

# GIS Applications for Cave Management at Jewel Cave

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## Abstract

Jewel Cave's length and complexity offer unique challenges for cave data managers. With over 21,000 survey stations and several databases tied to these stations, combining this data in a usable format can be an unwieldy task. Geographic Information Systems (GIS) technology provides the tools necessary to quickly search for and graphically display relationships between data sets. It can also easily determine and display the cave's location in relation to other GIS layers (including surface features). At Jewel Cave, a more accurate cave-surface overlay was generated by adjusting the cave survey to fit 35 control points. Once this was done, the overburden of the cave was determined by joining surface and cave layers. Data sets tied to survey stations were linked to the survey data and displayed in relation to each other and to other layers in the GIS. It is now possible to perform complex queries across these large data sets and search for relationships which help us to better understand and manage the cave.

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## Introduction

South Dakota's Jewel Cave, over 127 miles long, is well-known for its size and complexity. The cave is a network maze with several distinct levels of passage in a vertical extent of 631 feet. The survey data consists of over 21,000 survey stations under a surface area of just three square miles. It is challenging to visualize the location of a cave this size in relation to surface developments, overlying topography, and political boundaries.

In the past, a rough topographic overlay has been created by processing the cave survey data (using SMAPS 4, a DOS-based cave survey program), printing a scaled line plot, then overlaying the print-out on a topographic map. Depth below the surface could only be calculated by adding the Z values in SMAPS to the elevation of the cave entrance, then subtracting this value from the surface elevation above the station in question. The surface elevation was manually determined by finding the closest topographic contour to the survey station on the overlay. This was a time-consuming process and could not easily be done for all survey stations.

Cave radio locations tied to survey stations have been established over the last 15 years. This data set has been used to adjust the cave survey by entering control points into COM-PASS cave survey software, but in the past there

has been no easy way to graphically compare corrected and uncorrected data. Such a comparison can help data managers narrow down blunders and/or identify compounding errors.

Data tied to cave survey stations, such as radon concentration and feature inventory data, has previously been difficult to interpret without being placed in its spatial context. For example, the current inventory database (Visual dBASE) can perform queries and return lists of stations nearest to specified combinations of inventoried items, but the list is not very useful without a graphical representation of both the cave and the inventory data.

Geographic Information Systems (GIS) technology has provided the link between such databases of information, cave survey data, and surface features. Any information that is geographically referenced (such as data tied to survey stations) can be incorporated in GIS. This has provided managers with the ability to view and analyze spatial relationships of features inside the cave as well as spatial relationships between cave passages and overlying surface features.

## Control Point Adjustment and Cave-Surface Overlay

Once the cave has been surveyed, the survey can be registered to a known surface location

(the entrance), and a line plot of the cave can be overlain on other GIS layers. The accuracy of this overlay relies on the accuracy of the cave survey and, in a large cave system, compounding errors can lead to imprecise overlays. To correct for errors in the survey, cave radio locations were used.

Coordinates of 35 radio-located surface control points were determined by surveying from benchmark locations. These latitude-longitude values were used to create an ArcView GIS theme, then were projected and displayed together with their corresponding cave survey stations. As expected, the surface and in-cave points closest to the origin of the cave survey (the entrance) overlap almost perfectly. Offset between the pairs of points becomes greater as the survey moves farther from its point of origin. (Figure 1)

In COMPASS, the X and Y coordinates of the radio locations were entered as control points, using the Z coordinate from the original cave survey. The depth determined by the cave radio is subject to large, non-systematic errors, and was therefore not used to calculate a new Z coordinate. The cave was then re-plotted and exported to ArcView.

Once the cave data set was corrected, it was combined in the GIS with Digital Line Graphs representing hydrography, roads, political boundaries, and topographic contours (Figure 2). It was also overlain on images supported by

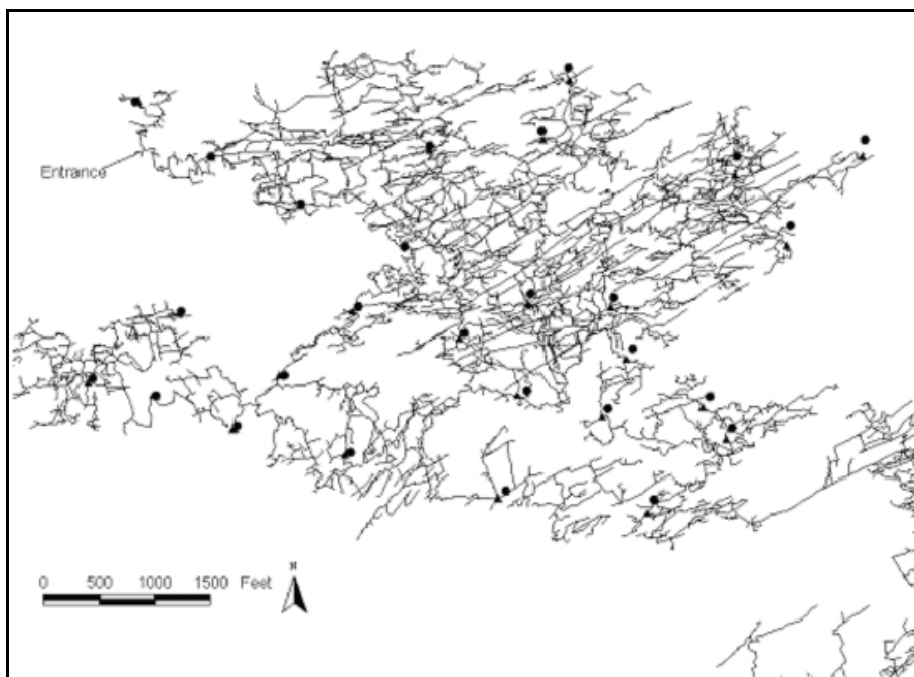
ArcView, such as Digital Raster Graphics and Digital Orthophotoquads.

### Overburden Determination

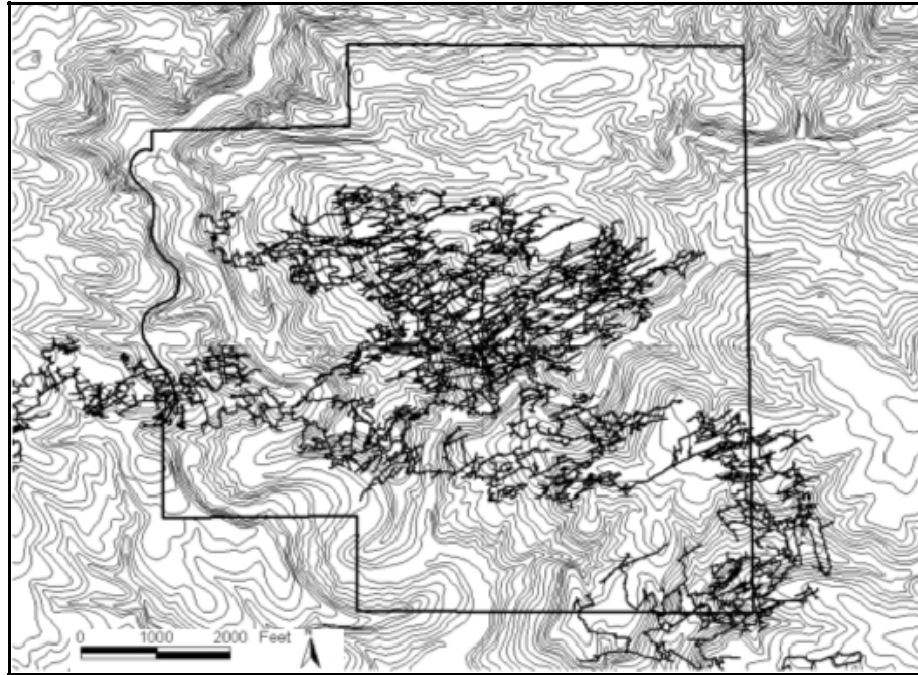
Determining the depth of cave passages beneath the local surface is an important cave management tool. Prior to the use of GIS, vertical relationships with the entrance could be easily calculated from the cave survey, but overburden could not. GIS layers such as Digital Line Graphs of topographic contours or Digital Elevation Models provide the elevation at any point on the surface. The cave survey data layer provides the elevation for every survey station in the cave. Joining the two data sets together, then subtracting the surface and cave elevations, yields the depth.

The accuracy of this depth determination is limited by the accuracy of the surface elevations and the accuracy of the cave survey. Since Digital Line Graphs of 20-foot topographic contours were used to determine surface elevations, the accuracy of the surface elevation can conservatively be given as  $\pm 10$  feet.

The radio locations discussed in the previous section have revealed a relatively accurate cave survey, however survey error cumulatively increases far from the entrance. Although the survey was corrected in the X-Y direction to match the radio locations, using the elevations determined by the original cave survey could introduce error to the depth determination in



**Figure 1.** Surface control points (circles) and corresponding in-cave points (triangles) for a portion of Jewel Cave.



**Figure 2.** *Portion of Jewel Cave line plot overlain on Digital Line Graphs of topographic contours and the National Monument boundary.*

the far southeastern part of the cave, where survey error is greatest.

The deepest point in Jewel Cave was determined to be nearly 750 feet below the surface. Due to the errors described above, one survey station was found to be 8.2 feet above ground.

### **Feature Inventory and Radon Linkages**

Nearly half of Jewel Cave's 127 miles of passages have been extensively inventoried. The ability to quickly query this data and display the results on the cave line plot is extremely useful. Relationships between the inventoried items and other layers in the GIS (such as hypsography, hydrography, and surrounding geology) can be revealed, as well as ways in which the queried items spatially relate to each other.

The inventory data was added to ArcView as a table then linked and cross-linked to the cave survey stations theme. Complex queries for any combination of inventory items can now be performed, and the results of the queries can be highlighted on the cave line plot. (Figure 3)

A table of radon concentration values for several survey stations was also added to ArcView, then joined to the survey stations theme. The stations were then colored based on ranges of radon concentration in order to look for any trends in radon related to location.

Although more data is needed, it appears that radon concentration decreases far from the cave entrance.

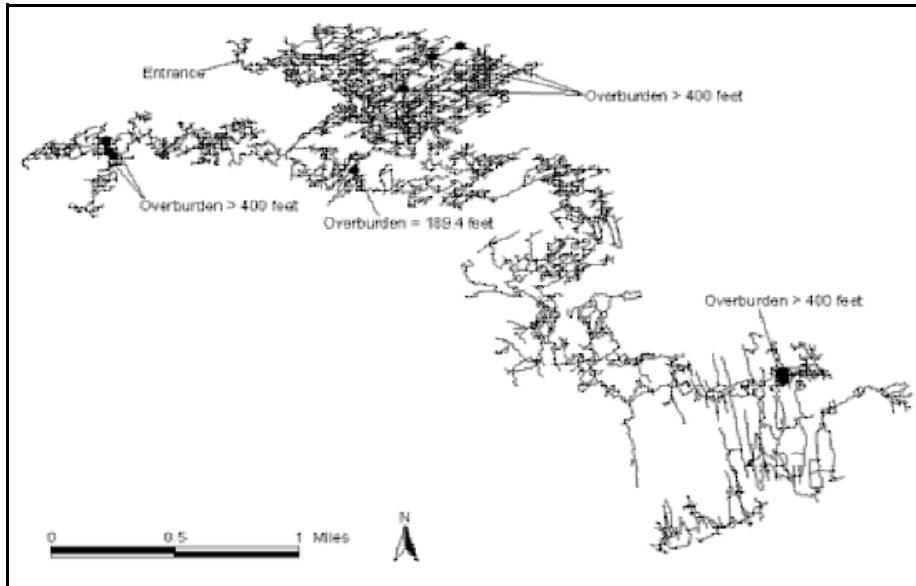
### **A Management Tool**

Developing an accurate cave-surface overlay for Jewel Cave has allowed us to identify cave passages that run beneath surface developments such as roads, buildings, and parking lots. This can tell us which areas of the cave are most vulnerable to contamination and redirected runoff associated with these developments.

A graduate student conducting research at Jewel Cave has also used the monument's GIS to determine which cave passages run beneath faults and fractures he has identified on the surface. He has then been able to look for fractures and evidence of faulting in those passages to better determine surface-subsurface geological relationships.

Currently, over 40% of Jewel Cave lies beneath USDA-Forest Service land, and GIS has allowed management to more precisely determine where the cave leaves the national monument boundary. An important first step in managing any cave is knowing where it is, and GIS can determine this to a great degree of accuracy.

Estimating overburden is also a very useful management tool. Identifying shallow areas of the cave, particularly in locations vulnerable to



**Figure 3.** Location of bat scratches in Jewel Cave as determined by cave feature inventory linkage. These may be locations of old entrances that have since been naturally filled. Note overburden for each area.

potentially harmful surface activities, can help to guide management decisions. Overburden information can also be used to choose the shallowest possible sites for new radio locations in order to receive the strongest magnetic signal possible.

GIS analysis has helped the resource management staff make better-informed decisions regarding the use of herbicides to treat non-native plants. It has been used to determine the location of noxious weed sites relative to Jewel Cave, to calculate the depth of the cave below these sites, to evaluate their proximity to drainages and other potential infiltration zones, and to find locations of in-cave water drips near these sites.

### **In the Future**

GIS is only as useful as the data available. Jewel Cave looks forward to incorporating more data into the GIS, which will allow for more complex analyses. Structural geologic contours have recently been determined and will be included as will a detailed surface geologic map of the area. The cave maps, which are currently hand-drafted, will be digitized in the coming years. Relationships between constricted, large, or complex parts of the cave and other GIS layers can then be determined. Such information will contribute to our understanding of the cave, and may help to guide continuing exploration.