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DELINEATION OF SPRING PROTECTION AREAS AT FIVE, FIRST-MAGNITUDE SPRINGS IN NORTH-CENTRAL FLORIDA

Prepared For The

Suwannee River Water Management District
Live Oak, Florida

By

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Tampa, Florida

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Cover Photograph

Blue Spring, located on the Withlacoochee River in eastern Madison County, Florida during a flood.

SDII Global Corporation
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Signature Page

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INTRODUCTION

There is considerable concern about the quantity and quality of water discharging from Florida springs (Florida Springs Task Force, 2000). Concerns about water quality deal largely with trends of increasing nitrate concentrations through time. The quantities of water discharged from some Florida springs have also declined. As a result, the Suwannee River Water District (District) has determined to establish spring protection zones in order to assist in protecting water supplies and quality at key springs within the District. Initial efforts for spring protection have focused on five, first-magnitude springs within the District. These springs (Manatee, Fannin, Ichetucknee, Troy, and Madison Blue) are located within Florida state parks and represent important economic, ecological, and water resources to the citizens of the District and state. Because of their close proximity and uncertainties as to the location of the ground-watershed between the two springs, the springsheds of Manatee and Fannin springs are treated as one basin in this report.

Spring protection zones are sub-areas of the ground- and surface-water basins of each spring or spring system that supply water to the springs and within which human activities, such as waste disposal or water use, are most likely to have negative impacts on the water discharging from the spring. Spring protection zones are likely to require special water-management efforts because

- Aquifers are highly vulnerable to contamination,
- There are direct connections between the protection area and the spring as a result of cavern development,
- The protection area is in close proximity to the spring, or
- Water withdrawals are likely to have direct impacts of spring discharge.

When one or more of these or similar conditions exist and a protection zone has been developed, adverse conditions at the spring as a result of land use within the protection zone can be minimized through use of

- Land-use management and zoning by county or municipal government,
- Adoption of best management practices (BMPs),
- Development of an informed and environmentally sensitive public,
- Engineered waste management or water use solutions obtained through cooperative efforts, such as assistance grants and agency cooperative programs, and
- If necessary, regulatory action.

On March 11, 2004, the District retained SDII Global Corporation (SDII) to develop a strategy for developing protection zones for the ground- and surface-water basins (springsheds) of the five first-magnitude springs under contract number 03/04-058. In addition to methodology development, interim protection zones were to be delineated for these springsheds. Finally, this preliminary spring protection zone delineation will provide part of the proposed interim springshed management plans that are being developed by the District (Upchurch et al., 2001).

Florida Statutes (Chapter 373.042 F.S.) require that each water management district establish minimum flows and levels (MFLs) for first magnitude springs in order to protect them from adverse withdrawals that will cause “significant harm.” The District is in the process of developing MFLs for these five springs and, after analysis and establishment of the MFLs is complete, final protection zones will be adopted to assist in managing the MFLs.

This report is divided into three major sections:

- Rationale and Methods, which explains the bases for protection zone delineation;
- Spring Protection Zones, introduce the protection zones for each of the springsheds; and
- Protection Zone Implementation, which suggests ways to implement the protection zones.

RATIONALE AND METHODS

On-Going Monitoring

The District is currently intensively monitoring the five springsheds. The high-resolution monitoring (Upchurch et al., 2001) includes potentiometric surface determinations, as well as other hydrologic, water-quality, climate, and biological data. This data collection effort was intended by the District to be utilized for

- Characterizing the hydrology of the springsheds and hydrology and environmental quality of the springs,
- Development of spring protection zones, and
- Development of management plans for each springshed.

These efforts are well underway and sufficient data have been collected to develop the preliminary protection zones. The data consist of high-resolution data on aquifer potentials and ground-water quality as well as data on spring discharge and stage, spring water quality, and spring ecological conditions.

As part of this effort, the potentiometric-surface and nitrate-concentration data from all five springsheds have been subjected to geostatistical analysis and potentiometric surface maps at a 1-foot contour interval have been prepared (Upchurch and Champion, 2003b, 2003c, 2004a, 2004b). These maps and the data developed as part of the springshed delineation efforts form the bases for the preliminary springshed protection zone delineations presented in this report.

Previous Work on Spring Protection Zone Delineation

There have been at least two earlier attempts at springshed protection area delineation within the District. Both deal with the Ichetucknee Springs basin (North Central Florida Regional Planning Council, 1978; Upchurch and Champion, 2002). These North Central Florida Regional Planning Council (1978) report was prepared for the Columbia County Commission without benefit of the District's high-resolution monitoring program. The North Central Florida Regional Planning Council report utilized topography and flooding estimates combined with existing data on the hydrologic regime. The report by Upchurch and Champion (2002) was developed based on prior investigations of the karst of the Ichetucknee basin (Lawrence and Upchurch, 1976; Upchurch and Lawrence, 1984; Karst Environmental Services, 1997; Upchurch, 2002; and others).

Since these projects were completed, an analysis of water sources for the springs in the Ichetucknee spring complex has been completed (Upchurch and Champion, 2003a) and the first round of high-resolution monitoring has been completed for the five spring systems. Review of the existing, high-resolution water-quality and Floridan aquifer potentiometric data indicates that interim protection zone delineation is now possible in the five basins.

Models for Protection Zones

Preliminary review of the high-resolution potentiometric data for the five springsheds indicates that there are at least two different springshed types represented in the five spring systems. These suggest somewhat different protection strategies, as discussed below.

Scarp-Bounded Springshed Model - Figure 1 illustrates an hypothetical springshed located in proximity to a karst escarpment. This model is based on conditions in the Ichetucknee Springs basin. Of importance in this model are:

1. A ground-water basin that includes confined aquifer conditions under a northern highlands-like geomorphic province;
2. A karst escarpment (i.e., the Cody Scarp) with large sinkholes and focused recharge originating from rainfall within the scarp and from runoff from the adjacent highlands;
3. Sinking streams that may originate outside of the ground-water basin;
4. A "trace" or relict stream/cavern system associated with a well-developed cave system; and
5. A karst plain characterized by relatively small sinkholes and localized recharge.

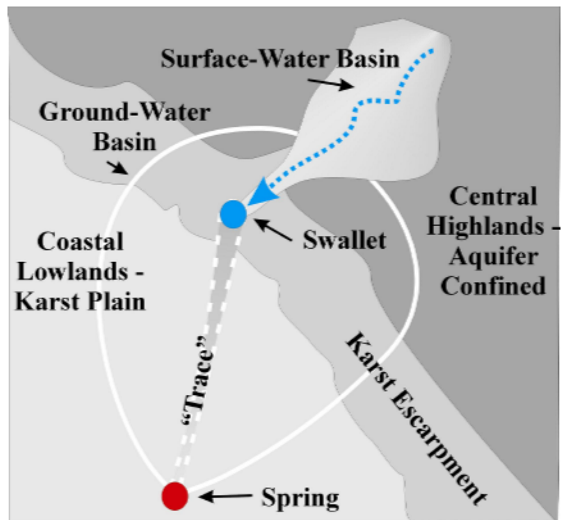

Figure 1 - Hypothetical springshed bounded by a karst escarpment.

Because of the differences in permeability and recharge amounts in this scenario, the potentiometric surface of the underlying aquifer responds to these features in terms of elevation and slope.

Given the combination of circumstances shown in Figure 1, the springshed can be logically subdivided into two ground-water protection areas and one surface-water protection area, as shown in Figure 2. These zones, tentatively designated the Spring Protection Area, the Springshed Protection Area, and the Surface Water Protection Area, represent the following threats to the ground water and discharge from the spring(s):

1. **Spring Protection Area** – The Spring Protection Area constitutes that part of the springshed characterized by close proximity to the spring and its cavern system (the caverns associated with the trace) where dilution and attenuation of pollutants

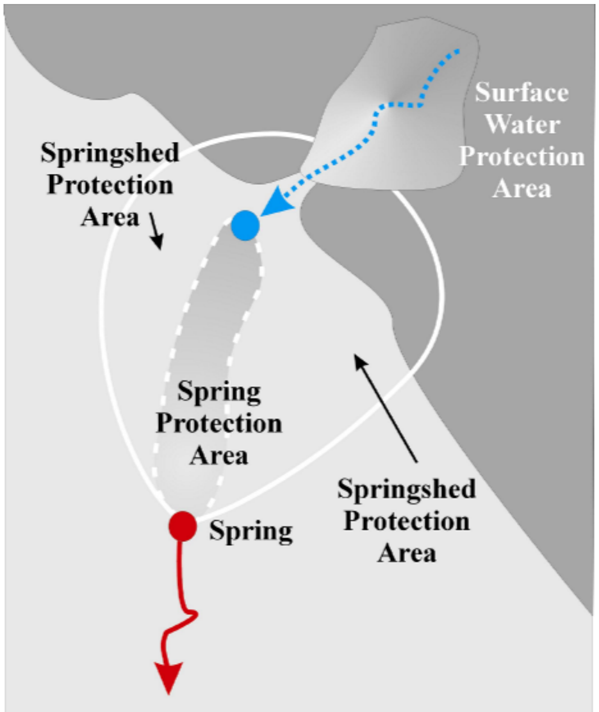

Figure 2 - Hypothetical spring protection zones in a scarp-bounded springshed.

is limited because of rapid transit times to the spring and a propensity for conduit flow. In addition, the surface-water component within the trace is included because of rapid recharge through swallets and potential for bypassing of interactions with soils that might otherwise remove or retard contaminants.

2. **Springshed Protection Area**– The Springshed Protection Area includes the remainder of the springshed where the aquifer system is either unconfined or semi-confined but that include longer transport times and distances so dilution and retardation of contaminants are probable.

3. **Surface Water Protection Area** – The Surface Water Protection Area includes surface watersheds that drain directly to swallets. These surface water drainage basins are included as Spring Protection Areas because of the possibility of contaminant spills and other releases that are likely to enter the cavern system that connects with the springs without benefit of sufficient dilution or retardation.

Unconstrained Springshed Models - Other springsheds are not obviously controlled by the presence of escarpments and highlands with confined aquifers and significant swallet systems. These springsheds appear to be relatively simple (Figure 3) and unconstrained by major changes in hydrogeologic conditions within the aquifer system. In this type of unconstrained springshed selection of protection areas is more difficult because of the absence of significant spatial changes in the hydraulics and potentiometric surfaces of the ground-water basin. The Madison Blue Springs springshed appears to be such a basin.

The same spring protection area classification (Spring Protection Area, Springshed Protection Area) is used in areas where unconstrained springsheds exist. Since the aquifer is not confined within the springshed, streams that drain to swallets are of minor importance and the Surface Water Protection Area is not likely to be utilized.

Figure 4 illustrates possible protection zones for this unconstrained, Madison Blue-type springshed. Here, the protection areas depend on knowledge of the ground-water flow system, travel times, and potential dilution and retardation estimates. This is the more difficult springshed to with respect to delineation of protection areas.

Criteria For Protection Area Identification

The criteria utilized for the delineation of protection areas in this report are discussed by springshed type. Critical data for delineation of the protection zones include

- Spatial topographic data, including locations and spatial characteristics of sinkholes and escarpments;
- High resolution potentiometric surface data and the location of the springshed ground-water basin;
- Knowledge of cavern system locations, such as cave maps and fracture trace maps;
- Spatial extents of surface water basins that drain into swallets within the springshed;
- Knowledge of the locations of swallets and, where possible, dye traces that connect the swallets with the spring system; and
- Spatial data indicating conditions of confinement of the aquifer.

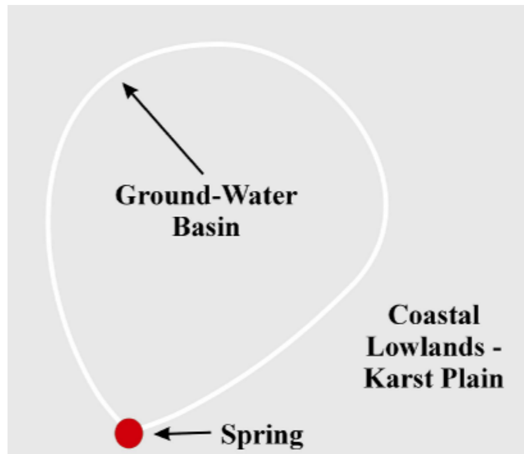

Figure 3 - Hypothetical unconstrained springshed.

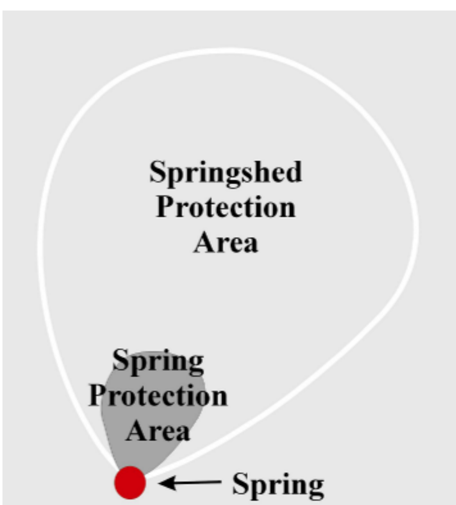

Figure 4 - Hypothetical spring protection areas in an unconstrained springshed.

Spring Protection Areas

Spring Protection area boundaries enclose the area that is most vulnerable to rapid movement of contamination to the spring and ground-water withdrawals from the spring or cavern system. The boundaries were drawn to include the following

- The spring or spring system if there are multiple vents,
- Known cavern systems and/or traces, and
- All areas predicted by the available ground-water flow model(s) to be within a distance over which water can flow to the spring within 20 years, or less.

Springshed Protection Areas

Springshed Protection Areas include all unconfined or semi-confined portions of the springshed that are not within the Spring Protection Areas. Therefore, the inner boundaries are the Springshed Protection Area boundaries and the other boundaries are the margins of the springshed (unconstrained model) or approximate location where the aquifer becomes more-or-less confined.

Practical Delineation of the Protection Areas

There is no attempt at this time to correlate the boundaries of the protection areas with political or natural boundaries that would allow for effective management. We recommend that the boundaries that are presented herein be redrawn to be inclusive of the natural boundaries but be described in terms of political or natural boundaries. For example, a 2-mile radius from a spring has meaning based on the estimated time required for water to flow to a spring but this line is a boundary that is not easily identified on the ground. A land description bounded by rivers, roads, or township and range designators will be more easily managed.

In many cases the locations of cavern systems are known to cave divers, but data are not available for public use. It is recommended that these data be obtained and the known locations of cavern system be outlined in the Spring Protection Areas in the same fashion as the Ichetucknee Trace and swallets were incorporated in this preliminary delineation exercise.

MFLs are being developed by the District for each of the springs. It is recommended that final protection area delineations be made in conjunction with the MFLs in order to utilize the delineations as part of the MFL management strategy, if appropriate.

SPRING PROTECTION AREAS

This section introduces the proposed spring protection areas for each of the five springsheds. They are discussed in order from north to south (Figure 5).

Madison Blue Spring

Figure 6 illustrates the preliminary, recommended protection area delineations for the Madison Blue springshed. MFLs for the spring are nearing finalization by the District, and the ground-water flow model for the Madison Blue Spring springshed has been refined for MFL development. The potentiometric surface up-gradient of the spring is relatively uniform in gradient. In the absence of significant potentiometric slope changes that indicate changes in permeability and/or recharge rates, the flow model and cavern system were utilized to identify the Spring Protection Area.

Madison Blue Spring has a well-developed cavern system with preferential flow to the spring through this feature. The model does not explicitly include the cavern system, so overall time of travel to the spring as calculated using the model was combined with the known and suspected extent of the cavern system. To include the cavern system, the extent of the Spring Protection Area was set at a 2-mile radius from the spring. The model indicates that travel times up to 20 years are included in this radius, although travel times through the cavern system will be a matter of days, not years. As the cavern system mapping progresses, the Spring Protection Area should be extended accordingly.

The Springshed Protection Area includes all of the mapped springshed outside of the Spring Protection Area. The head of the springshed to the north and northwest is within the Northern Highlands Physiographic Province where the Floridan aquifer is confined. These areas are not depicted in the figure, but portions of this area within Florida should be excluded from the Springshed Protection Area.

Troy Spring

Figure 7 illustrates the recommended protection areas for the Troy Spring springshed. The Troy Spring springshed has many characteristics of the scarp-bounded springshed. As shown in the figure, there is a significant slope break in the Floridan aquifer potentiometric surface 2 to 4 miles from the spring. Here, the potentiometric surface flattens and sinkhole development is pronounced, which indicate that there is an increase in recharge rates and permeability. These result in increased ground-water velocities and enhanced aquifer vulnerability. The Spring Protection Area was drawn to include this portion of the aquifer.

The Springshed protection area extends from the Spring Protection Area to the head of the Cody Scarp, which is northern-most extent of large karst features as shown on Figure 7.

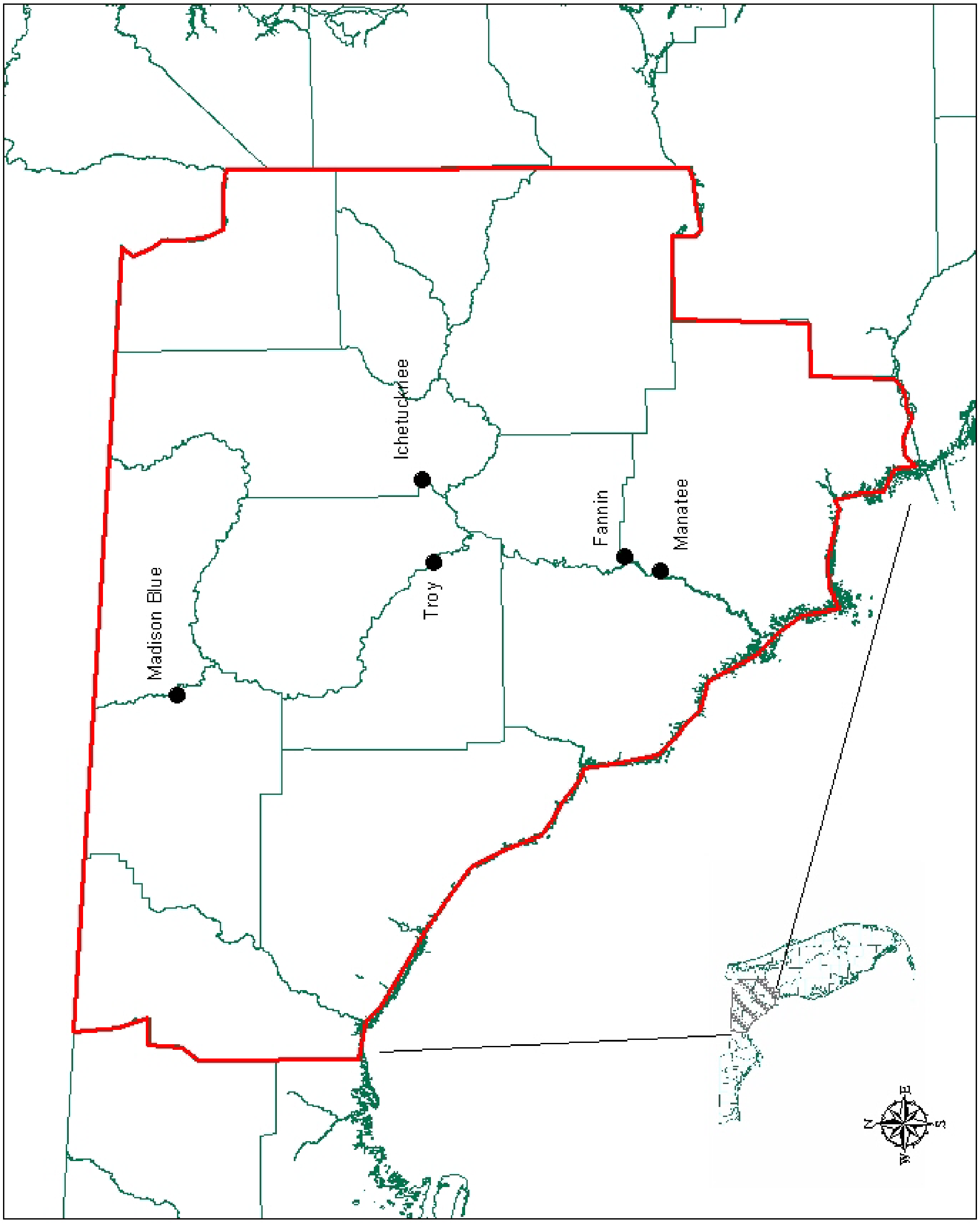

Figure 5. Location of first-magnitude springs in the Suwannee River Water Management District.

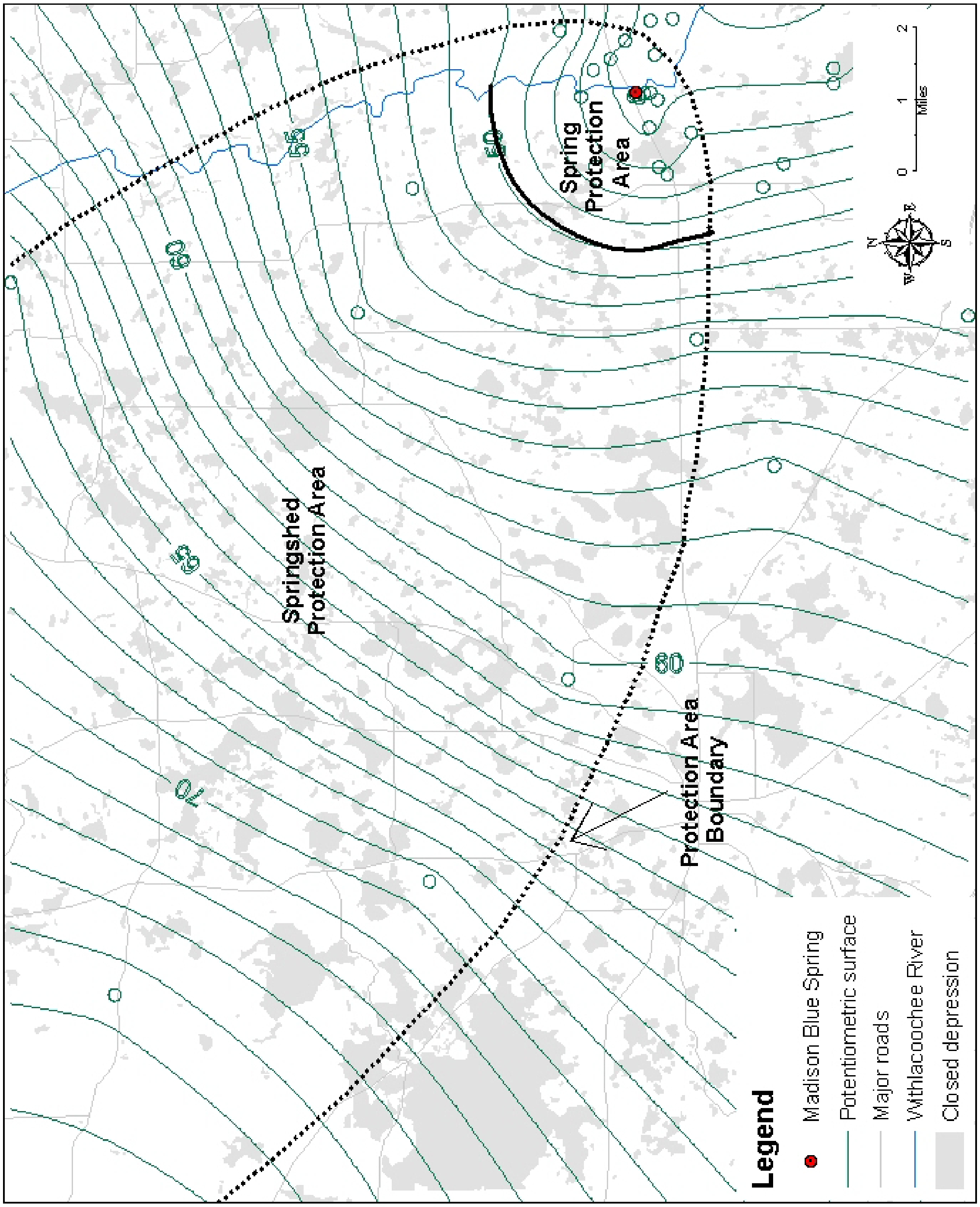

Figure 6. Spring protection area in the Madison Blue Spring springshed.

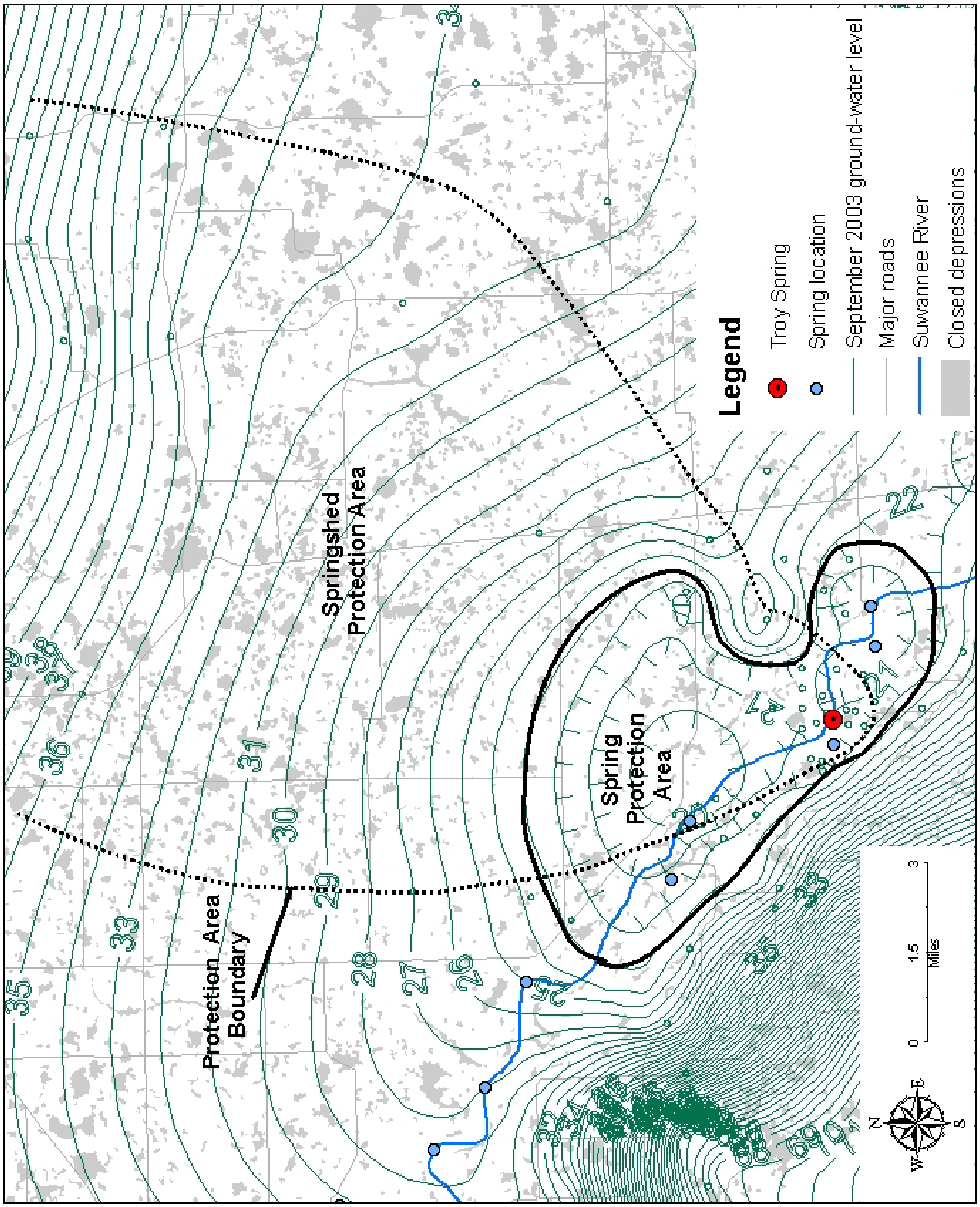

Figure 7. Spring protection area in the Troy Spring springshed.

Ichetucknee Springs

Figure 8 depicts the recommended protection areas for the Ichetucknee Springs springshed. This is the best-known system and more detail can be added to the protection area delineations. The Ichetucknee Springs springshed is also the only basin with mapped surface water protection areas.

The Spring Protection Area was drawn to include the area immediately around the springs and the Ichetucknee Trace. The area near the springs includes a portion of the potentiometric surface where slope increases as flow converges on the springs. This roughly corresponds with the 20-year flow paths utilized in other springsheds. Dye tests in Rose Sink and ground-water quality studies clearly connect karst features in the Ichetucknee Trace with discharge at the springs. The dye trace data (Karst Environmental Services, 1997) show that travel times are rapid (up to a mile per day) within the cavern system that connects the swallets to the springs. Therefore, the trace and a one-half mile buffer on each side are included in the Spring Protection Area. The Spring Protection Area extends to Cannon Sink and includes Clay Hole sink, Rose Creek Sink and Swallet, and other areas.

The Springshed Protection Area includes that portion of the springshed characterized by low potentiometric surface gradients and well-developed karst features (sinkholes, etc.). It extends to the top of the Cody Scarp and includes the steepened potentiometric surface gradient and large sinkholes within the Cody Scarp.

Surface Water Protection Areas include the drainage basins of the three major streams that discharge to swallets in the Trace. These basins (Cannon Creek, Clay Hole Creek, and Rose Creek) discharge storm water directly to the cavern system under the Trace, so protective measures should be taken to avoid discharge of deleterious constituents to the swallets.

Manatee and Fannin Springs

Figure 9 illustrates the proposed spring protection areas for the Manatee and Fannin springsheds. Because the two springsheds abut each other and the ground-water divide between the two springsheds is not distinctive, they have been combined. The two springsheds correspond with the scarp-bounded springshed model.

The Spring Protection Area includes an area with a two-mile radius from each spring. The two-mile radius was chosen on the basis of the District's ground-water flow model has recently been developed for the Lower Suwannee Basin by the U.S. Geological Survey (the model and report had not been released to the public by the Survey at the time of preparation of this report). The model was run under steady state conditions and travel times estimated for ground water near the springs. Based on the model, water takes 20 years or less to flow to the spring from 2 miles away. This travel time does not account for flow through the cavern systems that serve each spring, so we feel that this distance is protective of the spring and yet not restrictive of land uses in general. This travel time coincides with areas where the Floridan aquifer potentiometric surface flattens, indicating rapid flow times and enhanced aquifer vulnerability.

The cavern system under Fannin has not been explored. The cavern system under Manatee is being actively explored at the present time. The mapped and projected extent of the cavern system under Manatee Spring appears to extend outside of the 2-mile radius. Any areas outside of the 2-mile radius that are underlain by mapped caverns should be included in the Spring Protection Area. It is recommended that the width of the protection zone over the cavern system be at least one half mile on each side of the "roof print" of the cavern.

The Springshed Protection Area includes the relatively low gradient portions of the Floridan aquifer potentiometric surface and the steepened gradient areas on the flank of the potentiometric high under the Waccassa Flats. These areas are vulnerable to contamination because of high recharge rates, and ground-water withdrawals are likely to affect discharge from the springs.

The western margin of the Waccassa Flats appears to function much as the Cody Scarp hydrologically. While no major surface-water streams that discharge to swallets have been identified, an investigation for such areas is warranted and surface-water protections areas may be necessary.

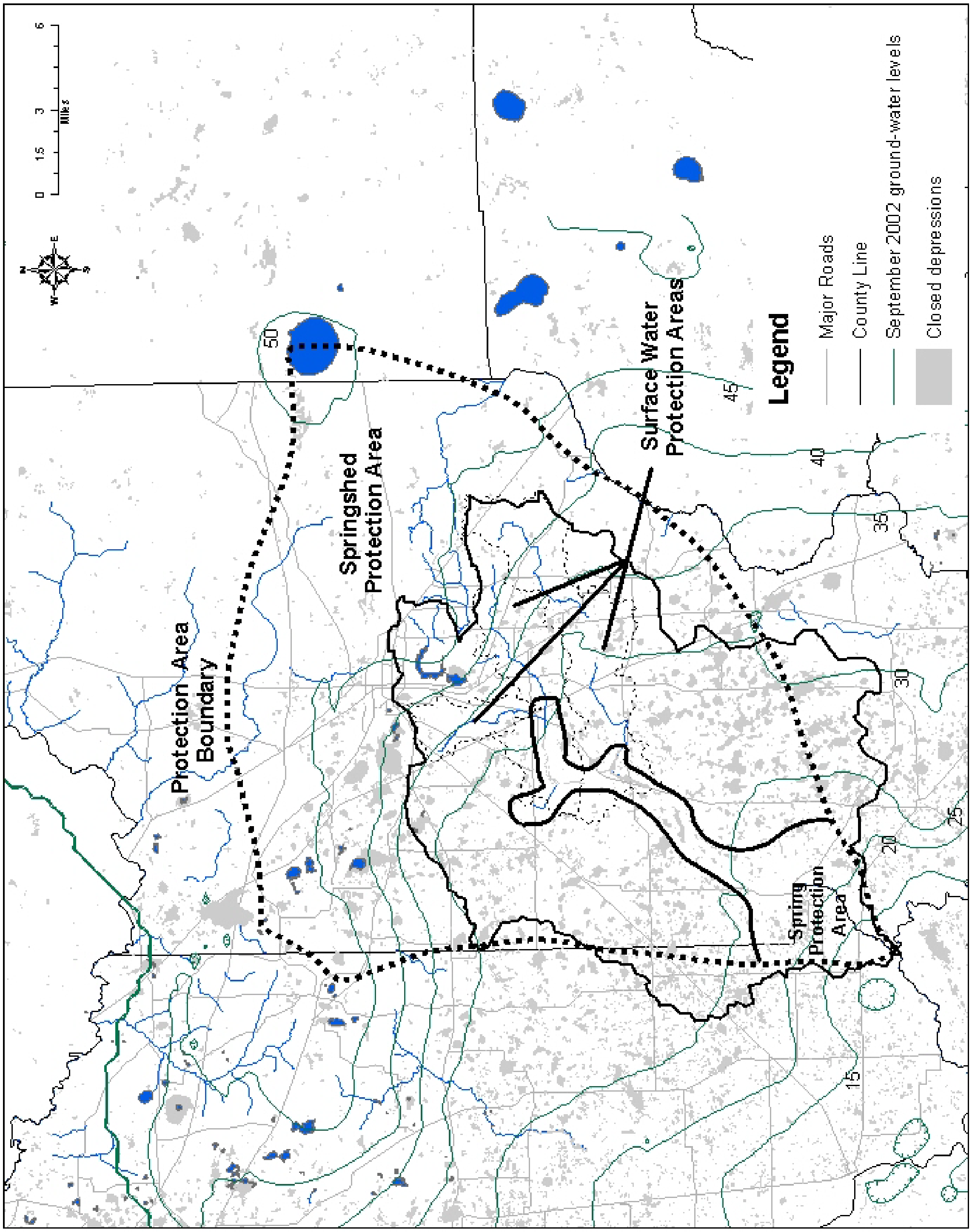

Figure 8. Spring protection areas in the Ichetucknee Springs springshed.

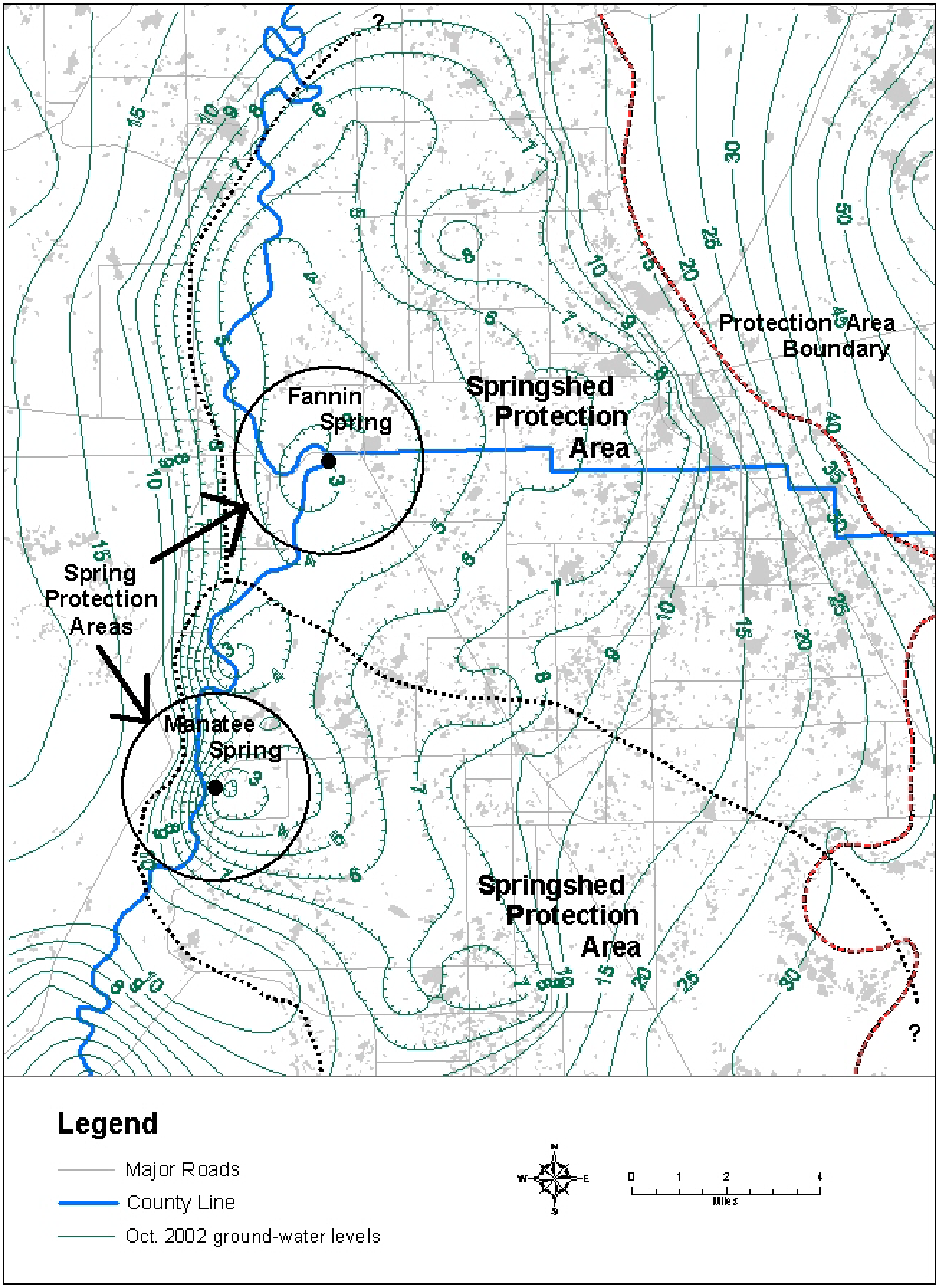

Figure 9. Spring protection areas in the Manatee-Fannin springsheds.

PROTECTION AREA IMPLEMENTATION

Implementation of spring protection areas is complex and largely unexplored as a water-management strategy. It will require an educated constituency and active cooperation between regulatory agencies, local government, industry, and residents of the springshed.

Three levels of management based on aquifer vulnerability and relative impact of ground-water withdrawals are suggested in this report. The most stringent is within the Spring Protection Areas, where we suggest either (1) that land uses that are most likely to affect spring water quality or quantity be avoided or, for existing uses, (2) that use of protective measures and a high level of monitoring be implemented. Within the Springshed Protection Areas, less stringent measures are suggested, but they remain protective. Suggested management measures in the Surface Water Protection Areas are similarly protective.

Development of MFLs for the five springs will assist in management of the protection areas, especially with respect to consumptive use of water. The protection areas should be refined during the MFL-development process and their extents modified as better data are obtained. Ultimately, the protection areas can be incorporated into the MFL process.

Table 1 summarizes the consequences of activities that may exist in a springshed and provides sample suggestions for management based on current understanding of the ground-water "plumbing" systems of springsheds and potentials for adverse impacts on springs as a result of contamination or water withdrawals.

The land uses, possible consequences, and management strategies within each protection zone listed in Table 1 are not intended to be exhaustive or representative of the specific effects of any land use. The management strategies are intended to represent scenarios that illustrate some of the management options that might be adopted. The examples are intended to reflect the relative rigor required to protect springs and some possible management strategies.

Table 1 - Consequences and management strategies for spring protection.

Land-Use Activity	Potential Adverse Outcomes of Land Use on Spring	Protection Area Strategies		
		Spring Protection Areas	Springshed Protection Areas	Surface-Water Protection Areas
Crop production	Increased nutrient loads	• Best management practices	• Best management practices	• Best management practices
Animal and animal product production	Increased nutrient loads	• Zone to avoid this use • Advanced waste management and spill protection	• Best management practices	• Best management practices
Landfill	Increased contaminant loads	• Zone to avoid this use • Remove existing unlicensed landfills • Closely monitor shallow and deep ground-water at permitted facilities, install leachate collection facilities if necessary	• Best management practices	• Best management practices
Land-spreading sewage treatment facilities	Increased nutrient loads	• Zone to avoid this use • Plug any conduits or sinkholes that lead to the Floridan aquifer and are within land application area • Advanced waste-water treatment to minimize potential contaminants	• Plug any conduits or sinkholes that lead to the Floridan aquifer and are within land application area • Advanced waste-water treatment to minimize potential contaminants	• Minimize direct discharge to area streams
Drainage wells	Increased metals and nutrient loads	• Remove all existing drainage wells • Dispose of runoff through percolation ponds that are hydraulically isolated from aquifer • In urban areas utilize lift stations to move storm water out of karst-dominated areas • Zone to avoid this use	• Dispose of runoff through percolation ponds that are hydraulically isolated from aquifer with peak-flow capture in wells, if necessary	• Not applicable
Storm-water percolation ponds	Increased metals and nutrient loads	• Dispose of runoff through percolation ponds that are hydraulically isolated from aquifer • Plug all sinkholes and other penetrations that direct storm water to aquifer	• Dispose of runoff through percolation ponds that are hydraulically isolated from aquifer • Plug all sinkholes and other penetrations that direct storm water to aquifer	• Dispose of runoff through percolation ponds that are hydraulically isolated from aquifer • Plug all sinkholes and other penetrations that direct storm water to aquifer
Septic tanks	Increased metals and nutrient loads	• Connect to regional sewerage in urban areas • Limit septic tank	• Connect to regional sewerage in urban areas • Limit septic tank	• Develop best management practices for tank cleaning and drain

		Protection Area Strategies		
Land-Use Activity	**Potential Adverse Outcomes of Land Use on Spring**	**Spring Protection Areas**	**Springshed Protection Areas**	**Surface-Water Protection Areas**
		density to 1 tank (residence) per acre in rural areas • Develop best management practices for tank cleaning and drain field maintenance	density to 1 tank (residence) per acre in rural areas • Develop best management practices for tank cleaning and drain field maintenance	field maintenance
Domestic water wells	Potential minor losses of discharge	• Encourage public supply where housing densities are appropriate • Encourage best management and water conservation practices	• Encourage public supply where housing densities are appropriate • Encourage best management and water conservation practices	• Encourage public supply where housing densities are appropriate • Encourage best management and water conservation practices
Municipal and industrial withdrawals	Potential large losses of discharge	• Do not permit • For existing uses, encourage alternative water supplies or transfer of wellfields to Springshed Protection Areas • Require best management and water conservation practices • Limit production during water shortages	• Encourage best management and water conservation practices • Utilize permitting process to manage effects of pumpage and enforce water shortage rules	• Encourage best management and water conservation practices • Utilize permitting process to manage effects of withdrawals and enforce water shortage rules
Bottled water use	Potential large losses of discharge	• Do not permit • For existing uses, encourage alternative water supplies or transfer of wellfields to Springshed Protection Areas • Require best management and water conservation practices • Limit production during water shortages	• Encourage best management and water conservation practices • Utilize permitting process to manage effects of pumpage and enforce water shortage rules	• Encourage best management and water conservation practices • Utilize permitting process to manage effects of withdrawals and enforce water shortage rules
Fuel handling facilities (including gas stations)	Potential contamination	• Do not permit • For existing facilities, require containment facilities, above-ground storage, and routine monitoring • Work with FDEP to ensure that monitoring is adequate	• Require containment facilities, above-ground storage, and routine monitoring	• Prevent offsite movement of storm water
Industry with chemical storage or permitted releases	Potential contamination	• Do not permit • For existing facilities, require containment facilities, above-ground storage, and routine monitoring	• Require containment facilities, above-ground storage, and routine monitoring, as appropriate	• Require containment facilities, above-ground storage, and routine monitoring, as appropriate

		Protection Area Strategies		
Land-Use Activity	**Potential Adverse Outcomes of Land Use on Spring**	**Spring Protection Areas**	**Springshed Protection Areas**	**Surface-Water Protection Areas**
		• Work with FDEP to ensure that monitoring is adequate		• Work with FDEP to ensure that discharge permits and monitoring are adequate
Mining (quarries, borrow pits)	Recharge of contaminated water, dewatering and loss of spring discharge	• Do not permit mining activities • For existing mines, utilize enhanced monitoring • Implement best water management practices	• Require appropriate monitoring • Implement best water management practices	• Require appropriate monitoring • Implement best water management practices

REFERENCES CITED

Florida Springs Task Force, 2000. Florida's Springs: Strategies for Protection & Restoration. Report prepared for the Florida Department of Environmental Protection, Tallahassee, FL. 58 p.

Karst Environmental Services, 1997. Ichetucknee Springs Water Quality Working Group Cooperative Dye Trace: Rose Creek Swallet-Ichetucknee Springs Group. Unpublished manuscript produced for the Ichetucknee Springs Working Group and the Suwannee River Water Management District.

Lawrence, F.W., and S.B. Upchurch, 1976. Identification of geochemical patterns in ground water by numerical analysis. In E.A. Zaleem (ed.), Advances in Groundwater Hydrology, America Water Resources Association, p. 199-214.

North Central Florida Regional Planning Council, 1978. Assessment of Development Potential – Ichetucknee River Headwaters Area. Study prepared for the Columbia County Board of County Commissioners for use in the County Comprehensive Plan, Appendix A.

Upchurch, S.B., 2002. Hydrogeochemistry of a karst escarpment. In J.B. Martin, C.M. Wicks, and I.D. Sasowsky (eds.), Hydrogeology and Biology of Post-Paleozoic Carbonate Aquifers. Charles Town, WV, Karst Waters Institute, Special Publication 7, pp. 73-75.

Upchurch, S.B., and K.M. Champion, 2002. Development Potential of the Ichetucknee Springshed, Florida. Tallahassee, Florida Department of Environmental Protection, Division of State Lands.

Upchurch, S.B., and K.M. Champion, 2003a. Delineation of Spring-Water Source Areas in the Ichetucknee Springshed. Tallahassee, Florida Department of Environmental Protection, Division of State Lands.

Upchurch, S.B., and K.M. Champion, 2003b. Geostatistical Analysis of Water-Level and Water-Quality Data for the Manatee-Fannin Springshed. Live Oak, Florida, Suwannee River Water Management District.

Upchurch, S.B., and K.M. Champion, 2003c. Geostatistical Analysis of Water-Level and Water-Quality Data for the Ichetucknee Springshed. Live Oak, Florida, Suwannee River Water Management District.

Upchurch, S.B., and K.M. Champion, 2004a. Geostatistical Analysis of Water-Level and Water-Quality Data for the Troy Springs Springshed. Live Oak, Florida, Suwannee River Water Management District.

Upchurch, S.B., and K.M. Champion, 2004b. Geostatistical Analysis of Water-Level and Water-Quality Data for the Madison Blue Spring Springshed. Live Oak, Florida, Suwannee River Water Management District.

Upchurch, S.B., and F.W. Lawrence, 1984. Impact of ground-water chemistry on sinkhole development along a retreating scarp. In B.F. Beck (ed.), Sinkholes: Their Geology, Engineering & Environmental Impact. Rotterdam, A.A. Balkema, pp. 23-28.

Upchurch, S.B., D. Hornsby, R. Ceryak, and W. Zwanka, 2001. A Strategy for the Characterization of First Magnitude Springs. Live Oak, Florida, Suwannee River Water Management District, WR01/02-01, 86 p.