USING GPS TO MAP FLORIDAÃ•S UNDERGROUND CAVERNS

Solving Wakulla Springs Underwater Mysteries

Located in the Woodville Karst Plain stretching south from Tallahassee to the Gulf of Mexico, Floridaâ€™s Wakulla Springs is one of the largest and deepest freshwater springs in the world. It is also a gateway into one of the longest underwater cave system in the United States, a system that remained largely unexplored until recently. Soon, however, thanks to one of the worldâ€™s most extreme scientific and exploration-related diving projects ever undertaken, visitors to Wakulla Springs State Park will be able to take a virtual tour through the Springâ€™s huge underwater labyrinth.

Using such cutting-edge technology as a 3D Digital Wall Mapper (DWM) and the Global Positioning System (GPS), the Wakulla 2 Expedition - with 151 volunteer cave divers, scientists and engineers from all over the world - created the worldâ€™s first three-dimensional digital map of an underwater cave.
Underwater caves are priceless treasures, helping supply fresh water to the region as well as acting as â€˜time capsulesâ€™ to the past. Home to creatures found in few other places, areas such as Wakulla face threats of pollution and over-development. Wakulla 2 hopes their 3D interactive â€˜swim throughâ€™ will help increase the understanding and preservation of these important areas.

Diving into the Mystery
While other cave diving projects have explored Wakulla Springs, none have been as extensive or far-reaching as Wakulla 2. Sponsored by the National Geographic Society (NGS), Wakulla 2 drew elite cave divers from as far as Germany, Denmark, Australia and the Bahamas to face this â€˜last frontierâ€™. To do so, they used cutting-edge technology, such as the Cis-Lunar MK-4 re-breathers. Re-breathers recycle a diverâ€™s breath, adding oxygen and eliminating carbon dioxide. They can also last for up to 12 hours, compared to traditional scuba cylindersâ€™ hour underwater time. Divers also used Diver Propulsion Vehicles (DPVs) to help pull them through the huge labyrinth.

The Pressure Builds
Dive times into the cavern averaged three to four hours at depths of up to 100m - and that meant time (up to 13 hours) decompressing to ensure that any dissolved gas in their blood was eliminated before reorienting to surface pressure. During preliminary dives, divers simply stopped periodically while ascending. But once the decompression chamber was set up - normally used by oil-rig divers in the Gulf of Mexico - divers were able to finish decompressing safely and comfortably in the chamber, which floated above the cave entrance on a barge. Divers were carried to the chamber above the surface in a special Personal Transfer Capsule pressurised to the diversâ€™ depth.

The Underwater Cave
A one-entrance cave, Wakulla Springs cave goes deep and stays deep, with huge primary tunnels extending radically up to 4km from the en-trance. The Wakulla 2 expedition mapped four primary tunnels: A, B, C and D. Some of the passages are small enough to allow full visibility; others, such as the â€˜Grand Canyon Domeâ€™ inside A Tunnel, are so large that the diversâ€™ lights couldnâ€™t reach both walls. While the diversâ€™ lights provided visibility, the cave explorers also installed thin nylon guidelines throughout the labyrinth to help them to feel their way out if necessary.

Cave Mapping Moves into the Future,/span>
Before Wakulla 2, just over 3.5km of the underwater labyrinth were explored with published maps. But the earlier explorations used rough line-and-compass mapping techniques - laying a compass along a guideline and counting knots tied at ~3 m (10ft) intervals, then recording depths with a wrist gauge at each bend in the line. Wakulla 2 wanted a map that would increase the accuracy of previous attempts while mapping as much of the underwater cave system as possible. By using the Digital Wall Mapper (DWM) as well as a unique â€˜cave radioâ€™ and GPS, Wakulla took underwater cave mapping far into the future.

Mapping the Walls Digitally
Designed specifically for the project, the DWM is a complex instrument controlled by eight onboard computers. Driven by the lead diver, the DWM uses sonar technology and the same Inertial Measurement Unit (IMU) usually used by fighter aircraft and for missile guidance. Powered by a DPV in the back, the DWM emits 32 simultaneous sonar pulses in a spiral pattern, four or more times a second. An onboard computer keeps track of how far the sonar travels, adjusting for the pitch and roll of the DPV. When adjusted for drift using GPS and the cave radio, the DWM data provided the exact dimensions of the cave tunnels, including walls, ceiling and floor. The DWM plotted nearly 10 million wall, ceiling and floor points of the 6,409m mapped passages.

The Cave Radio

Years before Wakulla 2, Brian Pease had developed a radio location system to locate cave positions on the earthâ€™s surface. This â€˜cave radioâ€™ uses beacons and an antenna along with GPS to connect points in the underground cave with real-world co-ordinates. The beacons, coiled wire attached to a time-delayed battery, were placed in the cave by divers. Divers placed beacons in predetermined locations, switched them on and swam away to steer clear of the beaconâ€™s strong magnetic field. Directly overhead, Pease carried a coiled antenna to pick up the electromagnetic signals through the limestone bedrock. When he located the magnetic fieldâ€™s null, he set a stake. Thirty-eight radio locations were surveyed during the expedition.

GPS Maps an Underwater Cave

To attain the high accuracy (centimetre level) Real-Time Kinematic (RTK) positioning of the surface points, horizontal control was extended from a High Accuracy Reference Network (HARN) point ~16 km (10 miles) away, using static GPS observation techniques and post-processing. The control was extended to a reference mark in the concrete floor of the dive platform located over the cave en-trance at Wakulla Springs. A Trimble GPS Total Station 4800 system placed on a tripod over this mark was used as the RTK reference receiver. The corrections generated by the reference receiver were sent to the roving RTK receiver via a 25-watt UHF transmitter that had its antenna on a ~6 m (20-ft) pole at the top of the dive platform. These correction signals could be received anywhere in the park.

Alligators and Other Obstacles

Pease used a GPS Total Station 4800 system to locate each surface point. In areas where the huge, old-growth cypress trees limited GPS reception, Pease would locate pairs of reference points in nearby open areas using the GPS receiver as a base; they would later use an optical total station to finish the survey. Where the sky was clearer, Pease often had to clear away underbrush at the pointâ€™s location. In addition, some points were located in the river. For one, Pease had to pole his canoe through the shallow waters and mud. He then set the receiver on an overhanging tree limb to get the GPS antenna exactly over the radio-location point. Pease operated the receiver - and his partner watched for alligators.

Tying the Data Together

Each dive mission mapped new reaches of the tunnels. Each section needed to be covered at least twice; once to place the beacons for the cave radio, then to â€˜mapâ€™ and locate the points and pick up additional visual data. Divers would â€˜tagâ€™ the data by hitting a trigger on the DWM when they flew directly over a beacon. To co-ordinate with surface locations, divers also noted the number attached to each beacon. By using the beacons as surface-fixed control points, they were able to register the 3D digital map to these high precision waypoints.

Beginning the Map

Getting the waypoints was one thing; creating a precise, seamless map was another - and GPS was critical for the accuracy of the outcome. First, the sonar times were converted to distances to the cave walls from the DWM; then the distances were combined with the location and orientation of the DWM, itself based on IMU data to identify X, Y, Z locations in 3-D space for each wall point. Drift in the IMU was corrected using the GPS-based radio-location points. Using these points meant the Wakulla 2 map has no cumulative errors as each location was surveyed separately. This is a vast improvement from most cave maps where error accumulates with distance from the entrance.

Wakulla Springs: A Virtual Reality

After registering the multiple datasets relative to one another and the radio locations, statistics were calculated and a virtual cave created. Initially, we are developing algorithms to mesh the points into polygons to form solid walls. Then the virtual walls will be texture mapped with simulated rock. Ultimately the virtual cave will be displayed using 3-D computer graphics, creating an â€˜interactive swim throughâ€™ for visitors, enabling them to explore Wakulla Springs safety, accurately - and dry.