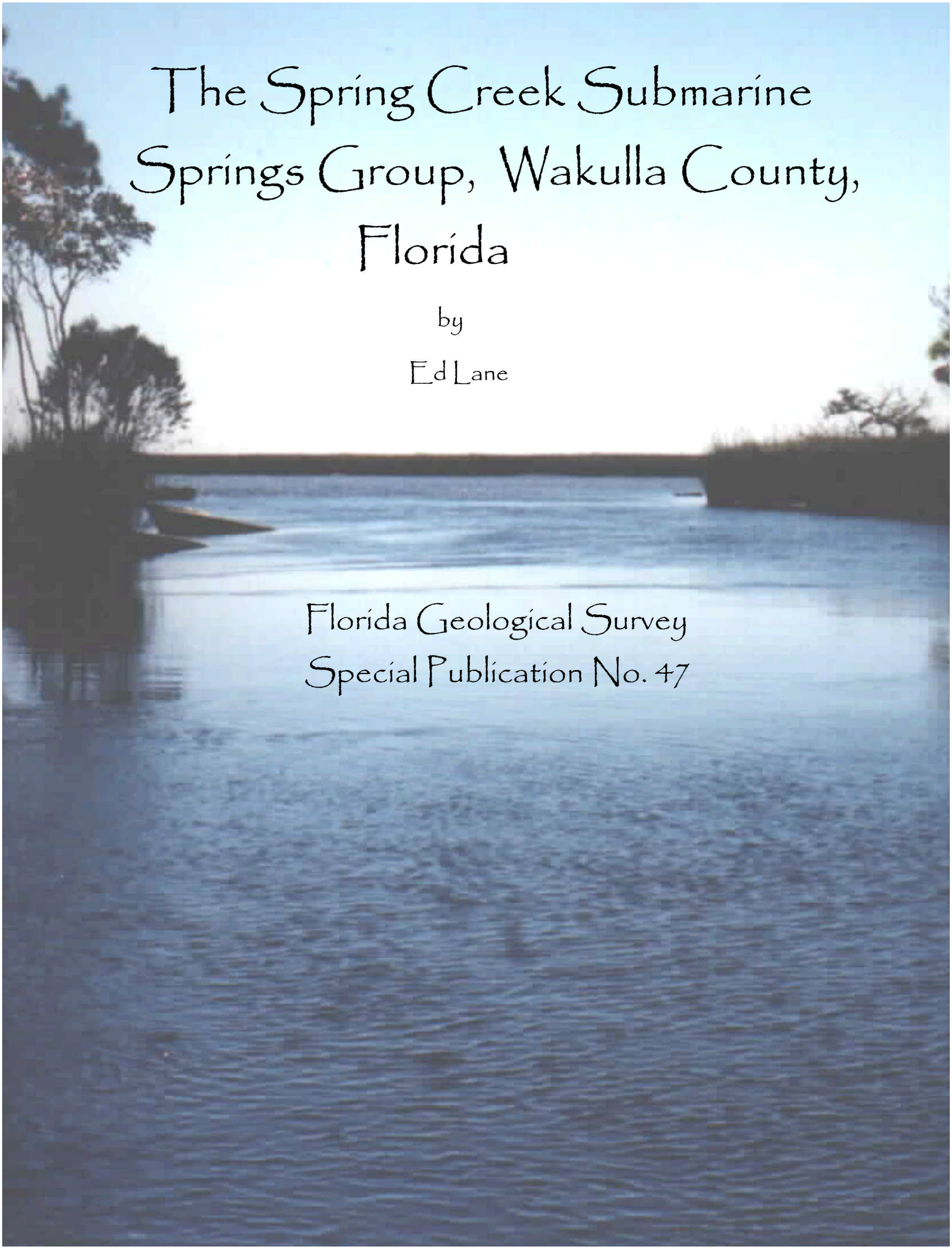

The Spring Creek Submarine Springs Group, Wakulla County, Florida

by

Ed Lane

Florida Geological Survey
Special Publication No. 47

METRIC CONVERSION FACTORS

To eliminate duplication of parenthetical conversion of units in the text of reports, the Florida Geological Survey has adopted the practice of inserting a tabular listing of conversion factors. For readers who prefer metric units to the customary U.S. units used in this report, the following conversion factors are provided.

MULTIPLY	BY	TO OBTAIN
inches	25.4	millimeters
feet	0.3048	meters
miles	1.609	kilometers
cubic feet per second (cfs)	0.02832	cubic meters per second
cubic feet per second (cfs)	0.646	million gallons per day

TEMPERATURE: ºC = (ºF - 32) / 1.8

SEA LEVEL: Sea Level refers to the National Geodetic Vertical Datum of 1929 -- a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Sea Level Datum of 1929."

ABBREVIATIONS USED IN THIS REPORT

FGS	Florida Geological Survey
USGS	U.S. Geological Survey
cfs	cubic feet per second
ft	feet
mgd	million gallons per day
msl	mean sea level
pers. com.	personal communication

Front cover: View to the southwest across the boil (calm area) of Spring Creek Spring #2.

STATE OF FLORIDA
DEPARTMENT OF ENVIRONMENTAL PROTECTION
David B. Struhs, *Secretary*

DIVISION OF RESOURCE ASSESSMENT AND MANAGEMENT
Edwin J. Conklin, *Director*

FLORIDA GEOLOGICAL SURVEY
Walter Schmidt, *State Geologist and Chief*

Special Publication No. 47

THE SPRING CREEK SUBMARINE SPRINGS GROUP, WAKULLA COUNTY, FLORIDA

by

Ed Lane

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LETTER OF TRANSMITTAL

FLORIDA GEOLOGICAL SURVEY
Tallahassee
2001

Governor Jeb Bush
Tallahassee, Florida 32301

Dear Governor Bush:

The Florida Geological Survey, Division of Resource Assessment and Management, Department of Environmental Protection, is publishing as Special Publication No. 47, *The Spring Creek Submarine Springs Group, Wakulla County, Florida*, prepared by staff geologist Ed Lane. This investigation of Spring Creek, one of Florida's major fresh-water spring systems, was done as part of the Survey's coastal research program. Information on these springs is important to better understand the local hydrogeology in the vicinity of the spring vents and the associated benthic ecosystem. This information is valuable to State land managers who must make informed decisions when responding to proposals to utilize fresh water discharge for various purposes.

Respectfully,

Walter Schmidt, Ph.D.
State Geologist and Chief
Florida Geological Survey

CONTENTS

FIGURES

TABLES

THE SPRING CREEK SUBMARINE SPRINGS GROUP, WAKULLA COUNTY, FLORIDA

by

Ed Lane, P.G. 141

ABSTRACT

Submarine springs are offshore discharges of groundwater. In Florida they are associated with coastal karst areas. Submarine karst springs and sinkholes on the Florida Platform constitute integral parts of Florida's hydrogeological regime. They are some of the ultimate down-gradient discharge points for fresh water from Florida's aquifers. Knowledge of their location, hydrology, and stratigraphy will add to an understanding of the overall structure and extent of Florida's aquifer systems. Conceivably, they may represent supplementary sources for fresh water supplies. In addition, they are micro-environments for fish nurseries; manatees use some of them; and some are known archaeological sites. They are key elements in the linked Earth systems among Florida's environments and ecosystems: the uplands, the coasts, and the continental shelf marine realms.

The Florida Geological Survey is gathering information on these karst features as part of ongoing Florida coastal research programs. This report documents the results of the first investigation, on the Spring Creek Springs Group, Wakulla County, Florida.

The Spring Creek Springs Group is comprised of at least 13 submarine springs situated in the mouth of Spring Creek and adjacent Stuart Cove, along the Gulf of Mexico coastline in Wakulla County, Florida. Combined flow of the group is about 2,000 cubic feet per second. The springs are fed by conduits, likely developed along fractures in the underlying carbonates. Analysis of local fracture trends suggests that one surface water source for the spring flow is Lost Creek, a stream captured by a sinkhole about six miles northwest of the springs. Regional groundwater of the Floridan aquifer system also supplies a portion of the total spring flow. Seismic surveys and depth-recorder profiles were conducted across 12 of the springs. The springs' cross-sectional profiles show them to be cone-shaped sinks, typical of springs developed in Florida karst. Water chemisty data collected at nine of the springs showed variation suggestive of mixing and possibly differing surface and ground-water sources for the springs. All the springs exhibit pulsating flow, alternating surges of boiling surface turbulence caused by rapidly upwelling water, followed by relatively quiescent flow. This suggests that the complex conduit system supplying the springs may be influenced by local recharge events and by tidal stage.

ACKNOWLEDGEMENTS

Particular thanks go to Jim Ladner, who provided support services for the boats and equipment used during the investigations. Special thanks go to Don Hargrove, who provided his own boat and depth recorder for the 1995 investigations. Jim Balsillie deserves specific thanks for making available his personal SITEX sonar depth recorder, which he extensively modified to operate from the FGS survey craft. Jim also collected the bathymetric data describing physiographic details of the springs used in Figures 15, 18, 19, 20, and 21, and is credited with the photos depicted in Figures 23, 24, and 25. Joseph Donoghue and Henry Freedenberg assisted at various times in the fieldwork. Paula Polson did the AutoCad drafting and Photoshop detailing of the report figures. Frank Rupert created digital images of the photographs and assembled the final report in QuarkXPress. The author expresses his appreciation to the staff of the Florida Geological Survey who assisted by editing this manuscript: Walter Schmidt, Jackie Lloyd, Tom Scott, Steve Spencer, Frank Rupert, Rodney DeHan, and Deborah Mekeel. Joseph Donoghue, of Florida State University's Department of Geological Sciences, also reviewed the manuscript and provided helpful suggestions.

INTRODUCTION

During the Pleistocene Epoch world sea levels are known to have fluctuated between 100 feet above present, to as much as 400 feet below present. Between these extremes, many smaller oscillations and still-stands occurred at intermediate elevations. Figure 1 shows the shape of the Florida Platform when sea level was at its lowest, between 300 to 400 feet below present, placing the shoreline over 100-miles west of Tampa. Periods of lowered sea level exposed vast areas of the platform to subaerial erosion and karst

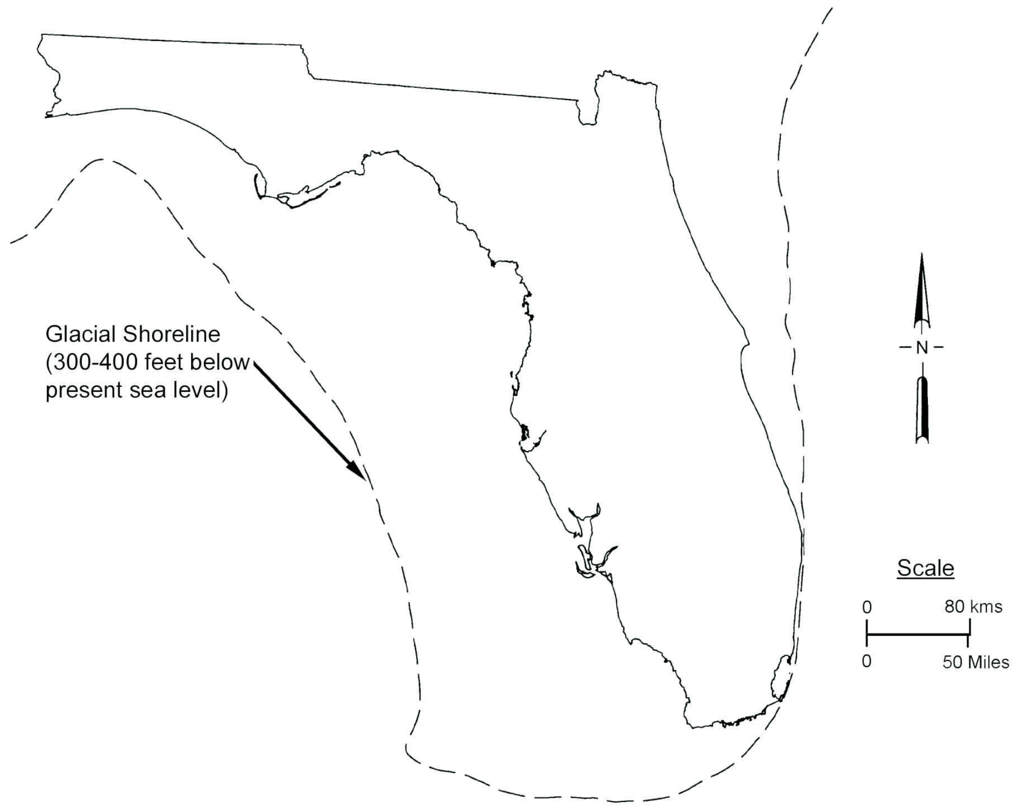

Figure 1. Approximate location of the shoreline of the Florida Platform when sea level was about 300 to 400 feet lower than present (Fairbanks, 1989).

processes, creating the many documented submarine springs and sinkholes. Such features continue to be discovered and explored from time to time (Land et al., 1995; Bowen, 1994; Wilson, 1991; Rupert and Arthur, 1990; Hine et al., 1988; Popenoe et al., 1984; Fanning et al., 1981 and 1982; Malloy and Hurley, 1970; Brooks, 1961; Jordan, 1954; Stringfield and Cooper, 1951).

Submarine springs occur on continental shelves around the world. A few are known to issue from lava tubes offshore of the Hawaiian Islands, but all others appear to be associated with offshore outcrops of carbonate rocks. Figure 2 shows the location of submarine springs and sinkholes known to occur on the offshore Florida Platform. The Florida Geological Survey has several ongoing coastal research programs along the coastline of Florida. One important goal of these programs is to gather information on springs, sinkholes, and other karst features that occur in the submarine realm. This report documents the results of the first investigation of submarine springs, on the Spring Creek Springs Group, Wakulla County, Florida.

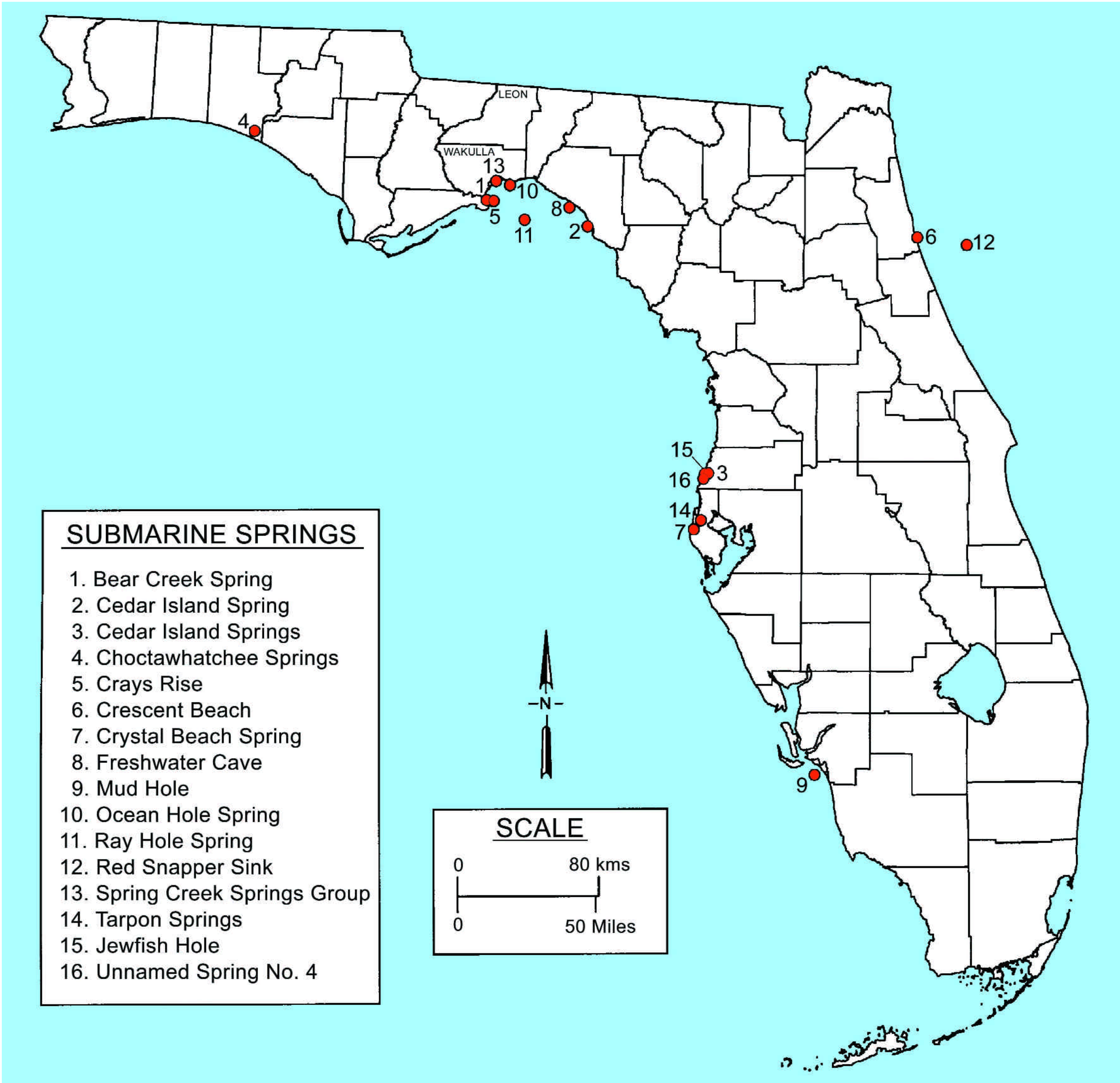

Figure 2. Map of Florida showing locations of 16 submarine springs described by Rosenau et al. (1977).

Purpose

There are few literature references to the submarine springs and sinkholes that occur on the offshore Florida Platform. The purpose of investigating the submarine karst features that occur on the Florida Platform is to determine the role that they play in Florida's linked Earth systems and how they relate to the hydrogeologic regime of the Florida Platform.

The immediate goal of the present investigation is to gather background information and hydrogeological data on the largest known group of submarine springs in Florida, the Spring Creek Springs Group. The long-term goal for future research will be to determine the linkages between the land and the ocean. More specifically, what are the linkages among the ecosystems and environments of the uplands, the coast, the coastal marshes, the marine realm, and the springs and sinkholes that occur on all of them?

The land-ocean linkages question is multifaceted, and involves climate, nutrient dynamics, pollution, hydrogeology, atmospheric and oceanic physics, ecology, physiology, and societal pressures. Understanding these land-ocean linkages and their scope within the regional environmental context is crucial to decision making processes in the private and public sectors.

This region is dominated by a wealth of good quality surface- and ground-water resources, and diverse ecosystems, including waterways, extensive shorelines, and broad marshes. Historically, the area is prone to natural disasters, including droughts, flooding, and wind damage from thunderstorms and hurricanes. There are tight links among atmosphere, hydrosphere, and biosphere. However, the interests and impacts of the linkages questions extend well beyond an academic interest into climate, hydrogeology, atmospheric chemistry, and ocean science.

Recent proposals to use some of the submarine springs on the Florida Platform as sources for large quantities of fresh water, which will be diverted to other drainage basins, have created an imperative need for investigations into the springs' hydrogeology. Major issues involved in assessing the environmental impacts of the proposed usage of these springs include the tangible impacts of human intervention, such as:

1. WATER MANAGEMENT -- The modeling of ground-water flow and contaminant transport in carbonate (karst) aquifer systems requires viewing karst aquifers as a composite of porous media and conduit flow. Without the parameters of these major components of the hydrogeological systems, the modeling of water resources at the regional level would be inadequate, resulting in the inability to assess many environmental impacts. Data obtained as a result of this and similar research are needed to sensibly consider the full range of mitigation and adaptation options. The results and conclusions will enhance our ability to improve water management strategies across local or regional districts.

2. HAZARD REDUCTION -- Issues include improved public health and safety, through better understanding of the relationship between ground-water pollution and karst features, and increased environmental conservation.

3. ECOLOGICAL IMPACTS -- Although beyond the scope of this study, local biotic ecosystems are dependent upon a delicate balance of physiochemical parameters, which may be controlled at least in part by submarine spring flow. Alteration of variables such as rate of flow, salinity, water clarity, or nutrient load may significantly affect the viability of these communities. Such changes impact the local human economy (see below).

4. ECONOMIC IMPACTS -- The regional economy as well as recent population and land use trends must be considered when studying the interaction between the geology and changes in the local and regional linkages. Obviously, any significant changes in the local or regional ecosystems could impact the economy and possibly land usage. For example, changes in the fresh-salt water interface, or changes to the salinities of bays, estuaries, or near-shore marine waters, could have major effects on floral and faunal assemblages, which would affect such industries as fishing, crabbing, scalloping and oystering, as well as tourism.

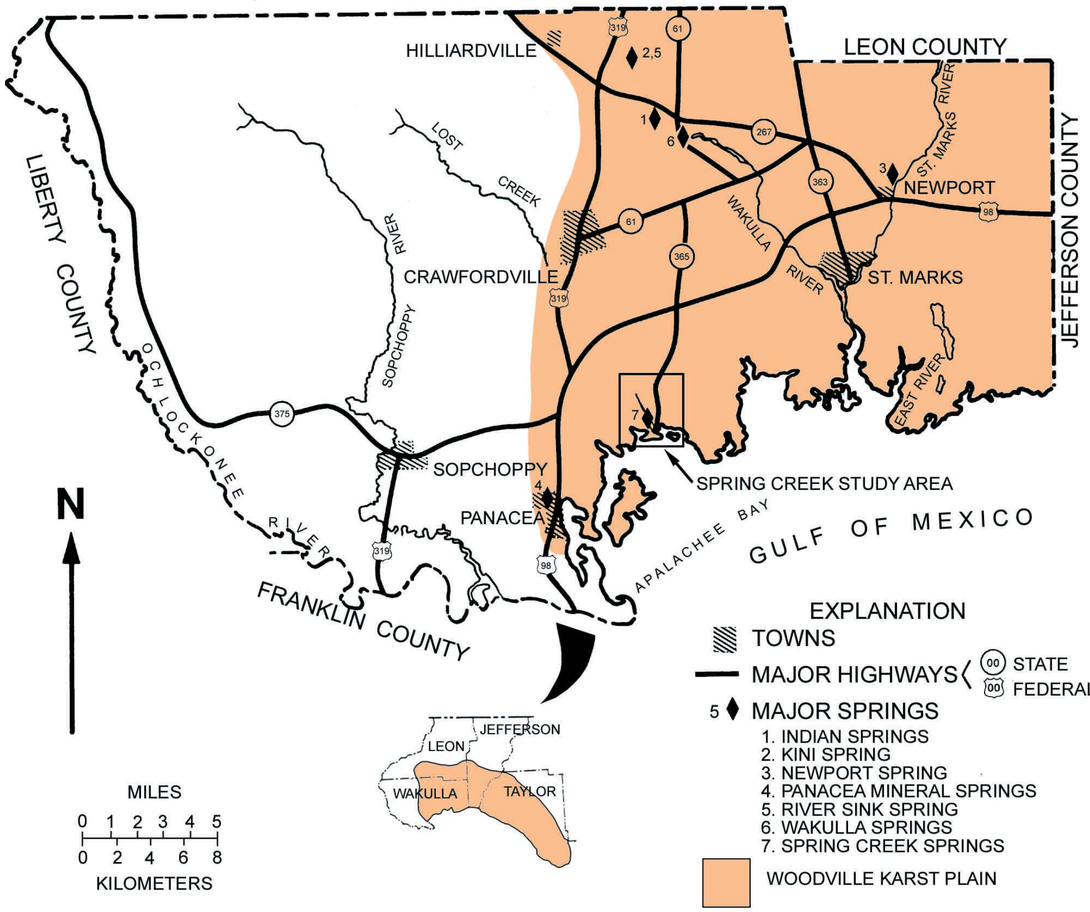

Figure 3. Map of Wakulla County showing location of study area and major springs (after Rupert and Spencer, 1988). Inset map shows extent of Woodville Karst Plain (Scott, 2000, in preparation).

5. SOCIETAL RESPONSES -- The results of these investigations should become a part of the decision making process. They are needed to understand and respond to the increasingly complex social issues involved in policy and regulatory decisions, which affect the private and public sectors.

Location of Study Area

The study area is located on the southern coast of Wakulla County, in the Big Bend area of the Florida panhandle (Figure 3). This portion of the northeastern Gulf of Mexico is a zero to low energy coast, characterized by muddy or fine grained sediments, small tidal ranges (1-3 feet), extensive marshes, and low gradient tidal streams.

GEOLOGY

Geomorphology and Marine Terraces

Puri and Vernon (1964) placed all of Wakulla County within the Gulf Coastal Lowlands physiographic province. Scott (2000, in preparation) placed this region in the newly-named Ocala Karst District. From south to north, the topography of Wakulla County slopes very gently upward from sea level at the Gulf

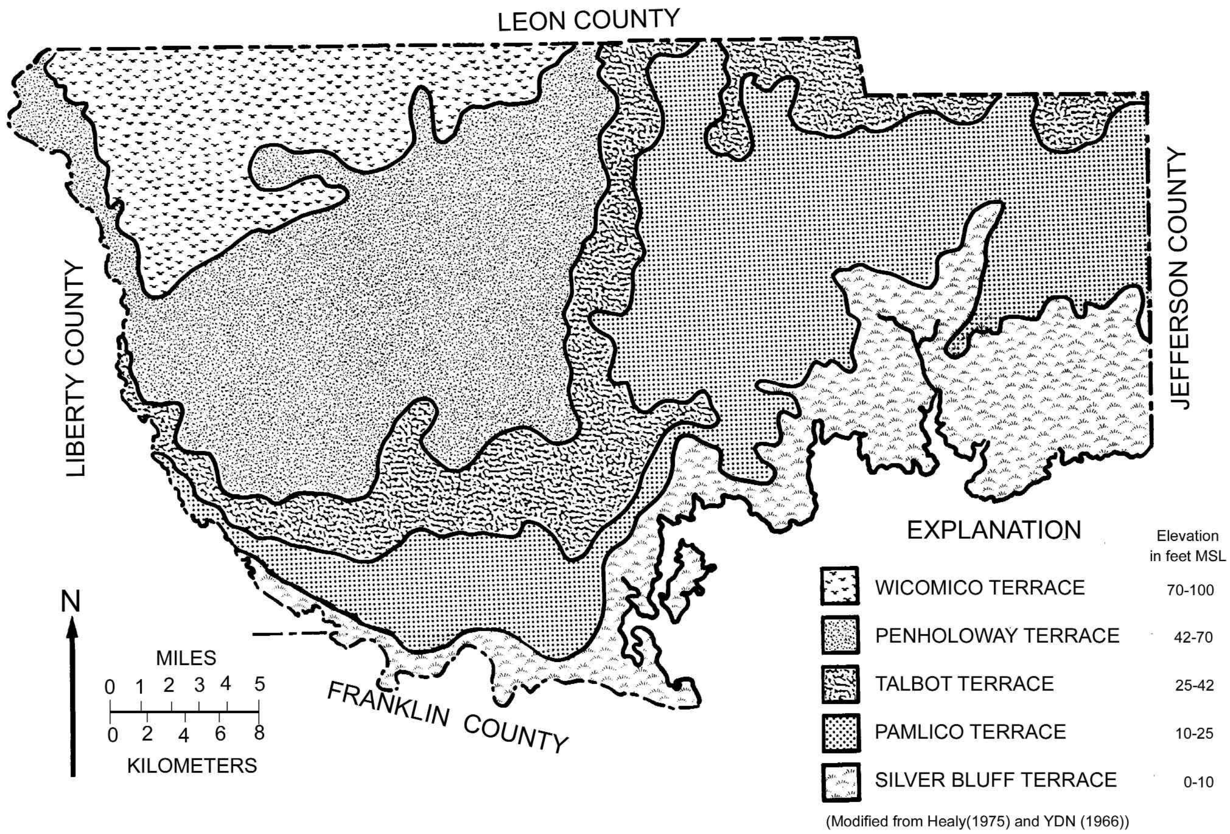

Figure 4. Marine terraces of Wakulla County (Rupert and Spencer, 1988).

coast, with some maximum spot-elevations being between 100 to 105 feet on the sand hills in the northwestern part of the county.

A marine terrace is a surface formed along a coast by wave erosion and deposition. Marine terraces are the former bottoms of shallow seas, usually floored with deposits of sand, silt, clay, and shells, and are bounded along their inner margin by shoreline features such as relict beach ridges, swales, or inner lagoons, seaward facing wave-cut scarps or sea cliffs, and offshore and bay bars (Healy, 1975). These step-like marine terraces that occur throughout Florida are the result of fluctuations in sea level, which were associated with the repeated growth and melting of great continental glaciers during the Pleistocene "Ice Ages."

Based on topographic elevations, Healy (1975) delineated five marine terraces in Wakulla County (Figure 4). These terraces step-down from higher to lower elevations: the Wicomico (70 - 100 ft. above mean sea level (msl)), the Penholoway (42 - 70 ft.), the Talbot (25 - 42 ft.), the Pamlico (10 - 25 ft.), and the Silver Bluff (0 - 10 ft.).

The coastal marshes and their tidal streams lie within the zone of the Silver Bluff terrace. The step-like nature of other low-relief, relict marine beach ridges, dune fields and marine terraces can best be seen by traveling on roads that cross the terraces in a south-to-north direction.

The Woodville Karst Plain, a major geomorphic subdivision of the Gulf Coastal Lowlands, was named by Hendry and Sproul (1966). It encompasses the entire eastern half of Wakulla County, extending eastward

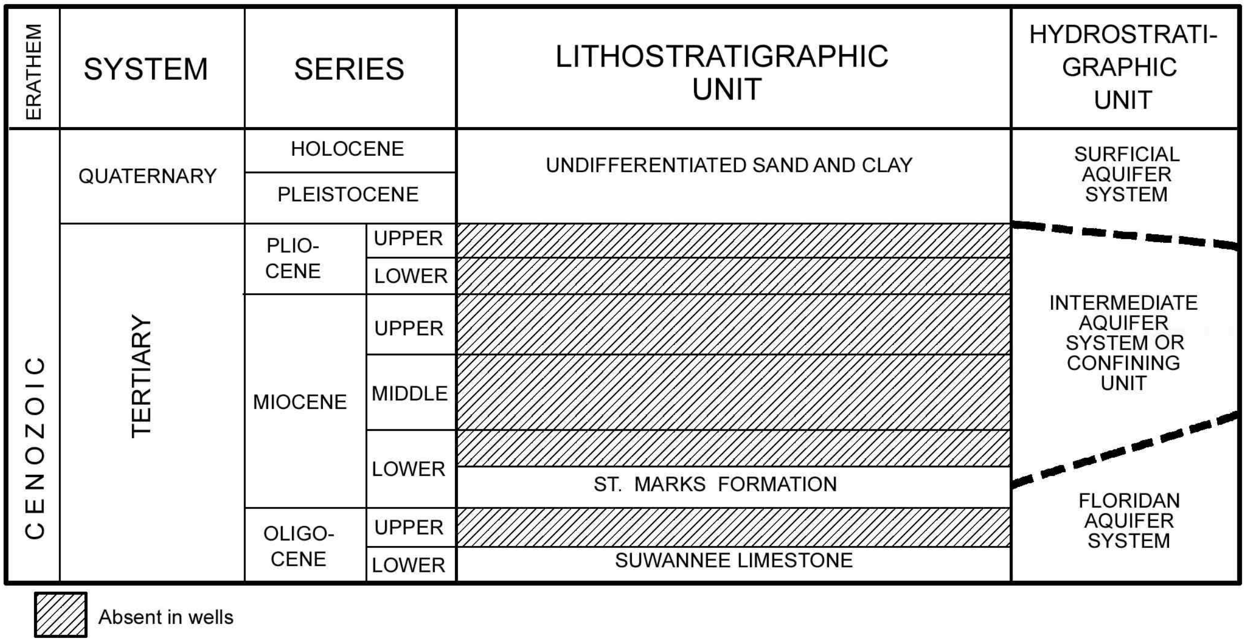

Figure 5. Shallow stratigraphic column, with corresponding hydrogeologic units, in Wakulla County (after Rupert and Spencer, 1988; and Scott et al., 1991).

into Jefferson County, and northward to the Cody Scarp at Tallahassee in Leon County. The extent of this karst plain has been expanded around the Big Bend coast to the southeast, to the Steinhatchee River, Taylor County (Scott, 2000, in preparation) (Figure 3).

Stratigraphy

Since this investigation is concerned with rocks down to depths of 500 feet or less below ground surface, only the shallow stratigraphy will be discussed (Figure 5). The Oligocene Suwannee Limestone is the oldest rock that crops out in Wakulla County, restricted to a small area in the extreme southeastern part of the county, in a narrow band along the coast and extending about five miles inland along the Wakulla - Jefferson county line (Rupert and Spencer, 1988; Yon, 1966). Yon (1966) reported that dolomitized Suwannee Limestone was exposed offshore of Jefferson County.

The Suwannee Limestone is a white to light-tan or a brown, recrystallized, calcarenitic limestone, that is frequently dolomitic and may be silicified in places. Foraminifera are the most common fossils, but echinoid fossils are also found (Rupert and Spencer, 1988; Yon, 1966). In the study area, the top of the Suwannee Limestone is between 125 and 150 feet below sea level, and the formation is more than 250-feet thick, extending to depths of over 400 feet below sea level (Rupert and Spencer, 1988). Examination of rock samples taken during the exploration of Wakulla Springs showed that the springs' main conduits are developed in Suwannee Limestone (Stone, 1989; Rupert, 1988).

Limestones of the Miocene St. Marks Formation underlie most of the county, cropping out in much of eastern Wakulla County, especially along the southeastern coast (Rupert, 1993; Yon, 1966). The St. Marks Formation is a pale orange, light gray to white, calcarenitic marine limestone (Rupert and Spencer, 1988). It is generally very fossiliferous, with foraminifera and mollusks being most common (Rupert and Spencer, 1988). In the study area, the St. Marks Formation either crops out or lies within 20 feet of the surface. In the Spring Creek area, it is about 100-feet thick (Rupert and Spencer, 1988). Many of the county's springs and sinks are developed in the St. Marks Formation, and most of the freshwater wells tap this source (Rupert and Spencer, 1988). Limestones of the St. Marks Formation and the Suwannee Limestone underlie the coastal marsh and estuarine sediments, and the shelf at shallow depths, or they subcrop on the shelf.

Undifferentiated siliciclastics form a surface veneer over all of Wakulla County (Rupert and Spencer, 1988). In the study area they range in thickness from zero to 20 feet. They generally consist of clean, white, nutrient-poor, quartz sand, with small percentages of silt and clay. Holocene alluvial and aeolian deposits are mostly fine quartz sand and are difficult to distinguish from Pleistocene sediments (Rupert and Spencer, 1988).

WATER RESOURCES

The region's climate is semi-tropical and an occasional hurricane delivers enough rain to cause extensive flooding. Convective storms and thunderstorms occur year-round, many of which drop large quantities of rain in a short time. For the 30-year period of record from 1951 to 1980, average annual rainfall was between 56 and 60 inches. Also, during this time the maximum amount of rainfall for the entire state during any 12-month period, 107 inches, was recorded at St. Marks, just 7 miles east of Spring Creek (Fernald and Patton, 1984). Because of this large amount of annual rainfall, the water table is usually close to land surface. Even in periods of low rainfall, the water table only drops a few feet.

Surface Water

The Woodville Karst Plain has very poorly developed surface drainage, with only two major streams: Wakulla River and St. Marks River (Figure 3). The Wakulla River originates at Wakulla Springs, flows southeasterly for approximately seven miles, where it joins the St. Marks River, which flows about one mile before emptying into Apalachee Bay. The St. Marks River originates in northeastern Leon County, flows southward through eastern Wakulla County, and empties into Apalachee Bay.

Another surface stream, Lost Creek, originates outside the Woodville Karst Plain, in southwestern Leon County, and flows southeasterly for several miles. When it reaches the western margin of the Woodville Karst Plain, about one mile west of Crawfordville, all of its flow disappears underground and does not reappear.

These streams' floodplains are narrow, have little relief, and are usually swampy. All of these streams' channels are shallow and incised into the karst plain's thin, unconsolidated sediments and the limestone bedrock.

Several smaller streams, such as Spring Creek, flow for short distances across the narrow coastal marsh belt. These streams are tidal through most of their runs. Some are known to have springs in their beds, such as Bear Creek, a tributary of the Ochlockonee River, about one-mile upstream of Ochlockonee Bay (Mike Wisenbaker, pers. com., 1997).

The flat, sandy terrain of Wakulla County has large areas of poorly drained swamps. These are karst swales that were formed by dissolution of limestone and the subsequent subsidence of the sandy overburden. Most of them are only a few feet deep, but they still intercept the shallow water table. Although they contain standing water for much of the year, they may dry up during prolonged droughts, when the local water table drops below their bottoms.

Hundreds of large sinkholes occur throughout the county, and contain freestanding bodies of water all year long. For many of them, karst dissolution of the limestone bedrock has advanced to the point that they extend well below the lower limit of the water table's annual fluctuations. Under these conditions, they are assured of a year-round supply of groundwater, and they only experience water level fluctuations of a few feet between dry and wet spells.

Groundwater and Aquifers

Groundwater is water that fills the voids and pores in the rocks and sediments beneath the Earth's surface. Aquifers are units of rocks and sediments that are porous and permeable enough to permit groundwater to flow freely enough through their interstices to produce useable quantities of water for human activities, usually through pumpage.

Wakulla County's aquifers, and their relationship to lithostratigraphic units, are shown on Figure 5. The hydrogeological framework of Wakulla County is discussed in Scott et al. (1991), and their usage is followed here. The Floridan aquifer system underlies all of Wakulla County. Miller (1986) defined the Floridan

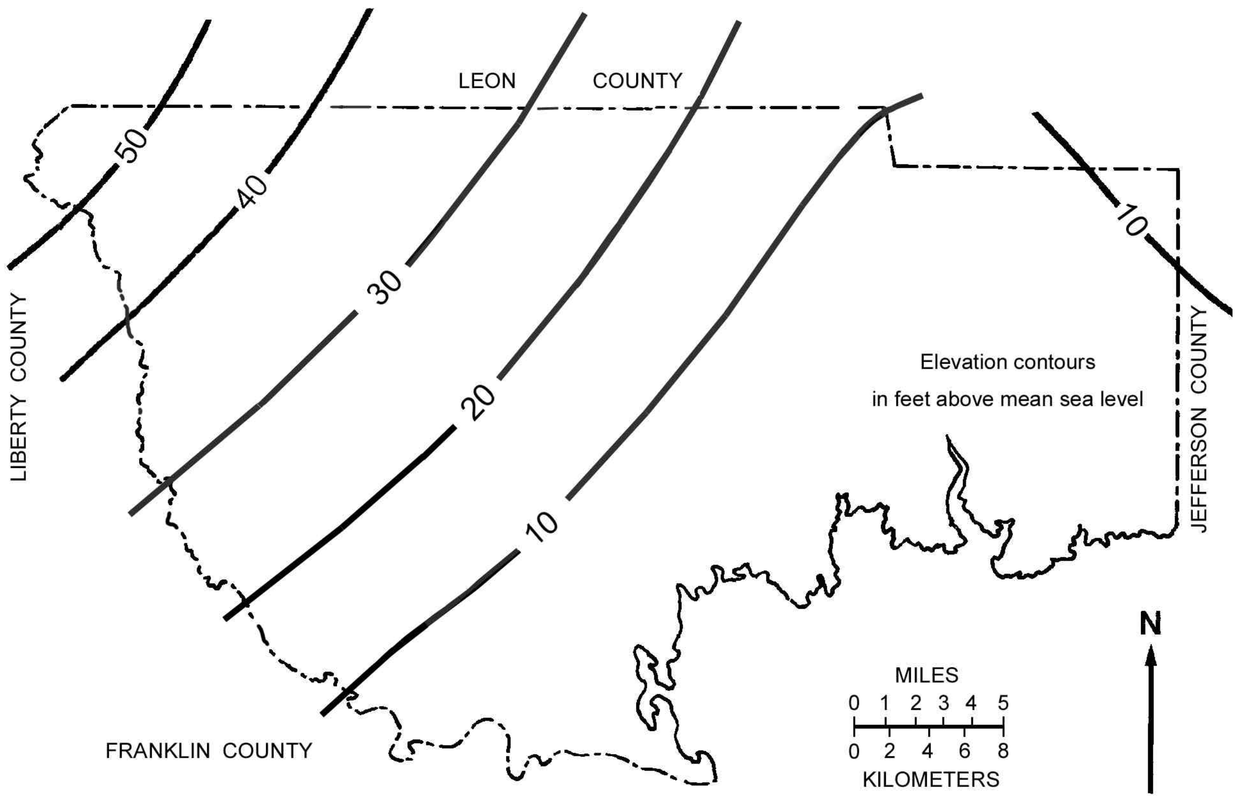

Figure 6. Potentiometric surface map of the Upper Floridan aquifer in Wakulla County during May, 1990 (after Meadows, 1991).

aquifer system as a vertically continuous sequence of carbonate rocks having generally high permeability, and that are hydraulically connected in various degrees. In the study area, the Floridan aquifer system extends from land surface to about 2,400 feet below sea level (Scott et al., 1991).

The St. Marks Formation and the Suwannee Limestone constitute the upper part of the Floridan aquifer system in the study area, and supply all of the potable groundwater used. In the Woodville Karst Plain there are no low-permeability units between land surface and the carbonate aquifer units, so the Floridan aquifer system is unconfined (i.e., it is at atmospheric pressure) and its potentiometric surface is essentially the elevation of the water table (Figure 6).

Ground-Water Recharge and Discharge

The ultimate source of all recharge to the aquifers in the study area is precipitation (Davis, 1996). The eastern part of Wakulla County (the Woodville Karst Plain) is classified as a high recharge area to the Floridan aquifer system, with rapid infiltration of rainfall through the thin layer of clean sand that overlies the limestone aquifer, as well as direct recharge through karst features, such as sinkholes, that breach the overburden (Scott, et al., 1991). In addition, large quantities of groundwater move down gradient from adjacent areas, supplying water to Wakulla Springs and the Spring Creek Springs Group.

Discharge from the aquifers is from pumpage, springs, upward leakage and evaporation from open bodies of water that intercept the water table, and diffuse submarine discharge that takes place offshore along the coast. It is probable that undetermined quantities of groundwater alternately recharge or discharge through interbasin flow, especially when their locally adjacent potentiometric surfaces fluctuate irregularly due to uneven distribution of rainfall, or during droughts.

Potentiometric Surface

The regional potentiometric surface slopes in a southeasterly direction from Gadsden and Leon Counties (Figure 6). The gentle, flat slope is suggestive of high transmissivity. The deep reentrant in northeastern Wakulla County probably indicates that large quantities of groundwater are being discharged to provide base flow for the Wakulla and St. Marks Rivers.

During high, onshore tidal surges caused by hurricanes, reversal of flow into Spring 1 of the Spring Creek Group (Figure 11) has been observed, taking brackish estuarine water and flotsam into the aquifer (Mr. Spears, pers. com., 1995). The reversal of flow caused by the relatively small amount of increased head over Spring 1's orifice due to hurricane tidal surge indicates that its potentiometric surface is so low that its flow is in tenuous balance with the marine environment. By inference, then, it appears that a change of only a few inches of head on the upland side of the aquifer system can make the difference between discharge from, or recharge to, the local aquifer system supplying the springs. The same thing could happen if the springs are exploited and pumped to such an extent that salt-water intrusion is induced.

Regional Fracture Systems, Conduit Geometry, and Ground-Water Flow

Ground-water flow in the karst drainage system of the upper Floridan aquifer system of the Woodville Karst Plain is likely controlled in part by the fracture (lineament) pattern in the carbonate bedrock (Figure 7). A primary underground conduit trend, extending northwest to southeast through the western Woodville Karst Plain, has been mapped by cave divers (see Figure 9). This trend closely mirrors the flow direction expected from the shape of the local potentiometric surface (Figure 6).

All of the surface streams exhibit angularity in segments of their channels, flowing generally from northwest-to-southeast, then, in near-right angle bends, flowing from northeast-to-southwest. Figure 7 is a lineament map of the western Woodville Karst Plain in Wakulla County, based on the orientation of segments of surface stream channels, and the alignment of sinkholes and karst depressions. This map illustrates further the preferential northwest-southeast and northeast-southwest orientation patterns.

The Wakulla Springs Project (Stone, 1989) mapped 2.3 miles of underwater tunnels that supply water to Wakulla Springs (Figure 8). This exploration established that the cavernous tunnels are preferentially developed along two primary lineament directions oriented north-south and east-northeast by west-southwest, and their maps show the angular, underground, drainage pattern following these orientations (Stone, 1989). Also, unpublished maps, done by cave divers, of the underground drainage systems of the Leon Sinks Geological Area show that sinkholes and associated conduits align in these same angular directions (Rupert, pers. com., 1998; and unpublished FGS maps) (Figure 9). The Leon Sinks cave system runs

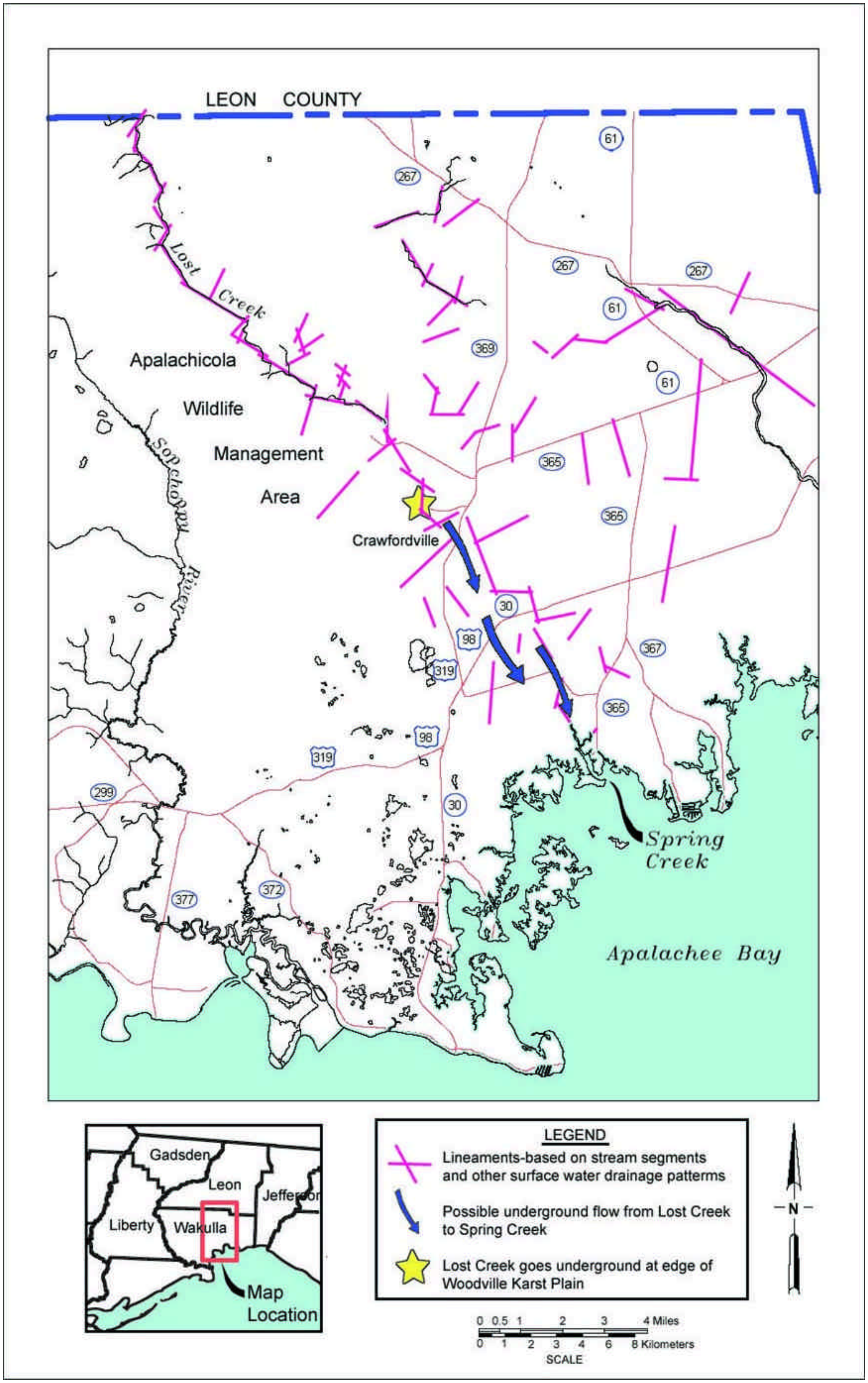

Figure 7. Lineament map of the western Woodville Karst Plain in Wakulla County (from topographic maps and aerial photographs).

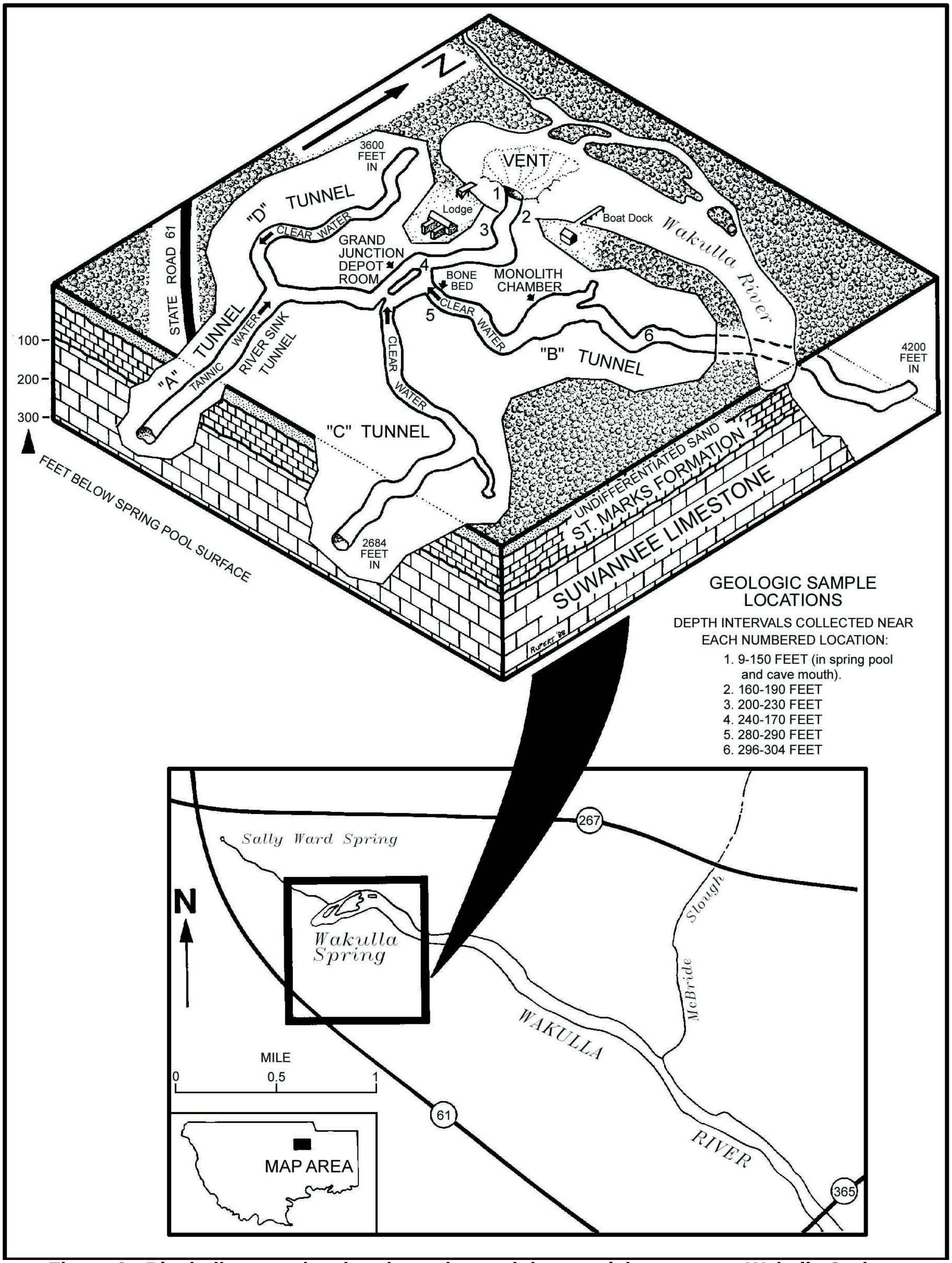

Figure 8. Block diagram showing the main conduits supplying water to Wakulla Springs (Rupert, 1988).

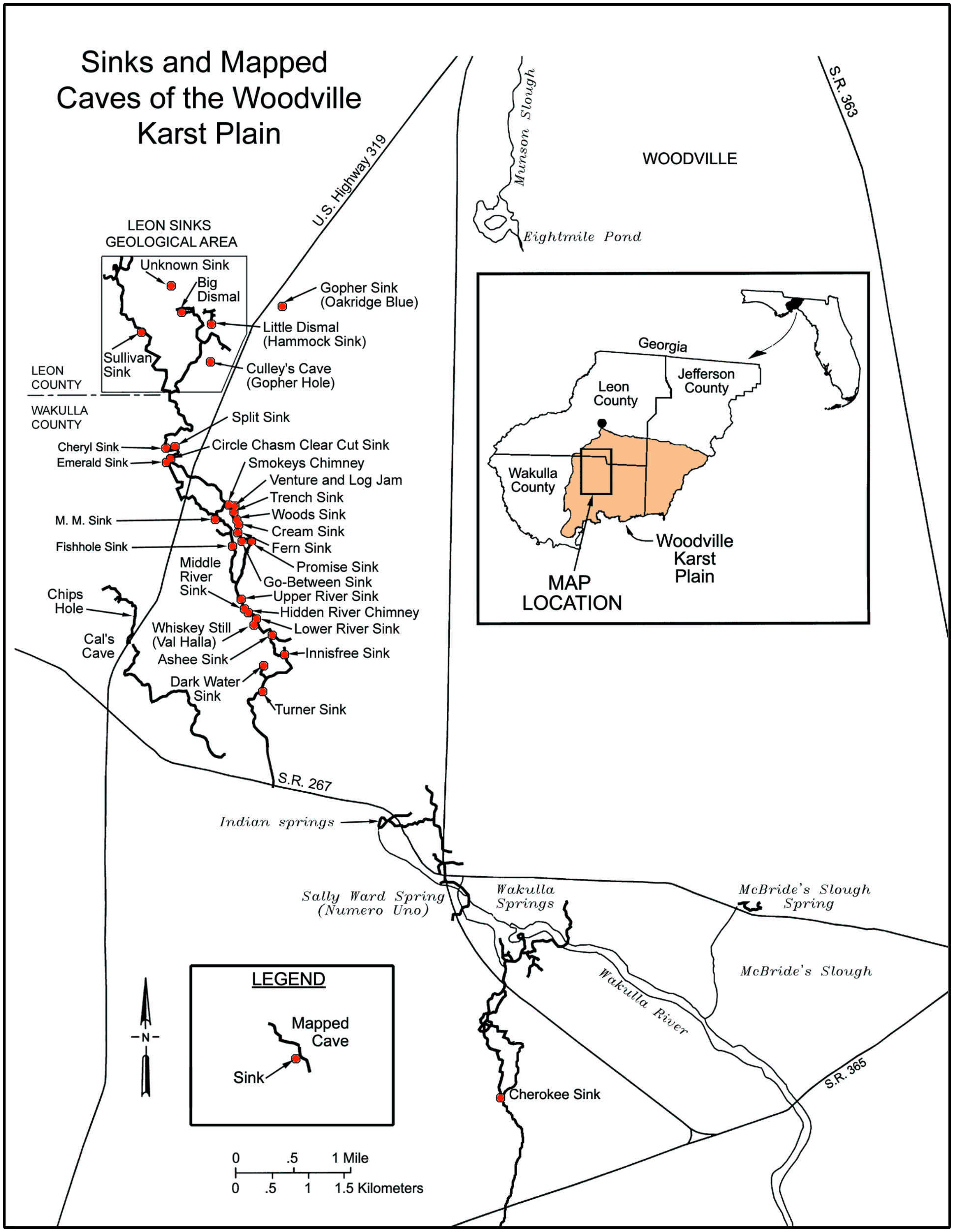

Figure 9. Detail map showing the flooded caverns, from the Leon Sinks Geological Area to Wakulla Springs, and nearby areas (Wisenbaker, 1999).

uninterrupted for more than 17 miles (Ringle, 1999).

Previous geological studies in various parts of Florida have shown the role of stratigraphy, fractures, and bedding planes in controlling the orientation and development of surface and ground-water drainage systems and, hence, in controlling regional ground-water flow. Vernon (1951) mapped large scale fracture trends of the northern portion of the Florida peninsula; one set trending northeast-southwest and one set trending northwest-southeast. He noted that the stream patterns in the counties commonly parallel these trends. Moore (1955) also reported angular stream patterns in Jackson County that paralleled the same orientations. Rupert (pers. com., 1998, using unpublished FGS data) showed similarly oriented lineaments throughout the panhandle and the northern peninsula.

Locally, other geological investigations have come to the same conclusions regarding lineament-control of surface and underground drainage systems. Hendry and Sproul (1966) noted two systems of lineations of geological features in Leon County; one bearing northeast-southwest and another bearing northwest-southeast. Yon (1966) observed similar lineaments in Jefferson County, projecting into eastern Wakulla County. Observing that some segments of stream channels flowed parallel to these linear trends, he speculated that preferential dissolution of the limestone bedrock might be responsible for such parallel channel development.

The underground drainage system that supplies water to the Spring Creek springs is analogous to that supplying Wakulla Springs. That system has been shown to extend to the northwest from Wakulla Springs at least to the Leon Sinks Geological Area, a distance of approximately six miles. All of the flow of Lost Creek goes underground about 1.3 miles southwest of Crawfordville (Figure 7), a distance of approximately six miles northwest of Spring Creek. Based on the predominant ground-water pattern of the

Figure 10. Northeasterly oblique aerial view of the Spring Creek area from an altitude of 1,000 feet, October 1998. FGS photograph.

Woodville Karst Plain, and the trend of the lineaments associated with both Lost Creek and Spring Creek, it is postulated that the upgradient source of groundwater supplying the Spring Creek springs is, at least in part, the surface water from Lost Creek.

SPRING CREEK SUBMARINE SPRINGS GROUP

Previous Investigations

Spring Creek is a low-gradient tidal stream in the northwestern part of Apalachee Bay (Figures 3, 7, 10 and 11). It is aptly named, for there may be as many as 14 submarine springs in its lower reaches. Rosenau et al. (1977) showed the locations of eight springs, and assigned numbers 1 through 8 to them (Figure 11). In 1972, 1973, and 1974, the U.S. Geological Survey collected water quality samples and estimated flow rates for the spring group. The results of their investigations were reported by Rosenau et al. (1977), and are summarized here, in Appendices 1 and 2.

On May 30, 1974 the U.S. Geological Survey measured aggregate stream flows of about 2,000 cubic feet per second (cfs) (3,096 million gallons per day (mgd)), attributable to the eight springs, and apparently to many other submarine springs thought to exist in the area (Rosenau et al., 1977). For comparative purposes, the maximum recorded flow of Wakulla Springs was 1,910 cfs (2,957 mgd) on April 11, 1973 (Rosenau et al., 1977).

As part of a U.S. Geological Survey hydrogeologic investigation of Leon County, river-discharge measurements were made at Spring Creek and Wakulla River, on November 1, 1996 (Davis, 1996). Spring Creek's discharge was 307 cfs (475 mgd), and the Wakulla River's was 350 cfs (542 mgd). Rivers in the area were at base-flow conditions due to several months of low rainfall.

Woodville Karst Plain Project

The Woodville Karst Plain Project is a continuing program to map the underground conduit systems that link the sinkholes and springs throughout the plain. The project was formally initiated in 1986, although sporadic, uncoordinated, cave diving activities go back to the 1950s. Investigations under the present project are conducted by experienced, certified cave divers. The main thrust has been to find and map, or otherwise prove, direct connections between the up-gradient components of the karst drainage system, starting at the Leon Sinks Geological Area, in Leon County, and the main down-gradient discharge point, which is thought to be Wakulla Springs.

Physical Descriptions of Springs

Spring Creek and its tributaries meander through low-lying coastal marshes. The streams' beds are mostly covered by a veneer of silt, mud, and mollusk debris. However, at extremely low tide, and when the water is clear, fragments of limestone of the St. Marks Formation can be seen in places around the rims of some of the springs' basins, apparently exposed where the springs' discharge scours away the thin sediments.

Several of these submarine springs were investigated by the Florida Geological Survey in August and September 1995, and water quality samples were taken (see Table 1). Another reconnaissance was made in November 1997, to gather background data on them. At that time, three new springs, not described by Rosenau et al. (1977), were located by their boils (springs 9, 10, 11 on Figure 11). Springs 1, 2, 3, and 8 were located by their surface boils, but springs 4, 5, 6, and 7 of Rosenau et al. (1977) were not located; their flows may have been too small to create surface boils at the time of these investigations. In November 1998, Jim Ladner (FGS) reported finding two more previously unreported spring boils in Stuart Cove, just east of Spring Creek. These are springs number 12 and 13 (Figure 11). Water quality samples were collected from them on December 4, 1998 (see Table 2).

On May 21, 1999, several seismic survey lines were run up the main channel of Spring Creek, across

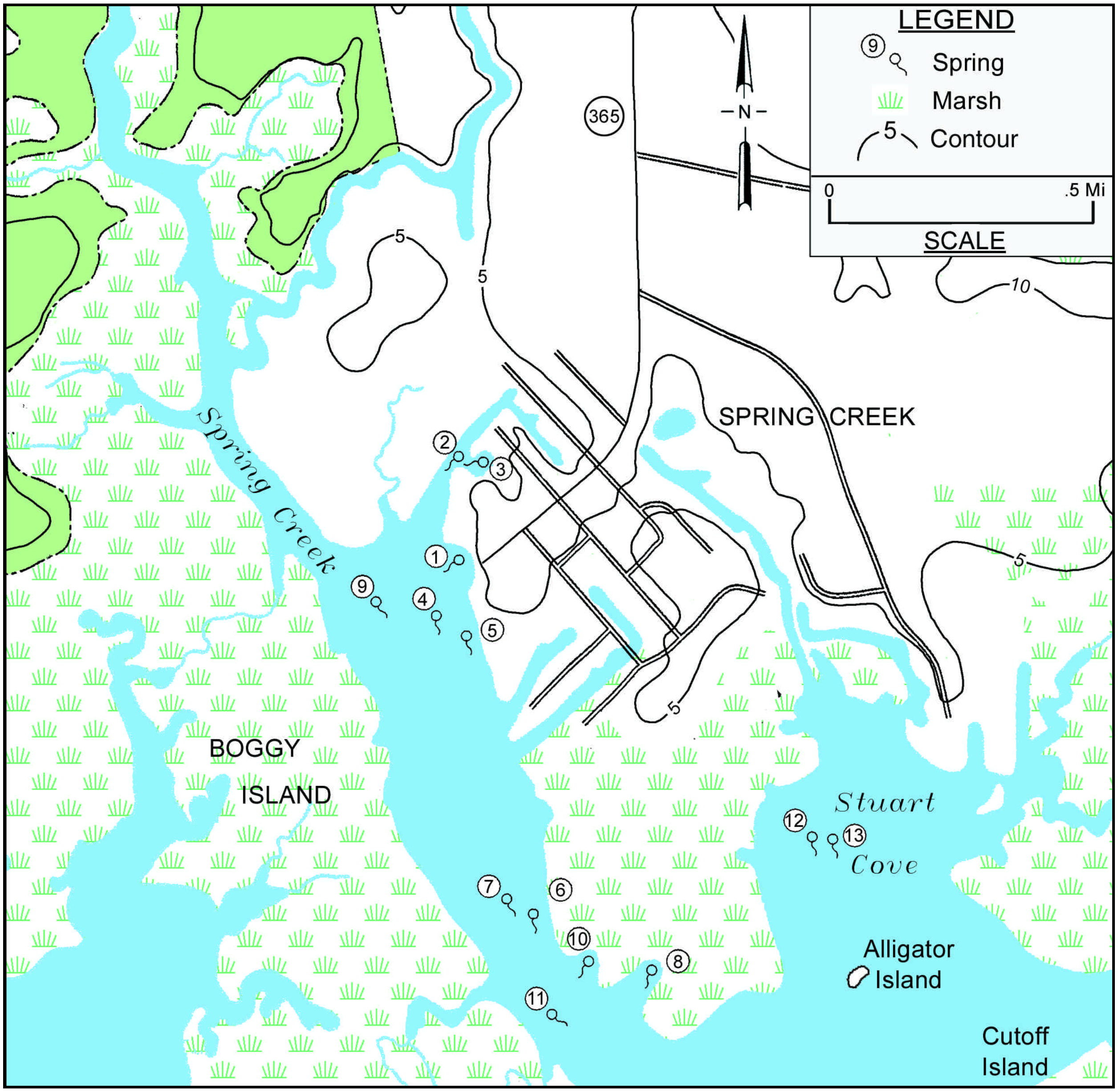

Figure 11. Map showing locations of the numbered submarine springs of the Spring Creek Springs Group (after Rosenau et al., 1977).

Stuart Cove, and up the unnamed, northwest-trending, headwater creek of Stuart Cove. The seismic system used was an FGS/FSU 3.5 kHz acoustic profiling system, consisting of a Geopulse 5430A transmitter, Massa TR57A piezoelectric transducers and an EPS GSP-1086 recorder. (Any use of trade names is for descriptive purposes only and does not imply endorsement by the FGS). Springs 4 and 6, in the main channel of Spring Creek, were located by seismic survey, although they showed no surface boils. Several runs were made across the approximate location of spring 7, but it was not found. Several seismic runs were made across Stuart Cove, which showed several large, karst-like features on the bottom (Figure 12). The seismic profiles indicated minimal sediment infill of the tidal channels and the spring mouths. No indication of submarine karst features was found up the unnamed creek.

A Sitek Model HE-203 sonic depth indicator, with a strip-chart recorder, was modified to obtain continuous cross-section bottom profiles of the individual springs. To obtain depth recordings, several boat-runs were made over each spring, from varying directions, in order to get the best quality print-out. Some spot-depths were taken using a calibrated boat pole and a lead line. The springs' basins and pools appeared to be relatively symmetrical, varying from broad, shallow bowl-shaped pools to steep-walled, conical shapes, as shown on Figures 15 through 21.

Spring 1 (Spring Creek Rise) (Figures 13 and 14): It was not possible to obtain a depth profile across Spring 1 due to the enormous amount of discharge, which created so much upwelling, surface turbulence that the boat could not be held steady over the spring. The active boil is about 40 to 50 feet in diameter and, in places, can rise nearly a foot above the level of the stream's surface. Rosenau et al. (1977) reported its depth as being 100 feet. During very low water it is possible to see a ledge of resistant limestone on the northwestern side of the spring's pool, and the wall of the pool drops precipitously here. Several round, karst pipes were noted in the limestone that floors the shallow stream bed surrounding the spring's basin; they were about one foot in diameter and were filled with dark sediment.

Spring 2 (Figures 15, 16, 17): This spring's basin is about 75-feet across. A small, partly manmade canal extends to the northeast, and a narrow channel on its southeastern side connects to Spring 3. This spring has the largest and deepest basin of any measured during this investigation. Approaching the pool from any direction the floor falls away precipitously, dropping to 90-feet deep or more. Based on the sizes of the surface boil and the pool, this spring has enormous flow.

Spring 3 (Figure 18): This spring's pool is circular, about 50 feet in diameter, and its pool floor drops precipitously to about 40-feet deep. At low tide irregular limestone blocks can be seen rimming its central pool. This spring has a substantial flow. Crumbling concrete and cement-block walls outline its southeastern side. These walls enclose what appears to be a very shallow, rectangular, wading pool, possibly the remnants of an old spa or hotel, which no longer exists.

Spring 4: This spring's basin appears to be elongated in a northwest-southeast direction, with a steep conical pool over its orifice.

Spring 6: This spring appears to have a relatively small, cone-shaped pool, about 15-feet deep.

Spring 8 (Figure 19): This spring's basin is about 80 feet in diameter, resembling a shallow bowl in cross section, whose bottom slopes at about a 60-degree angle, to over 45-feet deep. Although not as deep as Spring 2, it appeared to have a large flow, since its surface boil was about as large and as turbulent as that of Spring 2.

Spring 9 (Figure 20): This spring was located by a surface boil that was about 30 feet in diameter in the channel of Spring Creek, several hundred feet to the southwest of Spring 1. Its basin appears to have a symmetrical cone shape, with a depth of about 30 feet. The size and turbulence of its surface boil indicated a large flow. In November 1997, it was the only spring observed to be discharging muddy water. On December 4, 1998, its water was murky.

Spring 10 (Figures 21, 23) : The basin of this spring is circular, about 75 feet in diameter, with a narrow canal entering its northern side. The pool has a steeply sloping bottom, creating a bowl over 45-feet deep. As with Spring 8, the large, turbulent boil indicated considerable flow.

Spring 11 (Figures 22, 24, 25): This spring was located by a surface boil that was about 30 feet in diameter in the channel of Spring Creek, several hundred feet to the southwest of Spring 10. Its pool resembles that of Spring 9, although not as deep. The size and activity of its boil indicated significant flow.

Spring 12: This spring's surface boil was about 40-feet wide on December 4, 1998, and rose about 6-inches above the calm surface of the Cove's water, indicating significant flow. Soundings with a boat pole indicated that the sides of this spring's pool drop precipitously.

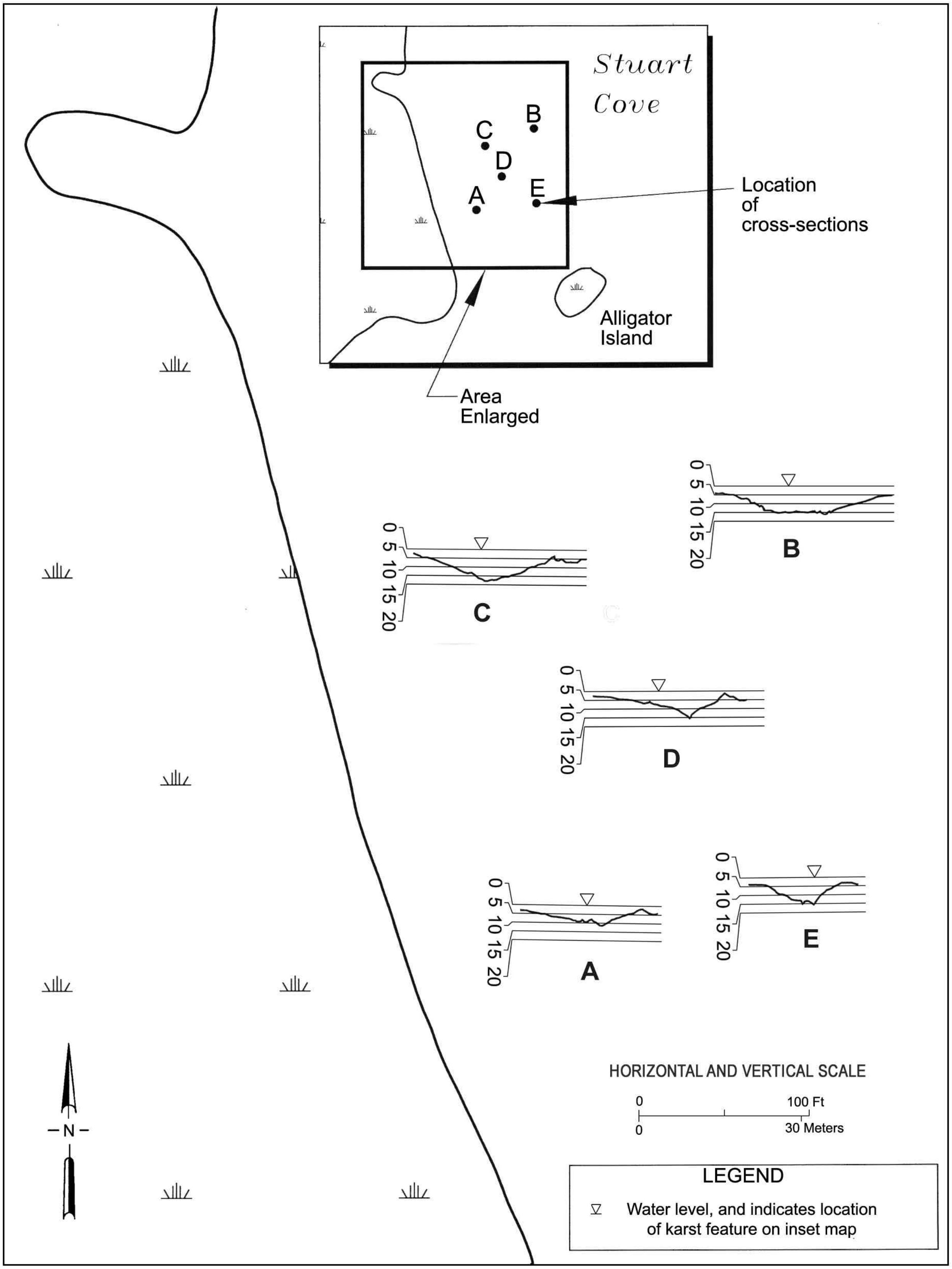

Figure 12. Map of Stuart Cove showing cross sections of submarine karst features.

Spring 13: This spring lies less than 100 feet east of Spring 12, so close that their boils nearly coalesce. On December 4, 1998, its boil was at least 20 feet in diameter, indicating a large flow. Soundings with a boat pole indicated that the sides of the spring's pool drop steeply.

Pulsating Flow

All the springs were observed to exhibit pulsating flow, a phenomenon characterized by alternating surges of boiling surface turbulence, caused by large quantities of rapidly upwelling water, followed by relatively quiescent flow. Each phase could take as long as several minutes to complete. Some of the more active boiling phases had noisy, splashing turbulence, that was created by what appeared to be surges of water that suddenly erupted above the stream surface.

A possible explanation for this phenomenon may lie in the spring group's underground karst drainage system. It seems reasonable to assume that the springs are fed by a complex, even tortuous, interconnected network of large-diameter tunnels, similar to those supplying Wakulla Springs (Figure 8) (Stone, 1989; Rupert, 1988; Rosenau et al., 1977), which lies only 10 miles north on the Woodville Karst Plain. Scuba divers have established that some of Wakulla Springs' largest conduits' flows change direction, and that their local source of water also changes (George Irvine, Director, Woodville Karst Plain Project, pers. com., March, 1998).

This phenomenon may be controlled in part by the state of Wakulla Springs' local potentiometric surface. Large rains over Wakulla Springs' recharge basin may temporarily change its potentiometric surface so that groundwater is routed differently within the underground drainage system supplying the springs. This balance of recharge-discharge routing within the underground drainage system is so sensitive to changes in head that it also appears to be influenced by tidal effects on the springs (Irvine, pers. com., 1998). The water surface of Wakulla Springs' main pool is less than five feet above sea level, and the Wakulla River is tidally influenced at least as far upstream as the bridge at US 365, about two-miles downstream from the springs, and possibly even further upstream to the spring-head, itself.

Given that the Spring Creek Springs Group probably has a similar maze-like "plumbing" system, it is easy to visualize how enormous quantities of water, moving rapidly and turbulently through the complex of conduits, could create both pressure and flow surges that would propagate through the system. In this scenario, a tunnel feeding a particular spring that had a pressure surge would momentarily get more of the system's water, resulting in an increase in its discharge. That surge would relieve pressure in that part of the system and the spring's discharge would decrease; then another tunnel would experience an increase in pressure, causing a pulse of water to its orifice; and so on.

Ground-Water Chemistry

Predominant flow paths along fractured, high-transmissivity trends affect ground-water chemistry. Conduits extending from recharge to discharge areas can transmit "plumes" of groundwater of differing quality, thereby providing a "drain" along which adjacent waters converge and mix. During the Wakulla Springs Project, this phenomenon was observed in the main conduits of Wakulla Springs, where murky water discharging from one conduit was seen to mix with clear water from other conduits (Stone, 1989). A similar phenomenon may be occurring at Spring No. 9, which was observed on two separate occasions to be discharging murky water, while all other springs' waters appeared to be clear.

Water-quality data were obtained for this investigation with a Grant/YSI 3800 water-quality meter. This instrument has a fast response time, enabling several parameters to be taken quickly at each station. This is an important consideration when trying to keep the boat stationary in a spring's surface boil. Results of water quality tests are given in Tables 1 and 2.

The U.S. Geological Survey tested the water quality of eight springs in 1972 and 1973. The results of those analyses are reprinted in Appendix 1.

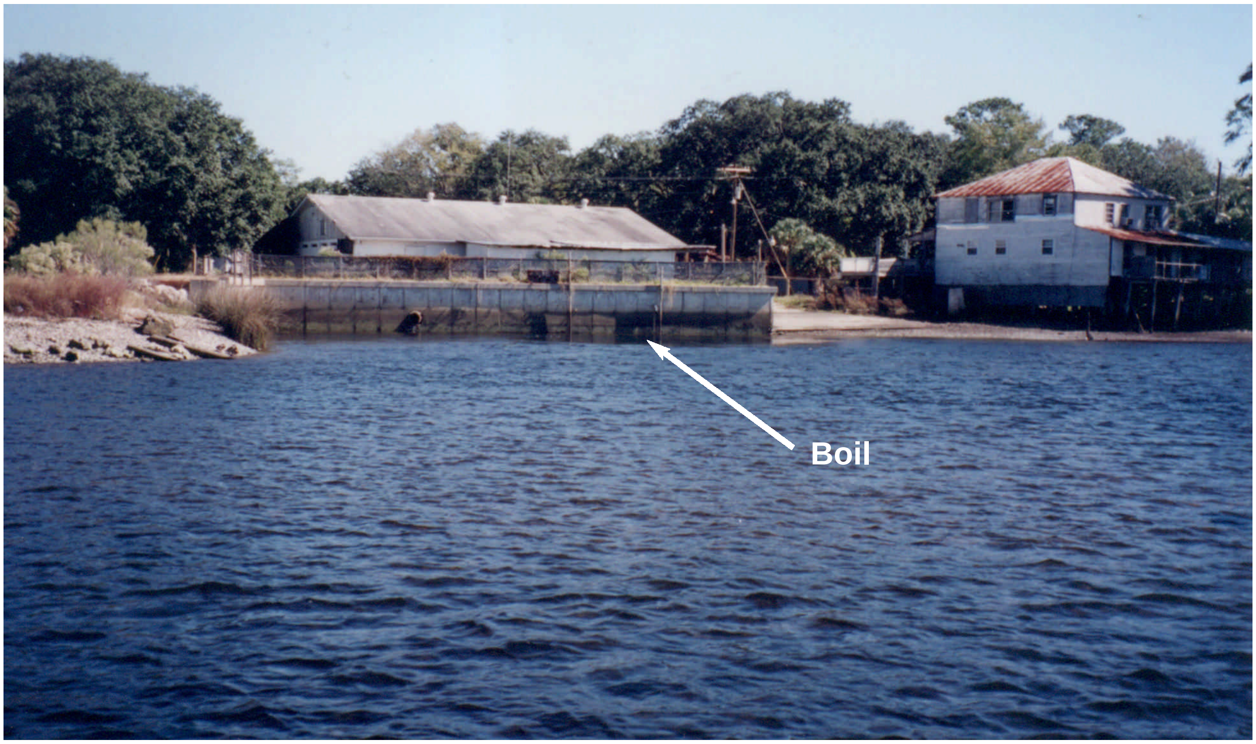

Figure 13. Photograph of Spring 1, view to the northeast, at low tide. Spring boil is the slick area in front of the sea wall, November 3, 1997. FGS photograph.

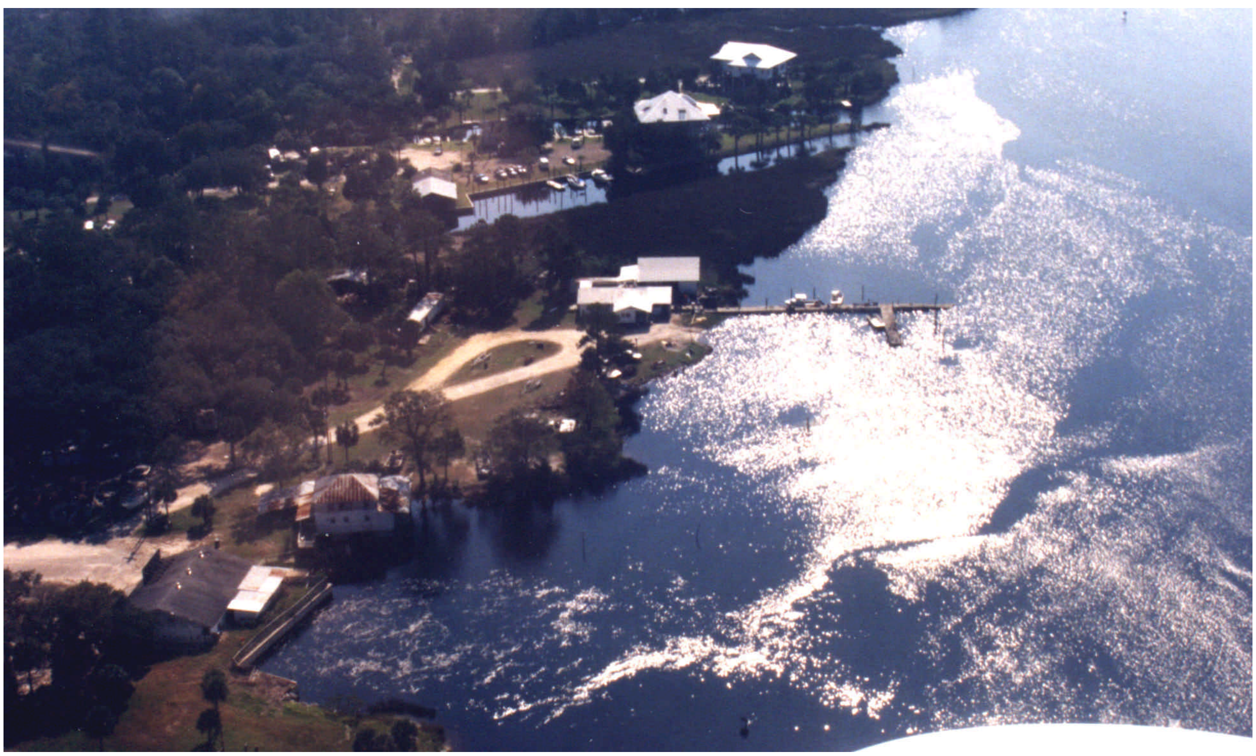

Figure 14. Aerial photograph of Spring 1, view downstream, October 1998. Spring boil shows as circular sun-glint directly to the right of the straight bulkhead in the lower left. Magnitude of the spring's discharge is indicated by its semi-circular slick, which extends half-way across the picture. FGS photograph.

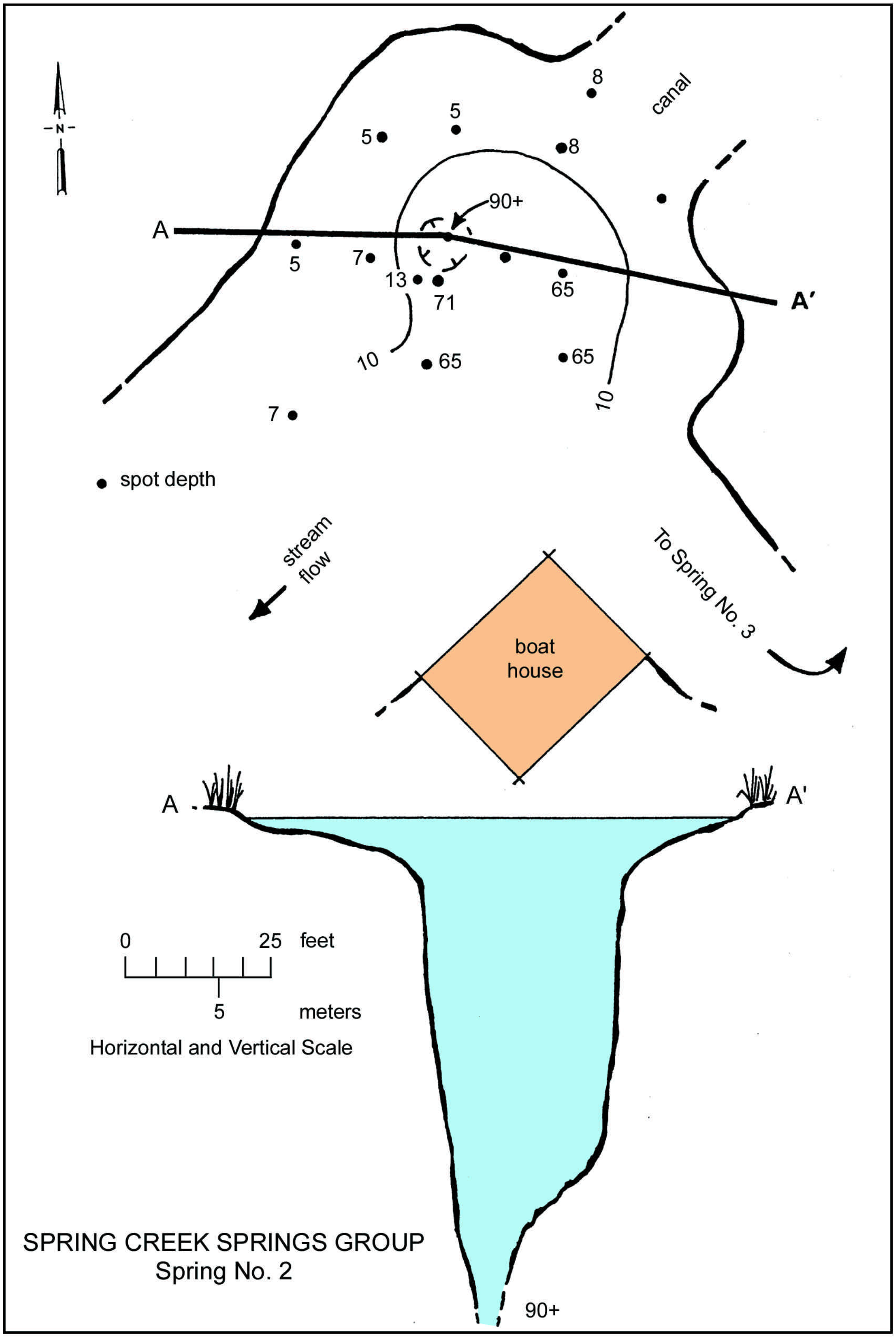

Figure 15. Spring 2, plan and cross section. Measurements taken at high tide, August 7, 1995. Tidal range is about 2-3 feet.

Figure 16. Photograph of Spring 2, view to northwest across boil (circular ripples), at low tide, November 3, 1997. FGS photograph.

Figure 17. Photograph of Spring 2, view to northwest across boil (circular ripples), at low tide, November 3, 1997. FGS photograph.

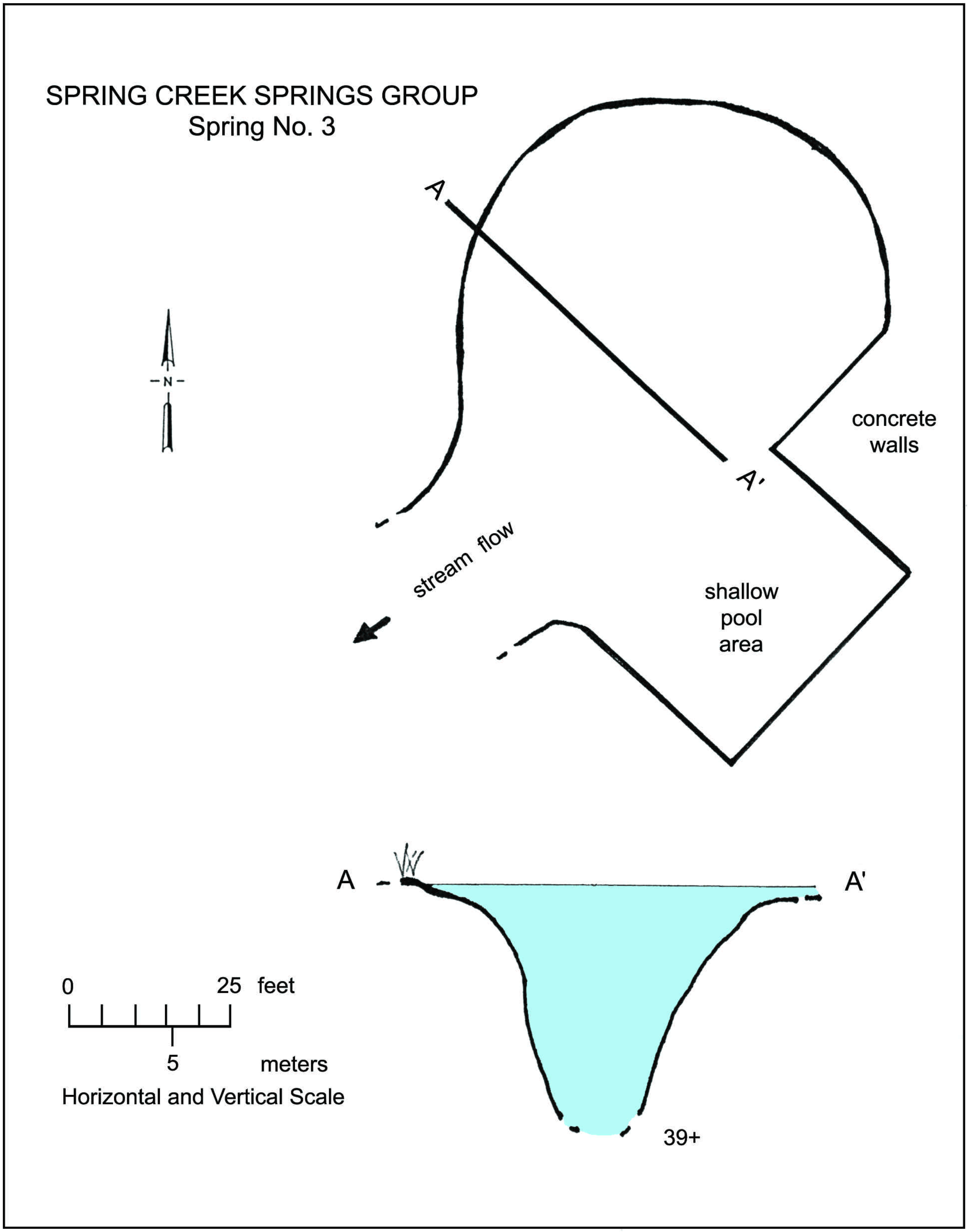

Figure 18. Spring 3, plan and cross section. Measurements taken at low tide, September 12, 1995. Tidal range is about 2-3 feet.

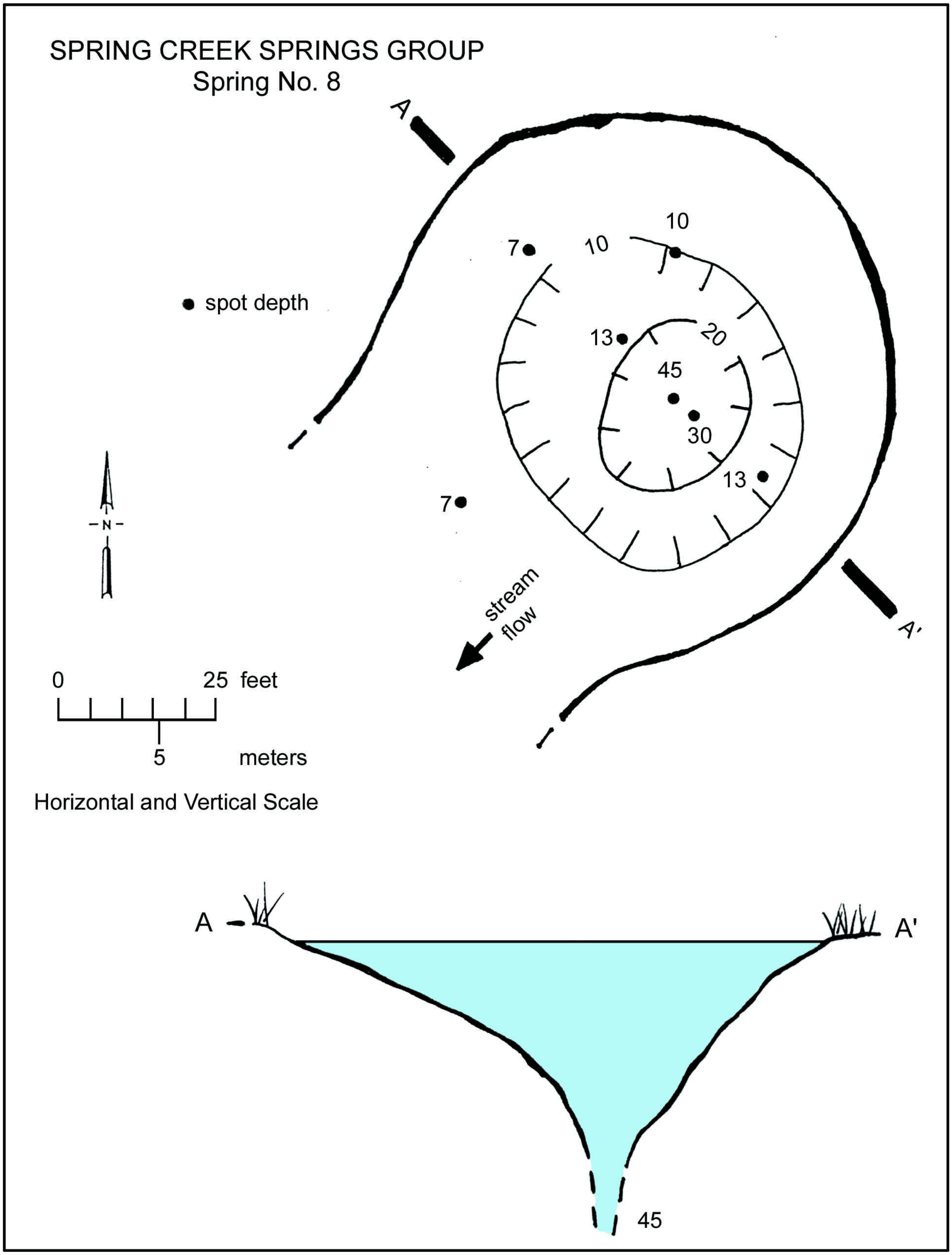

Figure 19. Spring 8, plan and cross section. Measurements taken at high tide, August 7, 1995. Tidal range is about 2-3 feet.

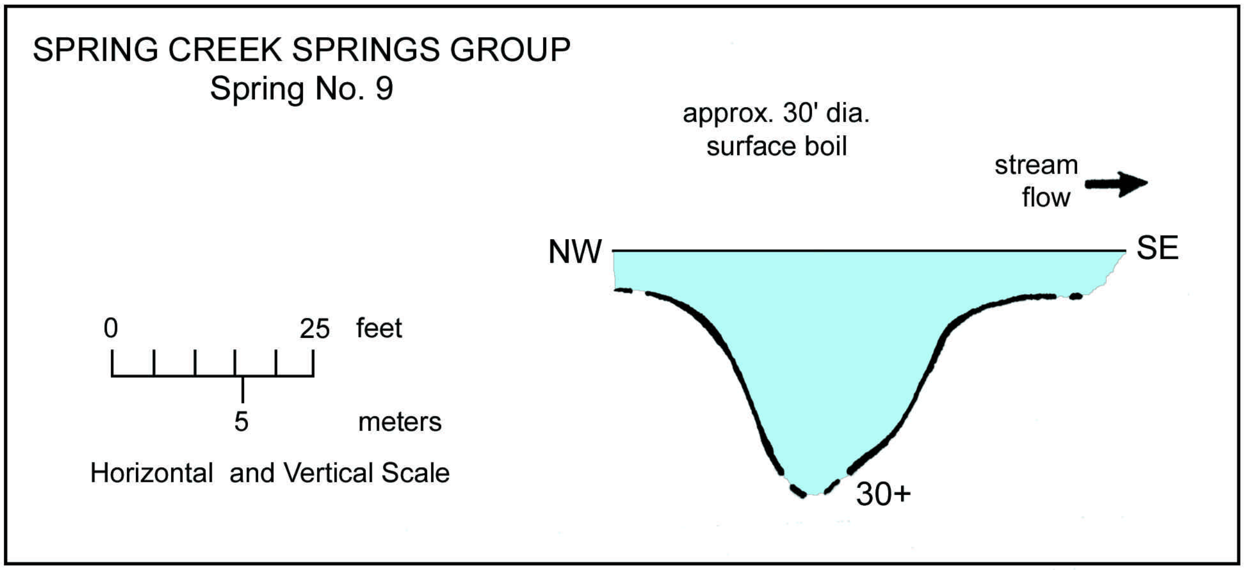

Figure 20. Spring 9, cross section. Measurements taken at extreme low tide, November 3, 1997. Tidal range is about 2-3 feet. This was the only spring that was noted to discharge muddy water.

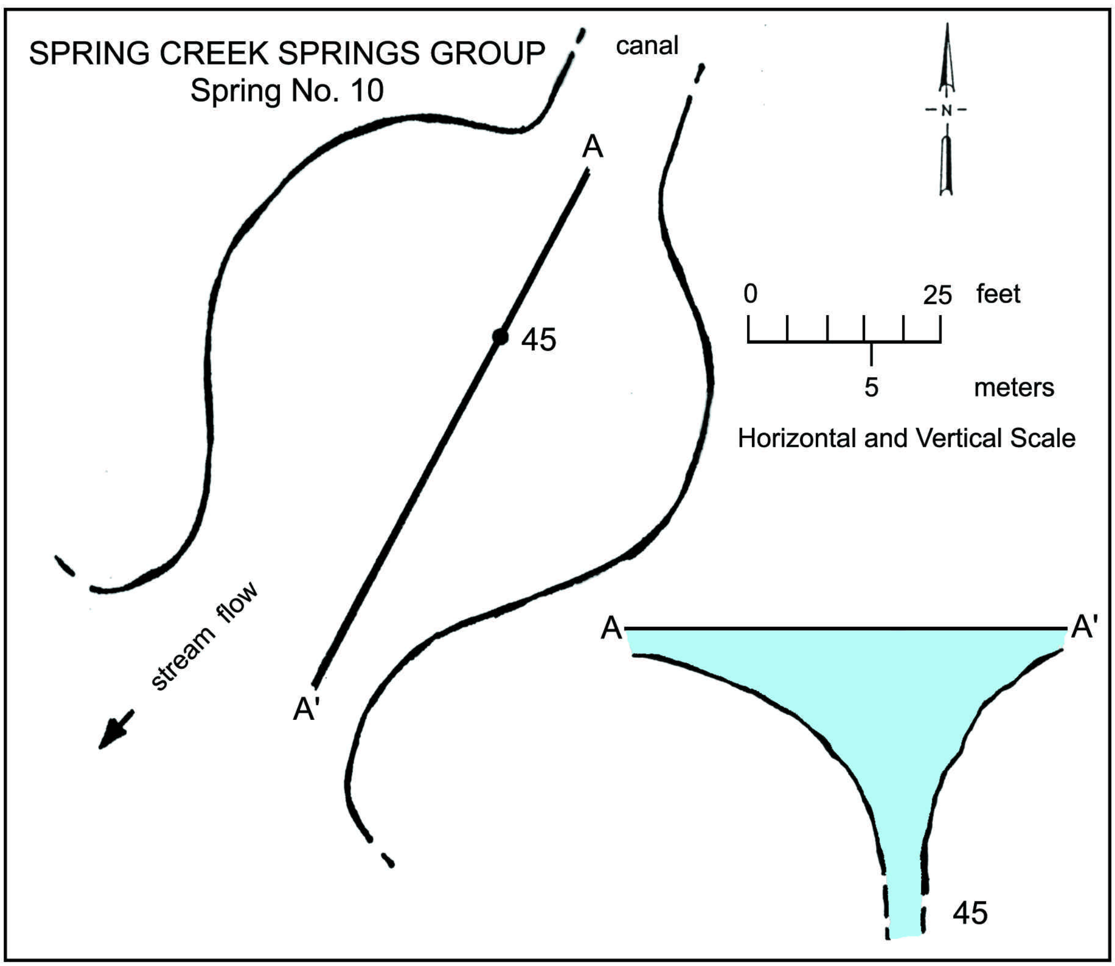

Figure 21. Spring 10, plan and cross section. Measurements taken at low tide, September 12, 1995. Tidal range is about 2 - 3 feet.

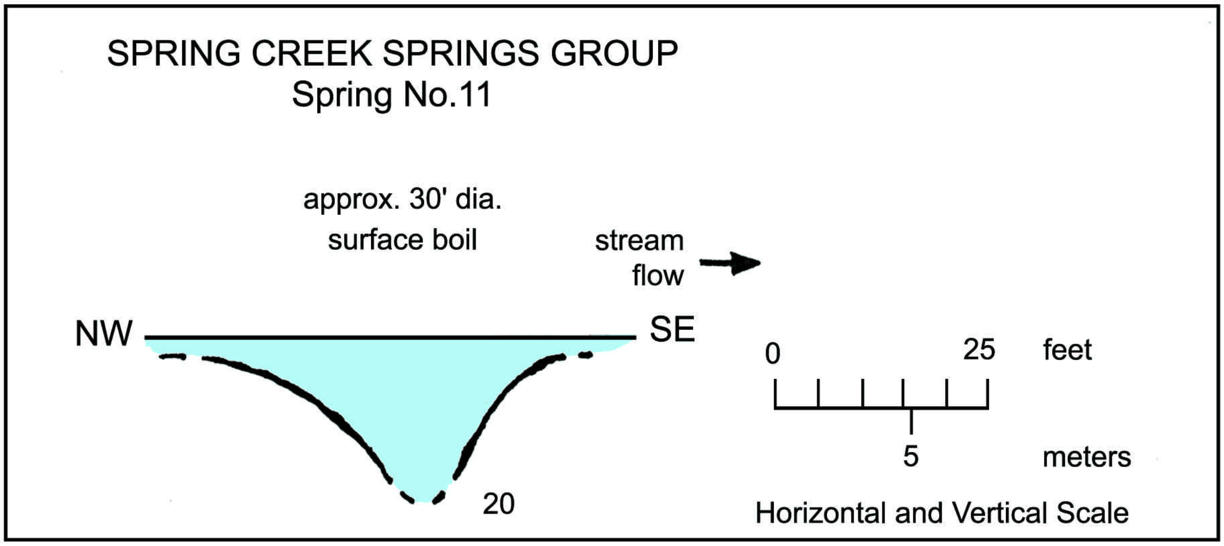

Figure 22. Spring 11, cross section. Measurements taken at low tide, September 12, 1995. Tidal range is about 2 - 3 feet.

Figure 23. Photograph of Spring 10, view to northeast and upstream showing boil, at low tide. November 3, 1997. FGS photograph.

Figure 24. Photograph of Spring 11, view to northwest, approaching the mid-channel boil from downstream. The fresh-water boil is about 30 feet in diameter, November 3, 1997. FGS photograph.

Figure 25. Photograph of Spring 11 showing surface boil about 30 feet in diameter. Turbulence on upstream side, caused by magnitude of flow, created an audible rippling sound. This view directly downstream shows the raised upwellings that are commonly seen over these springs' main vents. November 3, 1997. FGS photograph.

Table 1. Water-quality data for Spring Creek Springs Group, September 12, 1995.

Spring number	Depth	pH	Temp. °C(°F)	O_2	Cond.	Salinity	Eh
1	13	7.5	22.2(72.0)	0.04	8.65	4.8	296
2	5	7.65	21.9(71.4)	0.14	4.62	2.5	218
2	45.4	7.62	22.1(71.8)	0.13	4.02	2.1	227
3	1.2	7.76	22.0(71.6)	0.09	4.94	2.7	161
3	38.2	7.75	22.1 (71.8)	0.14	5.32	2.9	127
9	32.8	7.54	23.4(74.1)	0.81	13.25	7.6	227
10	14	7.6	22.2(72.0)	0.20	6.84	3.7	288

Spring number = keyed to Figure 11.
Depth = feet below water surface.
Temp. = water temperature, ºC (ºF).
O_2 = dissolved oxygen, mg/L.
Cond. = specific conductivity, mS/cm
Salinity = parts per thousand, ppt.
Eh = reducing potential, millivolts.

SUMMARY and CONCLUSIONS

The one geological element that controls or greatly influences much of Florida's coastal environments and ecosystems is the karstified limestones that underlie the state. These karstified limestones form a common, unifying linkage among the uplands, the coastal and estuarine environments, and the continental shelf marine realms -- they link the terrestrial environments to the marine environments. Also, they constitute the major part of the Floridan aquifer system, which supplies most of the state's fresh-water resources.

A significant portion of the Floridan aquifer system's dominant secondary porosity and permeability is likely developed along zones of weakness in the rocks, or fractures. Understanding fluid flow in dissolutional conduits formed along fracture trends is important in ground-water resource development, in the detection, disposal, and cleanup of hazardous waste, and in determining pollutant migration flow paths. Use of fracture data is a paramount requirement when modeling regional flow and solute transport in karstic carbonate aquifers. High permeability trends preferentially developed along fracture systems can create large-scale variations in flow rates and can determine if and where inter-basin flow will occur and, thus, the extent of regional flow systems. In these situations, many common assumptions about flow and transport in porous media are inappropriate. Conduits developed along fractures may be an important factor influencing the potentiometric surface configuration of the Woodville Karst Plain. They provide rapid, nearly linear routes for ground-water travel.

This study concludes that: (1) the Spring Creek Springs Group comprises a series of conduit-fed discharge points for waters of the Floridan aquifer system; (2) the configuration of the springs’ cross-sectional profiles show them to be cone-shaped sinks, typical of springs developed in Florida karst; (3) based on an analysis of fracture trends and local lineaments, a likely source for at least part of the spring flow is Lost Creek, a surface stream captured by karst drainage six miles northwest of the springs; (4) regional ground-water flows into the system through unmapped conduits, supplying the remainder of the spring flow; (5) variations in water chemistry and clarity in different springs indicate differing ground- and surface water sources within the spring system; and (6) pulsating flow observed at some of the springs may also reflect a complex conduit plumbing system supplying the springs, and flow rates in this system may be influenced by local recharge events and by tidal stage.

Exploitation of the Spring Creek Springs Group as a high-capacity source of freshwater could threaten the tenuous balance among the surface water and ground-water regimes, as well as the ecosystems associated with Spring Creek and Stuart Cove. Questions about the societal issues involved in large inter-basin transfers of fresh water are beyond the scope of this study.

By hydrogeological inference, therefore, these conclusions apply generally to all similar submarine springs on the Florida Platform. Each spring or spring system, however, must be studied individually to determine its range of hydrogeological parameters. These, in turn, will determine each site's usefulness for, or vulnerabilities to, exploitation.

Table 2. Water quality data for Spring Creek Springs Group, December 4, 1998. Data from Angela Chelette, Northwest Florida Water Management District. All readings were taken about 1 foot below water surface.

Spring Number	*Temp. ºC (ºF)*	*Specific Conductivity (mS/cm)*
1	21.5 (70.7)	19.50
		19.61
		19.41
		19.29
		19.36
		19.44
2	21.2 (70.2)	6.80
	21.1 (70.0)	6.76
	21.1 (70.0)	6.53
	21.1 (70.0)	6.24
	21.3 (70.3) *	6.71*
	21.1 (70.1)	6.60
3	21.1 (70.0)	6.60
	21.1 (70.0)	6.54
	21.1 (70.0)	6.65
	21.2 (70.2) *	6.51 *
8	21.4 (70.5)	18.64
	21.4 (70.5)	18.59
	21.4 (70.5)	18.45
	21.4 (70.5)	18.35
9	21.4 (70.5) *	19.43*
Water was somewhat murky.	21.7 (71.2) *	19.27*
10	21.4 (70.5)	16.40
	21.4 (70.5)	16.43
	21.4 (70.5)	16.33
	21.5 (70.7) *	16.23 *
11	21.3 (70.3) *	19.74 *
	21.5 (70.7)	19.49
12	21.2 (70.2)	19.70
	21.3 (70.3)	19.60
	21.2 (70.2) *	19.45 *
	21.1 (70.0)	18.60
	21.1 (70.0)	19.40
	21.1 (70.0)	19.20
13	19.5 (67.1)	16.30
	19.7 (67.5)	15.00
	21.1 (70.0)	17.02

* surface grab sample

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APPENDIX 1

Water quality data for eight Spring Creek springs, 1973

The U. S. Geological Survey sampled eight springs of the Spring Creek Springs Group on August 14, 1973. The results of the water quality analyses of those samples are reprinted here (Rosenau et al., 1977, p. 447). Analyses by field methods; units are in milligrams per liter (mg/L) unless otherwise indicated.

Spring No.	**1 (Spring Creek Rise)**			**2**		
Depth (ft)	Surface	20'	41'	Surface	40'	79'
Temp. ºC	22.0	22.0	22.0	22.0	22.0	22.0
pH (units)	7.1	7.1	7.0	7.2	7.4	7.4
HCO3	99	99	82	86	99	110
Sp. Cond.	4,100	4,100	4,390	1,000	1,100	1,600
Chloride	1,250	1,260	1,200	270	285	455
Hardness	570	520	510	220	200	255
Calcium	78	82	55	52	50	58

Spring No.		**3**			**4**	
Depth (ft)	Surface	20'	37'	Surface	20'	42'
Temp. ºC	23.0	23.0	23.0	22.5	22.5	22.5
pH (units)	7.1	7.1	7.2	7.1	7.1	7.2
HCO3	96	96	96	96	98	98
Sp. Cond.	880	880	880	1,700	3,400	3,800
Chloride	195	200	195	500	1,030	1,150
Hardness	180	185	210	270	455	490
Calcium	46	47	47	56	70	52

Spring No.		**5**			**6**	
Depth (ft)	Surface	10'	24'	Surface	10'	19'
Temp. ºC	23.0	22.5	22.5	22.5	22.5	22.5
pH (units)	7.1	7.2	7.2	7.0	7.2	7.2
HCO3	96	116	122	94	96	96
Sp. Cond.	3,300	16,000	21,100	930	950	940
Chloride	950	5,700	7,780	205	210	200
Hardness	450	2,005	2,755	190	180	190
Calcium	67	42	48	47	47	46

Spring No.		**7**			**8**	
Depth (ft)	Surface	10'	21'	Surface	10'	23'
Temp. ºC	22.5	22.5	22.5	22.5	22.5	22.5
pH (units)	7.27	7.2	7.2	7.0	7.3	7.5
HCO3	97	98	102	96	97	104
Sp. Cond.	2,900	3,000	3,200	930	980	890
Chloride	820	870	920	206	210	200
Hardness	395	445	445	190	195	195
Calcium	60	64	68	46	49	48

APPENDIX 2

Water quality data for Spring 1 (Spring Creek Rise), 1972 AND 1973

The U. S. Geological Survey sampled Spring 1 (Spring Creek Rise) on March 17, 1972 and August 14, 1973. The results of the water quality analyses of those samples are reprinted here (Rosenau et al., 1977, p. 451). Units are in milligrams per liter (mg/L) unless otherwise indicated.

Date of collection	March 17, 1972	August 14, 1973
Calcium (Ca)	80	55
Magnesium (Mg)	92	89
Sodium (Na)	710	730
Potassium (K)	26	40
Silica (SiO_2)	7.8	6.0
Bicarbonate (HCO_3)	130	82
Carbonate (CO_3)	0	0
Sulfate (SO_4)	200	360
Chloride (Cl)	1,200	1,200
Fluoride (F)	0.4	0.3
Carbon dioxide (CO_2)		13
Dissolved solids (calculated)	2,400	2,520
Hardness as $CaCO_3$	580	510
Noncarbonate hardness as $CaCO_3$	470	440
Alkalinity as $CaCO_3$	110	67
Specific conductance (µmhos/cm at 25 ºC)	4,300	4,390
pH (units)	8.0	7.0
Color (platinum cobalt units)	60	200
Temperature (ºC)	19.5	22.0
Turbidity (JTU)	---	2
Total organic carbon (TOC)	---	13
Total inorganic carbon (TIC)	---	19
Total carbon (TC)	---	32
Organic nitrogen (N)	---	0.51
Ammonium (NH_4 as N)	---	0.05
Nitrite (NO_2 as N)	0.00	0.01
Nitrate (NO_3 as N)	0.18	0.05
Orthophosphate (PO_4 as P)	---	0.03
Total phosphorus (P) (µg/L)	---	0.04
Boron (B)	---	220
Strontium (Sr)	---	800
Arsenic (As)	---	6
Cadmium (Cd)	---	1
Chromium (Cr6)	---	0
Copper (Cu)	---	10
Lead (Pb)	---	4
Zinc (Zn)	---	10
Iron (Fe)	---	300
Manganese (Mn)	---	40

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