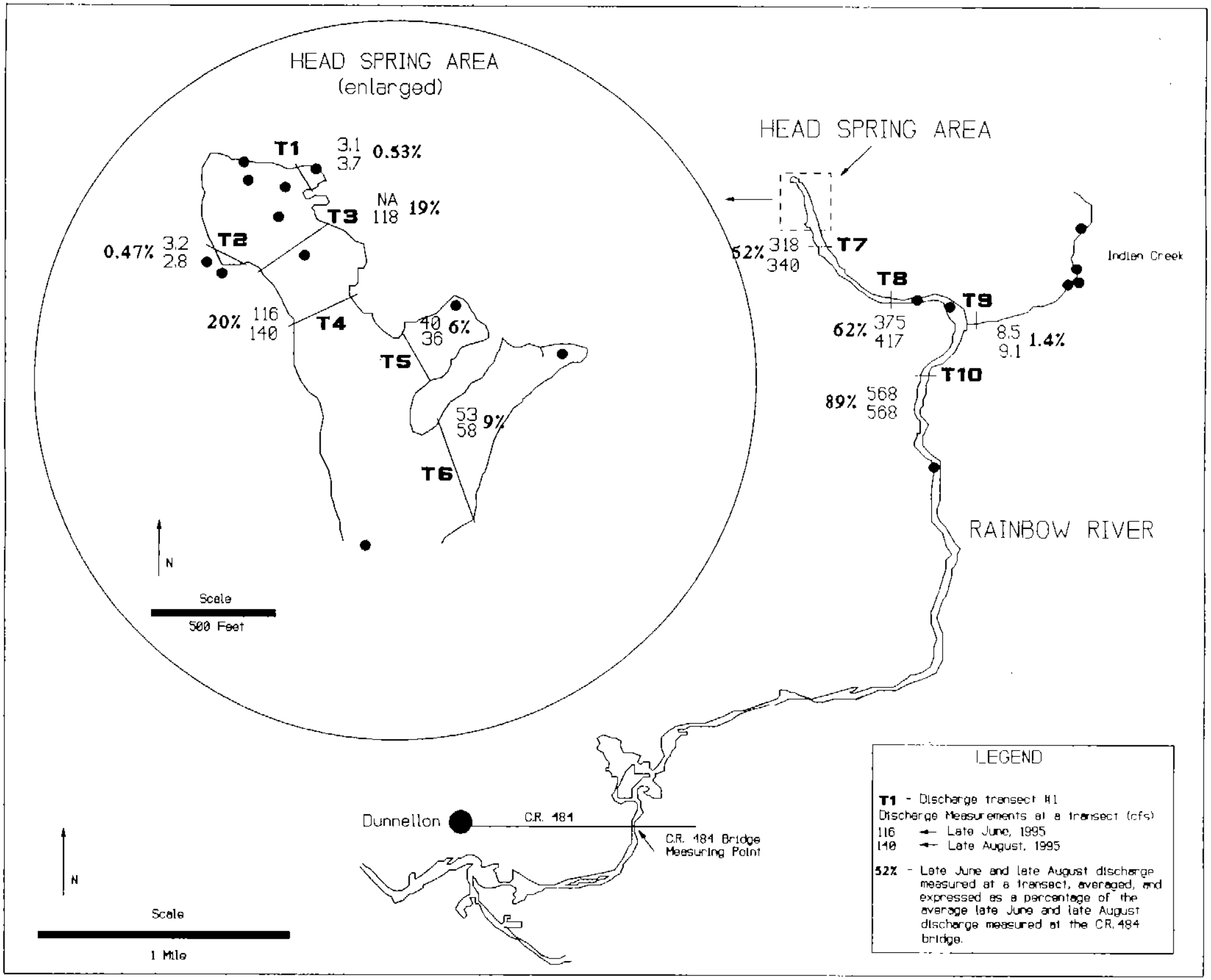


Figure 9. Discharge (cfs) at 10 transects in the Head-Spring Area, the Rainbow River, and Indian Creek.

only the more prominent ones were investigated. These include Rainbow Seep #1, East Seep, Bridge Seeps South and North, Rainbow Springs #1, #2, #3, #4, and #5, Waterfall Spring, and Bubbling Spring (Figure 2).

Rainbow Seep #1 discharges horizontally from beneath the north bank of the upper head-spring area. It was not possible to determine discharge. However, flow was visually estimated to not exceed 3.0 cfs.

East Seep discharges horizontally from beneath a small limestone outcrop on the east bank of the upper head spring area. The average of the late June and late August discharge measurements was determined to be 3.4 cfs.

Bridge Seeps South and North are located in a small recess on the west bank of the upper head spring area a few feet west of a small foot bridge. The springs are approximately 20 feet apart and discharge horizontally from beneath small limestone outcrops. The water flows about 30 feet before running into the upper head spring pool. The average of the late June and late August discharge measurements from the combined springs was 3.0 cfs.

Rainbow Springs #1, # 2, and #3, are located in close proximity to one another in the upper head spring area. The vents of these springs are irregularly shaped, linear fractures in the limestone approximately 30 to 50 feet in length and 10 to 15 feet below the surface. Discharge is not concentrated but faint boils can sometimes be seen on the surface above the vents. Although discharge could not be determined for these springs individually, late August discharge at transect #3, just downstream of Rainbow Spring #3, was 118 cfs.

Rainbow Spring #4 is located about 50 feet south (down stream) of Rainbow Spring #3. The vent is elliptical, about 5 feet long by 3 feet wide, and is located beneath a limestone ledge about 10 feet below the surface. Discharge is pronounced and a boil is easily discernable on the surface above the vent. The average of the late June and late August discharge measurements from Rainbow Spring #4 was 128 cfs as determined by measuring the flow of the Rainbow River at transect #3, a short distance upstream of Rainbow Spring #4 and at transect #4, a short distance downstream of the spring.

Waterfall Spring consists of the discharge of numerous sand boils and horizontal seeps in the Waterfall tributary to the head spring pool. Much of the water appears to emanate from horizontal seeps beneath limestone ledges in the southeast corner of the tributary. Other than very small sand boils, there are no vents of significance in the bottom of the tributary. The average of the late June and late August discharge measurements from Waterfall Springs was 38 cfs.

Bubbling Spring consists of the discharge from the Bubbling Spring tributary of the head spring pool. Most of the flow is from at least 3 cracks in limestone that floors the upper portion of the tributary. The cracks are under about 3 feet of water, and the largest crack is no more than 4 feet long by 6 inches wide. Water boils so vigorously from the largest crack that the sound of flowing water is clearly audible. The average of the late June and late August discharge measurements from Bubbling Springs was 55 cfs.

Rainbow Spring #5 is a depression on the west side of the southern-most portion of the lower head spring area. Flow emanates from an irregular-shaped vent in the bottom of the depression about 15 feet below the surface. Flow is barely perceptible on the bottom and no boil is visible at the surface. Flow could not be determined from this vent, but it is probably low. The average late June, late August discharge of the Rainbow River directly down stream of Rainbow Spring #5 at transect #7 is 329 cfs. This represents the discharge of the entire head-spring area.

Rainbow River

For the purposes of this report, the Rainbow River starts where the head spring area ends. Although there are numerous springs on the bottom of the river, only Rainbow Springs #6 and #7 had discharge that was vigorous enough to create a boil on the surface. The discharge of Rainbow Spring #8 is probably very low, but it was included in the study group because it was the last obvious spring in the upper portion of the Rainbow River. Although there are springs in the lower portion of Rainbow River, none appeared to be significant. The locations of the Rainbow River Springs are depicted in Figure 2.

Rainbow Spring #6 is a circular, limestone-floored depression approximately 100 feet across and 15 feet deep. The actual vent is elliptical; 5 feet long by 2 feet wide, and discharge is vigorous enough to make it very difficult to swim near the vent. A very pronounced boil is visible on the surface. Discharge could not be determined individually for this spring, so it was grouped with that of Rainbow Spring #7.

Rainbow Spring #7, located several hundred feet downstream of Rainbow Spring #6, discharges from a series of irregular cracks in a limestone-floored depression about 10 feet below the surface of the river. Discharge, while not of the same magnitude as Rainbow Spring #6, is vigorous enough to produce an obvious boil on the surface. Average discharge for late June and late August of the river segment between transects #8 and #10, which includes Rainbow Springs #6 and #7, was 163 cfs. This number does not include the transect #9 discharge which is the flow of Indian Creek

Rainbow Spring #8 discharges from a limestone floored depression about 10 feet below the surface of the river. Discharge is practically imperceptible and no boil is visible at the surface. Discharge was not determined, but is probably very low.

Indian Creek

Rosenau et al. (1977) speculated that Indian Creek, in much earlier times, may have been the course of an important spring run that was tributary to the Rainbow River. The average of the late June and late August discharge measurements from all the Indian Creek Springs, as measured at the mouth of Indian Creek, was 8.8 cfs.

Figure 2 depicts the location of the four springs in Indian Creek. Spring #1 is a very small spring at the upper end of Indian Creek that discharges into the creek from beneath a tree. Spring #2 is downstream and somewhat larger than spring #1 and discharges through the bottom of the creek. Most of the flow in the creek is probably from springs #3 and #4 which are located at either end of a small, oval-shaped pool approximately 1500 feet above the confluence of Indian Creek and the Rainbow River.

Rock Spring

Rock Spring, although not part of the Rainbow Spring Complex, was investigated because it is depicted as a spring on the USGS Dunnellon quadrangle map and it is located only 3 miles northeast of the Rainbow head-spring area. A field investigation of the map location revealed limestone boulders and a shallow, highly turbid pond at the bottom of a broad, shallow depression. There was no evidence of a boil on the water surface or that water had ever flowed out of the depression. It is highly probable that this area is simply a collapsed sinkhole that intersects the water surface at the top of the Floridan aquifer. The pond may have been called a spring because, prior to cultivation and livestock grazing in the area, the water probably had the crystal clear appearance of spring water.

STUDY DESIGN, METHODS, AND DATA COLLECTION

Introduction

The study design and methods of investigation were formulated in June and July of 1993 by members of the AGWQMP section and SWIM Department of the SWFWMD and Dr. Sam B. Upchurch of ERM-South. 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 Area of Investigation

As the study progressed, a number of considerations made it necessary to divide the region in and around the Rainbow Springs Ground-Water Basin into subregions. These divisions are 1) the Rainbow Springs study area and 2) the Rainbow Springs immediate recharge area (Figure 10). The following paragraphs discuss the purpose and extent of the Rainbow Springs Ground-Water Basin and the subregions.

Rainbow Springs Ground-Water Basin

The entire area contributing water to the springs is termed the Rainbow Springs Ground-Water Basin (RSGWB). This region was delineated using maps of the May and September 1994 potentiometric surfaces of the Floridan aquifer (Figures 11A and 11B). The size of the RSGWB fluctuates from approximately 645 square miles in May, the end of the dry season, to approximately 771 square miles in September, the end of the wet season. Much of the increase in area in the wet season occurs where the eastern and western boundaries of the northern-most portion of the basin undergo considerable expansion.

Recharge to the aquifer occurs everywhere within the RSGWB except where clays are thick enough to prevent the formation of sinkholes. In these areas, water enters the aquifer after flowing across the clay surface for a short distance to areas where the clays are thin or breached. Discharge from the basin occurs only in the Rainbow River Valley.

Rainbow Springs Study Area

Ground water discharging at the springs can enter the aquifer as far away as the potentiometric high near the town of Campville in Alachua County; approximately 50 miles to the northeast. Because travel times are sufficiently long to make the influences of activities in the distal parts of the basin less critical and because resources for the project were not sufficient to complete an in-depth characterization of an area this size, it was

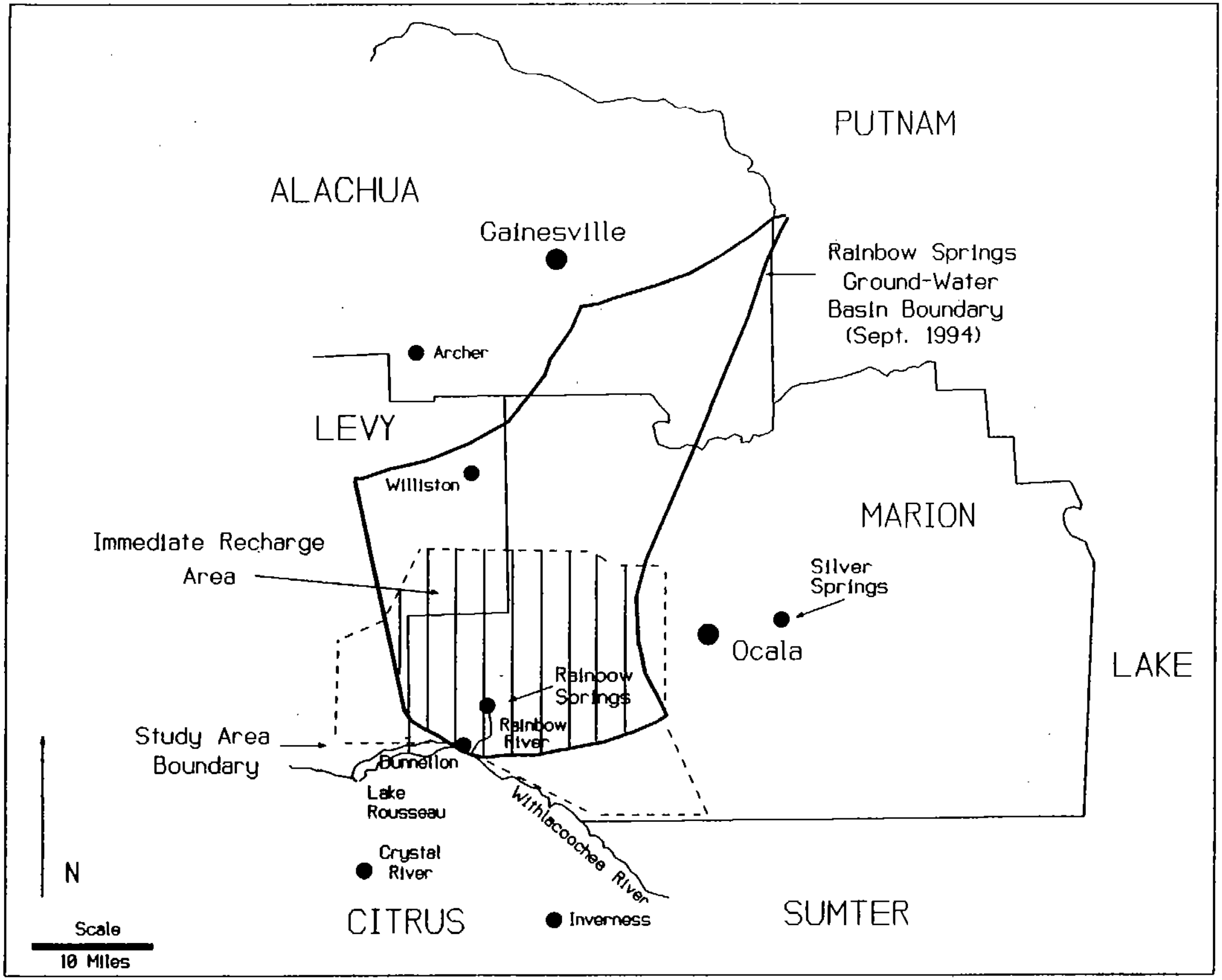


Figure 10. Extent of the Rainbow Springs Ground-Water Basin, the Study Area, and the Immediate Recharge Area.

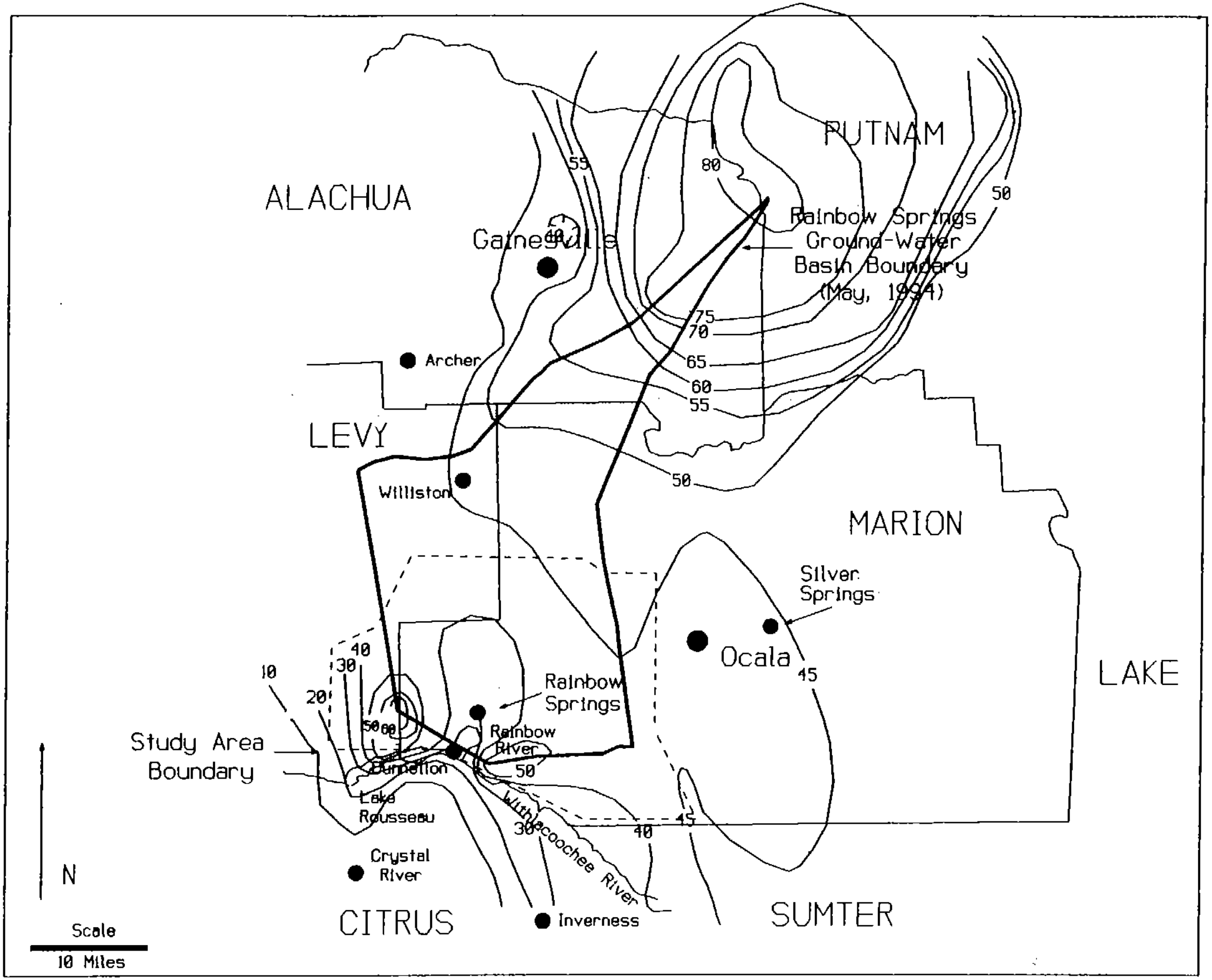


Figure 11A. May 1994 Potentiometric Surface in the Rainbow Springs Ground-Water Basin (modified from Schiffer et al, 1994).

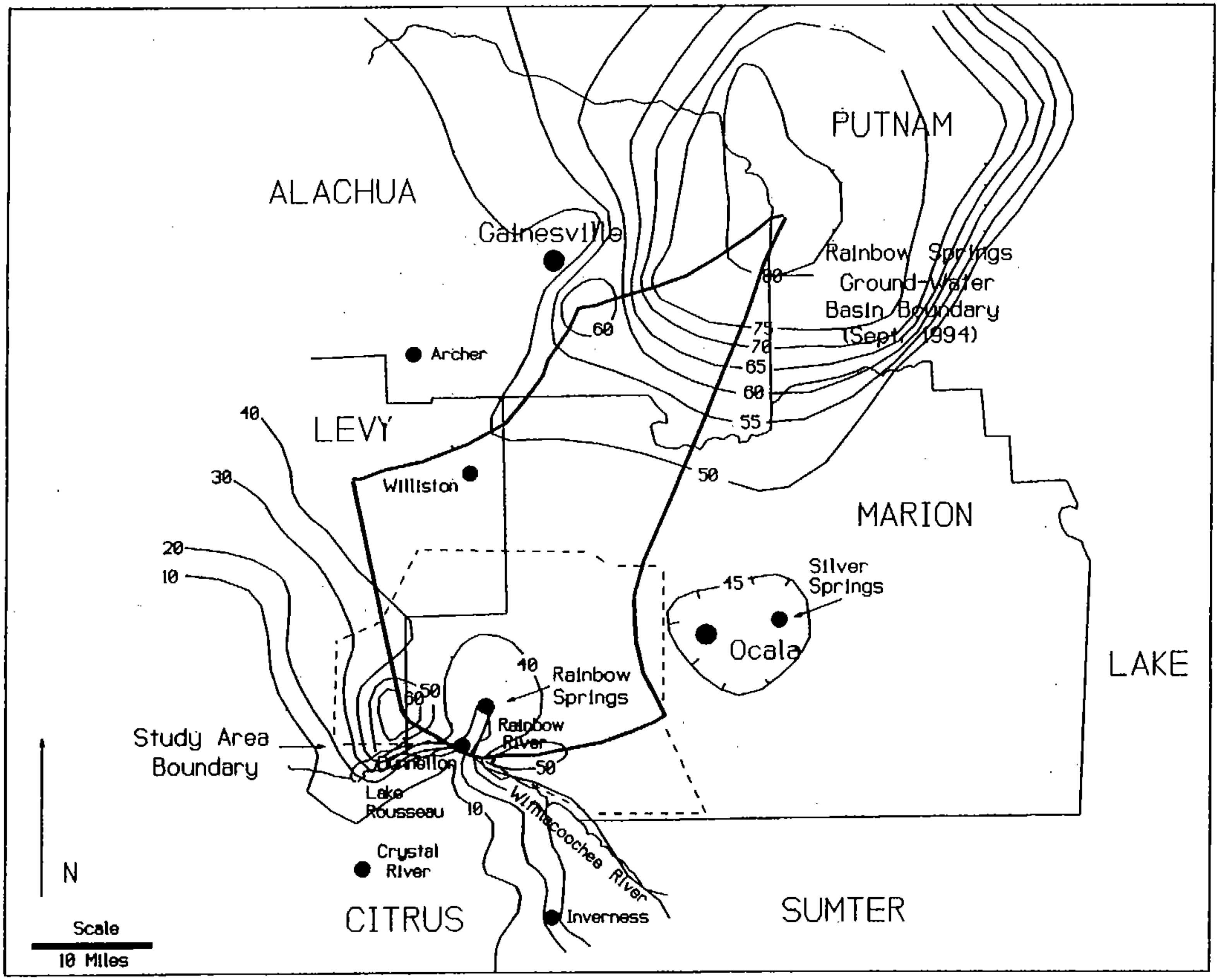


Figure 11B. September 1994 Potentiometric Surface in the in the Rainbow Springs Ground-Water Basin (modified from Knowles, 1994).

decided that the Rainbow Springs study area would be concentrated on an area of approximately 500 square miles nearest the springs. The most distal portions of the RSGWB in Alachua, northern Marion, and northeastern Levy Counties were not studied.

A significant area of adjacent ground-water basins was included in the Rainbow Springs study area. This was done for two reasons. First, the low gradient of the potentiometric surface across the RSGWB and poor well control made it very difficult to determine the exact boundaries of the RSGWB. To insure that the entire RSGWB nearest the spring was included in the study area and to insure that seasonal fluctuations of the boundaries were captured, significant overlap was necessary. Second, to obtain a complete understanding of the chemistry of ground near Rainbow Springs, it was considered necessary to sample wells and map ground-water quality in areas several miles outside of the RSGWB.

Rainbow Springs Immediate Recharge Area

The Rainbow Springs immediate recharge area is essentially the southern half of the RSGWB (Figure 10). The area encompasses approximately 350 square miles of the RSGWB and the majority of water discharging at the springs is probably recharging in this area. Transmissivity in this area is very high, recharge and flow are rapid, and residence time of water in the flow system is short. The use of the Rainbow Springs immediate recharge area was necessary to calculate the amount of nitrogen from various sources that could potentially reach ground water and travel toward the springs. Nitrogen reaching ground water from sources outside the immediate recharge area would either move away from the springs or would take so long to reach the springs that concentrations would probably be diluted to background levels.

Establishment of a Study-Area Monitor-Well Network

The most important tool in determining the source of nutrients in the springs was the water-quality data obtained from the monitor-well network. The network was established by offering well owners in the study area the opportunity to have their well water tested for a number of different parameters at no cost. Eighty four wells were initially included in the network. Eighteen were later eliminated because they were either too deep, too shallow, were in close proximity to wells with similar water quality, had filtration systems, or had construction problems. Sixty six wells were retained in the network. Total well depth was known for 80 percent of the wells and total depth and cased depth was known for 79 percent. Figure 12 is a map of the locations of sampled wells. Well specifications are listed in Appendix I.

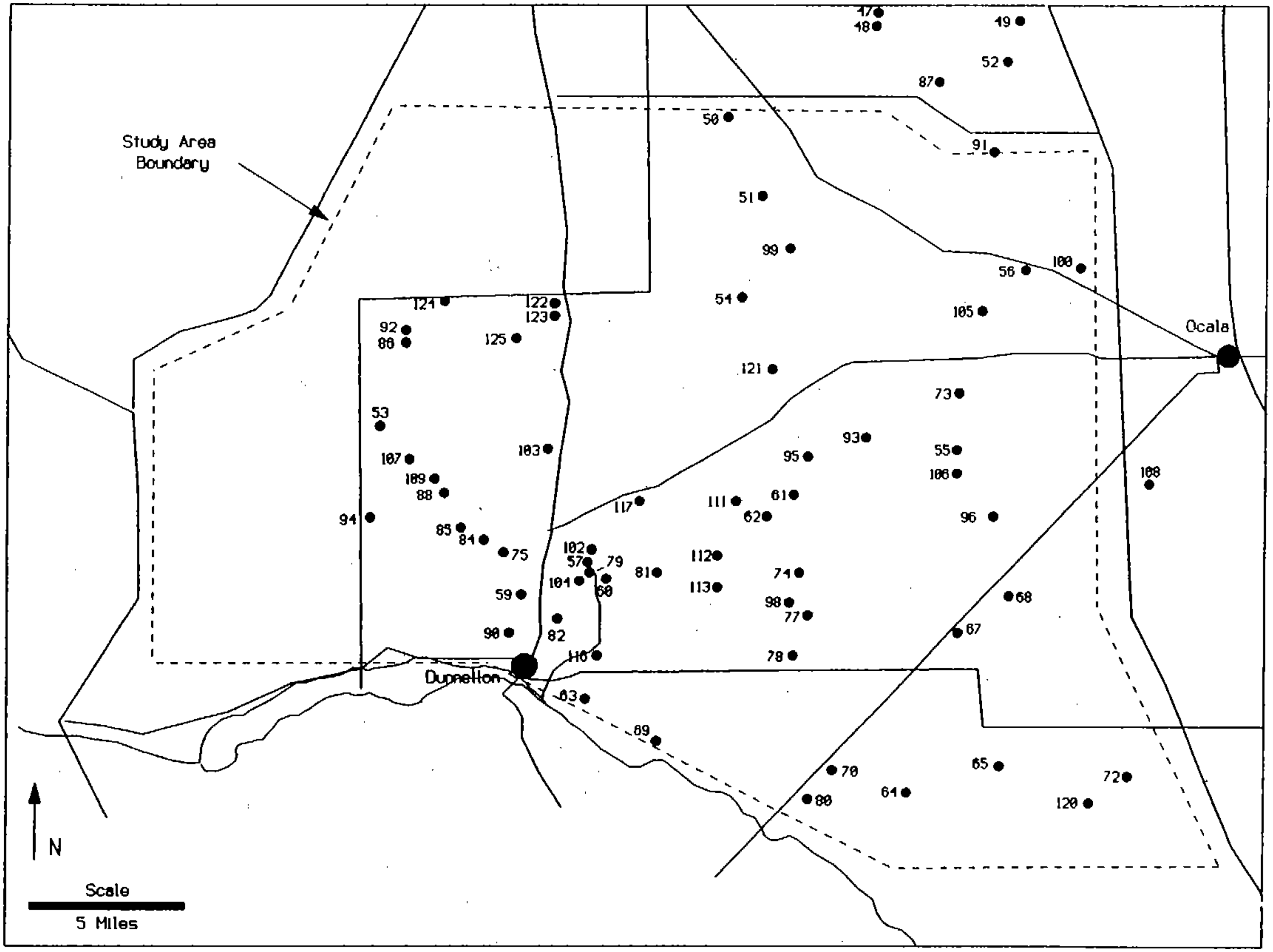


Figure 12. Location of Wells Sampled in the Study Area.

Evaluation of the Aquifer Interval Monitored by the Well Network

To insure that a relatively discrete interval of the Floridan aquifer with similar water quality was being monitored by the well network, depth below land surface of the 84 wells initially sampled was carefully evaluated. Seven wells were considered to be too deep and were eliminated. Although depths of the 66 wells retained in the network ranged from 46 to 243 feet, it was determined that most of the deeper wells are in the ridge areas while the shallower wells are in the lowland areas. Therefore, when depth below sea level of each well is compared, the difference in depth between the deepest and most shallow well is no more than 100 feet.

Water Quality Sampling of Monitor Wells and Springs

Water-quality sampling of springs and monitor wells by the AGWQMP was the most time consuming and labor intensive aspect of the study. All water-quality data obtained from the analyses of monitor well and spring samples are included in Appendix II and III respectively. Methods used are current, U.S. Environmental Protection Agency (US E.P.A.) -approved standard methods, where available.

Analytes

The list of analytes selected for analysis from spring and well samples are listed in Table 2. In addition to the traditional list of analytes, two isotopic analytes, nitrogen and uranium, were measured for selected samples. Tritium is also addressed in this report but wells in the network were not sampled for it. This was because sufficient work on characterization of tritium activities in ground water in and near the study area had been done previously. Because of the high cost of analysis, the number of samples analyzed for isotopic composition was limited. Samples were selected to cover the range of land uses and water-quality variability in the study area.

Table 2. - Analytes Used in the Study.

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

Uranium Isotopes

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 , 1978) of Florida State University to trace ground-water flow systems, determine relative ages of ground-water masses, and determine provenance of water masses. Cowart was contracted to analyze 23 samples from wells and springs in the study area and to determine similarities between the ground-water and spring samples, if possible.

Because uranium is most soluble in oxidizing environments where it forms uranyl (UO_2) ions, uranium concentration can be used to roughly determine age and history of ground water in Florida. Low concentrations (<0.1 µg/L) are typically associated with reducing conditions and deep, slow-moving waters. High concentrations (>0.1 µg/L) are found in oxidizing waters that are typically shallow and relatively young (recently recharged). The ratio of ^{234}U to ^{238}U is also sensitive to ground-water age. Alpha recoil (Osmond and Cowart, 1976) forces ^{234}U into ground water relative to ^{238}U. Thus, older waters tend to have higher $^{234}U/^{238}U$ than do younger waters.

Nitrogen Isotopes

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

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

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

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

Tritium

Tritium (^3H) is a rare isotope of hydrogen that is formed by cosmic-ray activation of nitrogen and by atmospheric testing of nuclear weapons. Determining the tritium content of aquifer water helps to determine whether the aquifer is being recharged locally or from a more distant source. Because of the dramatic increase in 1952, the onset of atmospheric testing of hydrogen bombs, tritium provides a useful marker for relatively young water in the hydrologic cycle. Before 1952, the tritium content of meteoric water ranged from 1 to 10 tritium units[3] (TU) (Kaufman and Libby, 1954). Water recharged in Florida prior to 1952 should have a tritium concentration of less than 2 TU (Yobbi, 1992).

Atmospheric, nuclear-weapons testing has raised tritium activities as much as two orders of magnitude. While tritium began to be introduced in the mid-1940s, the major build-up of tritium began with cold-war testing in the 1950s. This resulted in rainfall concentrations of tritium reaching 1,188 TU at Ocala, Florida, in 1963 (Yobbi, 1992). Tritium activities in meteoric waters increased until the mid-1960s when atmospheric test bans became effective. With the advent of the Nuclear Test-Ban Treaty in 1963, tritium levels have decreased, and in 1988 they averaged about 5 TU. Tritium has a half life of 12.4 years, so decay and cessation of atmospheric testing have resulted in a decline of tritium in precipitation to activities similar to background. Thus, any ground waters that contain tritium above background levels can be assumed to have been recharged in the period from 1950 to 1975. Ground waters with tritium activities less than 10 TU can be assumed to have been recharged before 1952 or within the last 20 years.

Monitor-Well Network

Sixty six wells in or near the study area were sampled for pH, temperature, conductivity, 8 major ions, 5 nutrients, total dissolved solids, total organic carbon, and iron. Nineteen of these wells were also sampled for isotopes of nitrogen and 17 wells were sampled for isotopes of uranium.

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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).

Springs Network

Eighteen springs in the study area were initially sampled in October 1993 for pH, temperature, conductivity, 8 major ions, 5 nutrients, total dissolved solids, total organic carbon, and iron (Table 2). Following the initial sampling, the springs were sampled quarterly through July 1995 for the parameters listed above. However, sampling was discontinued at some of the springs during this time period.

In addition to the conventional parameters, 5 of the springs were sampled for isotopes of nitrogen and 6 were sampled for isotopes of uranium.

Characterization of the Flow System

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

Sinkhole Reconnaissance and Fracture Trace Analysis

To delineate the areas of maximum recharge, karst features were mapped in the study area. USGS 7.5' topographic quadrangle maps of southwest Marion and southeast Levy Counties were searched for closed-depression type features. Locations and shapes of the features are plotted in Figure 13. From the figure it is apparent that a large number of areally extensive sinkholes, some covering up to 3 square miles, are located in the study area. Sinkholes are very abundant over most of the study area with the exception of a few areas. These include 1) the Fairfield Hills physiographic subdivision (Figure 4) where thick clays of the Hawthorn Group have inhibited sinkhole development, 2) the Western Valley physiographic subdivision, 3) and the Coastal Lowlands Physiographic subdivision in eastern Levy County. Plio-Pleistocene marine deposition has buried (and masked) karst in the latter two areas.

The surface expressions of subsurface fractures are known as fracture traces. Fracture traces can be composed of aligned hydrologic features such as lakes and rivers, sinkholes, and springs and linear vegetative and soil tonal patterns. The identification of fracture traces is important because the underlying fractures tend to control the development of karst features. In addition, fractures can be the primary paths of ground-water flow in a karst area. To facilitate the identification of fracture traces, satellite (LANDSAT) images were used in conjunction with USGS topographic maps and the map of closed depression features discussed in the previous paragraph. Fracture traces identified by the authors are plotted in Figure 13. The fracture traces are superimposed

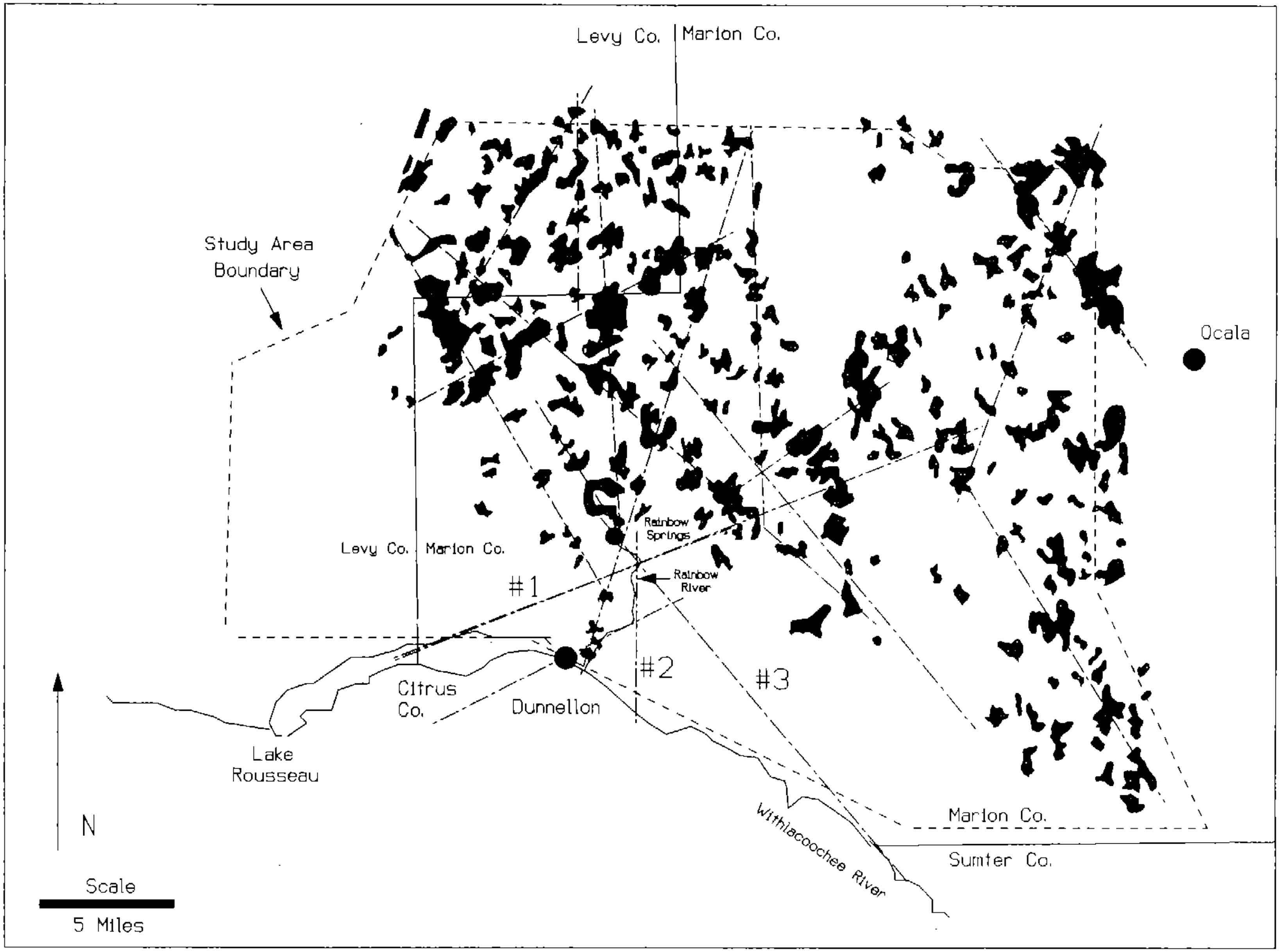

Figure13. Closed Depression Features and Selected Fracture Traces in the Study Area.

on the closed depression features to show how the fractures often control sinkhole development in an area.

From the figure it is apparent that 3 extremely prominent fracture traces pass directly through the head spring area and/or Indian Creek and the Rainbow River. These fractures are numbered on the figure. Fracture trace #1 trends northeast along the western-most portion of the Withlacoochee River, passes through the Rainbow River, continues up the small valley of Indian Creek, and finally disappears a few miles west of Ocala. In addition to controlling the position of the western-most segment of the Withlacoochee River, this fracture is probably responsible for the location of Indian Creek. Northeast of Indian Creek, the fracture may have facilitated the development of a major ground-water flow zone that is strongly indicated by the ground-water chemistry in the area. This fracture may supply large volumes of water to the springs in the Rainbow River and Indian Creek.

Fracture trace #2 trends slightly northwest, originating a few miles south of the Citrus/Marion County line, crosses the Withlacoochee River near Dunnellon, passes through the head spring area as it follows the north trending segment of the Rainbow River for approximately 2 miles, and disappears immediately north of the head spring area. This fracture probably controls the course of most of the Rainbow River and may be at least partially responsible for the existence of Rainbow Springs.

Fracture Trace #3 trends northwest, originating south of Lake Panasoffkee in Sumter County, follows the Withlacoochee River for approximately 15 miles, leaves the River as it enters Marion County, intersects the Rainbow River where Indian Creek and the Rainbow River come together, passes through head spring area, and disappears several miles northwest of the River. This fracture probably controls the course of at least 15 miles of the Withlacoochee River and may also be partially responsible for the existence of Rainbow Springs. Northwest of the head spring area, the fracture may have facilitated the development of a major ground-water flow zone that is strongly indicated by the ground-water chemistry in the area. This fracture may supply large volumes of water to the springs in the head spring area.

GROUND-WATER CHEMISTRY; STUDY AREA

Introduction

The following is an analysis of the chemical quality of ground water in the Rainbow Springs study area. The objective of the analysis is to delineate areas of distinctive water quality, relate these areas to geologic and hydrologic factors, then divide the areas of distinctive water quality into water-quality domains. These domains will then be used to determine the sources of water for the numerous springs in the Rainbow Complex.

Chemical data obtained from an initial sampling of the monitor-well network for major ions and nutrients were analyzed using PLOTCHEM, a program that produces Piper (Piper, 1944) and Stiff (Stiff, 1951) diagrams for the graphical representation of dissolved constituents in ground-water samples. These plots are used to identify hydrochemical facies.

The SURFER graphics package was used to machine contour chemical data. The plot files were edited to produce hydrogeologically reasonable maps. No changes were made to the contour patterns, only unsupported lines and inappropriate contours were changed. The maps, therefore, reflect an independent, quantitative interpretation of the data.

To assist the reader's understanding of the concentration contour maps, it should be remembered that a negative sign in front of a concentration indicates the concentration is below the laboratory detection limit.

Hydrochemical Facies

Hydrochemical facies analysis (Upchurch, 1993) is an excellent way to place a series of water-quality analyses into a spatial context. The analysis depends on pattern recognition techniques. Individual samples are plotted on Stiff (1951) diagrams, which show the relative proportions, in milliequivalents per liter, of major ions in a sample. The size of the Stiff diagram is proportional to the total dissolved solids content of the sample, and the shape conveys a rapid impression of the water type, or dominant ions in the sample. All samples are plotted on a Piper diagram (Piper, 1944), which relates the changes in proportions, but not concentrations, between samples.

Chemical data from the 66 wells sampled by the AGWQMP in the study area were used to construct a Stiff diagram for each well. A Piper diagram was also constructed. Figure 14 displays three Stiff diagrams that are representative of the different water-quality groups delineated from the well samples. Figure 14 also displays the Piper diagram.

The Stiff diagrams indicate that each sample is dominated by calcium and

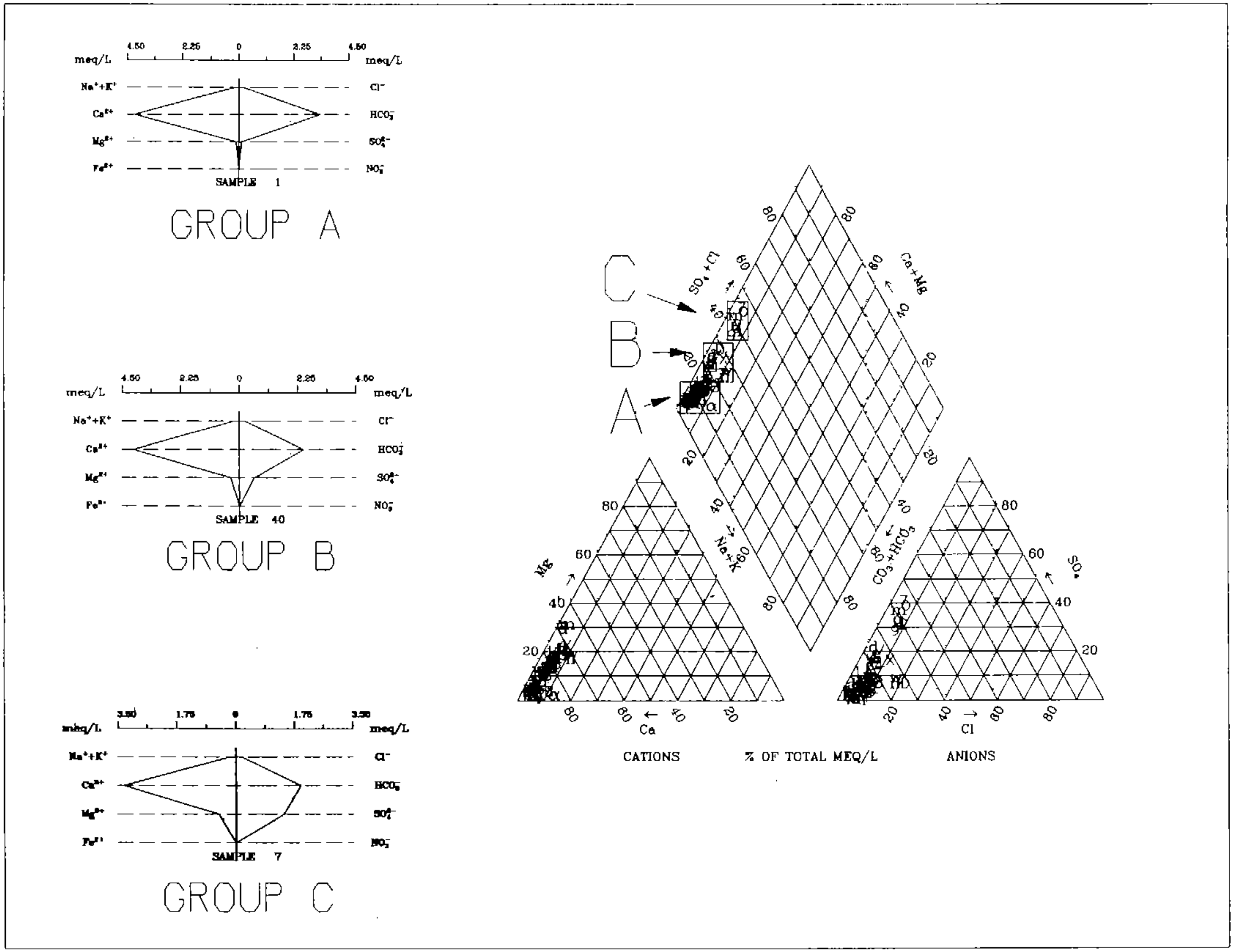

Figure 14. Characterization of Study Area Waters Using Piper and Stiff Diagrams.

bicarbonate. A much smaller number of samples contains a significant presence of the sulfate ion and to a lesser extent, the chloride ion.

Chemical data from the wells were then plotted on a Piper diagram. Examination of the diagram shows 3 distinct groups of samples (A,B,C). The fact that the groups are immediately adjacent to one another indicates that differences in chemistry are not extreme. All samples in all three groups are predominantly calcium-bicarbonate type water. The parameter that determines the slight difference in position of the groups on the Piper diagram is sulfate, which increases significantly from group A to C. Seventy percent of the samples are in group A, indicating that the chemistry of ground water over most of the study area is dominated by simple dissolution of limestone. The low sulfate content indicates that the flow system is shallow. The higher sulfate levels in groups B and C may result from the upconing of water that is influenced by dissolution of gypsum and anhydrite deeper in the Floridan aquifer, near the top of the middle confining unit. Well depth is not a factor since the well network only includes wells open to the shallow flow system.

Major Constituents

In this report the major constituents were considered to be pH, bicarbonate, calcium, chloride, sulfate, and TDS. Although pH is not a major constituent, it was included because it is intimately associated with bicarbonate and calcium and it controls chemical interaction with rock materials. TDS was also included because it is a measure of the concentration of all the major and minor constituents. In Figures 15 to 26, the concentration in mg/l (unless otherwise noted) of each major constituent is plotted next to the well from which it was sampled.

Other major constituents, such as sodium, magnesium, and potassium, occur in small but significant concentrations. These were not included because their utility was considered to be limited in characterizing ground-water quality in the study area and delineating spring water source areas.

Bicarbonate, Calcium, and pH

As rainfall passes through the soil layer it becomes increasingly acidic (low pH) as a result of its reaction with carbon dioxide (CO_2) to form carbonic acid (H_2CO_3) and by addition of natural organic acids (humic acid, etc.). Carbonic acid reacts with limestone ($CaCO_3$) to produce dissolved calcium (Ca^{2+}) and bicarbonate (HCO_3^-). As limestone is dissolved by carbonic acid, pH increases because carbonic acid is used up and calcium and bicarbonate are produced. The concentrations of calcium and bicarbonate ions and the pH of ground water in the study area are therefore important indicators of chemical maturity. Water that has been in contact with limestone for a relatively short length of time would have low concentrations of these ions and a relatively low pH while the opposite would be true for water that has been in the flow system for a long period of time. Figures 15, 16, and 17 show the distribution of bicarbonate, calcium, and pH in study area ground water.

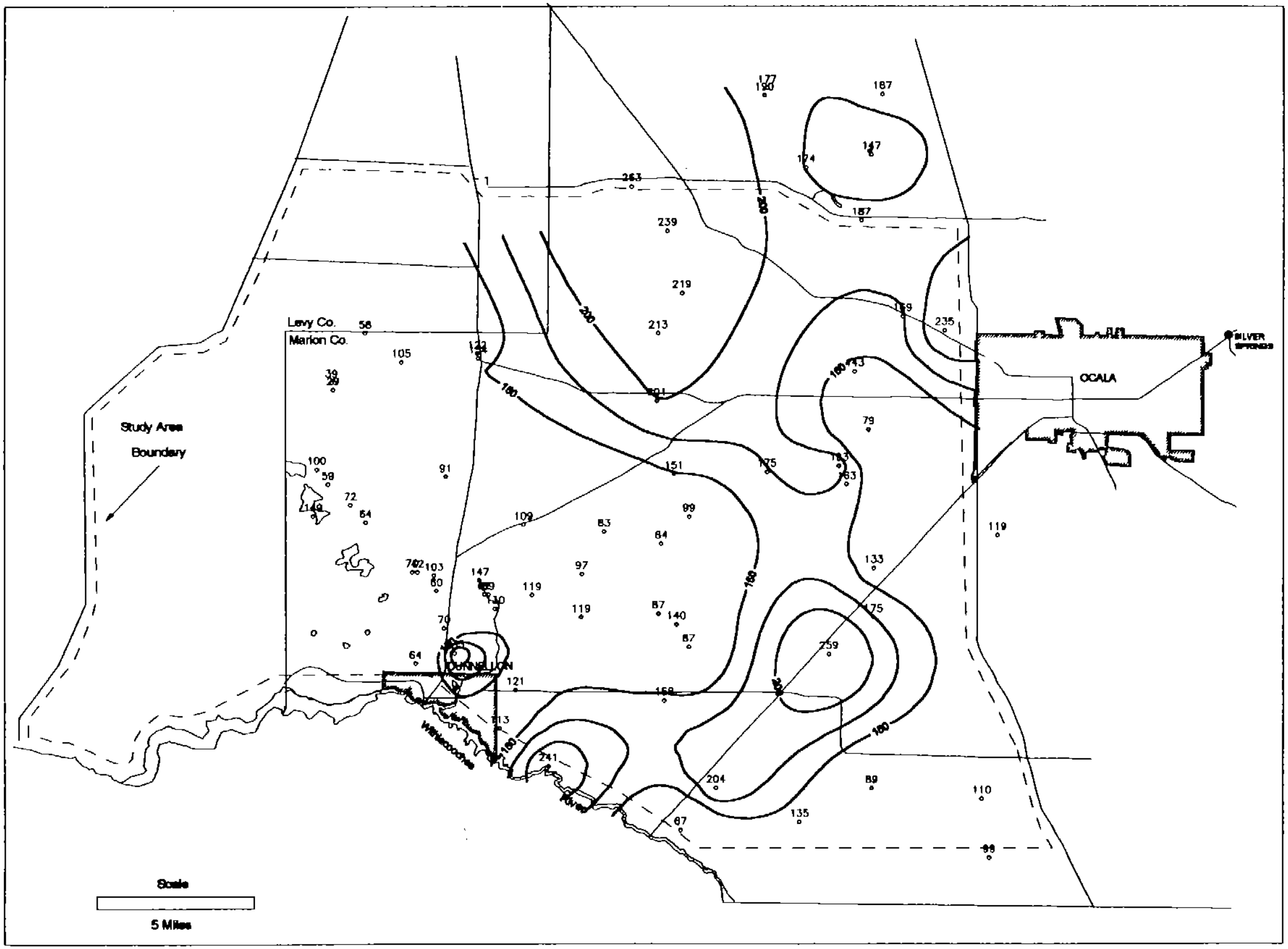

Figure 15. Bicarbonate Concentrations in Study-Area Ground Water.

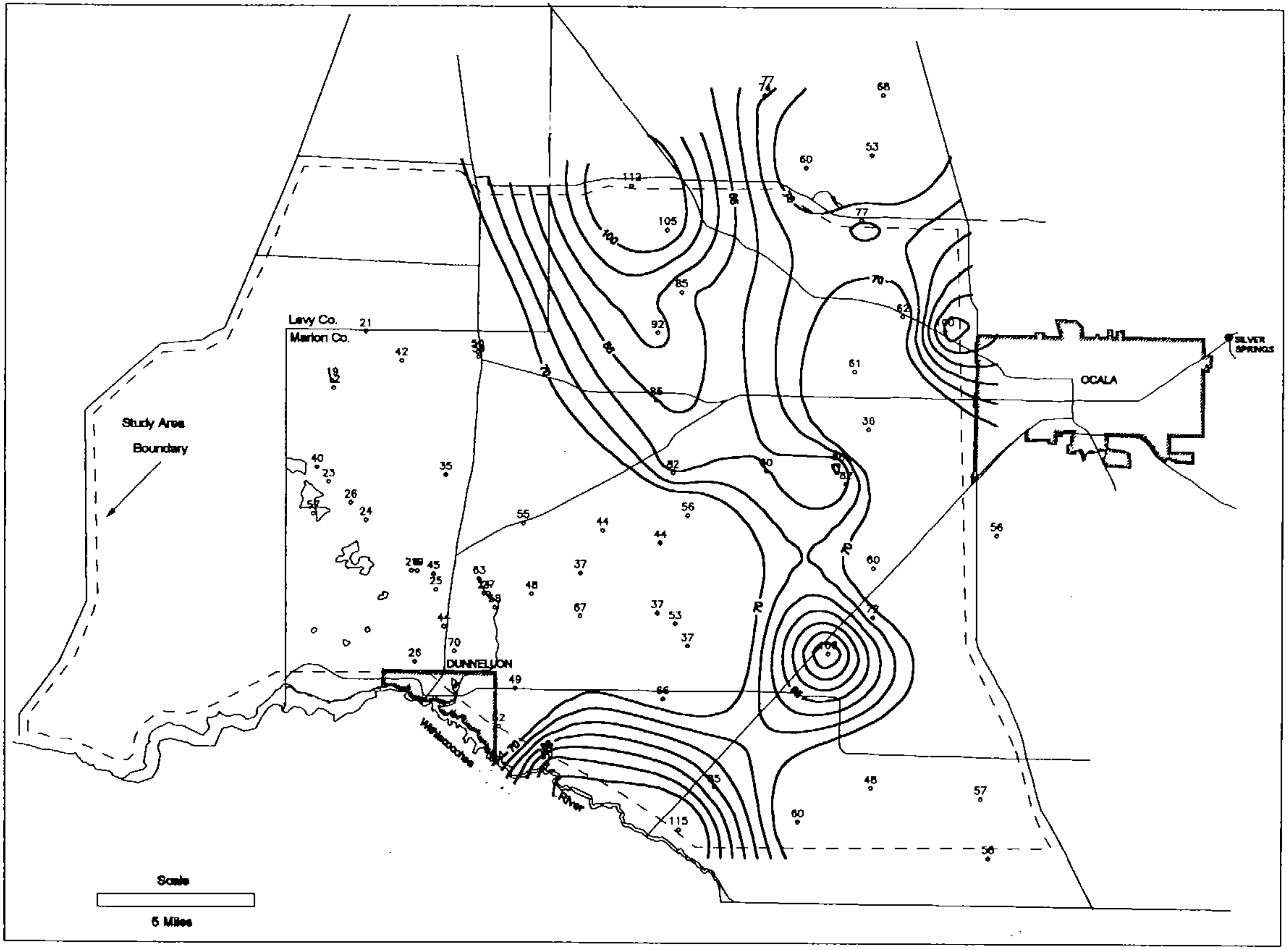

Figure 16. Calcium Concentrations in Study-Area Ground Water.

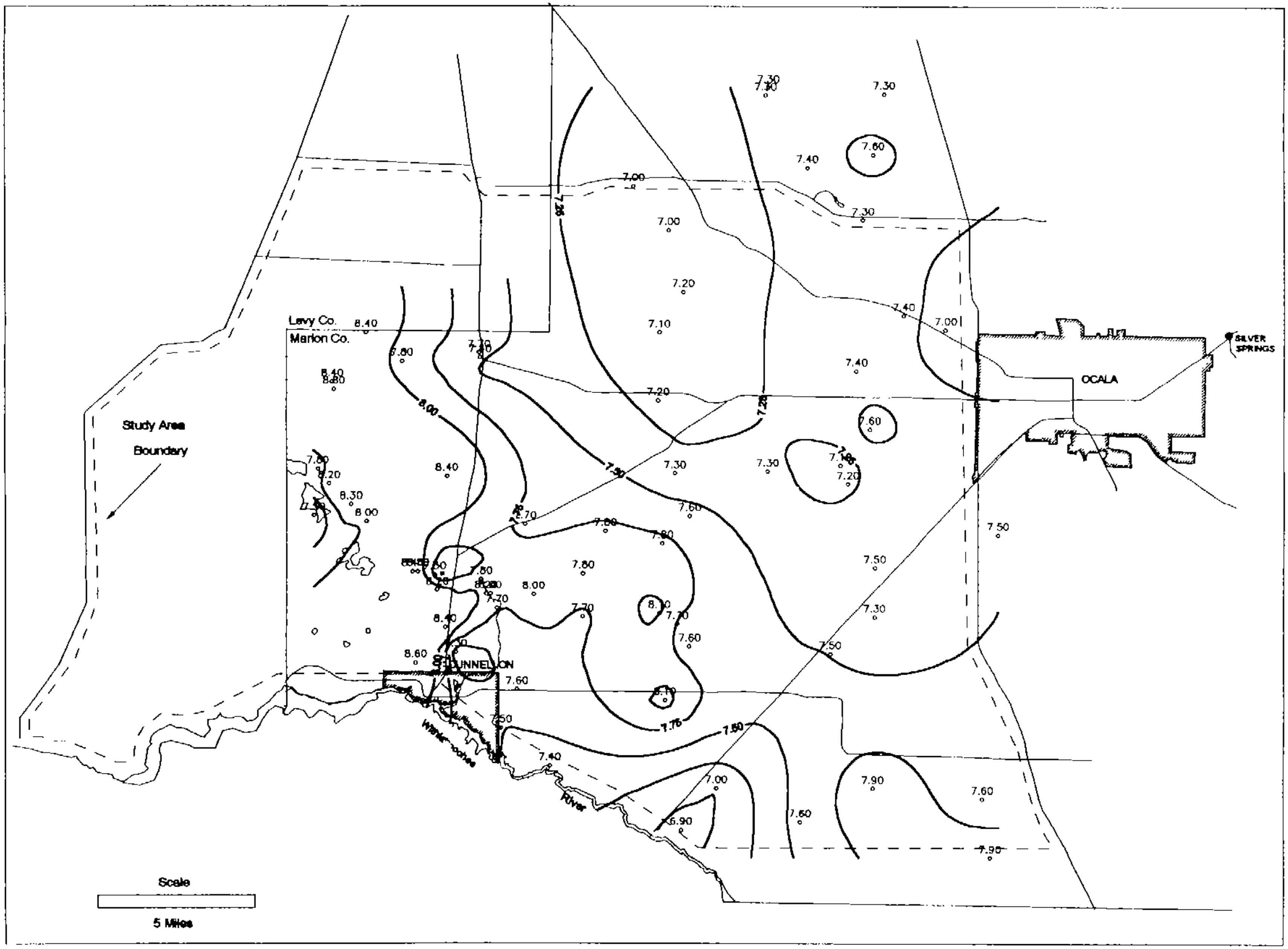

Figure 18. pH level (s.u.) in Study-Area Ground Water.

Concentrations of calcium and bicarbonate are low in the eastern portion of the study area and highest in the central portion. Concentrations are low in the vicinity of the springs and especially low in the western portion of the study area. Low concentrations near the springs are expected because the flow system is probably conduit-dominated and groundwater residence time is short.

In comparing pH to concentrations of calcium and bicarbonate, an apparent anomaly exists in the area nearest the springs and in the western portion of the study area. In this area, low calcium and bicarbonate should result in relatively low pH, similar to that seen in the eastern portion of the study area. However, pH regularly exceeds 8.0 in this area. This anomaly is addressed in greater detail on page 74 .

Chloride

Chloride is a chemically conservative[4] element, so it is usually used as a tracer of physical water flow. Rainfall typically contains less than 10 mg/l chloride (Upchurch, 1993). Figure 18 shows the distribution of chloride in the study area. Most of the area has chloride concentrations similar to rainfall, which suggests recently recharged water in a shallow flow system.

Chloride exceeds 10 mg/l in the north central portion of the study area (Fairfield Hills area). Chloride may be elevated in this area because the Hawthorn clays in the Fairfield Hills contain residual seawater or because low infiltration rates associated with clay-rich soils may afford opportunity for evaporative concentration of chloride. Chloride is also elevated in the area directly east of Dunnellon.

Sulfate

Sulfate (SO_4^{2-}) is formed by oxidation of pyrite (FeS_2), a common mineral in marine sediments; oxidation of organics; and dissolution of gypsum ($CaSO_4.2H_2O$) or anhydrite ($CaSO_4$). See Upchurch (1993) for samples of these reactions. Pyrite is widespread in Florida rocks, and it is especially abundant in the clays of the Hawthorn Group near Ocala. Oxidation of organics is also universally important. There is minimal gypsum and/or anhydrite in near-surface sediments, but the base of the upper Floridan aquifer is characterized by these minerals. Sulfate is also abundant in seawater. Therefore, with the exception of the transition zone, shallow flow-system waters typically contain minor concentrations of sulfate. Deep-flow systems that come in contact with the base of the

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

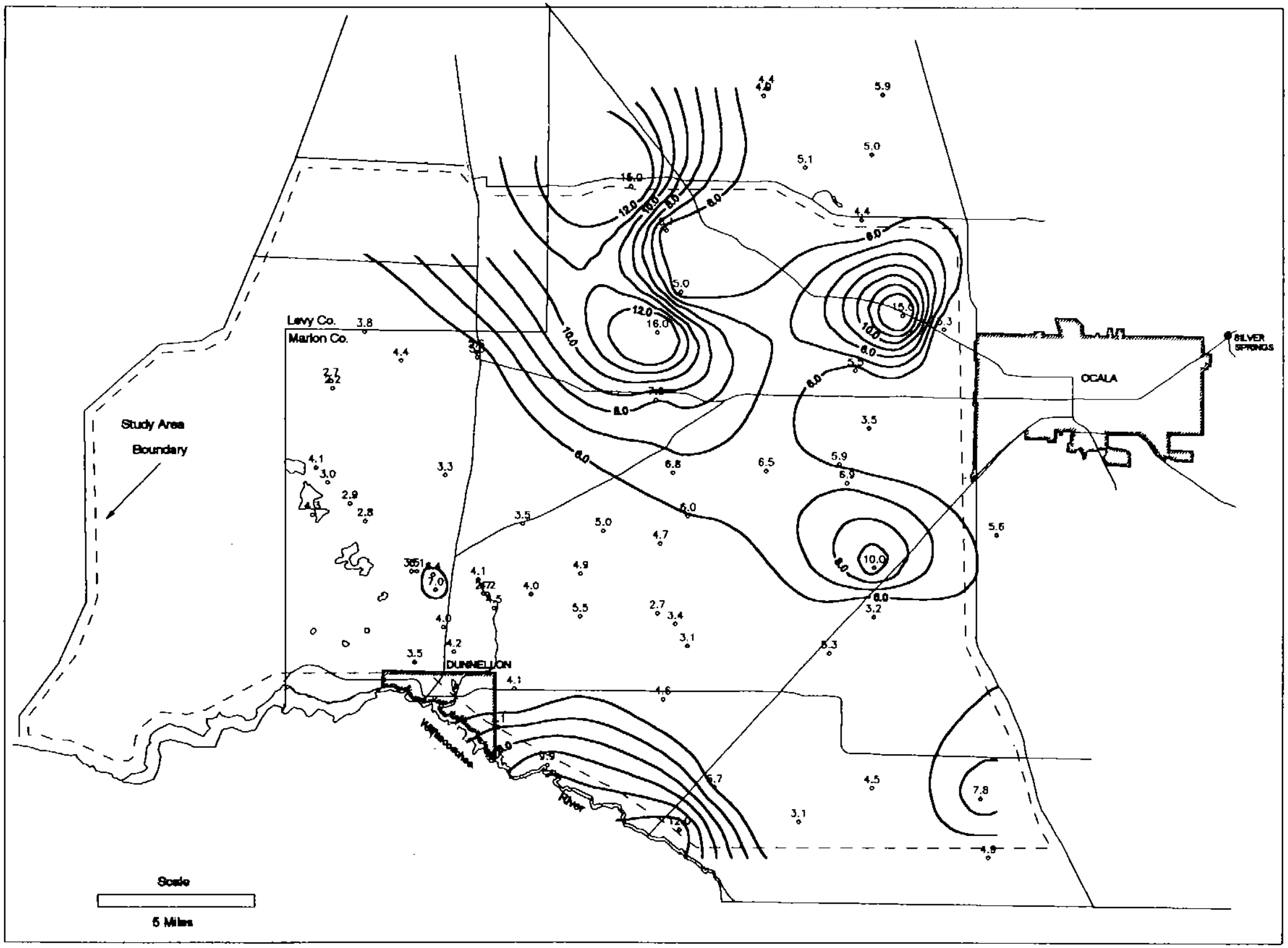

Figure 18. Chloride Concentrations in Study-Area Ground Water.

aquifer may contain significant sulfate, especially near the inner margin of the transition zone (Upchurch, 1993). Therefore, the distribution and concentrations of sulfate can be used to deduce the depth and extent of flow systems and interactions of ground water and host sediments.

Figure 19 shows the distribution of sulfate in study area ground water. There appears to be a zone of high sulfate that trends northeast-southwest from just northwest of Ocala to the Rainbow River. The linearity of the zone and the fact that the trend matches one of the principal fracture orientations in the region may indicate that the sulfate distribution is fracture controlled. The fracture may provide a conduit for the upward migration of sulfate-rich water from deeper portions of the Floridan aquifer where gypsum dissolution is occurring.

Total Dissolved Solids (TDS)

The distribution of total dissolved solids (TDS) in the recharge area is shown in Figure 20. The data reflect concentrations of calcium, bicarbonate, magnesium, sodium, sulfate and chloride in the ground water (Appendix II). The TDS content of ground water in the study area is a result of three processes: (1) residence time in the aquifer, (2) chemical reactivity of the aquifer rock with the water, and to a much lesser extent, (3) human influences (contamination). Limestones, dolostones, and evaporite deposits are relatively reactive, so residence time is the dominant natural process that influences TDS concentrations.

TDS concentrations are lowest to the west and northwest of the springs (Brooksville Ridge area). TDS is slightly higher east of the spring and in a narrow north- south trending band along the eastern boundary of the study area. The low TDS areas are locations where recharge is rapid and residence time in the aquifer is short.

TDS concentrations are elevated in the north-central portion of the study area (Fairfield Hills) and in the area east of Dunnellon. Transmissivity is probably lower in these areas which results in increased ground-water residence time. This allows for increased dissolution, which contributes to a higher TDS content.

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 Rainbow Springs, it is first necessary to discuss a few basic principals of nitrogen aqueous geochemistry. These principals are discussed in the following section, which contains excerpts from Upchurch (1993) and Bicki et al., (1984).

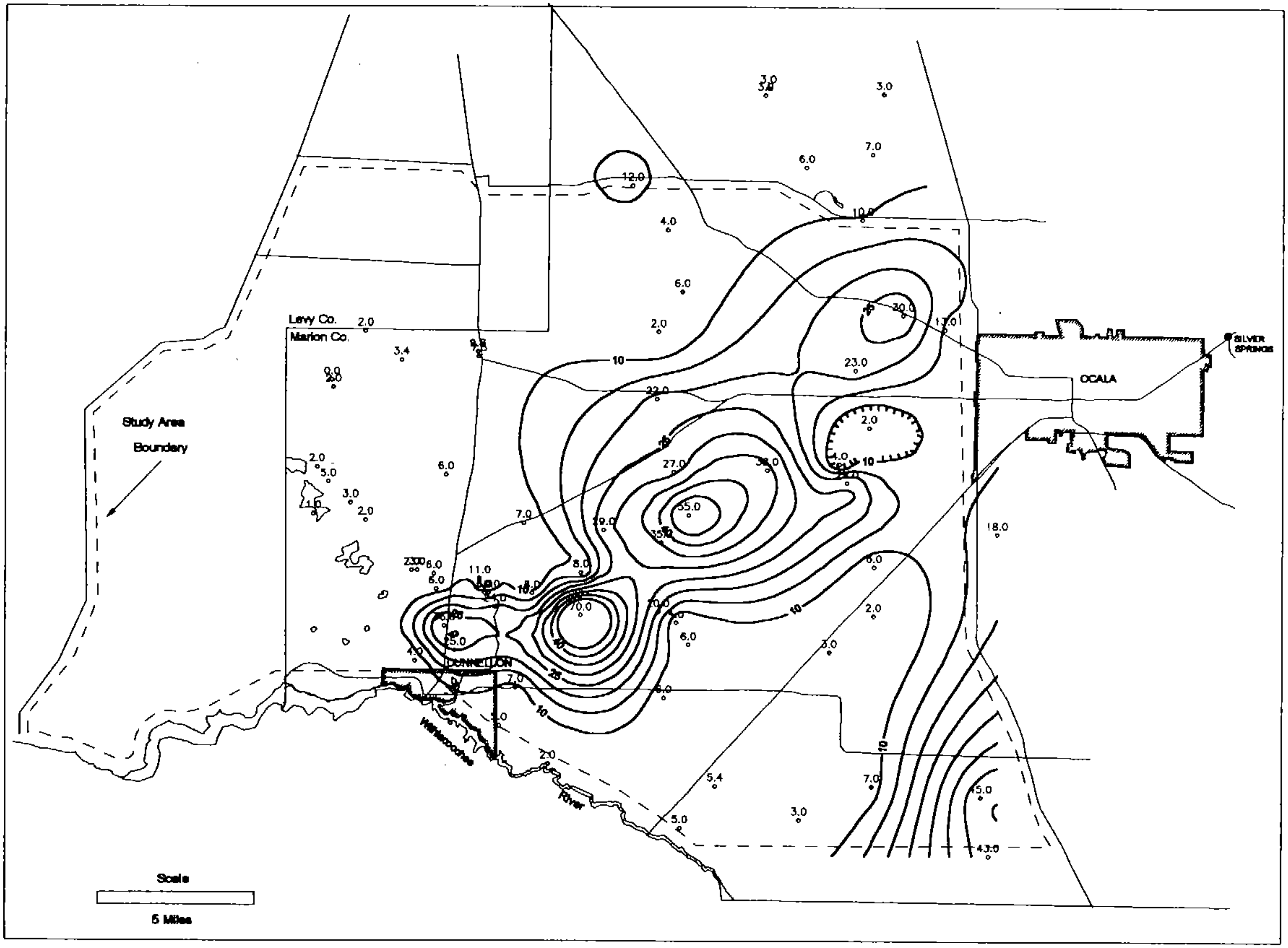

Figure 19. Sulfate Concentrations in Study-Area Ground Water.

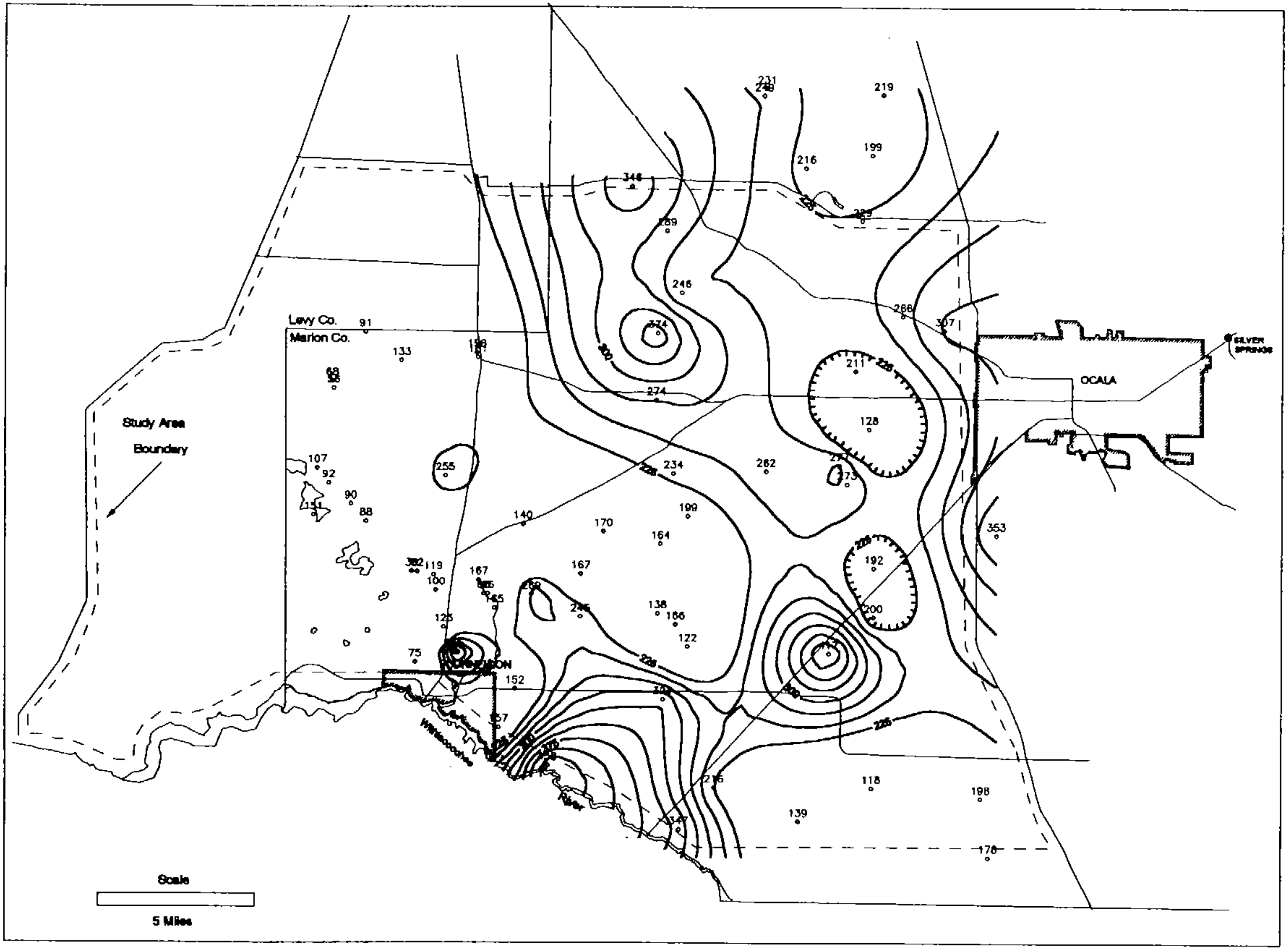

Figure 20. TDS Concentrations in Study Area Ground Water.

Nitrate (NO_3^-), which is one of the nitrogen species that has been targeted as a source of nitrogen in the Rainbow Springs 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^-), and a number of other inorganic and organic compounds. 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

$$\textit{Organic Nitrogen} \rightarrow NH_4^+ \rightarrow NO_2^- \rightarrow NO_3^-.$$
$$\text{---}\textit{Oxidation}\text{-}\rightarrow$$
$$\leftarrow\text{-}\textit{Reduction}\text{---}$$

The reduction/oxidation reactions indicated in the above reaction series can be driven by inorganic processes, but the primary mechanisms for the reactions are microbial. If the environment is chemically oxidizing, nitrate will be the final product. In these aerobic environments (>0.3 mg/l 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, 1993). 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 ground water discharging from the springs. 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, however.

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[5], 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

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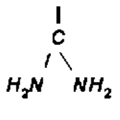
[5] Urea is a principal nitrogen product in urine. It has the structural formula  $H_2N{-}C({=}O){-}NH_2$. Urea is an excretion product of the liver.

mitigate ammonium migration. Septic-tank systems, land-application waste-treatment systems, and feed-lot wastes can, under circumstances of overloading or failure of sorption systems, cause widespread ammonium contamination.

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

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

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

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

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, which is subject to a Primary Drinking Water Standard (Florida Department of Environmental Regulation, 1989). The limit under the Primary standard is 10.0 mg/l as N, or 44.0 mg/l as NO_3^-. There is a health advisory for nitrate at 1.0 mg/l as N (4.4 mg/l as NO_3^-), as well. The major cause of concern is methemoglobinemia, an excess of methemoglobin[6], which causes oxygen deprivation. This condition is especially hazardous in infants and young children, where it produces a condition known as "blue baby syndrome" (Hersh, 1968; Hem, 1986). There are no standards for ammonium or other nitrogenous decay products in ground water (Florida Department of Environmental Regulation, 1989).

Each of the nitrogen species in ground water can cause problems where present in excess. If nitrification of ammonia does not deplete oxygen, it may form excess nitrate. Nitrate is very soluble and does not interact with soil components under aerobic conditions. It travels through the soil-water environment practically unimpeded. Unless conditions for denitrification exist, nitrate will not undergo further transformations once in the ground water (Preul and Schroepfer, 1968; Bouma, 1975; 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).

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/or in the immediate vicinity of a source.

The distribution of ammonium in study area ground water is shown in Figure 21. Ammonium concentrations are uniformly low throughout the study area. The presence of so little ammonium and so much nitrate in the Floridan aquifer is a strong indication that

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[6] 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.

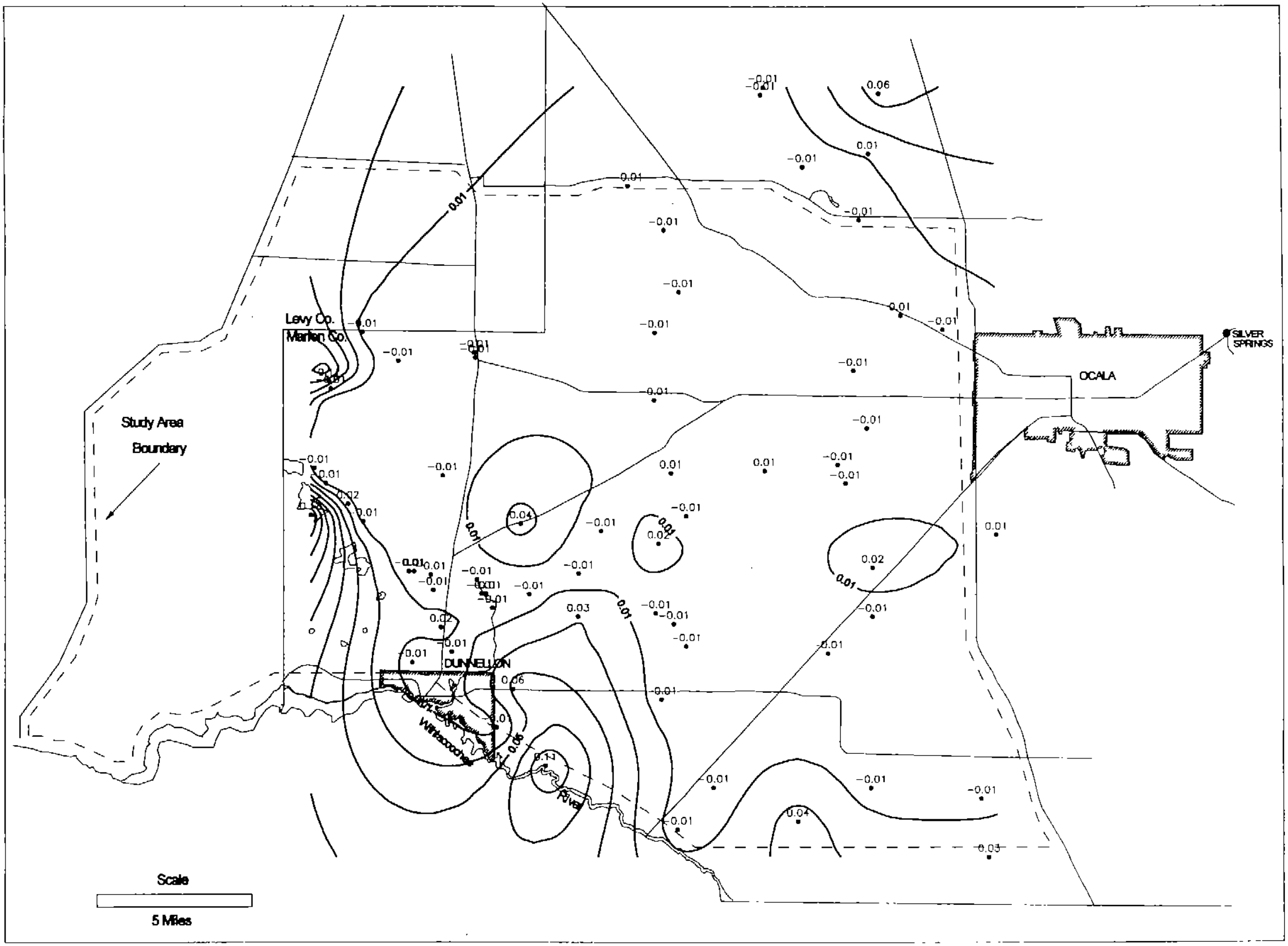


Figure 21. Ammonium Concentrations in Study-Area Ground Water.

ground water in the upper portion of the Floridan aquifer in the study area is flowing in a shallow, well oxygenated flow system, which allows rapid conversion of ammonium to nitrate.

Nitrite

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

Nitrite concentrations are very low in the study area. Similar to the low ammonium concentrations, the low nitrite concentrations are indicative of a shallow, well oxygenated flow system that allows rapid conversion of nitrite to nitrate. Figure 22 shows the distribution of nitrite in the study area. Elevated nitrite was found in only one well, located just east of Dunnellon. This well reflects a local source, not a regional problem.

Nitrate

Figure 23 shows the distribution of nitrate in the study area. From the figure it is apparent that ground water in the study area is widely enriched in nitrate. Sixty six wells were sampled for nitrate in the study area. Table 3 is a breakdown of nitrate concentrations in wells in the study area.

Table 3 - Summary of Nitrate Concentrations in Study Area Wells.

Nitrate Concentration Range (mg/l)	**Percentage of Wells**
3.0 to 5.2	6
1.0 to 3.0	23
0.5 to 1.0	24
0.1 to 0.5	30
0.01 to 0.1	3
<0.01	14

The table indicates that the majority of wells have concentrations that are significantly elevated above naturally-occurring levels (generally < 0.1 mg/l). Nitrogen isotopic ratios of ground water from monitor wells (p. 68) and springs (p. 92) indicate that the source of the nitrogen is mainly inorganic fertilizers.

The highest nitrate concentrations occur just west of Ocala. As stated in the TDS section, this is an area of high recharge. Because recharge is high, nitrogen applied to the surface as fertilizers or animal waste quickly enters the flow system which results in

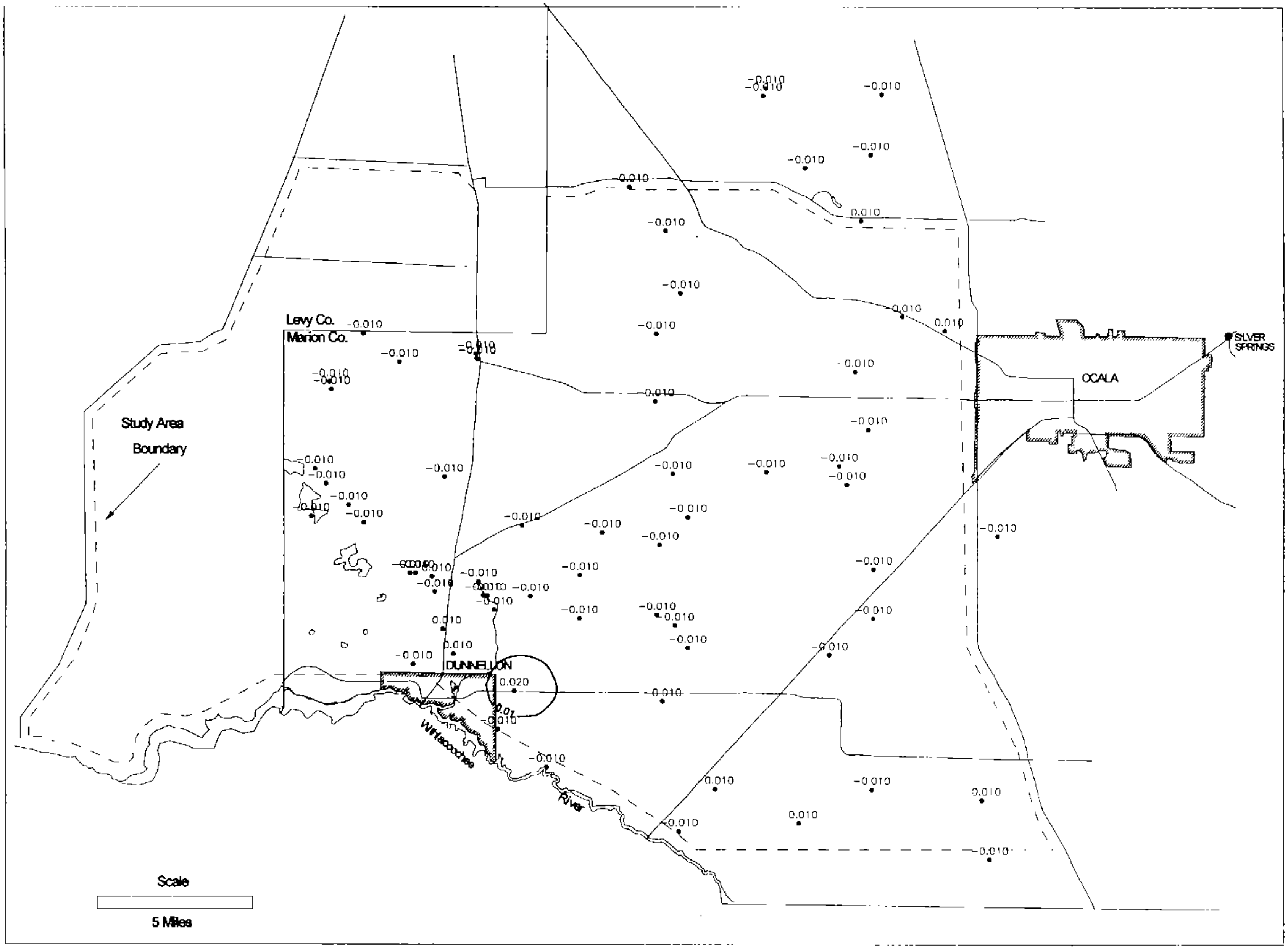


Figure 22. Nitrite as N Concentrations in Study-Area Ground Water.

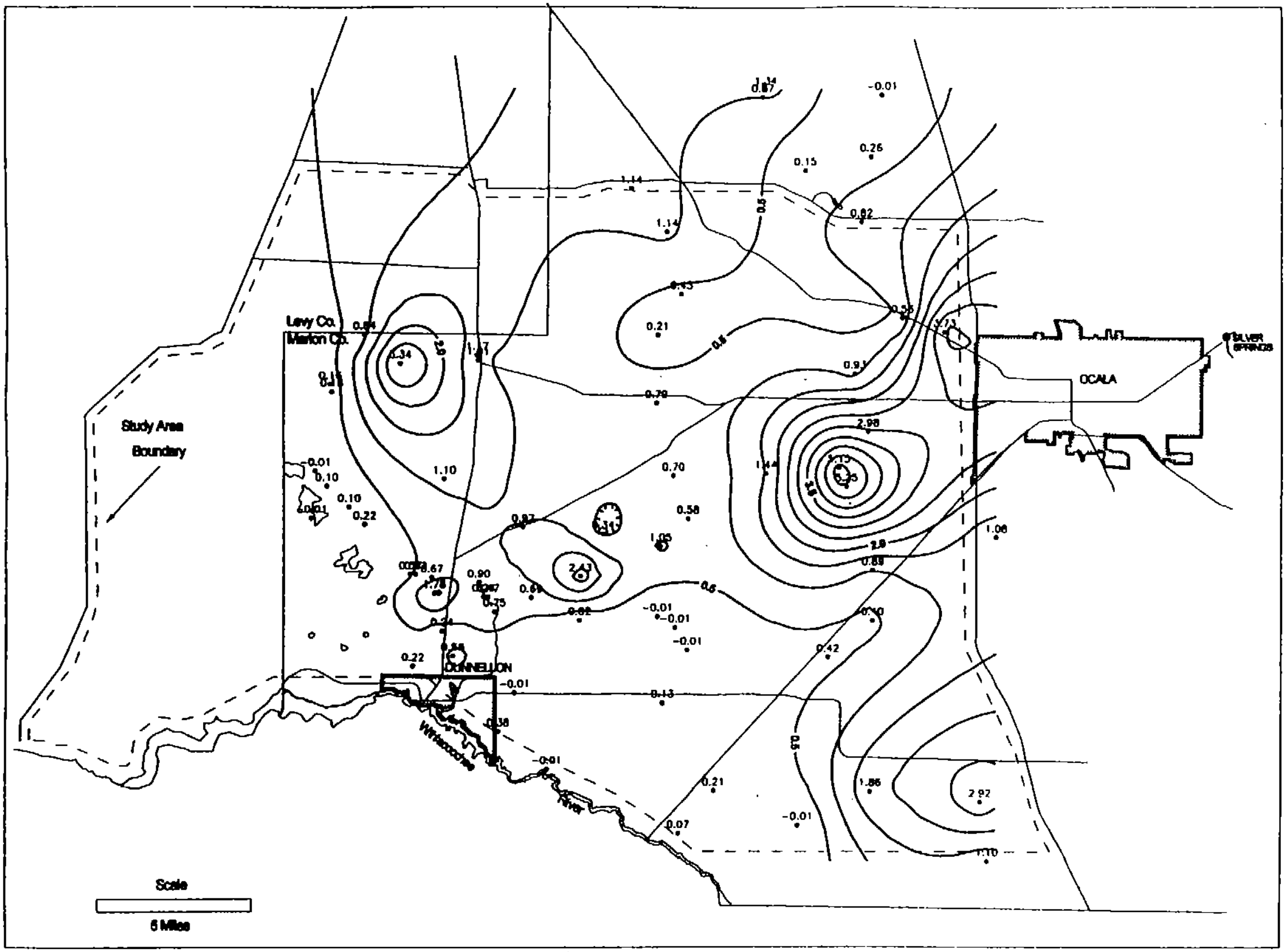


Figure 23. Nitrate as N Concentrations in Study-Area Ground Water.

enriched ground-water nitrate concentrations. It should be remembered that this area of elevated nitrate straddles the divide between the Rainbow Springs and Silver Springs ground-water basins. Therefore, a portion of this nitrate enriched ground water will flow east and eventually discharge at Silver Springs.

From this area of high nitrate concentrations west of Ocala, there appears to be a linear zone of elevated nitrate that extends southwest to the head spring area. This zone corresponds to the trend of the fracture system referenced in previous sections of this report (p. 42). If this zone is a fracture, it may serve as a conduit to transport nitrate from the area west of Ocala, directly to Rainbow Springs. In addition, the numerous, large, closed depression features along the zone would serve as entry points for nitrate-enriched surface runoff across the entire length of the zone.

Nitrate concentrations are also high in the western portion of the study area (Brooksville Ridge) in a linear zone extending to the northwest from the head spring area. This zone has also been identified previously in this report as a possible fracture zone that connects numerous, large, closed depressions.

Nitrate concentrations are lowest in the north central portion of the study area (Fairfield Hills). This is a result of the presence of Hawthorn clays that overlie the Floridan aquifer in the area. The clays are responsible for the very low nitrate concentrations because nitrogen applied to the surface is prevented from infiltrating into the Floridan aquifer. Nitrate concentrations are also low in the area directly east of Dunnellon because the forests and wetlands in the area are not significant sources of nitrogen.

Additional Nutrients

Total Organic Carbon (TOC)

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 1993), 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 surficial aquifer waters where confinement is breached.

Figure 24 shows the distribution of TOC in the study area. Elevated TOC values to the east of Dunnellon may result from recharge to the Floridan aquifer of organic-rich water generated in numerous wetlands in the area. High TOC values appear to be scattered randomly throughout the well-drained karst areas. These may be from wells in close proximity to sinkholes that receive organic-rich surface water.

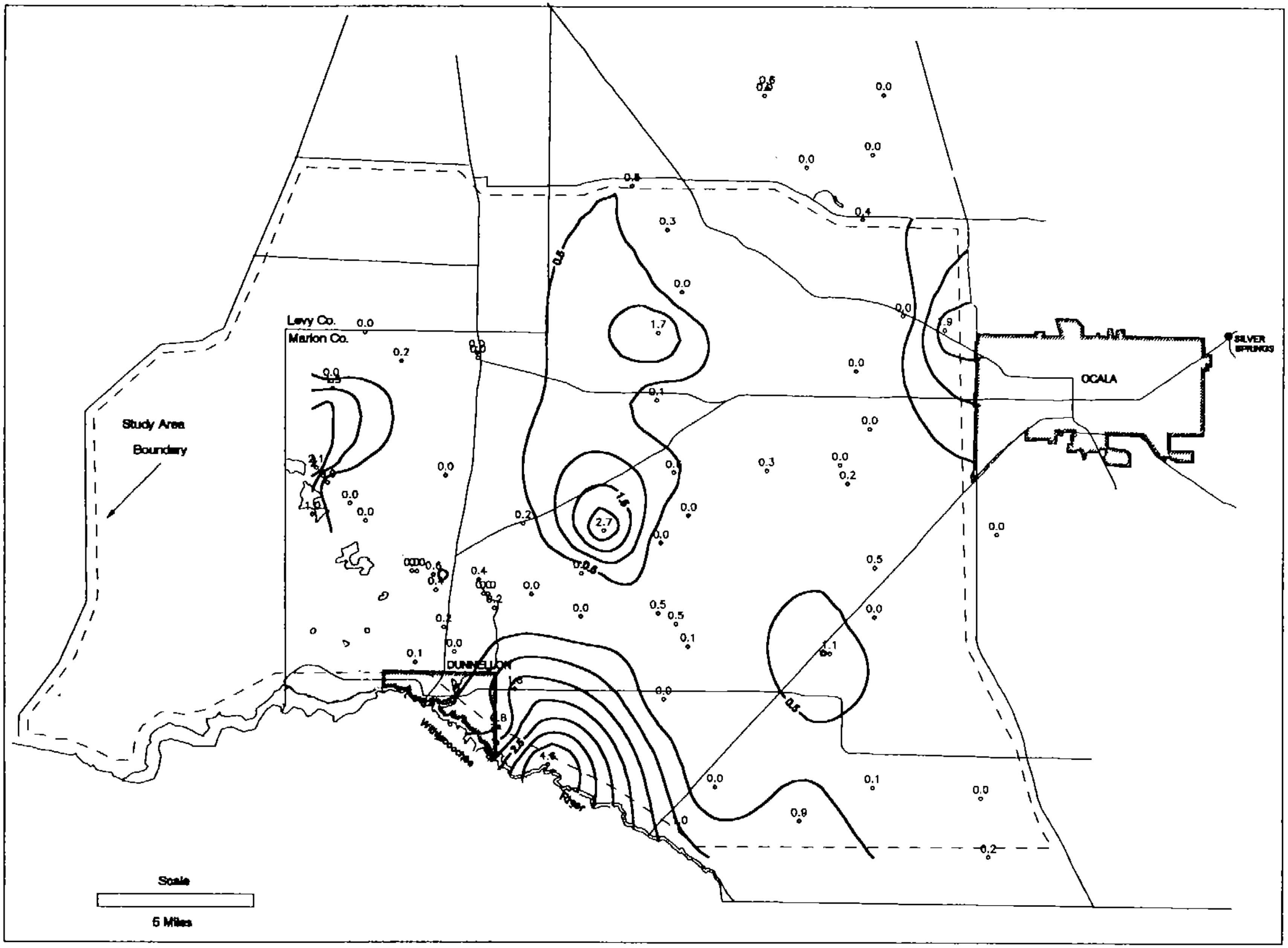


Figure 24. Total Organic Carbon Concentrations in Study-Area Ground Water.

Total Phosphorus and Orthophosphate

The analyte total phosphorus includes complex organic compounds as well as simple inorganics. It is an indicator of localized contamination by organic sources, such as animal wastes. Orthophosphate (PO_4^{3-}) is derived from certain detergents, decomposition of complex organics, food additives, and weathering of phosphatic minerals in the Hawthorn Group (Upchurch, 1993). Orthophosphate is relatively insoluble in alkaline, carbonate-rich aquifers, and carbonate-fluorapatite is a typical precipitate. If orthophosphate is present in the limestone aquifers of the intermediate or Floridan aquifers, local recharge is often indicated (Upchurch and Lawrence, 1984). Organic phosphorus compounds are destroyed by the microbial reactions discussed previously. Orthophosphate is strongly sorbed onto ferric hydroxides in soils and aquifers and quantitatively precipitated in alkaline waters, so it should also not travel far from its source. Orthophosphate concentrations were so low that they were not plotted and contoured.

Similar to TOC, phosphorus compounds (Figure 25) are elevated in the area to the east of Dunnellon and probably result from the recharge of phosphorus-rich water in wetlands into the Floridan aquifer. Phosphorus compounds are also elevated along the extreme eastern edge of the study are, immediately west and southwest of Ocala. This Area, which contains numerous horse farms, may be contributing phosphorus from animal waste into the Floridan aquifer.

Isotopes

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 can be useful in determining the source aquifer and recharge area of ground water discharging from the springs. The following two paragraphs are modified excerpts from Cowart and Osmond (1992).

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

Rapidly recharging waters in a shallow, karst flow system, which is characteristic of the study area, tend to have a distinctly different character. These waters exhibit higher

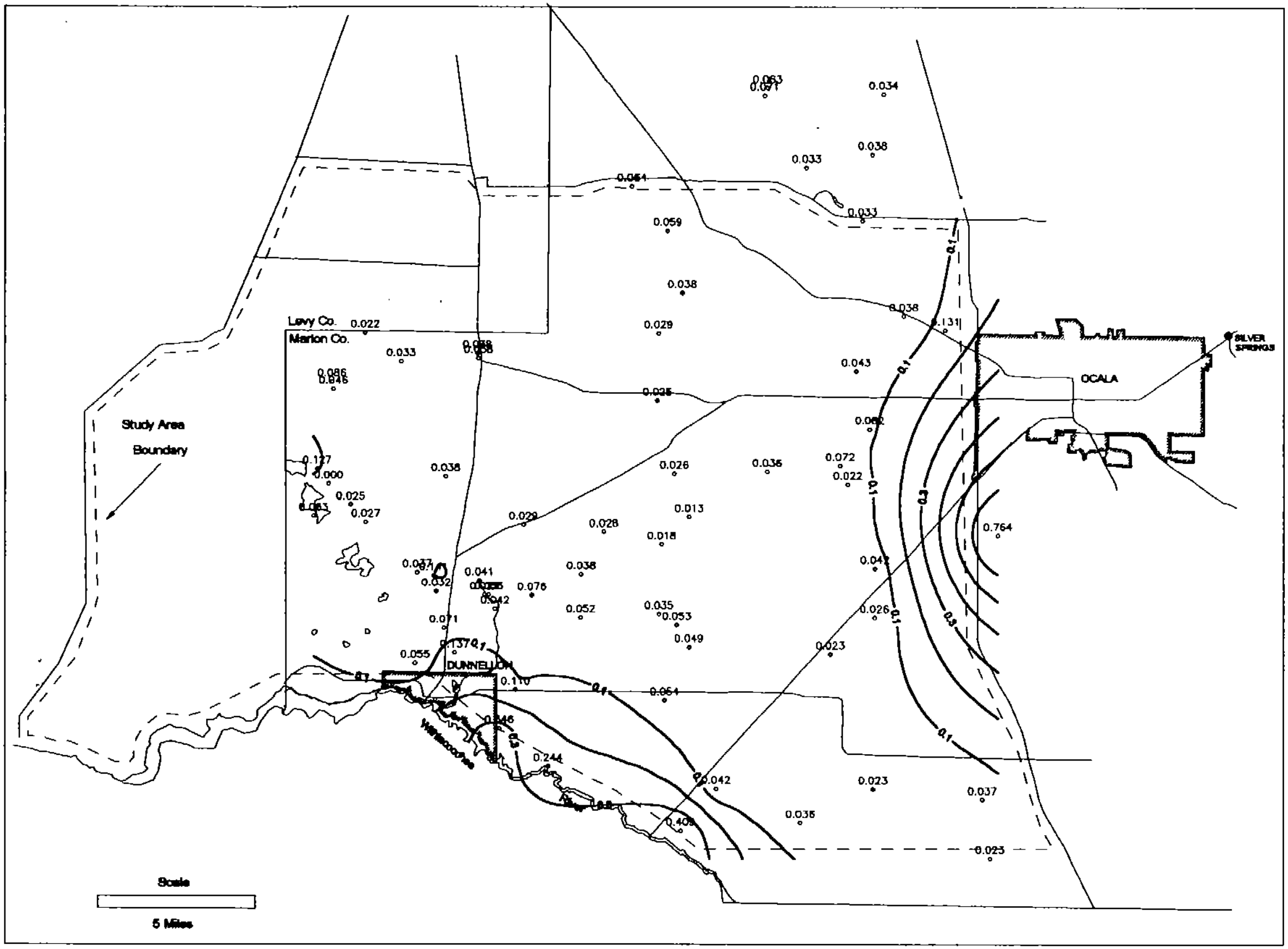


Figure 25. Total Phosphorus Concentrations in Study-Area Ground Water.

concentrations of uranium with much lower $^{234}U/^{238}U$ activity ratios (sometimes with less than the equilibrium value of 1). This results from: (1) the oxidizing nature of the rapidly recharging water mobilizes uranium as a complex of the U^{6+} ion (uranyl, UO_2^{+2}), (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.

Seventeen wells were sampled for uranium isotopes. The analysis and interpretation of the samples were completed by Dr. James Cowart at Florida State University. Uranium data from four additional wells (designated as CE, Figure 26) that were sampled for uranium isotopes in 1969 were added to the data set. The fact that the collection dates of the two groups of samples are separated by 25 years does not affect the comparability of the data (written communication, Dr. James Cowart).

The distributions of $^{234}U/^{238}U$ activity ratio and uranium concentration data are shown in Figure 26. Northwest of the head-spring area, wells #103 and #92, at approximately 5.0 and 10.0 miles from the head-spring area respectively, have the low activity ratio (<1.1), high concentration signature (> 0.1) that is indicative of rapid recharge and flow in a shallow, short system. These wells are located along the northwest-southeast trending fracture zone and their uranium content is consistent with the rapid recharge and flow that is probably occurring along the fracture. They are also in a region characterized by phosphate deposits. The observed low TDS concentrations in the area northwest of the springs are also consistent with this interpretation.

Wells #112 and #62, approximately 4.0 and 6.0 miles northeast of the head-spring area respectively, are located along the northeast-southwest trending fracture zone. These wells also have the low activity ratio, high concentration signature indicating rapid recharge and flow. Well #117, located approximately 3.0 miles to the northeast of the head-spring area has a similar signature.

Wells #63, #78, and #80, located approximately 4.5, 7.0 and 11.0 miles southeast of the head-spring area respectively, and wells CE 13, CE 73, and CE 22, located approximately 2.0, 5.0, and 8.5 southeast of the head-spring area respectively, all have the low activity ratio, high concentration signature. However, the uranium signature of well #80 may not be relevant because it is probably outside of the RSGWB.

Many of the remaining wells sampled for uranium isotopes are distant from the head-spring area. Typically, these wells have a higher uranium activity ratio (> 1.1) than the wells discussed previously. The higher ratios from these wells may be indicative of lower recharge and a more sluggish flow system resulting from the presence of the Hawthorn clays in the Fairfield Hills area.

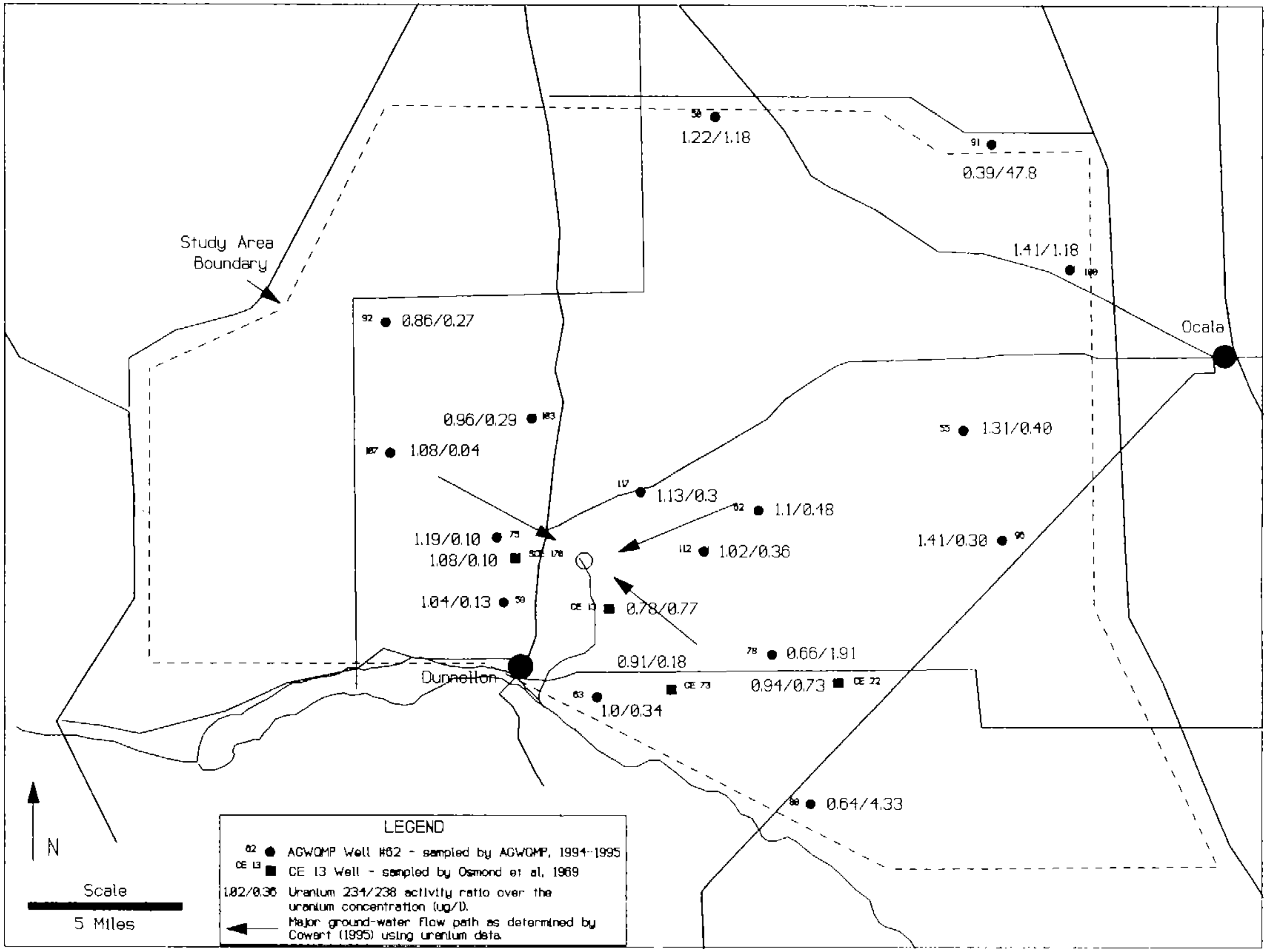


Figure 26. Uranium Isotopic Ratios and Concentrations in Study-Area Ground Water.

Cowart (written communication, 1995) showed that different geographic areas in the study area have a distinct uranium isotope character. This was accomplished by constructing a graph where the $^{234}U/^{238}U$ activity ratios of well samples were plotted against the reciprocal of their concentrations of ^{238}U. Wells to the northeast of the springs cluster in one field, wells to the southeast of the springs cluster in a separate and distinct filed, and wells to the northwest and west of the springs cluster in yet a different part of the plot. By similarly plotting the spring samples, Cowart noted the relationships between individual springs and well clusters and was able to establish three main flow paths in the vicinity of the upper Rainbow River (Figure 26). These isotopically-delineated flow paths correspond well with those delineated with the chemical parameters (p.95).

Nitrogen Isotopes: Differentiation of Nitrate Sources

Although many proven sources of nitrate, including septic-tank effluent, treated sewage effluent, commercial and residential landscape fertilizers, land spreading of septage and sewage sludge, and agricultural fertilizers are present in the study area, it is difficult to determine the relative contributions of these sources to the nitrate 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). 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 ppt to +8 ppt. Nitrate from animal-waste nitrogen ranges from +10 ppt to +20 ppt. 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 ppt to +6.2 ppt, with 90% of the samples ranging from -3 ppt to +2 ppt (Kreitler, 1975; Kreitler and Jones, 1975).

Nineteen wells in the study area were sampled for nitrogen isotopes. Figure 27 shows the spatial distribution of $\delta^{15}N$. The wells have $\delta^{15}N$ values that range from -0.5 ppt to +7.7 ppt with an average value of +2.4 ppt. Except for the 7.7 value, all of the $\delta^{15}N$ ratios are well within the inorganic nitrogen fertilizer range and all the values are within the range of natural decay in unfertilized soils. However, it is unlikely that the $\delta^{15}N$ ratios are the result of natural decay in unfertilized soils because the nitrate concentrations in the wells are probably too high to have originated from natural sources. It follows then that the $\delta^{15}N$ ratios strongly indicate that the principal source of nitrate in ground water in the study area is agricultural fertilizers.

Tritium: An Indicator of Ground-Water Travel Time

Tritium (^3H) is a rare isotope of hydrogen that is formed by cosmic-ray activation of nitrogen. Determining the tritium content of ground water in an aquifer helps to determine whether the aquifer is being recharged locally or from a more distant source. Because of

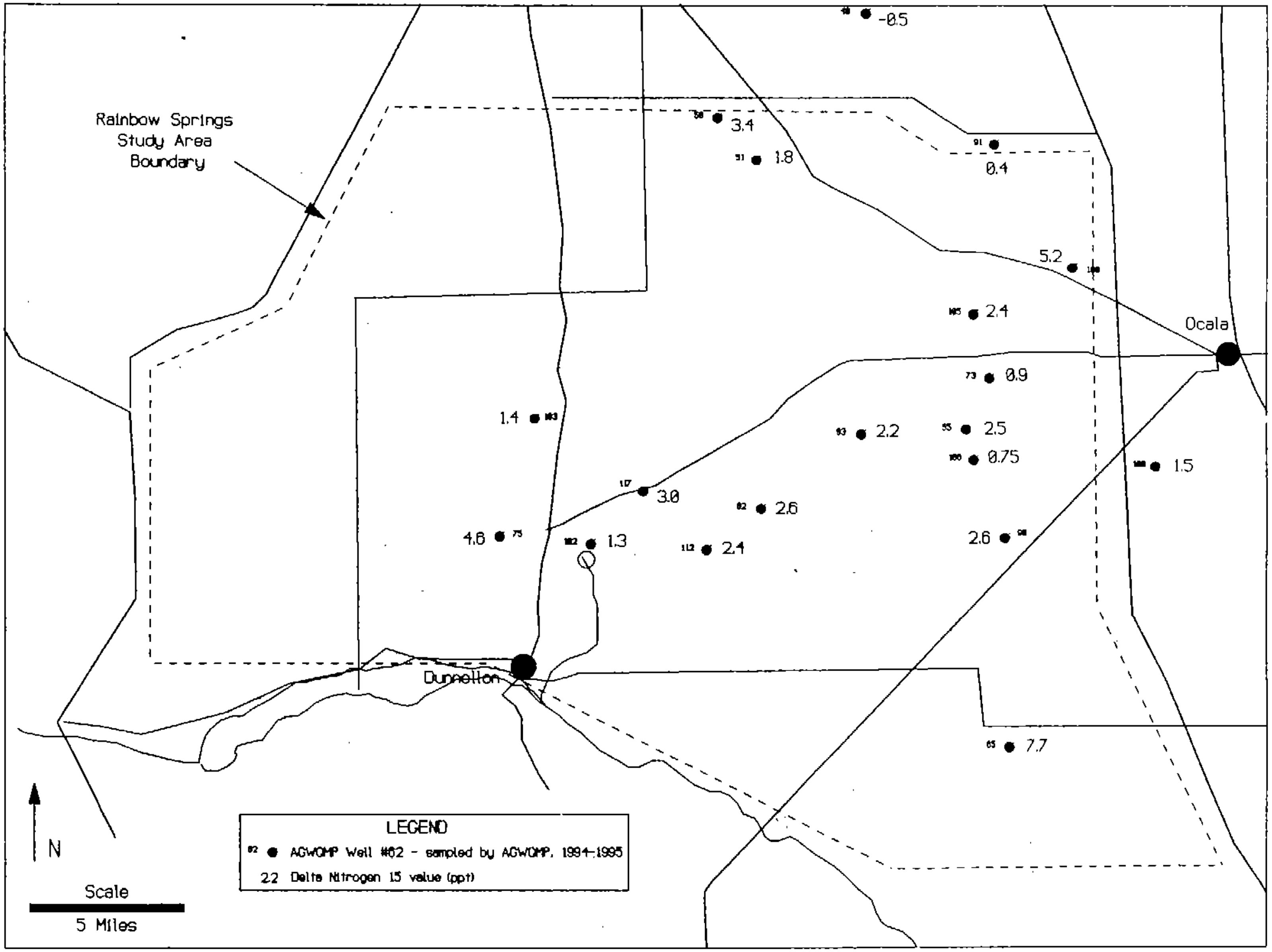


Figure 27. $\delta^{15}N$ Isotopic Ratios in Study-Area Ground Water.

the dramatic increase in 1952, tritium provides a useful marker for relatively young water in the hydrologic cycle.

A number of studies in the northern portion of the SWFWMD determined that ground water in the shallow portion of the Floridan aquifer has entered the aquifer very recently. Faulkner (1970) investigated the tritium content of ground water in the Rainbow Springs study area and found tritium activities in wells and springs as high as 174 TU at the same time (1966-68) that rainfall contained activities as high as 158 TU. Activities in Rainbow and Silver Springs ranged from 38 to 85 TU and 25 to 150 TU, respectively. This indicates that a large percentage of the water discharging from Rainbow and Silver Springs in 1966-68 could not have been in the flow system for more than 16 years at the most.

Swancar and Hutchinson (1992) used tritium to show that Floridan aquifer waters in the northern half of the District are relatively young, with activities of 8 to over 10 TU common. They also concluded that recent recharge water has relatively low tritium concentrations (on the order of 10 TU as opposed to higher activities) because of (1) relatively long periods required for recharge and (2) mixing with older waters in the Floridan aquifer.

Jones and Upchurch (1994), in a study of the King's Bay Spring System and recharge area in the northern half of Citrus County, used tritium to show that ground water in the Floridan aquifer entered the aquifer sometime between 1952 and the present.

DELINEATION OF GROUND-WATER QUALITY DOMAINS

Introduction

The Floridan aquifer in the study area was divided into 6 water-quality domains based on an analysis of the geology and water quality of the study area (Figure 28). Delineation of the domains was accomplished by grouping wells that exhibited similarities in chemical analytes. Table 4 displays the mean concentrations of 8 major constituents from wells within the 6 domains. The differences in water quality between groups of wells in the study area appear to be controlled by geologic factors such as the presence or absence of clays of the Hawthorn Group overlying the Floridan aquifer, the degree to which the clays are breeched by sinkholes, the transmissivity of the aquifer, and the presence of fractures. The following is a discussion of the process used to delineate the domains.

Domain I

Domain I straddles the divide between the Rainbow Springs/Silver Springs Ground-Water Basins. The water quality of domain I is very similar to that of domain III. The domains are distinguished on the basis of much higher sulfate concentrations in domain III ground water. Domain I is distinguished from domain II by relatively lower TDS, conductivity, bicarbonate, calcium, and chloride. The concentration of these parameters is relatively low because domain I is an area of high recharge where large amounts of low-TDS rainfall are entering the aquifer. The potential for high recharge in this area is indicated by the numerous, large, closed-depression features (Figure 13). In addition, the uranium signature of well #91 supports rapid recharge and flow. The mean nitrate concentration in domain I is much higher than that of the other domains. This is because the concentration of nitrate in domain I, in several wells located mainly in areas of extensive pasture, is much higher than nitrate concentrations in other wells in the study area.

Domain II

With the exception of sulfate and nitrate, the concentrations of domain II analytes are significantly higher than those observed in the other domains. This is probably a result of increased confinement of the aquifer and longer transport distances and residence times. The Floridan aquifer in the area of domain II is overlain by the Hawthorn clays of the Fairfield Hills physiographic subdivision. The clays inhibit the movement of low TDS rainfall into the Floridan aquifer and may contribute ions such as chloride to ground water. The presence of the clays may also have resulted in the development of a less transmissive flow system where relatively slow ground-water movement and relatively long residence times result in higher TDS concentrations. The lack of closed depression features in this area is an additional indication of a less transmissive flow system. In addition, the

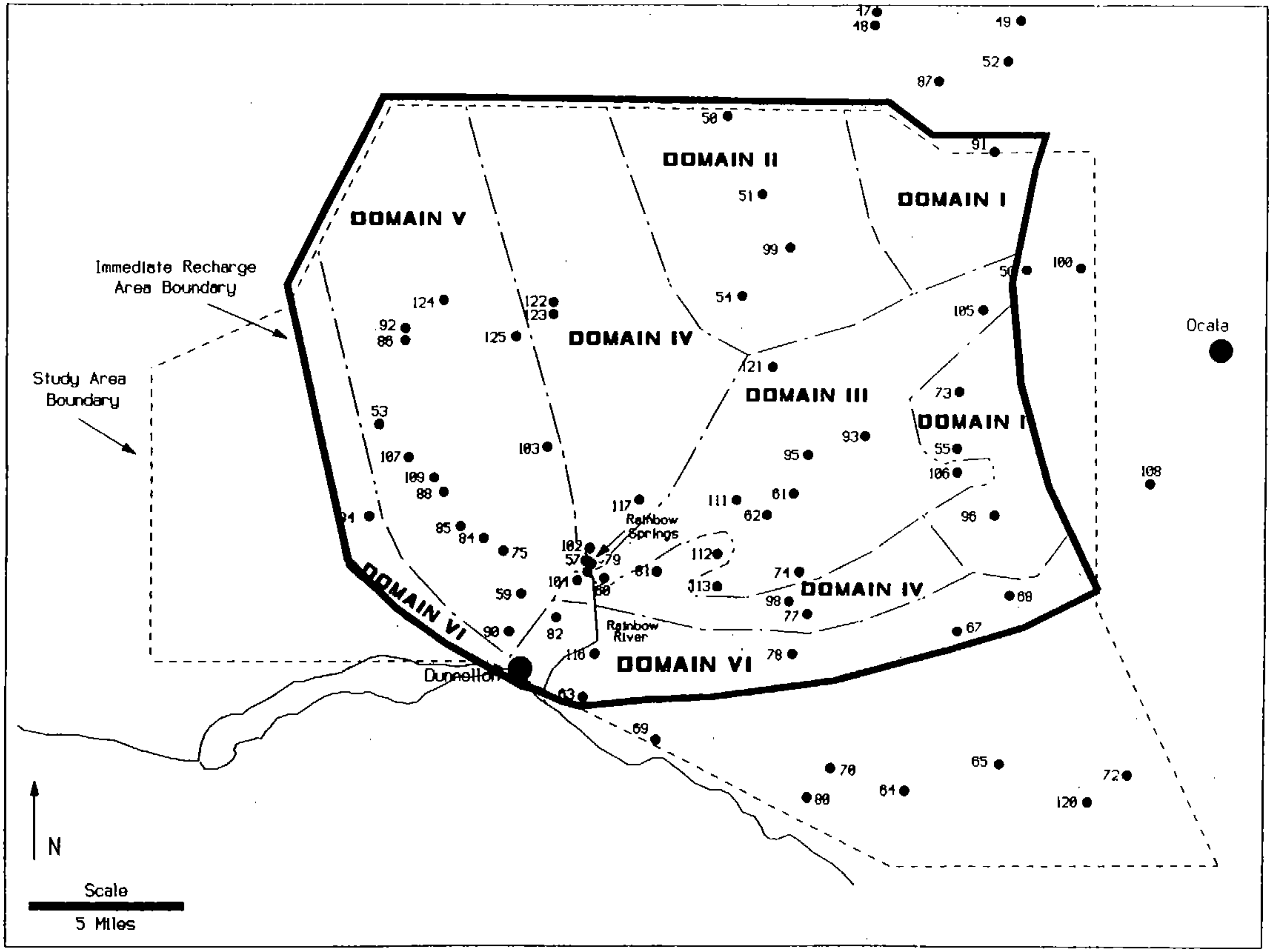


Figure 28. Location of 6 Ground-Water Quality Domains in the Immediate Recharge Area.

Table 4. Major Constituent Concentration Means for Wells within Ground-Water Quality Domains (mg/l unless otherwise noted).

DOMAIN	pH (std. units)	Sp. Cd. (umhos)	HCO_3	Cl	SO_4	Ca	NO_3	TDS
I	7.40	342.0	148.0	5.9	5.5	64.7	2.5	224.0
II	7.05	509.0	233.0	10.3	6.0	98.5	0.73	313.0
III	7.51	362.0	119.0	6.4	33.5	63.2	1.0	216.0
IV	7.67	255.0	116.0	4.5	7.0	48.0	0.87	165.0
V	8.25	165.0	64.6	3.9	5.4	26.3	0.63	96.4
VI	7.50	342.0	173.0	4.7	7.0	68.0	0.27	249.0

relatively high uranium activity ratios of wells #50 and #100 are further indications of low recharge in this domain.

Domain III

Domain III is delineated on the basis of sulfate concentrations that are elevated significantly over those in the other domains. These elevated sulfates probably result from the presence of the major northeast-southwest trending fracture zone discussed previously on page 42. The linearity of the area of elevated sulfate concentrations (Figure 19) supports the existence of a fracture. The fracture probably provides a conduit for the upward migration of sulfate-rich water from deeper portions of the Floridan aquifer where gypsum dissolution is occurring. Nitrate concentrations are higher in domain III than in all other domains with the exception of domain I. This is the result of high nitrate levels in several wells located mainly in areas of extensive pasture.

Domain IV

The water quality of domain IV is similar to that of domain III. The distinguishing characteristic is the elevated sulfate level of domain III wells. Both domain III and domain IV are characterized by numerous, large, closed-depression features and ground water with a relatively low TDS content and a high uranium concentration, low uranium ratio signature in wells #117, #112, and #62. This indicates that surface water is recharging rapidly, ground-water residence time is short, and flow is rapid in a well developed conduit system.

Domain V

Domain V wells have a mean TDS of 96.4 mg/l; the lowest TDS of the 6 domains. Domain V possesses all the characteristics of domains III and IV that indicate surface water is recharging rapidly, ground-water residence time is short, and flow is rapid in well-developed conduit systems. The uranium signature of wells #103 and #92 support this interpretation. As discussed previously on page 42, domain V, similar to domain III, is probably controlled to some degree by the presence of a major fracture zone (Figure 13). The fractures are probably responsible for the enhanced transmissivity in the domains and also serve as conduits for ground-water flow.

In comparing pH to concentrations of bicarbonate and calcium in domain V, an apparent anomaly is present. The mean bicarbonate and calcium concentrations, 64.6 and 26.3 mg/l respectively, are lower and pH is higher (8.25) than in the other domains. This is anomalous because the relatively low calcium and bicarbonate concentrations in domain V, which are indicative of limited dissolution in a conduit-dominated flow system, should produce a substantially lower pH. In domain I, the relationships are more reasonable. The mean bicarbonate and calcium concentrations are 148.0 and 64.7 mg/l respectively and the mean pH level is 7.4. This apparent anomaly in domain V can only be explained if another process is acting independently of carbonate dissolution to increase the pH to such high levels.

It has been suggested that the agricultural application of $CaCO_3$ (liming) to reduce the acidity of soils in the area, could account for the high pH levels. There are indications that large amounts of $CaCO_3$ are applied to pastures in domain V. However, this is probably not the source of the high pH levels because $CaCO_3$ applications should result in bicarbonate and calcium concentrations that are higher than what is observed.

Domain VI

TDS in domain VI is higher than the other domains with the exception of domain II. The elevated TDS in domain VI is probably a result of stratigraphic relationships in the area. The Ocala Limestone in the domain VI area has been eroded away and the Avon Park Formation is very close to the surface, covered only by a few feet of sand (Figure 6). The transmissivity of the Avon Park is low relative to the surrounding areas where the Ocala Limestone comprises the shallow Floridan aquifer flow system. According to Faulkner (1970), the low transmissivity of the Avon Park was responsible for the high in the potentiometric surface in the area. Because of the low transmissivity of the Avon Park, ground water recharges more slowly, flow is inhibited and residence time is longer. This causes ground water in the area to have a higher TDS content. Unfortunately, the low uranium activity ratios and high concentrations of the wells in domain VI, do not support slow recharge in the area of the potentiometric high. There is no obvious explanation for the apparent contradiction.

GROUND-WATER CHEMISTRY: RAINBOW SPRINGS COMPLEX

Introduction

The following is an analysis of the chemical quality of water discharging from springs in the head spring area, the Rainbow River, and Indian Creek. The objective of the analysis is to relate the chemical signature of individual or groups of springs to possible source areas within the six ground-water quality domains in the immediate recharge area.

A total of 18 springs were sampled in the Rainbow Springs study area; 11 in the head spring area, 3 in the bed of the Rainbow River, and 4 along Indian Creek. Locations of the springs are depicted in Figure 2. Although there are many more springs in the study area, the springs chosen for sampling were the largest and were therefore considered to be the most representative of water quality in a given area. The springs were not all sampled the same number of times. Bridge Seep South was sampled only once and was therefore not considered in this analysis. The remaining 17 springs were sampled from 2 to 8 times between July of 1993 and July of 1995. Six of the springs were sampled once for uranium isotopes and 5 of the springs were sampled once for nitrogen isotopes. Sampling information for the springs, including sampling frequency and chemical data, is located in Appendix III.

An introduction to the characteristics of the major constituents, nitrogen species, and additional nutrients, and isotopes is included in the Ground-Water Chemistry of the Recharge Area section of this report and will not be repeated here.

Hydrochemical Facies

The hydrochemical facies technique is used here to provide a preliminary appraisal of the chemistry of the springs. Chemical data from 17 springs sampled by the AGWQMP in the study area were used to construct a Stiff diagram for each spring. For a comparison of the chemistry of the individual springs, the 17 analyses were plotted on a Piper diagram. Figure 29 displays two Stiff diagrams that are representative of the different water-quality groups delineated from the spring samples. Figure 29 also displays the Piper diagram.

The Stiff diagrams indicate that each spring sample is dominated by calcium and bicarbonate. Two samples indicate a significant presence of the sulfate ion.

Chemical data from the springs were then plotted on a Piper diagram. Examination of the Piper diagram reveals two distinct groups of samples; group A and Group B. All of the springs, with the exception of Rainbow Springs #6 and #7, are in group A. These samples are dominated by calcium-bicarbonate type water which results from simple

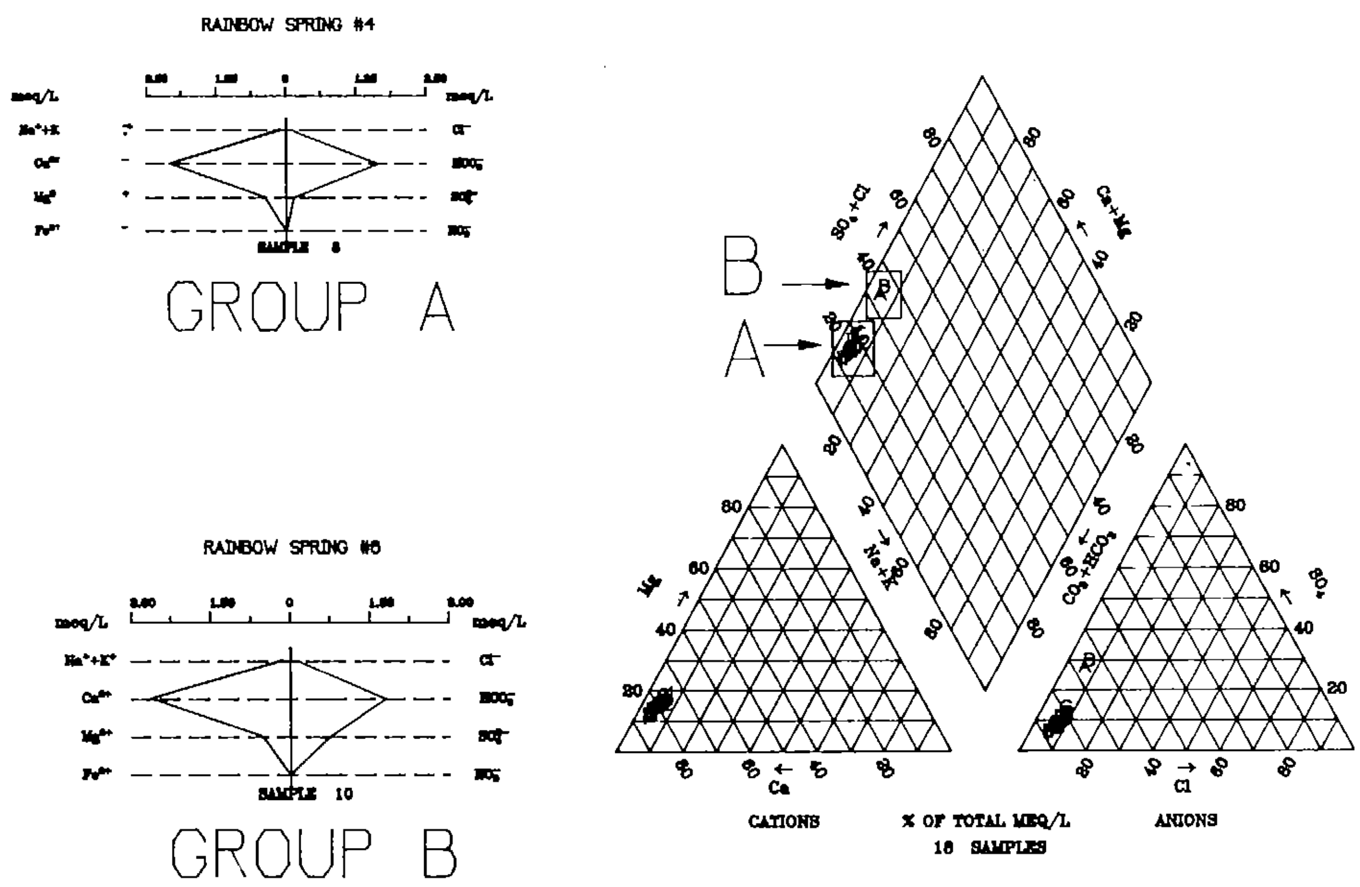


Figure 29. Characterization of Water Discharging from Springs in the Rainbow Complex Using Piper and Stiff Diagrams.

dissolution of limestone in the shallow Floridan aquifer flow system. Rainbow Springs #6 and #7 are in group B and are also dominated by calcium-bicarbonate type water. The difference in position of groups on the Piper diagram results from a significant increase in sulfate in the group B springs. This indicates that group B springs are probably receiving at least a portion of their flow from a deeper flow system that is influenced by the dissolution of gypsum and anhydrite at the top of the middle confining unit.

Major Constituents

As explained previously, the major constituents were considered to be pH, bicarbonate, calcium, chloride, sulfate, and TDS. pH was included because it is intimately associated with bicarbonate and calcium. TDS was included because it is a measure of the concentration of all the major and minor constituents. In Figures 30-37, the mean of the concentration of each major constituent (mg/l unless otherwise noted) is plotted next to the spring from which it was sampled. The concentration mean for each spring is also depicted in Table 5.

Other major constituents, such as sodium, magnesium, and potassium, occur in small but significant concentrations. However, these were not included because their utility was considered to be limited in characterizing the water quality of the recharge area and delineating spring water source areas.

In the following discussions, the concentration means of the major constituents of the springs were evaluated relative to concentrations of constituents sampled from 163 wells in the late 1980s in the northern portion of the SWFWMD (Jones et al., 1990).

Bicarbonate, Calcium, and pH

Figures 30, 31, and 32 show the bicarbonate and calcium concentrations and the pH of the sampled springs respectively. Bicarbonate and calcium concentrations range from 51.0 to 141.0 mg/l and 20.0 to 56.0 mg/l respectively. These concentrations are representative of short residence time and shallow flow in the upper Floridan aquifer in the northern portion of the SWFWMD. The lowest bicarbonate and calcium concentrations occur in the upper head-spring area while the highest occur in the Bubbling and Waterfall Spring tributaries and in Rainbow Springs #6 and #7 in the Rainbow River.

pH ranges from 7.6 to 8.4 standard pH units. The pH values for most of the springs are considerably higher than the pH of ground water in most wells open to the upper Floridan aquifer in the northern portion of the SWFWMD. While there is no obvious reason for the higher pH levels, the location of the higher pH springs and their apparent source areas (see p. 95) suggests that either non-carbonate alkalinity or dissolution of fine-grained wastes from phosphate washing may be a possible source. Springs with the highest pH occur in the upper head-spring area while springs with lower pH occur in the Bubbling and Waterfall Spring tributaries and in the Rainbow River.

Table 5. Major Constituent Concentration Means for Sampled Springs (mg/l unless otherwise noted).

SPRING NAME	pH (std. units)	Sp. Cd. (umhos)	HCO_3	Cl	SO_4	Ca	TDS	NO_3 as N
Rainbow Seep #1	7.8	162.0	72.0	3.5	5.4	27.0	98.0	0.88
East Seep	7.9	197.0	79.0	3.7	5.3	33.0	110.0	1.03
Bridge Seep N.	8.4	125.0	51.0	3.0	4.5	20.0	74.0	0.49
Rainbow Spring #1	8.3	158.0	64.0	3.4	5.0	25.0	90.0	0.89
Rainbow Spring #2	8.0	195.0	87.0	3.9	6.7	35.0	124.0	1.03
Rainbow Spring #3	8.1	219.0	97.0	3.9	5.2	38.0	130.0	1.03
Rainbow Spring #4	7.9	236.0	102.0	4.0	4.9	41.0	132.0	1.22
Waterfall Spring	7.7	267.0	129.0	4.2	5.9	47.0	147.0	1.13
Bubbling Spring	7.6	317.0	141.0	4.5	7.3	56.0	174.0	1.06
Rainbow Spring #5	7.9	202.0	94.0	3.8	6.8	35.0	108.0	0.45
Rainbow Spring #6	7.9	310.0	108.0	5.3	35.0	52.0	185.0	0.83
Rainbow Spring #7	7.9	302.0	100.0	5.1	37.0	51.0	181.0	0.87
Indian Creek #1	7.8	245.0	101.0	4.1	10.4	45.0	144.0	1.30
Indian Creek #2	7.8	247.0	84.0	4.2	9.5	41.0	124.0	1.22
Indian Creek #3	7.7	249.0	93.0	4.5	10.6	43.0	139.0	1.37
Indian Creek #4	7.9	252.0	108.0	4.2	9.9	43.0	135.0	1.26
Rainbow Spring #8	7.8	208.0	83.0	4.0	12.0	35.0	119.0	0.47

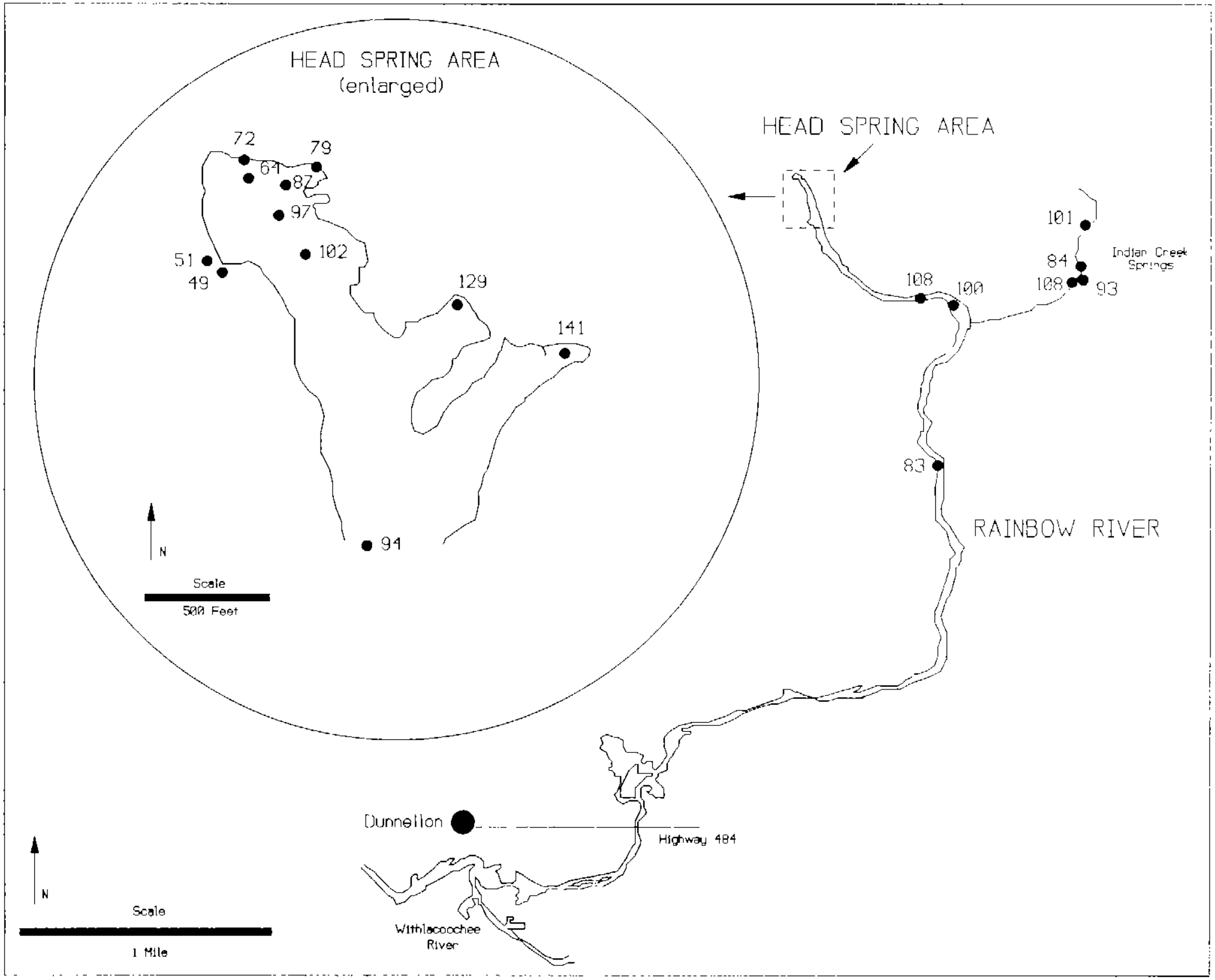


Figure 30. Bicarbonate Concentrations in Water Discharging from Springs in the Rainbow Complex.

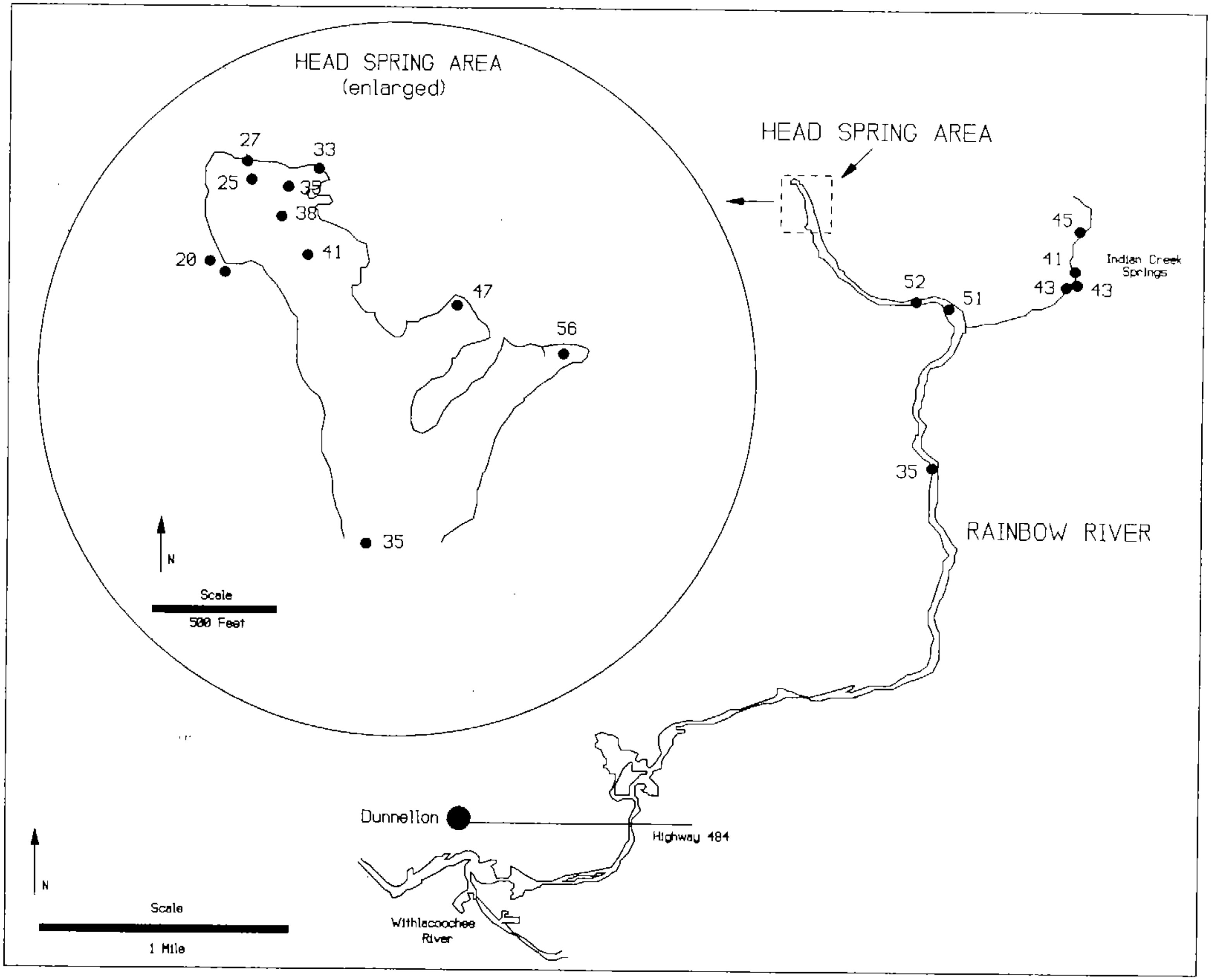


Figure 31. Calcium Concentrations in Water Discharging from Springs in the Rainbow Complex.

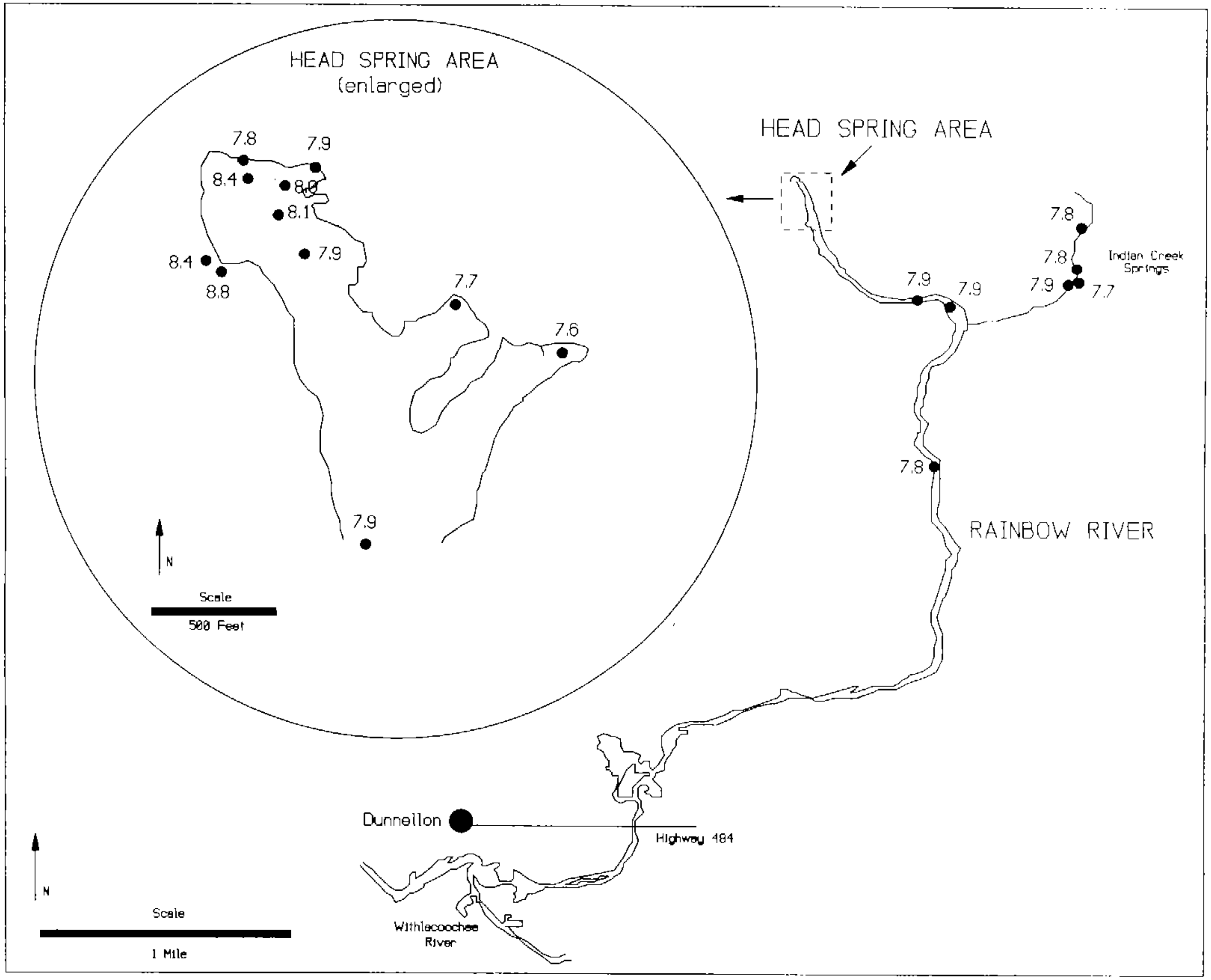


Figure 32. pH Level (s.u.) in Water Discharging from Springs in the Rainbow Complex.

Chloride

Figure 33 shows the chloride concentrations of the sampled springs. Concentrations range from 3.0 to 5.3 mg/l. These concentrations are typical of shallow flow system ground water in the upper Floridan aquifer in inland areas in the northern portion of the SWFWMD. The lowest concentrations occur in the upper head spring area while the highest occur at Rainbow Springs #6 and #7 in the Rainbow River.

Sulfate

Figure 34 shows the sulfate concentrations of the sampled springs. Concentrations range from 5.3 to 37.0. The lowest concentrations occur in the springs in the upper head spring area while the highest occur in the springs in the Rainbow River.

Fifteen of the springs had concentrations less than 12.0 mg/l. These concentrations are typical for shallow flow-system ground water in the upper Floridan aquifer in inland areas in the northern portion of the SWFWMD. The concentrations at Rainbow Springs #6 and #7, 35.0 and 37.0 mg/l respectively, are considerably higher than the other springs and most other wells in the northern portion of the SWFWMD. These may reflect somewhat deeper flow systems.

Total Dissolved Solids (TDS)

Figure 35 shows the TDS concentrations of the sampled springs. Concentrations range from 74.0 to 185.0 mg/l. These concentrations are typical for shallow flow-system ground water in the upper Floridan aquifer in inland areas, in the northern portion of the SWFWMD. The lowest concentrations occur in the springs in the upper head spring area while the highest occur in the Bubbling Spring tributary and Rainbow Springs #6 and #7 in the Rainbow River.

Nitrogen Species

Ammonium

Ammonium concentrations are all less than the detection limit of 0.01 mg/l. Therefore, a concentration figure was not included. Because ammonium concentrations in the springs are low and nitrate concentrations are high, all ammonium in ground water must oxidize to nitrate before reaching the springs. The fact that this process occurs rapidly in shallow karst flow systems indicates the major contributors of nitrogen in the recharge area are not within the immediate vicinity (several thousand feet) of the springs.

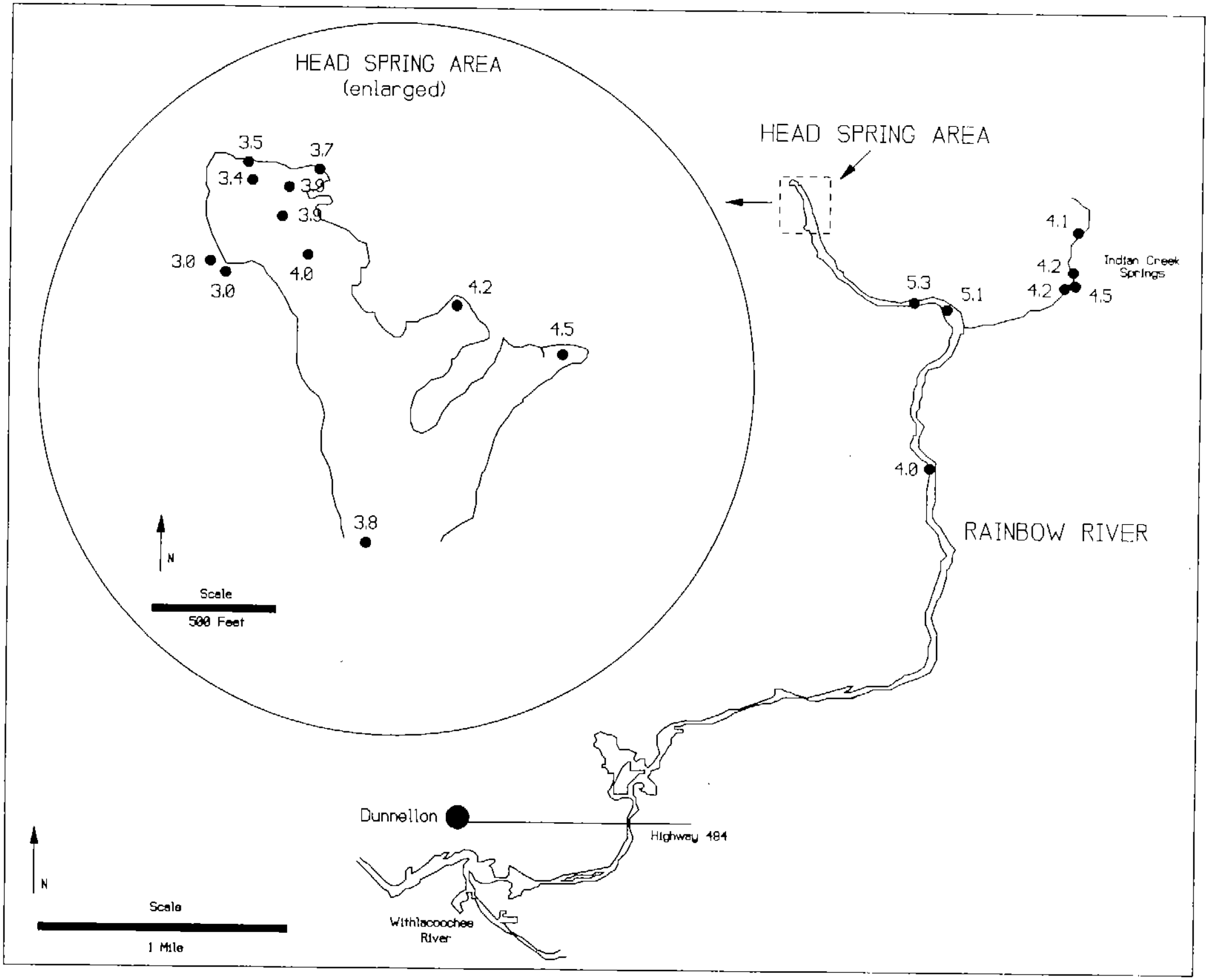


Figure 33. Chloride Concentrations in Water Discharging from Springs in the Rainbow Complex.

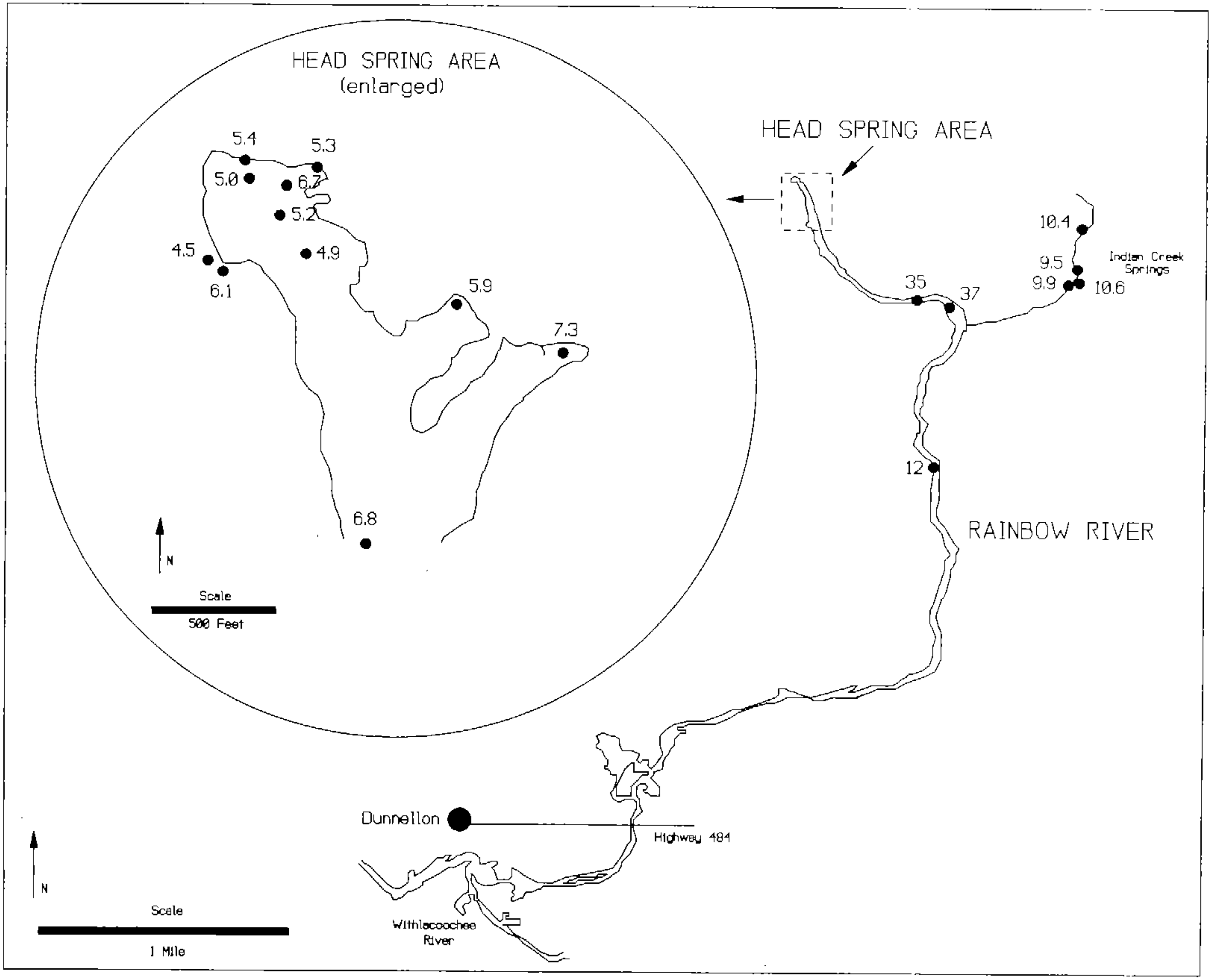


Figure 34. Sulfate Concentrations in Water Discharging from Springs in the Rainbow Complex.

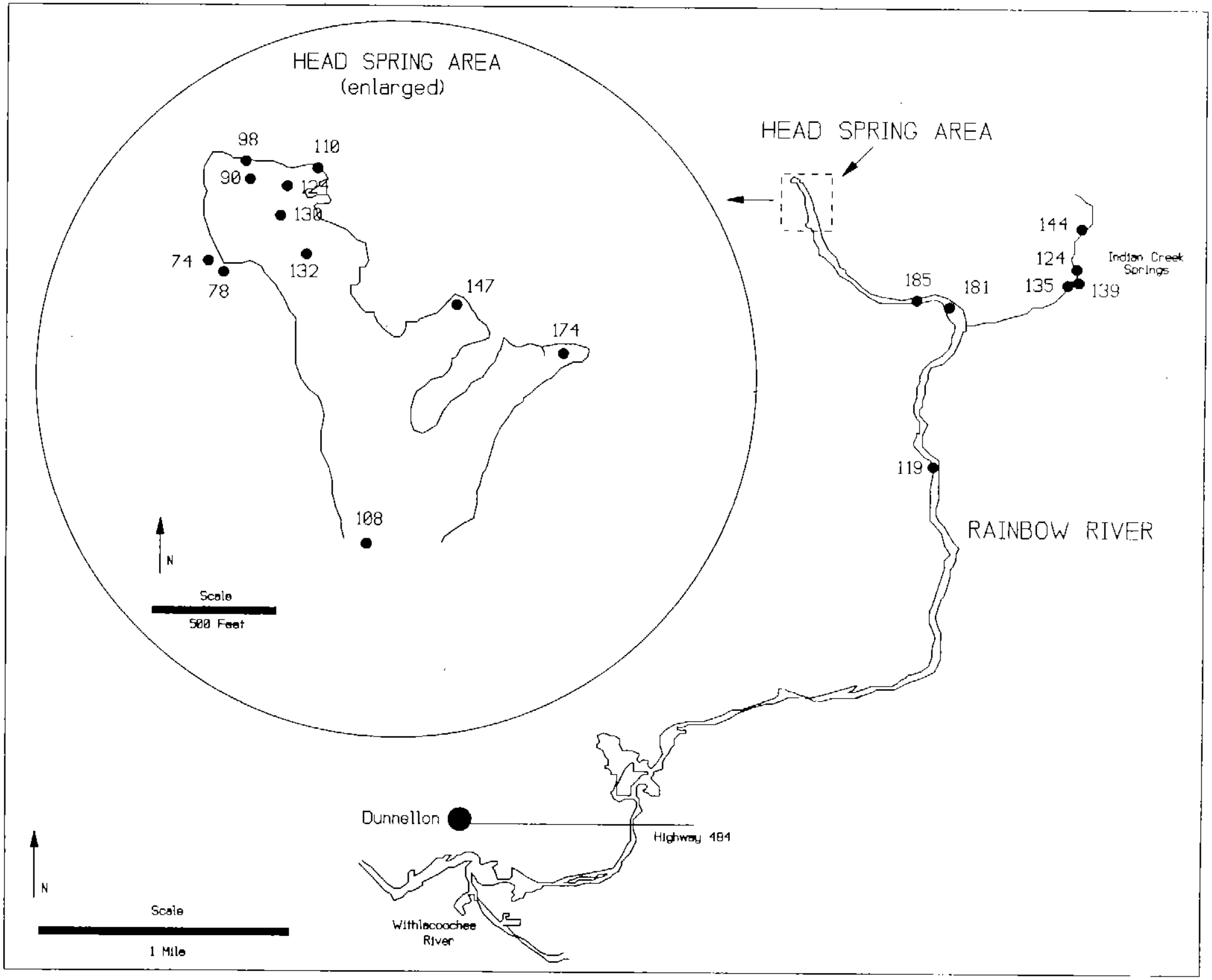


Figure 35. TDS Concentrations in Water Discharging from Springs in the Rainbow Complex.

Nitrite

Nitrite concentrations are all less than the detection limit of 0.01 mg/l. Therefore, a concentration figure was not included. The low nitrite concentrations and high nitrate concentrations in the springs indicate that all nitrite in ground water oxidizes to nitrate before discharging at the springs. Similar to ammonium, this process occurs rapidly in shallow karst flow systems and is an indication that the sources of nitrogen in the recharge area are not in the immediate vicinity (several thousand feet) of the springs.

Nitrate

Figure 36 shows the nitrate concentrations of the sampled springs. Concentrations range from 0.45 to 1.37 mg/l. Concentrations are lowest in Bridge Seep North and Rainbow Spring #1 in the upper head spring area, in Rainbow Spring #5 in the lower head spring area, and in Rainbow Spring #8 in the Rainbow River. Concentrations are highest in the Indian Creek Springs.

Additional Nutrients

Total Organic Carbon (TOC)

TOC concentrations are all less than 0.5 mg/l. Therefore, a concentration figure was not included. These low concentrations may indicate that organic carbon that entered the aquifer in surface water has been metabolized by aquifer microbes before discharging from the springs. This may also be an indication that significant surface-water recharge is not occurring in close proximity to the springs.

Total Phosphorus

Figure 37 shows the total phosphorus concentrations of the sampled springs. Concentrations are low, ranging from 0.03 to 0.06 mg/l. Since orthophosphate is relatively insoluble in an alkaline environment, the low concentrations indicate minimal orthophosphate and organic phosphorus and suggests that significant sources of phosphorus, such as organic-rich surface water or animal wastes, are not in close proximity to the springs.

Isotopes

Uranium

Six springs in the study area were sampled for uranium isotopes. The $^{234}U/^{238}U$ activity ratio and uranium concentration data for the sampled springs and the locations of the sampled springs are shown in Figure 38. All 6 springs have the low activity ratio and high

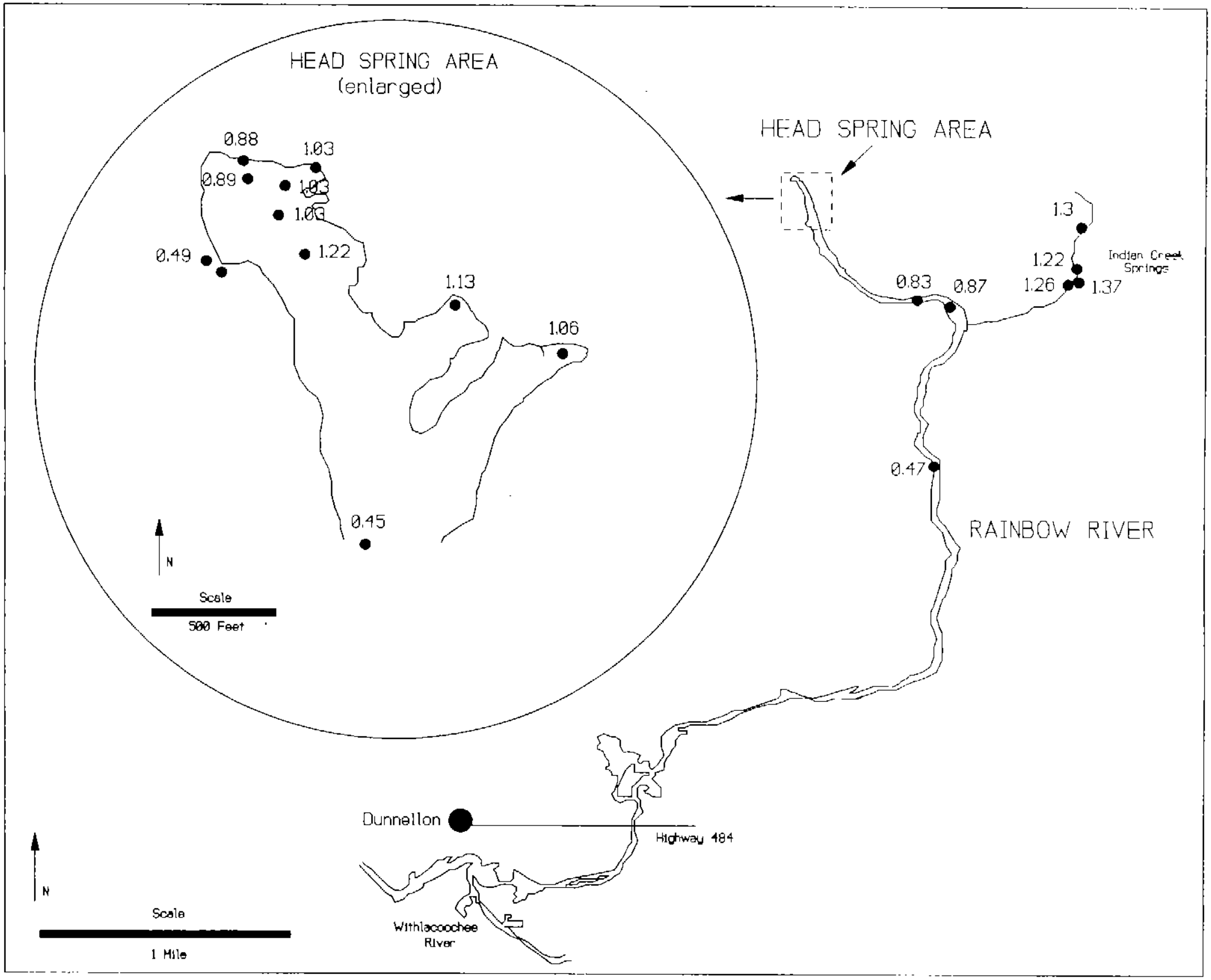


Figure 36. Nitrate as N Concentrations in Water Discharging from Springs in the Rainbow Complex.

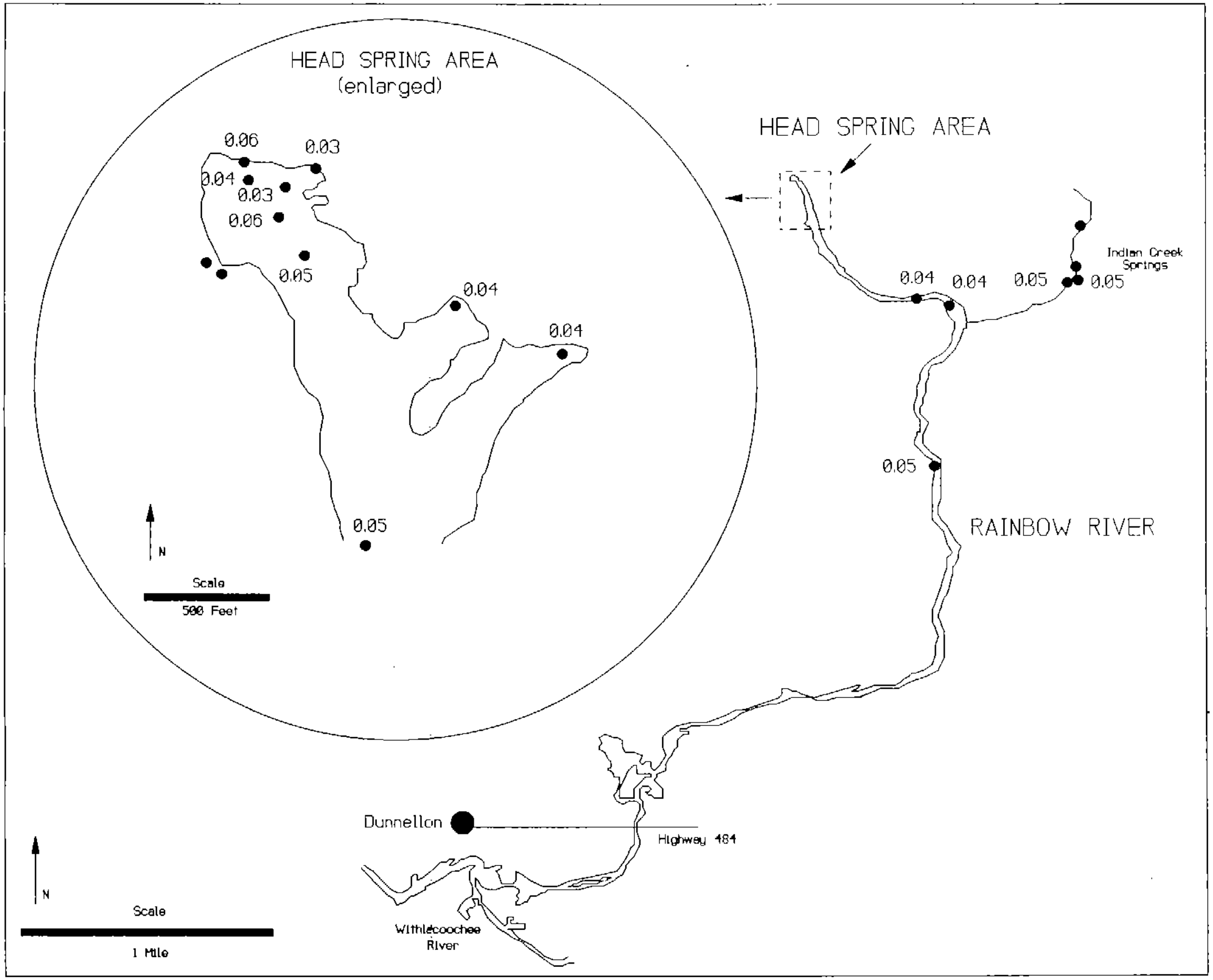


Figure 37. Total Phosphorus Concentrations in Water Discharging from Springs in the Rainbow Complex.

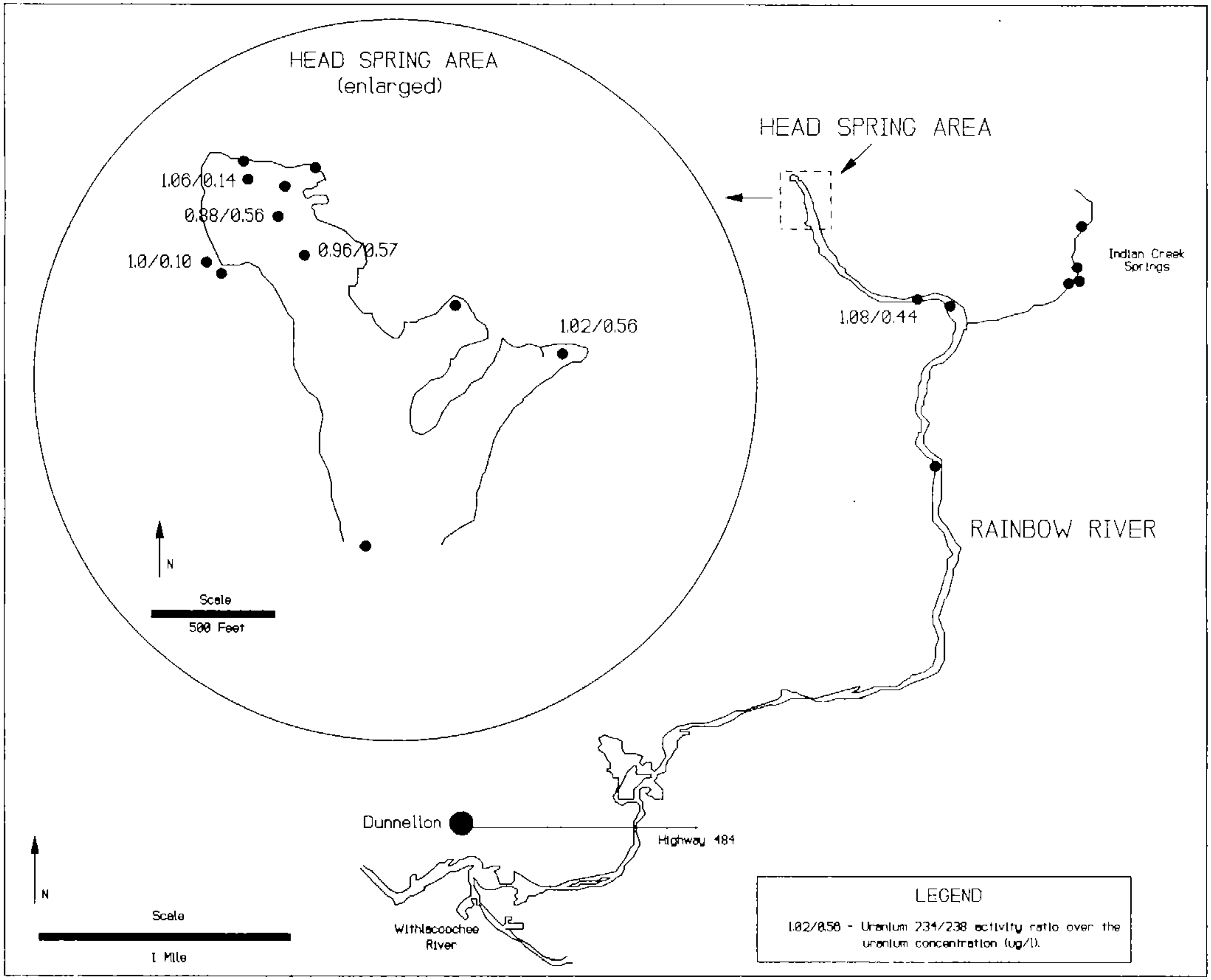


Figure 38. Uranium Isotopic Ratios and Concentrations in Water Discharging from Springs in the Rainbow Complex.

concentration characteristic of ground water that has recharged rapidly and traveled a relatively short distance (more than several thousand feet) in a shallow flow system.

Nitrogen

Five springs in the study area were sampled for nitrogen isotopes. Figure 39 shows the spatial distribution of $\delta^{15}N$. The $\delta^{15}N$ ratios for the springs range from 0.7 to 2.6 ‰ with an average value of 1.9 ‰. All of the $\delta^{15}N$ ratios are well within the inorganic nitrogen fertilizer range and all the values are within the natural decay in unfertilized soils range. It is unlikely that the $\delta^{15}N$ ratios are the result of natural decay in unfertilized soils because the nitrate concentrations in the wells and springs appear to be too high to have originated from natural sources. It follows then that the $\delta^{15}N$ ratios strongly indicate that the principal source of nitrate in ground water discharging from the springs in the study area is inorganic, agricultural fertilizer.

Tritium

As discussed previously, Faulkner (1970) investigated the tritium content of ground water in the Rainbow Springs study area and found tritium activities in wells and springs as high as 174 TU at the same time (1966-68) that rainfall contained activities as high as 158 TU. Activities in Rainbow and Silver Springs ranged from 38 to 85 TU and 25 to 150 TU, respectively. This indicates that a large percentage of the water discharging from Rainbow and Silver Springs in 1966-68 could not have been in the flow system for more than 16 years at the most.

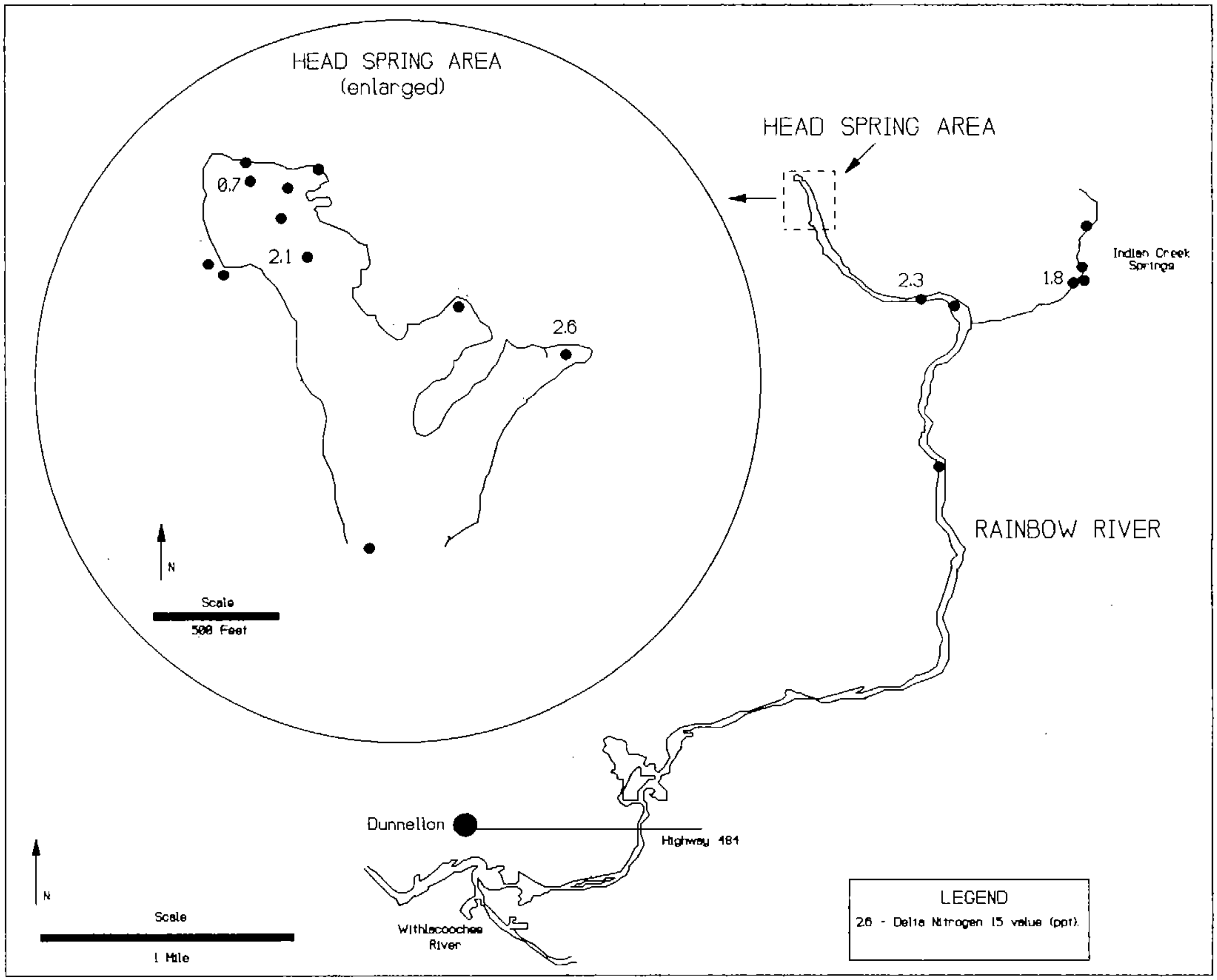


Figure 39. $\delta^{15}N$ Isotopjc Ratios in Water Discharging from Springs in the Rainbow Complex.

DELINEATION OF SPRING-WATER SOURCE AREAS

Introduction

In the previous section, the hydrochemical facies analysis determined that two groups of springs were present based on the dominant ions in each sample. The next step was to determine whether the springs could be further subdivided based on differences in pH, the concentrations of the major constituents, and uranium and nitrogen isotopic ratios, and concentrations. This was done by calculating the mean of the concentration of the major constituents sampled from each spring and then comparing the means. Table 6 shows the means of the major constituent concentrations for the 17 springs.

A qualitative evaluation of differences in major constituent means between the springs and the differences in ratios and concentrations of uranium isotopes revealed that the differences were marked enough to readily allow the division of most of the springs into 5 different groups (Table 6) (Figure 40). Three springs could not readily fit be into any group.

Once the springs were grouped, the chemistry of each group was compared to the chemistry of the 6 ground-water quality domains in the immediate recharge area using star diagrams. The length of each axis in a star diagram corresponds to the relative concentration of a major constituent; the higher the concentration, the longer the axis. Thus, if a spring group and a domain have similar concentrations of the major constituents, their star diagrams will be similar. Figure 41 shows the star diagrams for the 5 spring groups and 6 water-quality domains. The figure also indicates the correlations between spring groups and water-quality domains. Figure 42 matches the spring groups with their sources in the various domains.

Spring Group 1

Spring group 1 consists of Bridge Seep North and Rainbow Spring #1, located in the extreme northwestern end of the head spring area. In these springs, the means of the concentrations of TDS, sulfate, nitrate, and the pH level are 82.0 mg/l, 4.7 mg/l, 0.69 mg/l, and 8.35, respectively. The uranium activity ratios and concentrations from the 2 springs are very similar (Figure 38).

Comparison of the star diagrams for the springs and domains indicates that domain V, the area to the west and northwest of the springs, is supplying most of the water to spring group 1. In domain V, a conduit-dominated flow system has probably developed along the northwest- southeast trending fracture discussed previously. The high recharge and short residence time has produced water with very low TDS (< 100 mg/l). The low sulfate levels in domain V are very similar to those of Spring Group 1.

Table 6. Major Constituent Concentration Means for Spring Groups (mg/l unless otherwise noted).

SPRING GROUP	SPRING NAME	pH (std. units)	Sp. Cd. (umhos)	HCO_3	Cl	SO_4	Ca	TDS	NO_3 as N
Grp 1	Bridge Seep N. Rainbow Spring #1								
Grp 1 Mean		8.35	141.0	57.5	3.2	4.7	22.5	82.0	0.69
Grp 2	East Seep Rainbow Spring #2 Rainbow Spring #3 Rainbow Spring #4								
Grp 2 Mean		7.97	212.0	91.2	3.9	5.5	36.7	124.0	1.07
Grp 3	Waterfall Spring Bubbling Spring								
Grp 3 Mean		7.65	292.0	135.0	4.3	6.6	51.5	160.0	1.09
Group 4	Rainbow Spring #6 Rainbow Spring #7								
Grp 4 Mean		7.9	306.0	104.0	5.2	36.0	51.5	183.0	0.85
Grp 5	Indian Creek #1 Indian Creek #2 Indian Creek #3 Indian Creek #4								
Grp 5 Mean		7.8	248.0	96.5	4.2	10.1	43.0	135.0	1.29
Mixture Grp 1/Grp 2	Rainbow Seep #1	7.8	162.0	72.0	3.5	5.4	27.0	98.0	0.88
?	Rainbow Spring #5	7.9	202.0	94.0	3.8	6.8	35.0	108.0	0.45
?	Rainbow Spring #8	7.8	208.0	83.0	4.0	12.0	35.0	119.0	0.47

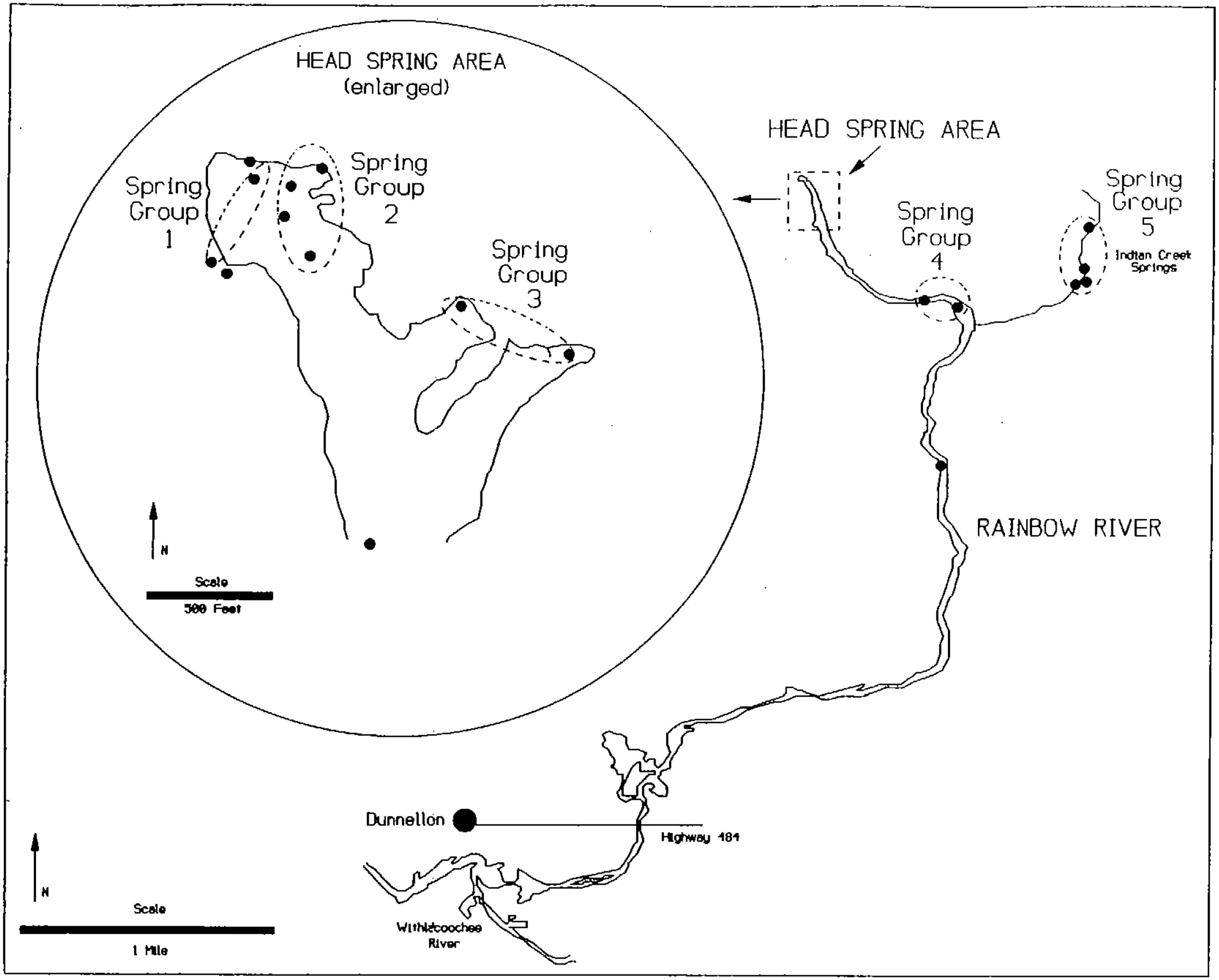
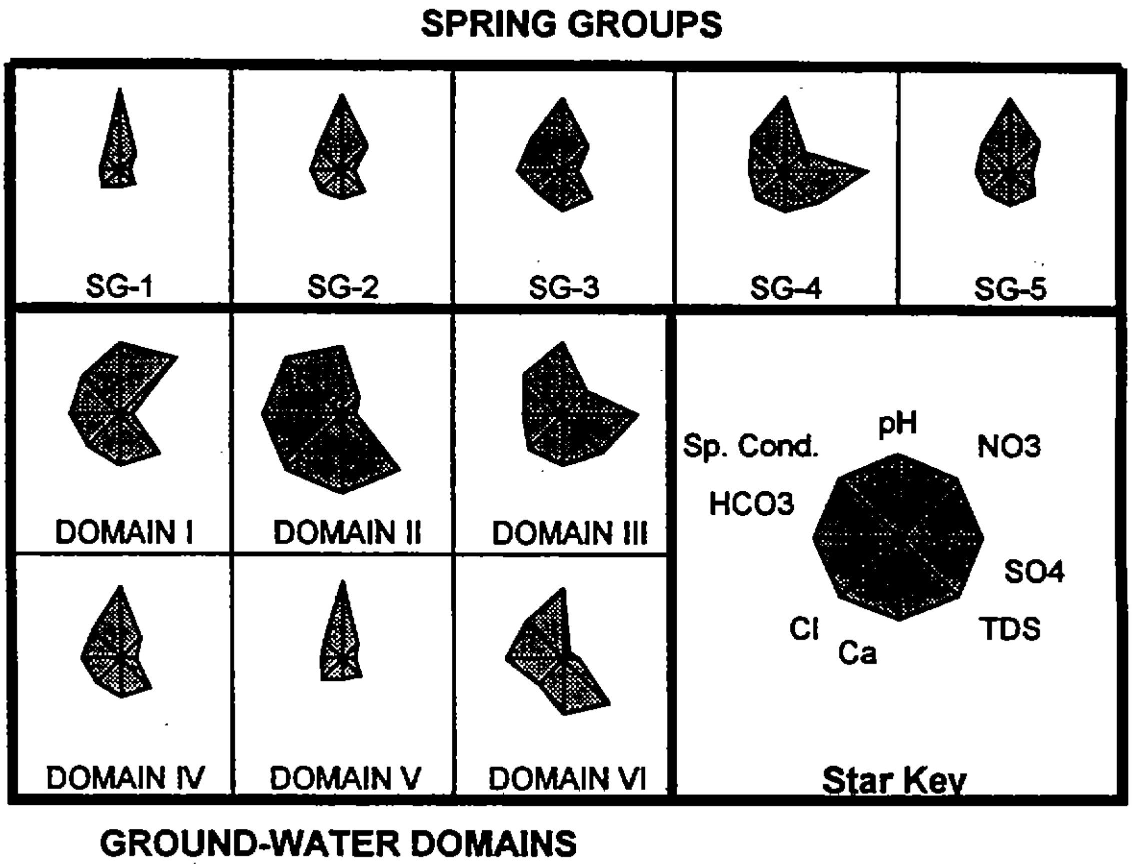


Figure 40. Springs in the Rainbow Complex Grouped on the Basis of Similar Water Quality.



SPRING GROUP	*MATCHING GROUND-WATER DOMAIN*
SG-1	V
SG-2	IV
SG-3	IV
SG-4	III
SG-5	IV

Spring Group - Ground-Water Domain Correspondence

Figure 41. Star Diagrams of Spring Groups and Water-Quality Domains. Correlations between Groups and Domains are Indicated.

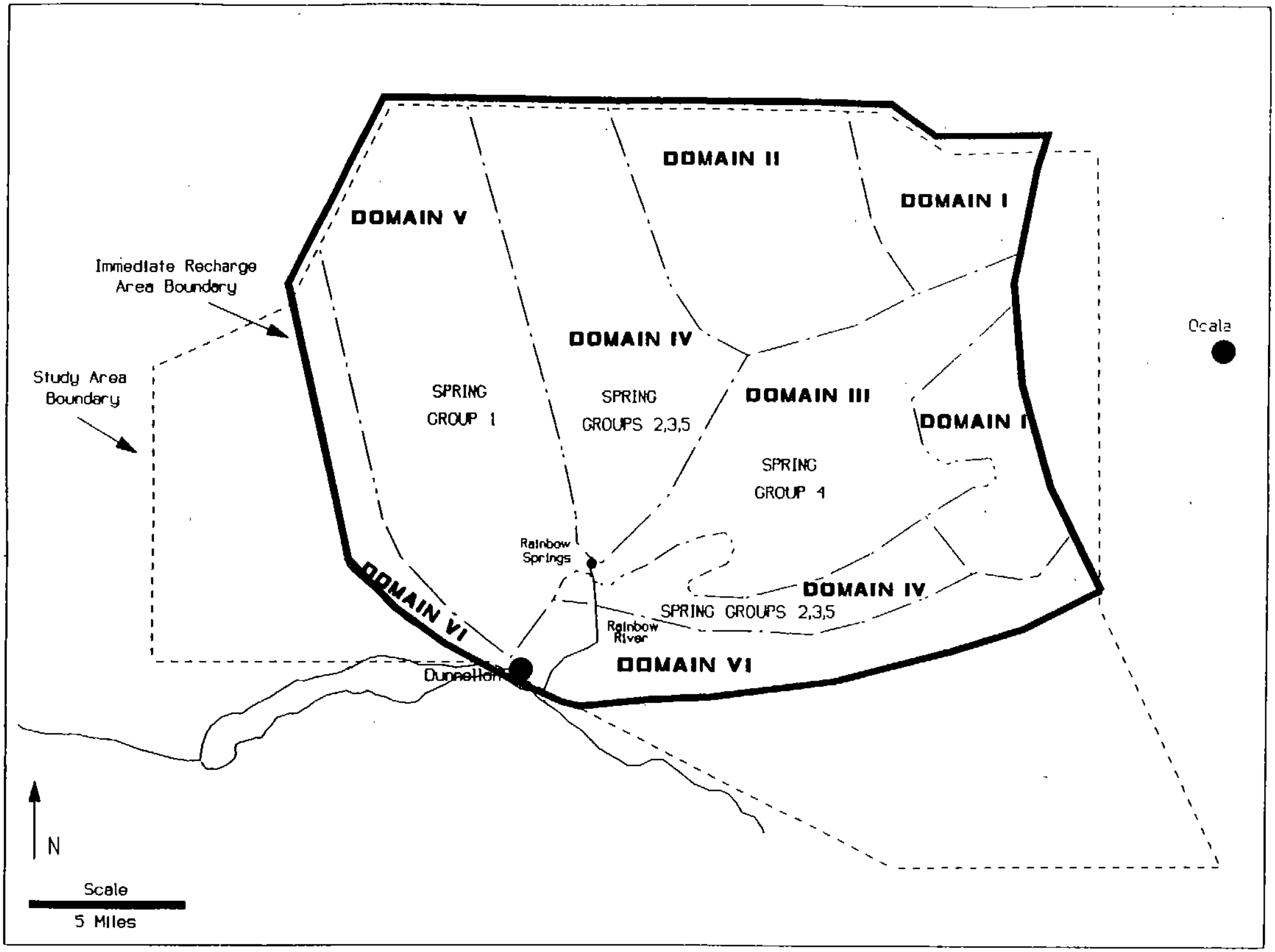


Figure 42. Spring Groups Matched with Source Domains.

Nitrate in spring group 1 probably originates between the head spring area and the nitrate high to the northwest, near the Marion-Levy County line (Figure 23). Nitrate concentrations in this area consistently exceed 1.0 mg/l and are as high as 3.3 mg/l. The lower nitrate levels in spring group 1 are probably a result of the mixing of high nitrate water from the northwest with very low nitrate water from the area directly west of the spring. This conclusion is supported by the uranium data discussed below.

The uranium activity ratios and concentrations of the group 1 springs, while similar to the uranium ratios and concentrations of all the wells in domain V (Figure 38) , are more similar to the wells to the west and southwest of the springs (#75, SCE 170, and #59) (figure 26). This supports the conclusion that a significant amount of water is reaching the springs from portions of domain V that are not influenced by the fracture.

The high pH (>8.0) in domain V is very similar to the pH of spring group 1. As discussed previously, the existence of such high pH levels is problematic because the high recharge, short residence time, low bicarbonate and calcium concentrations that are characteristic of domain V and spring group 1 should produce a lower pH.

The $\delta^{15}N$ of Rainbow Spring #1 is 0.7 ppt. This ratio, which is considerably lower than that of the other 4 springs sampled for nitrogen isotopes, indicates that the origin of the nitrate in spring group 1 is agricultural fertilizers. This correlates well with the lack of horse farms and limited number of cattle that, if present, would provide animal-waste nitrogen. The large amount of land that is planted in pasture grass in domain V (Figure 5) is probably the source of agricultural fertilizer nitrogen.

Spring Group 2

Spring group 2 consists of East Seep and Rainbow Springs #2, #3, and #4. These springs are located on the eastern side of the upper head spring area. In these springs, the means of the concentrations of TDS, sulfate, nitrate, and the pH level are 124.0 mg/l, 5.5 mg/l, 1.07 mg/l, and 7.97, respectively. The uranium activity ratios and concentrations from the two springs in group 2 that were sampled for uranium (Rainbow Springs #3 and #4) are very similar (Figure 38).

Comparison of the star diagrams indicates that most of the flow of spring group 2 is originating to the east and northeast in domain IV. The $\delta^{15}N$ of Rainbow Spring #4 is 2.1 ppt. This ratio, while considerably higher than that of Rainbow Spring #1 in spring group 1, is still well within the agricultural fertilizer range. This is consistent with Figure 5 which shows that domain IV is dominated by the pasture land use.

Spring Group 3

Spring group 3 consists of Waterfall and Bubbling Springs, located to the east of the head spring area at the head of two short tributaries. The means of the concentrations of TDS, sulfate, nitrate, and the pH level in these springs are 160.0 mg/l, 6.6 mg/l, 1.09 mg/l, and 7.65, respectively. The uranium activity ratio and concentration of Bubbling Spring are similar to that of well #112 located in domain IV. The star diagrams and the uranium isotope data indicate that, similar to spring group 2, most of the flow of spring group 3 is originating to the east and northeast in domain IV.

Spring Group 4

Spring group 4 consists of Rainbow Springs #6 and #7. These springs are located in the bed of the Rainbow River approximately 1 mile down river of the head spring area. A conduit-dominated flow system has probably developed in this area along the northeast-southwest trending fracture that bisects domain III. The group 4 springs are located on a bend in the Rainbow River that is probably controlled by the fracture.

The means of the concentrations of TDS, sulfate, nitrate, and of pH of the group 4 springs are 183.0 mg/l, 36.0 mg/l, 0.85 mg/l, and 7.9 respectively. The uranium activity ratio and concentration of Rainbow Spring #6 are depicted in Figure 38. Comparison of the star diagrams indicates that most of the flow of spring group 4 is originating to the northeast in domain III.

The group 4 springs are unique in that their sulfate concentrations are 3 to 7 times higher than those of the other spring groups. The sulfate almost certainly originates in domain III where sulfate concentrations are as high as 70.0 mg/l. Sulfate concentrations are high in domain III because sulfate appears to be upwelling along the trend of the fracture. This is evident in the linearity of the northeast-southwest trend of contoured sulfate concentrations (Figure 19).

Nitrate in spring group 4 probably originated between the head spring area and the ground-water basin divide to the northeast. Nitrate concentrations exceed 5.0 mg/l in the area just west of the divide near Ocala and exceed 1.0 mg/l in most of the wells in the area to the southwest toward the head spring.

The $\delta^{15}N$ of Rainbow Spring #6 is 2.3 ppt which is indicative of inorganic fertilizer as a source. This is consistent with the conclusion that most of the water in spring group 4 is originating in domain III where crop and pasture fertilization is occurring.

The uranium activity ratio and concentration of Rainbow Spring #6 are similar to that of wells #117, #112, and #62 located in domains III and IV.

Spring Group 5

Spring group 5 consists of the four Indian Creek Springs. These springs are spread along the bed of Indian Creek to the east of the upper Rainbow River. The springs are small and together discharged an average of 9.5 cfs during June, August and November.

The means of the concentrations of TDS, sulfate, nitrate, and pH for spring group 5 are 135.0 mg/l, 10.1 mg/l, 1.29 mg/l and 7.8, respectively. None of the group 5 springs were sampled for uranium. Comparison of the star diagrams indicates that the flow of spring group 5 originates in domain IV.

The group 5 springs have the highest nitrate concentration of the 5 groups (1.3 mg/l). These high nitrate levels may be derived from the high concentrations in domain III. This is supported by the fact that the group 5 springs have sulfate levels that, while not as high as those of spring group 4, are the second highest sulfate concentration of the spring groups. The elevated sulfates in spring group 5 are probably a result of the group being located on the fracture that contributes high sulfates to spring group 4 from domain III.

The $\delta^{15}N$ of Indian Creek Spring #4 is 1.8 ppt. This value indicates an agricultural fertilizer component.

NITROGEN LOADING OF THE GROUND-WATER SYSTEM

Introduction

It is estimated that approximately 684 tons of nitrate is dissolved in the combined yearly discharge of Rainbow Springs. From previous discussions it is clear that the majority of nitrate in the waters of Rainbow Springs enters the Floridan aquifer system within the western third of Marion County. A number of sources that have the potential to contribute nitrate to ground water exist in this area. These include: 1) naturally occurring nitrate from organic decay, 2) rainfall, 3) residential and commercial development serviced by septic tanks, 4) fertilization of residential turf, 5) fertilization of golf course turf, 6) sewage effluent disposal, 7) land disposal of sewage sludge, 8) land disposal of septage sludge, 9) pasture and row crop fertilization, 10) cattle production, and 11) horse farms.

The following section is a discussion and, where possible, a quantification of the contribution of nitrate from each of these sources to the 350 square-mile area that is considered to be the immediate recharge area of the Rainbow Springs Complex. To provide a better understanding of where nitrogen loading is occurring, the immediate recharge area has been divided longitudinally into more-or-less equal thirds which will be referred to as the eastern, central, and western regions. Where possible, nitrogen loading estimates for each source have been computed for each of the 3 regions. It is important for the reader to remember that discussions of land use and land-use acreage in this section refer to the situation that existed in the study area in late 1990 as depicted in Figure 5.

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 generally small as microbes and plants in the soil layer utilize and recycle the nitrogen as soon as it is made available. This observation is verified by the fact that nitrate concentrations in Floridan aquifer ground water average less than 0.1 mg/l in undeveloped and unaffected portions of the study area where the only sources of nitrogen are organic decay and rainfall.

Rainfall

The average nitrogen concentration in rainfall in Marion County was determined using data from a study of the chemical characteristics of rainfall in Florida (Irwin and Kirkland, 1980). Nine rainfall samples collected from a station in northwestern Citrus County contained an average of approximately 1.0 mg/l total nitrogen. Using this figure, for the average rainfall year (56 inches), the calculated rainfall load of nitrogen for the immediate recharge area for Rainbow Springs is approximately 1,442 tons/yr. When broken out by region the loadings are as follows:

Region	Nitrogen Loading (tons/yr)
Eastern	471
Central	504
Western	467
Total	1,442

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

Septic Tanks

Numerous investigators have characterized septic tank effluent for various chemical species including major ions, trace metals and nutrients. Nitrogen is present in high concentrations in septic-tank effluent at a ratio of 75-80% ammonium-nitrogen to 20-25% organic nitrogen (Otis *et al.*, 1975). Total nitrogen concentrations in septic tank effluent vary from 25 to 100 mg/l with the average being in the range of 35 to 45 mg/l (U.S. EPA, 1980). Aerial photo analysis and delineation of the extent of sewer systems have indicated there are at least 5,000 septic tanks within the immediate recharge area. The density of septic tanks is delineated in Figure 43. Because much of the residential development in Marion County has been designed for retirees and a significant percentage of the residences may be occupied only during the winter, it is probably reasonable to assume that each septic tank services an average of 2 people. The annual nitrogen contribution per septic tank would then be approximately 35 lbs (Walker *et al.*, 1973a). Research indicates that 20 to 40% of the nitrogen in effluent may be removed by mineralization, nitrification, denitrification, adsorption, biological uptake, fixation, or volatilization before the effluent reaches ground water (de Vries, 1972; Andreoli *et al.*, 1979; Harkin *et al.*, 1979; Peavy and Brawner, 1979; Laak, 1982). If 30% removal is achieved, then each septic tank contributes approximately 25 lbs/yr of nitrogen to ground water, which, according to Hantzsche and Finnemore (1992), is fully converted to nitrate. Using this figure, the total nitrogen contribution for septic tanks in the immediate recharge area is approximately 63 tons/yr. When broken out by regions the loadings are as follows:

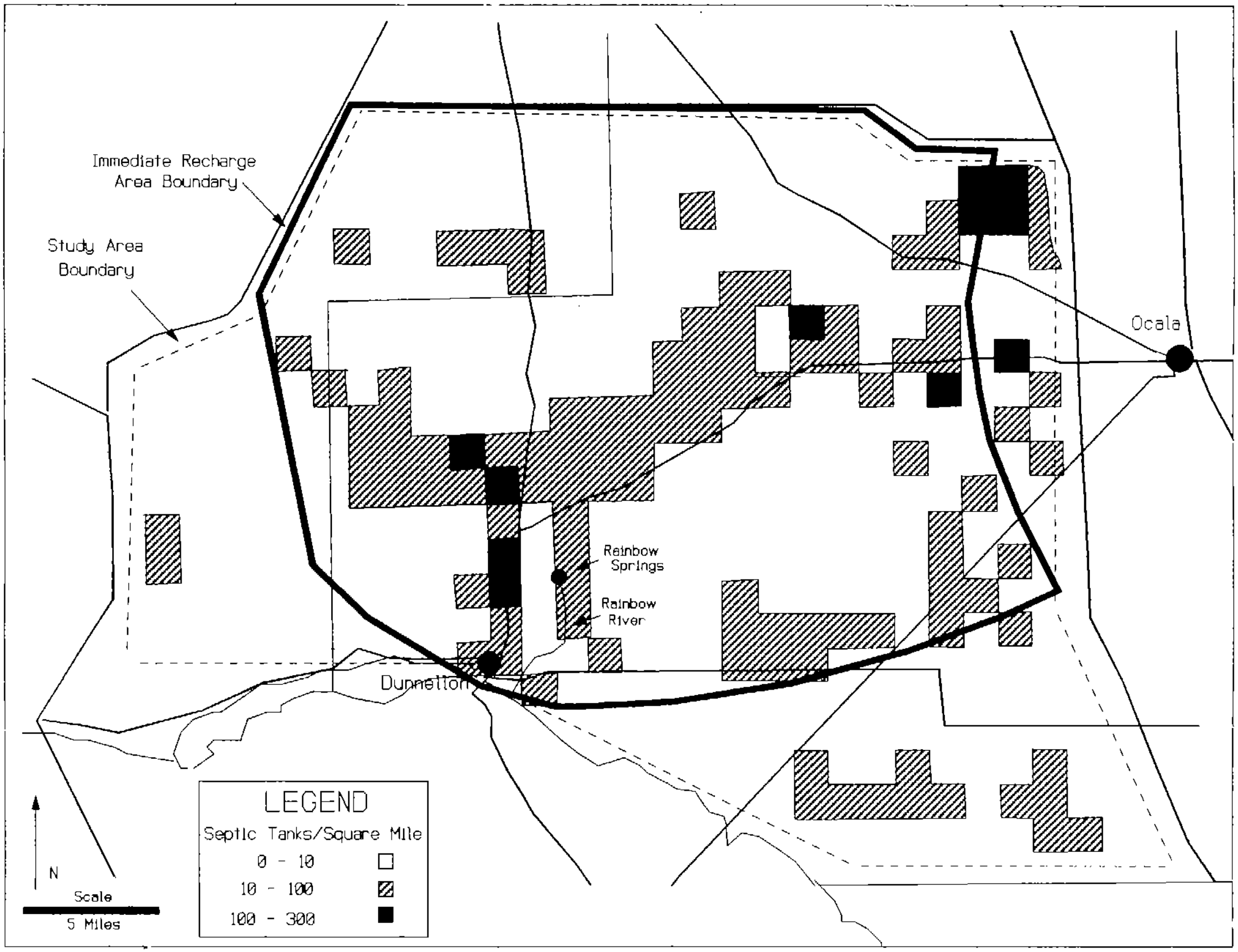


Figure 43. Septic Tank Density in the Study Area and Immediate Recharge Area.

Region	Nitrogen Loading (tons/yr)
Eastern	22
Central	17
Western	24
Total	63

Septic tank nitrate takes on increased significance because the calculated value represents the amount of nitrogen that is loaded directly to ground water, rather than to the land surface. The calculated nitrogen loading from the other sources reflects the amount applied to the surface and the amount of nitrogen that actually reaches ground water is probably significantly less because of the nitrogen removal mechanisms discussed previously. However, because the overall nitrogen loading from septic tanks is much lower than some of the other sources, septic tanks, at their current densities, are not a significant threat to regional ground-water quality. Local problems may exist, however.

Turf Fertilization

Approximately 19,146 acres in the immediate recharge area are occupied by low, medium, and high density residential land uses. A large percentage of this area has associated landscaping, such as lawns, shrubs, trees, and gardens. Accurately quantifying the nitrogen contribution from the fertilization of landscaping is highly problematic. This is because it is extremely difficult to determine the percentage of landscaping that is maintained with fertilizers, how much fertilizer is applied, and how much of the fertilizer directly percolates to ground water. However, through interpretation of aerial photography and the use of a number of assumptions that may or may not be accurate, an attempt was made to estimate nitrogen loading of ground water from turf fertilization. The results should only be considered a starting point for those interested in pursuing a more accurate number; it is left to the reader to judge the validity of the assumptions and recalculate the loading estimate if more accurate data are available.

Six residential sites were chosen based on location and density type (low, medium, and high density residential). It was assumed that these six sites were representative of their respective density type. A careful review of some 170 "blue-line" aerial photographs tended to support this assumption. Next, the six sites were scaled to a more manageable size (tens of acres for low density, less than five acres for medium to high density) to facilitate the calculation of turf percentages. The scaled-down sites were then measured for total acreage, structure acreage, driveway and sidewalk acreage, and undeveloped and unfertilized acreage.

From the investigation of the six residential sites, the percentage of turf for a given acreage of each density type was determined.

Residential Density Type	Percent of Turf/Acre of Density Type
Low	17%
Medium	66%
High	34%

This number was then used to determine the total turf acreage for each density type in the immediate recharge area (listed below).

Residential Density Type	Turf Acreage
Low	2,432
Medium	1,898
High	670
Total	5,000

Approximately 5,000 acres of turf are contained in the immediate recharge area. If it is assumed that 60 percent of the total turf acreage is owned by individuals who fertilize (this may not be an unreasonably high figure because homeowners include a large number of retirees that may have the time, inclination, and income to fertilize on a regular basis) then approximately 3,000 acres in the immediate recharge area is fertilized turf.

The University of Florida Cooperative Extension Service (personal communication) recommends 2 lbs/yr of nitrogen per 1000 ft^2 (0.023 acres) of turf. Fertilizing 3,000 acres with this quantity would result in an application rate of 131 tons of nitrogen/yr to the immediate recharge area. A study of nitrate sources in a sewered housing development in Long Island New York (Flipse *et al.*, 1984) estimated that at least 60 percent of the nitrogen applied as fertilizer to turf leached below the root zone and eventually reached ground water. If the results of the Long Island study can be applied to the immediate recharge area, approximately 79 tons of nitrogen from turf fertilizers could reach ground water. This number may be conservative given the sandy soils of the area, the higher rainfall compared to Long Island, and the difference in growing season and climate. Broken out by region the amount of nitrogen estimated to be reaching ground water is listed below.

Region	Nitrogen Loading (tons/yr)
Eastern	50
Central	11
Western	18
Total	79

To determine the accuracy of these figures, it is recommended that a program of long-term monitoring of ground-water quality in the vicinity of several recently-constructed, sewered subdivisions in the area begin in the near future.

Compared to a number of nitrogen sources in the immediate recharge area, 79 tons/yr of nitrogen from turf fertilization is insignificant. However, the amount of residential turf in the immediate recharge area is currently very low. As development accelerates in the area, the amount of fertilized turf will greatly increase. This may cause residential turf to become a much more important source of nitrogen in the future.

Storm-water runoff from residential areas is high in nitrogen (U.S. EPA, 1983). This indicates that excess nitrogen applied to landscaping is leached from the land surface by rainfall and carried away by storm water. Since storm water in the study area eventually reaches the Floridan aquifer, it is important to determine the amount of nitrogen contributed to storm water from turf fertilization and how much of that nitrogen reaches ground water. Although it is not possible to quantify the contribution to ground water, it is possible to quantify the amount of nitrogen contributed to storm water from residential areas. This figure is 8 tons/yr (calculated on page 122), which is 6 percent of the 131 tons of nitrogen that may be applied to residential areas as fertilizer. Once again, the accuracy of the 131 tons/yr overall figure is very much in doubt. However, if it is accurate, then only a small amount of nitrogen from turf fertilization is removed by storm water.

Golf Courses

There are eight golf courses in the study area (Figure 44) covering approximately 1,309 acres. Five of these golf courses lie within the immediate recharge area for Rainbow Springs. The other three golf courses are located south of the immediate recharge area, and are not included in the loading calculations.

Determining the amount of nitrogen applied to golf courses as fertilizer is highly problematic. However, a study commissioned by the Sarasota Bay National Estuary Program (1992) estimated that 28 tons/yr of nitrogen is applied to a golf course with 15 acres of tees and greens and 200 acres of fairways. Therefore, the 912 acres of golf

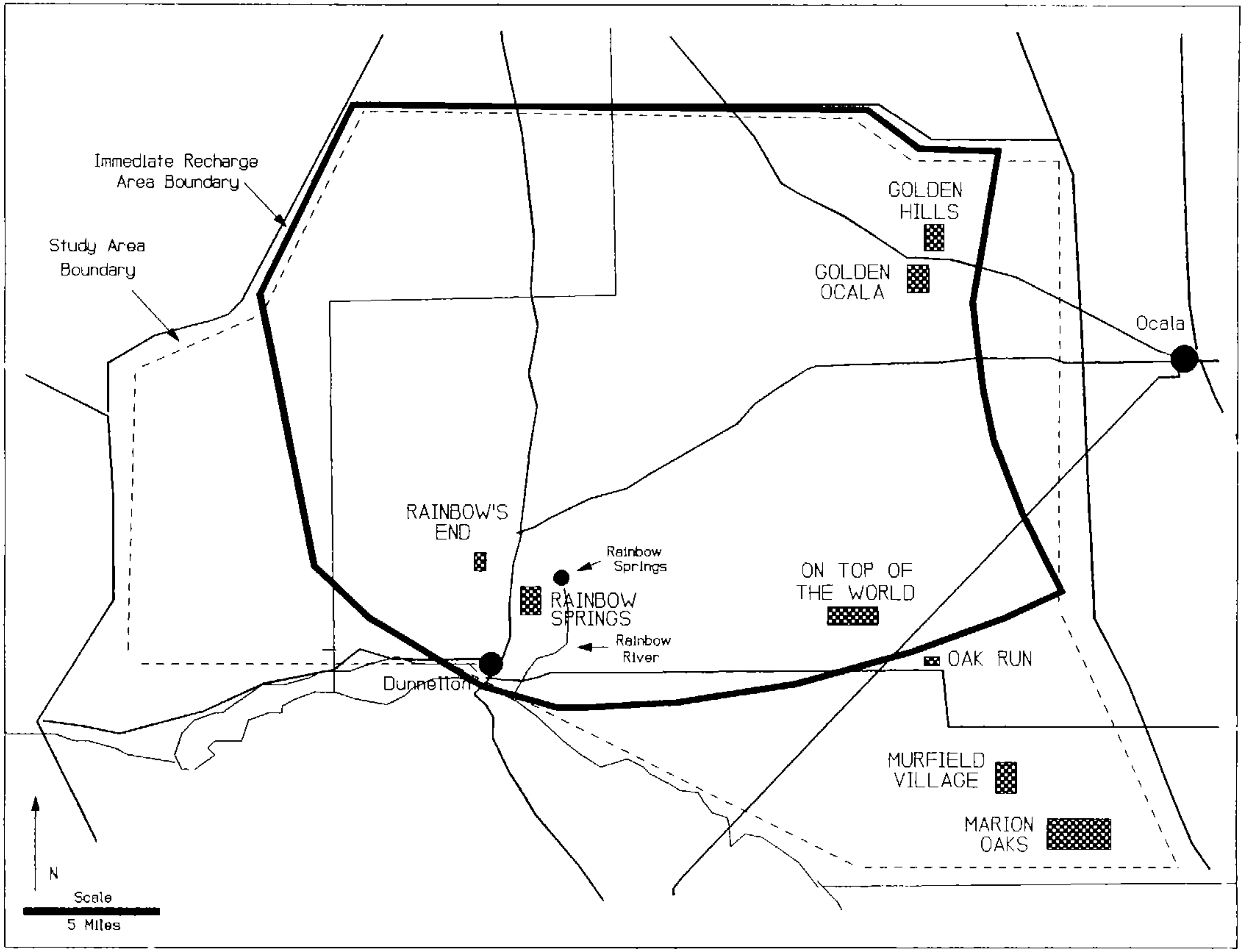


Figure 44. Golf Courses in the Study Area and Immediate Recharge Area.

courses in the immediate recharge area may be receiving approximately 119 tons/yr of nitrogen. When broken out by region the loadings are as follows:

Region	Estimated Golf Course Acreage	Nitrogen Loading (tons/yr)
Eastern	643	84
Central	0	0
Western	269	35
Total	912	119

Since there are only 5 golf courses in the immediate recharge area, they are probably not contributing a significant amount of nitrogen to Rainbow Springs relative to other sources. This is especially true given the fact that a significant portion of the nitrogen is probably removed by the uptake mechanisms discussed previously. To determine the effect of golf course fertilization on ground water, it is recommended that a program of long-term monitoring of ground-water quality in the vicinity of golf courses begin in the near future.

Effluent and Sludge Disposal from Sewage Treatment Plants

There are approximately 47 active wastewater treatment facilities in the study area with a total permitted capacity of 2.9 mgd. The average daily volume of waste water processed in the study area during 1993 was 1.4 mgd. Figure 45 is a location map of the wastewater facilities. Table 7 contains the name, map index number, volume of effluent treated in 1993, and effluent disposal method for each facility. The facilities in the study area range from small package plants for mobile home parks and businesses with permitted capacities of <20,000 gallons per day (gpd) to large regional plants serving residential areas with permitted capacities of 500,000 gpd.

The total volume of municipal wastewater entering treatment plants in the study area in 1993 was 496 million gallons. Total nitrogen concentrations in municipal wastewater range from 20 to 85 mg/l (U.S. EPA, 1981). An important factor that must be considered in determining an accurate value from this range is the degree to which the nitrogen concentration in raw sewage is diluted by ground-water inflow to buried sewer pipes. Because many areas in Florida have a high water table, ground-water inflow to pipelines is probably significant, which would result in a lower nitrogen concentration of effluent entering the treatment facility. A value of 40 mg/l, the median nitrogen concentration (U.S. EPA, 1981) of municipal sewage, was chosen to represent the nitrogen content of wastewater. Using 40 mg/l, the total amount of nitrogen in 496 million gallons of raw wastewater is 83 tons. All of the wastewater treatment plants currently treat

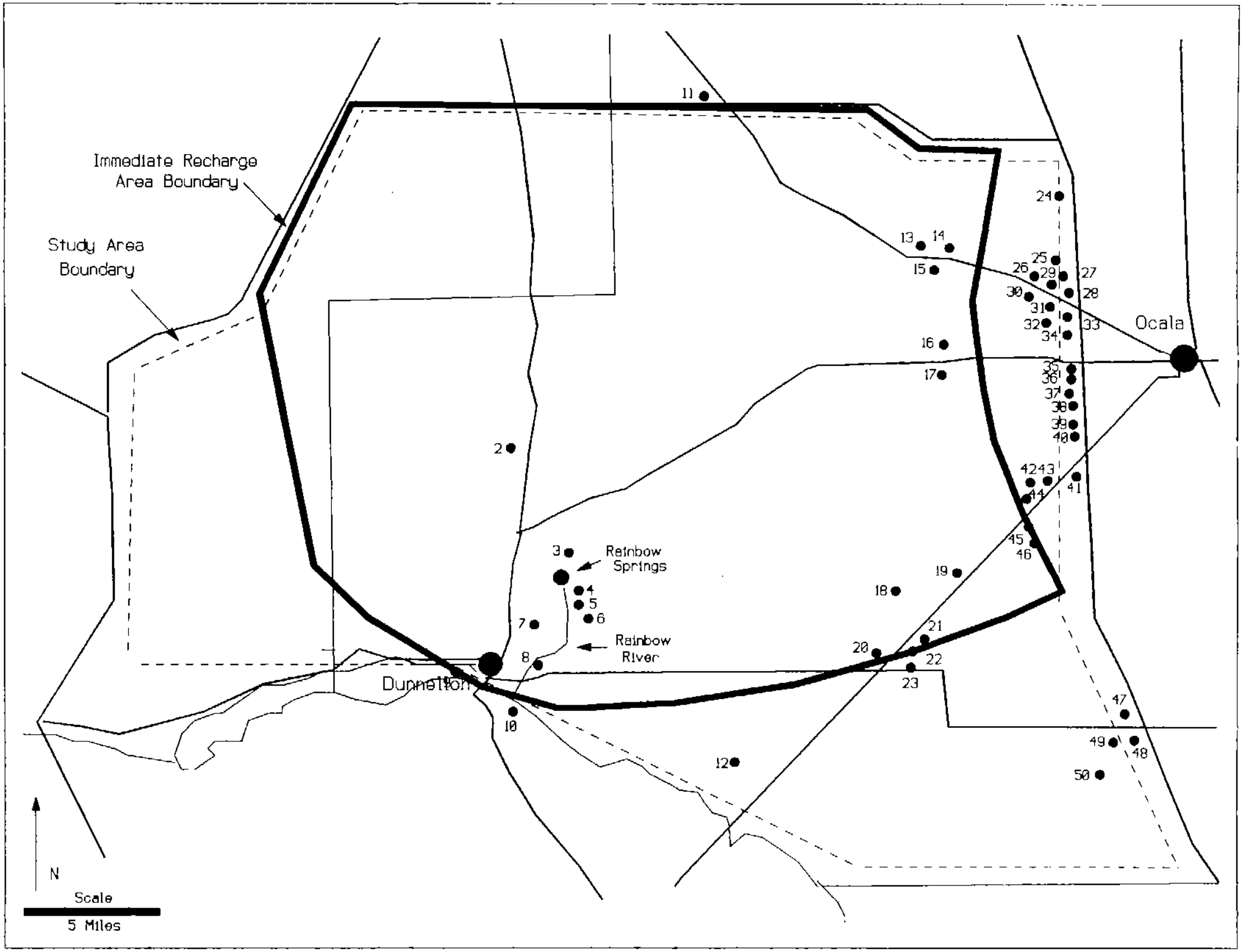


Figure 45. Wastewater Treatment Facilities in the Study Area and Immediate Recharge Area.

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

FACILITY	MAP INDEX	WASTEWATER TREATED IN 1993 (GALLONS)	EFFLUENT DISPOSAL METHOD
INGLIS VILLAS (LEVY CO.)	1	915,000	perc pond
ROMEO ELEM. SCHOOL	2	1,276,000	drain field
RAINBOW SPRINGS COUNTRY CLUB EST.	3	15,743,000	spray field
RAINBOW RIVER CAMP.	4	1,309,000	spray field
SATEKE VILLAGE	5	1,518,000	perc pond
MARION-LEVY H.S.	6	2,807,000	perc pond
RAINBOW SPRINGS #2	7	4,424,000	perc pond
RIO VISTA	8	1,452,000	perc pond
DUNNELLON SQ. SHOPPING CENTER	9	1,004,000	drain field
DUNNELLON, CITY OF	10	43,074,000	perc pond
CRYSTAL SPRINGS MHP	11	73,000	perc pond
M&S LIME STABILIZATION	12	NOT IN USE	perc pond
SANDLIN WOODS	13	4,135,000	spray field
GOLDEN HILL QUAD	14	4,440,000	perc pond
GOLDEN OCALA	15	NOT IN USE	
GOLDEN HILLS PARK	16	5,876,000	perc pond
FALLS OF OCALA	17	2,701,000	perc pond
ON TOP OF THE WORLD CENTRAL	18	85,787,000	perc pond
CIRCLE SQUARE	19	1,342,000	perc pond
BIG SUN NURSING CARE	20	3,074,000	perc pond
103RD STREET SQ.	21	1,578,000	drain field
OAK TRACE	22	179,000	perc pond
OAK RUN	23	111,274,000	perc pond
MARK III INDUST.	24	5,596,000	perc pond
SWEETWATER OAKS	25	2,449,000	perc pond
MASTER HOST	26	5,169,000	perc pond

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

FACILITY	MAP INDEX	WASTEWATER TREATED IN 1993 (GALLONS)	EFFLUENT DISPOSAL METHOD
OAK TREE VILLAGE	27	12,786,000	spray field
H. JOHNSON M. LODGE	28	5,131,000	perc pond
TRAVELERS CHOICE	29	4,879,000	perc pond
FOXWOOD FARMS	30	13,398,000	spray field
RED CARPET INN	31	6,572,000	perc pond
ARROWHEAD CAMP	32	7,124,000	perc pond
MID-FLORIDA MOTELS	33	6,660,000	perc pond
HORNE'S MOTOR LODGE	34	5,284,000	perc pond
CLASSIC OAKS	35	1,705,000	perc pond
WESTWOOD MHP	36	10,430,000	perc pond
DOGWOOD ACRES	37	3,389,000	perc pond
MAGNOLIA GARDENS EST	38	2,861,000	spray field
WHITE OAKS TP	39	7,081,000	spray field
KOA OF OCALA	40	1,788,000	perc pond
EXECUTIVE PARK	41	NOT IN USE	
FAIRFIELD VILLAGE	42	7,000,000	perc pond
SADDLE OAK CLUB	43	13,069,000	perc pond
MARION-CITRUS MENTAL HEALTH	44	1,885,000	drain field
PIDGEON PLAZA	45	800,000	perc pond
MARION LANDINGS	46	13,056,000	perc pond
OCALA MFG. MALL	47	310,000	perc pond
PILOT OIL	48	3,412,000	spray field
484 TRUCK STOP	49	2,137,000	perc pond
MARION OAKS	50	57,290,000	perc pond

to the secondary level. Secondary treatment typically removes approximately 10 to 40 percent of the total nitrogen from domestic wastewater (Ayers and Associates, 1991). Using an average of 25 percent removal, 21 tons is removed from the wastewater and incorporated into the sludge fraction of the waste while 62 tons remain in the effluent fraction. When limiting the area of effluent production to the immediate recharge area, the 62 tons of nitrogen in effluent is reduced to only 17 tons.

It is not possible to quantify the amount of nitrogen from the treatment and disposal of municipal waste water that bypasses the vegetative and soil uptake mechanisms and reaches ground water. However, a discussion of the potential for nitrate to reach ground water from the disposal of both treated effluent and sludge is presented in the following sections.

Sewage Effluent

The 17 tons of nitrogen in effluent from treatment facilities in the immediate recharge area is disposed of in several different ways. Percolation ponds are used at 11 facilities, 3 use spray fields, and 1 uses a drain field. Since the disposal facilities are near the treatment facilities, the 17 tons of nitrogen loaded to the immediate recharge area can be broken out by region:

Region	Nitrogen Loading (tons/yr)
Eastern	13
Central	3
Western	1
Total	17

According to the Florida Department of Environmental Protection (FDEP), many of the percolation ponds in the study area drain extremely rapidly. This is because many of the ponds have highly porus bottoms composed of clean, fine-grained filter material. Since the geology of the study area is such that low permeability confining units are either not present or are frequently breached by sinkholes, the treated effluent rapidly percolates directly into the Floridan aquifer.

To further substantiate the connection between effluent percolation ponds and the Floridan aquifer, nitrate concentrations were obtained from monitor wells at the Oak Run sewage treatment plant. The Oak Run development, composed of a large number of single family homes in a relatively small area, is located in the southeastern portion of the Cotton Plant Ridge physiographic province (Figure 4). As shown in Figure 13, the Ridge is characterized by numerous sinkhole features, some encompassing areas as large as several hundred acres. Much of the Oak Run development occupies a high sandy ridge bounded by several moderately sized sinks. The sewage treatment plant and effluent disposal area are situated near the western flank of this ridge between several small sinkholes. The facility is large relative to most treatment facilities in the study area (Table 7), and, because it is permitted to treat in excess of 100,000 gpd, monitoring of ground-water quality is required. Three shallow monitor wells, ranging in depth from 57 to 77 feet, encircle the effluent-disposal site. Sixteen additional borings were constructed to depths as great as 120 feet (FDEP, 1994). Lithologic samples from the monitor wells and borings indicate the site is mainly underlain by fine-grained sands with discontinuous lenses of silty sands and clay. The limestone surface, encountered in nine borings at depths of approximately 25 to 65 feet, appears to closely mimic the present-day topographic surface. The shallow borings also indicate that the underlying limestone surface displays considerable variation in elevation over short distances which is characteristic of karst terrains.

Water samples obtained from the wells in 1993 and 1994 indicate that nitrate concentrations frequently exceeded the drinking water standard of 10 mg/l as N, and frequently were as high as 13 mg/l. Because a competent confining layer was not indicated by the borings (FDEP, 1994) and the data in this report show significant recharge in this area, the relatively inert, sandy sediments are unlikely to attenuate the nitrate. The fact that high levels of nitrate are migrating into the Floridan aquifer beneath percolation ponds proves that this method of disposing of secondarily-treated effluent, contributes significant amounts of nitrate to the Floridan aquifer.

The conclusion that nitrate from effluent disposal in percolation ponds will reach ground water is verified by the fact that nitrate concentrations in wells monitoring the waste disposal systems of several other large treatment facilities in the study area also show high levels of nitrogen (FDEP, 1994). In addition, Jones and Upchurch (1994) detected significant nitrate contamination of the Floridan aquifer in Citrus County from effluent disposal in percolation ponds.

Fortunately, the current volume of effluent disposal in percolation ponds in the immediate recharge area is small and, therefore, the regional impact on ground water is limited. However, this is likely to change as western Marion County is developed.

Sewage Sludge

Sludge generated by the 47 wastewater treatment plants in the study area is no longer disposed of in the immediate-recharge area, and the two facilities previously dedicated to sludge disposal are now inactive. The Domestic Waste Section of the DEP is responsible for overseeing sludge disposal. The calculations discussed previously indicate that sludge generated in the study area may contain approximately 21 tons of nitrogen. According to the FDEP, most of the sludge is disposed of at the Swift III and Central Process facilities, both of which are outside the immediate recharge area.

Septage Spreading

Land spreading of septage waste is regulated by the Marion County Public Health Unit. Although both septage and sludge wastes can be disposed of at the same site, they must be spread in separate, designated areas. When the data were compiled in 1993, there were four active sites in the immediate recharge area (Figure 46). Information concerning acreage and status of each site is listed in Table 8.

Table 8. Active Septage Spreading Sites in the Study Area (Marion County Public Health unit, 1993).

SITE	SECTION	ACRES	VOLUME SPREAD gal/yr (x 1000)
Castro	Eastern	201	3,000
Mills/Toma	Eastern	75	2,846
Brown's	Eastern	38	1,011
Romeo	Western	130	2,868

Septage sites are privately owned agricultural lands. Septage waste is brought to the spreading sites by disposal companies that revitalize septic tanks. Septage contains high concentrations of nutrients, trace metals, and organic compounds which can contaminate ground water if the application rate exceeds the capacity of the vegetation or soils to utilize or adsorb these compounds.

In January of 1993, disposal sites began to be permitted for the maximum amount of septage waste they could accept each year. Using the actual amount applied in 1993, as determined by FDEP and Marion County Public Health Unit personnel, an estimated total of 9.7 million gallons/yr was applied in the immediate recharge area. The county allows approximately 19,200 gallons/acre to be applied each year at each site. This is considered to be the amount of nitrogen that is utilized by 1 acre of Bahia grass each year (Florida Department of Environmental Regulation, 1989). This volume contains approximately 320 lbs of nitrogen. Using the volume spread and acreage information listed in table 8 for each site, the following nitrogen loading estimates were calculated for each region of the immediate recharge area:

Site	Region	Nitrogen Loading (tons/yr)
Castro	Eastern	25
Mills/Toma	Eastern	24
Brown's	Eastern	9
Romeo	Western	24
	Total	82

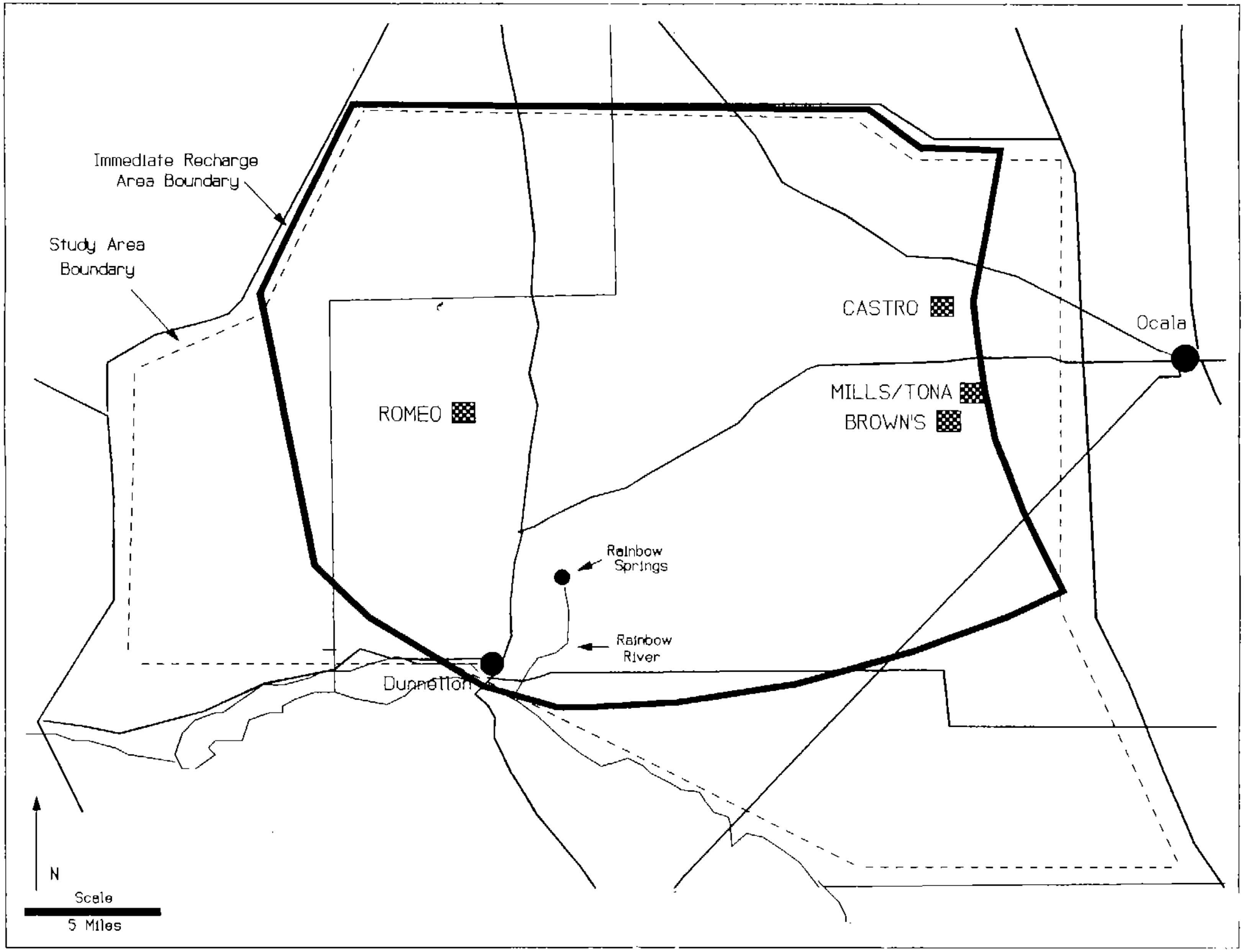


Figure 46. Active and Inactive Septage Spreading Sites in the Study Area.

This amount of nitrogen is probably not significant on a regional basis. However, the fact that the total amount of nitrogen was being applied to four relatively small sites may result in localized areas of elevated nitrate concentrations in ground-water.

Agriculture

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

Row Crops

Row crops, such as watermelon and peanuts, are a relatively minor land use in Marion County covering approximately 2800 acres in 1993 (personal communication, Marion County Agricultural Extension Service (AES)) with most of the crop acreage concentrated near the small communities of Romeo and Marion Oaks. Between these two communities as much as 800 acres of watermelons and 2000 acres of peanuts were planted during 1993 (personal communication, Marion County AES). According to the University of Florida Cooperative Extension Service, watermelons require approximately 120 lbs/ac/yr of fertilizer. This means that approximately 48 tons of nitrogen fertilizer is applied each year to watermelons in the study area. Peanuts, on the other hand, are legumes and require approximately one-third as much fertilizer as watermelons (personal communication, Marion County AES). This means that approximately 40 tons of nitrogen fertilizer is applied each year to peanuts in the study area. Therefore, the total amount of nitrogen fertilizer applied to the 2800 acres of row crops in the study area is approximately 88 tons/yr. This amount is insignificant because row crops planted in the Marion Oaks area probably do not contribute nitrate to the immediate recharge area. This reduces the amount of fertilizer applied in the immediate recharge area to 44 tons. In addition, vegetative uptake and soil removal mechanisms may easily remove the relatively small amount of nitrogen applied to row crops.

Region	Nitrogen Loading (tons/yr)
Eastern	0
Central	0
Western	44
Total	44

Dairies

Dairies have been determined to be a significant source of nitrate to springs in Hillsborough County (Jones and Upchurch, 1993). However, interpretation of aerial photographs and discussions with the Marion County AES indicate that dairies do not exist and have not existed in the study area. Therefore, there are no nitrogen contributions to ground water from dairies.

Cattle Production

Cattle production in Marion County is a major land use and occupies a significant portion of the study area. According to the Florida Department of Agriculture and Consumer Services (1993), there were approximately 52,500 head of cattle in Marion County in 1992. If it is assumed that cattle are evenly distributed across the 135,156 acres of unimproved and improved pasture in Marion County, then the 53,746 acres of pasture in the immediate recharge area contains approximately 20,877 head.

According to the Soil Conservation Service (personal communication) cattle produce 0.33 lbs of nitrogen per day per 1,000 lbs of body weight. If it is assumed that the individual cattle weigh an average of 1,000 lbs, then the total amount of nitrogen supplied by the 20,877 head of cattle in the immediate recharge area is approximately 1,256 tons/yr. Dividing this figure by the percentage of pasture in each region of the immediate recharge area provides the loading amounts listed below.

Region	Nitrogen Loading (tons/yr)
Eastern	410
Central	439
Western	407
Total	1,256

The significance of the nitrogen contributed by cattle is lessened because the cattle are widely dispersed and not concentrated into small feedlot areas. Because they are dispersed, the nitrogen in their waste is more likely to be removed by the many uptake mechanisms discussed previously. When these factors are taken into account, the amount of nitrogen contributed by cattle in the immediate recharge area, while significant, is probably not a major source.

Horse Farms

Horse Farms are a major land use in Marion County, and occupy a significant portion of the study area (Figure 5). According to the Florida Department of Agriculture and Consumer Services (1993), there were approximately 50,000 horses in Marion County in 1992. If it is assumed that horses are evenly distributed across the 54,387 acres of specialty farms in Marion County, then the 25,550 acres of specialty farms in the immediate recharge area contain approximately 23,500 head.

Horses produce approximately 0.35 lbs of nitrogen per day per 1,000 pounds of body weight (personal communication, Dr. Ed Ott, University of Florida Animal Sciences). If it is assumed that the average weight of a horse is 1,000 pounds, the total amount of nitrogen supplied by horses in the immediate recharge area is 1,629 tons/yr.

Dividing this figure by the percentage of specialty farms in each region of the immediate recharge area provides the loading amounts below:

Region	Nitrogen Loading (tons/yr)
Eastern	991
Central	510
Western	< 1
Total	1,501

The significance of the nitrogen produced by horses is lessened because the horses are widely dispersed and not concentrated into small areas. Because they are dispersed, the nitrogen in their waste is more likely to be removed by the many uptake mechanisms. When these factors are taken into account, the amount of nitrogen contributed by horses in the immediate recharge area, while significant, is probably not a major source.

Pasture Fertilization

Nitrogen fertilizers are applied to pastures to promote the growth of pasture grasses. Bahia grass, the most common pasture grass in the Marion County region, is a warm-season perennial grown for livestock and hay. It can withstand heavy grazing stress, and produces good quality hay if well fertilized. Bahia grass readily takes up mineral nutrients in the soil and recycles them within the upper soil zone. If harvested, however, the mineral nutrients contained within the hay are not recycled into the soil and must be supplemented by fertilization (personal communication, Dr. Carrol Chambliss, University of Florida Agronomy Dept.).

The multi-nutrient fertilizer, 10-10-10, and ammonium nitrate (NH_4NO_3), were the most commonly sold nitrogen fertilizers in Marion County during 1992-1993, accounting for nearly three-quarters of all nitrogen fertilizers sold in the county (Florida Department of Agriculture and Consumer Services, 1993). Ammonium nitrate, a widely favored form of nitrogen fertilizer, is commonly applied to pasture grasses throughout northern Florida (personal communication, Dr. Carrol Chambliss, University of Florida Agronomy Dept.).

The Institute of Food and Agricultural Sciences (IFAS, 1990) at the University of Florida, Gainesville, recommends 50-180 lbs N/ac/yr for pasture in the north Florida region depending on how the pasture is utilized. Less nitrogen would be applied if the pastures will be used only for livestock grazing, more if hay will be produced. There should be 1-3 applications each year depending on grass type and frequency of hay removal. For Bahia grass, an initial spring application of 100lbs N/ac and an additional 80lbs N/ac in early August are recommended if a late-season cutting of hay is anticipated.

Within the immediate recharge area there are approximately 53,746 acres of improved and unimproved pasture, and 25,550 acres of pasture associated with horse farms for a total of 79,296 acres. Using an average application of 100 lbs N/ac/yr for pasture grasses, a yearly application of approximately 3,965 tons of nitrogen would result. Dividing this figure by the percentage of pasture in each region of the immediate recharge area provides the loading amounts below:

Region	Nitrogen Loading (tons/yr)
Eastern	1,728
Central	1,364
Western	871
Total	3,963

The possibility for over or under estimating the actual amount of fertilizer applied in the immediate recharge area that would eventually reach the Rainbow-Springs Complex is significant. Inaccuracies may result from the inability to accurately estimate how much of the total pasture acreage is fertilized, at what frequency the pastures are fertilized, and how much fertilizer is applied during each application. It is also very difficult to determine how much fertilizer nitrogen reaches ground water because a large percentage of the applied nitrogen could be removed prior to reaching ground water by the numerous vegetative and soil uptake mechanisms. However, the effect of nitrogen fertilizers on ground-water quality can not be discounted when it is considered that the calculated nitrogen loadings from pasture fertilization, using the stated assumptions, are considerably higher than any other source, and since the nitrogen isotopic content of ground water in the study area is indicative of inorganic fertilizers.

In addition, Figure 47 shows that when ground-water nitrate concentration contours are superimposed on a map of land use, the highest nitrate levels correspond very closely with areas of extensive pasture.[7]

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[7] At the time of publication, the authors received information indicating that the very high nitrate concentrations located approximately 3 miles west of Ocala (Figure 47), may have originated at least partially from the past production of row crops in the area.

Taken together, these factors strongly indicate that pasture fertilization is contributing significant amounts of nitrogen to ground water in the immediate recharge area. Therefore, to better define the relationship between pasture fertilization and ground-water nitrate, it is recommended that a study focusing on pasture fertilization be initiated in the near future.

Storm-Water Runoff

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. 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.

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

To calculate the nitrogen in storm-water runoff from various land uses, data from the EPA's Nationwide Runoff Program (USEPA, 1983) were utilized. Table 9 lists the event mean concentration (EC) 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).

Table 9. Event Mean Nitrogen Concentration and Runoff Coefficient for Important Land Uses in the Immediate Recharge Area.

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

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

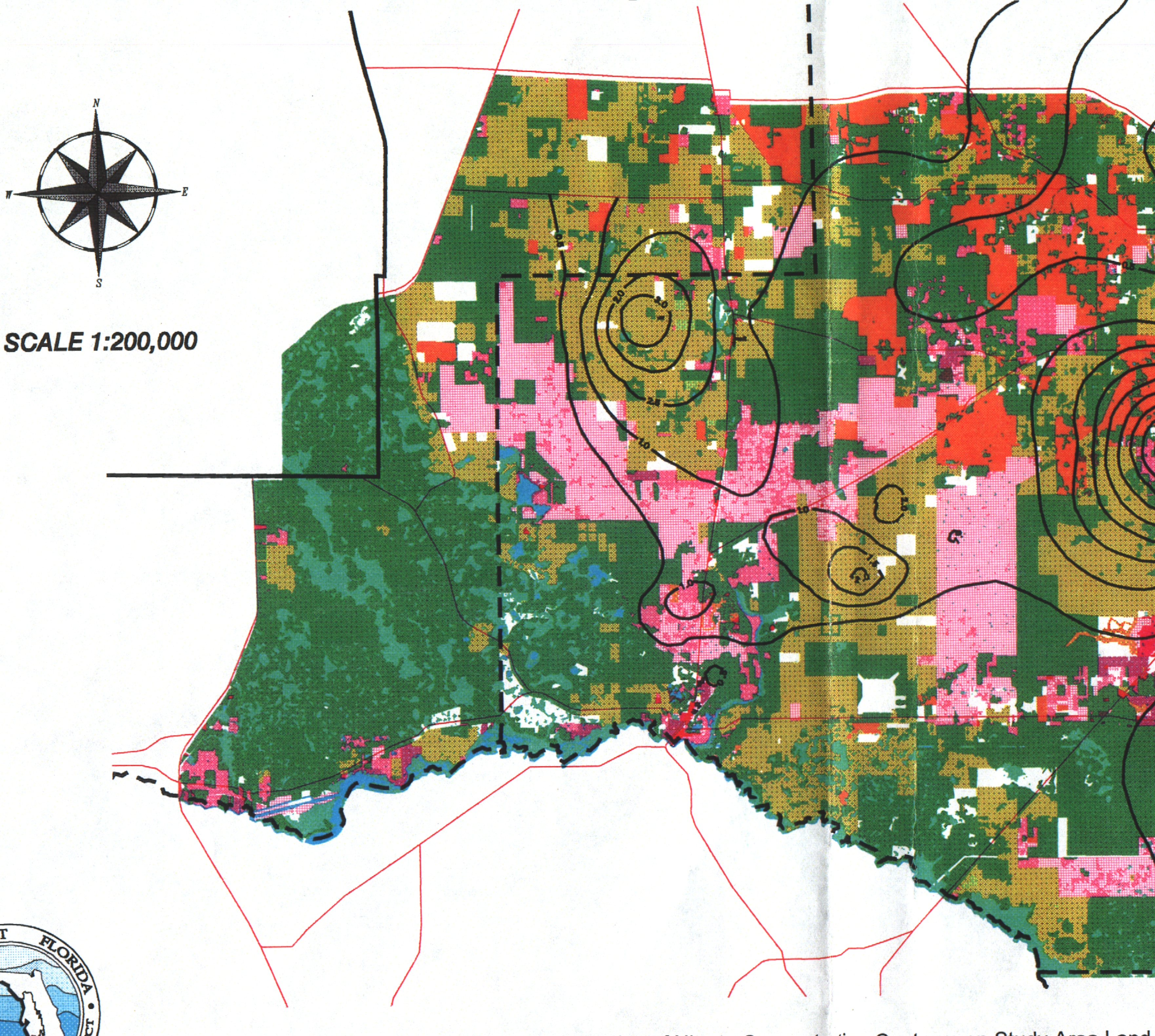

Figure 47. Overlay of Nitrate Concentration Contours on Study Area Land

For total nitrogen, the EC values are highest for golf courses, cropland, and low-to medium-density single-family residential land uses. This results from the fertilization of these areas. Industrial and commercial areas have the lowest EC values because they are not fertilized. However, it should be noted that nitrogen loading depends not only on the EC 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 lbs/ac/yr, even though they are characterized by lower EC values.

The only land uses that were included for the storm-water nitrogen calculations were golf courses, residential, commercial, and cropland. Other land uses such as industrial, pasture, and unimproved areas were not included either because the acreage of the land use in the immediate recharge area was insignificant or an EC value 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:

$$N = r \cdot EC \cdot A \cdot R,$$

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);

EC = event mean concentration (mg/l);

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

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

Table 10 lists some of the land uses that contribute significant amounts of nitrogen to storm water and the amount of nitrogen estimated to be contributed annually by each land use to storm water using the above calculation. Approximately 16 tons of nitrogen are contained in storm water from the listed land uses in the immediate recharge area.

Table 10. Storm Water Nitrogen Contribution from Four Land Uses in the Immediate Recharge Area.

LAND USE	IMMEDIATE RECHARGE REGION EASTERN	 CENTRAL	 WESTERN	TOTAL NITROGEN (tons/yr)
RESIDENTIAL	5	1	2	8
COMMERCIAL	0	0	1	1
GOLF COURSES	1	0	1	2
CROPLAND	0	0	5	5
TOTAL	**6**	**1**	**9**	**16**

It is impossible to determine how much of the nitrogen in storm water may actually reach ground water. Many factors, such as partially blocked or plugged sinkholes and the many other uptake and removal mechanisms discussed previously, could serve to lessen the impact of storm water nitrogen on ground water. Overall, storm water is not currently a significant contributor of nitrogen to ground water in the immediate recharge area. This is because land uses that produce large amounts of storm water are not abundant in the immediate recharge area.

Nitrogen Loading Summary

Table 11 is a summary of the nitrogen contributions of the various sources in the Rainbow Springs immediate recharge area. It must be stressed that the high uncertainty involved in calculating the estimates brings the accuracy of the estimates into question. It must also be stressed that, with the exception of septic tanks and turf fertilization, the amount of nitrogen that reaches the land surface, not that which reaches ground water is being estimated for each of the sources. Since the removal mechanisms can drastically reduce the amount of nitrogen that actually reaches ground water, the nitrogen loading estimates, except for septic tanks and turf fertilization, do not give a definitive indication of the degree to which a specific source is enriching the nitrogen content of ground water. The utility of the estimates lies in the information they provide as to the relative nitrogen contributions of the sources. This allows regulatory agencies to place less emphasis on sources that produce relatively small amounts of nitrate and concentrate their efforts on those that produce significant quantities.

Important sources include fertilization of pasture, and to a lesser degree, cattle and horses. Sources that can currently be discounted as regional contributors to nitrogen in ground water include organic decay, rainfall, septic tanks, residential turf fertilization, golf courses, sewage effluent disposal, land disposal of sewage and septage sludge, and row crops.

Table 11. N Loading Sources and N Loaded Within the Rainbow Springs Immediate Recharge Area (tons/yr).

LAND USE	REGIONAL N LOADING (TONS/YR)				SIGNIFICANCE
	EAST	CENTRAL	WEST	TOT	
Naturally Occurring	?	?	?		Insignificant. Ground-water N in undeveloped areas is low.
Rainfall	471 (reaches surface)	504	467	1,442	Probably insignificant as indicated by low ground-water N in undeveloped areas. Most rainfall N probably removed by vegetative uptake or immobilized in soil layer.
Septic Tanks	22 (reaches ground water)	17	24	63	Insignificant - current number of septic tanks is too small to be a regional problem.
Residential Turf Fertilizer	50 (reaches ground water)	11	18	79	Insignificant - turf area is concentrated in relatively small areas and total acreage is small. N loading probably results in minor, localized problems only.
Golf Courses	84 (reaches surface)	0	35	119	Insignificant - fertilization of the 5 golf courses probably results in localized problems only.
Sewage Effluent Disposal	13 (reaches surface)	3	1	17	Insignificant - level of effluent disposal is currently too small to cause a problem.
Land Disposal of Sewage Sludge	0 (reaches surface)	0	0	0	Insignificant - sludge disposal sites are no longer active in the immediate recharge area.
Land Disposal of Septage Sludge	58 (reaches surface)	0	24	82	Insignificant - quantity of N spread at sites in the immediate recharge area probably results in localized problems only.
Row Crops	0 (reaches surface)	0	44	44	Insignificant - row crops are a minor land use in the immediate recharge area.
Cattle	410 (reaches surface)	439	407	1,256	Somewhat significant - N loading is very high, but cattle are widely dispersed. N in waste utilized by pasture grasses and attenuated in soil layer, possibly to a high degree.
Horse Farms	991 (reaches surface)	510	< 1	1,501	Somewhat significant - N loading is very high but horses widely dispersed. N in waste utilized by pasture grasses and attenuated in soil, possibly to a high degree.
Fertilized Pasture	1,728 (reaches surface)	1,364	871	3,963	Highly significant - vegetative uptake and soil attenuation remove N to some degree but N isotopes indicate fertilizers are main N source in the immediate recharge area.

The largest contributor of nitrogen to the immediate recharge area is the fertilization of pasture. This includes the fertilization of horse and cattle pasture as well as hay fields. Using the assumptions discussed previously, pasture fertilization may contribute 3,963 tons of nitrogen each year to land surface in the immediate recharge area.

Although, as discussed previously, the possibility of over or under estimating the value for pasture fertilization is very high, the nitrogen isotopic content of ground water in the study area and the correlation of elevated nitrate concentration contours with extensive areas of pasture (Figure 47) are strongly indicative of inorganic nitrogen fertilizers. Pasture fertilization is the most likely source of these fertilizers because other sources, such as residential turf and row crops, are relatively insignificant.

Nitrogen from horse and cattle waste may have a significant impact on ground water in the immediate recharge area. The amount of nitrogen contributed to the land surface by horses and cattle is approximately 1,501 and 1,256 tons/yr, respectively. Although this amount of animal waste nitrogen (2,757 tons/yr) is high, the nitrogen isotopic content of ground water strongly suggests an agricultural fertilizer source with little indication of an animal waste source. Therefore, much of the animal-waste nitrogen is either removed before it reaches ground water or masked by fertilizer nitrogen. A possible explanation is that the wide dispersal of cattle and horses throughout the immediate recharge area allows the nitrogen in their waste to be efficiently removed by the many vegetative and soil uptake mechanisms.

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

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

The remaining sources are the least significant regional contributors of nitrogen to ground water. In order of importance from most important to least, these are golf course fertilization, residential turf fertilization, septic tank effluent, and sewage effluent disposal. These sources are associated with an increase in the pace of residential and commercial development that has occurred in the study area within the last 10 years. It is important to note that, although these sources are regionally insignificant at present, their importance will greatly increase as rapid residential and commercial development proceeds in the study area. It is therefore, extremely important that waste disposal practices that are compatible with the region's karst geology and extreme vulnerability to ground-water contamination be implemented prior to the onset of the massive development projected for the near future.

CONCLUSIONS

1. Between 1965 and 1993, the numerous springs and seeps of the Rainbow Springs Complex discharged ground water at an average rate of approximately 450 mgd.

2. Approximately 684 tons of nitrate as N are discharged each year in ground water emanating from the Rainbow Springs Complex.

3. The concentration of nitrate-nitrogen in ground water discharging from the largest springs in the Rainbow Complex is approximately 1.0 mg/l. This is elevated considerably over the concentration of nitrate in ground water in undeveloped portions of the study area (<0.1 mg/l).

4. Historic nitrate concentration data from springs in the Rainbow Complex is very limited. However, the quantity of data is sufficient to indicate that a 20-fold increase in nitrate concentrations during the past 40 years in the largest springs is not unreasonable.

5. Water discharging from the springs originates in the Rainbow Springs Ground-Water Basin. The basin ranges in size from approximately 645 square miles at the end of the dry season in May to approximately 770 square miles at the end of the wet season in September. The basin extends from near Gainesville at its northern extremity, to Ocala on the eastern side, to east-central Levy County on the western side, to Dunnellon on the southern side.

6. Fifty two percent of the Rainbow River discharge, measured at the County Road 484 bridge near Dunnellon, discharges from the head spring area; the first 1500 feet of the Rainbow River. Eighty nine percent of the discharge enters the river in the first 1.5 miles.

7. Sixty six wells were sampled for nitrate in or near the Rainbow Springs Study Area. Six percent had concentrations between 3.0 and 5.2 mg/l, 23 percent had concentrations between 1.0 and 3.0 mg/l, 24 percent had concentrations between 0.5 and 1.0 mg/l, 30 percent had concentrations between 0.1 and 0.5 mg/l, 3 percent had concentrations between 0.01 and 0.1 mg/l, and 14 percent had concentrations below the detection limit (0.01 mg/l). These figures indicate that the portion of the study area where nitrate is significantly elevated above naturally occurring levels (<0.1 mg/l) is extensive.

CONCLUSIONS (continued)

8. The chemistry of water discharging from the springs in the Rainbow Complex indicates that the water has moved through a short, shallow flow system. That is, the water has probably not been in the aquifer for more than a few decades.

9. Much of the water discharging from the springs may have traveled rapidly through two major fractures in limestone of the Floridan aquifer. The fractures are conduits for the transport of large amounts of ground water to the springs. One fracture trends northwest from the springs along the Marion/Levy County line and the other trends northeast from the springs toward Ocala.

10. Two areas were identified in the study area where nitrate concentrations are uniformly high; these are northwest of the springs, just south of the Levy County line, and northeast of the springs, several miles west of Ocala.

11. The two major fracture systems discussed above pass through the areas of high nitrate.

12. Nitrogen isotopic data suggest that the main source of nitrate in the study area is inorganic fertilizer.

13. Ten anthropogenic sources of nitrate were identified in the study area. The amount of nitrogen each source contributes to the study area in tons/yr was estimated. The 3 highest sources were pasture fertilization (3,963 tons/yr), horses (1,501 tons/yr), and cattle (1,256 tons per yr).

14. Pasture fertilization was identified as the principal source of nitrate in the springs of the Rainbow Complex. Supporting data include: 1) identification of inorganic fertilizers as the source of nitrate in the study area using nitrogen isotopes, 2) nitrogen loading calculations showing that pasture fertilization contributes the largest amount of nitrogen to the study area, and 3) the highest nitrate concentrations in the Floridan aquifer in the study area coincide with pasture lands.

15. The development-related nitrogen sources, such as septic tanks, sewage, and residential turf and golf course fertilizers, are currently only minor contributors of nitrogen to the study area. However, the contributions of these sources will greatly increase as the density of these sources increases.

RECOMMENDATIONS

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

2. An investigation of the application of inorganic nitrogen fertilizers in the Rainbow Spring Ground-Water Basin should be initiated in the near future. The study should focus on identifying the specific areas of application, the amount applied, and the amount of nitrogen reaching ground water following application. The study should also attempt to reduce the affect of fertilizers on ground-water quality by developing best management practices.

3. Best management practices should also be developed for preventing waste from horses and cattle in the study area from reaching ground water.

4. Sources, such as residential and golf course turf fertilization, septic tank effluent, and sewage effluent disposal, are regionally insignificant at present. However, their importance will greatly increase as rapid residential and commercial development proceeds in the study area. It is therefore, extremely important that waste disposal practices that are compatible with the region's karst geology and its accompanying extreme vulnerability to ground-water contamination be implemented prior to the onset of the extensive development projected for the near future. These practices include:

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

5. The springs should be sampled annually for nutrients, major analytes, trace organics and nitrogen-isotopic ratios to determine the effects of changing land use, and to determine the effectiveness of remedial efforts, such as the implementation of best management practices for agricultural fertilizers.

RECOMMENDATIONS (continued)

6. The District should work with Marion County and other interested agencies to formulate land-use plans that would prevent additional nitrogen loadings to the study area.

7. A detailed map of the upper head spring area containing surveyed locations of all the spring vents and detailed drawings of the spring bottom should be prepared in the near future. This would insure the integrity of long-term data collection by making it easier for future samplers to determine the locations of historic sampling points.

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APPENDICES

APPENDIX I

Specifications of Monitor Wells

Appendix I. Specifications of Monitor Wells

WELL OWNER	MAP REFERENCE NUMBER	DATE SAMPLED	TOTAL DEPTH (FT)	CASED DEPTH (FT)	CASING DIAMETER (IN)
ANDREWS, G.	73	06/21/94	75	42	
BARBER, M.	74	06/15/94	180	133	4
BARRETT, B.	75	06/07/94	60	46	4
BIEDERMAN, D.	60	06/08/94	120	92	4
BOUEHARD, W.	122	12/14/94			
BROWN, C.	56	06/20/94	120	84	4
BUMPUS, B.	62	06/20/94	90	79	4
BUSTER, P.	64	06/08/94	80	61	4
CE #12	117	06/14/94	46	38	2
CE-14 D	116	06/16/94	190	112	6
CONTENTO,(BIGWOOD)	72	12/07/94	105	72	4
COOMER	77	06/07/94			
CUBBAGE, J.	69	06/22/94	60	50	4
CULBREATH, R.	78	06/22/94	80	63	4
DAMIEN, P.	54	06/23/94	100	50	4
DIKEMAN, F.	79	12/07/94	145	82	4
DRAKE RNCH SH	80	06/27/94			
DUNNELLON HS 3	81	06/22/94	155	59	6
DUNNELLON MSN	82	06/22/94			
EDWARDS, R.	84	06/07/94			
ENGEL, R.	85	06/21/94	100	84	4
ERMEL, R.	86	06/27/94	183		4
FARLESS, W.	68	06/21/94	80	63	4
FERGUSON, J.	65	06/09/94	50	42	8
FERGUSON, R.	87	06/20/94	200	132	4
FLEEGLER, D.	88	06/21/94	165	143	4
FRIEDMAN, K.	55	06/21/94	80	42	4
GRUSENMEYER, T	47	06/06/94	185	156	4
HENDERSON, S.	70	12/07/94	60	58	4
HOBBS, M.	90	06/08/94	161	153	4
JENSEN, A.	67	06/22/94	100	74	4
KEEN, D.	91	06/06/94	84	63	4
KING, J.	92	06/15/94	163	122	4
KINSMAN,MAIN	93	06/20/94	110	51	4
KNOUSE, L.	49	06/20/94	175	146	4
KOON, R.	123	12/14/94			
LUCKY, Q.	50	06/06/94	75	51	4
MANCINI, N.	94	06/08/94	75	75	4
MATHIS, E.	95	06/15/94	88	63	4
MAUGHAN, P.	63	06/07/94	82	63	4
MCFARLAND, S.	96	06/16/94	105	62	4
MURPHY, M.	98	06/15/94	204	79	4
NEIDER, J.	99	06/21/94	85	58	4
NELSON, J.	100	06/16/94	115	105	4
PRUITT CENTRAL	112	06/28/94			
PRUITT NORTH	111	06/28/94			
PRUITT SOUTH	113	06/28/94			
RB SPG #2 WEST	102	06/07/94			
ROMEO ELEM. S.	103	06/22/94	243	160	6

Appendix I. Specifications of Monitor Wells

WELL OWNER	MAP REFERENCE NUMBER	DATE SAMPLED	TOTAL DEPTH (FT)	CASED DEPTH (FT)	CASING DIAMETER (IN)
RUGGIERO, R.	124	12/14/94	120		4
SEIBT, R.	104	06/08/94	60	46	4
SHEFFIELD, K.	105	06/15/94			
SHEFFIELD, O.	106	06/16/94	105	83	4
SIEBEL, R.	121	06/27/94			
SKINNER, C.	107	06/27/94	110	105	4
SKIPPER, J.	59	06/08/94	240	220	4
STROMBERGER, K	52	06/20/94	145	141	4
TEAGLE, J.	51	06/06/94	70	57	4
TSAO, M.	108	06/23/94	95	65	4
TURNER	109	06/07/94	160	145	4
UMHOLTZ, A.	53	06/08/94	182	169	4
WAITE, E.	120	06/09/94	126	105	4
WALDRON, W.	125	02/02/95			
WARE	57	06/07/94	60	42	4
WILLIAMSON, B.	48	06/20/94	200	154	4
YONKE, R.M.	61	06/21/94	105	81	4

APPENDIX II

Water Quality Data for Sampled Monitor Wells

Appendix II. Water-Quality Data from Sampled Monitor Wells

WELL		FIELD	FIELD	FIELD		DIS	DIS	DIS	DIS	DIS	DIS	DIS				ORTHO	TOTAL		
NAME	DATE	pH	TEMP	COND	HCO3	Cl	SO4	F	Ca	Mg	K	Na	NH3	NO2	NO3	PO4	PO4	TDS	TOC
ANDREWS, G.	06/21/94	7.58	24.00	199.00	79.00	3.50	2.00	0.09	38.00	0.70	-0.05	3.30	-0.010	-0.010	2.978	0.045	0.082	128.00	-0.50
ANDREWS, G.	12/07/94	7.64	23.70	191.00									-0.010			0.074	0.080		-0.50
BARBER, M.	06/15/94	8.07	23.70	227.00	87.00	2.70	20.00	0.10	37.00	9.90	0.20	2.40	-0.010	-0.010	-0.010	0.038	0.035	138.00	0.51
BARRETT, B.	06/07/94	8.21	23.50	161.00	60.00	7.00	6.00	0.08	25.00	4.10	0.10	4.40	-0.010	-0.010	1.784	0.032	0.032	100.00	-0.50
BARRETT, B.	12/07/94	8.20	23.30	171.00									-0.010			0.030	0.030		-0.50
BIEDERMAN, D.	06/08/94	7.65	23.40	315.00	130.00	4.50	24.00	0.14	58.00	6.70	0.20	3.80	-0.010	-0.010	0.745	0.027	0.042	165.00	-0.50
BOUEHARD, W.	12/14/94	7.69	23.20	289.00	122.00	5.60	9.80	0.10	50.00	3.90	0.20	3.20	-0.010	-0.010	1.174	0.047	0.038	158.00	-0.50
BROWN, C.	06/20/94	7.36	24.70	432.00	169.00	15.00	30.00	0.31	62.00	12.00	0.50	7.40	0.012	-0.010	0.529	0.032	0.038	266.00	-0.50
BUMPUS, B.	06/20/94	7.76	24.30	272.00	84.00	4.70	35.00	0.15	44.00	4.30	0.20	3.50	0.016	-0.010	1.051	0.012	0.018	164.00	-0.50
BUMPUS, B.	12/07/94	7.74	23.50	295.00									-0.010			0.023	-0.010		-0.50
BUSTER, P.	06/08/94	7.60	22.90	278.00	135.00	3.10	3.00	0.04	60.00	1.50	-0.05	2.70	0.040	-0.010	-0.010	0.029	0.036	139.00	0.93
CE #12	06/14/94	7.66	23.00	245.00	109.00	3.50	7.00	0.06	55.00	2.20	0.50	2.40	0.038	-0.010	0.969	0.034	0.029	140.00	-0.50
CE-#12	12/08/94	7.67	22.70	230.00									0.025			0.028	0.028		-0.50
CE-14 D	06/16/94	7.61	24.30	263.00	121.00	4.10	7.00	0.10	49.00	2.60	0.10	2.80	0.060	-0.010	-0.010	0.071	0.110	152.00	1.80
CONTENTO,(BIGWOOD)	12/07/94	7.61	25.00	363.00	110.00	7.80	45.00	0.13	57.00	6.60	0.50	4.50	-0.010	-0.010	2.920	0.040	0.040	198.00	-0.50
COOMER	06/07/94	7.63	24.60	195.00	87.00	3.10	6.00	0.08	37.00	3.90	-0.05	2.40	-0.010	-0.010	-0.010	0.034	0.049	122.00	-0.50
CUBBAGE, J.	06/22/94	7.35	23.40	510.00	241.00	9.90	2.00	0.14	99.00	2.50	0.20	5.20	0.112	-0.010	-0.010	0.197	0.244	458.00	4.60
CULBREATH, R.	06/22/94	8.05	24.20	338.00	158.00	4.60	6.00	0.08	66.00	1.40	-0.05	3.40	-0.010	-0.010	0.130	0.039	0.054	324.00	-0.50
CULBREATH, R.	12/13/94	7.38	23.70	332.00									-0.010			0.064	0.060		0.46
DAMIEN, P.	06/23/94	7.08	23.00	470.00	213.00	16.00	2.00	0.11	92.00	1.10	-0.05	5.90	-0.010	-0.010	0.206	0.020	0.029	374.00	1.70
DIKEMAN, F.	12/07/94	8.02	21.90	185.00	69.00	4.20	10.00	0.07	27.00	5.20	-0.05	2.60	-0.010	-0.010	0.473	0.055	0.055	96.00	-0.50
DRAKE RNCH SH	06/27/94	6.93	22.40	570.00	67.00	12.00	5.00	0.08	115.00	1.60	-0.05	6.20	-0.010	-0.010	0.072	0.045	0.409	347.00	1.00
DRAKE RNCH SH.	12/13/94	7.03	20.40	569.00									-0.010			0.052	0.050		0.87
DUNNELLON HS 3	06/22/94	7.96	23.40	268.00	119.00	4.00	8.00	0.10	48.00	2.10	-0.05	2.40	-0.010	-0.010	0.694	0.056	0.076	269.00	-0.50
DUNNELLON MSN	06/22/94	7.31	23.80	430.00	235.00	4.20	25.00	0.14	70.00	11.00	0.20	3.40	-0.010	-0.010	0.561	0.128	0.137	345.00	-0.50
EDWARDS, R.	06/07/94	8.51	23.70	119.00	42.00	6.10	3.00	0.06	19.00	2.80	0.10	4.00	0.010	-0.010	0.619	0.031	0.037	82.00	-0.50
EDWARDS, R.	12/13/94	8.67	23.30	122.00	44.00	6.50	-0.10	0.05	16.00	2.50	-0.05	3.70	-0.010	-0.010	0.720	0.050	0.040	68.00	-0.50
ENGEL, R.	06/21/94	8.41	23.40	158.00	70.00	3.50	2.00	0.09	24.00	4.20	-0.05	2.40	-0.010	-0.010	0.365	0.039		30.00	-0.50
ERMEL, R.	06/27/94	8.79	23.40	68.00	29.00	2.20	2.00	0.08	12.00	0.30	-0.05	1.60	-0.010	-0.010	0.175	0.056	0.046	56.00	1.48
FARLESS, W.	06/21/94	7.25	24.00	349.00	175.00	3.20	2.00	0.07	72.00	1.10	-0.05	2.30	-0.010	-0.010	0.395	0.033	0.026	200.00	-0.50
FERGUSON, J.	06/09/94	7.93	22.40	226.00	89.00	4.50	7.00	0.04	48.00	0.80	0.20	5.30	-0.010	-0.010	1.856	0.010	0.023	118.00	-0.50
FERGUSON, J.	12/13/94	7.75	21.90	239.00									-0.010			0.022	0.011		-0.50
FERGUSON, R.	06/20/94	7.39	23.10	365.00	174.00	5.10	6.00	0.30	60.00	8.60	0.40	3.90	-0.010	-0.010	0.151	0.021	0.033	216.00	-0.50
FLEEGLER, D.	06/21/94	8.28	24.50	157.00	72.00	2.90	3.00	0.10	26.00	3.40	-0.05	2.10	0.019	-0.010	0.104	0.024	0.025	90.00	-0.50
FRIEDMAN, K.	06/21/94	7.09	23.50	462.00	193.00	5.90	4.00	0.10	86.00	1.00	0.20	3.20	-0.010	-0.010	5.150	0.065	0.072	277.00	-0.50
FRIEDMAN, K.	12/07/94	7.17	23.20	455.00									-0.010			0.070	0.070		-0.50
GRUSENMEYER, T	06/06/94	7.29	23.20	374.00	177.00	4.40	3.00	0.15	77.00	2.90	0.20	4.30	-0.010	-0.010	1.336	0.048	0.063	231.00	0.55
GRUSENMEYER, T	03/23/95	7.26	22.40	377.00									-0.010			0.060	0.080		0.64
GRUSENMEYER, T.	05/15/95	7.25	22.50	378.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.018	-0.010	1.204	0.058	0.064	0.00	-0.50
HENDERSON, S.	12/07/94	7.04	22.90	423.00	204.00	5.70	5.40	0.05	85.00	1.30	-0.05	3.40	-0.010	-0.010	0.210	0.050	0.040	216.00	-0.50
HOBBS, M.	06/08/94	8.56	26.10	150.00	64.00	3.50	4.00	0.09	26.00	4.60	0.10	2.90	-0.010	-0.010	0.216	0.044	0.055	75.00	-0.50
JENSEN, A.	06/22/94	7.45	25.20	527.00	259.00	5.30	3.00	0.05	108.00	1.70	0.20	3.50	-0.010	-0.010	0.423	0.014	0.023	417.00	1.09

Appendix II. Water-Quality Data from Sampled Monitor Wells

WELL NAME	DATE	FIELD pH	FIELD TEMP	FIELD COND	HCO3	DIS Cl	DIS SO4	DIS F	DIS Ca	DIS Mg	DIS K	DIS Na	NH3	NO2	NO3	ORTHO PO4	TOTAL PO4	TDS	TOC
KEEN, D.	06/06/94	7.30	23.30	393.00	187.00	4.40	10.00	0.11	77.00	6.10	0.10	3.70	-0.010	-0.010	0.816	0.029	0.033	229.00	-0.50
KEEN, D.	12/07/94	7.45	23.10	392.00									-0.010			0.041	0.044		-0.50
KING, J.	06/15/94	8.37	23.80	95.80	39.00	2.70	0.00	0.12	19.00	2.30	0.10	2.10	0.106	-0.010	0.163	0.090	0.086	68.00	-0.50
KING, J.	12/06/94	8.34	23.50	95.00									-0.010			0.090	0.100		-0.50
KINSMAN,MAIN	06/20/94	7.32	25.10	440.00	175.00	6.50	38.00	0.19	80.00	5.70	0.20	4.10	0.014	-0.010	1.437	0.026	0.036	262.00	-0.50
KINSMAN,MAIN	12/08/94	7.35	23.60	388.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.010			0.032	0.028	0.00	-0.50
KNOUSE, L.	06/20/94	7.30	22.50	385.00	187.00	5.90	3.00	0.23	68.00	6.70	0.50	3.90	0.059	-0.010	-0.010	0.017	0.034	219.00	-0.50
KOON, R.	12/14/94	7.43	22.50	337.00	154.00	5.30	7.50	0.12	59.00	4.80	-0.05	2.90	-0.010	-0.010	1.009	0.047	0.038	181.00	-0.50
LUCKY, Q.	06/06/94	6.99	22.90	576.00	263.00	15.00	12.00	0.10	112.00	2.00	0.10	19.00	-0.010	-0.010	1.139	0.058	0.064	346.00	-0.50
LUCKY, Q.	12/07/94	6.99	22.50	572.00									-0.010			0.077	0.077		-0.50
MANCINI, N.	06/08/94	7.51	23.20	311.00	149.00	4.30	1.00	0.87	57.00	7.20	0.10	3.50	0.181	-0.010	-0.010	0.066	0.063	151.00	0.99
MATHIS, E.	06/15/94	7.28	24.60	382.00	151.00	6.80	27.00	0.14	82.00	4.10	0.10	4.80	0.011	-0.010	0.700	0.020	0.026	234.00	0.59
MAUGHAN, P.	06/07/94	7.45	23.30	265.00	113.00	7.10	5.00	0.19	52.00	2.80	0.20	4.80	-0.010	-0.010	0.375	0.311	0.346	157.00	0.84
MAUGHAN, P.	12/06/94	7.46	23.20	267.00									-0.010			0.330	0.390		0.48
MCFARLAND, S.	06/16/94	7.48	24.20	319.00	133.00	10.00	6.00	0.08	60.00	0.90	-0.05	5.00	0.023	-0.010	0.888	0.046	0.042	192.00	-0.50
MCFARLAND, S.	12/12/94	7.45	22.90	322.00									-0.010			0.053	0.044		0.12
MURPHY, M.	06/15/94	7.72	24.70	290.00	140.00	3.40	4.00	0.12	53.00	4.20	-0.05	2.50	-0.010	-0.010	-0.010	0.053	0.053	166.00	0.51
NEIDER, J.	06/21/94	7.18	22.60	440.00	219.00	5.00	6.00	0.16	85.00	4.60	0.10	3.30	-0.010	-0.010	0.426	0.040	0.038	246.00	-0.50
NELSON, J.	06/16/94	6.95	25.90	512.00	235.00	3.30	13.00	0.09	100.00	1.90	0.70	6.30	-0.010	-0.010	3.733	0.117	0.131	307.00	1.85
NELSON, J.	12/07/94	7.01	26.00	513.00									-0.010			0.110	0.115		1.10
PRUITT CENTRAL	06/28/94	7.75	24.40	231.00	97.00	4.90	8.00	0.10	37.00	2.70	0.30	2.90	-0.010	-0.010	2.432	0.038	0.038	167.00	-0.50
PRUITT CENTRAL	12/06/94	7.83	23.80	224.00									-0.010			0.050	0.040		-0.50
PRUITT NORTH	06/28/94	7.75	24.00	290.00	83.00	5.00	29.00	0.13	44.00	4.70	0.30	3.30	-0.010	-0.010	0.343	0.026	0.028	170.00	2.72
PRUITT SOUTH	06/28/94	7.72	25.10	407.00	119.00	5.50	70.00	0.16	67.00	6.20	0.20	3.50	0.031	-0.010	0.019	0.045	0.052	245.00	-0.50
RB SPG #2 WEST	06/07/94	7.51	23.00	331.00									0.010	-0.010	0.940	0.030	0.050		1.00
RB SPG #2 WEST	12/08/94	7.50	23.00	320.00									-0.010			0.039	0.033		-0.50
ROMEO ELEM. S.	06/22/94	8.41	23.30	212.00	91.00	3.30	6.00	0.15	35.00	4.00	-0.05	2.40	-0.010	-0.010	1.102	0.033	0.038	255.00	-0.50
ROMEO ELEM. S.	12/13/94	7.91	23.00	204.00									-0.010			0.042	0.037		-0.50
RUGGIERO, R.	12/14/94	8.40	22.90	140.00	58.00	3.80	2.00	0.07	21.00	2.40	-0.05	2.30	-0.010	-0.010	0.841	0.033	0.022	91.00	-0.50
SEIBT, R.	06/08/94	7.33	23.60	244.00	103.00	6.40	6.00	0.10	45.00	4.50	0.10	4.00	-0.010	-0.010	0.665	0.123	0.141	119.00	0.55
SHEFFIELD, K.	06/15/94	7.44	24.20	357.00	143.00	5.50	23.00	0.17	61.00	5.80	0.20	3.80	-0.010	-0.010	0.933	0.051	0.043	211.00	-0.50
SHEFFIELD, K.	12/07/94	7.51	23.40	313.00									-0.010			0.056	0.055		-0.50
SHEFFIELD, O.	06/16/94	7.15	23.40	437.00	163.00	6.90	29.00	0.12	82.00	3.10	0.10	4.20	-0.010	-0.010	5.249	0.027	0.022	273.00	-0.50
SHEFFIELD, O.	12/07/94	7.23	23.20	434.00									-0.010			0.029	0.029		-0.50
SIEBEL, R.	06/27/94	7.21	23.00	470.00	201.00	7.80	22.00	0.22	85.00	6.20	0.30	5.60	-0.010	-0.010	0.791	0.032	0.025	274.00	-0.50
SKINNER, C.	06/27/94	8.17	23.90	138.00	59.00	3.00	5.00	0.07	23.00	2.30	-0.05	2.20	-0.010	-0.010	0.101	-0.010	-0.010	92.00	-0.50
SKINNER, C.	12/06/94	8.19	23.30	138.00									-0.010			0.030	0.020		-0.50
SKIPPER, J.	06/08/94	8.41	24.70	233.00	70.00	4.00	36.00	0.09	44.00	13.00	0.20	3.60	0.022	-0.010	0.243	0.063	0.071	123.00	-0.50
SKIPPER, J.	12/06/94	8.37	22.10	269.00									-0.010			0.060	0.070		-0.50
STROMBERGER, K	06/20/94	7.57	22.80	319.00	147.00	5.00	7.00	0.29	53.00	7.10	0.30	3.90	0.011	-0.010	0.263	0.029	0.038	199.00	-0.50
TEAGLE, J.	06/08/94	7.04	22.80	494.00	239.00	5.10	4.00	0.15	105.00	2.80	0.10	3.60	-0.010	-0.010	1.136	0.053	0.059	289.00	-0.50
TEAGLE, J.	12/13/94	7.01	21.70	502.00									-0.010			0.074	0.082		-0.50

Appendix II. Water-Quality Data from Sampled Monitor Wells

WELL NAME	DATE	FIELD pH	FIELD TEMP	FIELD COND	HCO3	DIS Cl	DIS SO4	DIS F	DIS Ca	DIS Mg	DIS K	DIS Na	NH3	NO2	NO3	ORTHO PO4	TOTAL PO4	TDS	TOC
TSAO, M.	06/23/94	7.53	23.40	301.00	119.00	5.60	18.00	0.11	56.00	2.20	0.10	3.40	0.014	-0.010	1.084	0.010	0.764	353.00	-0.50
TSAO, M.	12/07/94	7.55	23.10	313.00									-0.010			0.020	0.010		-0.50
TURNER	06/07/94	7.97	23.90	143.00	64.00	2.80	2.00	0.08	24.00	3.70	0.10	2.60	-0.010	-0.010	0.216	0.018	0.027	88.00	-0.50
UMHOLTZ, A.	06/08/94	7.76	23.20	217.00	100.00	4.10	2.00	0.08	40.00	4.90	0.10	3.30	-0.010	-0.010	-0.010	0.136	0.127	107.00	2.07
WAITE, E.	06/09/94	7.87	23.60	310.00	99.00	4.90	43.00	0.11	58.00	6.70	0.40	4.80	0.031	-0.010	1.096	0.019	0.023	178.00	-0.50
WALDRON, W.	02/02/95	7.83	20.90	237.00	105.00	4.40	3.40	0.08	42.00	4.00	-0.05	2.50	-0.010	-0.010	3.342	0.031	0.033	133.00	-0.50
WALDRON, W.	03/23/95	7.74	23.40	240.00									0.038	-0.010	3.125	0.027	0.036		-0.50
WARE	06/07/94	8.24	23.70	143.00	62.00	2.70	6.00	0.07	24.00	4.10	0.10	2.30	-0.010	-0.010	0.236	0.018	0.025	85.00	-0.50
WILLIAMSON, B.	06/20/94	7.28	23.10	379.00	190.00	4.90	3.00	0.15	74.00	2.50	0.30	3.60	-0.010	-0.010	0.868	0.062	0.071	249.00	-0.50
WILLIAMSON, B.	12/07/94	7.27	22.20	387.00									-0.010			0.079	0.066		-0.50
YONKE, R.M.	06/21/94	7.64	26.20	333.00	99.00	6.00	55.00	0.14	56.00	5.00	0.20	4.00	-0.010	-0.010	0.575	0.016	0.013	199.00	-0.50

APPENDIX III

Water-Quality Data for Sampled Springs

Appendix III. Water-Quality Data from Sampled Springs

SPRING	DATE	FIELD	FIELD	FIELD		DIS	DIS	DIS	DIS	DIS	DIS	DIS				ORTHO	TOTAL		
NAME	SAMPLED	pH	TEMP	COND	HCO3	Cl	SO4	F	Ca	Mg	K	Na	NH3	N02	NO3	P04	PO4	TDS	TOC
BRIDGE SEEP NORTH	10/07/93	8.73	23.40	122.00	47.00	3.10	6.10	0.050	19.00	2.90	0.30	2.00				0.020	0.030	85.00	1.70
BRIDGE SEEP NORTH	02/21/94	8.35	23.10	123.00	75.00	3.10	4.30	0.060	20.00	3.30	0.10	2.30				0.030		81.00	-0.50
BRIDGE SEEP NORTH	04/11/94	8.38	23.50	131.00	47.00	3.10	5.60	0.050	21.00	3.00	0.10	2.00		-0.01	0.460	0.030	-0.010	64.00	-0.50
BRIDGE SEEP NORTH	07/18/94	8.18	23.90	124.00	40.00	2.70	5.00	0.080	19.00	3.10	-0.05	2.10	0.32	-0.01	0.470	0.030	0.060	77.00	-0.50
BRIDGE SEEP NORTH	10/31/94	8.31	23.50	125.00	51.00	3.30	4.00	0.080	19.00	3.30	-0.05	2.00	-0.01	-0.01	0.464	0.030	0.030	75.00	-0.50
BRIDGE SEEP NORTH	12/08/94	8.37	23.30	122.00	49.00	3.20	3.80	0.060	19.00	3.10	-0.05	2.00	-0.01	-0.01	0.450	0.040	0.030	64.00	-0.50
BRIDGE SEEP NORTH	03/29/95	8.38	23.40	130.00	52.00	3.00	3.80	0.060	21.00	3.40	0.05	2.10	0.01	-0.01	0.565	0.023	0.090	74.00	0.50
BRIDGE SEEP NORTH	07/20/95	8.26	23.70	125.00	48.00	2.60	3.70	0.060	18.00	3.60	-0.05	2.30	-0.01	-0.01	0.518	0.037	0.041	72.00	-0.50
BRIDGE SEEP SOUTH	10/07/93	8.82	23.40	123.00	49.00	3.00	6.10	0.050	20.00	2.50	0.30	2.10				0.020	-0.010	78.00	-0.50
EAST SEEP	10/07/93	7.92	23.30	197.00	86.00	3.70	6.30	0.090	33.00	3.90	0.30	2.50				0.030	0.020	123.00	-0.50
EAST SEEP	02/21/94	8.01	24.00	199.00	86.00	3.80	4.60	0.100	34.00	4.40	0.20	2.70	-0.01	-0.01	1.000	0.030	0.030	117.00	-0.50
EAST SEEP	04/11/94	7.88	23.10	199.00	63.00	3.80	6.10	0.090	35.00	4.00		2.00	-0.01	-0.01	1.110	0.050	0.070	103.00	-0.50
EAST SEEP	07/18/94	7.96	24.00	199.00	79.00	3.30	5.10	0.120	32.00	4.20	-0.05	2.60	0.05	-0.01	1.020	0.020	0.020	107.00	0.58
EAST SEEP	10/31/94	7.97	23.80	193.00	82.00	4.10	4.20	0.130	32.00	4.20	-0.05	2.40	-0.01	-0.01	0.992	0.030	0.024	102.00	-0.50
RAINBOW SEEP 1A	02/21/93	8.03	23.30	163.00	85.00	3.10	4.70	0.090	27.00	3.90	0.20	2.60	-0.01	-0.01	0.850	0.030		99.00	-0.50
RAINBOW SEEP 1A	10/05/93	7.30	23.80	164.00	68.00	3.50	5.50	0.150	27.00	3.90	0.30	2.40				-0.010	-0.010	102.00	-0.50
RAINBOW SEEP 1A	04/11/94	7.92	23.40	164.00	68.00	3.70	6.70	0.080	28.00	4.00		2.00	-0.01	-0.01	0.940	0.050	0.070	99.00	-0.50
RAINBOW SEEP 1A	07/18/94	8.02	23.50	163.00	64.00	3.20	5.60	0.120	26.00	3.70	-0.06	2.50	0.15	-0.01	0.920	0.040	0.060	107.00	-0.50
RAINBOW SEEP 1A	10/31/94	7.91	23.70	155.00	73.00	3.80	4.50	0.116	25.00	3.70	-0.05	2.40	-0.01	-0.01	0.799	0.036	0.063	81.00	-0.50
RAINBOW SPRING #1	10/05/93	8.44	24.50	151.00	63.00	3.40	5.30	0.090	24.00	3.70	0.40	2.40				-0.010	0.020	96.00	-0.50
RAINBOW SPRING #1	02/21/94	7.96	23.70	139.00	52.00	2.90	4.70	0.070	23.00	3.50	0.10	2.40				0.030		92.00	1.59
RAINBOW SPRING #1	04/11/94	8.18	23.60	150.80	63.00	3.60	7.50	0.080	25.00	3.00	-0.05	2.00	-0.01	-0.01	0.860	0.050	0.060	85.00	-0.50
RAINBOW SPRING #1	07/18/94	9.57	23.90	146.00	57.00	3.00	5.70	0.110	22.00	3.30	-0.05	2.30	0.14	-0.01	0.740	0.030	0.040	77.00	-0.50
RAINBOW SPRING #1	10/31/94	7.92	24.00	172.00	73.00	4.10	4.40	0.119	28.00	3.70	-0.06	2.50	-0.01	-0.01	0.900	0.037	0.037	95.00	-0.50
RAINBOW SPRING #1	12/08/94	8.31	23.60	143.00	57.00	3.30	4.00	0.070	22.00	3.40	-0.05	2.10	-0.01	-0.01	0.690	0.030	0.040	79.00	-0.50
RAINBOW SPRING #1	03/29/95	7.82	23.40	163.00	69.00	3.50	4.30	0.089	28.00	4.00	0.05	2.50	0.01	-0.01	1.021	0.026	0.036	90.00	0.50
RAINBOW SPRING #1	07/20/95	7.84	24.40	196.00	82.00	3.20	4.00	0.100	31.00	4.60	-0.05	2.60	-0.01	-0.01	1.088	0.045	0.040	104.00	-0.50
RAINBOW SPRING #2	10/05/93	7.06	23.80	206.00	89.00	3.80	6.30	0.100	36.00	4.40	0.30	2.40				-0.010	0.030	128.00	-0.50
RAINBOW SPRING #2	02/21/94	7.91	23.90	180.80	78.00	3.80	5.40	0.090	32.00	4.20	0.10	2.70	-0.01	-0.01	0.810	0.030		109.00	-0.50
RAINBOW SPRING #2	04/11/94	8.00	23.60	183.80	79.00	3.70	6.30	0.020	32.00	4.00	-0.05	4.00	-0.01	-0.01	1.030	0.040	0.060	116.00	-0.50

Appendix III. Water-Quality Data from Sampled Springs

SPRING NAME	DATE SAMPLED	FIELD pH	FIELD TEMP	FIELD COND	HCO3	DIS Cl	DIS SO4	DIS F	DIS Ca	DIS Mg	DIS K	DIS Na	NH3	N02	NO3	ORTHO P04	TOTAL PO4	TDS	TOC
RAINBOW SPRING #2	07/18/94	8.93	23.70	202.00	97.00	3.90	11.00	0.100	42.00	3.60	-0.05	2.80	-0.01	-0.01	1.280	0.020	0.020	125.00	-0.50
RAINBOW SPRING #2	10/31/94	8.18	23.80	204.00	91.00	4.20	4.30	0.131	33.00	4.10	-0.05	2.30	-0.01	-0.01	1.008	0.042	0.024	143.00	-0.50
RAINBOW SPRING #3	10/05/93	7.83	23.60	226.00	103.00	3.80	5.10	0.010	40.00	4.70	0.30	2.50				-0.010	0.020	137.00	-0.50
RAINBOW SPRING #3	02/21/94	7.82	23.80	205.00	87.00	3.90	4.90	0.100	35.00	4.40	0.10	2.70	-0.01	-0.01	0.880	-0.010	0.020	137.00	-0.50
RAINBOW SPRING #3	04/11/94	7.88	23.40	207.00	93.00	3.90	6.10	0.010	37.00	4.00	-0.05	2.00	-0.01	-0.01	1.100	0.050	0.070	130.00	-0.50
RAINBOW SPRING #3	07/18/94	8.64	23.70	226.00	99.00	3.60	5.30	0.130	39.00	4.60	-0.05	2.60	0.03	-0.01	1.080	0.040	0.180	120.00	-0.50
RAINBOW SPRING #3	10/31/94	8.21	23.70	229.00	101.00	4.30	4.40	0.134	38.00	4.60	-0.05	2.40	-0.01	-0.01	1.049	0.041	0.019	126.00	-0.50
RAINBOW SPRING #4	10/05/93	7.87	23.90	234.00	104.00	4.00	5.20	0.010	41.00	4.70	0.30	2.50				-0.010	0.030	141.00	-0.50
RAINBOW SPRING #4	02/21/94	7.78	23.50	233.00	103.00	4.00	4.90	0.100	42.00	4.80	0.20	2.80				0.030		134.00	-0.50
RAINBOW SPRING #4	04/11/94	7.79	23.50	234.00	102.00	4.00	6.50	0.100	42.00	5.00	-0.05	2.00	-0.01	-0.01	1.130	0.040		122.00	-0.50
RAINBOW SPRING #4	07/18/94	8.54	23.70	240.00	93.00	4.00	5.70	0.100	42.00	3.50	-0.05	2.80	-0.01	-0.01	1.270	0.020	0.050	142.00	-0.50
RAINBOW SPRING #4	10/31/94	8.22	23.70	240.00	106.00	4.40	4.40	0.138	42.00	4.80	-0.05	2.60	-0.01	-0.01	1.105	0.044	0.038	129.00	-0.50
RAINBOW SPRING #4	12/08/94	7.74	23.20	231.00	103.00	4.20	4.30	0.110	39.00	4.50	-0.05	2.60	-0.01	-0.01	1.230	0.040	0.100	124.00	-0.50
RAINBOW SPRING #4	03/29/95	7.77	23.50	232.00	103.00	3.90	4.10	0.103	42.00	4.90	0.05	2.60	0.02	-0.01	1.199	0.033	0.037	132.00	0.50
RAINBOW SPRING #4	07/20/95	7.90	24.10	243.00	104.00	3.50	3.80	0.100	40.00	5.30	-0.05	2.70	-0.01	-0.01	1.370	0.043	0.039	128.00	-0.50
RAINBOW SPRING #5	10/05/93	7.65	23.80	232.00	99.00	4.10	8.10	0.100	40.00	4.90	0.40	2.60				-0.010	0.020	140.00	3.35
RAINBOW SPRING #5	02/21/94	7.41	23.70	181.00	80.00	3.50	4.20	0.070	31.00	4.30	0.20	2.60				0.030		105.00	-0.50
RAINBOW SPRING #5	04/11/94	7.85	23.90	190.90	105.00	3.60	8.00	0.070	33.00	4.00	-0.05	2.00	-0.01	-0.01	0.400	0.050	0.070	110.00	-0.50
RAINBOW SPRING #5	07/18/94	8.60	24.10	198.00	85.00	3.30	6.70	0.130	33.00	4.30	-0.05	2.40	-0.01	-0.01	0.460	0.030	0.070	69.00	-0.50
RAINBOW SPRING #5	10/31/94	8.25	24.00	209.00	101.00	4.30	6.90	0.110	36.00	4.60	-0.05	2.50	-0.01	-0.01	0.490	0.049	0.055	115.00	-0.50
RAINBOW SPRING #6	10/05/93	7.93	24.00	308.00	105.00	5.60	38.00	0.130	51.00	6.00	0.50	3.50				-0.010	0.020	194.00	-0.50
RAINBOW SPRING #6	02/21/94	7.54	23.80	308.00	107.00	4.90	35.00	0.120	53.00	6.30	0.30	3.70	-0.01	-0.01	0.720	0.030		192.00	-0.50
RAINBOW SPRING #6	04/11/94	7.73	23.80	310.00	111.00	5.50	37.00	0.120	54.00	6.00	-0.05	3.00	-0.01	-0.01	0.840	0.030	0.060	166.00	-0.50
RAINBOW SPRING #6	07/18/94	8.25	23.60	310.00	117.00	5.00	35.00	0.150	52.00	6.20	0.20	3.70	0.02	-0.01	0.830	-0.010	-0.010	184.00	0.52
RAINBOW SPRING #6	10/31/94	8.28	24.00	308.00	98.00	5.70	38.00	0.151	50.00	6.20	0.20	3.50	-0.01	-0.01	0.777	0.032	0.075	172.00	-0.50
RAINBOW SPRING #6	12/08/94	7.70	23.40	307.00	107.00	5.50	35.00	0.130	49.00	5.80	0.20	3.50	-0.01	-0.01	0.880	0.030	0.030	200.00	-0.50
RAINBOW SPRING #6	03/29/95	7.70	24.00	312.00	110.00	5.30	33.00	0.123	53.00	6.30	0.20	3.60	0.03	-0.01	0.863	0.029	0.033	191.00	0.50
RAINBOW SPRING #6	07/20/95	7.79	24.40	318.00	108.00	4.80	31.00	0.120	52.00	6.60	0.20	3.80	-0.01	-0.01	0.910	0.039	0.034	178.00	-0.50
RAINBOW SPRING #7	10/05/93	8.00	23.80	303.00	103.00	5.40	37.00	0.120	49.00	5.80	0.50	3.50				-0.010	0.020	192.00	-0.50
RAINBOW SPRING #7	02/21/94	7.62	23.70	301.00	102.00	5.40	37.00	0.110	52.00	6.10	0.30	3.70	-0.01	-0.01	0.760	0.020		183.00	-0.50

Appendix III. Water-Quality Data from Sampled Springs

SPRING NAME	DATE SAMPLED	FIELD pH	FIELD TEMP	FIELD COND	HCO3	DIS Cl	DIS SO4	DIS F	DIS Ca	DIS Mg	DIS K	DIS Na	NH3	N02	NO3	ORTHO P04	TOTAL PO4	TDS	TOC
RAINBOW SPRING #7	04/11/94	7.77	24.00	301.00	101.00	5.40	37.00	0.100	53.00	6.00	-0.05	3.00	-0.01	-0.01	0.940	0.030	0.060	176.00	-0.50
RAINBOW SPRING #7	07/18/94	7.71	24.00	304.00	93.00	4.80	36.00	0.150	50.00	5.90	0.20	3.60	-0.01	-0.01	0.910	0.030	0.050	186.00	-0.50
RAINBOW SPRING #7	10/31/94	8.31	24.10	299.00	102.00	4.60	9.60	0.140	49.00	5.90	0.20	3.40	-0.01	-0.01	0.850	0.030	0.020	168.00	-0.50
RAINBOW SPRING #8	10/05/93	7.75	23.40	216.00	85.00	4.00	12.00	0.090	36.00	5.10	0.40	2.60				0.010	0.030	134.00	-0.50
RAINBOW SPRING #8	02/21/94	7.73	23.50	204.00	83.00	4.10	11.00	0.080	34.00	5.10	0.20	2.80				0.040		123.00	17.12
RAINBOW SPRING #8	04/11/94	7.91	24.00	205.00	83.00	4.10	12.00	0.080	35.00	5.10	-0.05	2.00	-0.01	-0.01	0.460	0.050	0.090	108.00	-0.50
RAINBOW SPRING #8	07/18/94	7.88	23.80	212.00	83.00	3.60	12.00	0.110	35.00	5.10	-0.05	2.80	-0.01	-0.01	0.460	0.040		120.00	-0.50
RAINBOW SPRING #8	10/31/94	7.90	23.50	204.00	82.00	4.40	12.00	0.104	33.00	5.10	-0.05	2.70	-0.01	-0.01	0.479	0.046	0.037	111.00	-0.50
WATERFALL SPRING	10/07/93	7.70	23.10	261.00	117.00	4.20	6.80	0.100	46.00	4.40	0.30	2.60				0.020	0.020	156.00	-0.50
WATERFALL SPRING	02/21/94	7.90	23.60	260.00	129.00	4.20	5.60	0.110	46.00	5.10	0.10	2.90	0.01	-0.01	1.100	0.030		148.00	2.25
WATERFALL SPRING	04/11/94	7.68	23.20	265.00	179.00	4.20	6.20	0.090	49.00	5.00		2.00	0.01	-0.01	1.180	0.030	0.070	145.00	-0.50
WATERFALL SPRING	07/18/94	7.77	24.90	281.00	103.00	3.60	5.80	0.140	46.00	5.00	0.05	2.70	0.01	-0.01	1.200	0.020	0.020	147.00	-0.50
WATERFALL SPRING	10/31/94	7.69	23.60	270.00	111.00	4.60	5.20	0.140	46.00	5.10	0.05	2.60	0.01	-0.01	1.072	0.032	0.027	138.00	-0.50
BUBBLING SPRING	10/07/93	7.47	23.10	306.00	140.00	4.50	8.80	0.110	55.00	5.00	0.30	2.80				-0.010	0.020	182.00	-0.50
BUBBLING SPRING	02/21/94	7.60	23.40	311.00	137.00	4.10	7.00	0.120	56.00	5.80	0.20	3.10	-0.01	-0.01	0.990	0.040	-0.010	180.00	-0.50
BUBBLING SPRING	04/11/94	7.64	23.00	315.00		4.80		0.110	59.00	6.00		3.00	-0.01	-0.01	1.110	0.050	0.090	173.00	-0.50
BUBBLING SPRING	07/18/94	7.60	25.60	339.00	139.00	4.00	7.90	0.140	56.00	5.70	-0.05	3.00	0.13	-0.01	1.050	0.020	0.040	175.00	-0.50
BUBBLING SPRING	10/31/94	7.58	23.90	316.00	143.00	5.20	7.30	0.150	56.00	5.90	-0.05	2.80	-0.01	-0.01	0.970	0.039	0.030	167.00	-0.50
BUBBLING SPRING	12/08/94	7.60	22.80	315.00	141.00	4.90	7.20	0.123	55.00	5.70	-0.05	2.80	-0.01	-0.01	1.043	0.042	0.033	169.00	0.50
BUBBLING SPRING	03/29/95	7.61	23.40	309.00	144.00	4.70	6.80	0.125	57.00	5.90	0.05	2.90	0.02	-0.01	1.184	0.028	0.100	178.00	0.50
BUBBLING SPRING	07/20/95	7.58	23.30	321.00	140.00	4.10	6.20	0.110	54.00	6.10	0.10	3.10	0.01	-0.01	1.075	0.046	0.042	166.00	-0.05
INDIAN CREEK #1	02/14/94	7.79	23.10	245.00	102.00	3.90	9.90	0.070	45.00	3.80	-0.05	2.60						141.00	-0.50
INDIAN CREEK #1	04/11/94	7.80	23.50	246.00	101.00	4.40	11.00	0.070	46.00	4.00	-0.05	2.00	0.02	-0.01	1.300	0.040	0.070	148.00	-0.50
INDIAN CREEK #2	02/22/94	7.79	23.20	264.00	72.00	4.30	11.00	0.160	44.00	3.70	0.20	2.80						138.00	-0.50
INDIAN CREEK #2	04/12/94	7.91	23.60	237.00	95.00	4.50	12.00	0.060	46.00	3.00		2.00	-0.01	-0.01	1.330	0.060	0.100	134.00	-0.50
INDIAN CREEK #2	07/18/94	7.76	24.00	240.00	86.00	3.30	4.90	0.140	33.00	4.20	-0.05	2.50	-0.01	-0.01	1.020	0.040	0.000	104.00	-0.50
INDIAN CREEK #2	10/31/94	7.82	23.00	158.00	135.00	4.90	10.00	0.096	42.00	3.50	-0.05	2.60	0.01	-0.01	1.306	0.031	0.030	121.00	-0.50
INDIAN CREEK #3	02/22/94	7.83	23.30	294.00	96.00	4.40	11.00	0.060	44.00	3.70	0.20	2.70	-0.01	-0.01	1.100	0.030		136.00	0.68
INDIAN CREEK #3	04/12/94	7.89	23.50	237.00	95.00	4.50	12.00	0.060	45.00	3.00		2.00		-0.01	1.960	0.050	0.080	134.00	-0.50

Appendix III. Water-Quality Data from Sampled Springs

SPRING	DATE	FIELD	FIELD	FIELD		DIS	DIS	DIS	DIS	DIS	DIS	DIS				ORTHO	TOTAL		
NAME	SAMPLED	pH	TEMP	COND	HCO3	Cl	SO4	F	Ca	Mg	K	Na	NH3	N02	NO3	P04	PO4	TDS	TOC
INDIAN CREEK #3	07/18/94	7.79	23.80	239.00	94.00	4.00	11.00	0.100	42.00	3.50	-0.05	2.70	-0.01	-0.01	1.350	0.040	0.050	143.00	-0.50
INDIAN CREEK #3	10/31/94	7.83	23.00	137.00	74.00	4.90	9.70	0.093	43.00	3.50	-0.05	2.50	-0.01	-0.01	1.210	0.034	0.032	132.00	-0.50
INDIAN CREEK #3	12/08/94	7.80	23.20	234.00	97.00	4.70	10.00	0.070	41.00	3.40	-0.05	2.50	-0.01	-0.01	1.370	0.040	0.030	130.00	-0.50
INDIAN CREEK #3	03/29/95	7.14	23.50	242.00	101.00	4.40	9.70	0.071	46.00	3.80	0.20	2.70	0.01	-0.01	1.254	0.036	0.041	157.00	0.50
INDIAN CREEK #4	02/22/94	7.85	23.30	285.00	134.00	3.90	11.00	0.060	43.00	3.60	0.20	2.80	-0.01	-0.01	1.200	0.020		145.00	-0.50
INDIAN CREEK #4	04/12/94	7.95	23.80	235.00	93.00	4.50	12.00	0.060	45.00	3.00		2.00	-0.01	-0.01	1.360	0.050	0.080	127.00	-0.50
INDIAN CREEK #4	07/18/94	7.84	24.70	236.00	107.00	3.60	5.70	0.140	42.00	4.70	-0.05	2.60	-0.01	-0.01	1.180	0.030	0.040	137.00	-0.50
INDIAN CREEK #4	10/31/94	7.86	23.30	151.00	97.00	4.80	11.00	0.096	41.00	3.50	-0.05	2.70	-0.01	-0.01	1.289	0.029	0.025	131.00	-0.50