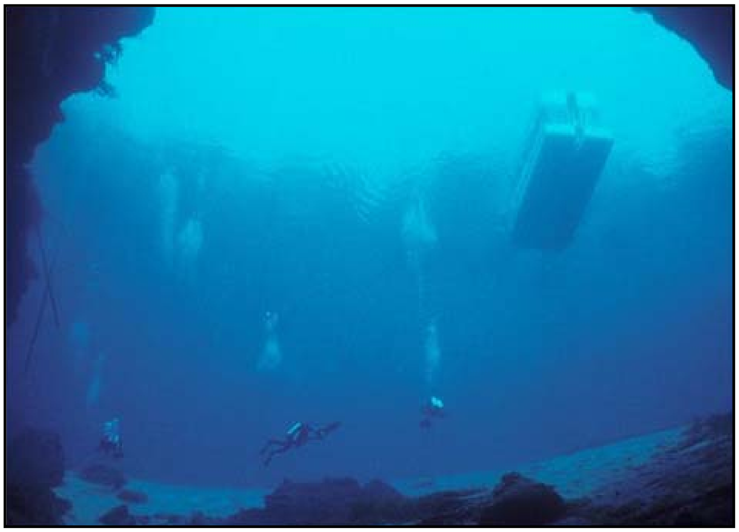
Karst Hydrogeology of the Woodville Karst Plain
Wakulla & St. Marks River Basins



Field Trip Guide
Trip Leader
Todd R. Kincaid, Ph.D.

Meet: 7:45 AM, Saturday Dec. 2, 2006
Florida Dep. of Env. Protection
Parking Lot, 2600 Blairstone Road,
Tallahassee

Contributing Organizations

Southeastern Geological Society S·E·G·S

FAPG

GUE Global Underwater Explorers

Hydrogeology Consortium

Hazlett-Kincaid, Inc. Specialized Geological Modeling Services

Itinerary & Overview Map

Be prepared for rain (rain jacket & small umbrella) and/or cold (jacket, hat, & long pants), wear comfortable walking shoes, bring sunscreen, hat, bug repellant, water, sunglasses and a snack or two.

Time	Stop	Agenda	Lat/Lon Distance
07:45 - 08:00		Meet at DEP Building - 2600 Blairstone Road, Tallahassee	
08:00 - 08:15		*Drive to Lake Munson Park*	8.5 miles
08:15 - 08:45	1	Lake Munson Dam / Tallahassee storm water runoff Walking Distance: ~ 0.30 miles	30.36488 °N 84.30180 °W
08:45 - 09:00		*Drive to Ames Sink*	4.6 miles
09:00 – 10:00	2	Ames Sink / tracer test results / overflow sinks Walking Distance: < 0.10 miles	30.31867 °N 84.29757 °W
10:00 - 10:10		*Drive to Leon Sinks Geological Area*	4.3 miles
10:10 – 11:40	3	Leon Sinks Geological Area - Sinkhole Tour Walking Distance: ~ 2.2 miles	30.30523 °N 84.34653 °W
11:40 - 12:10		LUNCH – Leon Sinks Geological Area	
12:10 – 12:15		*Drive to Emerald Sink*	0.7 miles
12:15 – 13:00	4	Emerald & Cheryl Sinks / cave explor. / remote sensing Walking Distance: < 0.50 miles	30.30308 °N 84.36900 °W
13:00 - 13:10		*Drive to Black Creek*	1.8 miles
13:10 - 13:40	5	Black Creek / sinking streams / tracer test results Walking Distance: < 0.50 miles	30.27873 °N 84.34293 °W
13:40 - 13:55		*Drive to Indian Spring*	7.4 miles
13:55 - 14:10	6	Indian Spring / cave siphon tunnels / and overflow springs Walking Distance: < 0.10 miles	30.25137 °N 84.32195 °W
14:10 - 14:20		*Drive to Wakulla Spring*	2.3 miles
14:20 - 15:00	7	Wakulla Springs State Park / cave explor. / cave metering Walking Distance: < 0.10 miles	30.23326 °N 84.30093 °W
15:00 - 15:20		*Drive to Lost Creek Sink*	12.3 miles
15:20 - 15:50	8	Lost Creek drainage and probable Spring Creek connection Walking Distance: ~ 0.3 miles	30.16635 °N 84.39530 °W
15:50 - 16:05		*Drive to Hatchet Sink*	6.7 miles
16:05 - 16:20	9	Hatchet & Bucket Sinks / coastal caves Walking Distance: < 0.10 miles	30.13090 °N 84.35123 °W
16:20 - 16:50		*Drive to Natural Bridge*	22.3 miles
16:50 - 17:20	10	Natural Bridge / groundwater - surface water exchange Walking Distance: < 0.10 miles	30.28426 °N 84.15084 °W
17:20 - 18:00		*Drive to Bird Sink*	25 miles
18:00 - 18:20	11	Bird Sink / underground flow of the St Marks River Basin Walking Distance: < 0.10 miles	30.48712 °N 84.04805 °W
18:20 - 18:45		Return to cars at DEP Blairstone Road	18.6 miles

Hydrogeologic Setting

Woodville Karst Plain

The Property is located in an extensively karstified topographic lowland known as the Woodville Karst Plain (WKP) that in turn, is part of a broader karst belt that extends around Florida's Big Bend from Ochlockonee Bay to Tampa Bay (Figure 2). Within this belt, the Floridan aquifer is unconfined and is therefore more vulnerable to contamination because the clay-rich geologic formations usually overlying the limestone formations in much of the rest of Florida have eroded away. The WKP constitutes the northwestern section of this karst belt and is defined by its western boundary in the Apalachicola Coastal Lowlands and the Steinhatchee River in the east (Scott et al., 2001). The WKP is a gently sloping and extensively karstified topographic lowland that extends from just south of Tallahassee in the north to the Gulf of Mexico in the south (Hendry and Sproul, 1966).

The geology of the WKP consists of a thin veneer of unconsolidated and undifferentiated Pleistocene quartz sand and shell beds overlying a thick sequence of relatively horizontal carbonate rocks that comprise the upper Floridan aquifer. Within the WKP, the karstification is intensified by surface water that flows from north of the region, where the aquifer is confined or partially confined by clay-rich sediments in the Hawthorn Formation and parts of the Torreya, Chipola, Tamiami, Jackson Bulff, and Micosukee Formations, onto the exposed carbonate rocks creating numerous dolines, sinkholes, karst windows, sinking streams and springs (Lane, 1986).

Recharge to the Floridan aquifer in the WKP occurs by: 1) sinking streams, 2) direct infiltration of precipitation through sinkholes, 3) infiltration through the variably thick sands and soils overlying the aquifer, and 4) groundwater flow into the WKP from the north. The Florida Department of Environmental Protection (FDEP) and Florida Geological Survey (FGS) are engaged in an effort to physically document all of the sinkholes and sinking streams within the WKP. To date, more than 400 ephemerally or perennially water filled sinkholes have been mapped in the northwestern quarter of the WKP by the FDEP. This suggests the presence of more than 1000 such features across the entire WKP. Of these 1000+ sinkholes, several are known to receive water, either perennially or ephemerally, from surface streams that drain upland regions, with flows ranging seasonally between 10^{-2} m^3/s and 100 m^3/s. The five largest such streams are, in order of relative average flow: Lost Creek, Fisher Creek, Munson Slough, Black Creek and Jump Creek in the western WKP. In the eastern WKP, the largest such sinking streams are the St. Marks River, Natural Bridge, Still Creek, Lake Drain Creek, Lloyd Creek and Burnt Mill Creek (not in order of relative average flow due to a lack of available data). Figure 1 shows the locations and orientations of all of these sinking streams.

Within the WKP, discharge from the Floridan aquifer occurs at springs in the southern and eastern parts of the basin and submarine springs in the Gulf of Mexico. The largest up-gradient discharges are Wakulla Spring, the St. Marks River Rise, and Wacissa Spring. All three discharges form the headwaters of the three largest rivers in the WKP, the Wakulla, Lower St. Marks, and Wacissa Rivers respectively. Significantly more data is available for Wakulla Spring than for the other two though it is not necessarily the largest of the three discharges. The average discharge from Wakulla Spring, as determined by a multi-year period of regular measurement is 11 m^3/s whereas fewer measurements collected from the other two indicate discharges of 12 m^3/s for the St. Marks Rise and 11 m^3/s for the Wacissa spring group (Scott et. al, 2002).

All three springs exhibit considerable fluctuations in discharge, which indicates that they are significantly influenced by local precipitation. Seasonal discharge from Wakulla Spring ranges from 0.7 m^3/s to 54 m^3/s (Scott et al., 2002), which is the largest reported range of discharge recorded for any spring in Florida (Rupert, 1988). Groundwater tracing to Wakulla Spring and regular flow measurements collected from numerous points within the Wakulla Cave system have revealed the large discharge fluctuations are primarily caused by local rainfall events. During these periods runoff flows into sinking streams to the west and north, which then flows rapidly to the spring through karst conduits (Kincaid et al., 2004; Kincaid et al., 2005; Loper, et. al, 2005). During low flow periods, groundwater flowing from a 2500 km^2, including parts of Leon, Wakulla, and Jefferson Counties and portions of five Georgia counties as far as 80 km north of the Florida-Georgia border (Gerami, 1994; Davis, 1996) accounts for the majority of the spring flow.

The largest down-gradient springs are the Spring Creek group of springs and the resurgence of the Aucilla River at Nutall Rise. The Spring Creek group includes at least 14 underwater vents along the coast of Apalachee Bay in the Gulf of Mexico. The combined discharge from all the vents ranges from 8.5 to 56 m^3/s (Scott et al., 2002), which is considered to be the largest spring in Florida. Less is known about the Nutall Rise, however the reported discharge is 10.2 m^3/s (Scott et al., 2002).

Regional groundwater flow is generally from north to south toward Apalachee Bay of the Gulf of Mexico. The large caves and spring discharges create troughs in the potentiometric surface, however that reflect convergence of flow into very high permeability karst conduits and even create localized south-north flow directions in the region between Wakulla and Spring Creek Springs (Figure 1). Though less is known about the shape of the potentiometric surface in the eastern part of the basin, it is believed that caves associated with the St. Marks River Rise and the Wacissa Spring group create similar complexities.

SIGNIFICANCE OF CAVES

Cave divers of the Woodville Karst Plain Project (WKPP) have mapped numerous underwater caves that trend for more than 16 km across the basin from north to south at depths ranging from 15 to 85 m (Werner, 2001). The five largest mapped caves in the WKP, ordered by length of mapped conduits, are: Leon Sinks Cave system (> 24 km), Wakulla Cave (>16 km), Chip's Hole Cave (>6.5 km), Indian Springs Cave (>3.5 km), and Sally Ward Cave (>2 km) – Figure 2. Conduit diameters within these caves range from less than 2 meters to greater than 30 meters and average approximately 10-15 meters (Kincaid, 1999; Werner, 2001). It has been hypothesized that a similar sized cave system exists in the Natural Bridge area (the Natural Bridge Cave System – NBCS), though until this project commenced, little effort had been invested in finding and exploring caves in that region.

Caves are both a consequence and control on groundwater flow through the WKP. The caves have formed over geologic time as a result of limestone dissolution by groundwater and provide exponentially more permeable pathways for groundwater flow as they develop. As such, cave development can be described as a positive feedback wherein dissolution increases permeability, which increases the preferential convergence of groundwater flow into the high permeability features, which then fosters more rapid dissolution. In the WKP, this process has resulted in dendritic cave systems that emanate from large single conduits at springs and trend upward into the basin splitting into more numerous and smaller conduits as they get farther from the springs.

The significance of this process to groundwater flow directions and velocities cannot be understated because, in essence, the caves are the primary conveyance system for the underground flow of water through the basin. The caves provide the mechanism by which surface water flows into the aquifer and travels rapidly to springs, which has been well documented by extensive groundwater tracing (Kincaid et. al, 2004; Kincaid et. al, 2005). The caves also provide the mechanism for convergence of older groundwater flowing from more distant recharge areas into spring capture zones, which is marked by well-defined troughs in the potentiometric surface around Wakulla Spring and the St. Marks River Rise (Chelette et. al, 2002). In both cases, the caves provide for very rapid flow (1/3 – 1 miles/day) to springs once water from either source enters the WKP (Kincaid et al., 2005; Hazlett-Kincaid, 2006).

In addition to conveyance, caves also provide a mechanism for exchanges of water between neighboring spring capture zones and within the aquifer matrix driven by changing water level conditions. During floods, a cave's conveyance capacity is dominated and can be overwhelmed by water from sinking streams. Under these conditions, water that would normally flow to a single spring can overflow into adjacent spring basins. In addition, the resulting gradients can also drive the very recent recharge from the caves into the surrounding aquifer matrix. Once the floods subside, flow conditions will return to an equilibrium condition wherein the exchange of water between neighboring basins is reduced or stopped and water from the aquifer matrix flows back toward the nearest conduits. The situation above can be accurately described as overlapping drainage basins wherein the degree of overlap depends on water level conditions.

The fundamental problem associated with the role of caves in the hydrology of the WKP, is the inability to locate and map the caves from the land surface, which significantly hinders effective groundwater sampling efforts. Traditional methods of groundwater sampling depend on the use of monitoring wells sparsely distributed around a basin that provide the ability to collect periodic water samples from what is thought to be a representative block of aquifer. Even in basins where caves are pervasive such as the WKP, the statistical likelihood of penetrating a cave with a well drilled from the surface is miniscule. The associated water samples will, therefore not be representative of the active groundwater flow through the aquifer but rather some body of water within the aquifer matrix that can be stationary for long periods of time before it finally flows into a cave. It is therefore becoming ever more clear to hydrogeologists and water resource managers that large springs (Wakulla, St. Marks Rise, Wacissa, Nutall Rise, Spring Creek, etc), rather than wells, provide the best means of sampling the water quality of an aquifer because their discharge represents a composite of all water sources in the basin. Moreover, springs and caves with numerous tunnels and access points like Wakulla, St. Marks Rise, Leon Sinks, and the NBCS provide the added ability to easily sample multiple points in the caves in the up-gradient direction from the springs and thereby potentially describe both composite and component water qualities.

CAVE & SPRING PROTECTION

A ten-year decline in water quality at Wakulla Spring and the ecological health of the spring basin (Chelette et al., 2002) has attracted considerable public and government attention and conservation efforts on protecting Wakulla Spring from further degradation. Part of this attention has focused on revising zoning ordinances, regulations on development and best management practices in an effort to minimize the potential impacts of development on the quality of water at Wakulla Spring. In this context, the most important aspects of protecting the spring should center on a determination of where and how water is recharged within the springshed and how a given development will likely impact the quality and mechanism of that recharge.

The decline of water quality at Wakulla Spring can be separated into two basic categories: 1) increasing tannin-stained water resulting in decreased water clarity, and 2) increasing nitrate loading resulting in the explosive growth of algae in the basin and possibly exacerbated problems with hydrilla (Loper et al., 2005b). Groundwater tracing demonstrates that the sinking streams along the western and northern margins of the WKP are the sources of dark tannin-rich waters in the spring discharge (Kincaid et al., 2005). It follows that developmental actions invoking a change in the rate or quantity of runoff to these sinking streams will impact the quantity and timing of dark tannin-rich water flow to the spring, thereby affecting the water clarity.

Determining the source of the increasing nitrate to Wakulla Spring has been a far more contentious issue than the dark water problem. The consensus of scientific opinion at present, however, has identified septic systems and the City of Tallahassee's wastewater spray field as the two predominant sources of nitrate in the spring discharge (Chelette et al., 2002; Loper et al., 2005b). Of those two sources, the City's wastewater spray field has been identified as the primary current source though septic systems represent a potentially more chronic and long-term problem (Loper et al., 2005b).

The most rigorous effort aimed at establishing guidelines for protecting water quality at Wakulla Spring was convened as a public workshop in 2005 entitled "Solving Water Pollution Problems in the Wakulla Springshed of North Florida." This workshop convened scientists, engineers, regulators, and other interested parties to present the most recent data describing the problems and debate the implications of that data for protection efforts and develop specific recommendations on how the government and public can most effectively endeavor to protect and restore water quality at Wakulla Spring (Hydrogeology Consortium, 2005; Loper et al., 2005b). Of those recommendations, the following guidelines summarize the recommendations from the workshop that we believe to be the most relevant to, and actionable by, private parties wishing to engage in development within the Wakulla Springshed section of the WKP.

- Delineate zones of aquifer vulnerability as defined by rapid recharge at sinking streams or sinkholes connected to the Floridan aquifer by conduits (via active sinkholes) and minimize surface water runoff into such features.
- Minimize the use of onsite waste disposal systems (septic systems) by using some form of centralized waste management system for all new developments whenever possible.
- Use only EPA rated Level 4 or Level 5 onsite disposal systems that can achieve at least 70% nitrogen reduction, 95% reduction in BOD and TSS, and 98% reduction of fecal coliforms when centralized waste management systems cannot be used.
- Protect high aquifer vulnerability zones through the use of conservation easements.

- Reduce development density to 5 acres or more when centralized waste water systems cannot be used.
- Make it a primary goal of all wastewater disposal activities in Leon and Wakulla Counties to reduce nutrient loading (nitrogen and phosphorus) to the aquifer.
- Reduce and eliminate, if possible, the use of fertilizers within the Wakulla Springshed.
- Engage in public education on the above recommendations to the long-term health of Wakulla Springs and its ecosystems.

In addition to these, we also suggest that all hydrogeological characterizations performed to evaluate the potential impacts of proposed developments to Wakulla Spring or other springs, such as the Natural Bridge Spring, St. Marks River Rise and Rhodes Springs, in the karst belt of Florida specifically focus on the hydrologic relationship between the karst conduits that convey water to the springs and the surrounding surface water and groundwater environments.

Many of the proposed actions suggested to help with the water quality degradation occurring at Wakulla Spring can be preemptively initiated to future residential and commercial developments in eastern Leon and Jefferson counties. The expansion of Tallahassee's residential communities eastward, for example Southwood and Piney Z Plantation, poses significant challenges to maintaining the quality and quantity of natural waters issuing from the springs of the Natural Bridge Cave System, St. Marks River Rise and adjacent springs such as Horn Spring, Rhodes Spring and Wacissa Spring.

Cave Systems

Leon Sinks Cave System (LSCS)

The LSCS is characterized by a series of 27 connected sinkholes and karst windows with total cave passage of 87,750 ft making it the longest underwater cave in the United States. Figure 3 provides a map of the explored extent of the LSCS as of August 2006. The majority of the conduits in the system are between -180 ft and -240 ft below the water table (Werner, 2001). Though passage enlargement is seen in some parts of the cave system, many of the passages are covered by extensive mineralization on the conduit walls, thus preventing further dissolution and passage growth. Recent dye tracing experiments have confirmed the hydrologic connection of LSCS with that of Wakulla Cave, wherein the combined system contains more than 150,000 ft of mapped conduits. Water flows through the cave from North to South at velocities of between a few hundred feet per day to more than a mile per day.

Natural Bridge Cave System (NBCS)

The NBCS currently has 15 connected karst windows and a total of 12,108 ft of explored cave passage that are less than -110 ft below the water table. Figure 4 provides a map of the explored extent of the NBCS as of June 2006. Further exploration has the potential to add several more miles to the above total, some of which may extend to deeper depths. Conduit walls contain little to no mineralization, which combined with the prevalent acidity of the water, indicates that the passages are actively enlarging. The westward section of the NBR-Tunnel system (NBR-4) is likely to connect to the Rhodes Springs (either #1, #2 and/or #4 as defined in Scott et al., 2004). The unexplored Rhodes Springs may contain significant lengths of passage radiating toward the northwest of the Property. The small spring vents to the west of the St. Marks River Rise will likely connect to Monroe Spring (karst window) and several other small karst window to the east on the adjacent St. Joe Company parcel. The Natural Bridge Spring likely has significant lengths of underwater cave passage that radiate toward the northeast. RQ-Tunnel continues with a likely trend of passage toward the east-northeast. This potential for significant underwater cave passage represents one of the greatest attributes of this cave system. Further exploration should elucidate the present passage trends and help to define the contributions of the localized groundwater basins.

By comparison, the NBCS appears to be younger than the LSCS based on observed passage depths and lack of mineralization, however both systems have similar hydrologic functions. Both contain a large and extensive network of conduits that connect numerous karst windows. Both have easily discernable connections to both recent recharge from sinking streams and older groundwater flow. Water flow through the cave is toward the St. Marks River Rise.

WAKULLA CAVE

Wakulla Cave is the second longest known cave in Florida and one of the largest in terms of conduit diameters. Exploration and survey of the conduits within Wakulla Cave began in the 1950's with the work of FSU students Gary Salsman and Wally Jenkins who made penetrations of up to 1000 ft into the cave. The U.S. Deep Cave Diving Team conducted some additional exploration and survey dives in 1987 and published the first comprehensive map of the cave system in 1989 (Stone, 1989). Since that time, Wakulla Cave has been extensively explored and surveyed by the Woodville Karst Plain Project (WKPP) who continue to explore and survey new passages and support scientific research in the cave at the present time.

The cave surveys conducted by these teams represent the best available data describing the length, trend, and morphology of the cave passages. Most of these surveys focused on measuring the trend, length, and depth of the cave passages with compass, knotted line, and depth gauge. Passage morphologies, in terms of width and height were typically estimated by the divers conducting the surveys and reported as notes in the survey logs. At numerous points in the cave, more detailed measurements of location and morphology have been collected with the use of cave radio transmitters, used to locate a particular point in the cave at the land surface, and hand-held sonar depth finders used to measure the distance from a survey station to the adjacent cave walls.

The data indicate that Wakulla Cave is comprised of a dendritic network of conduits that extend for more than 10.1 miles in the northeast, northwest, south and southwest directions from Wakulla Spring (Figure 1). All of the conduits are underwater and trend at depths of predominantly between –245 ft and –280 ft below the water table surface. The longest conduit, labeled A-Tunnel and O-Tunnel by the explorers, trends south from the spring / cave entrance for over 3.7 miles. M-, P-, and Q-Tunnels are other large conduits that trend for >0.8 miles, >0.7 miles, and >0.6 miles respectively in south-southwest directions from the southern part of the cave system. B-Tunnel and D-Tunnel, measuring >1.1 miles and >0.2 miles respectively, are the two largest tunnels that trend north from Wakulla Spring. The conduits can be roughly characterized as long tubes wherein the diameter and depth of any tube is relatively consistent though larger chambers of varying geometries typically divide individual or joining tubes (Kincaid, 1999; Werner, 2001).

Groundwater tracing and flow gauging within the conduits as well as observations from the cave explorers has shown that, under high flow conditions, the southern tunnels convey dark water from Fisher Creek, Black Creek, and Munson Slough to Wakulla Spring within ten to fourteen days of a precipitation event, whereas the northern tunnels convey clearer groundwater to the Spring (Macesich and Osmond, 1989; Kincaid et al., 2004; Kincaid et al., 2005; McKinlay, 2006). Scallop marks on the cave walls have been observed throughout the cave and indicate the persistence of large ground water flow velocities operating over extended periods of geologic time. Under baseflow (low flow) conditions, the cave explorers have reported southerly groundwater flow directions in the southern reaches of O-Tunnel, P-Tunnel, and Q-Tunnel. Together with the variability in water clarity and discharge at Wakulla Spring, these data and observations indicate that Wakulla Spring and Spring Creek Springs are discharges from a connected conduit network wherein the southern conduits in Wakulla Cave function as an overflow valve, delivering water to Spring Creek Springs under low flow conditions and overflowing to Wakulla Spring at higher flow conditions (Werner, 1998). This hypothesis is further supported by a strong and rapid correlation between sharp tidal fluctuations driven by the passing of Hurricanes Ivan and Francis in 2004 and discharge at the Wakulla Spring vent (Loper et al., 2005a).

References

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