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IMPLEMENTATION AND APPLICATION OF GIS AT TIMPANOGOS CAVE NATIONAL MONUMENT, UTAH

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Recent advances in accessibility and functionality of geographic information systems (GIS) have allowed Timpanogos Cave National Monument (TICA), Utah, to implement and apply this valuable management and interpretive tool. This implementation is highlighted by successful collaborations and the development of a 2-m resolution Digital Terrain Model. Applications of GIS at TICA are useful for the interpretation, resource management, and maintenance areas of park management. Specific applications with importance to the management decisions of TICA include interpretive mapping, 3-D visualization, cave resource management, and surface rockfall hazard.

Timpanogos Cave National Monument (TICA), a 100 hectare site surrounded by U.S. Forest Service Wilderness areas, is easily accessible by over one million people along the Wasatch Front, Utah (Fig. 1). It is set in American Fork Canyon, a limestone gorge with spectacular cliffs, avalanche chutes, pinnacles, and caves. The Monument was created in 1922 to protect the Timpanogos Cave system, a set of three caverns perched in a cliff band 460 m above the canyon floor. The cave system is known for its spectacular colors and abundant helictites. Over 70,000 visitors tour the caves each year and are placing increasing demands on the resources.

Applications

Geographic information systems (GIS) has long been known as a valuable tool to better manage, interpret, and maintain resources as well as a proven decision support system. Data collection and development is paramount to applications in a GIS and must be customized to study area requirements and limitations. At TICA, all data must be high resolution, highly accurate, and function relative to the extreme topography and/or three-dimensional cave environment. Data have been collected and developed from a variety of sources, including GPS, hard copy maps, existing information databases, and aerial photography. Many applications are made possible through the development of a high resolution Digital Terrain Model (DTM). This DTM serves as the key base layer for TICA's GIS (Fig. 2). This 2-m resolution DTM has been created through digitizing and interpolating 10-ft contour lines obtained from a hard copy, 1 inch = 100 feet scale map (Eklundh & Martensson 1995). This terrain model has been checked for accuracy through the collection of 75 randomly distributed, highly accurate GPS control points (Holmes *et al.* 2000). This process found a mean elevation error of 3.216 m (1σ = 3.219 m). The errors are assumed to be randomly distributed to topographic variation as error is not found to be correlated to slope (r^2 = 0.1441). The accuracy and resolution of the DTM allows the GIS at TICA to visualize features and model phenomena in ways not possible with commonly available terrain models (e.g., USGS 30 m DEM).

A demonstration of the power and usefulness of the DTM has come through the completion of a rockfall hazard model. The unstable Deseret Limestone, steep topography, and multitude of visitors all combine to make rockfall a grave concern for managers at TICA (Fig. 3). While rockfall chutes and many hazard prone areas along the trail to the cave are well known, the GIS is now a powerful tool to quantify and objectify the rockfall hazard to TICA visitors, employees, and structures. The relative hazard model uses the DTM to delineate rockfall paths and determine slope while incorporating a vegetation map to account for friction. Van Dijke and Van Westen (1990) showed that the velocity of falling rocks can be calculated for every location (grid cell) in a hazard area. Using their method, the rock's velocity is calculated at each cell using a mathematical equation accounting for friction, gravity, horizontal distance, and vertical distance of the rock's fall. As the equation was translated into an ArcInfo GRID modeling environment, the velocity was calculated through running the FLOWLENGTH GRID command over a cost-distance surface simulating resistance to rockfall (McNeil 2002). Because it was not possible or necessary to obtain exact rockfall velocities, the model results in output maps representing hazard in relative terms (e.g. Low, High, and Extreme) and identifying dangerous rockfall paths (Fig. 4). These maps are used by TICA management as planning and decision-making tools for source area stabilization and hazard mitigation.

The DTM and the GIS now allow the management at TICA to visualize the cave and overlying terrain for purposes ranging from interpretation to natural resource management. A virtual field trip was created using the DTM and cave maps as background images. While this field trip is structured and realized in a web-based design, it is inherently a GIS application,

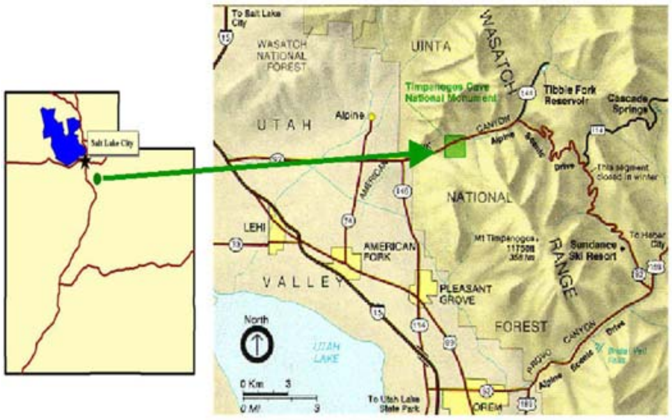

Figure 1: Location of Timpanogos Cave National Monument.

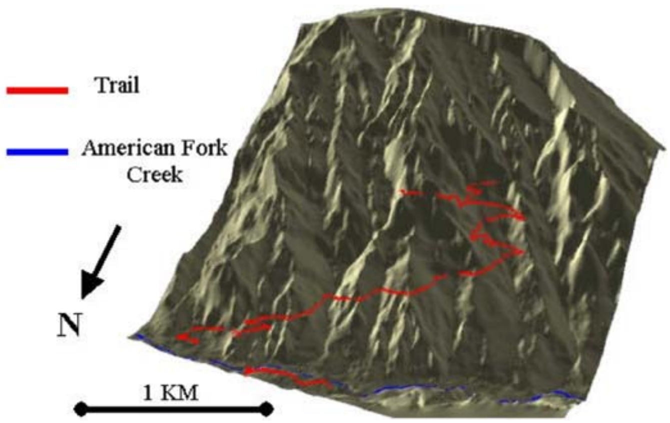

Figure 2: A visualization result showing the DTM, cave trail, and American Fork Creek.

interactively displaying and managing spatial information in the form of maps. The TICA virtual field trip is designed in a web based format in order to embrace the largest possible virtual visitor population and allow that population the freedom to explore the cave and cave trail from anywhere at anytime.

The inspiration to create a virtual field trip for TICA arose largely out of the limited accessibility of the caves and the limited nature of interpretation along the trail leading to the caves' entrance. Because the Timpanogos cave system is located high on the south wall of the American Fork Canyon, visitors must climb 325 m over 2.4 km of hard surfaced trail in order to reach the entrance to the caves. This climb is challenging for most visitors and prevents a significant population from being able to reach the caves. During the late fall and winter months, the cave is closed to the public because of dangerous ice and snow on the trail as well as increased rockfall hazard. Virtual field trips enable people to experience the full resources of TICA regardless of their physical condition or time of year. It is hoped that TICA will soon be able to provide access to the virtual field trip from their visitor center so that visitors will be able to enjoy the park during times of inclement weather or even if unable to hike the trail. Visitors to TICA's virtual field trip may choose to "Hike the Trail" or "Tour the Cave" from the home page: http://www2.nature.nps.gov/grd/parks/tica/tica_virtual_fieldtrip/Index.htm

The trail leading from the visitor center to the caves is depicted on this three dimensional visualization of the DTM in order to give visitors a clear understanding of the steep terrain adjacent to the cave system. Points of interest along the trail have been marked and linked to photographs and educational descriptions of identified resources (Fig. 5). Visitors can choose to move directly from one point of interest to the next or return to the map and select only the places that interest them. Visitors may enter the cave portion of the virtual tour either by returning to the home page and choosing "Tour the Cave," or linking to a map of the cave from the entrance shown on the trail map. Once visitors have reached the map of the cave, they will be able to navigate through points of interest in the same manner as the trail to the cave (Figure 6).

Virtual field trips like the one created for TICA promise to become valuable interpretive tools because of the freedom they give to visitors and interpreters alike. Maps play a vital role in this and other virtual field trips by allowing visitors to better understand the spatial relationships between resources. These virtual visitors can explore the caves at their leisure, taking time to read the educational descriptions accompanying photographs taken at the monument, or quickly glance at the pictures that interest them. Additionally, virtual field trips provide a wide range of interpretive possibilities unavailable in the past because of their ability to be accessed from a remote

Figure 3 (left). Rockfall danger to the trail as seen from the cave entrance looking northeast. Note the visitors on the trail in the bottom left and the loose rockfall debris directly above and below them. Red lines on trail warn visitors of dangerous rockfall areas. (Photo by J. Jasper)

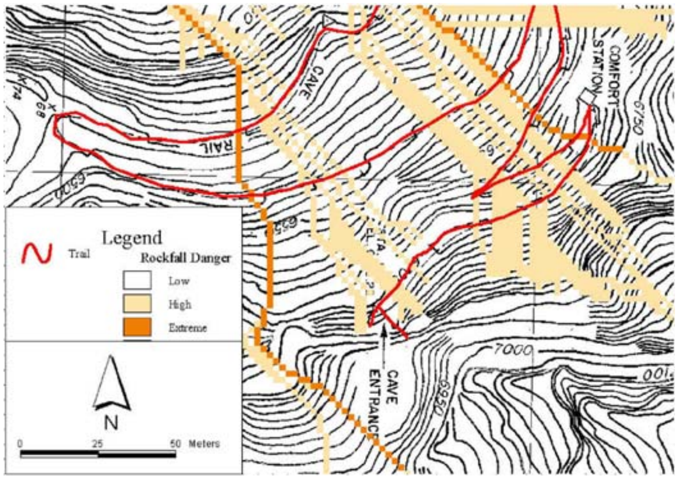

Figure 4: Hazardous rockfall paths to the upper portions of the cave trail with 10 foot contour lines. Note the comfort station visible in Figure 3.

location. Now interpreters are able to share resources located deep within wilderness areas or in fragile environments such as caves. Virtual field trips also allow interpreters to explain features in thorough detail seldom afforded by time constraints during visits. GIS has enabled the virtual field trip concept to be realized at TICA and presents a new paradigm for the interpretation of cave resources.

Natural resource management has also benefited greatly from the visualization opportunities of the GIS at TICA. One of the most basic gains in understanding the cave resource comes through visualizing the cave and its overlying topography (Fig. 7). The 3-D cave lineplot is created through reading the survey coordinates (distance, bearing, and altitude) into COMPASS software (Fish 2002). The CAVETOOLS extension of ArcView (Szukalski 2002) will then convert the COMPASS data to a 3-D ArcView shapefile (the standard output format in ArcView). GPS locations of surface features identifiable on the original cave survey are used to geo-reference the 3-D shapefile.

Creating GIS layers of cave features is problematic since aerial photography and GPS techniques are not possible. To overcome these obstacles, a scanned Timpanogos Cave map was geo-referenced to the lineplot shapefile. This map provides an excellent base for recording and planning management actions. The cave map is the ultimate utility for management of cave-related data (Fig. 8). Currently, the park is documenting its cave cleaning efforts, photomonitoring points, cave habitat zones, electrical corridors, place names, and significant cave features. GIS provides the framework for managing all these data in its natural, spatially interconnected environment. This more spatially aware information management facilitates powerful resource management decisions and conclusions. All of these utilities allow TICA to increase their understanding of the active cave processes and use this knowledge to make better management decisions.

Figure 5: Virtual field trip web screens.

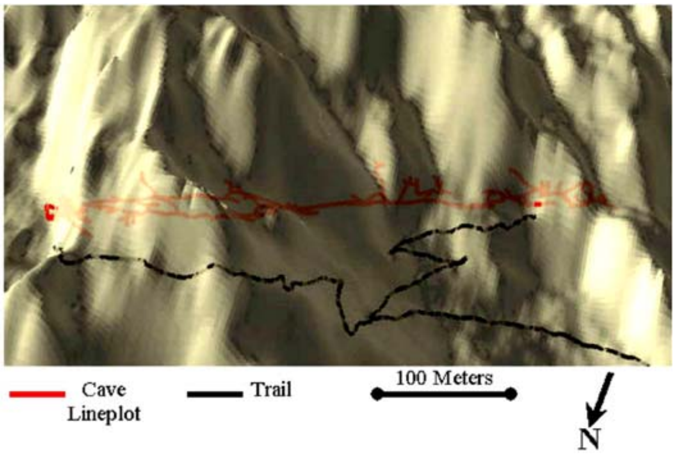

Figure 6: A 3-D visualization of the cave lineplot, cave trail, and the overlying topography as represented by the DTM.

Conclusions

GIS has been implemented at TICA because of its utility to effectively and efficiently manage and interpret cave and aboveground resources. Collaborations between TICA staff and academic researchers have catalyzed the implementation of a GIS framework that provides valuable applications and decision making support. To date, many unique and powerful datasets have been developed, facilitating rockfall hazard modeling, a virtual field trip, and a host of cave resource management applications. With high quality data, software, and hardware, the GIS at TICA is a glimpse of the vast possibilities that GIS holds for the management and interpretation of cave and karst ecosystems.

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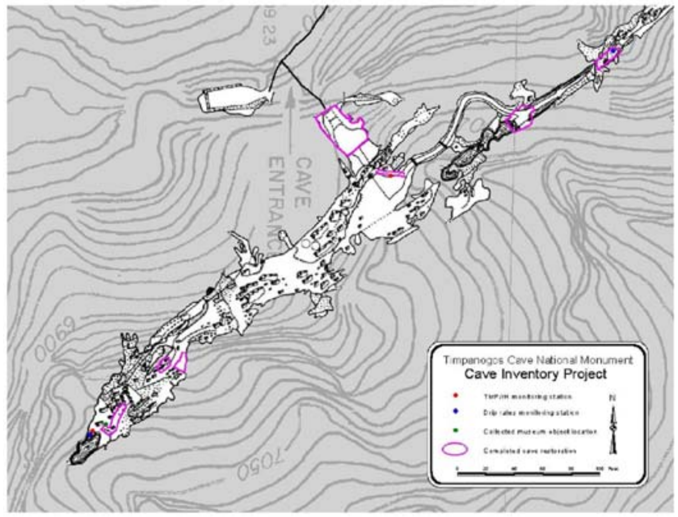

Figure 7: The geo-referenced cave map showing with overlying 10 foot contour lines. Note the scale and legend.

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