Campbell, C. Warren; Abd El Litif, Mohamed and Foster, Joseph W.—Application of Thermography to Karst Hydrology. Journal of Cave and Karst Studies 58(3):163-167.

APPLICATION OF THERMOGRAPHY TO KARST HYDROLOGY

C. Warren Campbell and Mohamed Abd El Latif
Department of Civil and Environmental Engineering, The University of Alabama in Huntsville
Huntsville, AL 35899, campbell@ebs330.eb.uah.edu

Joseph W. Foster
SAIC, Navarre, FL 32566

Thermography was used to locate hydrological "features" in karst watersheds. The approach was demonstrated by flying a thermal camera over the Keel Mountain area of north Alabama. Known features were identified and features not on United State Geological Survey topographic maps and unknown to the authors were discovered. Springs with flow rates less than 3 liters/sec and a region of strong infiltration in a losing stream were easily identified.

Many authors have discussed the need for karst hydrogeologic inventories preceding quantitative dye traces in karst areas. For example, Jones (1984) recommends collection of all available geologic and hydrologic data for the watershed, including United State Geological Survey (USGS) topographic maps, previous hydrogeologic studies, and data collected by the investigator. All karst features including swallets and resurgences should be located and flow rates should be measured. Unfortunately, topographic maps do not show most of the springs in a watershed, and time consuming and exhaustive field work is often required to find the most important hydrologic features. Any method that could reduce field work is desirable. We will show herein how thermography can focus field work and speed karst hydrology investigations.

This paper describes the application of airborne thermography in locating karst hydrologic features on Keel Mountain in the Cumberland Plateau region of north Alabama. Though the methods described here can be applied in any karst area, Keel Mountain and Horse Cove were studied because the endangered Alabama cave shrimp (*Paleamonaias alabamae)* is found in Hering Cave there and an understanding of the hydrology is important for protection of the species.

Earlier studies have investigated thermography for locating springs. Bogle and Loy (1995) used thermography to locate submerged springs in a reservoir. Rinker (1975) used thermography to investigate the Greenland glacier and the Puerto Rican karst in an attempt to find underground cavities. Warren and Wielchowsky (1973) of the Geological Survey of Alabama used infrared photography, thermography, and side-looking radar to locate sinkholes and ponors, predict potential sinkhole collapses, and map faults, strikes, lineaments, and regional geological structures. These studies have proven the ability of thermal cameras to find karst features. The present study shows that thermography can be used to find very small features in the southeastern United States.

Keel Mountain, an outlier of the Cumberland Plateau, lies in eastern Madison and western Jackson Counties in north Alabama. The mountain is capped by the impermeable Pottsville Formation (sandstone, shale, coal) of Pennsylvanian age which forms the upper 50 to 70 m of the mountain. Below the Pottsville Formation are a series of Mississippian limestones. The mountain stands about 300 m above surrounding land. Numerous cave entrances, springs, pits, and sinkholes are found on the flanks of the mountain. Horse Cove is incised into the southwestern quadrant of the mountain.

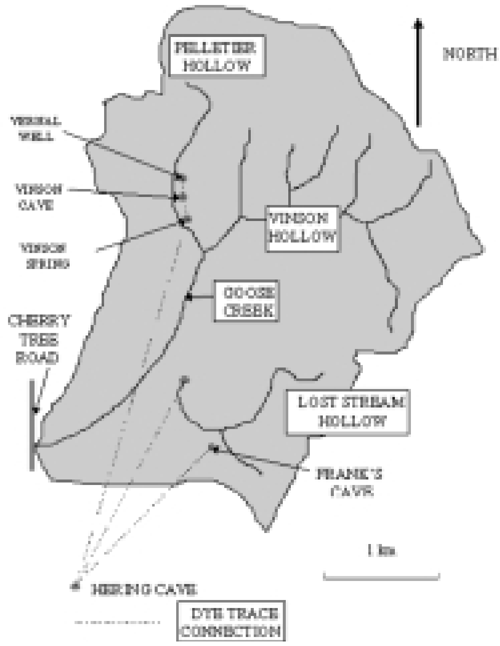

Figure 1. Horse Cove area showing hydrologic connections established by dye tracing.

Description of Horse Cove

Figure 1 shows Horse Cove, Hering Cave, and the known connections between caves, sinkholes, and springs which were determined from dye trace studies. The Horse Cove surface watershed is approximately 17 square kilometers (6.5 square miles). Surface topography implies that runoff from Horse Cove would discharge from Goose Creek. Estimates based on runoff for north Alabama show that the average annual flow from Goose Creek at Cherry Tree Road should be about 280 liters/sec (10 cfs) (LaMoreaux and Chermock, 1975). In fact, the flow from Goose Creek is much less than 3 liters/sec (0.1 cfs). Dye trace studies performed by the Geological Survey of Alabama (McGregor et al., 1994) show that most of the Horse Cove runoff (~ 70% to 80%) flows from Hering Cave which is outside of the Horse Cove surface watershed.

Developing a hydrologic model for pollution studies requires the identification of as many hydrologic “features” as possible. This includes locating as many springs, swallets, cave entrances, and infiltration points in streams, which may affect the water quality within the Hering Cave system.

Researchers from the University of Alabama in Huntsville have done many hours of field work in Horse Cove. The terrain is rough, and landowners limit access to some areas. This field work has resulted in the discovery of two swallets, two previously unknown caves, several infiltration points in stream beds, and several springs. None of these were indicated on USGS topographic maps.

We believed that airborne thermography could locate even more karst features. Since caves and springs are often warmer than the surroundings, thermography could be used to locate these features during times when the surface air and water temperatures were much lower than the springs.

Keel Mountain Thermography

Every object emits thermal radiation. Our eyes are sensitive to wavelengths as long as 0.7 *u*m (10^{-6} m). The light emitted by a surface depends on its physical characteristics and on its temperature. As a surface warms up, it emits at shorter wavelengths and higher energies. Neglecting changes in the emission properties of materials, warmer objects appear brighter on thermal images.

The MICOM thermal camera is similar to a Camcorder except that it is sensitive to thermal infrared wavelengths. The camera has a starring focal plane containing a fixed array of tiny radiation sensitive elements (“eyes”). This camera has a square array with 512 rows of 512 elements (~262,000 elements total). The adjective starring indicates that the matrix of “eyes” is fixed. The camera provided gray level data on VHS format with a field of view of 11º by 14º and a 2 to 5 mm sensitivity, yielding a temperature sensitivity of less than 0.1º C.

Three flights were conducted for this study. Flight altitudes ranged from 150 m to 800 m above ground level (AGL) with an average of about 500 m AGL. Typically, the images covered areas on the ground of approximately 1 hectare. The first two flights were at low altitude to assure enough resolution to see at least some features. A cloud deck at 1000 m AGL forced the third flight to low altitude.

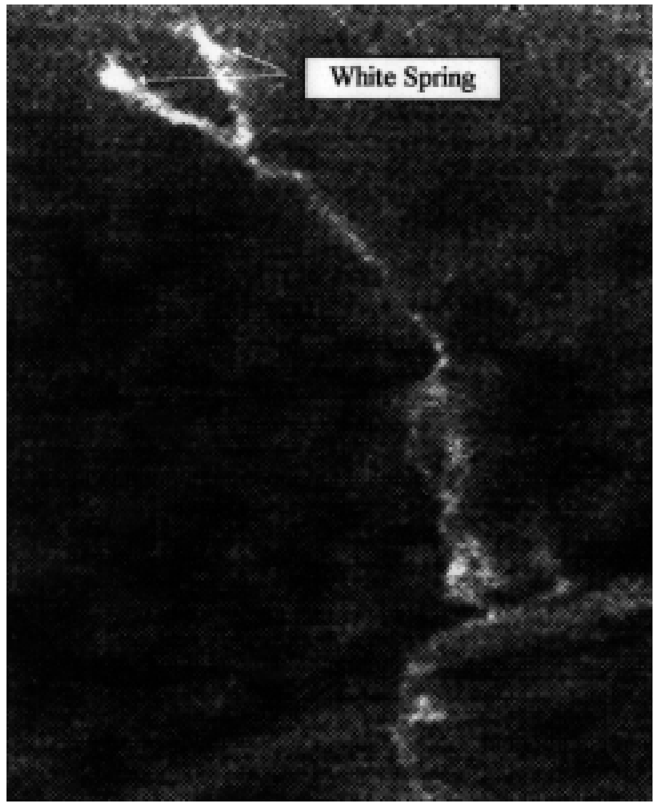

Figure 2. White Spring thermography.

Because of budgetary constraints, the flights were not in the best weather nor during the best time of day. The best conditions would be just before sunrise on a very cold clear winter day.

The first flight was between 6:00-7:00 PM CST on February 24, 1995. The weather was clear and with a flight time temperature at Huntsville Airport of 5º C (40º F). Despite the less than ideal conditions, the first flight identified the double spring (White Spring) shown in Figure 2. This image was captured when flying at an altitude of 650 m above mean sea level (MSL) (150 m - 500 m above ground level [AGL]). We interpreted the image to be a large double spring which joined and flowed down the mountain.

One of us (CWC) found the spring with help from landowners a week after the flight. From its size on the thermograph, we expected a very large spring, instead, it was very small, the right (west) fork being an area of seepage. On this day, the flow was approximately 2.8 liters/sec (0.1 cfs) or less. When we returned in the late spring to photograph it, the spring was dry.

The second flight was on February 27 between 9:30 AM and 11:15 AM with overcast weather and periods of drizzle and heavier rain with a temperature of about 15º C (58º F). The rain equalized surface temperatures and no significant features could be seen.

The third flight was on March 9 between 8:00 and 9:00 AM. Very heavy rain had fallen on the previous day with some

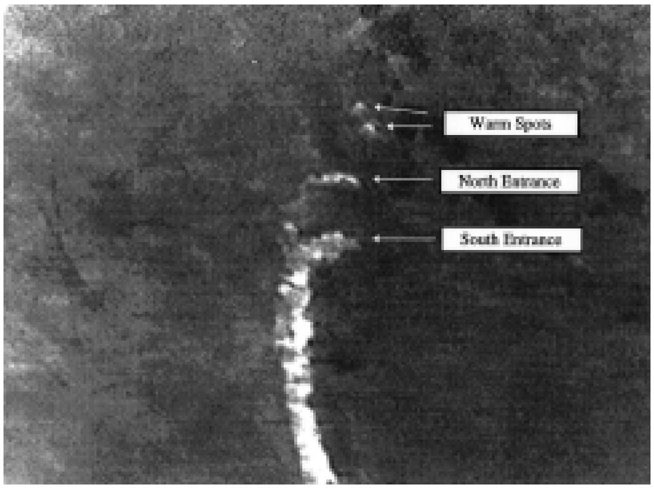

Figure 3a. Vinson Cave thermography.

Figure 3b. Vinson Cave entrances.

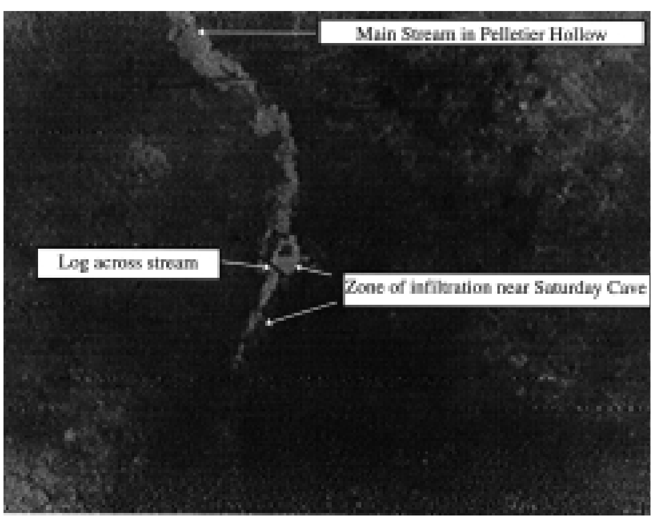

Figure 4a. Saturday Cave thermography.

tornadoes in the area. The flights began with a temperature below 0º C. A cloud deck over Horse Cove forced flights at altitudes below 1 km MSL. This flight produced the most useful data showing both known and previously unknown features. The known features included Saturday Cave (AL 563) and Vinson Cave (AL 561).

Saturday Cave is located on the bottom of a stream bed. When water is very high, the stream above Saturday Cave flows into the main entrance. 200 m from Saturday Cave is Vinson Cave. Vinson Cave has two main entrances separated by 10 m. The stream in Vinson Cave flows just inside the two entrances shown in Figure 3b. The thermal imagery shows both infiltration near Saturday Cave and water flowing from both entrances of Vinson Cave.

Figure 3a shows the Vinson Cave thermography, and Figure 3b the entrances to the cave. The north entrance is at the top center of Figure 3b, and the smaller south entrance is at the right side of the picture. The dry stream bed coming from the north entrance is shown clearly in the picture. During high water, the stream will flow from the south entrance. During very high water, streams will flow from both entrances into the normally dry stream bed. The thermography of Figure 3a was taken during very high water. Also visible on the image are two warm spots. These were not identified, but may be an area of seepage on the cliff above the cave. The subject to the left of the north entrance in Figure 3b is looking toward the seepage area.

The thermography of Figure 4a shows infiltration at or near Saturday Cave. Saturday Cave is approximately 200 m up the stream bed from Vinson Cave and 20 m higher in elevation than the Vinson Cave north entrance. Figure 4b shows Entrances 1 and 3 to Saturday Cave. Entrance 3 is a crawl-in just to the left of the large boulder in front of the subject. These two entrances lie in a small sink in the bottom of the stream bed. During spring floods, water falls over the lip above Entrance 1 and into the cave. Figure 4c shows Entrance 2 to Saturday Cave with water flowing in just below the subject. This entrance is a 7 m pit and is a main infiltration point in the stream bed during storms and is clearly visible on the thermography.

Figure 4b shows a large tree blown over across the stream bed above the Saturday Cave main entrance. We believe that this tree is visible as a dark line across the stream in Figure 4a. If the line on the thermal image is the tree, then some flow was reaching Entrance 1 when the image was made.

In addition to the images of Vinson Cave and Saturday Cave, the thermography revealed a new spring on the ridge to the west of Frank's Cave. The thermal and visual images are shown in Figure 5. We located the spring on March 12, photographed it, measured its temperature as 14º C, and estimated the flow as about 30 liter/sec.

On this same flight, we flew over Vinson Hollow, which is the one hollow in Horse Cove we had not yet surveyed on foot. We found a warm spring entering and mixing with the cooler surface stream. Because of the appearance of the feature on

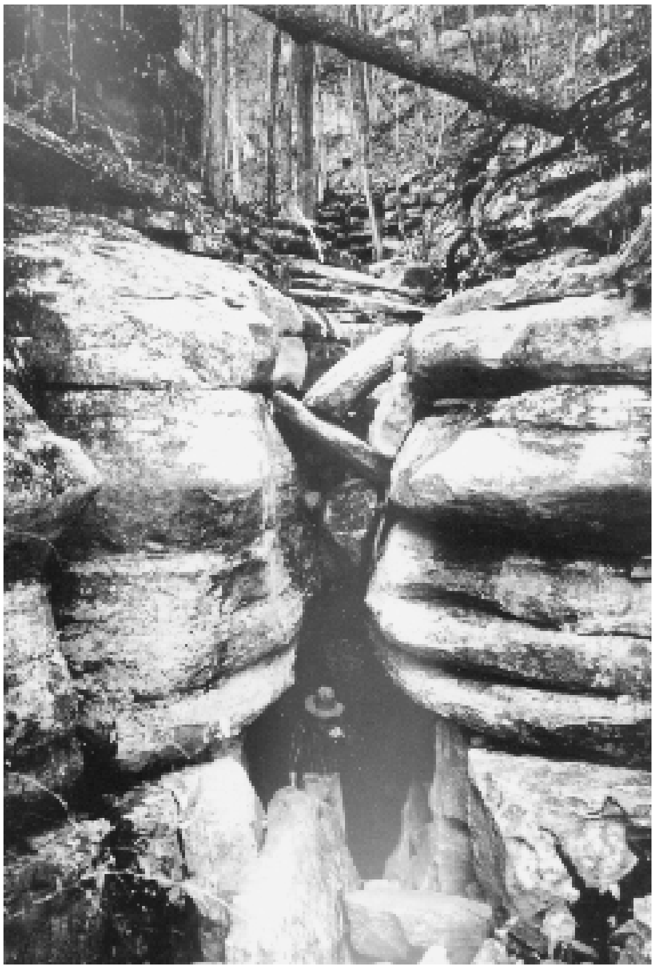

Figure 4b. Saturday Cave Entrances 1 and 3.

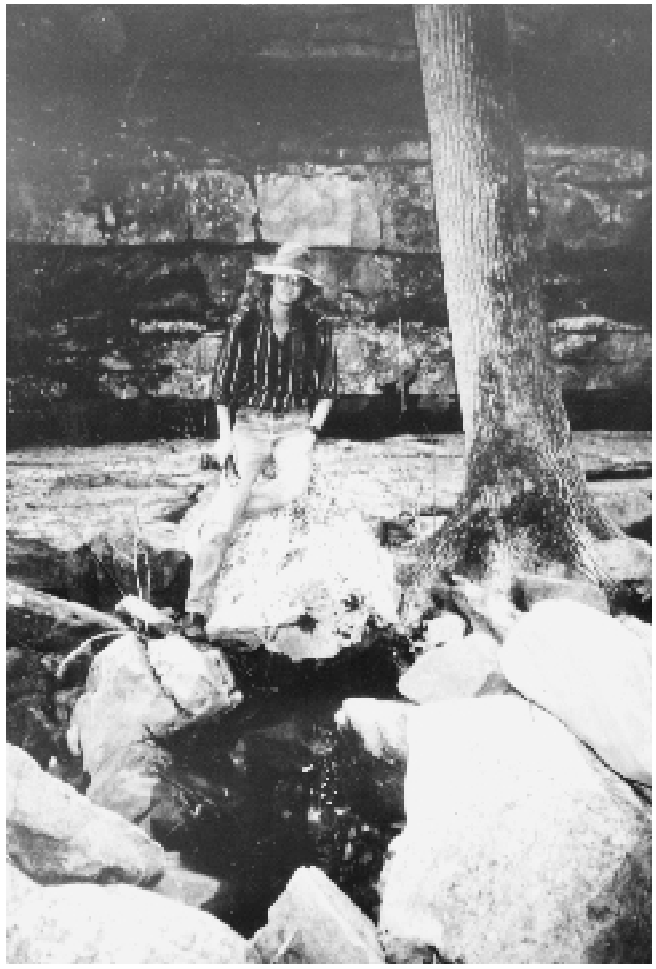

Figure 4c. Saturday Cave Entrance 2.

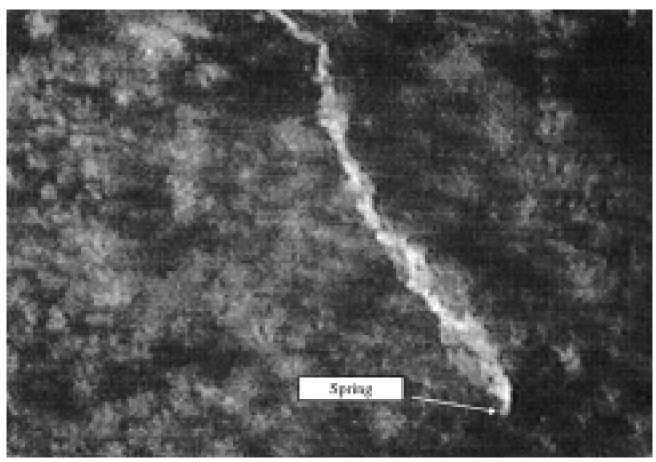

Figure 5a. Shelton Spring thermography.

the thermal image shown in Figure 6a, we felt that a cave could be associated with the spring. Figure 6b shows the spring flowing (1 liter/sec) from the cave entrance.

Figure 6a also shows solar thermal reflection on the sunny slope. The streaks in the picture are shadows of trees. The upper right of the picture is still in the shadow of the north facing slope. If the sun were a little higher, we might not have noticed this spring. Though springs are visible on south facing slopes, they are much harder to see on the thermography.

Conclusions

The imagery shown here demonstrates the ability of thermography to locate springs and areas of heavy infiltration in karst. Caves with springs discharging from the entrance are also clearly indicated. So far, three new springs and a cave were identified from thermal images. Many other features on the imagery await field work. From the information collected so far, we believe that airborne thermography is a valuable aid for identifying and locating features of hydrologic importance. We believe that had weather conditions been more favorable, we could have flown at much higher altitudes and covered more area with our scans. We base this conclusion on the size of the image, the resolution and sensitivity of the camera, and on a reduction of image size with the square of the altitude. Springs with flows less than 1 liter/sec were clearly visible

Figure 5b. Shelton Spring.

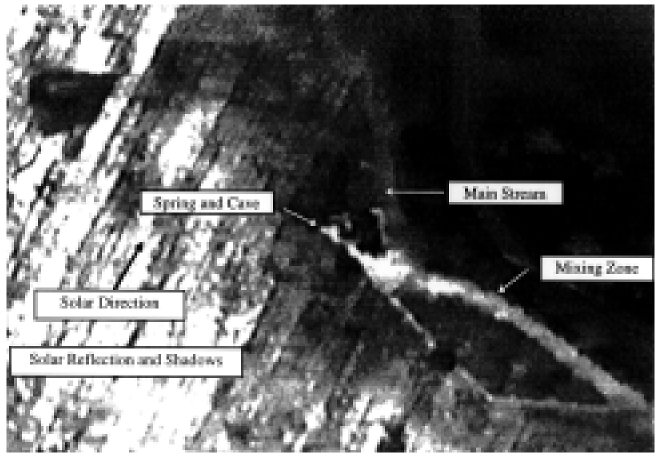

Figure 6a. Vinson Hollow spring and cave.

Figure 6b. Vinson Hollow spring and cave.

from altitudes of 500 m AGL.

The data presented clearly show that very small springs (as small as 3 liters/sec) can be identified on the imagery produced by this thermal camera. Caves with springs discharging from the entrances are clearly visible. An area of infiltration in a losing stream was clearly identified. Three new springs and a new cave were found with the thermography.

The best time for thermographic flights in north Alabama is in the winter during cold weather when the leaves are off the trees. The best time of day is in the early morning before sunrise. However, our best flight was in the daytime. Thermography of shaded slopes can reveal many features. Springs can be seen on sunny slopes, though not as clearly.

Acknowledgments

We are grateful for support through a Summer Faculty Fellowship for one of us (CWC) provided by Danny Dunn of the U. S. Army Missile Command Environmental Office. We are indebted to Karen Rheams, a geologist with the Florida Pollution Control Division who shared her knowledge, her data, and her enthusiasm freely with us. Westinghouse Corporation provided the airplane and flight support for this effort. Special thanks to Gary Green, Dave Goodwin, Paul Rodrigues, James G. Hughes, and William J. Harris, all of Westinghouse. We are grateful for support by Bill Torode who provided maps, reference papers, and help finding the lower passage in Saturday Cave. Special thanks are due to Shane Strickland of the UAH Research Institute's Visualization and Simulation Lab who spent hours helping get our images from VCR to disk. We are also grateful to Frank R. Bogle who reviewed this paper carefully and made many helpful suggestions.

References

Bogle, F.R. & Loy, K. (1995). The application of thermal infrared photography in the identification of submerged springs in Chickamaugua Reservoir, Hamilton County, Tennessee. In Beck, B. F. (editor), *Karst Geohazards, Engineering and Environmental Problems in Karst Terrain, Proceedings of the Fifth Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst, Gatlinburg, Tennessee, 2-5 April, 1995*: 415-424.

Jones, W.K.. (1984). Dye tracer tests in karst areas. *National Speleological Society Bulletin 46*(2): 3-9.

LaMoreaux, P.E. & Chermock, R.L. (editors), (1975). Environmental geology and hydrology of Madison County, Alabama. *Geological Survey of Alabama, Atlas Series 8*.

McGregor, S., Rheams, K.F., O'Neil, P.E., Moser, P.H. & Blackwood, R. (1994). *Biological, Geological, and Hydrological Investigations in Bobcat, Matthews, and Shelta Caves and Other Selected Caves in North Alabama*. Prepared in cooperation with the US Department of the Interior, US Fish and Wildlife Service, Jackson, MS.

Rinker, J.N. (1975). Airborne Infrared Thermal Detection of Caves and Crevasses. *Photogrammetric Engineering and Remote Sensing 41*(11).

Warren, W.N., and Wielchowsky, C.C., (1973). Aerial Remote Sensing of Carbonate Terrains in Shelby County, Alabama. *Groundwater 11*(6).