Springsheds

There has been increased emphasis in the last few years on the drainage basins that supply water to Florida's springs as a result of awareness of increasing trends in contaminants, such as nitrate (Figure 8). The amount of water and the nature and concentrations of chemical constituents that discharge from a spring are functions of the geology, hydrology, and land uses within the ground- and surface-water drainage basins that collect water for discharge from the spring.

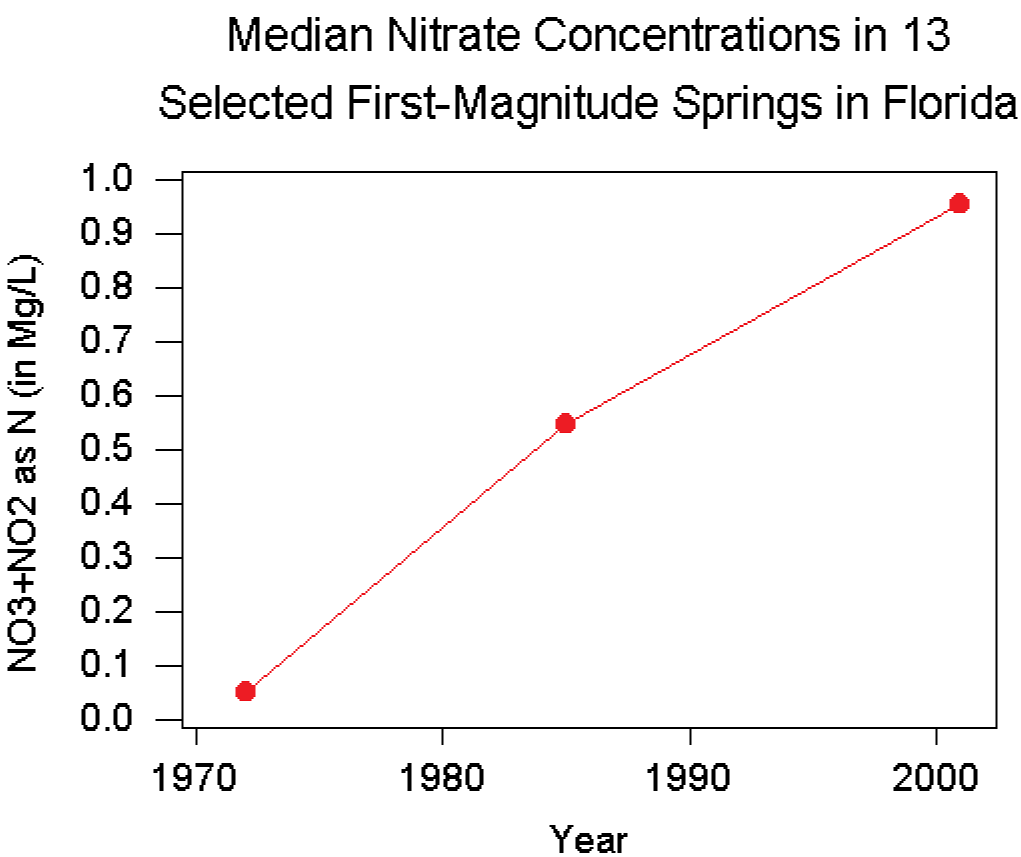

Figure 8. Median nitrate concentrations in 13 selected first magnitude springs in Florida.

Ground-water basins are traditionally identified through either (1) construction of a flow net and identifying divergent flow lines that delineate the hydraulic divides of the spring drainage system, (2) particle tracking within a computer-generated ground-water flow model, or (3) dye or chemical tracing to identify sources that contribute to the spring discharge. All of these methods have uncertainties. For example, delineation of a basin boundary from a flow net or potentiometric surface map is limited to the accuracy and resolution of the map and the flow lines which are subject to change with variations in rainfall, land use, and ground-water withdrawals. The accuracy of the computer model and our understanding of the aquifer system limit the accuracy of particle-tracking procedures. Dyes and other chemicals can be used to identify sources within a basin, but the chemicals may not be detected if they are (1) too diluted in the aquifer, (2) removed from the water (movement is retarded) by chemical interactions with aquifer materials, (3) transported to an un-monitored conduit system, or (4) travel times may be so slow that monitoring may not be feasible.

A spring recharge basin, or springshed, consists of "those areas within ground- and surface-water basins that contribute to the discharge of the spring" (DeHan, 2002; Copeland, 2003). The spring recharge basin consists of all areas where water can be shown to contribute to the ground-water flow system that discharges from the spring of interest. Because karst systems frequently include sinking streams that transmit surface water directly to the aquifer, the recharge basin may include surface-water drainage basins that bring water into the spring drainage from outside of the ground-water basin. This concept is important because contaminated surface water may be introduced to the springshed from sources well outside of the ground-water basin by streams that originate outside the basin.

The scenario shown in Figure 9 illustrates some possible contribution areas within a spring recharge basin. Two components of the springshed are shown: the ground-water basin and a surface-water basin. A portion of the ground-water basin is located within a karst plain where recharge is rapid through features such as sinkholes. Another portion extends under a highlands area where fine-grained sediments overlying the aquifer retard recharge and cause surface runoff and stream development. Because of the area of aquifer confinement, the active recharge portion of the ground-water basin is limited to unconfined portions of the basin. The surface-water basin may or may not extend outside the ground-water basin. The stream that originates on the highlands discharges onto the karst plain where it recharges the aquifer through a swallet. The hypothetical springshed (Figure 9) suggests that a springshed may be subdivided into at least three recharge-potential categories. The semi-confined area of the ground-water basin has low recharge potential and, therefore, low risk of ground-water contamination. The areas nearest the spring, where flow lines converge and transport times from recharge points (i.e., sinkholes) are short, and areas associated with swallets that receive surface water are highly vulnerable to ground-water contamination. Finally, the portions of the karst plain within the ground-water basin that are distant from the spring have an intermediate risk of contributing contamination to the spring discharge because of possible long travel times of water to the spring and a high probability of dilution or retardation of constituents. The stream is a special problem because storm water and permitted discharges upstream can cause contamination issues down gradient of the swallet. Similarly, water sources that originate outside of the springshed can cause potential contamination. For example, a sewage treatment plant that collects water from outside of the basin and disposes of the treated wastewater by land application can constitute a source that effectively extends the springshed to those portions of the wastewater collection system outside of the springshed.

The Suwannee River Water Management District has developed high-resolution monitoring programs for a number of first-magnitude spring systems, including the Ichetucknee Spring Group (Upchurch et al., 2001). High-resolution monitoring for water levels and water quality involves placement of a large number of monitoring wells within the spring basin. The number and spacing of the wells is determined by statistical methods (Upchurch, et al., 2001; Upchurch and Champion, 2003). As a result of the numerous monitoring wells, contour maps with higher resolution than normal (i.e., 1-foot contour intervals as opposed to 5-foot intervals) can be prepared.

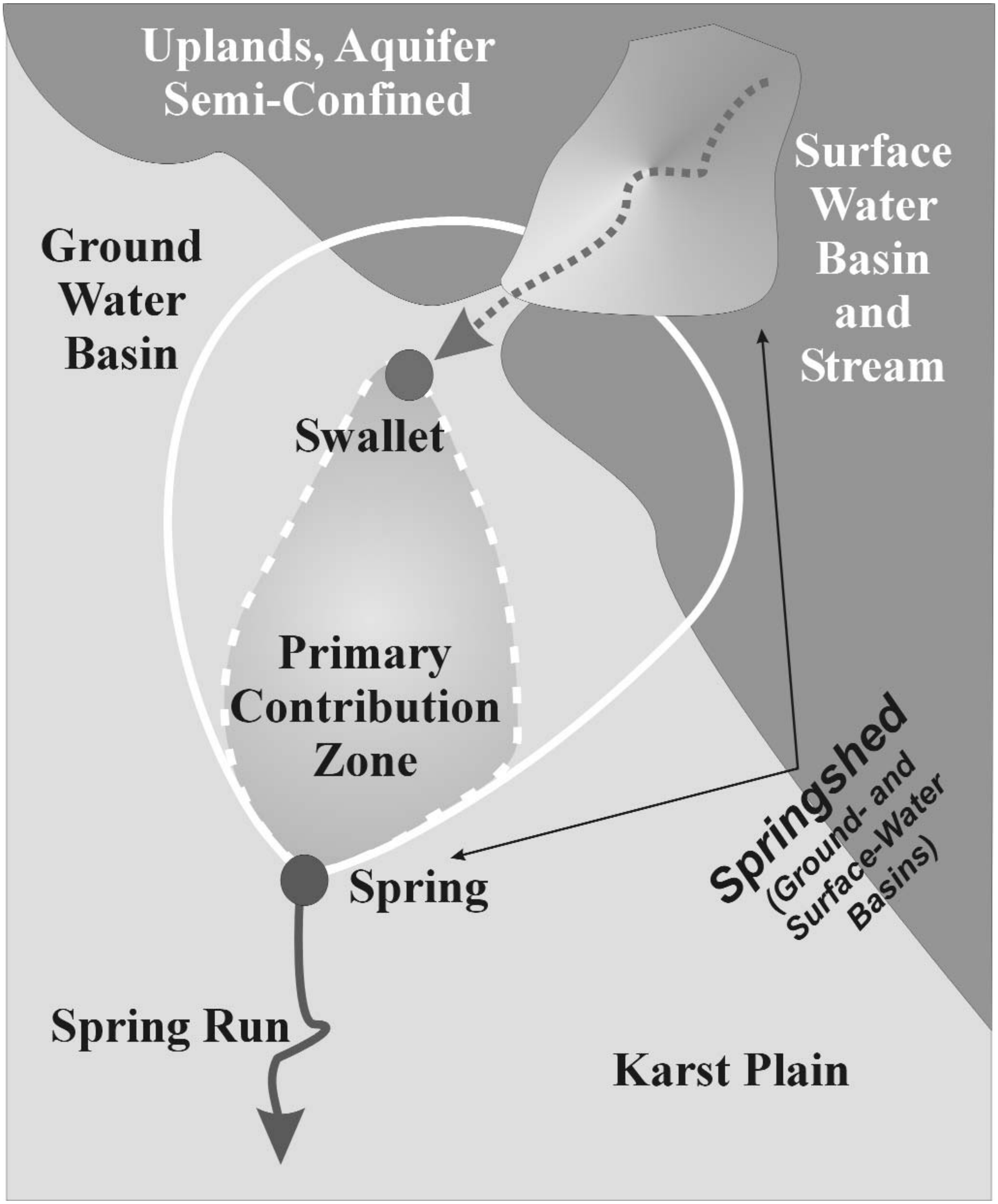

Figure 9. Idealized springshed delineation.

Figure 10 is an example that incorporates many of the features of the hypothetical springshed with a high-resolution potentiometric surface map used as a basis for delineation of the ground-water basin. This map, prepared for data collected in September 2003, shows the ground-water basin as defined by the potentiometric surface map of the upper FAS. Maps prepared for other time periods suggest that the basin boundaries change slightly over time. The zone where the isopotential lines are close together is the transition from the unconfined karst plain (Ocala Karst District) to the highlands where the FAS is confined. Up gradient from this transition zone, aquifer vulnerability is low; down gradient it is high. Aquifer vulnerability is particularly high in the transition zone where streams coming off the highlands discharge into swallets in the karst plain. The hatchered portion represents the drainage basins of the more important of those streams. Lake City is located on this transition zone and runoff from portions of the city as well as from a wastewater land application area enters the shaded area.

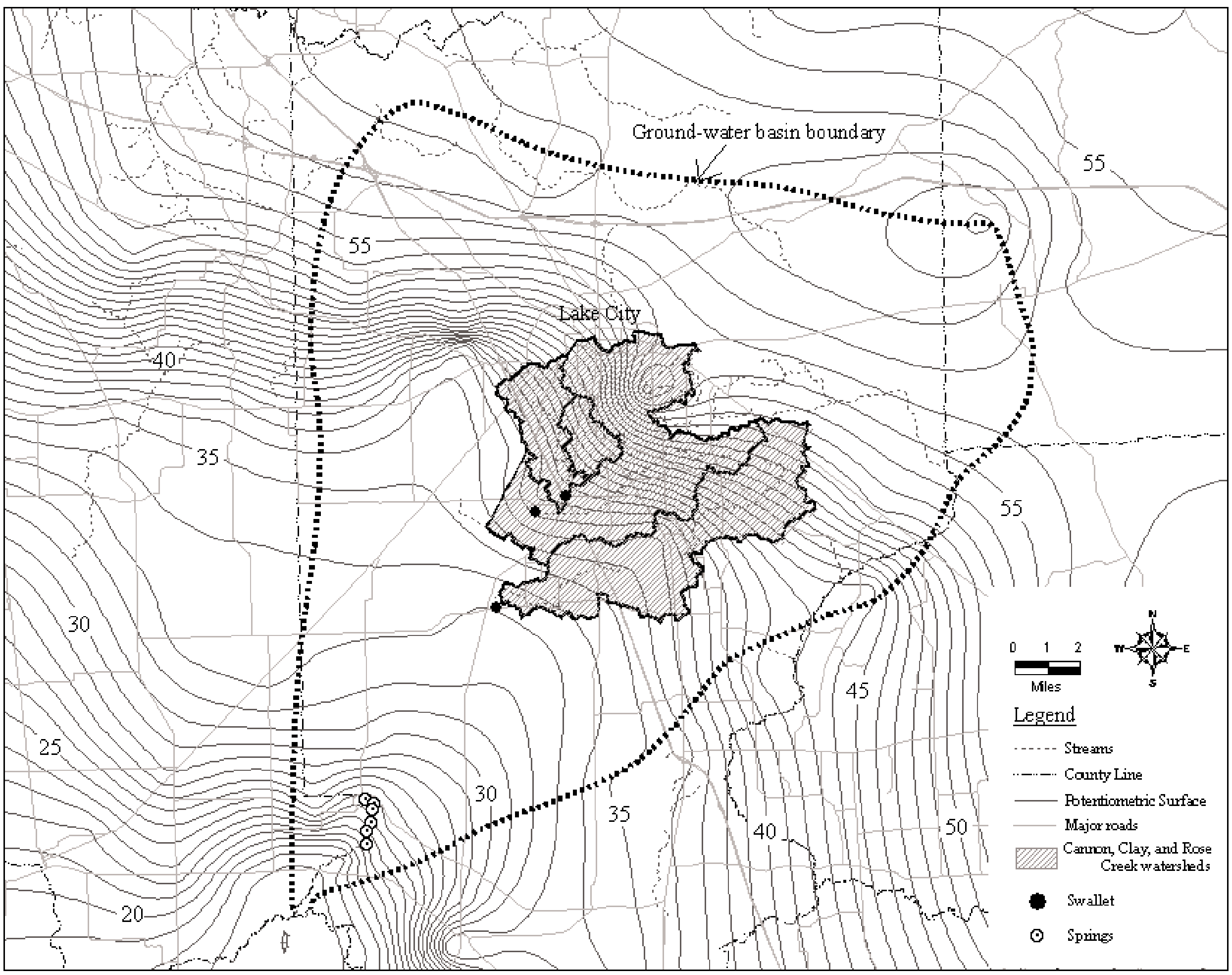

Figure 10. Potentiometric map of a springshed.

Delineation of ground- and surface-water portions of springsheds, identification of major swallets that receive storm water, and identification of land uses that may lead to contributions of nutrients or other constituents into the ground-water system are important steps in protecting Florida springs. High-resolution monitoring is an important aspect of this effort where the margins of the ground-water basin may include significant contamination sources or ground-water withdrawals. In addition, it allows for recognition of vulnerable recharge areas and potential jurisdictional issues.

Spring Water

Natural Factors Affecting Water Quality

In order to fully understand the water quality of Florida's springs, a rudimentary understanding of the origin and chemistry of Florida's groundwater is needed. Most people are aware that Florida is surrounded on three sides by salt water. Many are unaware however, that salt water also underlies the entire state. The reason for this is that the Florida Platform consists of carbonate rocks that were deposited in a shallow ocean. At the time of deposition of the rocks under the ocean, salt water existed in their intergranular pore spaces. Gradually over geologic time, sea level was lowered relative to its position when the carbonate sediments were deposited. Through compaction and downwarping of sediments on both sides of the Platform, a series of complex fracture patterns developed. The patterns are often reflected at land surface and have actually influenced the pathways of many of Florida's streams.

As sea level lowered, the central portion of the Florida Platform was exposed to the atmosphere. Over time, rainfall percolated downward and eventually replaced the upper portion of salt water in the carbonates with a fresh water "lens." Today, the "lens" is generally deepest in the central portion of the state and becomes narrower toward Florida's coastline. The lens is over 2,000 feet thick at its maximum (Klein, 1975). It should be understood that the base of the lens is transitional rather than a sharp boundary. Groundwater in the deeper portion of the lens, and along our coasts, is mixed and has relatively high concentrations of saline indicators such as sodium (Na), chloride (Cl), and sulfate (SO_4).

Water discharging from Florida's springs has its ultimate source from rainfall. Much of the rainfall reaching land surface flows overland to surface-water bodies, evaporates or is transpired by plants. However, a portion of the rainfall percolates downward through the sediments where it recharges our aquifers. During its travel downward from land surface to the water table, and while water resides within Florida's aquifer systems, many factors affect the water chemistry.

Residence time is the length of time that water is in contact with a particular portion of an aquifer system (Upchurch, 1992). A long residence time may allow sufficient time for chemical reactions between the water and the aquifer rock. As such, water chemistry reflects the composition of the aquifer rock. Typical residence times range from several days to thousands of years depending on the nature of the flow system (Hanshaw et al., 1965).

A second factor affecting ground-water chemistry is its flow path, which is the length and depth of the path that the groundwater follows as it flows through an aquifer

(Upchurch, 1992). In general, shallow, short flow paths, which are characteristic of the SAS, result in low residence times for chemical reactions. Consequently, the total dissolved solid (TDS) content is less than in longer flow-path systems. If the flow path is long (on the order of tens of kilometers), such as commonly occurs in the FAS, reactions between rock and water become more probable and the TDS content of the water increases as a result of continued rock-water chemical reactions. Because of its residence time and flow path, spring water quality is typically reflective of the interactions of the major rock types of the source aquifer and water within it.

A third factor that is of particular interest is intergranular porosity (pores through which water passes between the individual rock matrix grains). Even though Florida's karst features suggest the existence of large, secondary cavernous pores spaces, most of the pores tend to be small (Upchurch, 1992). Fortunately, whenever the pore throats are very small, they act as filters for microbes, small organic substances, and clay minerals. In general, this results in very clean groundwater that is extremely desirable for both drinking water and recreational purposes. Unfortunately, some contaminants originating from our land use activities are not always removed and contaminate groundwater.

Indicators of Water Quality Problems

Spring water, when it is in the aquifer, is considered to be groundwater. However, once spring water exits from the spring vent onto the earth's surface, it is considered to be surface water. Because of this change, the question arises whether scientists and regulators should apply ground-water or surface-water quality standards to the water. Contaminant criteria thresholds may exist for an analyte while the water is considered groundwater, but not for surface water; or vice versa. Nitrate ($NO_3 + NO_2$ as N) is a good example. Based on drinking water criteria, nitrate has a groundwater threshold value of 10 mg/l (FDEP, 1994). However, no nitrate criteria exist for surface water. The FDEP Division of Water Resource Management is currently developing criteria for spring water. Until legal criteria are established, it should be understood that any reference to threshold values in the following text simply infers potential water-quality problems.

One of the more disturbing aspects about Florida's spring water quality has been the documented steady increase of nitrate over the past several decades (Jones et al., 1996; Champion and DeWitt, 2000; Means et al., 2003). Figure 8 displays the nitrate increase in 13 selected first-magnitude springs (Alexander, Chassahowitzka Main, Fanning, Ichetucknee Main, Jackson Blue, Madison Blue, Manatee, Rainbow Group composite, Silver Main, Silver Glen, Volusia Blue, Wakulla, and Wacissa #2 Springs) between the 1970s and the early 2000s.

Of the 125 spring vents sampled in 2001-2002, none had nitrate concentrations exceeding the 10 mg/l threshold for drinking water. The natural background nitrate concentrations in groundwater in Florida are less than 0.05 mg/l (Maddox et al., 1992). Of the spring vents sampled, 52 had nitrate concentrations exceeding 0.50 mg/l (42%) and 30 (24%) had concentrations greater than 1.00 mg/l. Thus, over 40% of the sampled springs have at least a ten-fold increase in nitrate concentrations above background and approximately one quarter of them have at least a 20-fold increase. The effect of the increased concentrations of nitrate in surface water is not fully understood. Increasing nitrate concentrations may adversely affect the aquatic ecosystem in springs and spring runs. Further research is still needed and is currently being sponsored by the Springs Initiative.

The FDEP is aware of the nitrate issues and has worked with other governmental agencies to develop a series of steps to reduce nitrate concentrations in our groundwater and springs in the middle Suwannee River Basin where many of Florida's springs are located (Copeland et al., 2000). The FDEP Bureau of Watershed Management and the Florida Department of Community Affairs are active in coordinating the development of springs protection measures. In addition, in September 2003, Governor Bush and the Florida Cabinet voted unanimously to strengthen protection for Florida's freshwater springs. Improvements to the Florida Springs Rule, currently being proposed by FDEP, are designed to increase protection for water quality, flow and habitats.

Another spring-water quality concern is the influence of saline water. Sixteen of the sampled springs are "salty." Of these 16 springs, 13 had concentrations of chloride (a saline indicator) exceeding the 250 mg/l threshold for drinking water. Springs with this type of water tend to be located along Florida's coast and along the St. Johns River. The ultimate source of the saline indicators is from naturally occurring saline water within the FAS (Klein, 1975). The saline water may cause water-quality changes in spring water as the result of natural circumstances such as drought and upwelling within the FAS. The changes may also be attributed to ground-water withdrawal.

Bacteria, such as enterococci and fecal coliform, represent a third concern regarding spring water quality. It is generally believed that these bacteria originate in fecal matter from warm blooded animals (Center for Disease Control, 2004). Fecal coliform concentrations in 23 springs (18%) exceed the drinking water threshold (FDEP, 1994) of four colonies per 100 ml. However, because it has been determined that these bacteria can complete their normal life-cycle outside of warm-blooded animals, especially in a warm environment as in parts of Florida (Fjuioka and Byappanahalli, 2004), the concentrations of fecal coliform may not necessarily represent a direct link to warm-blooded animal pathogens. Further research is needed before definitive conclusions can be made regarding the source of the fecal bacteria.

FDEP encourages the development of best management practices (BMPs). BMPs are land use strategies designed to reduce pollution to our environment. In an effort to reduce nitrate concentrations in spring water FDEP cooperates with over 20 government and private organizations to develop and implement BMPs for the middle Suwannee River Basin where many of Florida's springs are located. It is believed that the net result of the BMPs will ultimately result in a reduction of nitrate concentration in spring water in the region.

The Florida Springs Initiative addresses the nitrate and microbiological issues by providing funds for the monitoring of nitrate in springs and by sponsoring research on the microbiology of caves and spring water. The FDEP also works very closely with the water management districts in monitoring salt-water intrusion and in the establishment of minimum flows for our streams and minimum levels for our aquifers. Florida law (Chapter 373, *Florida Statutes*) requires Florida's water management districts to establish minimum flows and levels (MFLs) for water courses, water bodies, and aquifers. The goal of the minimum flows and levels program is "to establish minimum flows and levels in accordance with Chapter 373.042, *Florida Statutes*, to protect Florida's water resources from significant harm caused by water withdrawals or diversions." Minimum flows and levels are designed to assure adequate quantities of water for our streams and springs. This statute also provides authority to reserve water from permit allocation to protect fish and wildlife (Chapter 373.223(4) *Florida Statutes*). These water reservations provide the highest level of protection allowed by law and will aid in protecting historical spring flows.

Offshore Springs

Offshore or submarine springs are known to exist off Florida's Atlantic and Gulf of Mexico coastlines. These springs are most common in the offshore portion of the Florida Platform from Tampa north and west to the Ochlocknee River south-southwest of Tallahassee. Offshore springs have also been identified off the northern and southwestern parts of the peninsula and the western panhandle (Rosenau et al., 1977) (Figure 11). Water-quality data from some of these springs indicate that, at best, the water is brackish. Anecdotally, there are reports of "fresh water" flowing from offshore springs.

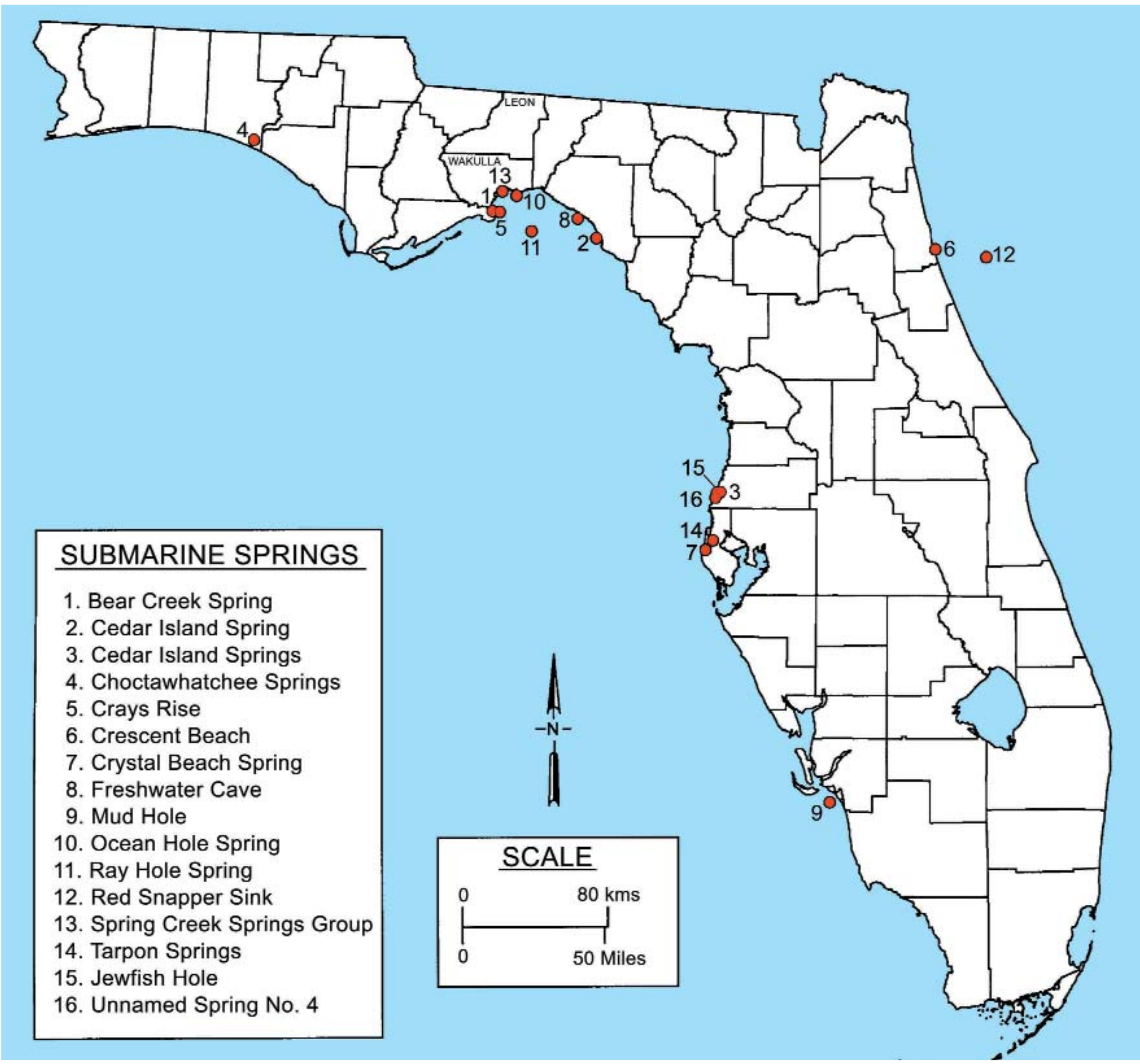

Figure 11. Offshore springs (from Rosenau et al., 1977).

The area offshore from Tampa to the Ochlocknee River has carbonate rocks of the FAS exposed on the sea bottom or slightly buried. At lower sea levels, particularly during the Pleistocene, this area was exposed and dissolution created numerous karst features. Many of these sinkholes are known to fisherman and divers (Figure 12). Some offshore karst features are springs but how many of the karst features discharge water is not known. However, to fully understand the water budget of the FAS, the determination of the flows is necessary. The FGS, along with SRWMD and SWFWMD, are investigating offshore springs to determine flow characteristics and water quality. Results of these investigations will be published in the near future.

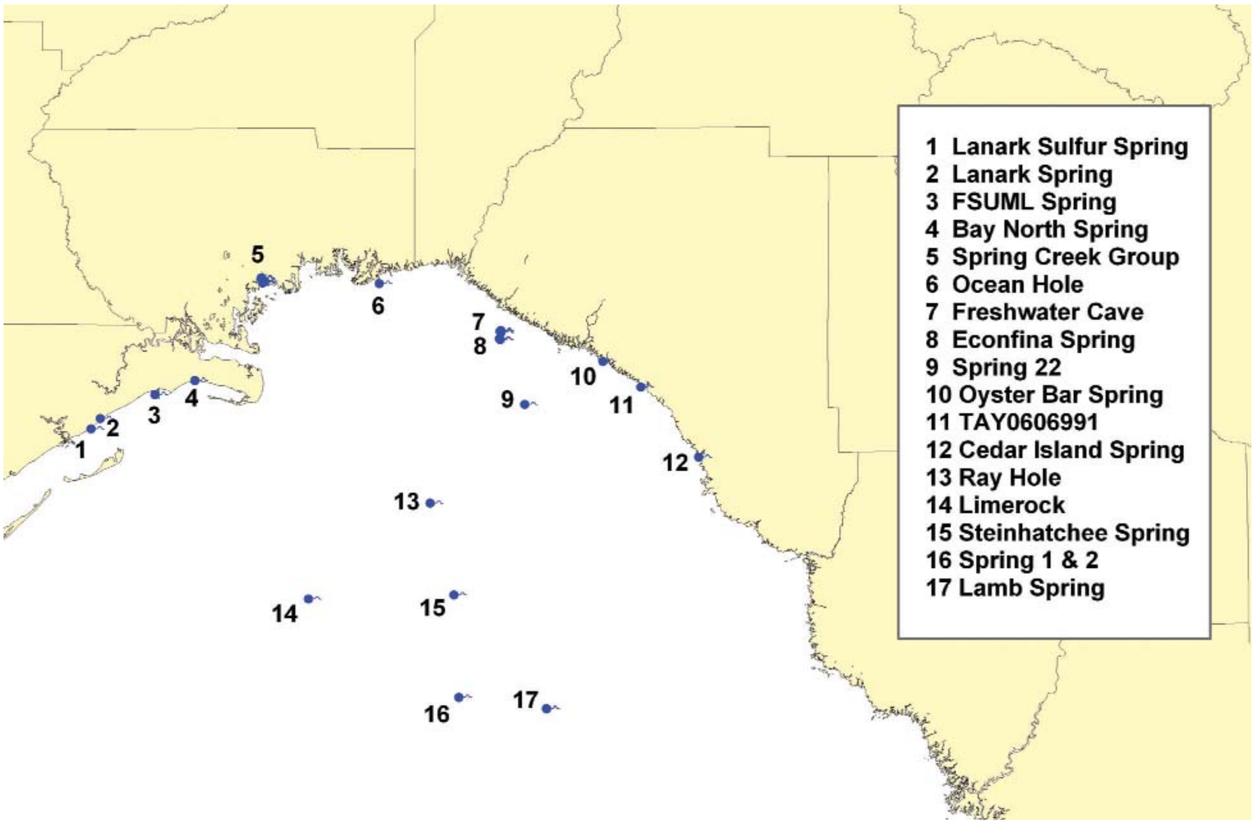

Figure 12. Known offshore springs in the Florida Big Bend Region.

WATER QUALITY

Methodology

One hundred eleven springs, two submarine springs, eight river rises, and four karst windows were sampled from September 2001 through August 2003 (Figure 13). Tidally influenced springs were sampled at low tide to minimize the influence of salt water on the water-quality samples. Standard FDEP sampling protocols were followed for each sampling event (Watershed Monitoring Data Management Section, Florida Department of Environmental Protection, 1991). Any mention of brand names does not imply an endorsement by the Florida Geological Survey or the Florida Department of Environmental Protection.