Karst Potential and Development Indices: Tools for Mapping Karst Hazard Areas Using GIS

James C. Currens
Matthew M. Crawford
Randall L. Paylor

Kentucky Geological Survey
University of Kentucky
Introduction

Over half of Kentucky has karst - primarily defined by the presence of soluble (calcareous) bedrock at the surface.

The degree of karst development in the state is a serious planning and hazard issue that needs to be addressed on a statewide basis.
Why a Kentucky Karst Index?

- Classification schemes bring order to a collection of observations as an aid to understanding the mechanisms leading to those observations. They can be utilized as planning tools.

- There have been many karst classifications proposed over the years, but most existing classifications are subjective and non-quantitative.

- Recent objective classification methodologies use labor-intensive site specific data for evaluation, and most of these methods do not use the types of data that are available statewide in Kentucky.

- The completion of the Digitally Vectorized Geologic Quadrangles for Kentucky along with new efforts to inventory statewide karst features now make it possible to evaluate the state’s karst potential and development on a broad scale.
Some Previous Classification Methods

- **DRASTIC - EPA Groundwater Sensitivity.**
  Hydrogeologic settings form the system and incorporate major hydrogeologic factors that control ground-water movement: depth to water, net recharge, aquifer media, soil media, topography, impact of the Vadose zone media and hydraulic conductivity of the aquifer. Hydrogeologic settings are combined with these factors to create units to rank pollution potential.

  *Does not address karst issues effectively.*

- **KARSTIC - Adaptation of EPA methods to include karst groundwater flow.**

  *Uses data not readily available in Kentucky.*
Some Previous Classification Methods

- **EPIK** - European method.
  
  *Uses four attributes: epikarst, protective cover, infiltration conditions and karst network development, rating and weighting them. Vulnerability depends on residence time of the water in very thick soil and sediment cover typical of alpine karst. Also takes infiltration through ponors into account.*

  *Not effective for flat-lying Interior Plateaus province.*

- **KISBC** - Canadian method developed in British Columbia.
  
  *The process considers three major criteria: 1) epikarst sensitivity; 2) surface karst sensitivity; and 3) subsurface karst potential. The procedure also allows for the integration of three modifying factors: 1) fine-textured, erodible soils; 2) karst roughness; and 3) unique or unusual flora/fauna and/or habitats.*

  *Extremely field intensive and site-specific.*
Defining Karst Potential and Karst Development

Karst Potential: A rank, based on stratigraphic and lithologic data, of areas that are subject to the development of caves, sinkholes, and springs.

Karst Development: A measure of “real world” karst based on the actual presence of caves, sinkholes, springs and similar features.
Dual system approach

Although they are typically readily available, lithologic and stratigraphic data have not been widely used by themselves to indicate karst development.

This fact suggests that GIS stratigraphy layers must be calibrated with karst feature data before using the files to make karst maps.

We propose that such a dual potential-development approach can overcome pitfalls with either method alone, and produce a more accurate final product.
COMPILING THE KARST DEVELOPMENT INDEX

Criteria and Methods
## List of criteria considered for the Karst Development Index

<table>
<thead>
<tr>
<th>Karst Development Index Criteria</th>
<th>Descriptive Range of Values</th>
<th>Hydrogeologic Relevance of Criteria</th>
<th>Data Source or GIS Coverage</th>
<th>Analogous DRASTIC Factor</th>
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<tr>
<td><strong>Epikarst Development</strong></td>
<td>Range of thickness in the polygon</td>
<td>Relates to capacity to filter recharge and cover-collapse size</td>
<td>SSURGO or measurements in the field</td>
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<td>Groundwater Data Repository-Water wells drilled since 1984</td>
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<tr>
<td><strong>Sinkhole Density</strong></td>
<td>Percentage of polygon within highest mapped closed contour</td>
<td>Relates to capacity to filter recharge and epikarst development</td>
<td>DEM, SSURGO &amp; KGS/KSS Sinkhole coverage</td>
<td>Net Recharge</td>
</tr>
<tr>
<td><strong>Intercepted Voids</strong></td>
<td>Unknown: Potentially Zero to 50% of hole depth</td>
<td>Directly measures the karst porosity</td>
<td>Voids not recorded digitally for core or other drilling records</td>
<td>Hydraulic Conductivity/ Missing bedrock</td>
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<tr>
<td><strong>Hydrograph Coefficients for Study Area Springs</strong></td>
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<td>Count of entrances per unit area</td>
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<td>Length of groundwater dye-trace vectors;</td>
<td>Integration of Flow (Ray and O’Dell, 1993)</td>
<td>KGS Karst Groundwater Basin Maps</td>
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<tr>
<td><strong>Conduit Density: Cave Maps</strong></td>
<td>Percent: (cave plan length) / (area of polygon)</td>
<td>Estimator of gross porosity</td>
<td>MAY NOT BE AVAILABLE</td>
<td></td>
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DVGQ of the Tell City quadrangle
Digitized 7.5-minute topographic sinkholes
Karst conduit trace vectors
Depth to bedrock measurements
Final KDI polygon cut
### Scoring matrix for evaluating the Karst Development Index

<table>
<thead>
<tr>
<th>Sinkhole Area Ratio Percent Coverage ((R_c)) (W = 4)</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
<th>Depth to Bedrock (Surrogate for Epikarst Development) (W = 1)</th>
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</thead>
<tbody>
<tr>
<td>(\geq 75%) 4th Quartile over 7.11()</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Depth &lt; 2.5m (7.5ft)</td>
</tr>
<tr>
<td>Conduit Density: 3rd Quartile 0.23 to 0.39 km/km(^2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Depth 3.3 m to 5m (8 to 32 ft.)</td>
</tr>
<tr>
<td>Conduit Density: 2nd Quartile 0.09 to 0.24 km/km(^2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Depth 3.3 m to 15 m (13 to 15 ft.)</td>
</tr>
<tr>
<td>Conduit Density: 1st Quartile &lt; 0.09 km/km(^2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Depth &gt; 4.65 m (&gt; 15 ft.)</td>
</tr>
</tbody>
</table>

\(\uparrow\) Length of Surveyed Cave or Inferred Groundwater Flow Route per unit area \(W = 2\)

<table>
<thead>
<tr>
<th>Cave and Spring Density 4th Quartile Greater than 0.52 per km(^2)</th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
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<tr>
<td>Cave and Spring Density 3rd Quartile from 0.26 to 0.52 per km(^2)</td>
<td></td>
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COMPILING THE KARST POTENTIAL INDEX

Criteria and Methods
Stratigraphy

Lithology

Karst Potential

% insolubles

= <10%

= 10-50%

= >50%

high

moderate

low
Kentucky Karst Potential Map based on 500,000-scale geology

KARST OCCURRENCE IN KENTUCKY
Randall L. Payler and James C. Callans

Karst is a terrain characterized by karstic features such as sinkholes, caves, underground pipes, and springs. It is often associated with soluble rocks like limestone, dolomite, and gypsum. Karst landscapes are well-known for their unique features and challenges, including sinkholes, underground rivers, and karst springs.

This map was created from a digital version of the 1:500,000-scale geologic map of Kentucky (N. C. Stanier and T. C. C. Cartwright, 1988). The geologic map was used to identify areas with karst potential, which are then displayed on the map.

The karst potential map is based on the geology and hydrogeology of Kentucky. The map provides a detailed view of the karst features and their distribution across the state.
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<td>Less than 10 cm to 100cm</td>
<td>Initial flow path availability and mechanical strength for conduit development</td>
<td>Lithologic descriptions in stratigraphic and other geologic reports and maps</td>
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</tr>
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<td>Grain Size</td>
<td>Range in diameters: equivalent clay grain size to pebble size</td>
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<td>No GIS data. Basin specific data for a small number of springs available</td>
<td>Hydraulic Conductivity</td>
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<td>Climate</td>
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<td>Directly measures recharge</td>
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Lithologic data gathering

Limestone—finely to coarsely crystalline; some argillaceous, minor very fissiliferous dolomite beds; chartreuse, slightly dolomitic in places; characterized by gray to dark gray on fresh and weathered surfaces; thick bedded to massive, few medium-gray oolitic beds near top, somewhat below those of limestone beds in Ste. Genevieve. Large rugose colonial corals commonly identified as *Lithostrotion* and *Sonderothonia* occur throughout; generally silicified, abundant in soil. Gray to black chert occurs in numerous beds, stringers, and nodules; weathers white, cream, and various shades of reddish brown; generally less blocky weathering than chert in Ste. Genevieve; nodular chert particularly abundant at top.
New lithologic attribute data compiled

<table>
<thead>
<tr>
<th>FMCODE</th>
<th>TEXT</th>
<th>ZCALCITE</th>
<th>MINRANK</th>
<th>GRAIN_SIZE</th>
<th>GRAIN RANK</th>
<th>BEDDING</th>
<th>BED RANK</th>
<th>ZINSOLUBLE</th>
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<tbody>
<tr>
<td>332SLDE</td>
<td>Slade Formation</td>
<td>75.0</td>
<td>6</td>
<td>calcilutite to calcarenite</td>
<td>3.0</td>
<td>medium to thick</td>
<td>5.0</td>
<td>15.0</td>
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<tr>
<td>332SMPL</td>
<td>Sample Sandstone</td>
<td>0.0</td>
<td>2</td>
<td>fine to calcarenite</td>
<td>3.0</td>
<td>medium to thick</td>
<td>5.0</td>
<td>98.0</td>
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<tr>
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<td>medium to thick</td>
<td>5.0</td>
<td>98.0</td>
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<td>3.0</td>
<td>thin to thick</td>
<td>4.0</td>
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<td>332TSGL</td>
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<td>fine to coarse</td>
<td>3.0</td>
<td>thin to thick</td>
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## Scoring matrix for evaluating the Karst Potential Index

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<td>NORMALIZED CONDUIT LENGTH (KMKM²)</td>
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Karst Index Calibration

Unique KPI vs. Average KDI

$R^2 = 0.7123$
Karst Index Calibration

Unique KPI vs. Average KDI - no caprock polygons

$y = 1.4483x - 14.538$

$R^2 = 0.8709$
Final Karst Index applied to DVGQs

Karst Potential Index for Kentucky

- Very high potential for karst
- Moderate potential for karst
- Low to no potential for karst
Final Karst Index applied to DVGQs - Original Data

MADISON

FALMOUTH

LOUISVILLE

LEXINGTON
Final Karst Index applied to DVGQs
Final Karst Index applied to DVGQs

BOWLING GREEN NORTH
DISCUSSION

- The KDI/KPI project has developed a regional karst classification method that is more appropriate for Kentucky and the Interior Plateaus province than previously used methods.

- The KDI and KPI methods correlate well, suggesting that they are good criteria for classifying karst in Kentucky.

- The detailed karst maps produced from this study can aid in many areas, including planning, hazard evaluation and environmental investigations.
  - Groundwater issues are not directly addressed using the KDI/KPI classification, but it can be used to augment karst groundwater classification methods. Does not currently address non-karst catchments draining onto karst areas.

- The classification system proposed here does not remove the necessity for field investigations when evaluating site specific karst issues.
Groundwater dye tracing can delineate drainage basins and identify general conduit flow routes.
Surveys by cavers directly reveal karst porosity and groundwater flow routes.

Daniel Boone Cave
Jessamine County, Kentucky

Surveyed by the Blue Grass Grotto Cave Surveying Workshop Feb. 23, 2003
Kentucky Speleological Survey Cave Database


Map represents 3337 cave entrances with known location data. Another ~1100 caves included in the KSS files have little or no location data. 318 new cave locations have been added in 2006.

http://www.ksscaves.org/
Further Work

- The KDI as currently calculated is based on four 100K quad sheets. The KDI will be evaluated for all the remaining quads and recalculate for more accurate results.

- Investigate the use of relief (derived from DEMs) to further refine the KDI matrix.

- Address the problem of “quad boundary faults” where necessary.

- Include the final Karst Index map as a base layer on the KGS Internet Map Server.
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