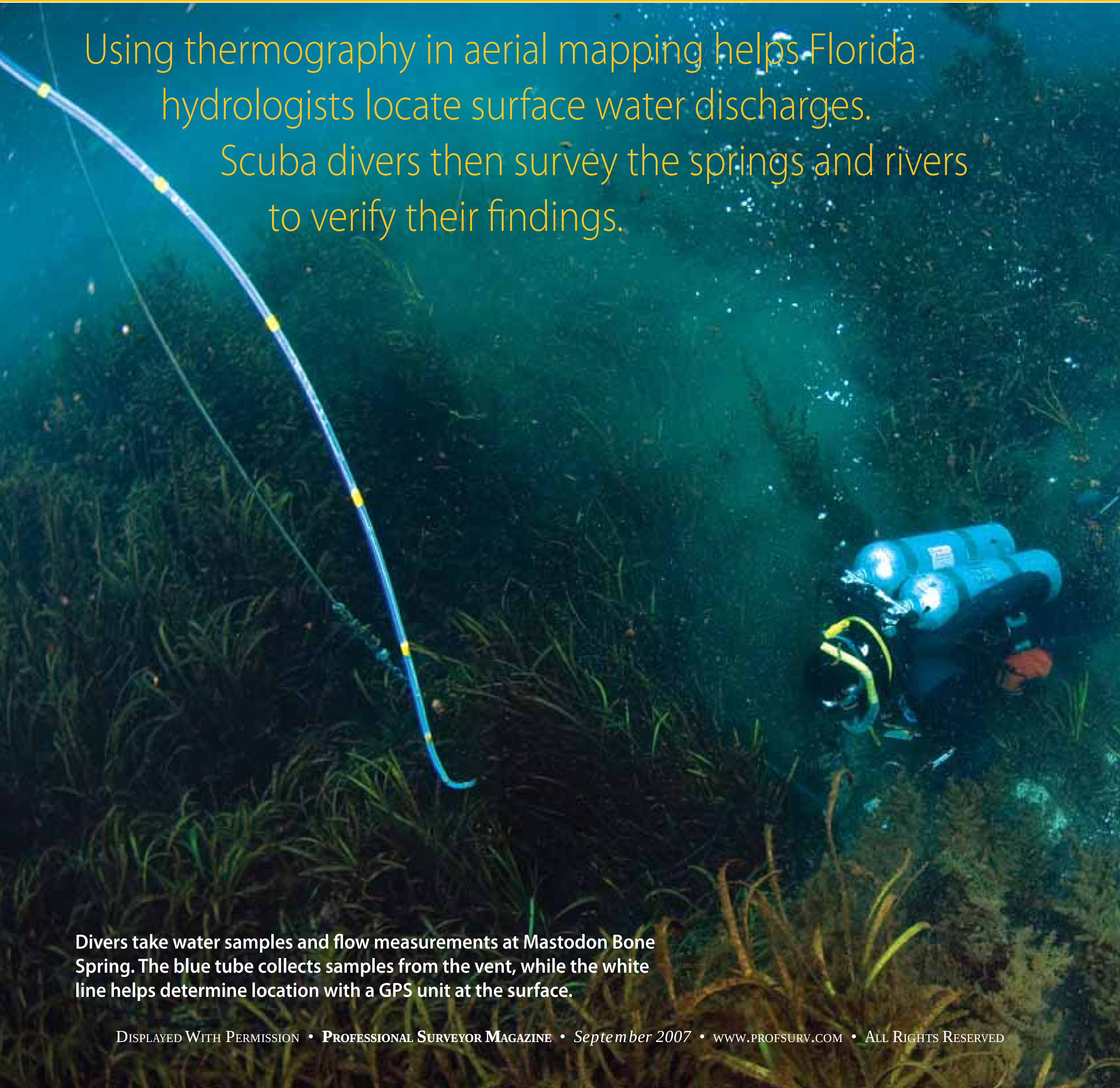
Springs Eternal

Using thermography in aerial mapping helps Florida hydrologists locate surface water discharges. Scuba divers then survey the springs and rivers to verify their findings.



Divers take water samples and flow measurements at Mastodon Bone Spring. The blue tube collects samples from the vent, while the white line helps determine location with a GPS unit at the surface.

By Jeffrey Davis

Aerial thermography surveys have become a hot topic in northeast Florida, as the St. Johns River Water Management District uses the technique to locate groundwater discharge to surface water bodies. This form of aerial photography uses an infrared heat sensor mounted on a plane to sense temperature variations as it scans the land and water below to generate an image.

The District has the mission to "ensure the sustainable use and protection of water resources for the benefit of the people of the District and the state of Florida." Therefore, it is critical to locate all discharge points to guide water quality sampling efforts and provide input for groundwater and surface water flow models.

Over 40 percent of the area within the 18 counties comprising the District has the potential for groundwater discharge, so the potential for locating additional springs is high. Within the district lie 91 named springs (some of which have multiple discharge points) that have been field-verified. Aerial thermography has shown identifiable thermal anomalies at all the discharging springs surveyed. An example of data collected at the Silver River in Marion County shows how effective this technique is.

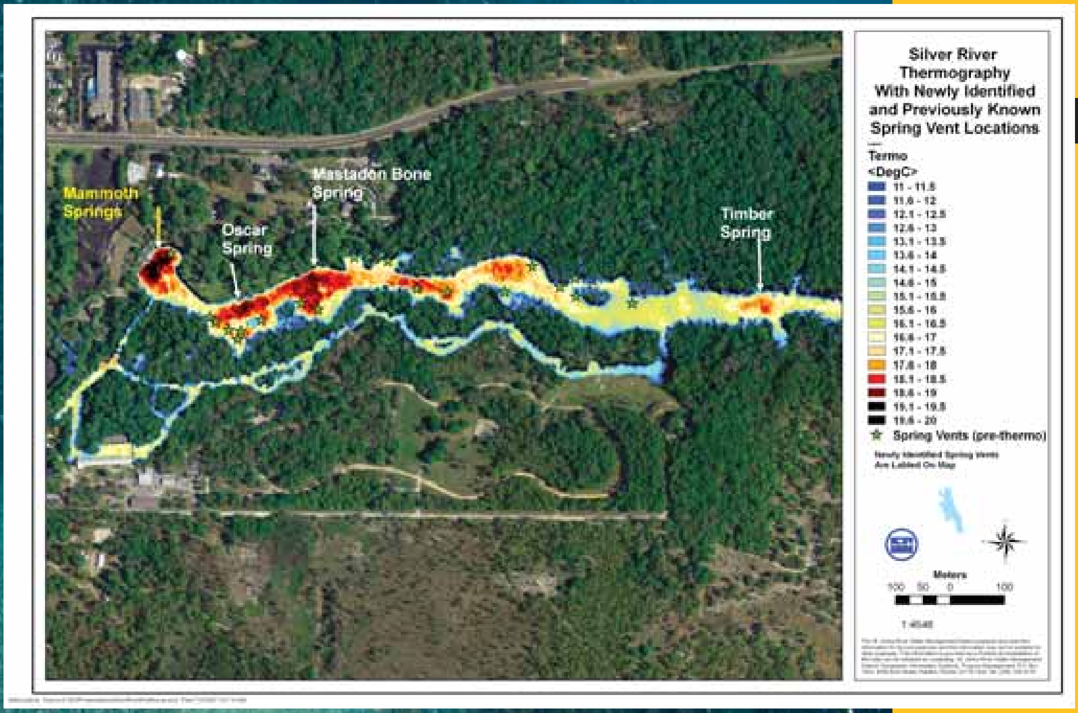


Figure 1

Thermography data is overlaid on a digital orthophotograph of the upper 1,200 meters of the Silver River. The two largest springs are shown in the western headwaters (left) as the warmest zones (pixels color-mapped black).

The Silver River is a world-famous first magnitude spring, meaning it flows at more than 100 cubic feet of water per second. It begins with Mammoth Spring at its headwaters discharging 240 cfs (107,750 gallons per minute), and the output from 26 additional vents nearly doubles the flow of the river in its upper 1,200 meters. Humans have been drawn to the site since the ice ages in the late Pleistocene, when lowered sea level allowed human habitation in now-submerged caves from which the springs emanate.

In 1845, the U.S. Government sold 80 acres surrounding Silver Springs to a private individual, and the Native

Americans that inhabited the region were evicted. Steamboat tours became popular, and with the advent of the glass-bottom boats in the 1920s, tourism grew even more. The depth and clarity of the water made a perfect setting for the film industry. In the 1930s, Johnny Weissmuller and Maureen O'Sullivan made six movies there. *The Creature From the Black Lagoon* and *I Spy* also used the famous springs for filming. Today, millions of people a year visit the site to take in the attractions of Silver Springs, a 350-acre nature theme park that has developed around the river near Ocala.

A noticeable increase in algae growth has heightened the need for protection of spring-fed rivers such as this. Local and state governments are working to identify potential sources of pollution, groundwater pathways to the rivers, and effects from increased water withdrawal. Citizen groups are taking an active part in protecting this natural gem.

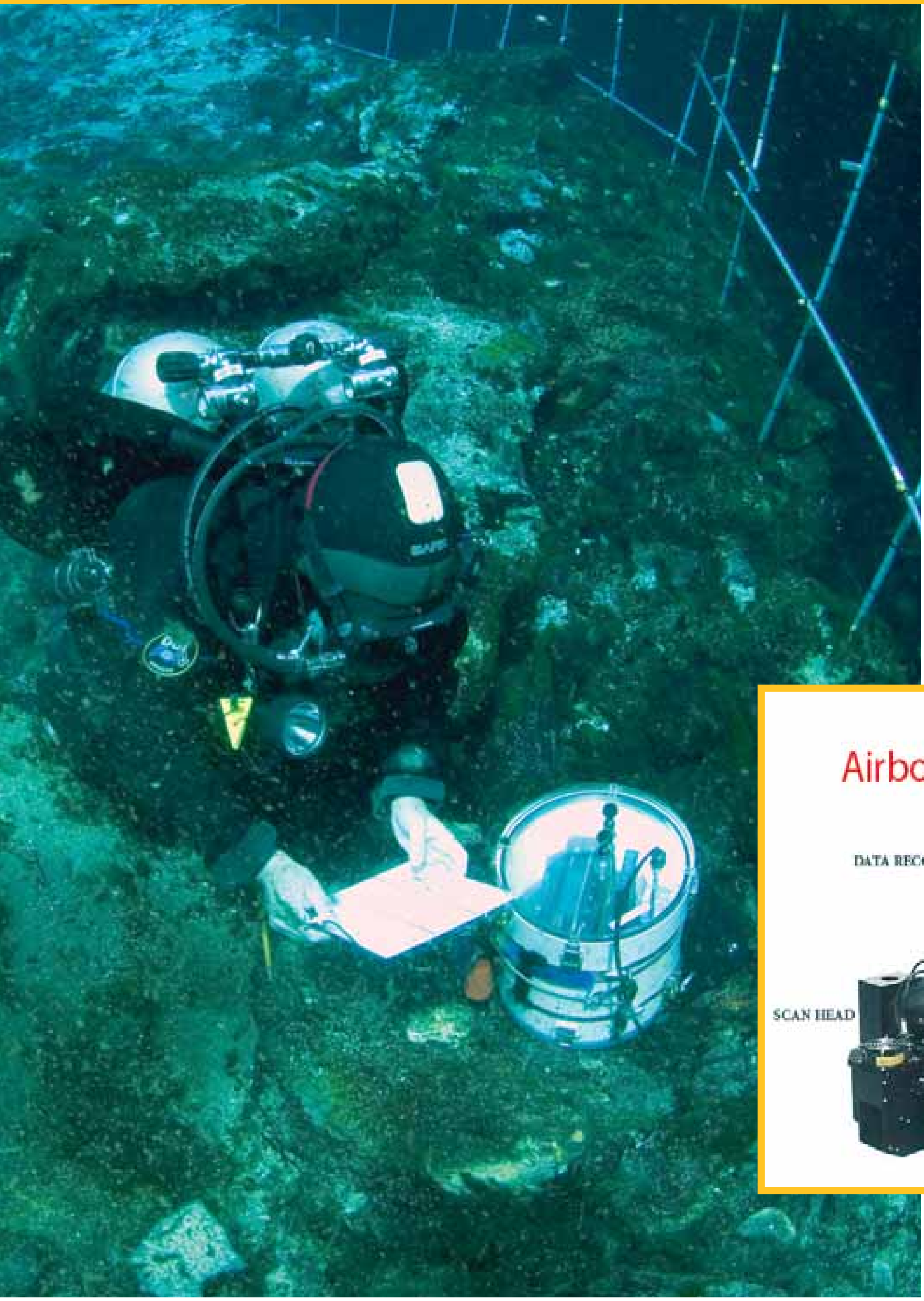
Divers survey the main discharge vent of Mammoth Springs in the headwaters of the Silver River. They have constructed a grid to use in measuring flow.

More Sensitive Than a Thermometer

In Florida, thermography surveys are best flown in the winter when there is maximum contrast between surface water and groundwater temperatures. The temperature measurements derived by sensing emittance of thermal infrared radiation from surfaces provide a more efficient and effective means to identify groundwater discharge than measurements with a standard thermometer. Small changes in absolute temperature can have much greater impact on emissive power. Springs may be missed by measurements with a standard thermometer because the actual temperature may vary only slightly within a short distance from the discharge, whereas the aerial thermography signature will be much more pronounced. Detecting the relative changes (i.e. thermal anomaly) in thermal emittance from one point to the next is more important for our purposes than knowing the absolute temperature values. The known springs provide good reference values for interpretation of the data in other areas of a water body.

Aerial thermography data for the District's projects were collected through contracts with SenSyTech (now known as Argon ST, Inc.) based in Ann Arbor, Michigan. Silver Springs was included in a cooperative agreement with the Florida Geological Survey (FGS) in which the FGS contracted directly with SenSyTech, Inc.

A dual-port airborne multispectral scanner (AMS) was used to collect the data. This can gather eight bands in the visible/near infrared spectrum and includes a dual-element thermal-infrared detector. The system includes an internal blackbody (a theoretical perfect radiator with an emissivity of 1.0) calibration reference source to insure accuracy and repeatability of the data set. Data was collected with a two-meter pixel resolution with navigation fixes supplied by an Applanix POS/AV 310 inertial measuring unit with differential GPS receiver. The final data set is georeferenced for use with the GIS used by the District.



the challenges that face a spring hunter when using aerial thermography. Water depths vary from about 13 meters to under one meter, and flow volume ranges from 240 cfs (107,750 gpm) at the main headwater vent to less than 0.24 cfs (106 gpm) at the smallest vent. Multiple spring vents occur within small geographical areas, and currents can move the discharge plume away from the source by the time it reaches the surface where it can be detected.

Throughout the springs' recorded history, only a portion of the spring vents had been mapped as points on a sketch map. Names such as Mammoth Springs, Catfish Reception Hall, and Shipwreck Spring were given to certain vents based on unique features observed and to enhance the tourist experience. The District initiated a project to formally map the vents in the upper 1,200 meters of the spring run and used GPS to relate coordinates to the historic vent names. A longtime monitoring site had been established at the 1,200-meter mark as it was thought most of the discharge to the river occurred upstream from this station.

The location of the vents were first identified by divers, and then coordinates were derived by standing over the vent in a glass-bottom tour boat or recording the position of a diver or float directly over the vent. The combination

▲ This system mounts in the plane used for aerial mapping the springs

Divers Down for Verification

In many cases, the discharge identified from a thermal anomaly is easily ground-truthed in the field since it forms the headwaters of a spring run, the volume is sufficient to create visible waves (boils) on the surface of a pool or stream, or movement can be seen in the bottom sediment and grasses. In other cases, the discharge may be obscured by water depth or clarity, vegetation, or low flow volume. Water quality sampling may help if there is sufficient contrast in the groundwater and surface water chemistry; however, for these cases, discharge is best documented by scuba divers and underwater video.

When trying to locate the discharge source in the field using the coordinates of individual pixels, it is important to keep in mind nuances of the system. The Silver River site presents many of of an electric boat and its operator's skill developed by years of hovering over the vents so tourists could take photographs proved invaluable for obtaining accurate positioning. One of the newly discovered springs was named in his honor —Oscar Spring.

Divers from Karst Environmental Services and sister company Karst Productions conducted the underwater reconnaissance, water quality sampling, and flow measurements. Wes Skiles, Peter Butt, Tom Morris, and Jytka Hynoiova have logged many hours diving submerged caves to create documentary films for National Geographic, Public Broadcasting Service, and A&E and have done many research dives at sites worldwide. The size of the vents range from the large main vent at about 22 meters wide and two meters at its highest at the headwaters, providing easy access for divers to the feeder caves below, to vents less than a meter at the long axis.

Resulting Thermographic Map

The thermography data from the upper 1,200 meters of the river has been mapped to show warmest areas in black and red and coolest areas in blue (**Figure 1**). All values less than 11 degrees C have been masked so just the submerged areas are shown. Although nearly half the flow volume in the upper 1,200 meters comes from these vents, there appeared to be no thermal masking in the thermal response for the area after about 130 meters downstream. Temperature anomalies caused by downstream discharges could therefore be resolved. The thermography data also indicated discharge in areas where no previous spring vents had been referenced. The green stars indicate a place where there is either a single discharge point or in some cases multiple vents within a close area.

Results from the main spring area demonstrate how effective the technique is at differentiating the heat source where warm water is constantly being pumped out from the downstream area with no new heat source being supplied. A standard digital laboratory thermometer varied less than 0.5 degrees C throughout the spring run. Downstream from the main springs, a group of eight vents comprise favorite spots for glass-bottom tourist boats to showcase the springs' natural beauty. The five vents shown on the southern shore near Oscar Springs lie in water as deep as 10 meters, demonstrating conditions to consider when trying to locate the actual discharge point. Although sufficient discharge exists to create a thermal anomaly over the springs, the deep water and number of spring vents make it impossible to distinguish individual vents in the thermal imagery.

Going further downstream, a thermal anomaly at the point labeled Mastodon Bone Spring in Figure 1 comes at the site of a vent with a cross sectional area of 2.755 square feet and a flowrate measured by the KES team of 1.45 cfs (650 gpm). This vent lies in four meters of water and is very difficult to see from the glass-bottom boats. Were it not for the thermal anomaly, the divers could easily have missed it if they didn't know the general area to search.

This summer will bring the dive team back to the Silver River to investigate the thermal anomalies downstream of the 1,200 meter station. Additional samples and flow measurements will be taken at the known vents, and more vents may be discovered. Other sites where thermography data was collected in the District also indicate groundwater discharge and will be documented.

Other promising applications of aerial thermography could include diffuse flow into lakes that may affect the water budget and water chemistry of these systems. Sections of some rivers exhibit thermal anomalies not as focused as the spring vents seen to date. Perhaps an answer will be found as to what causes these relatively large areas of similar high temperatures. This technique continues to find effective uses in mapping Florida's water resources.

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