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KARST GIS ADVANCES IN KENTUCKY

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Little statewide geospatial data was available for Kentucky caves and karst in the past. Recent trends in land development have prompted a distinct need for these data in order to help minimize impact to cave and karst resources. During the past two years, the I-66 Special Project of the National Speleological Society, The Kentucky Speleological Survey, and the Kentucky Geological Survey have gathered, archived, and developed karst data for the state. Current projects include publication of karst basin maps, archiving cave entrance locations, archiving and georeferencing cave maps, creating polygon coverages of cave conduits, and a statewide sinkhole digitization project. These data have proven useful in efforts to redirect planned developments, and to further the state of our knowledge about karst resources within Kentucky.

Karst is an integral part of the Kentucky landscape with ~55% of the state underlain by karstic limestone in 3 of 7 physiographic provinces and along the margins of the Eastern and Western Kentucky Coal Fields (KGS 1985) (Fig. 1). This allows for a great diversity in the state's caves and karst since each karst region has unique characteristics due to differing hydrogeologic conditions (KGS 1985). The abundance of karst in Kentucky affects everything from the state's biodiversity (Barr 1958) to the history of human settlement (Andrews 2001; O'Dell 2001). The widespread and intense karstification of the region also poses tremendous environmental impact issues due to continued population growth and industrialization (Crawford 2001). Increasingly, the karst areas of Kentucky face rapid development and a losing battle due to lack of knowledge about our subsurface environment (Florea *et al*. 1999).

Geographic information system (GIS) data are becoming an important component of today's technology. Kentucky organizations and agencies such as the Kentucky Geological Survey and the Office of Geographic Information have developed extensive coverages and databases for geographic features in the state. Some examples of available, on-line data are Digital Raster Graphic (DRG) maps, Digital Elevation Models (DEMs), and various hydrologic and geologic coverages. Until recently, however, little or no GIS data existed for statewide cave and karst resources in Kentucky. This lack of data has seriously impacted the ability to protect and manage our caves and karst.

KENTUCKY KARST GIS

Caves and karst have been studied intensely in Kentucky for decades. Extensive studies in the Mammoth Cave region have changed our thinking on speleogenesis (White *et al*. 1970; Ford & Ewers 1978; Palmer 1981; White 1988).

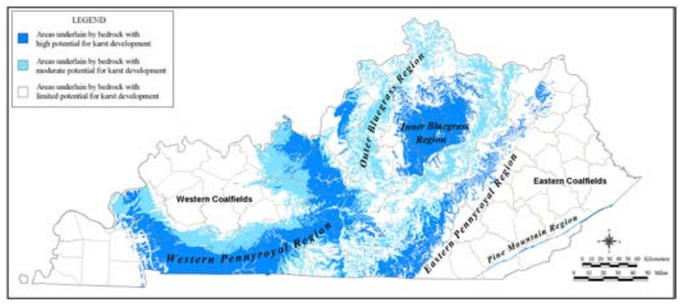

Figure 1. GIS karst map of Kentucky developed by the Kentucky Geological Survey.

Methods for karst aquifer analysis and tracer testing were perfected in the sinkhole plains of central Kentucky (Thrailkill 1972; Quinlan & Ewers 1981). Also during the 1970s and 1980s, cave systems were mapped throughout the state by various groups. Data from these studies were used in publications, theses, and dissertations, but were not widely known.

Much of the distribution problem was due to a lack of appropriate technology to expedite the transfer of these data. Data gathering was laborious, and data storage was always a point of concern. Further, holders of Kentucky karst data were widespread and not accustomed to working cooperatively. No appropriate statewide data repository existed, and the political climate was not conducive for any one organization to become a driving force to organize cave data collection.

During the course of the past several years, all of these factors challenged karst research and forced the advancement of our knowledge of karst on a statewide scale through the use of GIS technology. Recent developments in computer technology have alleviated many of these issues and have revolutionized the ways we communicate and visualize the results of our work. The issues driving development of Kentucky's cave and karst GIS projects can be summarized in three phases.

INITIAL DATA COLLECTION EFFORTS

Various organizations and individuals have been collecting cave and karst data in Kentucky for years. These individual projects, designed with particular goals in mind, have tested various methods of cooperative data sharing and presentation, resulting in essential lessons for future projects.

In the early 1990s, the Cave Research Foundation (CRF), Central Kentucky Karst Coalition, and the American Cave Conservation Association (ACCA) coordinated with other cavers and groups to co-produce a Dripping Springs Escarpment map displaying Mammoth Cave data and other known caves. This overlay of map information addressed several data issues, such as cooperative data sharing and effective presentation methods for large quantities of karst and tracing data.

Starting in 1996, the Kentucky Geological Survey (KGS) began developing a karst atlas of Kentucky composed of various plates (Currens & Ray 1999). KGS has completed five 30 x 60-minute quadrangle maps at a scale of 1:100,000 that show karst groundwater basins. The maps were compiled using data from dye traces performed by numerous researchers. The maps depict major karst springs and swallets, and the approximate path of groundwater flow (Paylor & Currens 2001).

In a more site-specific project, the ACCA, in cooperation with CRF, has modeled the Hidden River Cave System in Horse Cave, Kentucky using ESRI ArcView and 3D Analyst software. This project has been useful in testing methods of incorporating Digital Line Graph (DLG), Digital Ortho Quarter Quad (DOQQ) data and cave survey data to display the relationship of the sub-surface conduits to the overlying topography and town of Horse Cave.

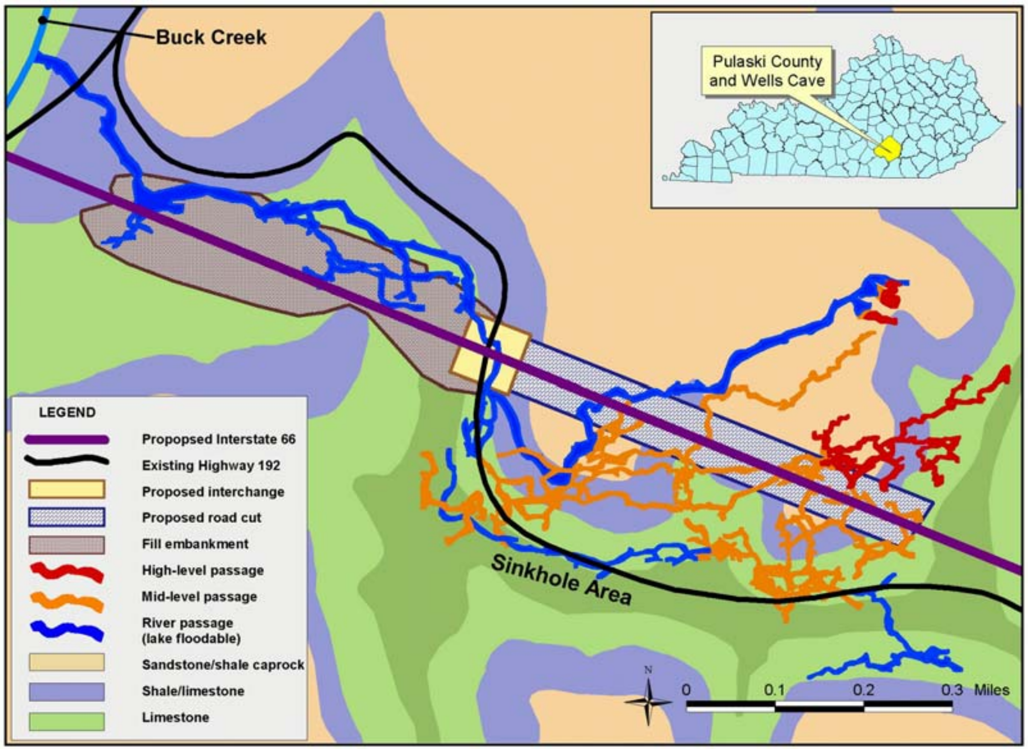

Figure 2. Relationship between the originally proposed I-66 corridor and Wells Cave (adapted from overlay by Larry Simpson).

The Ohio Valley Region (OVR) of the NSS and the Sloans Valley Conservation Task Force have gathered and developed Sloans Valley Cave data for several years. Sloans Valley Cave, the longest mapped cave in the eastern part of the state, has a long history of environmental problems. A large landfill lies adjacent to the cave and within part of its drainage basin, and the cave receives polluted runoff in these areas. Reservoir water from Lake Cumberland permanently inundated much of the cave. As the reservoir level fluctuates as much as 12 m throughout the year, thermal pollution wreaks havoc with the cave's biological systems. The complicated system of hydrologic and biologic interactions is perfectly suited to GIS analysis.

In addition to these specific examples, much of the original data on Kentucky caves has existed for years in individual databases and boxed files in basements or attics. Over time, data loss has taken its toll on the level of our knowledge of caves and karst in Kentucky. As the state continues the current population and industrialization trend, fully operational databases of Kentucky karst will be essential for proper planning and zoning in karst regions, implementation of best management practices for karst, and advancing our knowledge about karst through well-informed research.

INTERSTATE 66 AND DEVELOPMENT ISSUES

When the Kentucky Transportation Cabinet (KTC) unveiled possible routes for the section of Interstate 66 between London and Somerset, KY (KTC 1999), karst researchers and cavers were dismayed. Of the alternatives presented in May of 1999, the KTC seemingly chose the most environmentally damaging route (the southern route) as the preferred alternative (Florea *et al*. 1999). This proposed corridor traversed undeveloped woodlands inside and outside the

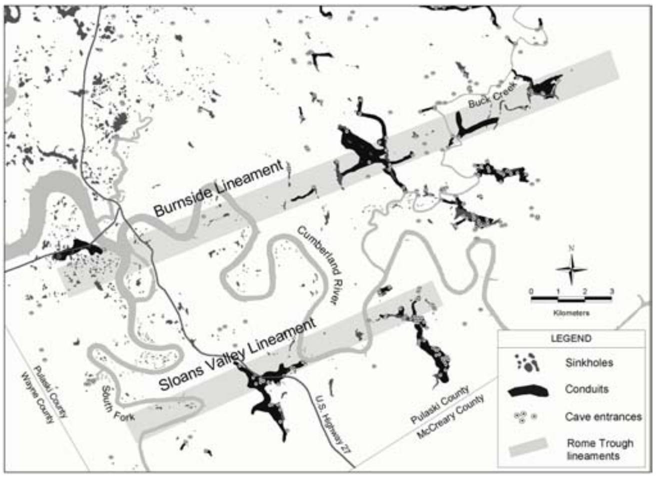

Figure 3. Karst resources in southern Pulaski County, Kentucky, showing newly recognized fracture lineaments that control cave and karst development.

Daniel Boone National Forest, crossed several high quality watersheds, and threatened severe damage to cave and karst resources including Wells Cave (20 km of surveyed passages) (Fig. 2). In response to the KTC planning study, the I-66 Special Project of the National Speleological Society in cooperation with dozens of other organizations initiated one of the first extensive cooperative data gathering campaigns in the region.

The response focused on collecting, maintaining, and presenting a GIS of karst resources in Pulaski County, Kentucky, using ESRI ArcView software. The first level of data included a point location database of cave entrances and other associated karst features provided by locals and members of the caving community. A second layer of information included scanned and georeferenced (registered to real-world coordinates) cave maps. From these raster images, polygons outlining the passages were digitized to display regions in which surveyed caves were known to lie underneath the surface. A third layer of information included sinkhole polygons digitized from depression contours on 7.5' topographic quadrangles (Fig. 3). The final layer of information in the GIS was a vector representation of the corridor alternatives for the I-66 project. This information was provided by the KTC. All data was created using NAD 1983 datum and the Kentucky State Plane South 1983 coordinate system, chosen to maintain consistency with GIS coverages in state developed databases, and to match the State Plane zone for the proposed corridor.

The data developed by this effort were used in several ways. Overlays of the corridor alternatives with a 1000 foot [~305 m] buffer and the conduit polygons and cave entrance data were used to determine potential karst impacts for each alternative. KTC and its consultants provided conduit polygons and the sinkhole coverages for the area affected by the proposed corridors for incorporation in a second planning study being completed to address the concerns raised by the first (KTC 2000). Images produced using the data were presented in publications and at various presentations throughout the region to help others understand the concerns (Florea *et al.* 1999; Florea 2000a).

The Kentucky Speleological Survey

As a result of the cooperative atmosphere of the I-66 research, a desire to gather the extensive but disorganized karst data for all of Kentucky prompted the formation of the Kentucky Speleological Survey (KSS) during 1999 and 2000. The KSS was formed to serve as a statewide database and repository for cave and other karst related data. The establishment of the KSS was an important step toward saving and inte-

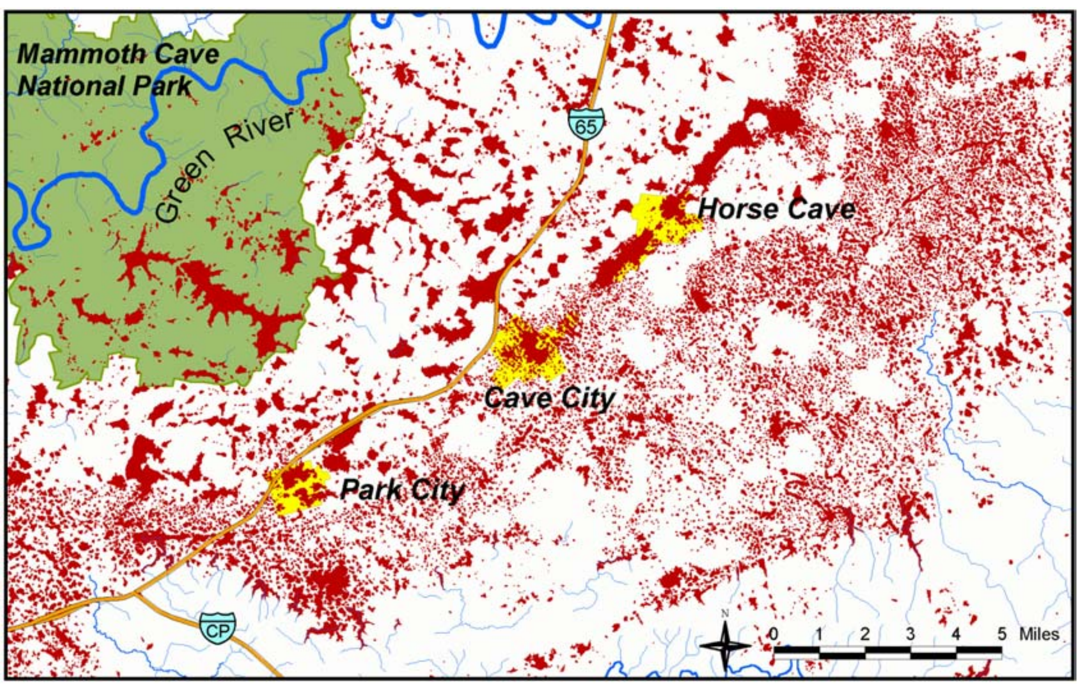

Figure 4. Portion of the Kentucky statewide sinkhole map showing sinkhole distribution near the Mammoth Cave area.

grating vital karst data before it was lost or forgotten (Florea 2000b).

The utilization of GIS as an integral component of the KSS's data gathering and archiving activities was emphasized during organization. The KSS currently uses ArcView GIS linked to Access databases and spreadsheets to manage all its spatial data, allowing users to link multimedia data such as narrative files, scanned maps and cave photographs to the primary spatial index of feature locations. This system provides the framework needed for an eventual, fully integrated database of material without the need for primary paper copies.

An example of one of the issues that KSS addressed arose during the I-66 conflict in Pulaski County. The interstate development problem illuminated the need for a detailed, statewide sinkhole delineation. Following a review of the results of the I-66 Special Project and considering the ongoing groundwater investigations occurring at KGS, a decision was made to complete a sinkhole digitizing effort for all of Kentucky on a 1:24,000 scale (Fig. 4) (Paylor & Florea 2001).

The sinkhole digitization raised several data issues, including the representation of complex uvalas (sinkholes with multiple sinkpoints), differences in contour intervals between topographic quadrangles and their effects upon data resolution, and manipulation of USGS hypsography files.

RESULTS AND CONTINUING STUDY

The impact of all the GIS work to date in Kentucky has been significant. Due to a combination of public opinion and evidence provided through karst GIS development, the second planning study for I-66 (released in June 2000) recommended a more northerly corridor, which avoid many known cave and karst resources (KTC 2000). Many concerns still exist with the current preferred corridor, and future efforts will involve continued exploration and data gathering of karst resources concurrent with the KTC environmental impact statement.

The efforts of the I-66 Special Project have opened the door to other research in the region including a cave-cricket/beetle predation study (White 2001), cave diving exploration in regional aquifers, and geomorphic studies of regional caves (Florea 2000b; 2001b). Other research stemming from this collected data has detected evidence of a previously unknown fault though sinkhole and conduit alignments (Fig. 3) (Florea 2001a).

A more recent offshoot of the I-66 effort temporarily averted a strip mine proposal in the vicinity of Wells Cave in Pulaski County. Due to the combined effort of several individuals and through use of GIS data collected during the I-66 Special Project effort, serious deficiencies were noted in the permit application. The Department for Surface Mining Reclamation and Enforcement technically withdrew the permit after the deficiencies were pointed out.

A 3D model of the Sloans Valley Cave System is being developed using ArcView GIS with the Spatial Analyst and 3D Analyst software packages (Paylor *et al.* 2001). The GIS is nearing completion and will be used to model water levels, cave stream and reservoir water mixing, siltation, and landfill runoff routes through the cave. In addition to hydrogeologic studies, endangered and threatened species populations and migrations will be tracked, and an attempt will be made to model airflow patterns through the complicated system and its 18 entrances.

Other ongoing karst GIS activities in Kentucky are occurring at Western Kentucky University's Hoffman Institute and the KGS (Glennon & Groves 2002). Other planned elements of KGS's karst atlas series will show karst flood-prone areas, and will detail carbonate bedrock lithologies, sinkholes, and springs as well as include results of long-term dye tracing projects in the Inner Bluegrass and Western Pennyroyal regions that are being used to update the atlas maps. In addition to updates to its karst groundwater basin map series, KGS will shortly be publishing a statewide karst occurrence map developed from new 1:100,000-scale ArcInfo geology coverages.

The statistics generated by the KSS sinkhole digitization project are impressive. Nearing completion, over 62,000 sinkholes have been digitized to date for Kentucky. The combined area of these polygons suggests that ~3% (>3100 km²) of the surface of Kentucky lies within a topographically mapped sinkhole. The sinkhole digitization effort has also helped KGS develop more effective dye tracing methods due to the recognition of regional sinkhole lineaments (Paylor & Currens 2001).

The completed statewide sinkhole coverage will be published through the KSS and KGS, and will include a descriptive folio and data CD-ROM. The coverage will be useful for many purposes, including planning, resource management, cave and karst research, groundwater studies, and statistical analysis.

CONCLUSIONS

Kentucky's abundance of karst has created tremendous land use concerns as population and industrialization in karst areas rapidly increases. The lack of statewide organization for gathering karst data in Kentucky once resulted in problems with dealing with issues of planning and resource management. GIS utilization is changing the outlook for statewide karst data availability for Kentucky. The I-66 Special Project of the NSS, the Kentucky Speleological Survey, the KGS, and others have been gathering, archiving, and developing karst GIS data for the past several years. Current GIS projects include groundwater dye trace information, cave entrance archiving, map archiving and georeferencing, conduit polygon coverage development, and a statewide sinkhole digitization project. The data from these efforts have proven useful in efforts to improve the outcome of planned developments, and to further the state of our knowledge about karst resources within Kentucky.

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