Investigation of Salinity Increases in Sulphur Spring, Tampa, Florida

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Abstract

Sulphur Spring is located along the Hillsborough River in an urban area of Tampa, Florida. Survey and water quality data were collected from the spring cave system as part of salinity control investigation. The City of Tampa initiated the study because the spring is an emergency water source when the water level in the Hillsborough River is low. When water is pumped from the spring pool for the city water supply, the hydraulic head of the system is drawn down and the chloride concentration of the spring discharge increases. Therefore, water can only be pumped from the spring intermittently.

Survey data show that 25% of the surveyed passages in the cave system have a height to width ratio greater than 1 compared to less than 10% for typical phreatic caves in Florida. In fact, the median height to width ratio of the Sulphur Spring cave system is 0.64 compared to 0.33 for typical phreatic caves, suggesting some fracture controlled passage development.

Water quality data show the water in the system is well mixed. The only change in water quality occurs at a penetration of 2,800 feet where the passage splits into the Orchid Tunnel and the Alaska Tunnel. The Alaska Tunnel has higher temperature, lower pH, and higher salinity than the Orchid Tunnel. Based on salinity of the two flows, about 70 to 80% of the flow is from the Orchid Tunnel and 20 to 30% is from the Alaska Tunnel. The Alaska Tunnel appears to be the source of the majority of the saltwater and, therefore, chloride entering the cave system.

Background

Sulphur Spring is located in Tampa, Florida, approximately 7 miles north of downtown Tampa. The spring is located on the north side of the Hillsborough River in the NE, SE, NE of Section 25, Township 28S, Range 18E. The spring water has a distinct sulfide odor. It was a popular bathing spot for people hoping to cure ailments in the late 1800s and early 1900s. Historic flows from the spring from 1917 to 1959 were 8.34 to 71.1 million gallons per day with an average flow of 37 million gallons per day. In the 1980s the average flow was only 25 million gallons per day.

As the City of Tampa developed around Sulphur Spring, stormwater runoff increased. In an effort to control runoff, stormwater was routed to sinkholes that are directly connected to the spring. This resulted in fecal coliform levels in the spring pool that exceeded Health Department standards. The spring was closed to swimming in June 1986; however, the City continued to use the spring as a source of drinking water during dry periods when flow in the Hillsborough River was too low to allow withdrawal.

Studies have shown that spikes in bacterial levels in the spring coincide with rainfall events and travel times from known sinkholes receiving stormwater runoff. Travel times have been measured between 2 and 3 centimeters per second. (Historical data from Wallace RE, 1992.)

Current Study

Subsurface Evaluations, Inc. in cooperation with scientific research divers from the Coastal Karst Foundation have performed distance survey and water quality measurements in the Sulphur Spring cave system as part of the Sulphur Spring Salinity Control Investigation. The study was initiated because the City of Tampa uses the Spring as an emergency water source when the water level in the Hillsborough River is too low to meet demand. When the Spring discharge pool is pumped for the water supply, the hydraulic head in the pool is drawn down and the chloride concentration of the Spring water increases. As a result, water can only be pumped from the Spring intermittently to prevent excessive chloride levels in the City's drinking water. The purpose of this investigation is to identify discrete locations where high salinity water enters the cave system. The objective of the investigation is to assist in evaluating methods for obtaining freshwater with lower salinity and chloride concentrations from the spring.

Methods

K. Michael Garman, PG, PE, was the lead diver for survey and water quality data collection. Other volunteer certified cave divers assisting with data collection included Sherry Garman, Jitka Hyniova, Jakub Rehacek, Andy Conneen, Alex Warren, Brice McMinn, David MacDonald, and Doug Daniel.

Distance Survey

The distance survey was performed by placing a braided nylon guideline along the floor near the center of the cave passage. The guideline was tied and secured to rocks or PVC stakes placed by divers. At every line tie-off or change in line direction by rubbing the cave wall, a survey station was marked. At each survey station, the depth of the line was noted and a compass reading was taken along the line to obtain the azimuth to the next station. Distances between stations were measured with a fiberglass tape. The survey data were input into the Compass mapping program to create a scaled plot of the survey data.

Positions within the cave system were located on the ground surface by performing a cave radio survey. A three-person dive team carried a cave radio beacon composed of a barium-ferrite magnet wrapped by copper wire through which a small current was passed. The beacon was carried in a vertical position to allow accurate position readings at the surface. The dive team used diver propulsion vehicles to travel through the cave system and paused for about two minutes every 200 feet along the cave passage. When the divers paused, the beacon was held stationary in a vertical position to allow the surface team to obtain an exact position and catch up to the dive team. The lead diver, Jitka Hyniova, located the distance markers within the cave system and blocked the flow from moving the beacon at the pause locations. The second diver, Michael Garman, carried the beacon. The third diver, Sherry Garman, maintained contact with the guideline when the other divers were positioning the beacon at the pause locations.

On the surface, Brian Pease tracked the divers using a metal loop antenna receiver connected to an audio system with variable sound intensity based on proximity to the beacon within the cave system. Shane Dunn followed Mr Pease with a Trimble differential GPS system to record the locations identified by the cave radio system. Mr Dunn also marked the locations with orange spray paint.

Water Quality Measurements

Water quality data were collected using a DataSonde 3 data logger manufactured by the Hydrolab Corporation in Austin, Texas. The data logger measured temperature, pH, depth, specific conductivity, salinity, and dissolved oxygen concentration. The DataSonde 3 was attached to the front of the diver propulsion vehicle used by the lead diver or hand carried in front of the lead diver so that divers' exhaust bubbles, which have a high oxygen concentration, would not influence the readings.

The DataSonde 3 is serviced and calibrated at the factory regularly. Prior to each dive, the pH and specific conductivity meters were calibrated using standard solutions provided by the manufacturer and the dissolved oxygen sensor was calibrated using a water saturated air method. The manufacturer's reported accuracy for the DataSonde 3 is:

- Temperature $\pm$ 0.10C;
- pH $\pm$ 0.2 standard units;
- Depth $\pm$ 0.3 meters;
- Specific conductivity $\pm$ 1% of reading;
- Salinity $\pm$ 0.2 parts per thousand (ppt); and
- Dissolved oxygen $\pm$ 0.2 milligrams per liter (mg/L)

Results

Observations

The Sulphur Spring cave system is unique for spring cave systems developed in the Floridan aquifer. The Sulphur Spring cave system receives a high input of biogeochemical oxygen demand from contaminants and detritus carried directly into the cave system by stormwater discharged to sinkholes that are directly connected to the cave system. As a result, the cave system is anoxic to microoxic and dark gray microbial mats composed of anaerobic bacteria coat all hard surfaces within the cave system. The mats form finger-like projections that hang down from the walls and ceilings. Similar mats are frequently observed on the walls of anoxic sinkholes in Florida.

Discrete saltwater vents in the cave system are easily recognizable by the presence of white, filamentous, sulfur oxidizing bacteria, which surround the vents (Photo 1 through 3). This is an indicator that the vent water contains hydrogen sulfide. Sulfide is available to chemolithotrophic sulfur oxidizing bacteria as an electron donor in energy producing biologic reactions that use oxygen or nitrate as an electron acceptor.

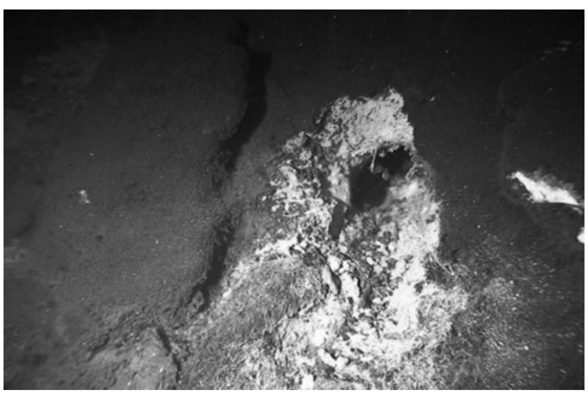

Photo 1: Small saltwater vent, diameter is 5 centimeters.

Photo 2: Distortion from halocline is visible in close-up of vent.

Photo 3: Collection Hydrolab data from a vent.

One side room less than 300 feet penetration from the entrance has carbonate crystals actively precipitating underwater (Photo 4). This room is known as the Crystal Room. Just downstream of the Crystal Room is another small room, the Black Room, which is coated by black mineral precipitates, possibly metal sulfides (Photo 5).

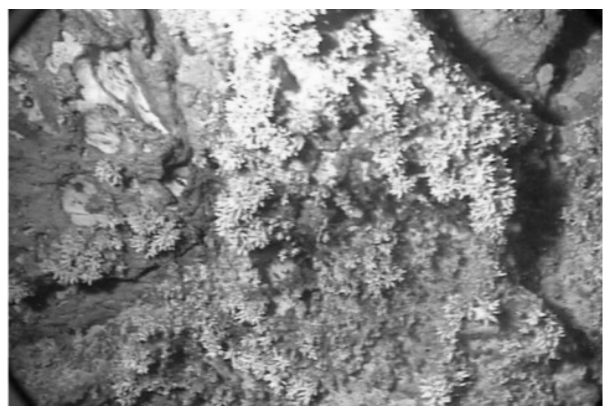

Photo 4: Low magnesium calcite crystals forming underwater in the Crystal Room in Sulphur Spring Cave System. Crystals are about 2 to 5 centimeters long.

Distance Survey

The 3,376 feet of survey data compiled to date show that the cave system generally trends north along Nebraska Avenue (Figure 1). At the main split in the cave passage in the Terminal Room 2,800 feet from the entrance, the Orchid Tunnel continues north while the Alaska Tunnel trends southeast. The survey statistics are shown in Table 1. The estimated volume of the surveyed cave is 327,134 cubic feet.

The cave conduit (passage) height distribution, width distribution, height to width ratio, and area distribution are shown on Figures 2 through 5 and Table 2. These data are particularly interesting because more than 25% of the

Photo 5: Black Room in Sulphur Spring Cave System. Possible deposition of metal sulphides may increase pH leading to calcium carbonate deposition in adjacent Crystal Room.

surveyed passages in the Sulphur Spring cave system have a height to width ratio greater than 1 compared to less than 10% for all phreatic caves in Florida (Figure 6a). In fact, the median height to width ratio of the Sulphur Spring cave system is 0.64 (Table 2) compared to 0.33 for all phreatic caves in Florida.

Water Quality Measurements

The water quality data collected with the DataSonde 3 on seven different days (Novem-

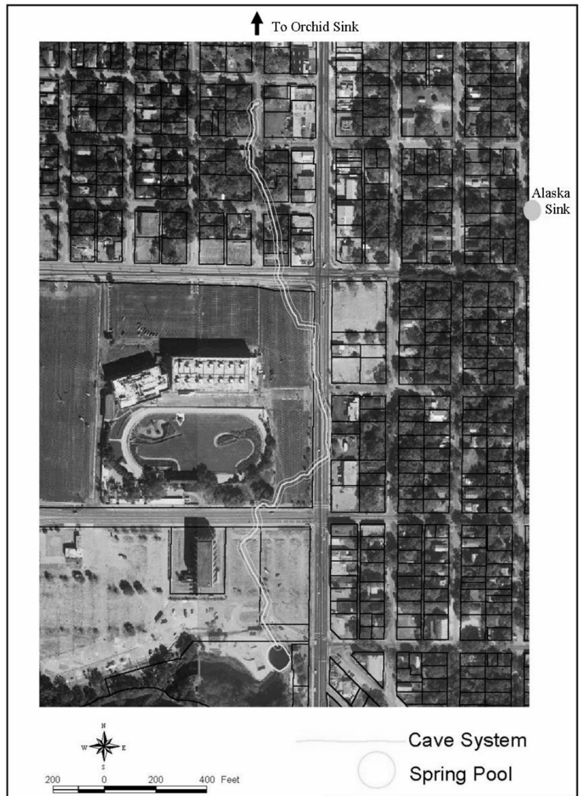

Figure 1. Location of Sulphur Spring Cave System based upon cave radio data points. Survey performed by Subsurface Evaluations, Inc. (SEI) on February 8th, 2003.

Table 1: Data Summary

Number of Files =	1	Station Aliases =	3
Number of Surveys =	2	Number of Stations =	209
Included Shots =	212	Excluded Shots =	0
Ignored Shots =	0	Number of Loops =	0
Absolute Stations =	1		
Included Length =	3,376.0 feet	1,029.0 meters	0.64 miles
Excluded Length =	0.0 feet	0.0 meters	0.0 miles
Total Surveyed =	3,376.0 feet	1,029.0 meters	0.64 miles
Horizontal Length =	3,194.0 feet	973.5 meters	0.60 miles
Horizontal Excluded =	0.0 feet	0.0 meters	
Cave Depth =	117.0 feet	35.7 meters	
Surface Length =	412.9 feet	125.9 meters	
Surface Width =	2,573.9 feet	784.5 meters	
Surface Area =	1,062,814.0 feet^2	98,738.6 meters^2	
Enclosed Volume =	124,346,860.3 feet^3	3,521,111.0 meters^3	
Cave Volume =	327,134.0 feet^3	9,263.4 meters^3	
Average Diameter =	9.8 feet	3.0 meters	
Volume Density =	0.26%		
Average Inclination =	10.9 degrees		
Difficulty =	14.6		

Highest Station =	ss1	0.0 feet	0.0 meters
Lowest Station =	ss116	-117.0 feet	-35.7 meters
North Most station =	ss2088	10,177,114.6 feet	3,101,984.5 meters
South Most station =	ss1	10,174,540.7 feet	3,101,200.0 meters
East Most Station =	ss111	1,169,605.4 feet	356,495.7 meters
West Most Station =	ss36	1,169,192.5 feet	356,369.9 meters
Average Shot Length =	16.2 feet	4.9 meters	
Longest shot =	69.0 feet	21.0 meters	
Shortest shot =	1.0 feet	0.3 meters	

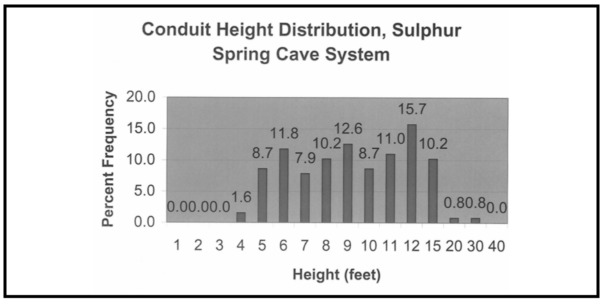

Figure 2

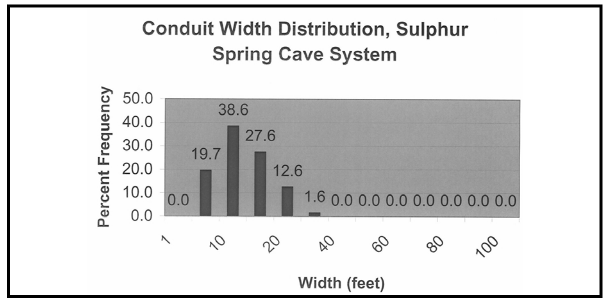

Figure 3

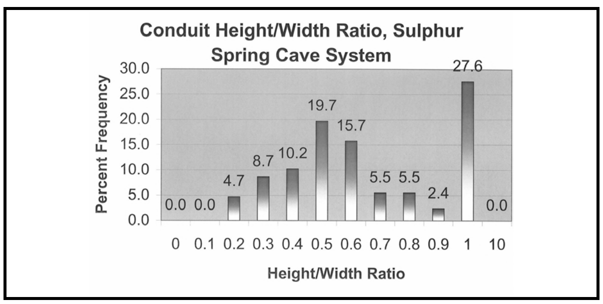

Figure4

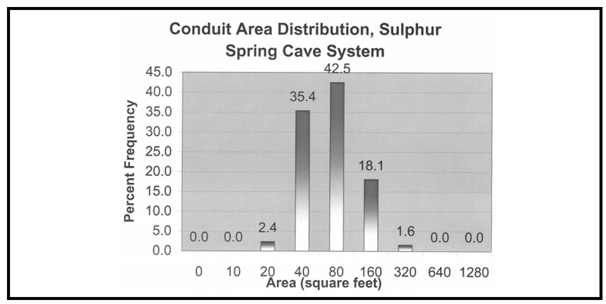

Figure5

Table 2: Sulphur Spring Cave System Water Quality Data			+
Parameter	**Main Tunnel**	**Orchid Tunnel**	**Alaska Tunnel**
Temperature (C)	24.3 to 25.2	24.3 to 25.15	24.3 to 25.3
pH (standard units)	6.73 to 7.12	6.73 to 7.25	6.62 to 6.97
Salinity (ppt)	1.1 to 2.2	0.9 to 1.4	1.8 to 4.4
Dissolved oxygen (mg/L)	0.00 to 0.08	0.00 to 0.08	0.00

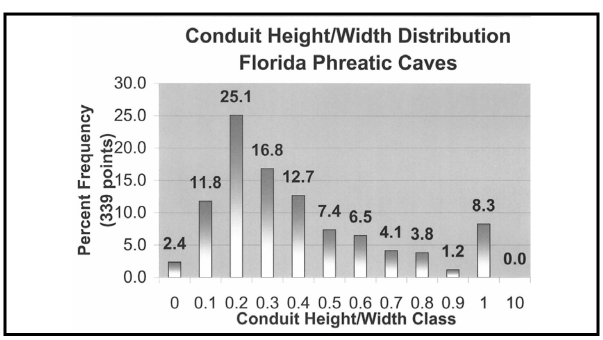

Figure6a

ber 15, 1998, June 27, 2001, July 7, 2001, July 21, 2001, October 14, 2001, December 22, 2001, and January 2, 2002) are summarized below. A typical data set, showing temperature, pH, salinity, and dissolved oxygen versus distance from entrance, is included as Figures 6 through 9. Typical values for these parameters are shown in Table 2.

From the spring discharge pool to the Terminal Room, the water in the cave system is well mixed. The only significant change occurs where the Main Tunnel splits into the Orchid

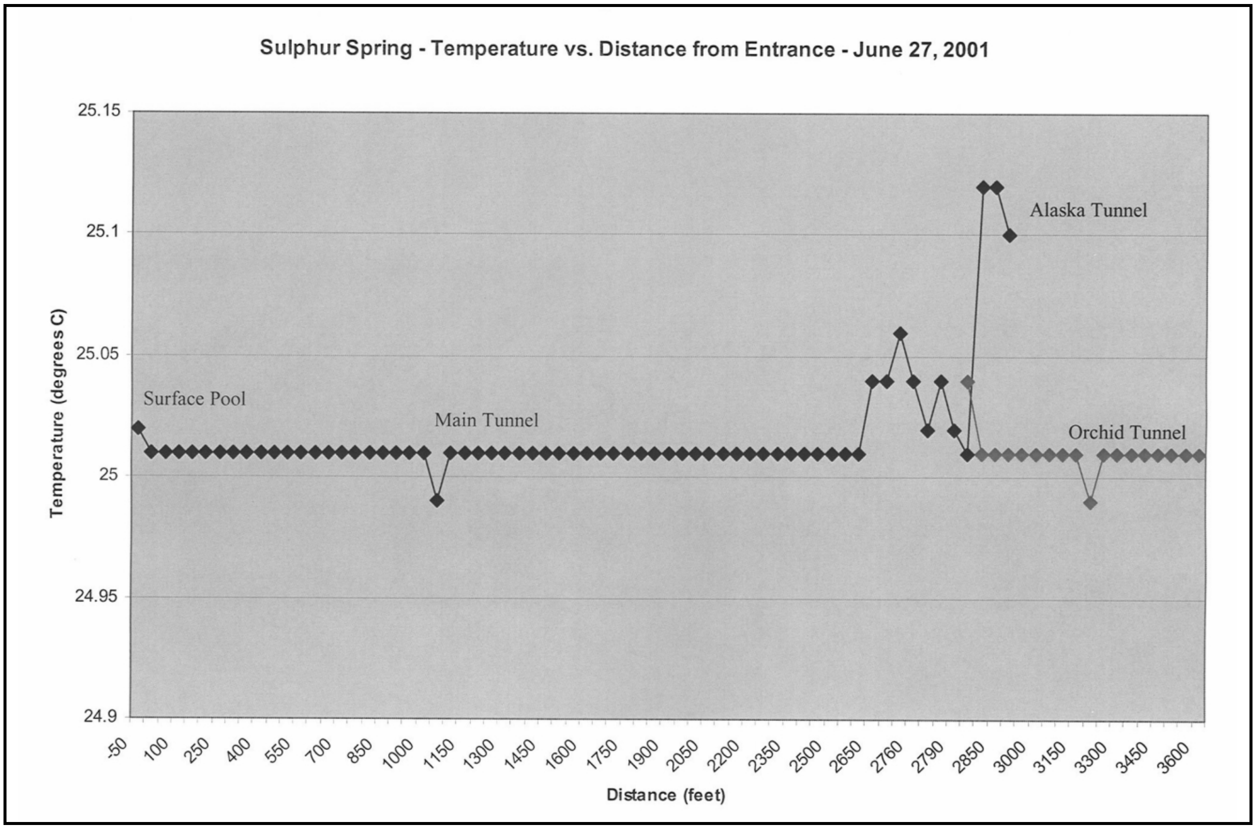

Figure 6

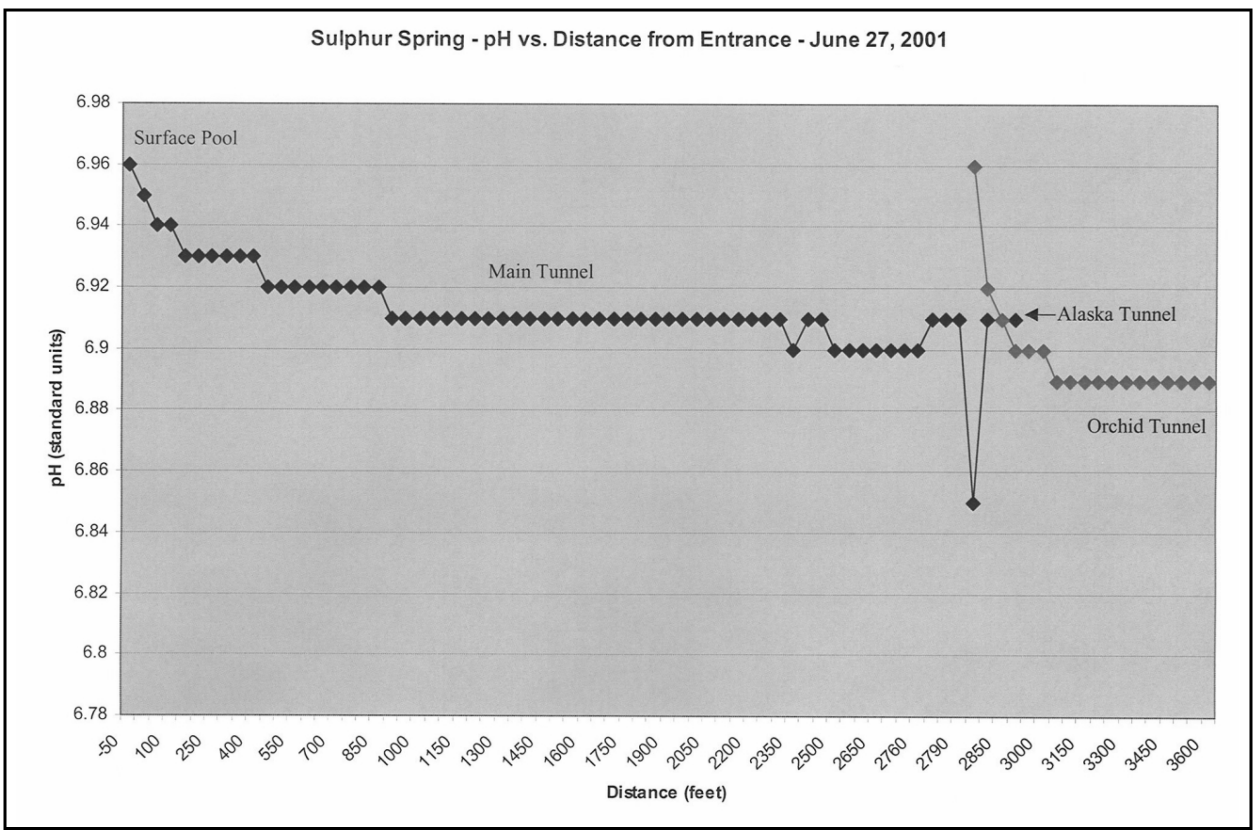

Figure 7

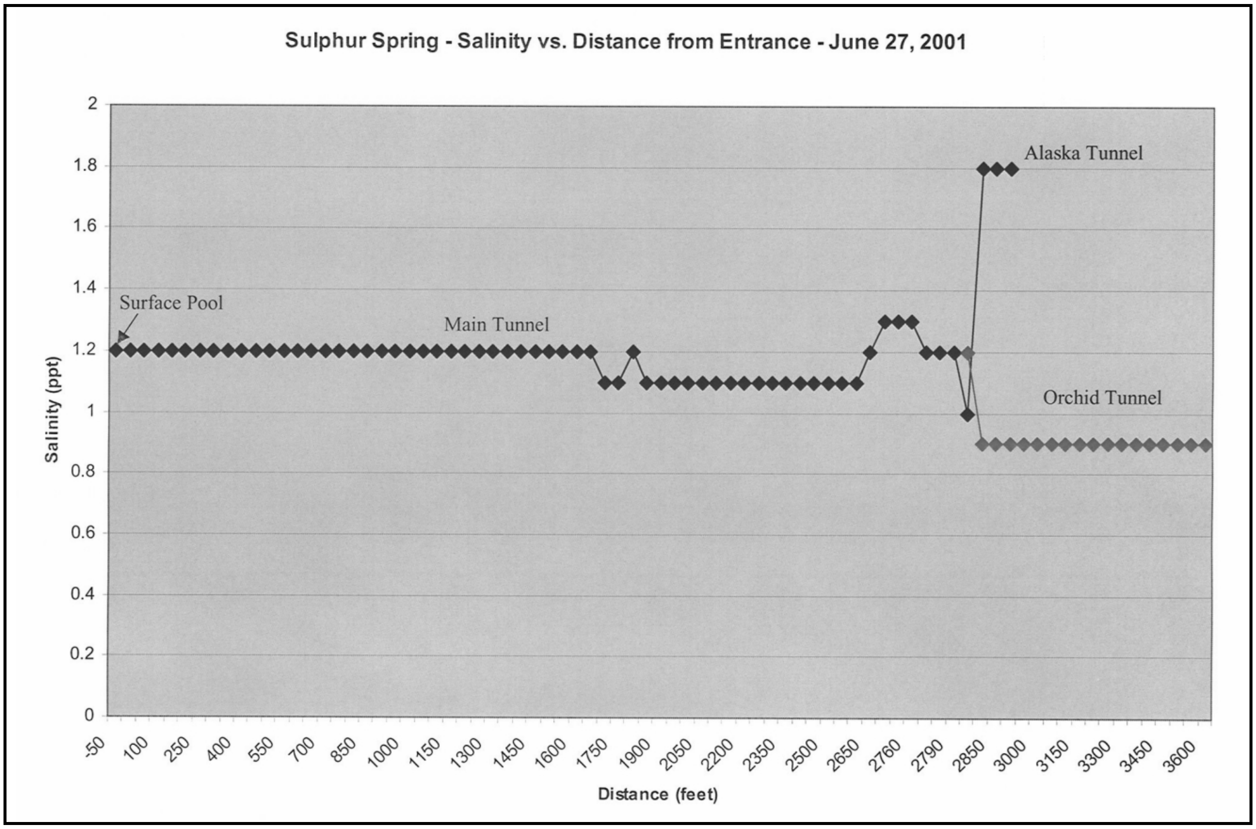

Figure 8

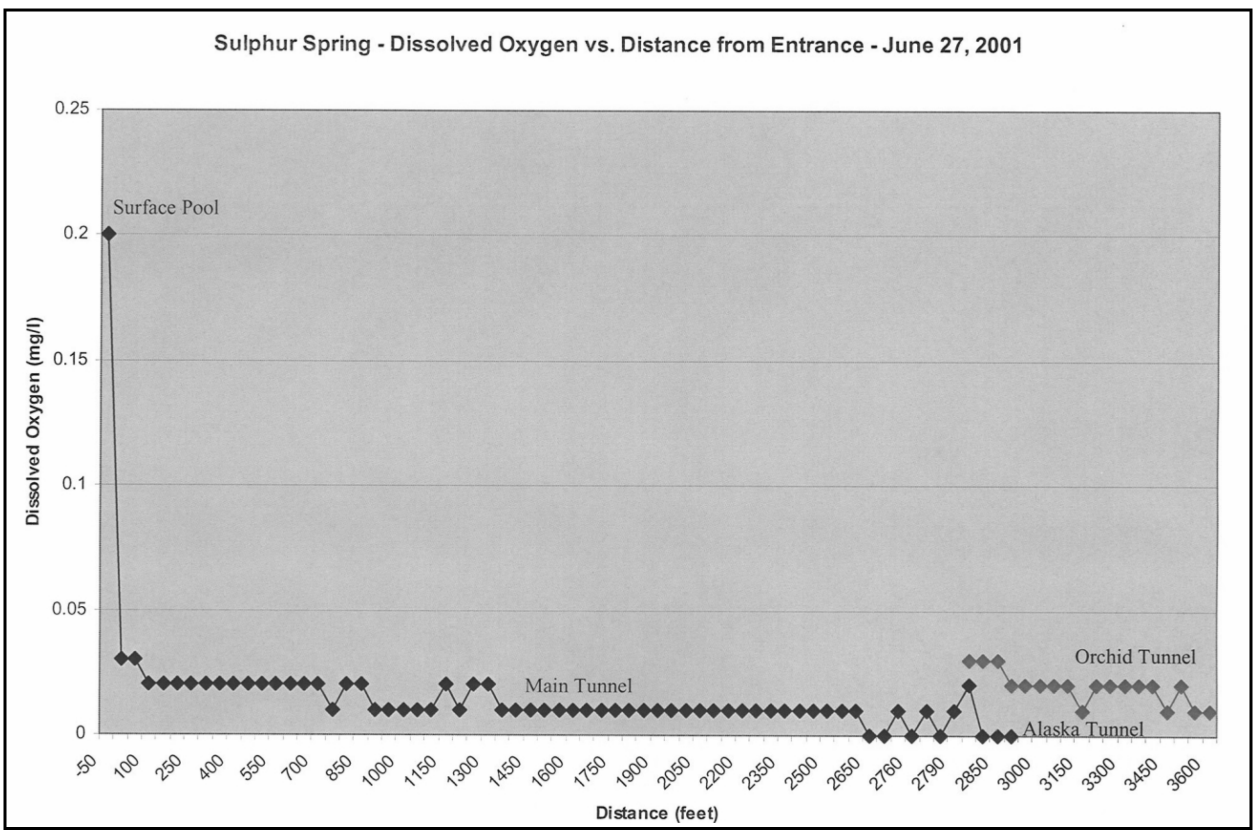

Figure 9

Tunnel and the Alaska Tunnel at the Terminal Room. The Alaska Tunnel generally has higher temperature, lower pH, and higher salinity than the Orchid Tunnel. The values vary some depending upon the influx of rainwater. Data-Sonde 3 data show that the flows from these two tunnels completely mix within about 200 feet of the junction because of the turbulent flow in the cave system. Based on salinity and conservative mixing of the two flows, about 70 to 80% of the flow is from the Orchid Tunnel and 20 to 30% is from the Alaska Tunnel (Table 2). The water in the entire cave system is anoxic or microoxic with values less than 0.10 mg/l in the cave system.

During 2001 and early 2002, one discreet saltwater vent was identified in the Alaska Tunnel approximately 3,017 feet from the entrance. The vent did not flow continuously and when saltwater was observed in the vent there was no measurable flow. The saltwater accumulated in the vent on the floor and was slowly mixed into the flow of the tunnel by the passing turbulent flow. The water quality from the active vent was measured on October 14, 2001, and January 6, 2002. Following a year of above normal rainfall, water quality data were collected on September 21, 2003. At this time, two discreet saltwater vents were identified in the Main Tunnel at penetrations of 144 and 335 feet. The values are shown in Table 3.

The salinity and temperature from the vents were higher than the Alaska Tunnel water and the pH was lower.

The temperature and pH readings from the Crystal Room are extremely high compared to the rest of the cave system and the salinity is lower. Just downstream of the Crystal Room in the Black Room, the pH values are the same as the typical readings from the cave system but the temperature and salinity are elevated.

Table 3: Sulphur Spring Cave System, Vent Water Quality Data

Parameter	**Alaska Tunnel Vent**	**Main Tunnel Vent**
Temperature (°C)	25.67 to 26.05	25.49
pH (standard units)	6.39 to 6.47	6.41
Salinity (ppt)	14 to 17.7	15.1
Dissolved oxygen (mg/l)	0.00	0.02

Table 4: Sulphur Spring Cave System Crystal and Black Room Water Quality Data

Parameter	**Crystal Room**	**Black Room**
Temperature (°C)	26.63 to 26.72	25.42 to 25.50
pH (standard units)	8.54 to 10.3	6.78 to 6.81
Salinity (ppt)	1.3 to 1.6	5.5 to 6.6
Dissolved Oxygen (mg/l)	0.00	0.00

Discussion

The unusually high height to width ratio of the Sulphur Spring cave system is probably because it is located in an area of proposed faulting along the Hillsborough River. This would cause the cave passages to develop along vertical fractures resulting in passages that are taller than they are wide. Typically, bedding plane features control phreatic cave development in Florida, resulting in cave passages that are wider than they are tall. Even though Sulphur Spring is located in an area of possible fractures, bedding plane development still dominates the cave passages, as the majority of the passages are wider than they are tall.

The Alaska Tunnel appears to be the source of the majority of the saltwater and, therefore, chloride entering the cave system. Even though only one discreet saltwater vent has been identified in the Alaska Tunnel, the water in the Alaska Tunnel is typically more than twice as saline as the water in the Orchid Tunnel, whether saltwater was flowing from the vent or not.

The presence of discreet saltwater vents in the Main Tunnel did not appear to affect the water quality of the Main Tunnel flow. Water from the vents does not flow into the cave system but slowly mixes in the turbulent flow. No changes in the water quality of the flow in the Main Tunnel are detectable between locations downstream and upstream of the vents.

It seems likely that the fractures in the area allow saltwater from deep in the aquifer to leak upward into the Sulphur Spring Cave System, which is in the freshwater zone of the aquifer. The fact that the saltwater vents remain active after above-normal rainfall during 2003 indicates that the aquifer, which is the source of the sulfidic saltwater, is receiving above normal recharge just like the shallow Floridan aquifer, which is the primary water source for Sulphur Spring.

The chemistry of the Crystal Room appears to be related to the production of sulfide-rich water from anaerobic respiration of organic matter by sulfate reducing bacteria. When the hydrogen sulfide degasses by reaction with oxygen or metals, the pH increases, the carbonate anion is the dominate form in solution, and calcium carbonate precipitation occurs. The degassing and precipitation reactions appear to be occurring in the Crystal Room. If chemolithotrophic sulfur oxidizing bacteria were present, such as are present at the saltwater vents, they produce sulfate and sulfuric acid by using sulfide as an electron donor resulting in pH decrease and, thereby, preventing calcium carbonate precipitation (Castanier S *et al*, 1999).

Recommendations

Based upon the data collected to date, it does not appear to be feasible to seal discrete saltwater vents and have a noticeable reduction in the salinity of the water in the cave system as a result. It appears that the best method for collecting fresh, less saline, water from the cave system would be to install a well in the Orchid Tunnel upstream of the junction with the Alaska Tunnel.

Acknowledgements

The Coastal Karst Foundation coordinated the volunteer research diving in Sulphur Spring. The research diving was supported by the National Association for Cave Diving (research and exploration fund), American Underwater Lighting (lights, line, line arrows), Liquid Fit (wet suits), Watermark Scuba – Sea Soft (hoods, booties, gloves), Advanced Diver Magazine, Cochran Undersea Technology (dive computers), and Clay Creek Products (dive bags).

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