PANEL II

DELINEATION OF SPRINGSHED BOUNDARIES

Moderator: Dr. Jonathan D. Arthur, Florida Geological Survey
Panelists: Dr. Sam Upchurch, SD II Global
Mr. Wes Skiles, Karst Environmental Services
Dr. Todd Kincaid, Hazlett-Kincaid, Inc.
Mr. Hal Davis, U.S. Geological Survey
Mr. Brian McGurk, St. Johns River Water Management District

This panel was assigned the task of addressing a critical component in the protection and restoration of Florida's springs: the delineation of their boundaries. To protect our natural resource we must first understand the system. In the case of springs, the natural resource is a complex hydrogeologic system that includes significant variations in space and time, such as dual porosity of the aquifer matrix, temporal variations in flow, water chemistry, and changes in springshed boundaries. Today we will discuss what is needed to account for these variations, including groundwater flow models, well-defined potentiometric surface maps, and adequate monitoring at appropriate times and places.

Consider Einstein's words: "Not everything that counts can be counted, and not everything that can be counted counts." We will discuss what kind of data we need and how much is enough. We will also identify challenges, hear about case studies, learn from each other's perspectives and collectively carve out a template for spring basin delineation.

We will identify what is being done, assess if we have the right tools, and recommend action. During our discussion, we need to consider human resources, statutes, education, politics, and funding as well as science.

Panel presentations

Dr. Sam Upchurch, SDII Global

A basin (springshed) boundary is the position of the divide of orthogonals to isopotential lines. From a resource protection viewpoint, a basin needs to include the surface-water basin, the groundwater basin, and the relative recharge to the groundwater within the basin.

We analyzed 14 spring basins to determine an approach to springshed delineation and to establish a water quality monitoring plan for first-magnitude springs in the Suwannee River Water Management District. We've developed a five-year program in two phases. The district will use the results of this work in land-owner assistance, land acquisition, regulatory, and education programs.

SUWANNEE RIVER WATER MANAGEMENT DISTRICT
--District Springs Initiative--

1. Five spring basins
    a. Fannin and Manatee
    b. Troy
    c. .Ichetucknee
    d. Madison Blue

2. Five year program in two phases

3. Phase I (two years)
    a. Delineate draft ground-water drainage basins
        i. Wells of opportunity plus WARN wells
        ii. Geostatistical analysis
        iii. Preliminary delineation based on potentials
    b. Develop and implement monitoring plan for hydraulic and water-quality behavior at spring and in basin
    c. Develop Interim Basin Management Plan

4. Phase II (three years)
    a. Final Basin Management Plan
    b. Optimize long-term monitoring
    c. Characterize hydraulic and water-quality behavior of system

5. Basin Management Plan and knowledge gained will be used for guide District in
    a. Land owner assistance projects
    b. Land acquisition
    c. Regulatory programs
    d. Education programs

Because springs have complex plumbing, we need to develop a geostatistically optimized monitoring program. How do we go about developing such a monitoring program? First we need to look at what we know and what we don't know about Florida spring basins. What are the consequences of what we know and what we don't know. We know many things in general about Florida spring basins: the structure of aquifers, the behavior of groundwater, the interplay of groundwater and surface water, and the sources of contamination, but we don't know the details of these for most spring basins in the state. Poor management, speculation, and inability to target "on-point" solutions are consequences of our lack of knowledge.

WHAT WE KNOW, WHAT WE DON'T KNOW ABOUT FLORIDA SPRING BASINS

WHAT WE KNOW	CONSEQUENCES
1. Limestone aquifer	a. Subject to development of karst b. Fractured rock prevalent c. Calcium-bicarbonate water type
2. Fractures and caverns dominate flow	a. Aquifer is anisotropic and heterogeneous b. Flow pathways poorly understood c. Basin boundaries may be variable d. Basin boundaries may not follow orthogonals to isopotential lines
3. Aquifer has dual porosity (conduits, intergranular porosity)	a. Ground-water velocities highly variable b. Dilution and dispersion varies locally within aquifer c. Contaminants stored in low conductivity rock bodies d. Computer models unable to replicate details of basin "plumbing" e. Model codes being developed

WHAT WE KNOW, WHAT WE DON'T KNOW ABOUT FLORIDA SPRING BASINS

4. Conduits vary in permeability (size, contents)	a. Recharge and transport rates in conduits unpredictable without testing b. Attenuation of contaminants ranges from minimal to something less than minimal
5. Springs have drainage basins	a. Sizes of basins are not known b. Basins appear to have "proximal" and "distal" recharge areas c. Drainage basin margins are ill defined d. Interior of basin predictable, edges difficult to identify e. Positions of divides may change with season, climate, land use

WHAT WE KNOW, WHAT WE DON'T KNOW ABOUT FLORIDA SPRING BASINS

6. Sinkholes are common	a. Recharge likely to be localized to sinkhole b. Recharge rate a function of sinkhole area and stratigraphy c. Contamination may be localized d. Sinkhole lakes may drain periodically e. Many sinkholes are "plugged"
7. Parts of basins are confined to semi-confined	a. Recharge more-or-less limited in confined areas b. Areas of confinement that are "perforated" are leaky c. Streams carry water and contaminants to karst portions of the basin d. Surface-water and ground-water basins of a spring system differ

WHAT WE KNOW, WHAT WE DON'T KNOW ABOUT FLORIDA SPRING BASINS

8. Sinkhole drainage basins vary significantly in size	a. Large sinkholes (uvalas, poljes) more likely to be developed than small b. Recharge amounts vary with sinkhole basin size c. Sediment flux to limestone aquifer varies
9. Sinkholes vary in density	a. High sinkhole density results in many local recharge points b. Low density leads to reduced aquifer vulnerability
10. Sinking streams drain to unconfined basin	a. Surface- and ground-water basins of a spring vary in size and locations b. Aquifer vulnerability increased by the presence of sinking streams
11. Many basins have stream traces (flood-water chutes)	a. Traces likely to flood during extreme precipitation events b. Traces may represent locations of enhanced aquifer vulnerability

WHAT WE KNOW, WHAT WE DON'T KNOW ABOUT FLORIDA SPRING BASINS

12. Land use highly variable and dynamic	a. Management of land use for water supply and water-quality protection complex b. Identification of non-point pollutant sources difficult
13. Many land uses prone to contamination of ground water	a. No one land use has resulted in ground-water contamination b. Identification of contamination sources is difficult c. "Finger pointing" common response d. Targeting of specific land uses as contaminant sources for management may not result in achieving objectives

WHAT WE KNOW, WHAT WE DON'T KNOW ABOUT FLORIDA SPRING BASINS

14. "Bulk" age of water at spring is young (15 - 25 years)	a. Contaminant sources near spring ("proximal" recharge areas) appear to prime sources of contamination b. Swinnerton-type flow model appears operative c. It may be possible to clean-up springs on time scale of decades d. There may be contaminated water "queued" up to exit spring in future (clean-up times on scales of centuries)
15. Nitrate contamination is common	a. Many (most) springs affected by nitrate b. There are different sources of nitrate c. Nitrate appears to result from fertilizer use and waste disposal

WHAT WE KNOW, WHAT WE DON'T KNOW ABOUT FLORIDA SPRING BASINS

16. Nitrate concentrations typically began to increase in the 1970s	a. Nitrate increases correlate with increases in population and fertilizer use b. Population appears to be the root cause of nitrate problem
17. Present-day water quality in springs may reflect past land uses	a. It may be too late to manage nitrate loading b. We may target wrong land uses for management

WHAT WE KNOW, WHAT WE DON'T KNOW ABOUT FLORIDA SPRING BASINS

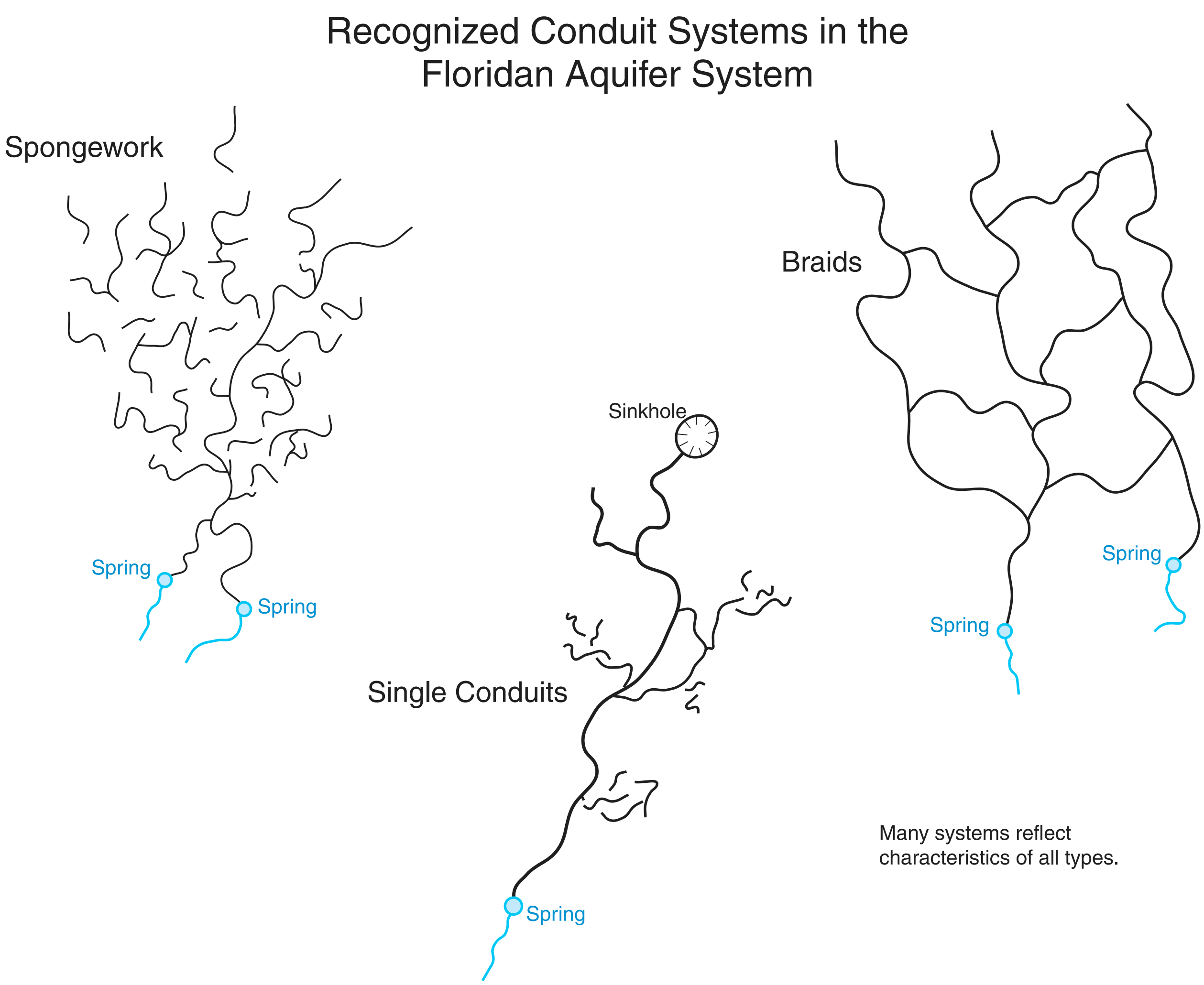
WHAT WE DON'T KNOW	CONSEQUENCES
1. Details of the above for most spring basins	a. Poor management b. Speculation c. Inability to target "on-point" solutions

Mr. Wes Skiles, *Karst Environmental Services*

Twenty years ago we started mapping caves. This changed not only the way the water management districts perceived caves but also the way they managed the aquifer. The water management districts, however, thought the maps were too specific for their needs. They needed to deal with generalities.

Society needs to change the way it deals with groundwater protection. We have enough data. What we need is education and outreach. The solution is for all stakeholders to get involved.

We've identified three cave systems or conduit types: spongework (caves in High Springs Gap and Santa Fe area, for example), braided maze (Ichetucknee area, for example)**,** and single conduit (Falmouth and Little River, for example)**.** Typically spongework springs flow blue water, braids flow green water, and single conduits flow black/brown water during floods and rainfall events. The green water is the result of blue and brown. Many systems reflect characteristics of all three types.



Moderator announcement

See article "Florida's Springs in Jeopardy" by Tom Scott in *Geotimes,* May 2002 Issue.

Todd Kincaid**,** *Hazlett-Kincaid, Inc.*

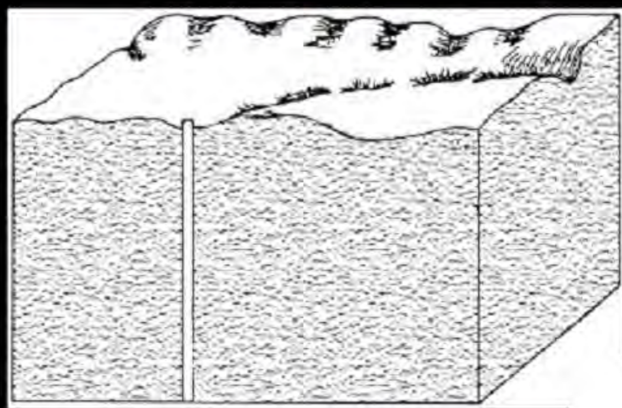
[Powerpoint presentation]

We are taking our resources for granted. We have degrading groundwater quality and increasing groundwater demand. We need to heighten public awareness of the problem, and we need to develop new concepts for modeling and managing Florida's groundwater. In the past, funded research has focused on rivers where groundwater mixes with surface water, The emphasis has been on surface water. We are developing predictive models and management strategies for groundwater incorporating what we know about caves.

One-third (27) of the 78 largest springs in North America discharge from the Floridan aquifer. The average total discharge from these springs is greater than 6.5 billion gallons per day. Wakulla Springs alone produces enough water to supply the entire population of the state of Wyoming with drinking water.

One model cannot be used to answer all questions. Models are tools and you have to use the right tool to get the correct answer. Permeability issues, for example, are different where flow is through a single type of medium and where flow is through two or three media. Standard approaches that work for a single medium do not apply to fractured rock and karst where flow is through two or three media.

Permeability (K) Issues



Porous Media Assumptions

- Flow through single media
- Standard approach
- Isotropy ($K_x = K_y = K_z$)
- Radial flow to wells & spring

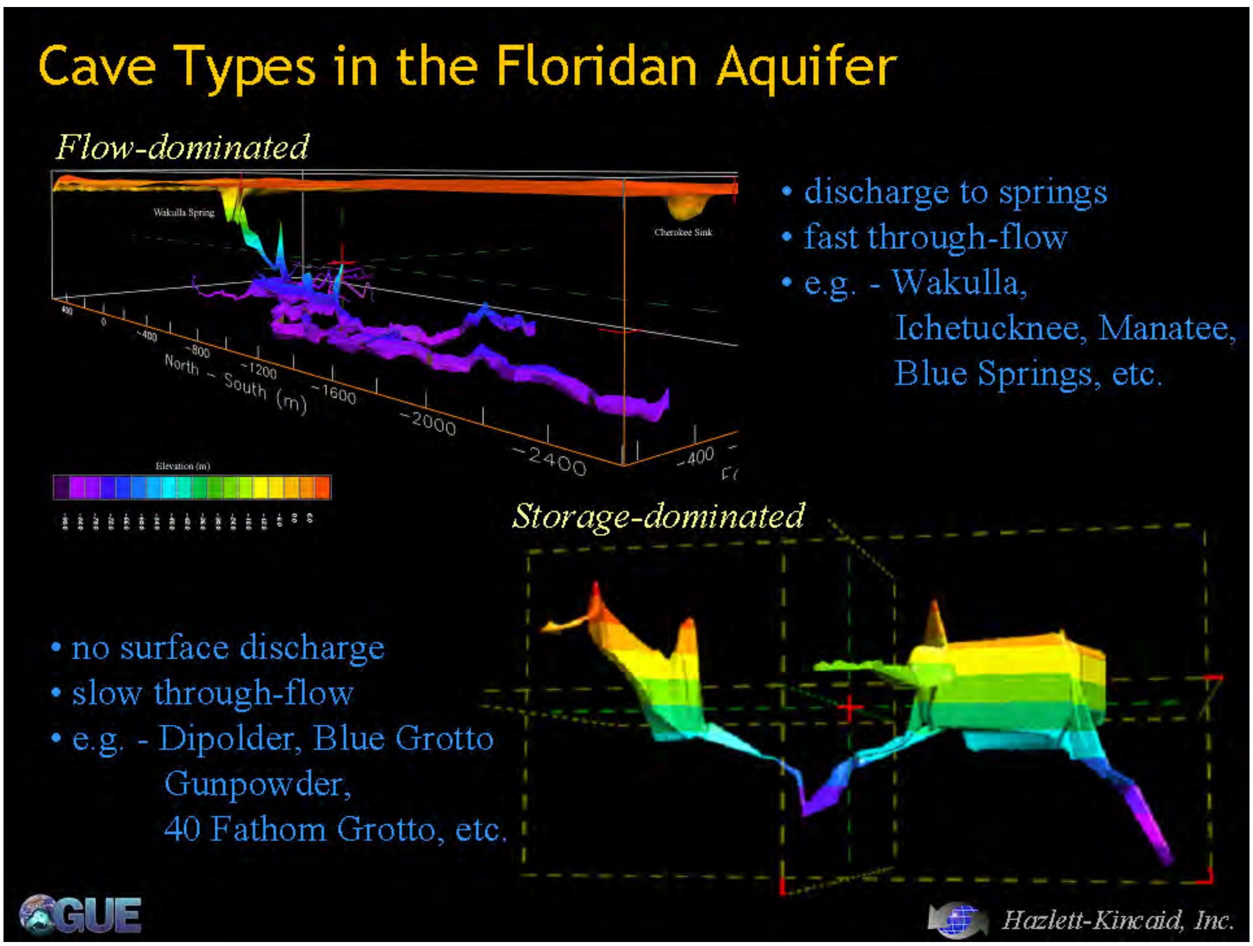
Fractured Rock & Karst

- Flow through 2 or 3 media
- Anisotropic ($K_x \neq K_y \neq K_z$)
- Flow trough fractures or conduits

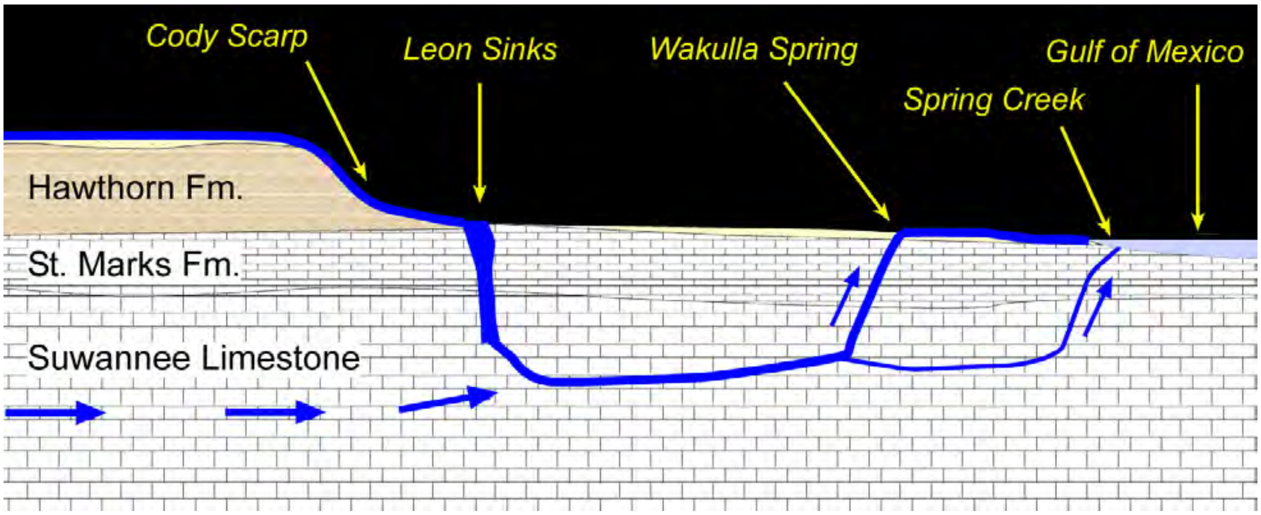
GUE

Hazlett-Kincaid, Inc.

In the Floridan aquifer, you find high matrix permeability and large and extensive conduits. Fractures are of less importance than they are in aquifers of other regions. Within the Floridan aquifer caves vary in terms of their hydraulic systems, some are flow dominated and some are storage dominated. In flow-dominated systems, such as Wakulla, through-flow is fast and discharge is to springs. In storage-dominated systems, found in the Highlands region, through-flow is slow and surface discharge absent. In these systems, you find huge underground "rooms." Some cave systems were formed under prior hydrogeologic conditions and thus reflect ancient flow paths. More recent hydrogeoloic conditions can overprint these ancient cave flow paths.

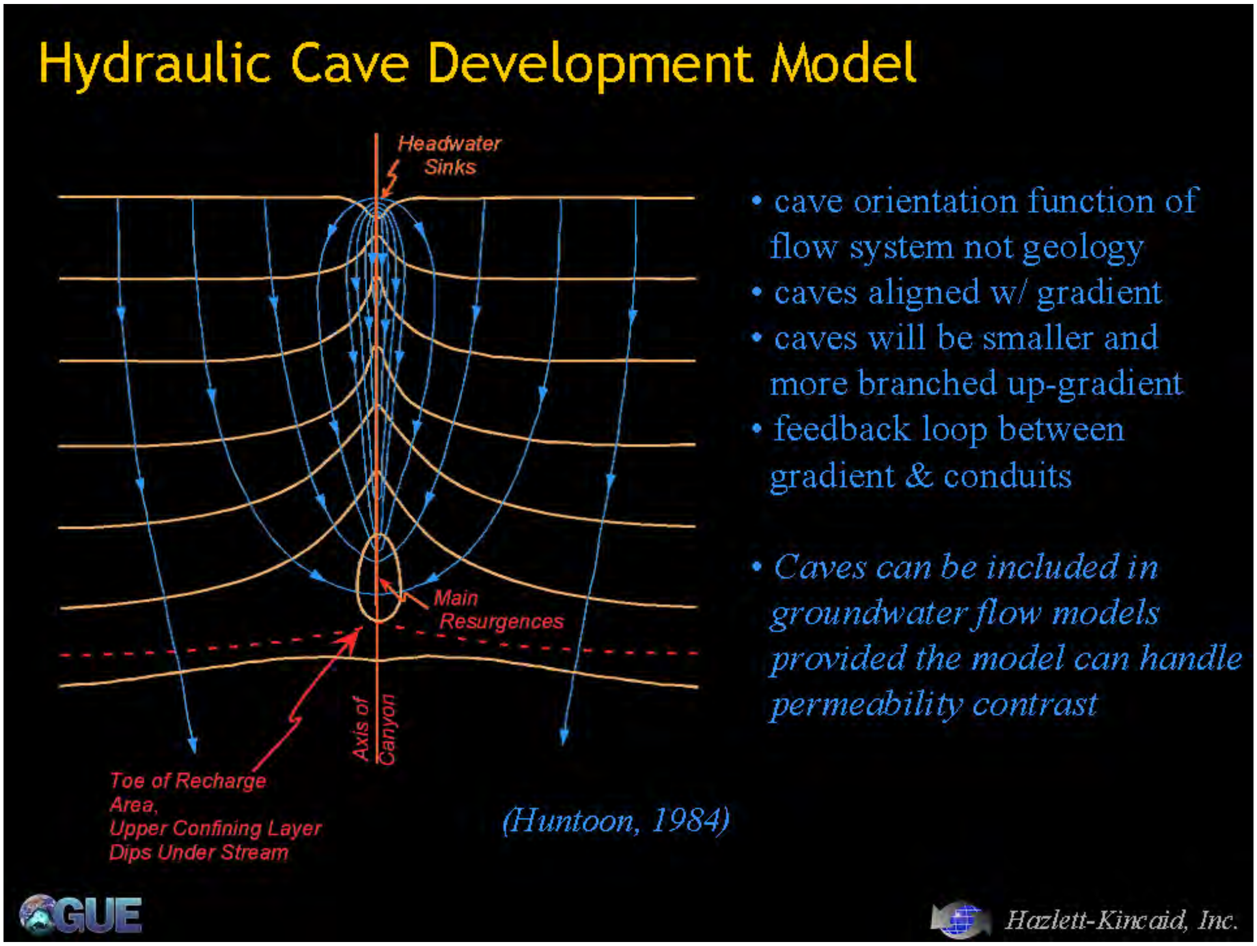


On the Woodville Karst Plain, you have the dual porosity system (both matrix and conduit) characteristic of the Floridan aquifer and rapid recharge through sinkholes and discharge at springs.



Caves can be included in groundwater flow models provided the model can handle variations in permeability. Incorporation of knowledge of caves in models can result in improved predictions regarding groundwater flow patterns and velocities, spring catchment areas, and contaminant transport times. We don't need to collect more data. So much is already there. We need to consolidate what we have in a centralized database. From there relationships can be explored and models developed.

We are currently working in collaboration with Florida State University on a groundwater model of the Wakulla Springs sub-basin that can be adapted to other spring basins. We are also making efforts to make better use of dye test results in these models.



Potentials for Groundwater Modeling

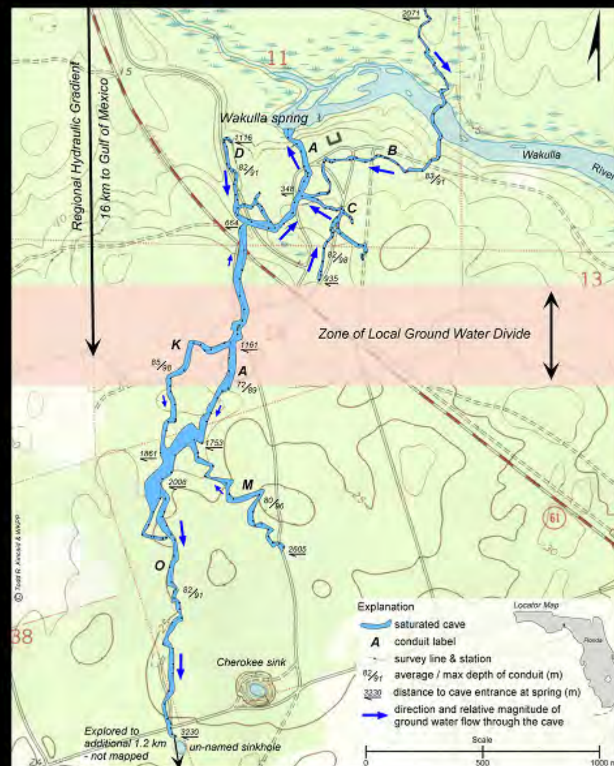
Improved Predictions

- groundwater flow patterns & velocities
- spring catchment areas
- contaminant transport times

Probable Cave Locations

- *iterative modeling*

Understanding Cave Development



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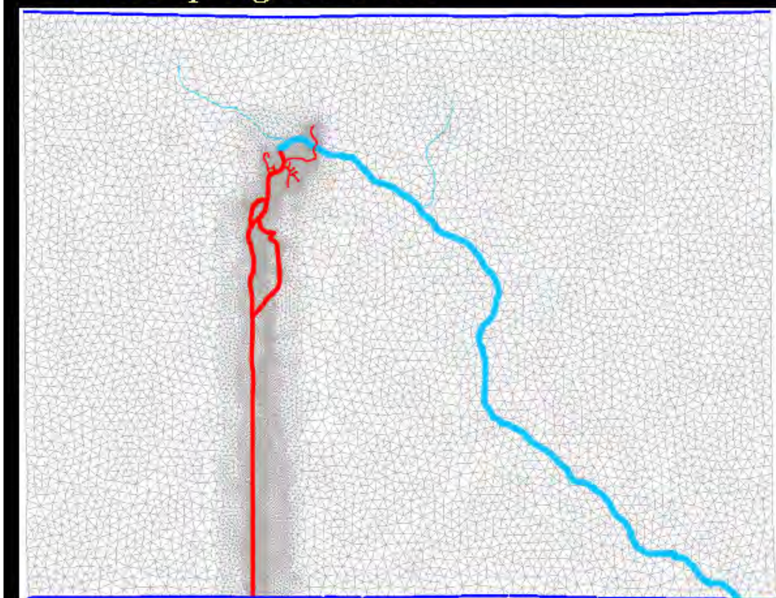
Preliminary Modeling

Wakulla Spring Sub-basin



Advanced Technology

- finite-element grid
- embraces anisotropy
- high permeability contrasts
- calibrate to spring discharge

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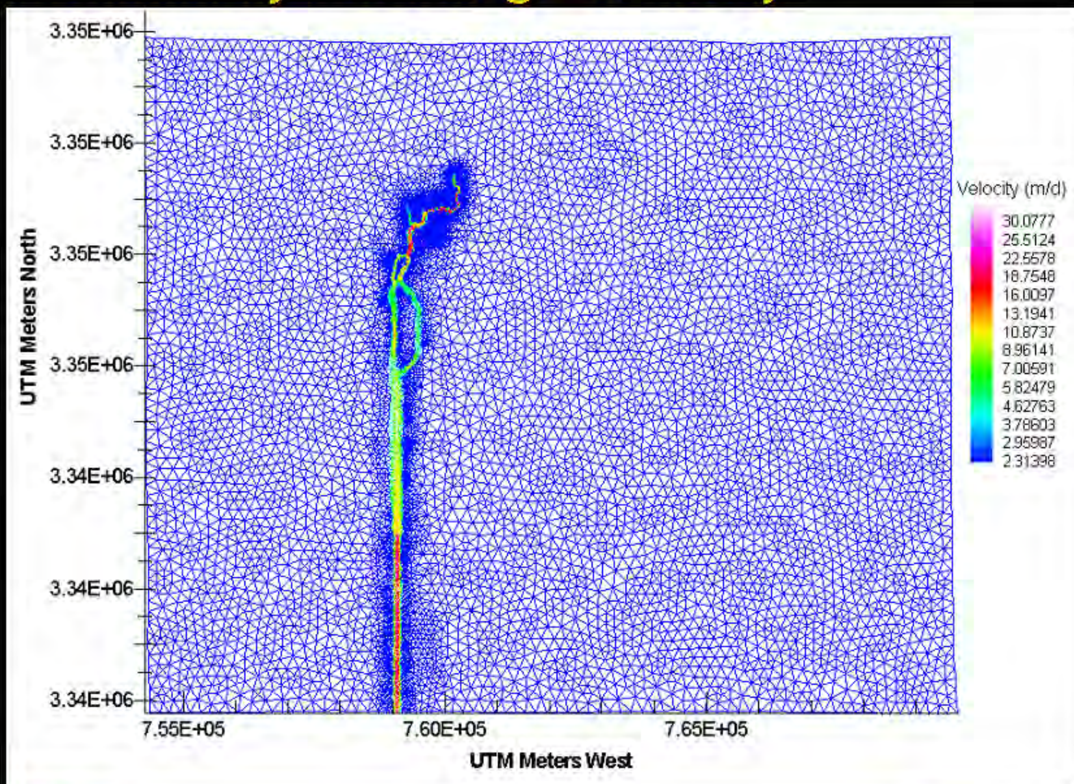
Preliminary Modeling - Velocity



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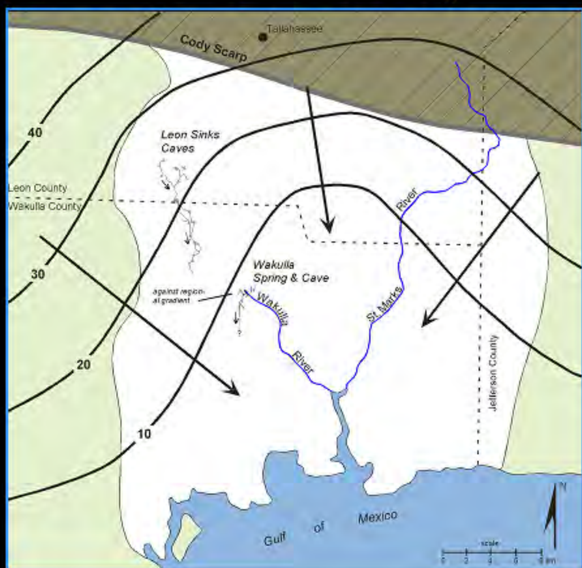
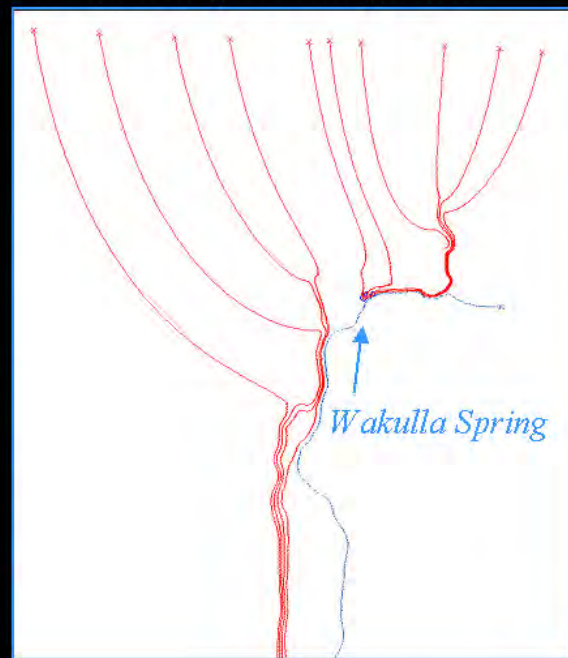
Preliminary Simulation – Particle Tracks

Standard Methods / Modeling



Our Modeling Including Cave



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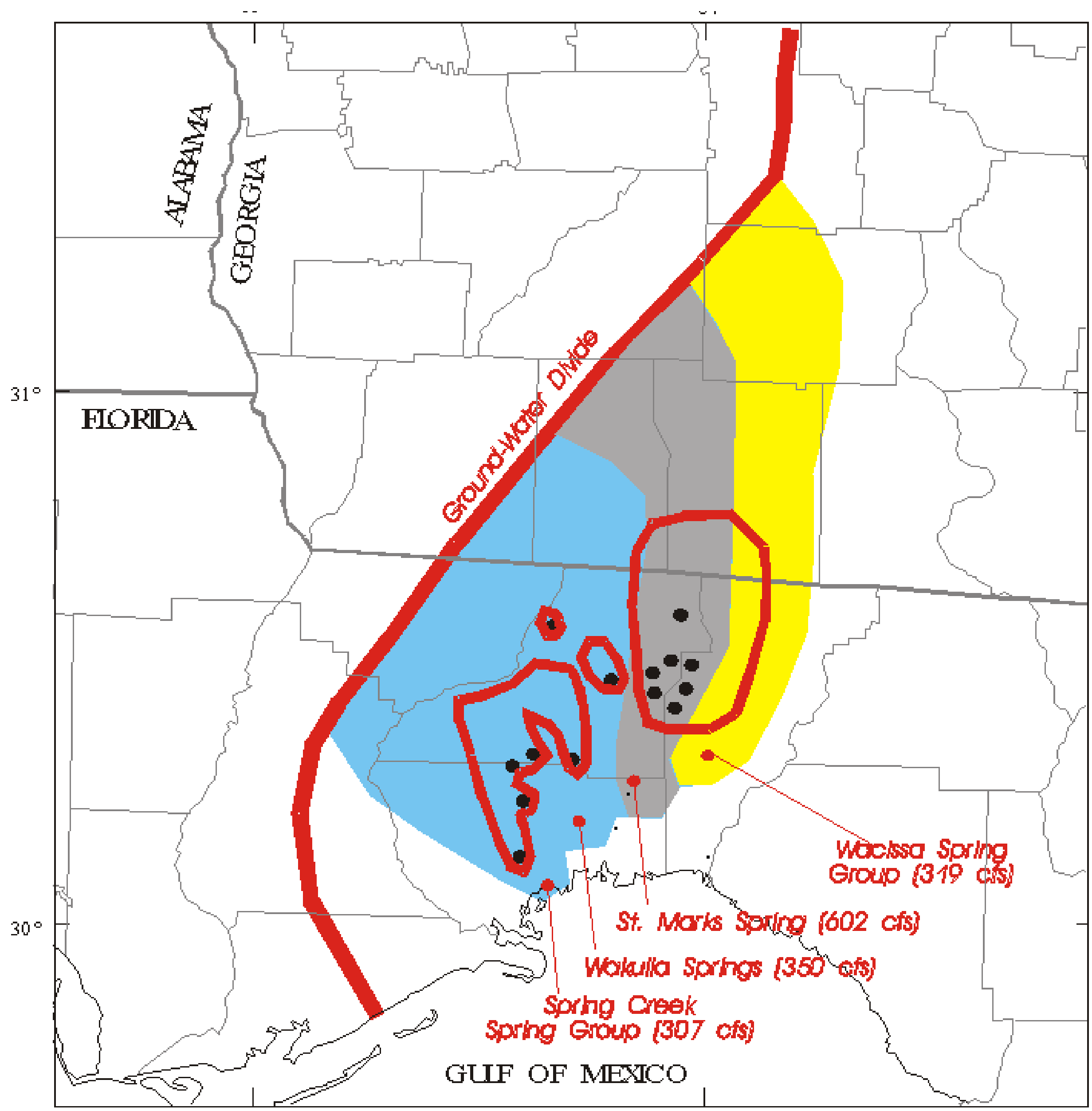
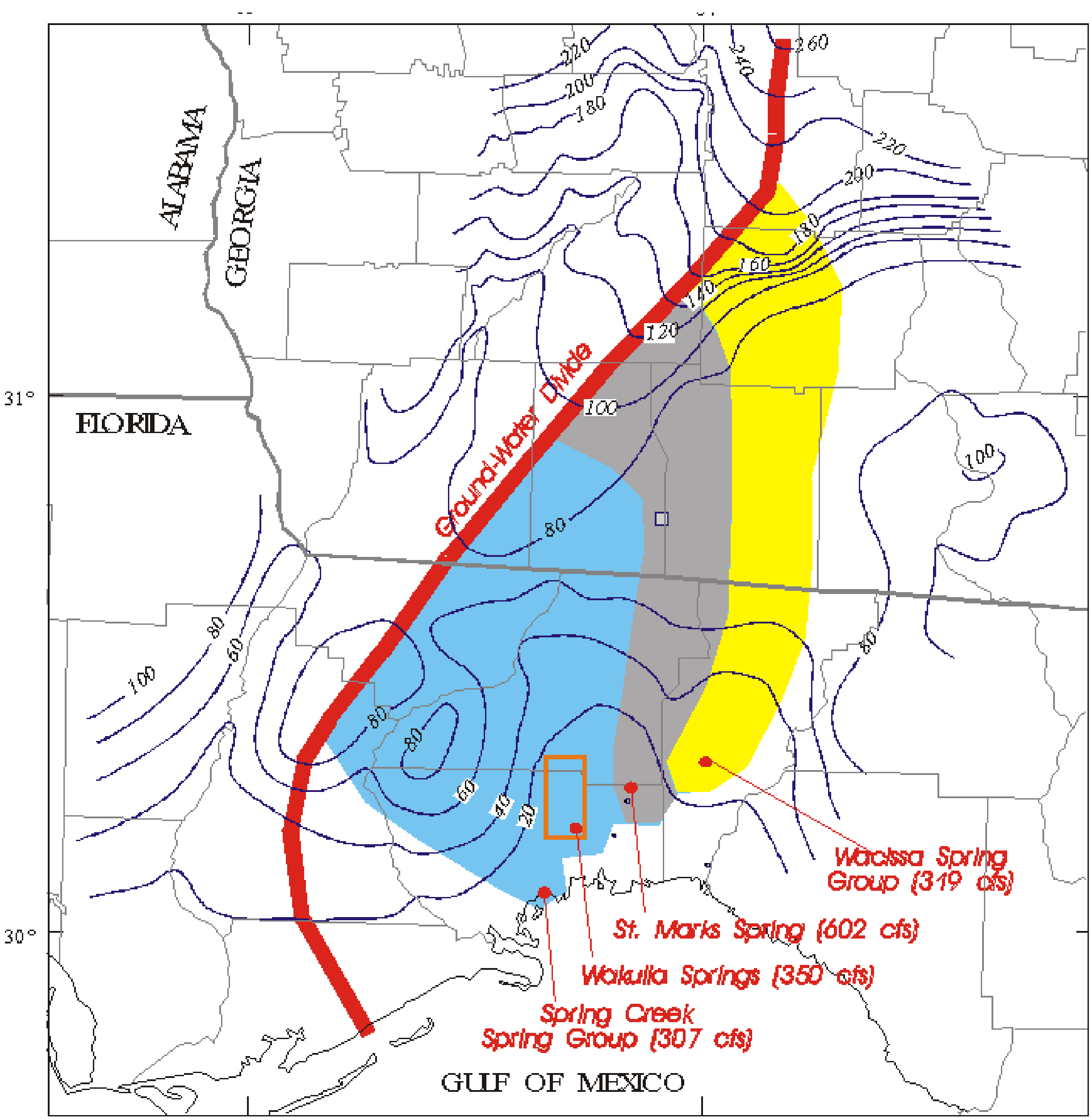
In conclusion, aquifer protection (both from contamination and overuse) is a critical issue. For example, in the Suwannee River basin, water quality is degrading. We need to improve our predictive capabilities regarding groundwater, and one of the ways to do so is to develop models that include conduit flow.

Mr. Hal Davis, *U.S. Geological Survey*
(Powerpoint presentation)

In the central panhandle of Florida stretching into southern Georgia is a regional groundwater divide. The regional groundwater basin (colored blue) supplies groundwater to the large springs south of Tallahassee and is delineated by the outermost flow paths.

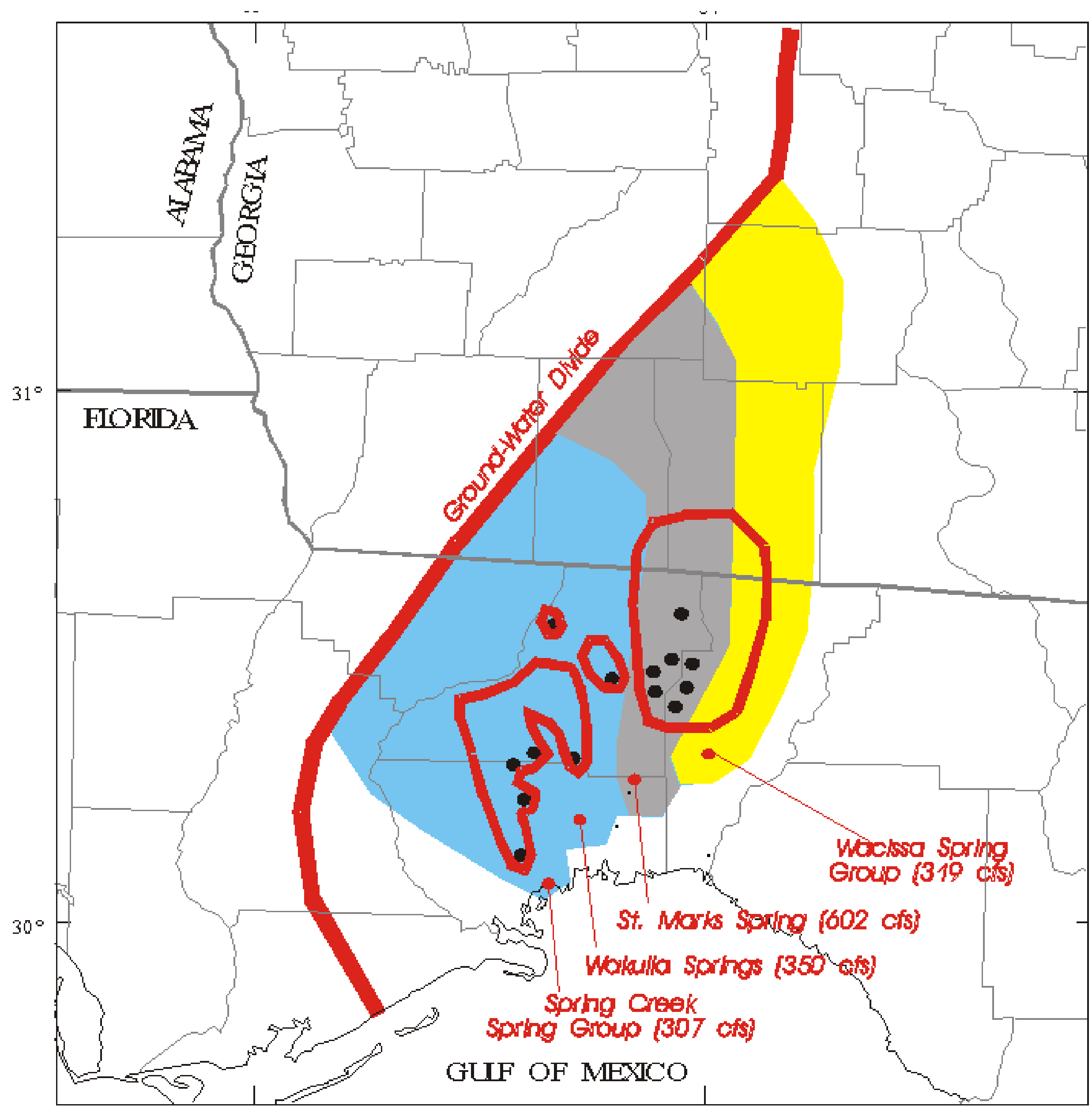


Map 2 shows groundwater subbasins tied to individual springs or spring groups. Observations on springs in the area: Spring Creek is pulling the deeper water from the Floridan aquifer. Wakulla Springs is pulling the shallower water. Wacissa Springs is consistently clean, even after large amounts of rain indicating the surface runoff is not affecting spring flow. The St. Marks River consistently has lower visibility than the other springs in the area indicating that surface runoff may be affecting the springs along the river.



On the third map delineated by red lines are the surface-water watersheds. To protect springs, you must be aware of sinkholes within the surface-water watersheds. On this map, sinkholes are indicated by black dots.

The capture zones of springs are dynamic and may overlap across several springshed boundaries. What we do to one spring may affect a couple of springs, several springs, or many springs. On a statewide basis, we need a starting point for springshed delineation; a map that shows springshed boundaries as we currently understand them – a map that provides an opportunity to review, critique, and improve our understanding of springshed boundaries.



Mr. Brian McGurk**,** *St. Johns River Water Management District*
[Powerpoint presentation]

This presentation summarized a study by the St. Johns River Water Management District in the Wekiva River basin. MODFLOW, MODPATH, and reverse particle tracking were used to define the springshed boundaries in the Wekiva River basin. Distal and proximal recharge areas were defined within the basin.

Moderator: Post-Presentations Discussion

We need to concur on one model of a springshed that can be legally defended. We need to acknowledge that different sets of laws govern groundwater and surface water. We need to consider the two major characteristics of groundwater and surface water: quality and quantity. These two cannot be separated. If the quality is poor, it doesn't matter how much water you have, and if you don't have enough water for your needs, quality is not an issue. Conservation and protection should go hand in hand. Both will affect the quality of life for all Floridians.

In our discussion we began to try to define a springshed, recognizing that such a definition clearly needs to include both groundwater and surface water and that boundaries of springsheds are dynamic. We also discussed the need for data to support springshed delineation and the appropriate frequency for collection of data. This frequency may vary from basin to basin depending on the demand for water resources. The definition needs to be functional; that is, easily understood and easily applied.

In our efforts to delineate springsheds, we need to begin with the end in mind and to think outside the box. What is the boundary of a springshed? I am reminded of a story where a geochemist, a paleontologist, and a geophysicist are asked: "What's 2+2?" The paleontologist says, 4, you dummy. The geochemist says: "Are you kidding? It's 2.00, depending on how many significant figures you have." The geophysicist gets a strange expression, closes the door and the window blinds, sits down and mysteriously says, "What do you want it to be?" The point being: what are our criteria for defining a springshed? How do we want the information used? How do we present it to the public in a way that can be easily understood? How do we represent relative recharge within a springshed? The definition of a springshed needs to take into account the influence of both the surface-water and groundwater basins and needs to meet the needs of springshed stakeholders.

The group agreed that the most effective/influential stakeholders are county commissioners as well as other decision makers in local and state government. Other stakeholders include environmental organizations, developers and the business community, and property owners and residents. The problem was raised that once county commissioners make decisions, actions of the state and federal governments are limited. We need more feedback between state government, county governments, and the water management districts.

The question was raised as to why it is important to delineate springsheds. Delineation is critical for planning and zoning decisions. How often a springshed boundary needs to be redefined depends on what is happening to land in and around the basin. Population growth, projected permitted groundwater withdrawals, and wellfields all impact springsheds. A major permanent change in the potentiometric surface would indicate a need to redefine springshed boundaries. An analogy was made to the state's minimum flows and levels program, which in theory is designed to prevent the quantity of the state's surface-water and groundwater resources from falling below a set quantity (minimum flows and levels).

The need for two versions of a preliminary springshed map was discussed: one a baseline map based on the natural system and another as a particular year (1998, 2003, etc). In selecting a scale for the map, a number of factors need to be considered:

- Availability of cave maps
- Individual spring or spring group?
- Is the scale justified by the data, especially the data on which the potentiometric surface map is based.

Consensus was reached on the definition of springshed: Those areas within groundwater and surface-water basins that contribute to the discharge of the spring.

The group discussed data needs with respect to springshed delineation**:**

- caves/karst features
- geomorphological features/provinces
- springs locations
- lineaments, faults, fractures
- potentiometric surfaces- predevelopment, all aquifer systems
- hydrographs, stage, discharge
- dye traces
- groundwater rage
- geochemical and physical data-wells, springs
- land use changes
- surface-water basin boundaries
- evapotranspiration, rainfall
- recharge rates
- geophysical (specific)
- aquifer performance test data
- soils
- consumptive use data

The group discussed data products that need to be generated:

1. Potentiometric surface maps

    Factors to be considered in constructing these maps
    -well heads
    -spring/river locations

-three-dimensional locational accuracy
-adequate control for scale required
-well construction data
-well use

2. Lithostratigraphic maps
   Should include:
   -Formation boundaries
   -lithologic descriptions of cores and cuttings from wells
   -accurate well locations

3. Hydrostratigraphic Maps
   Should include:
   -correlation to lithostratigraphic units where possible
   -water level data during drilling
   -laboratory or geophysical data that characterize permeability
4. Cavernous Zone Maps
   Data to generate may include:
   -logs of "lost circulation" zones from well logs, geophysical log data
   -karst features
   -freshwater/saltwater boundary maps
5. Vulnerability (to contamination) maps
6. Geomorphology maps
7. Sub-basin delineation maps
8. Models – transient
   Data and map resources needed for models:
   -aquifer performance test data
   -hydrostratigraphy
   -potentiomentric surface
   -hydrographs, stage, discharge, precipitation, recharge, ET
   -leakage
9. Water quality of specific spring vents over time

The question was posed of all the data needs, what is minimally needed to generate a preliminary springshed map. Two things are critical: potentiometric surface of the aquifer system and surface-water basin boundaries.

The issue of relative recharge within the springshed was raised and its importance for providing different levels of protection and for helping local governments prioritize actions regarding land acquisition and land use practices.

Discussion of Preliminary Basin Delineation

What are the steps in preliminary basin delineation:

1. Design data gathering infrastructure
   -Establish frequency and distribution of hydrologic data for both surface water and groundwater
2. Infrastructure construction
   -install monitor wells, lake gages, etc.
3. Collect field data
4. Collect "non-infrastructure" data and analyze
   -Karst features/domains,
   -Photolineamets
   -Land use, loads
   -Soils
   -Hydraulic parameters
5. Develop flow models
   -Establish travel times
   -Inverse and forward particle tracking
   -Calibrate with groundwater ages, tracers
   -Validation
6. Water quality analysis (i.e. interpretation)
7. Develop potentiometric surface maps
8. Develop and implement long-term monitoring plan

In this panel, our goals are now to define "relative vulnerability" within a springshed, prioritize data gathering and analysis via a timeline, to develop approaches for delivery of preliminary maps, and to make recommendations. An ongoing project at the Florida Geological Survey may serve as a good model for estimating the relative vulnerability to contamination within a springshed:

Florida Aquifer Vulnerability Assessment (FAVA) presentation
[see FGS website for more detail]

FAVA is a GIS-based system that looks at natural systems without the human component. Data sets include depth to water, soil conductivity, thickness of confinement, and karst feature density. The different layers of data have different resolutions. The data will depict relative recharge rates from land surface to aquifer system. The result is a raster (GRID) mapping product.

A presentation was also made on the FGS Hydrogeology Program, including a recent DEP-wide hydrogeology needs assessment and research funded during the most recent fiscal year [**FGS website].**

Participants discussed basin attributes that are important in determining the vulnerability of a springshed.

These include:
- land use/ pollutant loads
- consumptive use
- proximity to karst/lineaments/drainage wells
- thickness of confinement
- hydraulic conductivity (K) of soils, K of vadose zone materials and, K of the confining unit
- proximity to the springs
- depth to water
- relief/slope, topography, potentiometric surface
- head difference
  depth to "rock"

A two-tiered approach was discussed in which "critical areas of concern" are delineated within a springshed based on factors such as nutrient levels, flow declines, and algal and nuisance plant blooms. The second approach would entail determination of "springs of most concern." We need to move forward.

"Information today is better than a lot of information too late"
-Anonymous

How do we now move forward without the material being used improperly? It was suggested that preliminary springshed delineation maps be constructed with these characteristics:

- regional in scope
- defined by fuzzy boundaries (color shading)
- consider composite springsheds because neighboring springsheds do not always have discrete and clearly defined boundaries.
- shade places on the map where there is a known problem
- employ simple threee-dimensional graphics and two-dimensional cross sections to make the maps more visually attractive and informative
- perhaps include cartoons or other features that will enhance appeal and understanding.
- include importance of maps and how to use maps

How to Deliver Maps:

- through presentations to county commissioners, county planners, and regional planning councils
- through a web site
- through presentations at meetings
- through pamphlets

The maps would be of use to the Florida Department of Agriculture (Best Management Practices), the Florida Department of Community Affairs (zoning/planning), and the Florida Department of Environmental Protection (permitting) as well as the water management districts.

Timeline for Data Acquisition and Analysis toward Springshed Delineation

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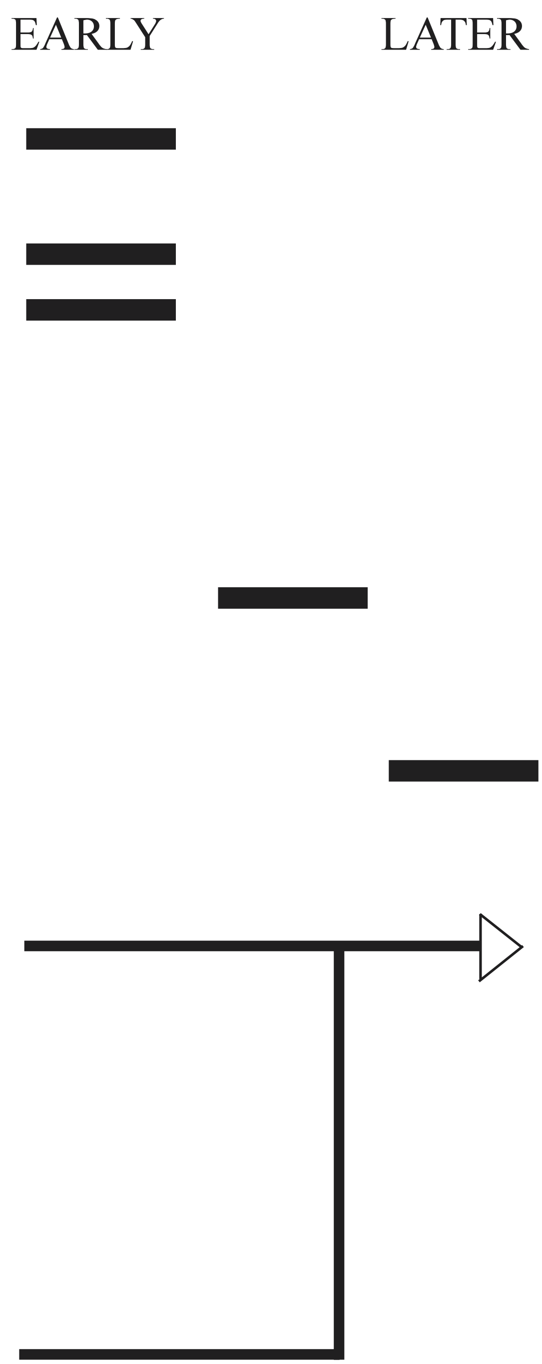


*Prelim. SS Delineation

*Design Data "Infrastructure"
    Estab. Monitoring Plan
        Well Locs/Types
        SPL Sched
    Ident Gage Locs.

"Infrastructure" Construction
    Install MW's, Gages

Collect Field Data
    Heads, WQ, Discharge

*Collect Other Data & Analyze
    Karst Features/Domains
    Photolineaments
    Land Use/Loads
    SW Basins
    Soils
    Hydraulic Parameters
    Tracers

*Data/Lit. Review

II

EARLY LATER

Develop Flow Models
- Est. Travel Times
- Inv. Particle Tracking
  - (& Forward)
- Calibration
  - Tracers
  - GW Age
- Validation

WQ Analyses
- (Hydrochem. Facies)

Pot. Surface Maps

I.D. Data Gaps

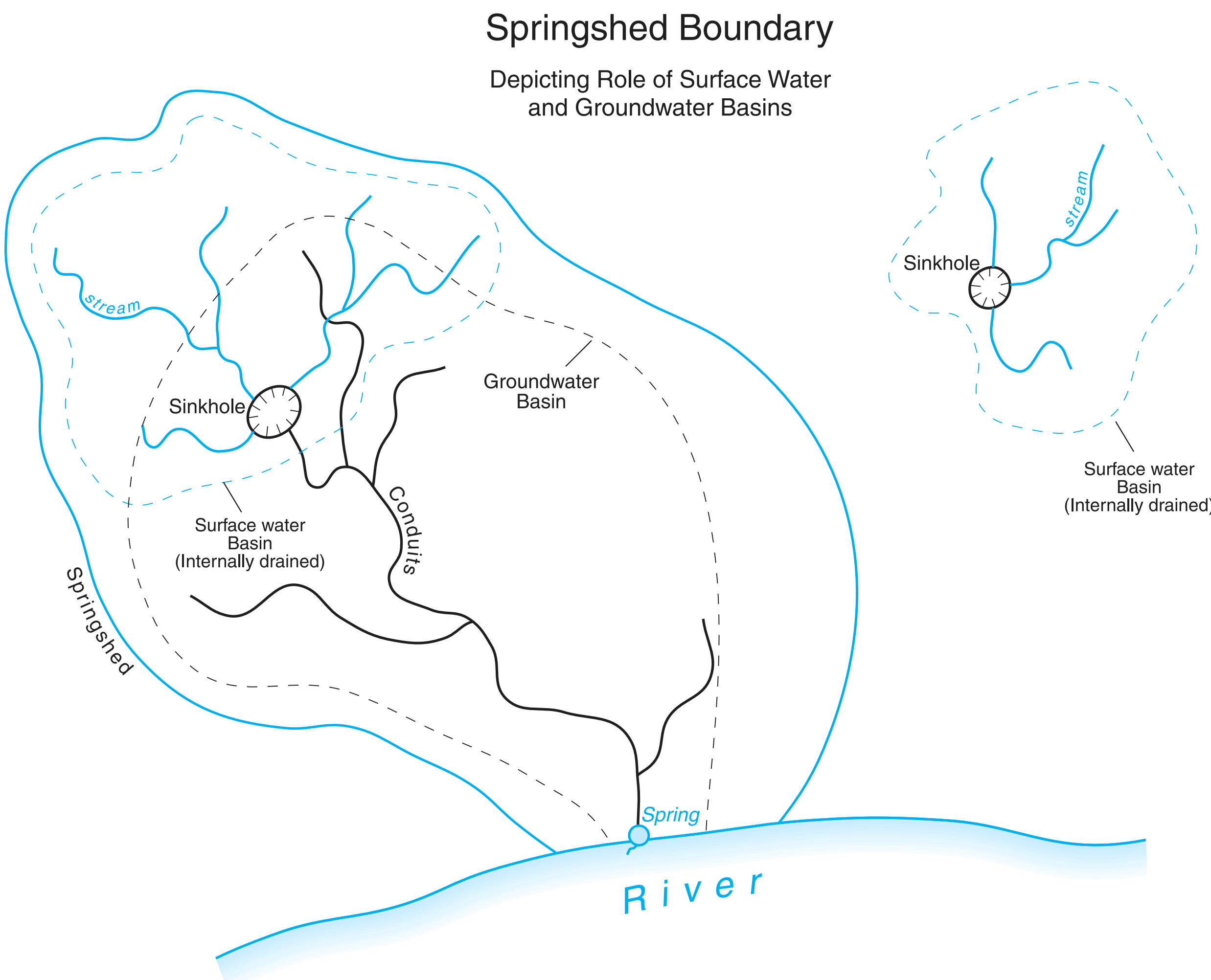
Long Term Monitoring

Late = 5 Years? 10 Years?

Data Sources: Mines, Wellfields, Landfills . . . .

Discussion of transport times in relation to establishing zones of protection

The faster the transport time of a contaminant from the land surface to the spring, the greater the vulnerability. This is not always clear based on proximity alone. For example, a sinkhole some distance away may be a direct conduit to the spring, but the connection will not be obvious until the conduits to a particular spring are mapped or until a dye trace test is conducted. Although preliminary springshed maps based on intuition and incomplete data may be somewhat inaccurate, they would be of value as a framework for environmental protection/management decisions and further, more refined research.



Revised Springshed Boundary