A Strategy for the Characterization of First Magnitude Springs

December 2001

Department of Water Resources
Suwannee River Water Management District
9225 County Road 49
Live Oak, Florida 32060
(386) 362-1001
FL Toll Free (800) 226-1066
www.srwmd.state.fl.us

WR 02-01

Prepared by:
Sam B. Upchurch, Ph.D., P.G.
SDII Global Corporation

David Hornsby
Ron Ceryak
Warren Zwanka
Suwannee River Water Management District

Introduction

The Suwannee River Water Management District (District) has contracted with SDII Global Corporation (SDII) to prepare a plan for characterization of first-order spring basins and development of management plans for these spring drainage basins. This "District Springs Initiative" (DSI) is intended to assist the District in (1) developing a basin management plan for each spring basin, (2) reducing existing or potential contamination of water discharging from the spring, and (3) maintain/protect some portion of the historic discharge of these springs. The format of this plan for developing the information necessary for preparation of Basin Management Plans is an "expanded outline".

The five first magnitude springs that will be characterized by the District are:

- Blue Springs (Madison County),
- Ichetucknee Springs (Columbia, Suwannee counties),
- Troy Spring (Lafayette County),
- Fannin Springs (Levy County), and
- Manatee Springs (Levy County).

The District has completed preliminary spring drainage basin delineations of these springs. Because the basins of Fannin and Manatee springs cannot be easily distinguished, their basins will be considered as one for characterization purposes. Therefore, there are four spring basin study areas (study area) to be characterized.

The District has developed a conceptual plan (Figure 1) that begins with a two-year, Phase I study. This phase includes installation of monitoring facilities, initiation of monitoring, and sufficient data analysis and research to result in a preliminary Spring Basin Management Plan for each spring. Phase II, which is planned to last three years, includes continued monitoring and data analysis, a more intensive research effort, and development of a final management plan for each spring basin.

Primary short-term goals of Phase I of the DSI are to

- Delineate a draft ground-water drainage basin for each spring and, more specifically, determine the areas within each basin that are most vulnerable in terms of recharge and contamination of ground water traveling to the springs,
- Develop a monitoring plan that will allow for determination of the hydraulic and water-quality characteristics of each spring and its basin, and

- Develop an Interim Basin Management Plan that will allow the District and other interested parties to coordinate and enhance efforts to reduce contamination in the springs.

The longer-term goals of the Phase II effort are to

- Develop a final Basin Management Plan to coordinate and enhance efforts to reduce contamination in the springs,

- Optimize long-term monitoring so that the results of implementation of the measures adopted in the Basin Management Plan can be documented and defended, and

- Characterize the hydraulic and chemical behaviors of each spring basin to the extent that there is an understanding of the consequences of activities, such as water use, within each spring basin on the spring systems.

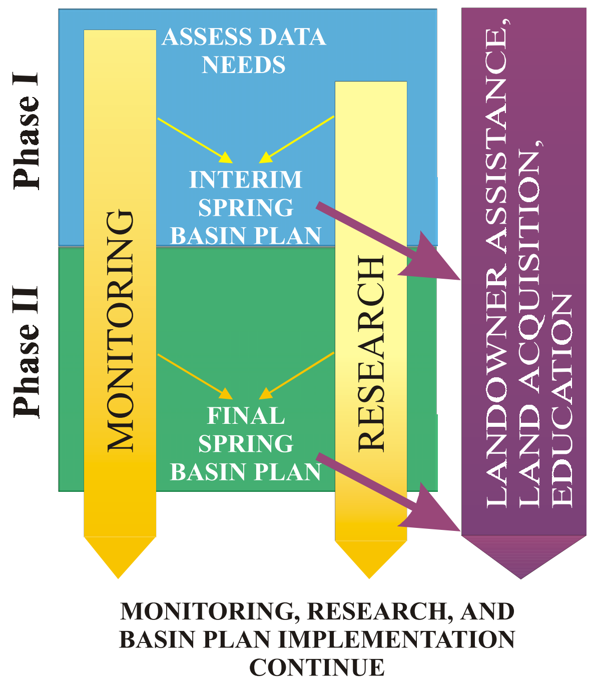


Figure 1 - Phased approach for spring basin plan development.

As shown in Figure 1, the initial step of the District's phased approach is to assess data needs. This activity is essentially complete and is not included in this plan. In order to obtain the necessary data, monitoring begins prior to development of "research" activities. The term "research", as used by the District, refers to interpretation and analysis of monitoring and other data to achieve the goals of the DSI, including synthesis of the data to develop the management plans. At the end of two years (Phase I) the monitoring and research efforts will be combined to develop an Interim Spring Basin Plan. This plan will be used to guide

- Land owner assistance projects,

- Land acquisition programs,

- Regulatory programs, and

- Education programs

which will enhance public and private efforts to protect the springs and restore spring water quality. All activities continue through Phase II (Figure 1) and until the final

Spring Basin Plans are developed and implemented. Presumably, monitoring and research will continue after completion of Phase II and development of the Spring Basin Plans.

Plan Design

This report constitutes the expanded outline of the monitoring and research plan. The plan is designed to be generic and deals with characterization of a single spring basin. In other words, the plan should be separately implemented for each of the four study areas.

The plan is divided into eight "Task Groups". Each Task Group includes multiple tasks that have a common purpose or deliverable. For ease of implementation of the plans, deliverables are assumed to be due six weeks after completion of the task. Deliverables are not included in the draft Gantt diagrams showing timing of the tasks (Figures 2 - 10). This expanded outline includes a section describing each task, its timing, and, where relevant, some literature citations.

Each Task Group and task is discussed separately. The tasks that are essential to the primary goals of the project and that are either dependent upon earlier tasks or critical to the accomplishment of later tasks are defined as "critical path tasks". Critical path tasks are indicated by the symbol © in the upper right hand corner of the task description.

The relationships of Task Groups are indicated on Figure 2. Task Groups 1, 2, and 4 have short-term and long-term components. The short-term components include

- Preliminary investigation of the properties of the basin, and
- Installation of monitoring facilities.

The long-term components consist of continued monitoring over the five-year length of the project. All other Task Groups are more-or-less sequential where there is a critical path issue; otherwise, they are concurrent.

Where appropriate, references are presented to accompany each task. References cited in the text are included along with other, potentially useful references.

Plan Timing

The plan is set up so that the starting times for each study area investigation can be concurrent or staggered, however, it should be clear that the timeframes are general and subject to change. If they are concurrent, the tasks can probably be accomplished for the four study areas more-or-less synchronously. There is "flex time" allotted to most tasks. If the four investigations are implemented sequentially, the preliminary projects can be completed within the allotted two years for Phase I. The only loss will be in the length of the long-term monitoring record for the investigations that are began last.

The plan is set up to load as much of the fundamental monitoring and research into Phase I as possible on the chance that funding may be limited in Phase II. There is a limit to available resources, however, so non-critical path activities may be postponed. Implementation depends on funding and staff availability. .

Data Management and Reporting

The individual task descriptions include a section called "Deliverables". This section deals with data management and dissemination. It is proposed that much of the data obtained as part of plan implementation be managed through use of a geographic information system (GIS). All point source data, areal coverages, and time-series data can be made available through this data-management platform for use by the District, outside researchers and managers, and the public. The finalized data can also be made available on the internet through the GIS platform. It is recommended that data be made available for use on the internet only after it has been thoroughly qualified and reviewed. State GIS standards for locations must be used wherever possible. All data must be thoroughly reviewed for accuracy and qualified as to appropriate uses.

Throughout this plan it is suggested that data and investigation results be made available as "open-file reports". The USGS and Florida Geological Survey have publication series that utilize this name. These publications are prepared to expedite release to the public. It is recommended that the District utilize a similar format to report on the results of the tasks in this plan. All data and results should be checked for quality control and/or marked "draft".

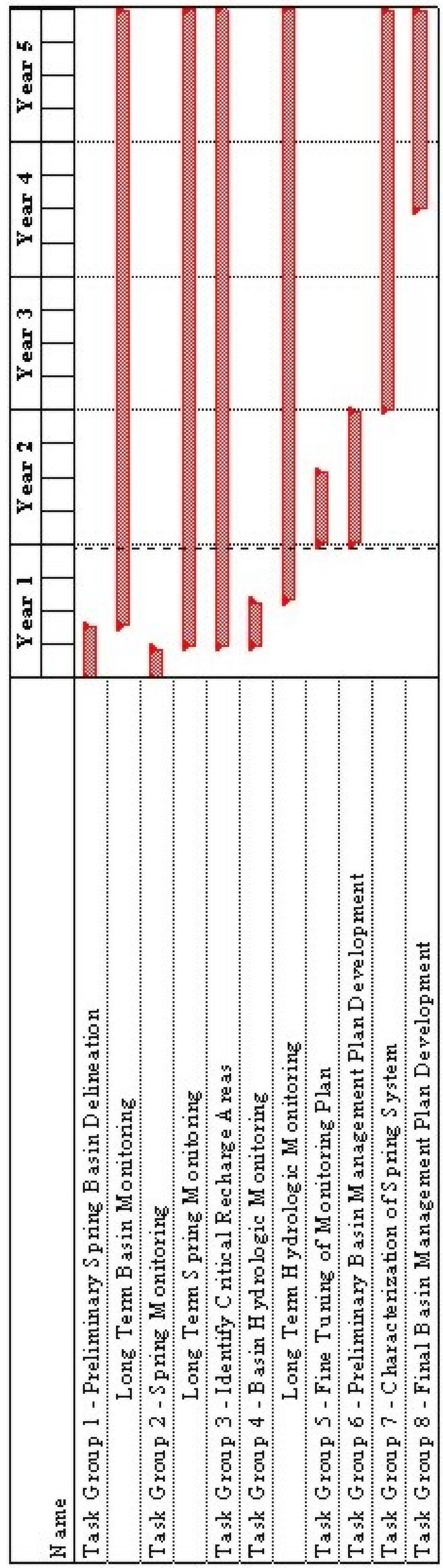
Map Resolution

The topographic maps used for this study are digitized from 1:24,000 USGS quadrangle maps. These maps are typically accurate to approximately 100 feet. Accuracies of spatial coverages (i.e., land use) should conform to State GIS accuracy standards. Contoured data, such as aquifer potentials and water-quality maps, should strive for accuracies that are as high as possible. It is recommended that geostatisical analysis be used to demonstrate uncertainties in these maps. Where it is not possible to perform geostatistical analysis, such as spring basin and water-quality domain delineations, indicators on the maps should convey uncertainty, such as through use of dashed lines and/or color shading without line boundaries.

Consensus Building and Cooperative Efforts

The success of the District's Spring Basin Management Plans will ultimately depend upon the support of the Florida Legislature, state and local governments, industry, and the public. It is critical, therefore, that the District begin consensus building to support the approaches implemented in this spring characterization plan and the conclusions of the Basin Management Plans. The landowner assistance programs, land acquisition initiatives, and best management practices implemented to protect the springs are wholly dependent on support from outside of the District. Therefore, this spring characterization plan includes tasks dedicated to identification of stakeholders, consensus building, information transfer to interested parties, and public participation.

Figure 2
SUGGESTED SCHEDULE FOR ALL TASK GROUPS
Suwannee River Water Management District

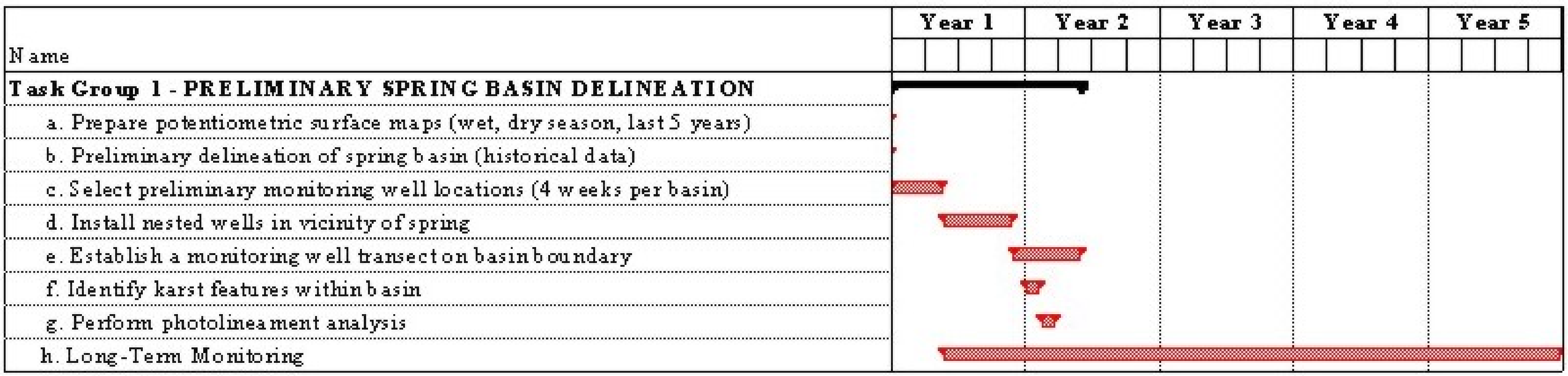


Note: Modifications of the schedule may occur depending on the availability of staff and funds

Task Group 1 - Preliminary Spring Basin Delineation

The first Task Group is intended to assist in delineation of the spring basins. Once the basins are characterized, monitoring can be optimized. Figure 3 illustrates the proposed temporal relationships and durations of the seven tasks within this Task Group.

Figure 3
SUGGESTED SCHEDULE FOR TASK GROUP 1
Suwannee River Water Management District



Note: Modifications of the schedule may occur depending on the availability of staff and funds

Task 1a - Prepare potentiometric surface maps of the Floridan aquifer ©

Purpose - Maps illustrating the wet- and dry-season potentiometric surfaces of the Floridan aquifer for the last five years of measurement should be utilized to determine the approximate boundaries of each drainage basin. As noted on Figure 3, it is assumed that this task has been completed through the cooperative program with the U.S. Geological Survey. Therefore, no additional time is allocated to this task.

Method - Sufficient data density does not exist to allow precise potentiometric surface contouring. The 10-foot contour interval presently being published by the U.S. Geological Survey (Meadows, 1991; Mahon et al., 1997) is marginally sufficient, but contouring at 5-foot intervals, or less, is optimal. No time is allowed for further action on this task (Figure 3). Existing maps are to be utilized and the task is complete at the time of preparation of this plan.

Discussion - Care should be taken that the surfaces are accurate. The existing contour maps are hand contoured and there is considerable interpretation of the data.

Deliverables - Preliminary basin delineations have been completed by the District and are available.

References

Bonacci, O., and A. Magdalenic, 1993. The catchment area of the Sv. Ivan karst spring in Istria (Croatia). Ground Water, 31:767-773.

Meadows, P.E., 1991. Potentiometric Surface of the Upper Floridan Aquifer in the Suwannee River Water Management District, Florida, May 1990. U.S. Geological Survey, Open-File Report 90-582.

Mahon, G.L., A.E. Choquette, and A.A. Sepulvida, 1997. Potentiometric Surface of the Upper Floridan Aquifer in the Suwannee River Water Management District, Florida, May and June 1995. U.S. Geological Survey, Open-File Report 96-617.

Task 1b - Preliminary Delineation of Spring Basins from Historical Data ©

Purpose - Maps illustrating the wet- and dry-season potentiometric surfaces of the Floridan aquifer for the last five years of measurement should be utilized to determine the approximate boundaries of each drainage basin.

Method - The preliminary basin delineation should utilize the existing maps with 10-foot contour intervals. Sufficient data density does not exist to allow for more precise basin delineation. Basins should be delineated by constructing orthogonals to the isopotential lines. If the spring discharges to a regional stream, such as the Suwannee, Santa Fe, or Withlacoochee Rivers, the basin delineation should allow for the possibility of underflow of the stream, including discharge to the stream bed or the opposite side of the river from the spring basin. If the spring discharges to a long run (i.e., Ichetucknee Springs), there is less likelihood that there is underflow of a regional stream.

As noted on Figure 3, it is assumed that this task is essentially completed, at least to the extent that preliminary basin delineations have been completed. Therefore, no additional time is allocated to this task.

The basin boundaries should be prepared as a GIS coverage. Where the boundary is indistinct, a dashed line is appropriate. Where the boundary shifts significantly from season to season or year to year, the most extensive and least extensive delineations should be depicted along with the median boundary. For the present, the largest basin area identified from the multi-year data should be used for monitoring design. Basin boundaries will be modified and "finalized" at the end of Phase II (Task 6a).

Discussion - Delineation using wet season and/or wet years is likely to be most accurate as the ground-water potentials at drainage divides may be steep and distinct. During the dry season, the divides are likely to have less distinct divides. Allow for uncertainty in basin extents when using dry-season or dry-year data.

Deliverables - Maps showing the basin delineations, cultural features, and hydrography should be prepared for internal use. The maps should be boldly marked "Draft" or "Preliminary", as they will be finalized near the end of the five-year program.

References

Gierwielaniec, J., and S. Koscielniak, 1987. Sanitary protection zones around therapeutical mineral springs in selected Sudetic health resorts. International Association of Hydrogeologists, Symposium on Ground-Water Protection Areas, pp. 168-180.

McCann, M.R., and N.C. Krothe, 1992. Development of a monitoring program at a Superfund site in karst terrane near Bloomington, Indiana. Proceedings of the Third Conference on Hydrogeology, Ecology, Monitoring, and Management of

Ground Water in Karst Terranes. National Ground Water Association, pp. 349-371. [describes behavior of a spring-basin drainage divide over time]

Wilson, W.l., and W.C. Skiles, 1988. Aquifer characterization by quantitative dye tracing at Ginnie Springs, northern Florida. National Water Well Association, Proceedings of the Second Conference on Environmental Problems in Karst Terranes and their Solutions, pp. 121-141.

Task 1c - Select Preliminary Monitoring Well Locations

©

Purpose - The preliminary monitoring well locations are to be selected in order to prepare potentiometric maps of the spring basins with more precision than is available from the U.S.G.S. maps. The wells selected should be within, or near, the boundaries identified in Task 1b. It is recommended that existing data be subjected to geostatistical analysis to assist in identifying the optimal locations of existing wells.

Method - The District's current selection policy developed for the WARN network is sufficient. Long-term access is critical and monitoring wells, rather than water-supply wells should be selected where possible. The density of wells (number per unit area) should be greatest in approximately the half of the basin nearest the spring system. Wells should be selected to extend at least to the most extensive spring basin divide, if not beyond. Existing monitoring and domestic wells can be utilized for this task, if appropriate.

The elevations of all wells will have to be surveyed and all well locations determined by GPS to State standards for accuracy.

Geostatistical analysis has been used to optimize the District's Floridan aquifer water-level and water-quality monitoring (Environmental Resources Management, 2000). The optimal spacing of monitoring wells in each spring basin should also be subjected to a preliminary geostatistical analysis to assist in selection of existing wells. Task 5a proposes that the final monitoring-well network be subjected to geostatistical analysis in order to formalize the monitoring plan and ensure that the monitoring plan is defensible.

This task is underway at the time of preparation of this plan. As noted on Figure 3, four weeks are allocated per spring basin to the hypothetical timeline to finish the task for a total of 20 weeks.

Deliverables - The well locations should be posted on the basin delineation maps (Task 1b).

References

Environmental Resources Management, 2000. Ground Water Monitoring Plan. Contract report prepared by Environmental Resources Management (S.B. Upchurch and B.W. Goodwin), Tampa, FL, for the Suwannee River Water Management District.

Task 1d - Install Nested Monitoring Wells Near the Spring

Purpose - There is concern that some of the ground water from the spring basin may not discharge at the spring system. Some of the water from the basin may bypass the spring and discharge at the coast or another spring. Furthermore, Katz et al. (2001) have argued that water quality in some springs may result from mixing of shallow and deep flow systems. Nested monitoring wells will assist in characterizing deep and shallow flow systems in the vicinity of the spring and, by matching water-quality data, mixing and underflow can be addressed.

Method - Three monitoring wells should be installed no more than 1 mile upgradient of each spring system. All monitoring wells should have screened intervals of no more than 10 feet and they should be installed according to District/Florida Department of Environmental Protection (FDEP) specifications. One well should be screened near the top of the Floridan aquifer, the second at about mid-aquifer, and the third near the base of the potable portion of the aquifer.

The elevations of all wells will have to be surveyed by a registered land surveyor and all well locations determined by GPS to State standards for accuracy.

In the timeline (Figure 3) 27 weeks are allocated for securing access and installing the well cluster. Task 1d is not a critical-path task. The task should be completed as soon as practicable, however.

Deliverables - The well locations should be posted on the basin-delineation map. Locations and well construction details should be prepared as an open-file report.

References

Katz, B.G., J.K. Bohlke, and D. Hornsby, 2001. Sources and chronology of nitrate contamination of ground water, northern Florida (abs.). Presented at the Southeast FOCUS Ground Water Conference, National Ground Water Association, Atlanta.

Task 1e – Establish a Monitoring Well Transect at the Spring Basin Divide

Purpose - There is concern that ground-water basin boundaries shift with variations in recharge rates, pumpage, and other factors. In order to determine the uncertainty of basin boundary delineation, it is proposed that four monitoring wells be located or installed along one transect crossing the preliminary basin boundary.

Method - Four shallow, Floridan aquifer monitoring wells spaced to span the preliminary boundary should be installed at a location selected to address the regions of apparent greatest uncertainty in boundary delineation. If there are special considerations, such as potential nitrate sources, the transect can be co-located to address the boundary uncertainty and water-quality issues.

All monitoring wells should have screened intervals of no more than 10 feet and they should be installed according to District/FDEP specifications. The wells should be screened near the top of the Floridan aquifer and at comparable depths. Existing monitoring or domestic water supply wells can be incorporated into this transect if they have comparable construction and position in the aquifer.

The elevations of all wells will have to be surveyed by a registered land surveyor and all well locations determined by GPS to State accuracy standards.

In the timeline (Figure 3) 27 weeks are allocated for securing access and installing the well transect. Task 1e is not a critical-path task. The task should be completed as soon as practicable, however.

Deliverables - The well locations should be posted on the basin-delineation map. Locations and well construction details should be prepared as an open-file report.

References

McCann, M.R., and N.C. Krothe, 1992. Development of a monitoring program at a Superfund site in karst terrane near Bloomington, Indiana. Proceedings of the Third Conference on Hydrogeology, Ecology, Monitoring, and Management of Ground Water in Karst Terranes. National Ground Water Association, pp. 349-371. [describes behavior of a spring-basin drainage divide over time]

Task 1f - Identify Karst Features Within the Preliminary Drainage Basin

Purpose - Recharge is largely determined by the presence of karst depressions (Lawrence and Upchurch, 1982; Upchurch and Lawrence, 1984) in the Cody Scarp and Coastal Lowlands areas, which include the five spring study areas. These high-recharge karst features are potential sources of ground-water contamination (Trommer, 1987). Therefore, it is essential that the karst depressions be identified in each spring basin. Identification of these features will assist in identifying areas of enhanced recharge and aquifer vulnerability. In addition, the patterns of karst features can be used to detect photolinear features that may represent fractures and aquifer conduiting.

Method - The District's GIS-based topographic map coverages should be used to prepare spring basin themes at the 1:24,000 scale. All contour lines with closed hachure properties (i.e., closed depressions) should be identified in the coverage. The highest closed contour represents the area occupied by each sinkhole or closed depression. The coverages will probably have to be edge matched between quadrangle areas. It is recommended that the closed depression polygons be filled with a colored pattern in order to assist in data interpretation.

Concurrent with karst delineation, a GIS-based map showing the District's existing delineations of confined, semi-confined, and unconfined conditions in the Floridan aquifer should be prepared for comparison to the karst map and consideration of recharge potential.

While much of this work is complete, six weeks are allocated to this task (Figure 3), largely to allow for transfer of the existing delineations to the spring basin maps. This task is not a critical path task, and the activity is assigned to year 2.

Deliverables - The karst maps are of great interest. They will serve as significant sources for the project as well as for other uses. The karst features should be published as a draft map along with basin boundaries, hydrography, and cultural features.

References

Lawrence, F.W., and S.B. Upchurch, 1982. Identification of recharge areas using geochemical factor analysis. Ground Water, 20:680-687.

Trommer, J.T., 1987. Potential for Pollution of the Upper Floridan Aquifer from Five Sinkholes and an Internally Drained Basin in West-Central Florida. U.S. Geological Survey, Water-Resources Investigations Report 87-4013.

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.

Task 1g - Perform a Photolineament Analysis

Purpose - Once the karst features map is complete for each spring basin, a photolineament analysis should be completed. Assuming that the photolinears reflect fracture traces, this task will assist in predicting any areas of preferential flow through karst conduiting in the Floridan aquifer.

Method - Photolineament analysis consists of identifying alignments of sinkholes, linear stream segments, soil tonal differences, vegetation, and other features detected in topographic maps (Task 1f), aerial photographs, and satellite images. Where possible, photographs and satellite images should be used in conjunction with the karst map prepared in Task 1f to complete the photolinear map. It is recommended that each photolinear be assigned a number and that a catalog of features, including the photolinear number, a check list of types of indicators identified, and the level of confidence (high, medium, low) be maintained for later use.

Cave maps and the local knowledge of the cave-diving community should be incorporated in the photolinear map. Cave maps and the results of dye traces should be placed as insets in each map.

Six weeks are allocated for the preparation of a photolinear map. The actual time needed is likely less than a week, however.

Deliverables - A GIS-based map showing the basin boundaries, hydrography, and cultural features should be prepared. The photolinears should be superimposed as a layer on this map. In addition, the latest dry and wet season potentiometric surface maps of the Floridan aquifer, land use, and the karst feature map should be available for superposition over the photolinear map.

Task 1h - Long-Term Water-Level Monitoring

©

Purpose - This task continues for the duration of the project, up to 5 years. All wells selected for monitoring in Task 1c and installed under Tasks 1d and 1e will be monitored.

Method - To conserve resources, it is proposed that continuous water-level recorders be placed in approximately 5 percent of the wells, with the continuous recorders dispersed over the basin. Care should be taken to avoid lead weights on the recorders if lead is to be an analyte of interest in the water quality sampling (Katz and Jelinski, 1999; Katz et al., 1999). The possibility of moving a subset of these recorders to different wells every year or two years should be considered in order to determine the pattern of water levels throughout the basin. A permanent, continuous recording gage should be placed in the shallow Floridan aquifer system well within the nested wells near the spring in order to allow correlation of aquifer water levels with spring discharge. This is especially important for springs that act as estevelles (springs that alternately discharge to the surface water body and take water from the surface water body when surface water levels are high).

All other wells should have water levels measured quarterly. Water levels should be completed within a 6-week interval each quarter.

The elevations of all wells will have to be surveyed and all well locations determined by GPS as part of the previous tasks. Water level measurements can begin prior to surveying and location determination as long as stable reference points are available.

Deliverables - Long-term monitoring is not conducive to the development of traditional interim publications. In addition to preparation of the final project report, it is recommended that a web site be developed that can include updated water-level data as soon as they have been qualified.

References

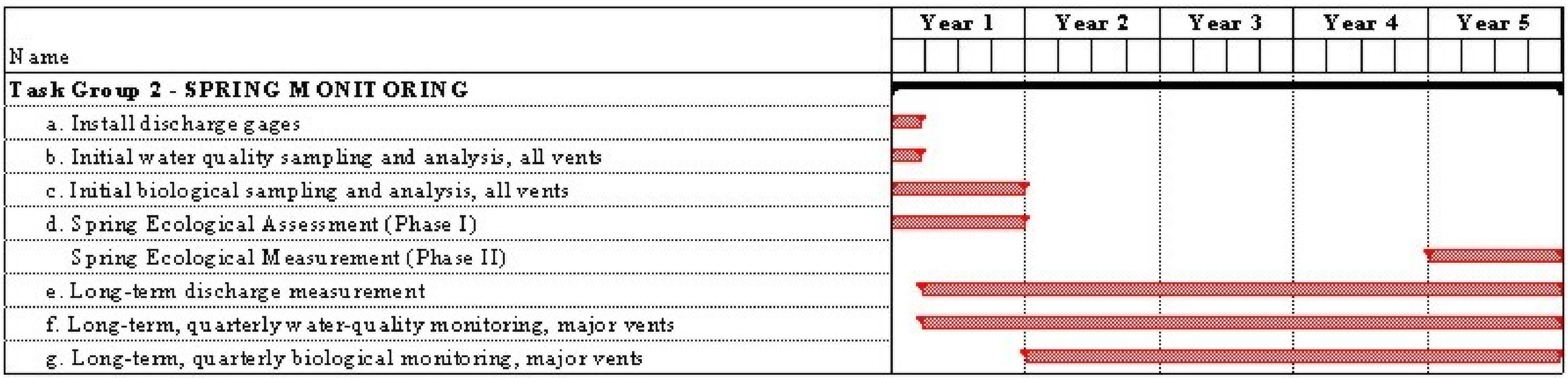
Katz, B.G., and J.C. Jelinski, 1999. Replacement Materials for Lead Weights Used in Measuring Ground-Water Levels. U.S. Geological Survey, Open-File Report 99-52.

Katz, B.G., M.P. Berndt, T.D. Bullen, and P. Hansard, 1999. Factors Controlling Elevated Lead Concentrations in Water Samples from Aquifer Systems in Florida. U.S. Geological Survey, Water Resources Investigations Report 99-4020.

Task Group 2 - Spring Monitoring

The second Task Group is intended to parallel Task Group 1 (Spring Basin Monitoring) at the spring or within the spring system. The tasks (Figure 4) develop a monitoring program for the spring and provide for long-term monitoring.

Figure 4
SUGGESTED SCHEDULE FOR TASK GROUP 2
Suwannee River Water Management District



Note: Modifications of the schedule may occur depending on the availability of staff and funds

Task 2a - Install Discharge Gages at Springs ©

Purpose - It is essential that continuous (daily) discharge be measured at each spring. Continuous spring-discharge measurements, combined with rainfall data and water level measurements in the spring basin, will assist in development of an understanding of the flow system, response of the spring to hydrologic events, and spring vulnerability.

Method - Available resources will determine the number of gages installed. Optimally, each significant spring vent should have a continuous recording gage. Alternatively, total discharge of the spring system, or a subset of vents, can be measured. It is recommended that discharge measurements be made where possible. At random times, at least twice a year, measurements should be made in each significant vent. These data can be utilized to proportionalize the discharge measured at the permanent gage.

Springs that function as estevelles or are tidal should be monitored through use of Doppler instrumentation. This will allow comparison of spring discharge with river behavior and assist in characterization of discharge as an artifact of river levels and in understanding the biological communities in the spring and spring run. Staff gages and water-level measurements can suffice in springs that are not estevelles or tidal. These discharge gages will require accurate locations and rating curve development (if required to convert stage to discharge).

Twelve weeks have been allowed for this task according to the timeline (Figure 4). This is a critical path task and the gages should be installed as quickly as possible.

Deliverables - Open-file reports should be prepared documenting the instrument type, installation design (if appropriate), gage location, and rationale the location of each gage. If the gage is placed to determine total discharge of a spring group, the positions of all locations used to take periodic vent discharge measurements should be accurately located so that they can be reoccupied.

Task 2b - Initial Water Quality Sampling and Analysis, by Vent

©

Purpose - In order to characterize the water quality discharging form each spring vent, a water-quality sampling event should occur early in the Phase I process. The water-quality data will be utilized to compare vents and determine if they have common sources of water. Later these data will be utilized to match spring water quality with source areas in the spring basin. Analyses for nutrients and herbicides will assist in determining if certain vents are responsible for the constituents discharging from the spring system.

Method - *In situ* sampling by a diver, Van Dorn bottle, or with a peristaltic pump as deep into each significant spring vent as possible is recommended to avoid contamination of the sample and loss of the dissolved gas fraction. Sampling shall be conducted in accordance with an approved FDEP QA/QC plan that outlines protocols for sample collection, preservation, and analysis.

Analytes to be determined in the first round of sampling are given in Table 1.

Table 1
Suggested First Round Chemical Analytes
Spring Characterization Plan
Suwannee River Water Management District

Field Analytes	**Laboratory Analytes**			
pH Temperature Specific conductance Dissolved oxygen Reduction-oxidation potential	**Cations** Sodium Potassium Calcium Magnesium Strontium Iron Manganese *Copper* *Arsenic*	**Anions** Chloride Sulfate Bicarbonate (alkalinity) Fluoride	**Nutrients** Total Kjeldahl nitrogen Ammonium Nitrite Nitrate Orthophosphate Total phosphorus	**Other** Turbidity Color Total organic carbon Dissolved organic carbon Silica *Atrizine* *Pesticide (Herbicide) Scan* Coliform bacteria $\delta^{15}N$ $\delta^{13}C$ δD $\delta^{18}O$

Analytes listed in *italics* are optional.

If the water samples are turbid, it is recommended that filtration through a coarse, analytical-grade filter be undertaken to avoid over reporting of analytes. Otherwise,

Upon receipt of the results from the first round of sampling, a decision should be made to determine if additional sampling is necessary immediately. Specifically, it should be determined in any vents are uniquely significant sources of nutrients to the spring system or if any vents are discharging water with a significantly different quality. These should have additional testing for the optional analytes listed in Table 1. These analytes include chlorofluorocarbons, helium isotopes, and tritium in order to date the water. Four of the five springs to be investigated in this program have been characterized as to average water age and isotopic compositions (Katz et al., 1999). Madison Blue Springs may not have been investigated. If this is the case, the work of Katz et al. should be extended to that spring as part of this task. If any vents are discharging high concentrations of ^{15}N relative to ^{14}N ($\delta^{15}N > 8$), the water should be analyzed for caffeine and possibly other anthropogenic analytes.

Herbicides, such as Atrizine, are being identified in spring discharge elsewhere in the U.S. (Rowden et al., 2001). The herbicides are listed as optional analytes in Table 1. Herbicide screening, especially for Atrizine, is an important optional consideration.

Twelve weeks are allotted for sampling, laboratory analysis, and interpretation of the vent water quality. This is a critical path task, so the task should be completed as soon as possible.

Discussion - The analyte list for the first round of sampling is comprehensive in order to provide the details necessary to understand the roles of multiple vents in the spring system. These samples will be used to match spring vent water quality with water quality from wells in order to determine source areas, as well.

Deliverables - Vent water-quality data should be reported at the end of Task 3g, which involves analysis of spring basin water quality and matching of springs with source domains. It is suggested that this report be published in a peer-reviewed journal.

References

Katz, B.G., H.D. Hornsby, J.F. Bohlke, and M.F. Mokray, 1999. Sources and Chronology of Nitrate Contamination in Spring Waters, Suwannee River Basin, Florida. U.S. Geological Survey, Water-Resources Investigations Report 99-4252.

Rowden, R.D., H. Liu, and R.D. Libra, 2001. Results from the Big Spring basin water quality monitoring and demonstration projects, Iowa, USA. Hydrogeology Journal, 9:487-497.

Task 2c - Initial Biological Sampling and Analysis, by Vent

Purpose - Concurrent with water quality sampling, the biological assessment of vent and spring run should be completed. This will allow correlation of some biological indicators with water quality.

Method - Methods for biological assessment remain to be developed. It is suggested that biological sampling of sufficient spatial and temporal frequency should be conducted to characterize the fauna and flora of the spring and its run. These biological data will be of sufficient detail such that, collected in conjunction with flow and water chemistry data, analyses can be performed which enable evaluation of quantitative relationships between spring physical/chemical characteristics and biological community responses.. In addition, chlorophyll-*a* should be measured in selected reaches of the spring vent and run.

Special attention should be given to determine the presence of intrusive vascular plant species, filamentous algae, and periphyton that may indicate degradation of the ecosystem. The spring vent and run should be videotaped underwater along GPS-located transects which can be revisited at future dates to establish a record of change.

Because of the need to develop methodology, twelve months have been allocated to this task. Unlike the water quality sampling, this task is not on a critical path. However, it is important that the biological assessments be completed simultaneously with water quality sampling so that correlations, if present, can be made.

Deliverables - A separate report on the biological quality and integrating water quality should be prepared at the end of the initial sampling.

Task 2d - Spring Ecological Assessment

Purpose - There is considerable anecdotal and observational information to suggest that the ecological systems within the springs and their runs have been subject to deterioration in recent years. Algal growths, losses of grass and other native plants, invasions of exotic plants, and changes in animal populations have been noted. Therefore, it is important to document the current status and extent of the plant and animal communities in the spring systems. This task involves two assessments, one at the beginning of Phase I and one near the end of Phase II. The two assessments will assist in detecting change and provide a baseline against which the consequences of the DSI can be measured.

Method - The following activities should be implemented in the springs and their runs and riparian lands as part of this task:

- Mapping of the distributions of plant communities;
- Mapping of habitats;
- Mapping of sediment types;
- Documentation of areas where human activities have degraded aquatic and riparian conditions;
- Assessments of plant community health, such as standing crops, productivity, and species diversity;
- Assessments of micro- and macro-invertebrate populations, including speciation and diversity, biomass, and sensitive species;
- Assessments of vertebrate populations, including speciation and diversity, biomass, and sensitive species;
- Assessment of troglodyte populations, including species present, diversity, and sensitive species; and
- Identification of troglodyte food sources, including detritus supply.

Detailed biological sampling [as described in 2c] will be conducted quarterly or at more intensive intervals, if necessary (e.g., monthly) to elucidate temporal patterns in biotic communities of the spring vent and run. Any methodologies developed to characterize unusual ecological systems, such as the troglodyte communities, should be thoroughly documented and applied uniformly throughout the study areas.

Since many of the field activities in this task require diving, health and safety must be of primary concern. Where possible and applicable, professional diving protocols should be adopted. It is recommended that the local cave-diving community be involved in this task to the maximum extent possible.

One year is allocated to this task (Figure 4) because of the need for development of methodology. Where possible, the task should be concurrent with Tasks 2b and 2c. The second ecological assessment should occur at the end of year 4 (Figure 4).

Task 2e - Long-Term Discharge Measurement

©

Purpose - Once the gages to measure discharge are installed, long-term monitoring should begin. The data will be used to correlate spring discharge with rainfall events, pumpage, and aquifer hydrographs in source areas.

Method - The gages should be continuous recording devices as described in Task 2a. Daily discharge and stage data are preferred. If there are multiple vents in the spring system and the gage(s) monitor total discharge, the individual vents should be monitored for discharge at least one time a year (see Task 2a). These instantaneous, vent-specific data will be used to proportionalize discharge between vents.

The timeline (Figure 4) shows that this task will extend for the duration of the project, through Phase II. Depending upon the results of Phase II investigations, monitoring will probably continue past conclusion of Phase II.

Deliverables - Long-term monitoring is not conducive to the development of traditional interim publications. However, to the extent the USGS does this work, the data will be included in the annual water resources yearbook. In addition to preparation of the final project report, it is recommended that a web site be developed that can include updated discharge and stage data as soon as they have been qualified.

Task 2f - Monthly Water-Quality Monitoring ©

Purpose - Task 2e represents the long-term monitoring of spring vents. Significant vents at each spring system will be monitored on a quarterly basis for selected analytes in order to determine the changes in water quality with discharge and to determine any outcomes of basin management options implemented during the five-year program.

Method - The quarterly samples will be analyzed according to the same processes outlined in Task 2b for the analytes listed in Table 2.

Table 2
Suggested Monthly Water-Quality Analytes
Spring Characterization Plan
Suwannee River Water Management District

Field Analytes	**Laboratory Analytes**			
	Cations	**Anions**	**Nutrients**	**Other**
PH	Sodium	Chloride	Total Kjeldahl nitrogen	Turbidity
Temperature	Potassium	Sulfate	Ammonium	Color
Specific conductance	Calcium	Bicarbonate (alkalinity)	Nitrite	Total organic carbon
Dissolved oxygen	Magnesium	Fluoride	Nitrate	Dissolved organic carbon
Reduction-oxidation potential	Strontium		Orthophosphate	
	Iron		Total phosphorus	
	Manganese			

.

Once a year, the spring system should be sampled for the complete list of analytes listed in Task 2b. This task will extend through the end of Phase II (Figure 4).

Deliverables - Long-term monitoring is not conducive to the development of traditional interim publications. In addition to preparation of the final project report, it is recommended that a web site be developed that can include updated water quality data as soon as they have been qualified.

Task 2q - Quarterly Biological Quality Monitoring

Purpose - This task includes the long-term monitoring for biological quality at each spring. The duration of the monitoring is the five-year project. The data will be utilized to correlate changes in community structure with seasons, discharge, water quality, and, possibly, basin management.

Method - Detailed biological sampling [as described in 2c] will be conducted quarterly or at more intensive intervals, if necessary (e.g., monthly) to elucidate temporal patterns in biotic communities of the spring vent and run. The task extends through the end of Phase II (Figure 4).

Deliverables - Long-term monitoring is not conducive to the development of traditional interim publications. In addition to preparation of the final project report, it is recommended that a web site be developed that can include updated biological quality data as soon as they have been qualified.

Task Group 3 - Identification of Critical Recharge Areas

This group of tasks is directed to identification of recharge areas within the spring basin and, more importantly, characterization of local areas where recharge may require special protection. The available data from springs within the District suggest relatively short residence times for nitrate (Katz et al., 1999). This has been interpreted to suggest that the sources of nitrate contamination are proximal to the springs. Therefore, there is likely to be an area within the larger spring basin where management may reduce the risk of contamination of the springs. These areas are preliminarily delineated in this task.

The District has developed a draft recharge potential map (Suwannee River Water Management District, 1994) that used much of the data proposed for use in this plan. This recharge study encompassed the entire district and included such factors as

- Depth to water in the Floridan aquifer,
- Geomorphology of the land surface,
- Thickness of the Hawthorn Group confining beds,
- Soil hydrologic groups, and
- Potentiometry of the Floridan aquifer.

In addition, the District, in cooperation with the FDEP, has prepared DRASTIC maps (Florida Department of Environmental Protection. 1999) showing aquifer vulnerability (Aller et al., 1987). The methodologies used to prepare these recharge and vulnerability maps are also used in this Task Group. Finally, the District is participating in development of a new aquifer vulnerability mapping technology for Florida known as the Florida Aquifer Vulnerability Assessment (FAVA) program. The FAVA program will provide high-quality data for comparison with the recharge maps developed as part of this Task Group.

Figure 5 depicts the proposed timelines for tasks within Task Group 3. The tasks are sequenced and timed to be completed within a year of installation of the monitoring facilities discussed in the previous tasks. By concluding these tasks within a year, approximately 9 months will remain at the end of year two of Phase I (Figure 1) for preparation of reports, especially the Interim Spring Basin Management Plan.

References

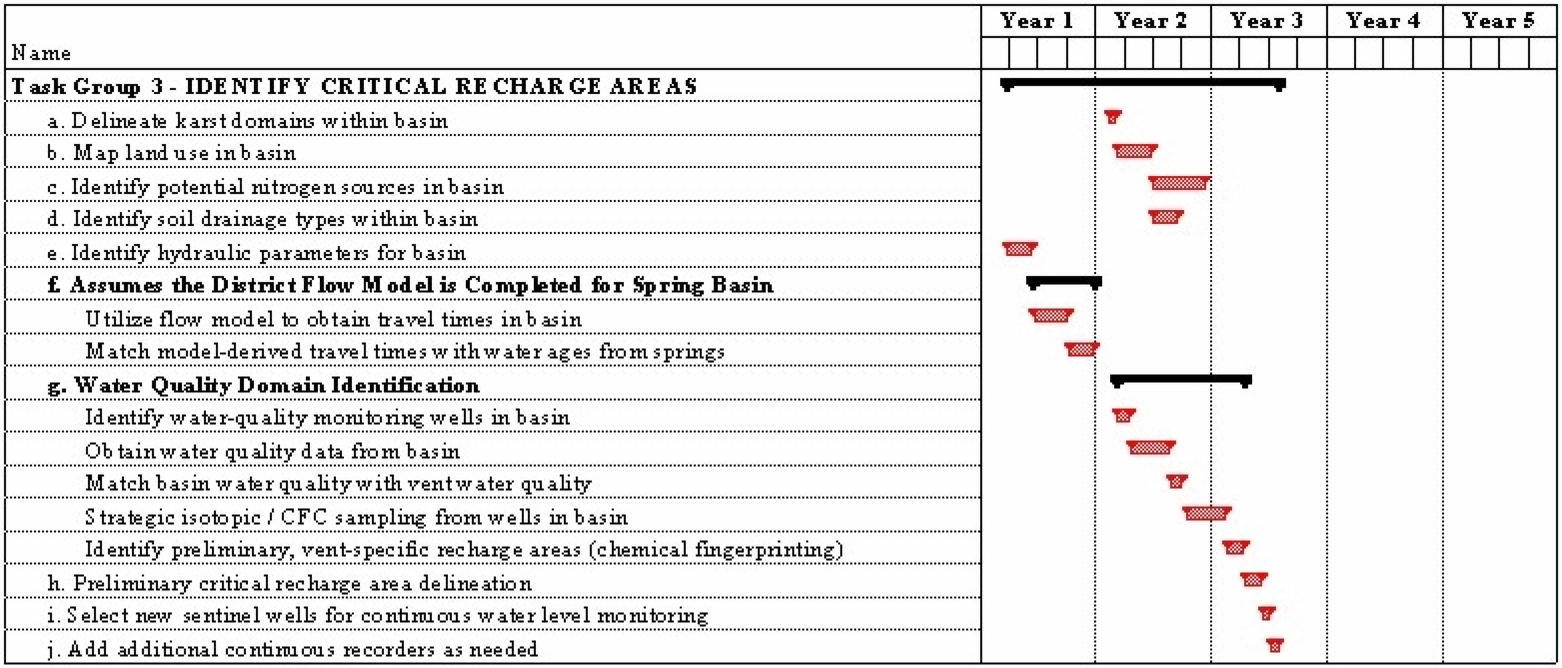
Aller, L., T. Bennett, J.H. Lehr, R.J. Petty, and G. Hackett, 1987. DRASTIC: A Standardized System for Evaluating Ground Water Pollution Potential Using Hydrogeologic Settings. Ada, Oklahoma, U.S. Environmental Protection Agency, EPA/600/2-87/035.

Florida Department of Environmental Protection, 1999. DRASTIC Aquifer Vulnerability Maps of Florida. Map images published on a CD ROM by the Tallahassee, FDEP Division of Water Resource Management, Watershed Management Program, Ambient Monitoring Section.

Katz, B.G., H.D. Hornsby, J.F. Bohlke, and M.F. Mokray, 1999. Sources and Chronology of Nitrate Contamination in Spring Waters, Suwannee River Basin, Florida. U.S. Geological Survey, Water-Resources Investigations Report 99-4252.

Sendlein, L.V.A., 1992. Analysis of DRASTIC and wellhead protection methods applied to a karst setting. Proceedings of the Third Conference on Hydrogeology, Ecology, Monitoring, and Management of Ground Water in Karst Terranes. National Ground Water Association, pp. 669-685.

Figure 5
SUGGESTED SCHEDULE FOR TASK GROUP 3
Suwannee River Water Management District



Note: Modifications of the schedule may occur depending on the availability of staff and funds

Task 3a - Delineate Karst Domains

Purpose - Task 1f included delineation of karst features within the spring basin. Task 1g included photolineament analysis. This task integrates these data and identifies areas where karst feature density (number per unit area) is maximal. Upchurch and Lawrence (1984) provide an example of karst domains near Live Oak, FL. The domains are closely related to traditional physiographic provinces (i.e., the Cody Scarp).

Method - The karst and photolineament maps will be superimposed and regions where karst feature and photolineament densities are maximal will be identified. In addition, areas of sinking streams and karst features known to be hydraulically connected to the spring (i.e., Rose Sink with Ichetucknee Springs) will be identified.

The delineation should be accomplished using GIS methods and a theme should be created to depict the domains. It is estimated that this task will require 4 weeks. It is not a critical path task. Completion of the task depends upon completion of Task 1f.

Deliverables - The results of this task should be combined with the results of Tasks 3g and 3h in a peer-reviewed journal article.

References

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.

Task 3b - Map Land Use in Basin

Purpose - Many different land uses have been shown to contribute to the nitrate problems in springs of the District (Katz and Hornsby, 1998). As a result, it is necessary to accurately catalog land uses in each of the study areas. Land use has been mapped within the District. Previous and the most recent land-use maps for the spring basins should be developed as coverages in GIS. The land use data will be used to identify potential contaminant sources within each basin. To this end, details of land uses that may cause ground water problems must be identified.

Method - The most recent land-use mapping was in 1994. Land uses within the spring basins should be updated. Small features that may pose problems should be identified and placed on the land-use maps, if not already there. Theses include any drainage wells (Hull and Yurewicz, 1979; Schiner and German, 1983) located in the spring basins Figures should be developed from the existing GIS coverage(s) that depict only potential sources as identified from the Level 3 FLUCS system. Land uses of concern include, but are not restricted to, dairies, poultry farms, row crops, residential areas on septic tanks, abandoned hard-rock phosphate mines, and others. Four months are allowed for this task.

Deliverables - A GIS-based map showing the land uses of concern, basin boundaries, hydrography, and cultural features should be prepared.

References

Andrews, W.J., 1992. Reconnaissance of Water Quality at Nine Dairy Farms in North Florida, 1990-91. U.S. Geological Survey, Water-Resources Investigations Report, 92-4058.

Andrews, W.J., 1994. Nitrate in Ground Water and Spring Water near Four Dairy Farms in North Florida, 1990-93. U.S. Geological Survey, Water-Resources Investigations Report, 94-4162.

Hull, R.W., and M.C. Yurewicz, 1979. Quality of Strom Runoff to Drainage Wells. U.S. Geological Survey, Open-File Report 79-1073.

Katz, B.G., and H.D. Hornsby, 1998. A Preliminary Assessment of Sources of Nitrate in Springwaters, Suwannee River Basin, Florida. U.S. Geological Survey, Open-File Report 98-69.

Schiner, G.R., and E.R. German, 1983. Effects of Recharge from Drainage Wells on Quality of Water in the Floridan Aquifer in the Orlando Area, Central Florida. U.S. Geological Survey, Water Resources Investigations Report 82-4094.

Task 3c - Identify Potential Nitrogen Sources in the Spring Basin

Purpose - This task will be used to identify land-use features and facilities that should be incorporated in the process of development of management plans and to determine their relationships to the recharge areas being delineated. In addition, loading estimates will be prepared to assist in evaluation of the relative importances of the sources.

Method - Many of the potential nitrogen sources have been identified within the District (Andrews, 1992, 1994; Katz and Hornsby, 1998). Others, such as drainage wells (Hull and Yurewicz, 1979) are seldom discussed, but have been documented to contribute nitrate to the Floridan aquifer. The purpose of this task is to catalog these in the context of the spring basins. In addition, the land-use map and the District's nitrate concentration map(s) should be compared to identify any additional potential sources in each basin.

Surface water drainage basin loading potentials for total nutrients (N & P) will be determined using the District's watershed assessment model.

Twenty-four weeks are allocated to this task (Figure 5). While it is not a critical path item, the data will be most useful in the final delineation of interim protection areas for the Preliminary Management Plan.

Deliverables - A GIS-based map showing the entities identified in this task should be developed with metadata indicating the locations, contact addresses, land use activities, ground-water quality data, and other relevant information for each entity. Until the Management Plans are developed, this information should not be published.

References

Andrews, W.J., 1992. Reconnaissance of Water Quality at Nine Dairy Farms in North Florida, 1990-91. U.S. Geological Survey, Water-Resources Investigations Report, 92-4058.

Andrews, W.J., 1994. Nitrate in Ground Water and Spring Water near Four Dairy Farms in North Florida, 1990-93. U.S. Geological Survey, Water-Resources Investigations Report, 94-4162.

Hull, R.W., and M.C. Yurewicz, 1979. Quality of Strom Runoff to Drainage Wells. U.S. Geological Survey, Open-File Report 79-1073.

Katz, B.G., and H.D. Hornsby, 1998. A Preliminary Assessment of Sources of Nitrate in Springwaters, Suwannee River Basin, Florida. U.S. Geological Survey, Open-File Report 98-69.

Task 3d - Identify Soil Drainage Types Within Each Basin

Purpose - Soils are classified by the National Resource Conservation Service (NRCS) into drainage categories based on hydrologic criteria, such as permeability, depth to the water table, and slope criteria. Identification of these soil drainage categories will assist in delineating the recharge areas of concern.

Method - There are two ways to obtain soil drainage data for a GIS theme. They are already available for many, if not all, counties in the District based on data provided by the NRCS. The nitrogen loading programs NLEAP and GLEAMS also have soil drainage databases.

The data should be developed as a GIS coverage, if not already available. While much of this task is complete, up to 12 weeks have been allocated to this task. The task is not a critical path issue.

Deliverables - A GIS-based map showing the land soil drainage characteristics, basin boundaries, hydrography, and cultural features should be prepared.

Task 3e - Identify Hydraulic Parameters for the Aquifer Systems Present Within a Basin

Purpose - Mapping of areas of low and high hydraulic conductivity within each aquifer system present within a spring basin is useful to assist in mapping recharge areas. This task provides time for accumulation of these data.

Method - The U.S.G.S. is presently developing a numerical flow model of the District on a one square mile grid. Therefore, some of the compilation of these data from aquifer performance tests should be complete. These data, including location, aquifer parameters, and data source, should be posted to the GIS system as points with associated metadata. In addition, the hydraulic parameter matrices being developed in the model should be contoured and incorporated in the GIS system for each spring basin.

While some of this task has been completed as part of the ground-water flow model development, twelve weeks are allowed to complete this task. The task is not a critical path item.

Deliverables - A GIS-based map showing the hydraulic conductivity distributions and locations of aquifer performance tests, basin boundaries, hydrography, and cultural features should be prepared.

Task 3f - Utilization of the U.S.G.S. Flow Model to Test Travel Time and Source Locations

Purpose - The U.S.G.S. numerical flow model can be used to test hypotheses concerning spring basin boundaries, water travel times, and recharge areas. This task is designed to provide preliminary testing of the model for this purpose.

There may be a problem with application of the regional flow model to flow in areas as small as a spring basin because of the movement of water through fractures and karst conduits (Ward et al., 1989). Dual porosity aquifers may behave in a scale-dependent fashion because of the scale-dependent importances of flow through fracture versus intergranular porosity.

Method - The U.S.G.S. is presently developing a numerical flow model of the District utilizing a one square mile grid with the MODFLOW code. The relatively large grid size may reduce the precision of the results of the use of the model to test travel times and recharge areas. It remains to be seen how the model will function within the limits of spring basins, and a telescoping grid may have to be developed to improve the results. If this is the case, the District-wide model can be used to establish boundary conditions for a local, spring basin model or the grid within the District-wide model can be refined.

As soon as the model is available (the portion in the vicinity of Manatee and Fannin Springs is nearing completion), the model's behavior in the vicinity of the spring basins should be investigated for stability, ability to predict aquifer potentials, and sensitivity to model parameter variations near the basins. If the model is deemed ready, then particle tracing and basin delineation should begin.

Ground-water flow vectors or "flow tubes" can be identified with the model and used to characterize basin boundaries. Also, MODFLOW has the capability of using particle tracking, which can be used to identify basin boundaries, local water velocities, and flow paths to the springs.

The MODFLOW module MODPATH can be used to calculate the movement of "particles" to, or from, the spring. This effort should begin as soon as the model is available. Particles should be "placed" in the spring for inverse modeling to determine model-predicted recharge areas and velocities. Particles should also be placed in areas thought to reflect high recharge potential and the basin boundaries in order to test their behavior.

Twelve weeks are allowed to accomplish this task in the Gantt diagram (Figure 6). This is almost certainly to little time for completion of the task. The task is not a critical path item, so delays in model development are not critical to the Phase I effort. If possible, particle tracking should occur within the two-year Phase I time frame, however, in order to maximize our ability to delineate recharge areas.

Given the high levels of uncertainty that typically follow from modeling in areas of sparse data, Monte Carlo simulations of the model varying uncertain parameters and/or recharge conditions can be used to simulate a confidence envelope for the model (Hunt et al., 2001). This should be considered as part of the Phase II, research effort. It is not included in the timeline at the present time.

Zhang et al. (1996) used a lumped-parameter model and least-squares methods to simulate spring discharge from hydrologic data collected within a karst spring basin. Their method may provide an alternative process for simulating spring discharge under differing climatic stresses.

Discussion - There is concern that the flow model, which will be an important tool for water management in the District, may not be available for effective use during Phase I of the DSI. As soon as it is available, use should begin. However, one should not expect the model to be a definitive tool; its primary use will be to test hypotheses and identify information needs for the short term.

Deliverables - The U.S.G.S. should prepare an Open-File Report as soon as possible after completion of model calibration. Optimally, this report should be ready by the time the Preliminary Management Plan is being written, or about 18 months into the two-year, Phase I program.

GIS-based maps showing the results of the simulations in the vicinities of the spring basins should be prepared for comparison to the other GIS coverages being developed for each basin.

References

Angelini, P., and W. Dragoni, 1997. Problem of modeling limestone springs: The case of Bagnara (North Apennines, Italy). Ground Water, 35:612-618.

Hunt, R.J., J.J. Steuer, M.T.C. Manson, and T.D. Bullen, 2001. Delineating a Recharge Area for a Spring Using Numerical Modeling, Monte Carlo Techniques, and Geochemical Investigation. Ground Water, 39:702-712.

Ward, D.S., D. Skipp, D.A. Griffin, and M.D. Barcelo, 1989. Dual-porosity and discrete fracture simulation of groundwater flow in west-central Florida. *In* Solving Ground Water Problems with Models, Proceedings of the Fourth International Conference on the Use of Models to Analyze and Find Working Solutions to Ground Water Problems, National Water Well Association, pp. 385-407.

Zhang, Y-K, E.W Bai, R. Libra, R. Rowden, and H. Liu, 1996. Simulation of spring discharge from a limestone aquifer in Iowa, USA. Hydrogeology Journal, 4:41-54.

Task 3g - Water-Quality Domain Identification ©

Purpose - Water-quality data collected during Task 2b characterize the chemical compositions of water emerging from the spring vents. Task 3g is a multi-activity task that includes collection of corresponding water-quality data from the spring basins and matching these data with the spring data in order to determine the proximal source areas for each major vent.

As part of this task, it may be desirable to undertake additional isotopic and chemical analyses of samples from selected wells. Swancar and Hutchinson (1992) have shown that tritium[1], dissolved oxygen and carbon dioxide, and deuterium and oxygen-18 analyses can be utilized to detect recharge areas at the district scale. Selective sampling for similar analytes within each spring basin can be used to refine and verify the recharge mapping and identification of recharge areas of special interest.

This task, therefore, will aid in directly identifying both contaminant source areas and ground-water protection areas.

Method - As indicated in Figure 5, the activities within this task include:

- Identification of water-quality monitoring wells in each spring basin,
- Obtaining water-quality data from each well,
- Matching basin water quality with spring vent water quality,
- Strategic isotopic and trace constituent sampling within the basin, and
- Identification of vent- or spring-specific recharge areas.

This task is a critical path activity and water-quality sampling in the spring basin should follow sampling of the spring vents as soon as possible. One hundred and sixty days are allocated for this task (Figure 5).

Six weeks are allocated for identification of wells to be sampled. This time estimate may be generous as on-going sampling as part of the WARN network will have provided information on well access and some historical data. In addition, Task Group 1 included some well identification and installation activities that should support this task as well. Wells selected for sampling as part of this task should have the following characteristics:

---

[1] Because of radioactive decay of tritium, the tritium deposited in ground water as a result of fallout from nuclear testing is nearing background activities. Therefore, this technique may be less useful today than it was in 1992.

- Broad spatial coverage of the wells within each spring basin,

- Known well construction details, especially well depth and screened/open interval, and

- Ready access with a strong likelihood that the well can be sampled frequently over the five-year period of the study.

The number of wells sampled can be less than the number of wells used for development of the potentiometric surface data. Wells near photolinear features, karst features, abandoned hard-rock phosphate mines, and other potential contaminant or recharge pathways should be included, but not to the exclusion of wells that can represent "background conditions" within portions of each basin. Domestic water supply and monitoring wells can be utilized as part of this network if they meet the requirements.

Once the wells have been identified, they should be sampled and analyzed for the same analytes listed in Task 2e in accordance with an FDEP approved QA/QC plan.

The water-quality data from the wells in the spring basin are then to be matched with vent water-quality data collected in Task 2b. There are many ways to match these data and there may be a need for some experimentation to find the best method. Graphical or shape-recognition approaches (Jones et al., 1996) are most easily understood and should be attempted first. Other approaches include partial correlation and canonical correlation (Upchurch, 1986; Upchurch et al., 2001).

To confirm the matches and further assist in understanding the transport system in each spring basin, selected wells within each basin should be re-sampled for stable isotopes, tritium, and chlorofluorocarbons.

Finally, the vent- or spring-specific recharge basins should be delineated.

Discussion - This task is important and is part of the critical path of the Phase I studies because it provides one of the most practical and defensible approach to identification of areas that should be considered for protection and enhanced management when coupled with data collected from the other tasks.

Deliverables - The ground-water domains and potential protection areas should be included as a GIS theme. In addition, the results of the study should be considered for publication as a stand-alone document.

References

Copeland, R.E., 1981. Identification of ground water geochemical patterns in the western portion of the Suwannee River Water Management District, Florida. Georgia Southwestern College, Special Publications, pp. 19-29.

Jones, G.W., S.B. Upchurch, and K.M. Champion, 1996. Origin of nitrate in ground water discharging from Rainbow Springs, Marion County, Florida. Brooksville, Southwest Florida Water Management District.

McKenzie, J.M., D.I. Siegel, W. Patterson, and D.J. McKenzie, 2001. A geochemical survey of spring water from the main Ethiopian rift valley, southern Ethiopia: Implications for well-head protection. Hydrogeology Journal, 9:265-272.

Swancar, A., and C.B. Hutchinson, 1992. Chemical and Isotopic Composition and Potential for Contamination of Water in the Upper Floridan Aquifer, West-Central Florida, 1986-89. U.S. Geological Survey, Open-File Report 92-47.

Upchurch, S.B., 1986. Time-series analysis of ground-water data. In J.M. Frazee, Jr. (Ed.), Monitor Wells and Computer Applications to Water Resources, Proceedings of the Southeastern Ground Water Symposium, Florida Water Well Assoc., Orlando, FL, pp. 241-255.

Upchurch, S.B., 1990. Quality of Ground Water in the Suwannee River Water Management District: Results of the First Sampling of the Background Water-Quality Network. Contract report submitted to the Suwannee River Water Management District.

Upchurch, S.B., 1992. Quality of Waters in Florida's Aquifers. *In* G.L. Maddox, J.M. Lloyd, T.M. Scott, S.B. Upchurch, and R. Copeland (eds.), Florida Ground Water Quality Monitoring Program -- Volume 2, Background Hydrogeochemistry, Florida Geological Survey, Special Publication No. 34, Ch. IV, pp. 12-52, 64-84,90-347.

Upchurch, S.B., A. Janicki, and R. Copeland, 2001. Designing Monitoring Programs to Measure Change and Evaluate Environmental Management Outcomes. Tallahassee, Florida Department of Environmental Protection.

Task 3h - Preliminary Critical Recharge Area Delineation ©

Purpose - All of the tasks in Task Group 3 lead to Task 3h. The Interim Spring Basin Management Plans will focus on identification of areas where enhanced monitoring, development of best management practices, land acquisition, and other approaches to protection of the springs will be implemented. This task constitutes the bringing together of all of the information gathered in previous tasks to delineate interim areas for management consideration.

Method - The GIS-based coverages will be integrated to delineate the interim areas of critical concern. Eight weeks have been allocated to this task (Figure 5). It is critical that the process of integration of the data and selection of areas of concern be thoroughly documented.

Discussion - There is likely to be some controversy about how the areas of concern were identified. Therefore, thorough documentation, use of as many approaches as possible (modeling, water quality finger printing, karst and photolinear delineation, land use, etc.) be utilized.

Deliverables - A GIS-based map showing the delineated areas, basin boundaries, hydrography, and cultural features should be prepared.

References

Fritz, F., and A. Pavicic, 1987. Hydrogeological aspect of protection of the karst spring Jadro in Croatia. International Association of Hydrogeologists, Proceedings of the Symposium on Ground-Water Protection Areas, pp. 161-167.

Novak, D., 1987. Methodology of the karstic ground water protection. International Association of Hydrogeologists, Proceedings of the Symposium on Ground-Water Protection Areas, pp. 254-267.

Pospisil, Z., and V. Reznicek, 1987. Hydrogeological investigation of spring structures of mineral and thermal waters for establishment of protection zones. International Association of Hydrogeologists, Proceedings of the Symposium on Ground-Water Protection Areas, pp. 302-313.

Task 3i - Selection of New Trend Wells for Continuous Water Level Measurement and Water-Quality Monitoring

Purpose - Once the areas of concern have been delineated, there is a probability that the existing WARN monitoring network may not have an appropriate Trend Well (or wells) within each of the areas of concern. This task is intended to allow for consideration of the District's needs for additional monitoring.

It is important that this task be implemented as the wells identified as Trend Wells within the critical areas will become key facilities for "outcomes analysis", or testing to determine if spring management plans are effective.

Method - The existing WARN monitoring wells and the new monitoring wells developed for the DSI should be compared to the delineated areas. If there is inadequate long-term monitoring within the delineated areas, then new WARN Trend Wells should be added. The wells can be either monitoring wells or domestic wells, although the latter are less desirable.

Four weeks are allowed to accomplish this task. The task is not a critical path item and can take as much time as needed. However, given the importance of these wells to the District's outcomes analysis, the installations should be completed by the end of Phase I of the springs studies.

Deliverables - The WARN monitoring manual and network design should be updated, as needed.

Task 3j - Addition of Additional Trend Wells, As Needed

Purpose - If Task 3i identifies any additional monitoring needs for the WARN network, this task provides for implementation of the additional monitoring through development of new Trend Wells.

Method - The District should follow existing protocols for addition of the additional monitoring facilities. Given that the new wells will be within areas preliminarily identified as being of critical concern for spring-basin protection, continuous water level recorders should be installed. Provisions should also be made for future water-quality monitoring. Wells can be either monitoring wells or domestic water-supply wells.

Four weeks are allowed to accomplish this task. The task is not a critical path item and can take as much time as needed. However, given the importance of these wells to the District's outcomes analysis, the installations should be completed by the end of Phase I of the springs studies.

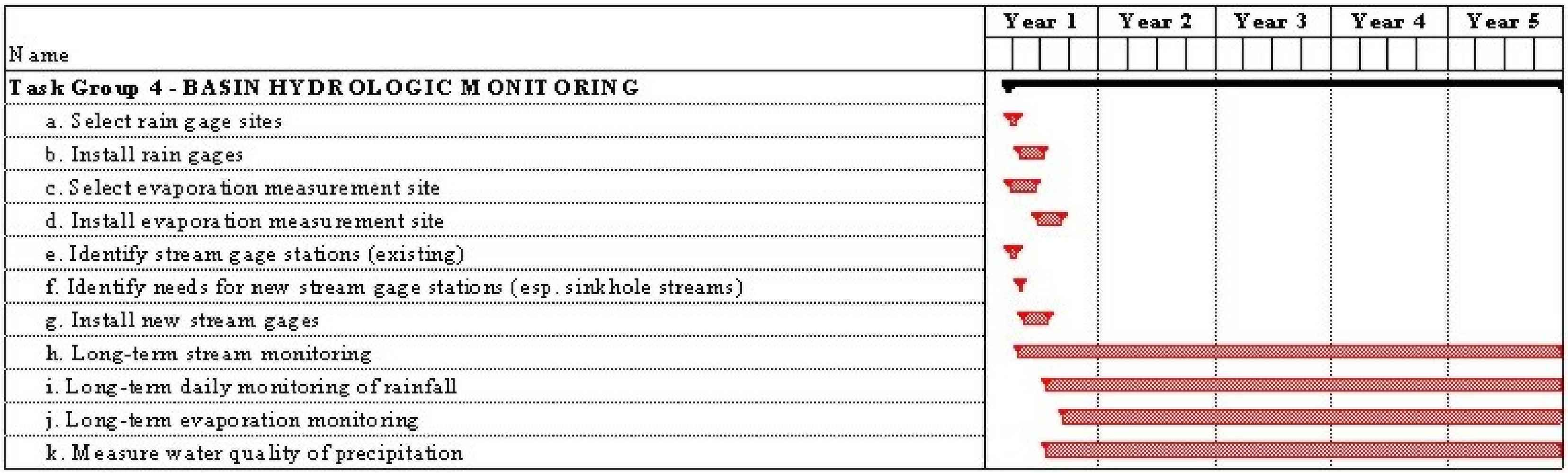
Deliverables - The WARN monitoring manual and network design should be updated, as needed.

Task Group 4 - Basin Hydrologic Monitoring

In order to better understand the hydraulic behavior of the spring basins, it is important to have data concerning precipitation, evaporation, and stream runoff within each spring basin. These data will allow for development of a water budget, provide better data for the District's ground water flow model, and provide for interpretation of how the springs respond to recharge and runoff events.

Figure 6 depicts the tasks included in Task Group 4 and the proposed time frame for completion of each.

Figure 6
SUGGESTED SCHEDULE FOR TASK GROUP 4
Suwannee River Water Management District



Note: Modifications of the schedule may occur depending on the availability of staff and funds

Task 4a - Selection of Precipitation Gage Sites

Purpose - Rainfall is the driving force for all spring behavior. This task is intended to ensure that rainfall data are available for each spring basin.

Method - There should be at least one recording precipitation gage located as close as possible to the center of each spring basin. This gage should be capable of recording daily precipitation to a hundredth of an inch. To avoid redundancy, geostatistical analysis (see Tasks 1c and 5a for more discussion of the method) of precipitation can be utilized.

Four weeks are allowed to accomplish this task. The task is a critical path item only because of the need for the data in order to complete Task Group 7, which is a Phase II activity. Therefore, installation of the precipitation gages can occur within the first year of Phase I.

Discussion - At the time of preparation of this plan it appears that the Phase I studies will be implemented during or at the end of a period of drought. As the precipitation returns to normal, the springs should respond with increased discharge. This should result in changes in spring flow and chemistry, which will be documented in Phase I monitoring. The rainfall data are critical elements in understanding these changes.

Deliverables - The WARN monitoring manual and network design should be updated, as needed, to include basin hydrologic monitoring.

Task 4b - Precipitation Gage Installation

©

Purpose - This task involves installation of new precipitation gages, as needed.

Method - There should be at least one recording precipitation gage located near the center of each spring basin. This gage should be capable of recording daily precipitation to a hundredth of an inch.

Twelve weeks are allowed to accomplish this task (Figure 6). The task is a critical path item only because of the need for the data in order to complete Task Group 7, which is a Phase II activity. Therefore, installation of the precipitation gages can occur within the first year of Phase I.

Deliverables - The WARN monitoring manual and network design should be updated, as needed, to include basin hydrologic monitoring.

Task 4c - Selection of Evaporation Gage Site ©

Purpose - Measurement of the true losses of moisture to the atmosphere through evaporation and transpiration is difficult. The most accurate/precise way to approximate these losses is through use of eddy correlation methods. This task is intended to ensure that evaporation-pan data are available.

Method - It is proposed that up to three evaporation sites be installed. Order of priority is as follows: One should be located midway between Troy and Ichetucknee springs. Another located midway between Manatee and Fannin springs. And the third should be located in the Blue Spring basin.

Twelve weeks are allowed to accomplish this task. The task is a critical path item only because of the need for the data in order to complete Task Group 7, which is a Phase II activity. Therefore, installation of the evaporation sites can occur within the first year of Phase I.

Deliverables - The WARN monitoring manual and network design should be updated, as needed, to include basin hydrologic monitoring.

Task 4d - Evaporation Site Installation ©

Purpose - This task involves installation of the new evaporation site.

Method - Each site should be capable of recording daily evaporation to a hundredth of an inch. Twelve weeks are allowed to accomplish this task (Figure 6). The task is a critical path item only because of the need for the data in order to complete Task Group 7, which is a Phase II activity. Therefore, installation of the evaporation pans can occur within the first year of Phase I.

Deliverables - The WARN monitoring manual and network design should be updated, as needed, to include basin hydrologic monitoring.

Task 4e - Identify Existing Stream Gage Sites ©

Purpose - In order to understand spring functions, it is necessary to account for water lost from the stream basin through streams and for ground water gained by sinking streams. Streams that transfer water out of the basin, other than spring runs, may exist. Most likely, these are associated with the Central Highlands and Cody Scarp and where ground- and surface-water basins are unlikely to coincide. Sinking streams, especially those that transfer water from the Highlands to sinks on the Cody Scarp, are extremely important.

Method - This task is intended for review of the streams, if any, within each spring basin. The streams should be identified as to drainage basin extent and receiving water resource. Streams that sink into sinkholes or swallets should be identified and their swallets located through GIS procedures. Streams that head up within, or cross, a spring basin and discharge outside of the spring basin should be identified.

For each stream, it should be determined if there is a gage to measure discharge or stage. Ideally, gage stations should be installed on major streams (Suwannee, Santa Fe, Withlacoochee) just upstream of the spring or spring run. Minor streams that may impact the spring basin should also be monitored, but such streams are unlikely to be present in the five study areas. Perennial sinking streams or sinking streams that are likely to be of importance to the spring system, such as on the streams that discharge to Rose and Clay sinks in the Ichetucknee basin, should also have gages on them.

Four weeks are allowed to accomplish this task, based on the assumption that the District has much of the needed information in house but that basin delineation may be incomplete. The task is a critical path item only because of the need for the data in order to complete Task Group 7, which is a Phase II activity. Therefore, installation of the stage/discharge gages can occur within the first year of Phase I.

Discussion - The Phase I studies will begin implementation during or at the end of a period of drought. As the precipitation returns to normal, the springs should respond with increased discharge. This should result in changes in spring flow and chemistry, which will be documented in Phase I monitoring. The stream discharge and stage data are critical elements in understanding these changes.

Deliverables - The WARN monitoring manual and network design should be updated, as needed, to include basin hydrologic monitoring. The basin delineations and gage locations should be entered as a GIS coverage.

Task 4f - Identify New Stream Gage Sites

©

Purpose - This task complements Task 4e, during which existing gage stations were reviewed. In this task, new gaging station needs are further refined.

Method - This task is intended for review of the need to install discharge- and/or stage-monitoring facilities on presently unmonitored streams, if any, within each spring basin.

For each stream, a gage to measure discharge or stage should be placed to measure discharge at the point of spring discharge or as the stream leaves the spring basin. It is proposed that gage stations be installed on perennial sinking streams or sinking streams that are likely to be of importance to the spring system, such as on the streams that discharge to Rose and Clay sinks in the Ichetucknee basin.

Two weeks are allowed to accomplish this task, based on the assumption that the District has much of the needed information in house. The task is a critical path item only because of the need for the data in order to complete Task Group 7, which is a Phase II activity. Therefore, installation of the stage/discharge gages can occur within the first year of Phase I.

Discussion - The Phase I studies will begin implementation during or at the end of a period of drought. As the precipitation returns to normal, the springs should respond with increased discharge. This should result in changes in spring flow and chemistry, which will be documented in Phase I monitoring. The stream discharge and stage data are critical elements in understanding these changes.

Deliverables - The WARN monitoring manual and network design should be updated, as needed, to include basin hydrologic monitoring.

Task 4g - Install New Stream Gage Sites ©

Purpose - This task is intended to provide for installation of any new gages identified in Task 4f, if any.

Method - Gage installation should follow U.S.G.S. or District standards.

Twelve weeks are allowed to accomplish this task. The task is a critical path item only because of the need for the data in order to complete Task Group 7, which is a Phase II activity. Therefore, installation of the stage/discharge gages should occur within the first year of Phase I.

Discussion - The Phase I studies will begin implementation during or at the end of a period of drought. As the precipitation returns to normal, the springs should respond with increased discharge. This should result in changes in spring flow and chemistry, which will be documented in Phase I monitoring. The stream discharge and stage data are critical elements in understanding these changes.

Deliverables - The WARN monitoring manual and network design should be updated, as needed, to include basin hydrologic monitoring. All new gage locations and the stream drainage basins they monitor should be included in the surface water GIS coverage.

Task 4h - Long-Term Stream Monitoring

©

Purpose - Once the stream gages are in place and the network is operational, long-term monitoring should begin.

Method - Daily discharge and stage should be measured at each gage. Monitoring should continue at least for the five-year duration of the project.

Deliverables - Long-term monitoring is not conducive to the development of traditional interim publications. In addition to preparation of the final project report, it is recommended that a web site be developed that can include updated stage and discharge data as soon as they have been qualified.

Task 4i - Long-Term Precipitation Monitoring

©

Purpose - Once the precipitation gages are in place and the network is operational, long-term monitoring should begin.

Method - Daily precipitation should be measured at each gage with an accuracy of 0.01 inch. Monitoring should continue at least for the five-year duration of the project.

Deliverables - Long-term monitoring is not conducive to the development of traditional interim publications. In addition to preparation of the final project report, it is recommended that a web site be developed that can include updated precipitation data as soon as they have been qualified.

Task 4j - Long-Term Evaporation Monitoring ©

Purpose - Once the stream gages are in place and the network is operational, long-term evaporation pan monitoring should begin.

Method - Daily evaporation should be measured at each gage. Monitoring should continue at least for the five-year duration of the project. The Thornthwaite (1948) formula for converting evaporation pan to potential evaporation should be considered for use in developing meaningful evaporation estimates from the pan data (Zhang et al., 1996).

Deliverables - Long-term monitoring is not conducive to the development of traditional interim publications. In addition to preparation of the final project report, it is recommended that a web site be developed that can include updated evaporation data as soon as they have been qualified.

References

Thornthwaite, C.W., 1948. An approach toward a rational classification of climate. Geographical Review, 38:55p.

Zhang, Y-K, E.W Bai, R. Libra, R. Rowden, and H. Liu, 1996. Simulation of spring discharge from a limestone aquifer in Iowa, USA. Hydrogeology Journal, 4:41-54.

Task 4k - Long-Term Precipitation Water-Quality Monitoring

Purpose - In order to complete estimation of chemical loadings in the spring basins, it is recommended that the chemical quality of rainfall be monitored.

Method - Because of the problems with short holding times for nitrate and other nutrients and the costs for sampling each rainfall event, it is impractical to collect rainfall samples at each spring for each rainfall event. It is recommended that rainfall be sampled at a centrally located gage. The gage should be able to measure rainfall to an accuracy of 0.01 inch. The water from the gage should be accumulated for chemical analysis on a random basis.

The following list of analytes should be measured: chloride, nitrate, ammonia, and orthophosphate. Sample fixation and handling protocols as listed in the District's FDEP-approved QA/QC plan should be followed. Sample volumes will be small, so ion chromatography should be used to reduce the required sample volumes.

A probabilistic approach should be used in selecting samples for chemical analysis. Thirty samples should be collected from the gage according to a schedule of pre-determined, random dates. Since rainfall cannot be predicted up to a year in advance, the sampling rule would be that a sample will be collected from the first rainfall after the pre-selected date.

The water-quality data should be weighted according to antecedent rainfall in order to obtain a load estimate. Cumulative distribution functions can be used to estimate the probabilities of chemical concentrations.

This task begins as soon as the precipitation network is in place and continues for the duration of Phase I and Phase II.

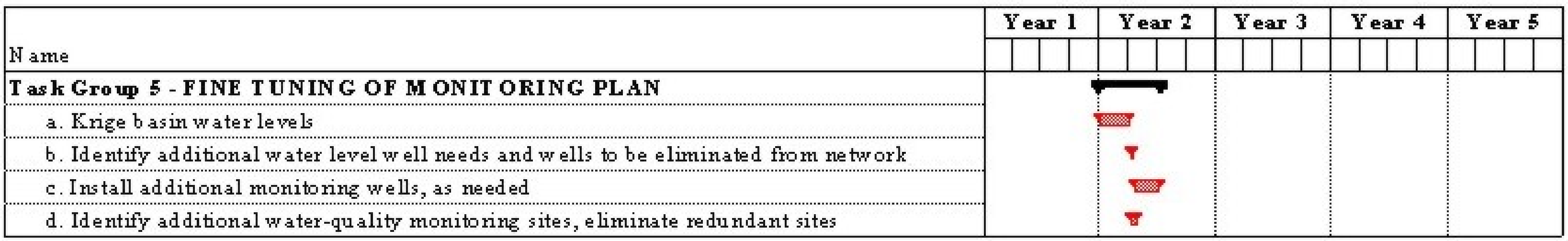
Deliverables - Long-term monitoring is not conducive to the development of traditional interim publications. In addition to preparation of the final project report, it is recommended that a web site be developed that can include updated rainfall water-quality data as soon as they have been qualified.

Task Group 5 - "Fine Tuning" of the Monitoring Network

As data are accumulated, the process of evaluation and optimization of the network should begin. This process is designed to begin the second year of Phase I (Figure 7) or as soon as appropriate data become available. The purpose of this group of tasks is identify any gaps in the initial monitoring plan and to eliminate any redundancies in monitoring facilities.

Figure 7 depicts the proposed timeline for this group of tasks.

Figure 7
SUGGESTED SCHEDULE FOR TASK GROUP 5
Suwannee River Water Management District



Note: Modifications of the schedule may occur depending on the availability of staff and funds

Task 5a - Krige Spring Basin Potentiometric Surfaces ©

Purpose - Kriging is a geostatistical technique used to optimize monitoring networks. It can be used to establish the appropriate levels of confidence of contoured maps, to identify data gaps, and to identify redundant data. This task is designed to provide this information for each spring basin.

A preliminary geostatistical analysis of the spring basins was recommended as part of Task 1c. The purpose of that task was to identify monitoring well locations. The purpose of Tasks 5a and 5b are to establish the final monitoring design and set up final spring basin delineation.

Method - The potentiometric surfaces of the Floridan aquifer within the District have been previously kriged (Environmental Resources Management, 2000). The information developed assist in the initial design of the spring basin monitoring, but they do not allow the level of refinement necessary to be able to contour spring basin potentials at one-foot intervals.

Wet- and dry-season potentials should be kriged (Isaaks and Srivastava, 1989) as soon as the first data are available. This task, therefore, can begin in year 1. The timeline (Figure 7) has the task beginning after installation and measurement of water levels in the new monitoring wells. Once the kriging is complete, the final spring basin boundaries should be developed.

Fourteen weeks are allocated to this task (Figure 7). The task is on the critical path because of the need to refine and complete the monitoring design well in advance of final Management Plan development.

Discussion - In order to complete spring basin delineation, better potentiometric maps are needed. Ideally, these maps should have one-foot contour intervals and there should be an assessment of uncertainty associated with each basin. This task will develop this data.

Deliverables - The contoured potentiometric surface maps and uncertainty maps should be completed and placed in the GIS system as coverages. An open-file report should be developed to detail the methods, results, and conclusions of the kriging investigations.

References

Environmental Resources Management, 2000. Ground Water Monitoring Plan. Contract report prepared by Environmental Resources Management (S.B. Upchurch and B.W. Goodwin), Tampa, FL, for the Suwannee River Water Management District.

Isaaks, E.H., and R.M. Srivastava, 1989. An Introduction to Applied Geostatistics. New York, Oxford University Press.

Task 5b - Identification of Additional Monitoring Needs and Wells to be Removed from the Monitoring Plan ©

Purpose - This task is intended for optimization of the spring basin monitoring networks. Any needs for new monitoring wells will be identified and any redundant wells eliminated from the monitoring plan.

Method - The kriged potentiometric surfaces will be used to identify data gaps, areas where well density is insufficient to allow detailed contouring, and wells that are clustered and redundant. Additional wells should be identified and installed as quickly as possible in order to complete the monitoring design. Identification of needed wells is, therefore, on the critical path. Removal of redundant wells from the network is not a critical path activity.

Deliverables - An open-file report should be prepared detailing which wells are to be added or removed from the network and why.

Task 5c - Selection or Installation of Additional Monitoring Wells

Purpose - This is the task allocated to selection or installation of the new monitoring wells.

Method - See Task 1e for general requirements for wells installation. Both monitoring wells and, if available, domestic wells can be utilized.

Deliverables - An open-file report documenting the details of construction or each new well should be prepared and the appropriate GIS coverages updated..

Task 5d - Identification of Additional Water-Quality Monitoring Needs and Wells to be Removed from the Monitoring Plan ©

Purpose - This task is intended for optimization of the spring basin water-quality monitoring networks. Any needs for new monitoring wells to be added to the subset of wells for water-quality monitoring will be identified and any redundant wells eliminated from the monitoring plan.

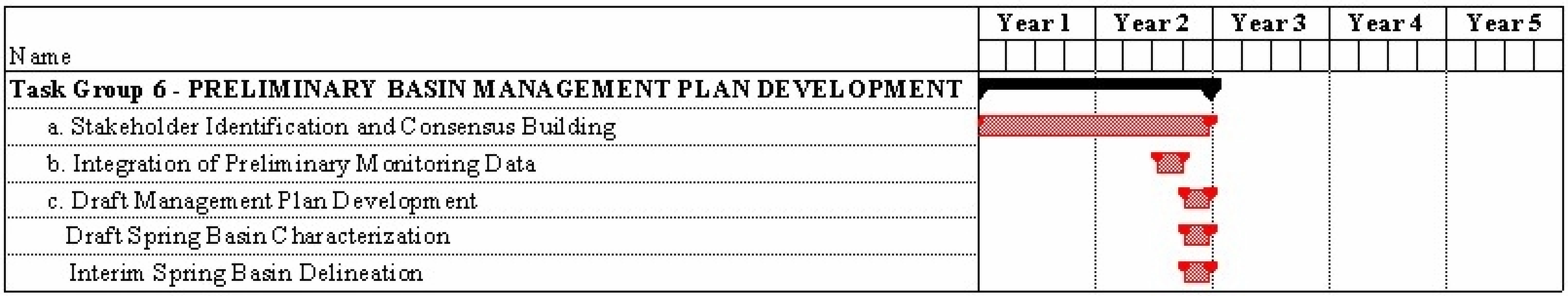
Method - The redesigned and optimized potentiometric surface monitoring network will be used to select a subset of additional wells for monitoring of water quality. The criteria outlined in Task 3g apply.

Deliverables - An open-file report should be prepared detailing which wells are to be added or removed from the water-quality monitoring network and why.

Task Group 6 - Preliminary Basin Management Plan Development

This group of two tasks is for development of an interim Basin Management Plan for each spring basin. Figure 8 illustrates the proposed timing of this process. Time is included for minor consensus building and public relations activities because it is anticipated that these activities will be included in Phase II.

Figure 8
SUGGESTED SCHEDULE FOR TASK GROUP 6
Suwannee River Water Management District



Note: Modifications of the schedule may occur depending on the availability of staff and funds

Task 6a - Stakeholder Identification and Consensus Building

Purpose - As noted in the Introduction, identification of stakeholders and building of consensus within the state and local governments, land owners and local industries, and local environmental groups is critical to the success of the DSI. This task is a flag to ensure that these activities are an integral part of the DSI.

Methods - Public meetings, formation of advisory committees, web-site postings, news releases, and informational leaflets should be used to inform the stakeholders and interested parties. Since cooperation of land owners will be required for the DSI to be successful, each spring basin should have a separate set of meetings, publications, and committees. The process should begin immediately.

Initially, the methods of the DSI and benefits to the stakeholders should be emphasized. As the process continues, the results should be shared and the stakeholders should be asked for ideas of means to solve problems as they are identified.

Deliverables - All of the methods of communication and consensus building mentioned above constitute deliverables.

Task 6b - Integration of the Preliminary, Phase I Monitoring Data ©

Purpose - Once the short-term, Phase I portions of Tasks 1 through 5 are nearing completion, the data should be integrated for incorporation into the Interim Management Plan. It is at this stage that the interim spring basin delineation should occur.

Method - The primary focus of integration of the data is delineation of the spring ground-water drainage basin and identification of areas that pose greatest risk to spring water quality through excessive recharge. The previous tasks were designed to accomplish these. In addition, the previous tasks have developed preliminary information as to:

- Monitoring needs for each spring and spring basin,
- Subareas within each basin that supply water to specific spring vents,
- Spring water and biological quality,
- Spring basin ground-water quality,
- Flow dynamics and timing of recharge and discharge events,
- Hydraulic behavior of estevelles, and
- Data to enhance flow model development.

GIS coverages should be available on a preliminary basis to illustrate most of the findings of the Phase I investigation.

It is proposed that detailed outlines for two reports be developed as part of Task 6b. The proposed reports are:

- **Draft Technical Basis for the Interim Spring Basin Management Plan** - This basis report would summarize the findings of the Phase I investigations, including the GIS maps, summary tables, and narrative descriptions. The outline for each draft basis document should include development and use of an *interim* spring basin delineation for each spring. The purpose of the report is to present the findings upon which the management plan is being based. At this stage the report should not be finalized and distribution should be limited to parties participating in development of the management plan.

  Given the extensive data collection effort, it is anticipated that the basis reports for each spring basin will be more extensive than the report on the Silver Springs Basin (Phelps, 1994). That report, however, should be used as a model for each basis report.

- **Draft Spring Basin Management Plan** - This draft report would present the preliminary, or interim, basin management plan. It would be a working document for distribution to parties participating in management plan development. It should indicate how spring basin management can be implemented and the discuss how best management practices (BMPs), land or conservation easement acquisition, assistance programs, and other management initiatives mesh to provide a holistic plan. At this stage the report should not be finalized and distribution should be limited to parties participating in development of the management plan.

As part of this task, the first draft report, the basis document, should be drafted. Task 6b is intended for management plan development.

Given the importance of the Spring Basin Management Plans to other District issues, such as minimum levels and flows and water supply planning, the draft plans should include discussions as to the applicability of the results of the DSI to these issues.

Twelve weeks are allocated to this task (Figure 8). It is a critical path task based on the District's Phase I goals. Much of the task can be initiated early, as data and graphics are generated.

Discussion - The basis document is a critically important document. Many are likely to feel threatened or misunderstood as the management plan is developed. The basis document can be utilized to defend the positions and initiatives of the Water Resources Managers.

Deliverables - Drafts of detailed outlines of the basis and management plan reports should be developed. A "mock-up" of the basis document with interim data presented in tables and figures should be developed for limited release to participants in management plan development.

References

Phelps, G.G., 1994. Hydrogeology, Water Quality, and Potential for Contamination of the Upper Floridan Aquifer in the Silver Springs Ground-Water Basin, Central Marion County, Florida. U.S. Geological Survey, Water-Resources Investigations Report 92-4159.

Task 6c - Development of the Draft Management Plan, Draft Spring Basin Characterization, and Interim Spring Basin Delineation

Purpose - This task is time sensitive because of the goals of the District's Phase I. The task provides time for preparation of each draft Spring Basin Management Plan and Spring Basin Characterization report. These documents are the ultimate deliverables of Phase I and they will used to guide Phase II activities.

Method - The outline of this draft report was developed as part of Task 6b. Twelve weeks are allocated for preparation of the draft management plan (Figure 8). More time can be utilized, if necessary, but Phase I goals have the plan developed by the end of the second year. Similarly, the draft Spring Characterization report, which will include the results of Phase I activities and the interim spring basin delineations to be used during Phase II, is allocated 12 weeks for preparation as a draft report. The spring basin characterization report is less critical to Phase II activities and draft report preparation can extend into Year 3, if necessary. Discussions with interested parties on both draft reports can continue into Phase II with no impact on project timing.

Given the importance of the Spring Basin Management Plans to other District issues, such as minimum levels and flows and water supply planning, the draft plans should include discussions as to the applicability of the results of the DSI to these issues.

Discussion - The format and wording of the draft management plan document is critically important. Many are likely to feel threatened or their needs and motives misunderstood as the management plan is developed. The stakeholders must be incorporated to the extent of comment submission and advisory committee review at this time.

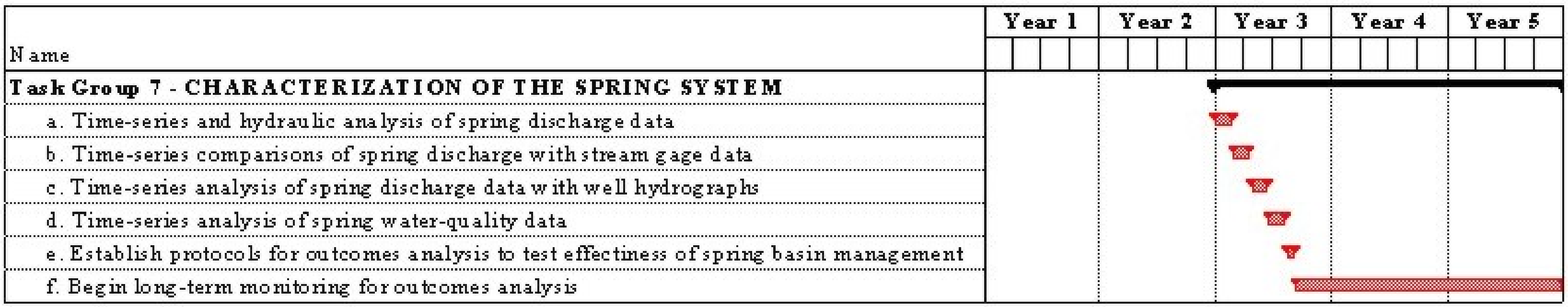
Deliverables - "Mock-ups" of the basin management and spring basin characterization documents with interim data presented in tables and figures should be developed for limited release to participants in management plan development.

A GIS-based interim spring basin delineation map should be prepared for each spring system. Each map should be marked "draft", and the text should clearly indicate that future revisions of the delineation may occur and Phase II nears completion.

Task Group 7 - Characterization of the Spring Group System

This group of tasks is a part of the "research" activities proposed for Phase II by the District. At the present time, the list of tasks must be considered limited because the uses of the data and needs for refinement of the management plan are unknown. If needed, additional tasks should be added to Task Group 7 as the draft management plans are developed (Task 6c). Phase II lasts for three years, so a number of "research" tasks can be accomplished. Figure 9 illustrates a proposed timeline for some proposed tasks.

Figure 9
SUGGESTED SCHEDULE FOR TASK GROUP 7
Suwannee River Water Management District



Note: Modifications of the schedule may occur depending on the availability of staff and funds

Task 7a - Time-Series and Hydraulic Analysis of Spring Discharge Data

Purpose - After two, or more, years of discharge data collection, there will be an extensive data set that is ideally suited for use in characterizing the temporal behavior of the springs and, especially, the hydraulics of the conduit system supplying water to the springs. Among other things, this task includes statistical analysis of the discharge data to determine periodicity, discharge probability curves, and discharge recession rates.

Springs have been classified by discharge characteristics (Perez, 1996). It is recommended that an attempt be made to develop a similar classification system for the five springs to be studied as part of the DSI. This classification can be revised and extended to other springs in the state of Florida at a later date.

Method - The analysis methods will be dictated by the nature of the data. Some possible data analysis methods include

- Autocorrelation of discharge data to determine periodicity of discharge events,
- Cross correlation of discharge data from different vents and springs for the purposes of comparison of discharge behavior and time lags between events at different vents,
- Development of log-Pearson Type III or similar curves to begin to characterize the probabilities of discharge and stage,
- Base-flow recession analysis to determine the rate at which peak discharge events dissipate and at which the aquifer releases water to the spring, and
- Discharge curves (Bonacci, 2001) to assist in characterization of the relationships of ground-water levels and spring discharge.

Discussion - The latter two analyses will be invaluable for model development and stochastic modeling of discharge events. They will also provide important information as to the degree of integration of the porosity that allows water to recharge, flow, and discharge. Discharge probabilities based on two years of data will be severely limited in terms of application to springs management. Development of probability curves will, however, set precedents for future use and updating as the data sets grow.

Deliverables - An open-file report can be prepared for use in model development and final basin management plan development. It is suggested that the results be published in a peer-reviewed journal, as well.

References

Bonacci, O., 2001. Analysis of the maximum discharge of karst springs. Hydrogeology Journal, 9:328-338.

Gonzalez, D.D., C.T. Warren, and C.L. Washington, 1973. Water Levels and Spring Discharges for Selected Wells and Springs in Nevada, 1966-69. U.S. Geological Survey Report USGS-474-171 [NTS-248], 69 p.

Interagency Advisory Committee on Water Data, 1982, Guidelines for Determining Flood-Flow frequency: Bulletin 17B of the Hydrology Subcommittee, Office of Water Data Coordination, U.S. Geological Survey, Reston, VA, 183p.

Perez, S.P., 1996. Springs in Spain: Classification according to their flows and lithologies and their hydraulic contributions. Ground Water, 34:1033-1041.

Perez, S.P., 2001. Distribution functions of spring discharges according to their lithologies and the influence of lower limit to flow: An example. Ground Water, 39:203-209.

Riggs, H.C., 1968. Frequency Curves. Techniques of Water-Resources Investigations of the United States Geological Survey, Book 4, Hydrologic Analysis and Interpretation, Chapter A2.

Thomas, D.M., 1968. Log-Pearson Type III Frequency Analysis by Computer. U.S. Geological Survey, preliminary report, Techniques of Water-Resources Investigations.

Task 7b - Time-Series Comparisons of Spring and Stream Discharge Data

Purpose - Several of the springs near the major rivers act as estevelles, of springs that alternatively discharge ground water and recharge surface water. The recharge events occur when the rivers are in flood. Ceryak (1977) has shown that sinking streams may adversely impact the Floridan aquifer adjacent to the swallet, and sampling of wells in the Lafayette County VISA showed reductions in nitrate concentrations during and shortly after the Suwannee River flooded (Katz et al., 1997; Cosper et al., 1999, in press). There does not appear to be any other published evaluations as to the impacts of recharging river water into the Floridan aquifer through the estevelles. The data collected for the DSI should provide substantial water-quality and aquifer potential data to allow for evaluation of this process.

Method - Assuming that rainfall patterns return to normal and that the regional streams flood and cause flow into the springs to occur, the process of evaluation of the effects of the estevelles is straightforward. Traditional time-series approaches can be used to compare stream and spring discharge and stage relationships. If water-quality data were obtained during or shortly after the flood, the area of impact can be evaluated, as well.

Discussion - Because of the possibility of contamination of the Floridan aquifer and loss of use of the springs for tourism, water supply, and other uses, there appears to be both human health and economic needs for this task.

Deliverables - An open-file report can be prepared for use in model development and final basin management plan development. It is suggested that the results be published in a peer-reviewed journal, as well.

References

Ceryak, R., 1977. Alapaha River Basin. White Springs, Florida, Suwannee River Water Management District, Information Circular 5.

Cosper, C., S. Upchurch, R. Copeland, P. Hansard, G. Maddox, J. Silvanima, D. Ouellette, and P. Craig, 1999, in press. Florida Ground Water Quality in Agricultural Land-Use Areas: Very Intense Study Area Results from North Lake Apopka, Fern Region of Putnam and Volusia Counties, Jackson County, Lafayette County, Martin County, Palm Beach County, and Polk County. Tallahassee, Florida Department of Environmental Protection.

Katz, B.G., R.S. DeHan, J.J. Hirten, and J.S. Catches, 1997. Interactions between ground water and surface water in the Suwannee River Basin, Florida. Journal of the American Water Resources Association, 33:1237-1254.

Lavanchy, Y., I. Muller, F. Zwahlen, and U. Schotterer, 1988. Several principle mechanisms of karstic springs in Switzerland related to physical and geological characteristics of their catchment. International Association of Hydrogeologists, Karst Hydrogeology and Karst Environment Protection, Proceedings of the 21st Congress, v. 1, pp. 386-393.

Task 7c - Time-Series Analysis of Spring Discharge Data and Ground-Water Hydrographs

Purpose - The response of the spring to fluctuations of water levels in the drainage basin provides information on flow dynamics, locations of recharge, and the extent of integration of conduits and other pores in the aquifer. This task provides for analysis of these aspects of the springs and their basins. Concurrently, the responses of the ground-water hydrographs to recharge events (Ceryak, 1982) can be characterized.

Method - Cross correlation of spring and well hydrographs will assist in determining lag times between recharge and discharge events. Recession analysis and comparisons will assist in determining the connectivity of the springs with the areas represented by the monitoring wells. The hydrographs can be used to categorize portions of the aquifer as to hydraulic behavior. Finally, multiple regression with time-lagged variables can be used to predict response times of the springs to events in the basin (Upchurch, 1996).

Discussion - This task will provide considerable insight as to the ability of the aquifer to flush and the residence time of water in portions of the aquifer system. This is important information because it impacts the lag time between reduction in nitrate loading within the basin and discharge of the lowered nitrate concentrations at the spring.

Deliverables - An open-file report can be prepared for use in model development and final basin management plan development. It is suggested that the results be published in a peer-reviewed journal, as well.

References

Bonacci, O., 1993. Karst spring hydrographs as indicators of karst aquifers. Hydrological Sciences Journal, 38:51-62.

Bonacci, O., and D. Bojanic, 1991. Rhythmic karst springs. Hydrological Sciences Journal, 36:35-47.

Ceryak, R., 1982. Response to recharge in the principal artesian aquifer and the Floridan aquifer in the upper Suwannee River Basin, North-Central Florida. Georgia Southwestern College, Special Publications, pp. 8-18.

Chen, J., and *S.B.* Upchurch, 1990. Water-impoundment problems resulting from water and air movement in karst terranes. In J. Moore (ed.), Minimizing Risk to the Hydrologic Environment, Kendall-Hunt, pp. 260-265.

Drogue, C., 1991. Velocities of piezometric waves caused by pumping in karstic aquifers. Proceedings of the Third Conference on Hydrogeology, Ecology, Monitoring, and Management of Ground Water in Karst Terranes. National Ground Water Association, pp. 307-312.

Estrella, T., and A. Sahuquillo, 1997. Modeling the response of a karstic spring at Arteta aquifer in Spain. Ground Water, 35:18-24.

Gonzalez, D.D., C.T. Warren, and C.L. Washington, 1973. Water Levels and Spring Discharges for Selected Wells and Springs in Nevada, 1966-69. U.S. Geological Survey Report USGS-474-171 [NTS-248], 69 p.

Korkmaz, N., 1990. The estimation of groundwater recharge from spring hydrographs. Hydrological Sciences Journal, 35:209-217.

Upchurch, S.B., 1996. Statistical Estimation of the Effects of Wellfield Pumpage. Contract report submitted to the West Coast Regional Water Supply Authority, Clearwater, Florida by ERM-South, Inc.

Task 7d - Time-Series Analysis of Spring Water-Quality Data

Purpose - Water-quality data can be correlated to discharge, seasonal fluctuations, and other events through time-series analysis. This task is intended to provide quantification of any relationships between water quality and spring hydrologic events.

Method - Simple correlation analysis, multiple correlation analysis, and cross correlation can be used to establish the relationships.

Discussion - To date, many of the water-quality sampling events at springs have not been systematic, so any variability between sampling events may cause confusion as to the meanings of the analytical data. This task addresses the variability and places the water quality data in temporal and hydraulic contexts.

Deliverables - An open-file report can be prepared for use in model development and final basin management plan development. It is suggested that the results be published in a peer-reviewed journal, as well.

References

Davies, G.J., 1992. Water temperature variation at springs in the Knox Group near Oak Ridge, Tennessee. Proceedings of the Third Conference on Hydrogeology, Ecology, Monitoring, and Management of Ground Water in Karst Terranes. National Ground Water Association, pp. 197-212.

Helfrich, L.A., and D.L. Weigmann, 1990. Long-term patterns in spring water quality: An approach to ground water education programs for rural communities. Journal of Soil and Water Conservation, 45:332-335.

Ryan, M., and J. Meiman, 1996. An examination of short-term variations in water quality at a karst spring in Kentucky. Ground Water, 34:23-30.

Task 7e - Develop Water Budgets for Each Spring Basin

Purpose - In order to understand how springs respond to recharge events, withdrawals, and climatic events, it is best to develop a water budget for the spring basin. The water budget is also the basis for modeling of flows, so it is a fundamental property of the spring system.

Method - Data collected as part of this program will include precipitation, evaporation (potential evaporation), ground-water levels, stream discharge (if any), and spring discharge. Assuming that the spring basins are well delineated, there should be no interbasin movement of ground water and the water budget is straightforward. The principle uncertainties are recharge rates and residence times/lag times of water as it moves through the system.

A simple water budget based on short-term hydrologic events and water use should be developed. As data accumulation continues, long-term budgets can be developed. In addition, stepwise multiple regression can be used to synthesize water budget interactions and time lags (Upchurch, 1996).

Discussion - The water budget is fundamental to understanding spring behavior. Development of water budgets for each spring basin should be a top priority.

Deliverables - It is suggested that a journal article be prepared to present the results of this investigation.

References

Phelps, G.G., and E.R. German, 1995. Water Budgets, Water Quality, and Analysis of Nutrient Loading of the Winter Park Chain of Lakes, Central Florida, 1989-92. U.S. Geological Survey, Water-Resources Investigations Report 95-4108.

Saks, L.A., A. Swancar, and T.M. Lee, 1998. Estimating Ground-Water Exchange with Lakes Using Water-Budget and Chemical Mass-Balance Approaches for Ten Lakes in Ridge Areas of Polk and Highlands Counties, Florida. U.S. Geological Survey, Water-Resources Investigations Report 98-4133.

Upchurch, S.B., 1996. Statistical Estimation of the Effects of Wellfield Pumpage. Contract report submitted to the West Coast Regional Water Supply Authority, Clearwater, Florida by ERM-South, Inc.

Task 7f - Establish Protocols for Outcomes Analysis ©

Purpose - The District is working closely with other agencies and local agricultural interests to develop best management practices, assistance programs, and monitoring to minimize nitrate and other contamination in the Floridan aquifer. The spring basin management plans will further this effort. The monitoring is of little use unless it can be used to document the success or failure of these management initiatives. The use of monitoring to evaluate the effects of management is known as "outcomes analysis". This task will establish how the monitoring data will be integrated with management initiatives to determine the effectiveness of the management activities.

Method - The monitoring data, including both historical monitoring data and data generated by the DSI, can be used to set up a "before-after, control-impact" (BACI) outcomes analysis design. The before-after component involves use of monitoring data to compare conditions before management plan implementation with conditions after implementation. The control-impact component is accomplished by comparing the monitoring data from spring basins that are not being managed with the five studied as part of the DSI. This latter comparison may be difficult unless the comparisons can be made between first-magnitude springs outside of the district, such as Juniper and Alexander springs which are located in the Ocala National Forest and are relatively unaffected by nitrates.

Establishing methods and criteria for identifying if implementation of the Basin Management Plans is successful is essential. Therefore, this task is a critical path activity. It must be completed prior to development of the management plans.

Discussion - This is a crucial step in measuring the success of the management strategies being implemented by the District, FDEP, and others.

Deliverables - An open-file report can be prepared for use in model development and final basin management plan development. It is suggested that the results be published in a peer-reviewed journal, as well.

Task 7f - Long-Term Outcomes Analysis ©

Purpose - This is a long-term task that should continue after completion of the five-year DSI. Given the relative ages of water being detected in the springs (Katz et al., 1999) and the apparent dynamics of the spring systems, it may require more than five years to begin to detect improvement in some of the springs. This task is the first step in this long-term process of validation of management strategies.

Method - Annually, the monitoring data should be re-evaluated using BACI comparisons to determine if there are improvements in spring water quality. It is suggested that a report be generated every five years to demonstrate the outcomes of the management efforts.

Determining if implementation of the Basin Management Plans is successful is essential. Therefore, this task is a critical path activity that will continue long after the end of the DSI program and development of the spring basin management plans.

Discussion - This long-term evaluation is an important reporting tool for the District Board, legislature, and citizens of the District.

Deliverables - An open-file report should be prepared every five years beginning with the last year of Phase II for use in reporting the results of basin management activities.

References

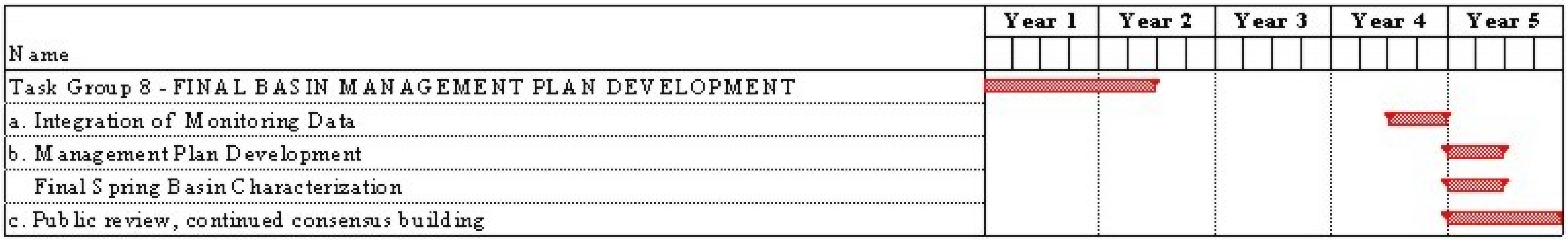
Katz, B.G., H.D. Hornsby, J.F. Bohlke, and M.F. Mokray, 1999. Sources and Chronology of Nitrate Contamination in Spring Waters, Suwannee River Basin, Florida. U.S. Geological Survey, Water-Resources Investigations Report 99-4252.

Task Group 8 - Final Basin Management Plan Development

Development of the final Spring Basin Management Plans for the four study areas should begin in year four of the DSI (Year 4, Figure 10). The final Spring Basin Management Plans will also provide important information pertinent to other issues of concern, such as water-supply planning and minimum flows and levels.

The final management plans should begin after at least three years of monitoring and near the completion of most of the delineation and research efforts. Three tasks are proposed (Figure 10). Two lead to the development of the plans and the third constitutes the public comment period.

Figure 10
SUGGESTED SCHEDULE FOR TASK GROUP 8
Suwannee River Water Management District



Note: Modifications of the schedule may occur depending on the availability of staff and funds

Task 8a - Integration of Monitoring Data ©

Purpose - Once Tasks 1 through 7 are either completed or nearing completion, the data should be integrated for incorporation into the Spring Basin Management Plans and final Spring Characterization Reports. Much of the integration of data should have been ongoing as the tasks were undertaken, so final assembly and development of management strategies are the primary activities in this task. Long-term monitoring will continue throughout the progress of this task.

Use of the data developed as part of the DSI should be considered in the context of other District issues, such as minimum levels and flows and water supply planning, should be considered as the data are integrated.

Method - The primary purposes of integration of the data are

- Finalizing delineation of the spring ground-water drainage basin,
- Finalizing delineation of areas that pose greatest risk to spring water quality through excessive recharge,
- Identification of long-term monitoring needs for each spring and spring basin,
- Identification of additional research needs,
- Organization, triage, and summarizing of the project findings for inclusion in the management plans,
- Prioritizing of management alternatives to address water-quality and ecological problems at the springs,
- Identification of public and private stakeholders who are either (1) concerned with preserving and/or improving springs or (2) involved in practices that may have an impact of spring water quality,
- Ensuring that there are adequate measures in place to monitor the outcomes of the management activities, and
- Use of the DSI data for water resource needs of the District.

GIS coverages should be available to illustrate most of the findings of the Phase I and II investigations.

In Task 6b it was proposed that detailed outlines for two reports be developed for each spring basin. The proposed reports were (1) draft Technical Basis for the Interim

Spring Basin Management Plan and (2) draft Spring Basin Management Plan. These outlines and the draft manuscripts should be reviewed and updated, as needed.

The basis document should be finalized and published as a summary of the Phase I and II investigations including the results of the monitoring and other investigations.

Twenty-six weeks are allocated to this task (Figure 10). This is a critical path task based on the District's Phase II goals. Much of the task can be initiated early, as data and graphics are generated.

Discussion - The basis document is a critically important document. The basis document can be utilized to present the positions and initiatives of the District and explain the needs that will be established in the management plans.

Deliverables - The basis documents with data presented in tables and figures should be developed for release to participants in management plan development and the public.

Task 8b - Management Plan and Spring Basin Characterization Report Development ©

Purpose - This task provides time for preparation of the penultimate drafts of the final Spring Basin Management Plans and the accompanying basis documents, the Spring Basin Characterization reports. It is assumed that there will be a period of public hearings and management discussions that may necessitate changes before the final reports are issued.

Method - The outlines of these reports were developed as part of Task 6b and updated in Task 8a. Twenty-six weeks are allocated for preparation of the management plans and basis documents (Figure 10). The proposed timeline (Figure 10) shows preparation of the penultimate draft beginning in the last half of year four of Phase II. Monitoring and completion of ongoing research projects can continue as the reports are being drafted, but the final opportunity for data inclusion in the draft report should be established early in Phase II. More time for management plan development can be utilized, if necessary, but Phase II goals have the plan completed fifth year. If time is to be provided for comment, the majority of this task should completed by the end of year four.

Discussion - The content of the management plan and basis document is important and probably controversial. Public and peer review and comment should be included as the management plan is finalized.

Deliverables - The basin management plans with supporting basis data, the majority of the data should be in the basis documents, should be developed for release to participants in management plan development. The penultimate drafts are for comment and the final reports should be completed at the end of the fifth year of the project.

Task 8c - Public Review, Continued Consensus Building

Purpose - As the Basin Management Plans and Spring Basin Characterization Reports near completion, interaction with stakeholders will become critical. This task is includes time for public review and continued consensus building. Long-term monitoring should continue throughout this task.

Method - The interactions with stakeholders should include public presentations, provisions for public, local and state government, and industry review.

Deliverables - Documentation and dissemination of information through the media previously discussed should continue.