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

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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.

Sinkhole Collapse

Environmental Issues

Flooding

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.

KGS

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

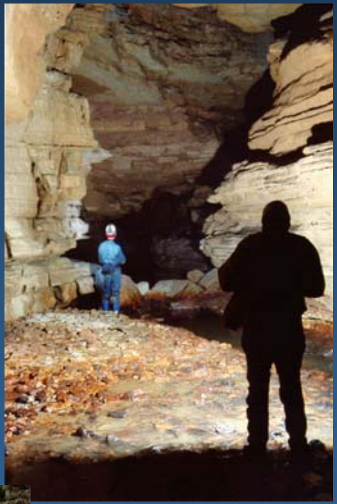
Mapped Sinkholes

Soil Thickness

Karst Development Index

Site-specific Data

Cave and Spring Locations



Mapped Caves and Dye Trace Routes

List of criteria considered for the Karst Development Index

Karst Development Index Criteria	Descriptive Range of Values	Hydrogeologic Relevance of Criteria	Data Source or GIS Coverage	Analogous DRASTIC Factor
Epikarst Development	Range of thickness in the polygon	Relates to capacity to filter recharge and cover-collapse size	SSURGO or measurements in the field	Impact of Vadose Zone
	Median depth to bedrock in the polygon		Groundwater Data Repository-Water wells drilled since 1984	
Sinkhole Density	Percentage of polygon within highest mapped closed contour	Relates to capacity to filter recharge and epikarst development	DEM, SSURGO & KGS/KSS Sinkhole coverage	Net Recharge
Intercepted Voids	Unknown: Potentially Zero to 50% of hole depth	Directly measures the karst porosity	Voids not recorded digitally for core or other drilling records	Hydraulic Conductivity/ Missing bedrock
Hydrograph Coefficients for Study Area Springs	Discharge or Stage 0.1 to 1,000 liters/second	Indirectly measures the epikarst and baselevel porosity	No GIS data. Basin specific data for a small number of springs available	Hydraulic Conductivity
Cave Entrances in Study Area	Count of entrances per unit area	Estimator of conduit permeability and integration of flow	KSS cave location database[1]	Basin Integration: The two data sets are of similar mode, format and informational value. Combined to provide a larger data set.
Springs within the Study Area	Count of Springs per unit area	Estimator of conduit permeability and integration	KGS Springs database	
Presence of Inferred Groundwater route	Length of groundwater dye-trace vectors;	Integration of Flow (Ray and O'Dell, 1993)	KGS Karst Groundwater Basin Maps	Hydraulic Conductivity The two data sets are combined to provide for a larger data set.
Conduit Density: Cave Maps	Percent: (cave plan length)/ (area of polygon)	Estimator of gross porosity	MAY NOT BE AVAILABLE	

Criteria utilized for the KDI

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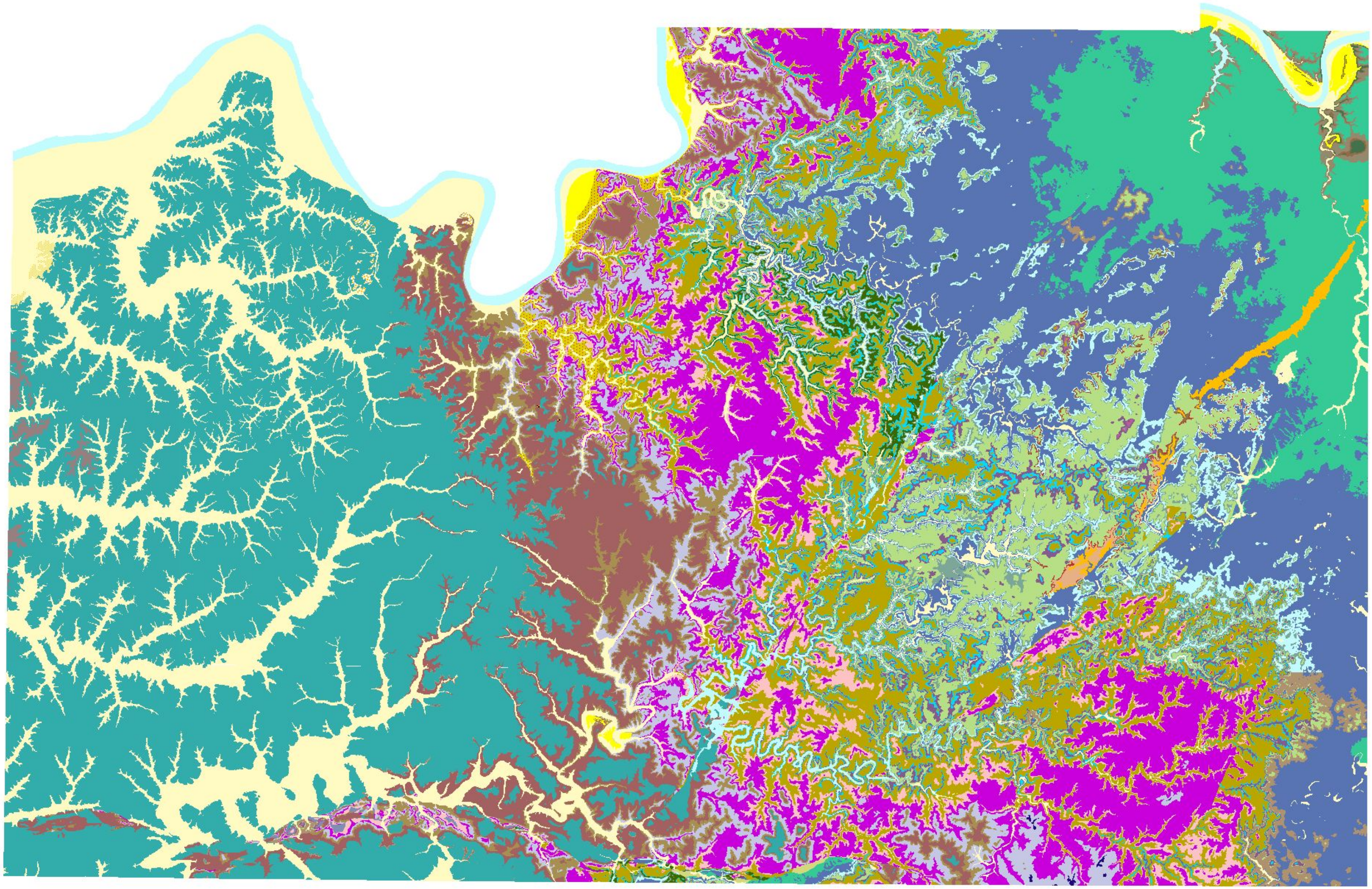
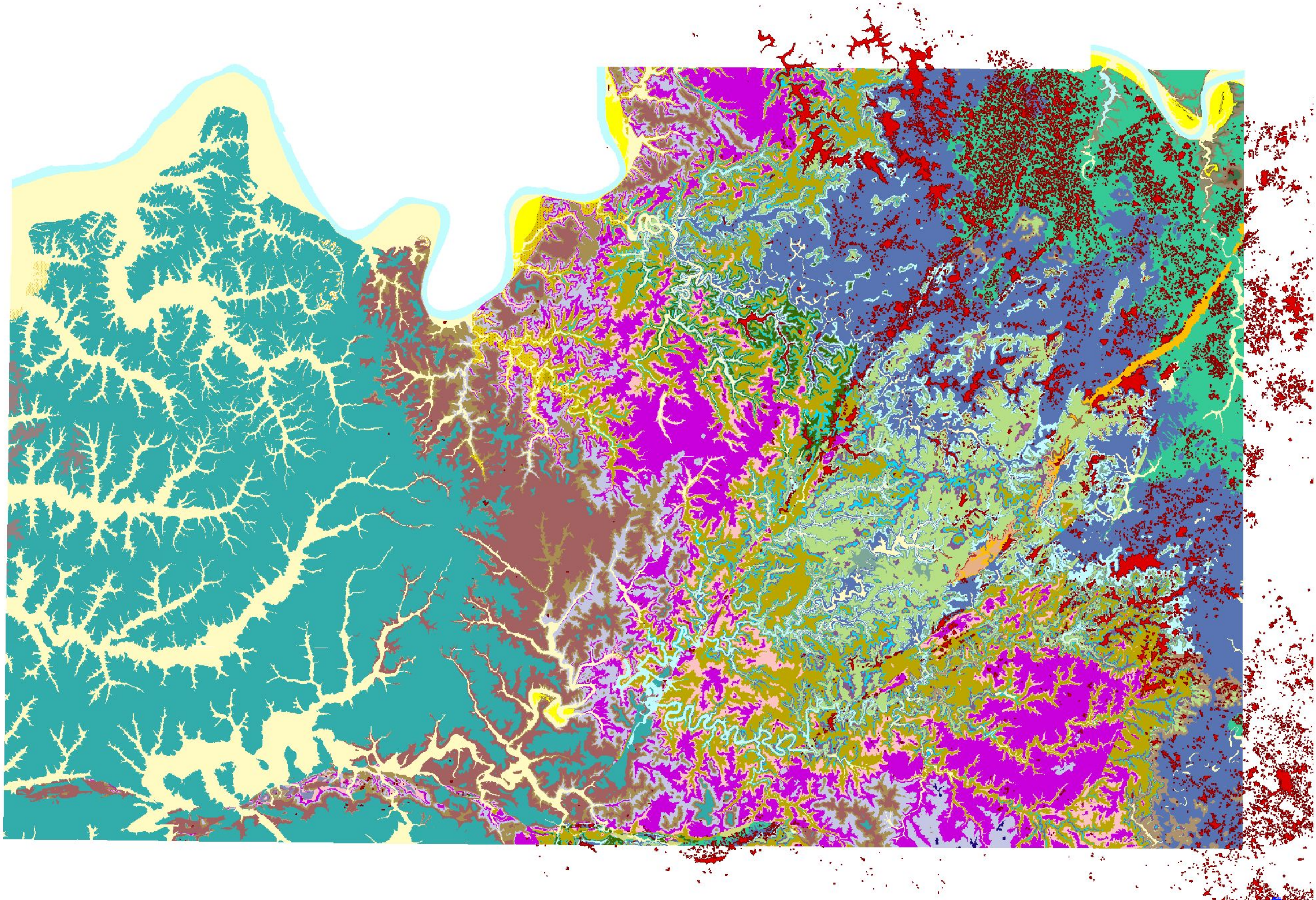
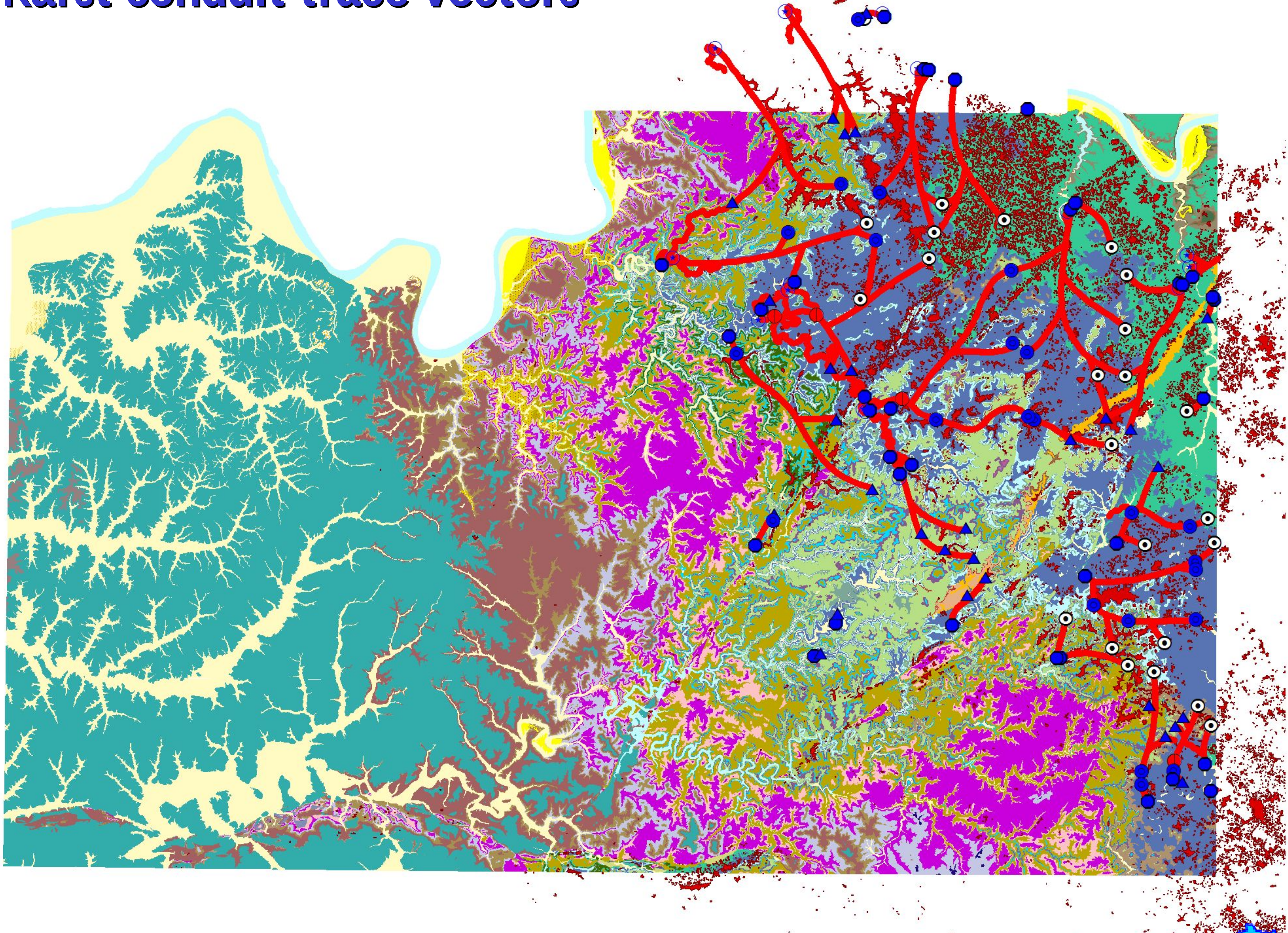
DVGQ of the Tell City quadrangle



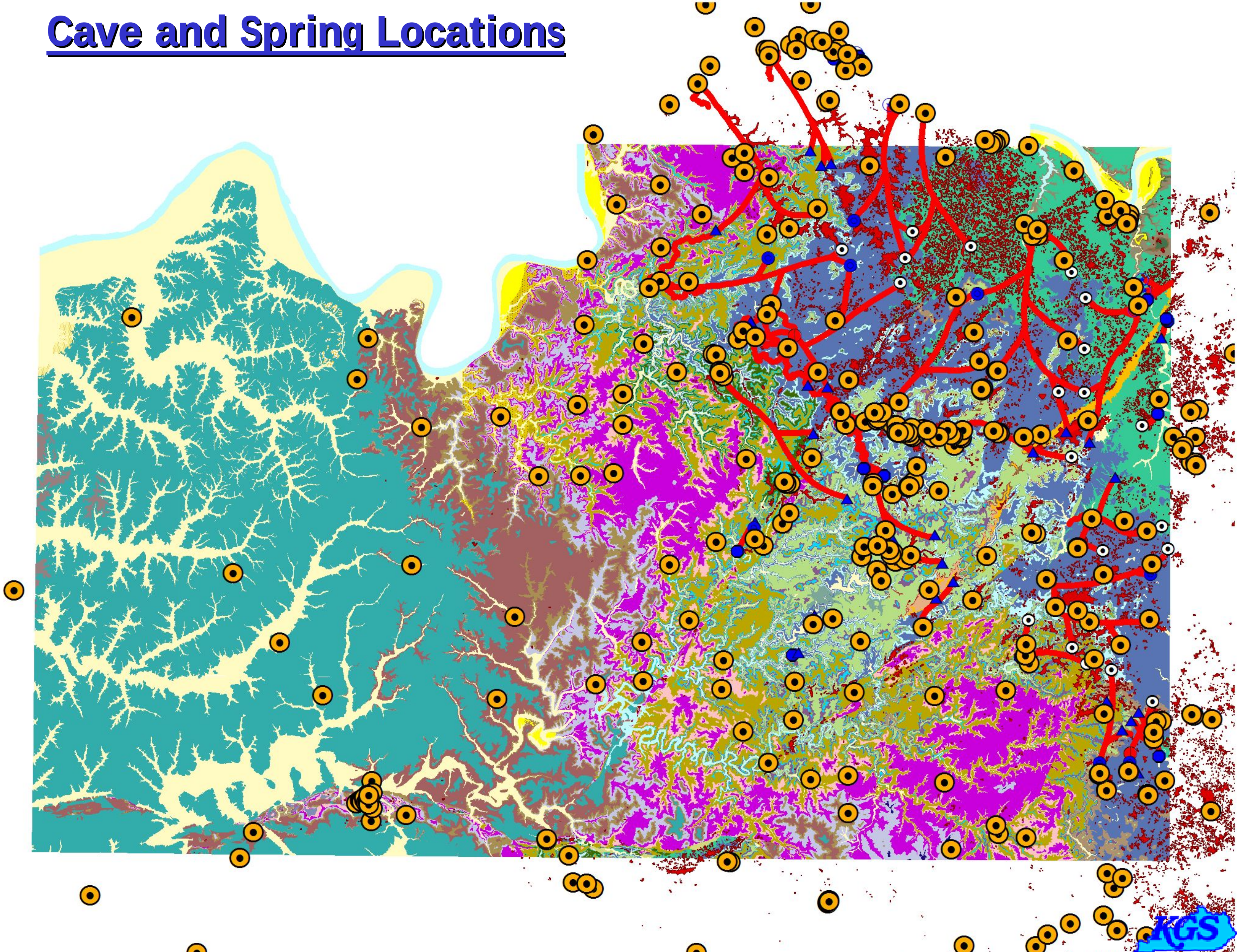
Digitized 7.5-minute topographic sinkholes



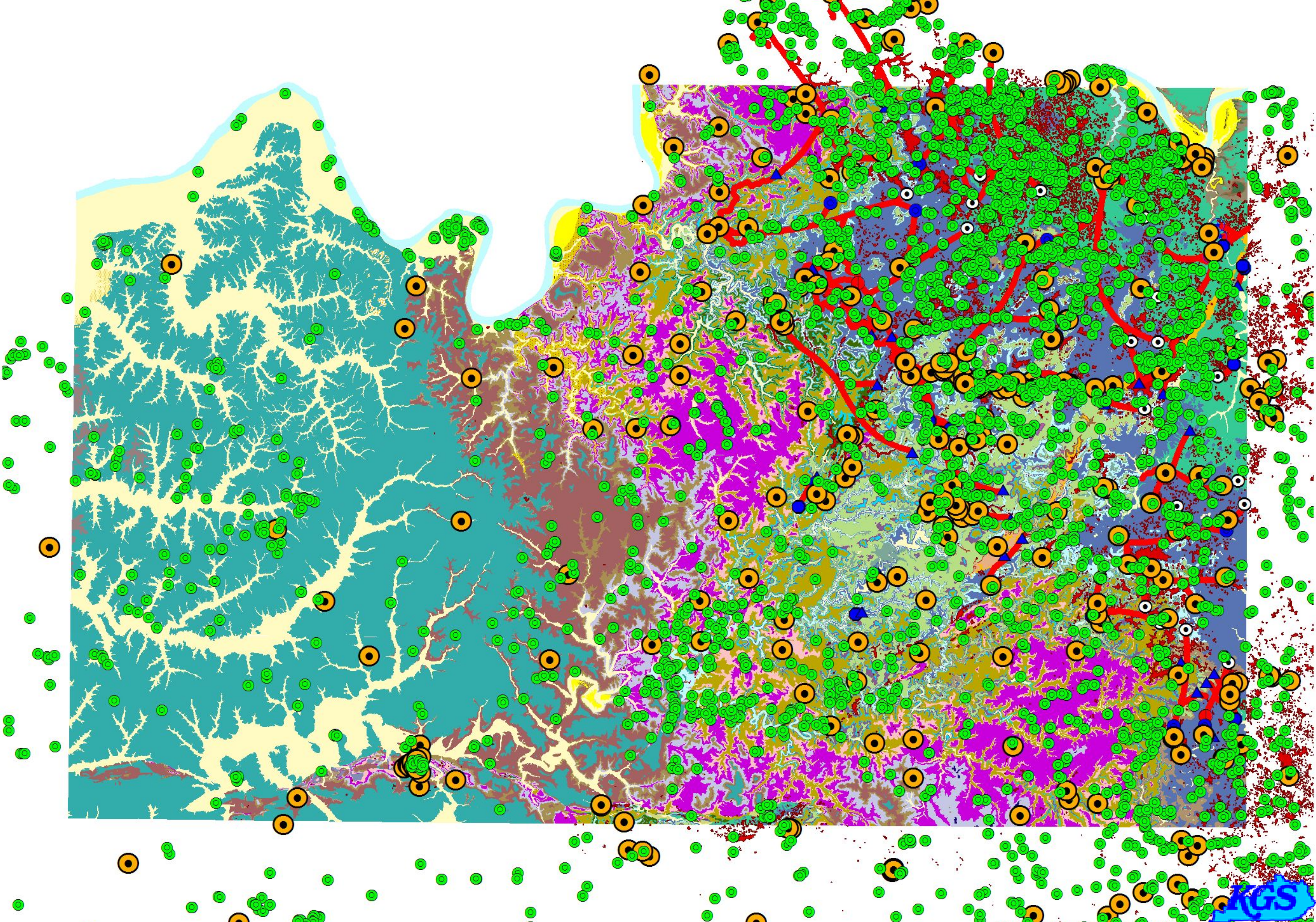
Karst conduit trace vectors



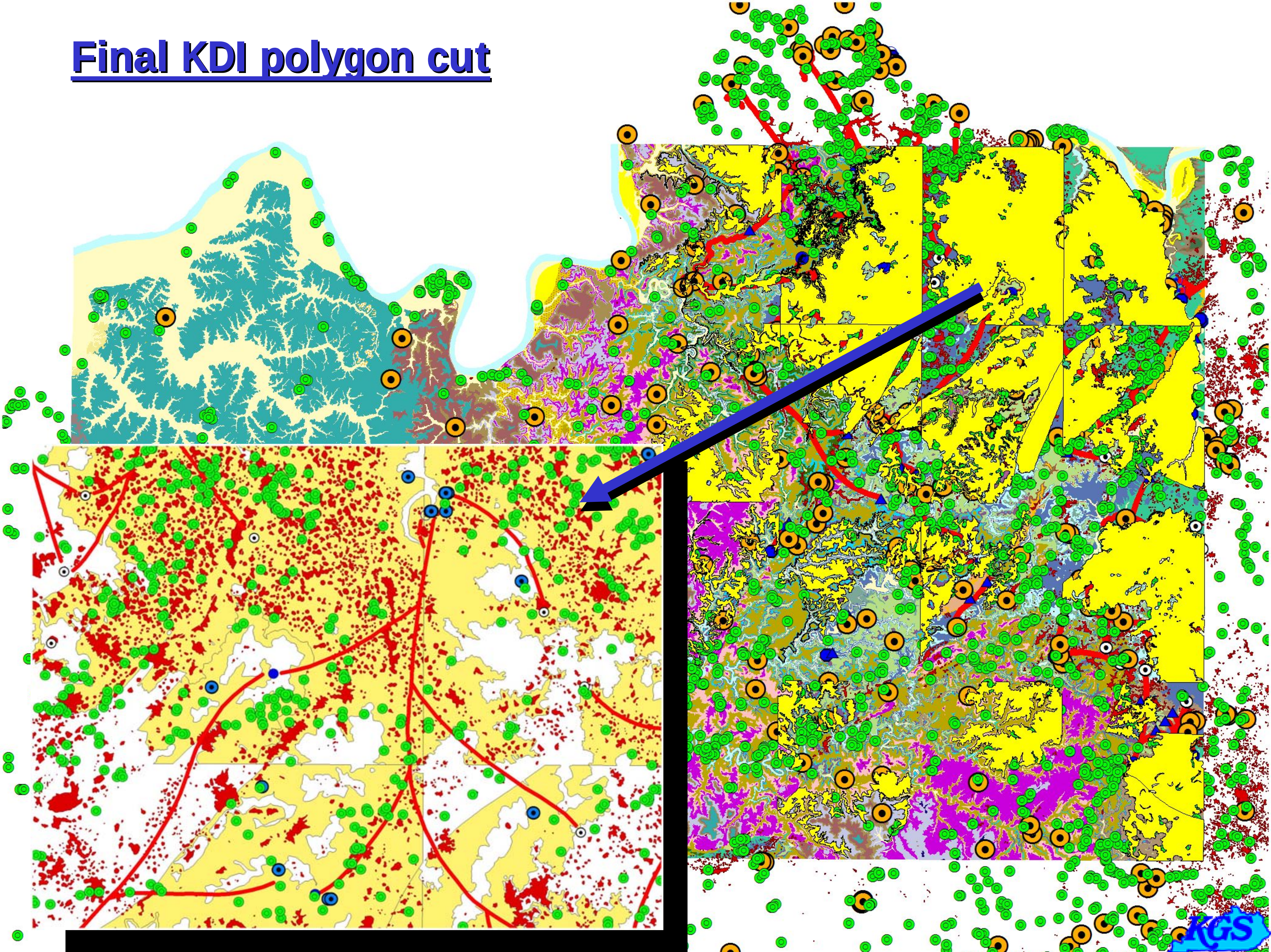
Cave and Spring Locations



Depth to bedrock measurements



Final KDI polygon cut

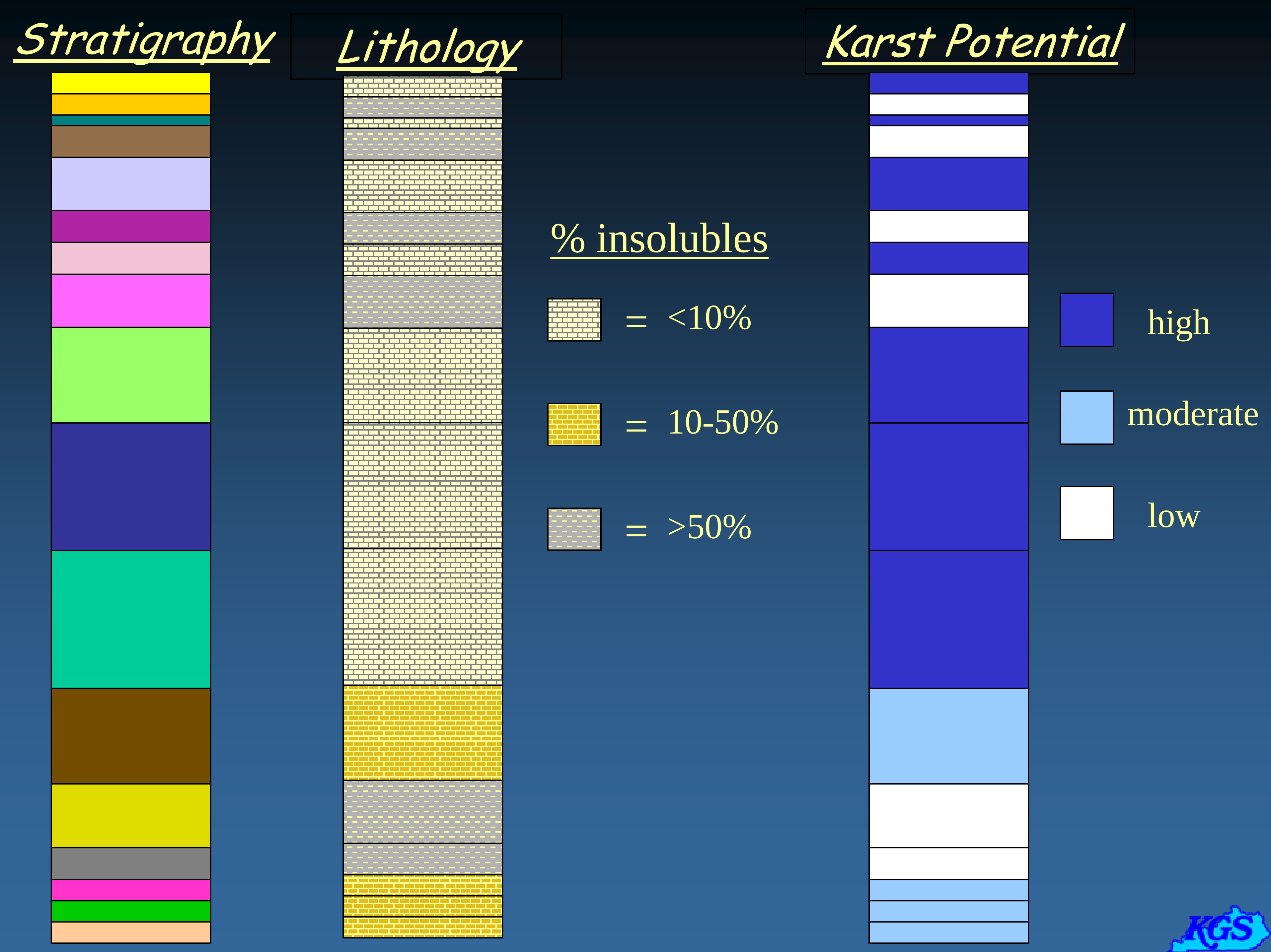


Scoring matrix for evaluating the Karst Development Index

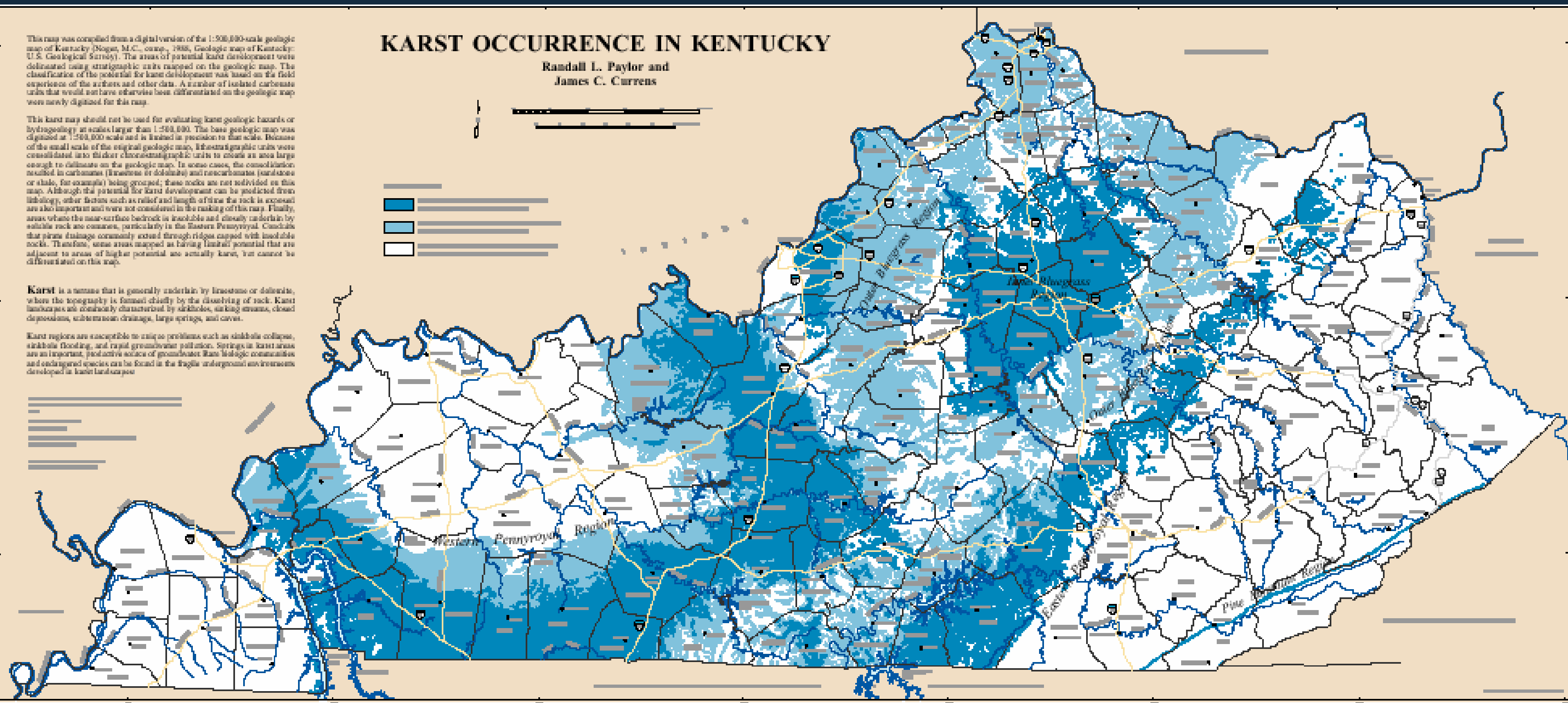
Sinkhole Area Ratio Percent Coverage (R_C) W = 4 ⇒		4	3	2	1	Depth to Bedrock (Surrogate for Epikarst Development) W= 1 ⇓	
		> 75% 4th Quartile over 7.11	50% to 75% 3rd Quartile 2.06 to 7.11	26% to 50% 2nd Quartile 2.06 to 0.39	0% to 25% 1st Quartile lest than 0.39		
4	Conduit Density: 4th Quartile > 0.39 km/km^2	**Highly Developed Karst**				Depth < 2.5m (7.5ft)	4
3	Conduit Density: 3rd Quartile 0.24 to 0.39 km/km^2		**Well Developed Karst**			Depth 3.3 m to 5m (8 to 32 ft.)	3
2	Conduit Density: 2nd Quartile 0.09 to 0.24 km/km^2			**Moderately Developed Karst**		Depth 3.3 m to 15 m (13 to 15 ft.)	2
1	Conduit Density: 1st Quartile < 0.09 km/km^2				**Poorly Developed Karst**	Depth > 4.65 m (> 15 ft.)	1
⇑ Length of Surveyed Cave or Inferred Groundwater Flow Route per unit area W = 2		Cave and Spring Density 4th Quartile Greater than 0.52 per km^2	Cave and Spring Density 3rd Quartile From 0.26 to 0.52 per km^2	Cave and Spring Density 2nd Quartile From 0.15 to 0.26 per km^2	Cave and Spring Density 1st Quartile Less than 0.15 per km^2	⇐ Number of Cave Entrances and Springs per unit area of Polygon W = 3	
		4	3	2	1		

COMPILING THE KARST POTENTIAL INDEX

Criteria and Methods


Stratigraphy
Lithology
Karst Potential
% insolubles
= <10%
= 10-50%
= >50%
high
moderate
low
KGS

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



List of criteria considered for the Karst Potential Index

Karst Potential Index Criteria	Descriptive Range of Values	Hydrogeologic Relevance of Criteria	Data Source or GIS Coverage	Equivalent DRASTIC Factor
Mineralogy of the carbonate rock	Less than 10% to 100%	Solubility of the carbonate unit	Lithologic or mineralogic descriptions in geologic reports and on maps	None
Bedding Thickness	Less than 10 cm to 100cm	Initial flow path availability and mechanical strength for conduit development	Lithologic descriptions in stratigraphic and other geologic reports and maps	None
Grain Size	Range in diameters: equivalent clay grain size to pebble size	Solubility	Lithologic descriptions in stratigraphic and other geologic reports and maps	None
Percentage of Stratigraphic Unit that is Insoluble	Less than 5% to 100%	Directly measures the epikarst and base level porosity	Lithologic descriptions in stratigraphic and other geologic reports and map	None
Joint Spacing	5 cm to 100's of cm	Influences Direct Recharge and Additional Indicator of Epikarst Development	No GIS data. Basin specific data for a small number of springs available	Hydraulic Conductivity
Climate	0 to many meters of precipitation	Directly measures recharge	National and State Climate Center Databases	Recharge

KGS

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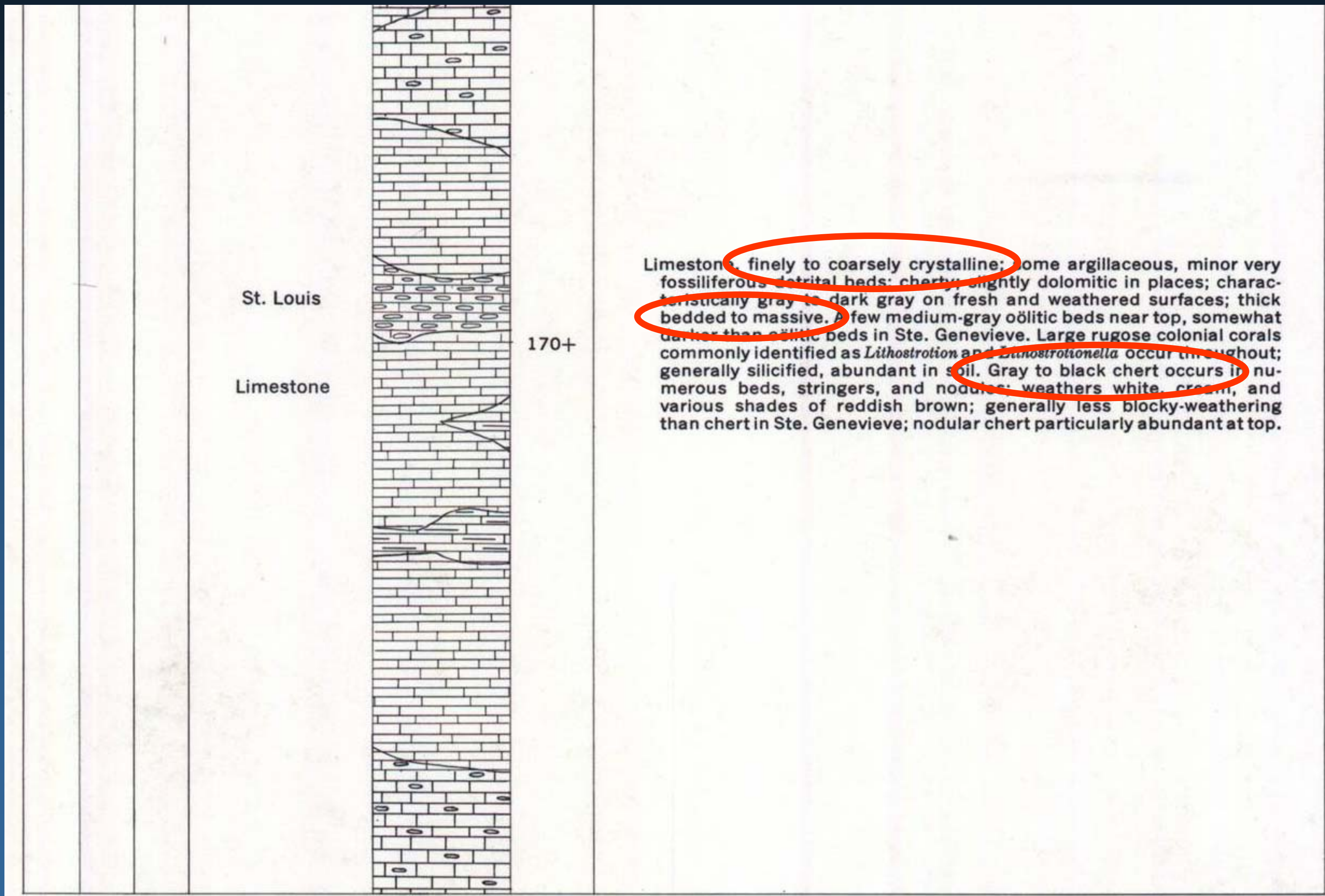
KGS

Lithologic data gathering



New lithologic attribute data compiled

FMCODE	TEXT	ZCALCITE	MINRANK	GRAIN_SIZE	GRAIN_RANK	BEDDING	BED_RANK	ZINSOLUBLE	I
332SLDE	Slade Formation	75.0	6	calcilutite to calcarenite	3.0	medium to thick	5.0	15.0	
332SMPL	Sample Sandstone	0.0	2	fine	3.0	medium to thick	5.0	98.0	
332STGP	Stony Gap Sandstone Member, I	0.0	2	very fine to fine	3.5	medium to thick	5.0	98.0	
332TSGD	Tar Springs Sandstone and Glen	100.0	8	fine to coarse	3.0	thin to thick	4.0	60.0	
332TSGL	Tar Springs Sandstone and Golc	90.0	6	fine to coarse	3.0	thin to thick	4.0	60.0	
332TSGLH	Tar Springs Sandstone, Golconda	90.0	6	fine to coarse	3.0	thin to thick	4.0	60.0	
332TSPG	Tar Springs Sandstone	100.0	8	fine to medium	3.5	medium to thick	5.0	75.0	
332UNML	unamed limestone	100.0	8	calcisiltite to calcarenite	2.5	thin	2.0	2.0	
332UNMS	unamed sandstone	0.0	2	calcilutite to calcisiltite	3.5	thin to medium	3.0	95.0	
332VINN	Vienna Limestone	60.0	6	calcisiltite to calcarenite	2.5	thin	2.0	30.0	
332WLBG	Waltersburg Sandstone	100.0	8	calcisiltite	3.0	thin	2.0	85.0	
332WLVN	Waltersburg Sandstone and Vien	80.0	6	calcisiltite to calcarenite	2.5	thin	2.0	50.0	
333HDBG	Harrodsburg Limestone	75.0	6	fine to coarse	3.0	thin to thick	4.0	20.0	
333LVIS	Levias Limestone Member, Ste. (	100.0	8	calcilutite	4.0	thin to medium	3.0	5.0	
333NWLFP	Lower part of Newman Limestone	50.0	4	calcilutite to calcisiltite	3.5	thin to medium	3.0	35.0	
333NWMNL	Lower member of Newman Limes	75.0	6	calcilutite	4.0	thin to medium	3.0	20.0	
333RCFR	Rosiclare Sandstone Member an	100.0	8	calcisiltite to calcarenite	2.5	thin to medium	3.0	20.0	
333RCLR	Rosiclare Sandstone Member, St	100.0	8	calcilutite	4.0	thin to medium	3.0	75.0	
333RENA	Renfro Member and Nada Membe	40.0	4	calcilutite to calcisiltite	3.5	thin	2.0	80.0	
333RNFO	Renfro Member of Slade Formati	70.0	6	calcilutite to calcisiltite	3.5	thin to thick	4.0	35.0	
333SALM	Salem Limestone	72.0	6	calcisiltite to calcirudite	2.0	thin to thick	4.0	17.0	
333SALMA	argillaceous limestone, Salem Li	100.0	8	calcilutite to calcisiltite	3.5	thick	3.0	50.0	
333SGSLU	Ste. Genevieve Limestone and U	95.0	8	calcilutite to calcisiltite	3.5	medium to very thick	5.0	10.0	
333SGVSL	Ste. Genevieve Member, Slade F	100.0	8	calcilutite to calcisiltite	3.5	thick	6.0	5.0	
333SGVV	Ste. Genevieve Limestone	95.0	8	calcilutite to calcisiltite	3.5	thick to very thick	6.0	5.0	
333SGVVM	Ste. Genevieve Limestone Memb	100.0	8	calcilutite to calcisiltite	3.5	thick	4.0	2.0	
333SGVVS	Ste. Genevieve sandstone and sh	100.0	8	calcilutite to calcisiltite	3.5	thin to medium	3.0	95.0	
333SLHD	Salem Limestone and Harrodsbu	90.0	8	calcisiltite to calcarenite	2.5	thick	6.0	15.0	
333SLSM	St. Louis and Salem Limestones	81.0	6	calcilutite to calcirudite	2.5	medium to thick	4.0	13.5	
333SLSML	St. Louis Limestone, Lower Mem	50.0	4	calcilutite to calcirudite	2.5	thin to thick	4.0	20.0	
333SLWW	Salem and Warsaw Limestones	85.0	6	calcilutite to calcirudite	2.5	thin to very thick	5.0	15.0	
333STLS	St. Louis Limestone	90.0	8	calcilutite to calcisiltite	3.5	medium to thick	5.0	10.0	
333STLSL	St. Louis Limestone, Lower Mem	85.0	6	calcilutite to calcarenite	3.0	thin to thick	4.0	15.0	
333STLSN	St. Louis Member of Newman Lir	95.0	8	calcilutite to calcarenite	3.0	thin to thick	4.0	10.0	

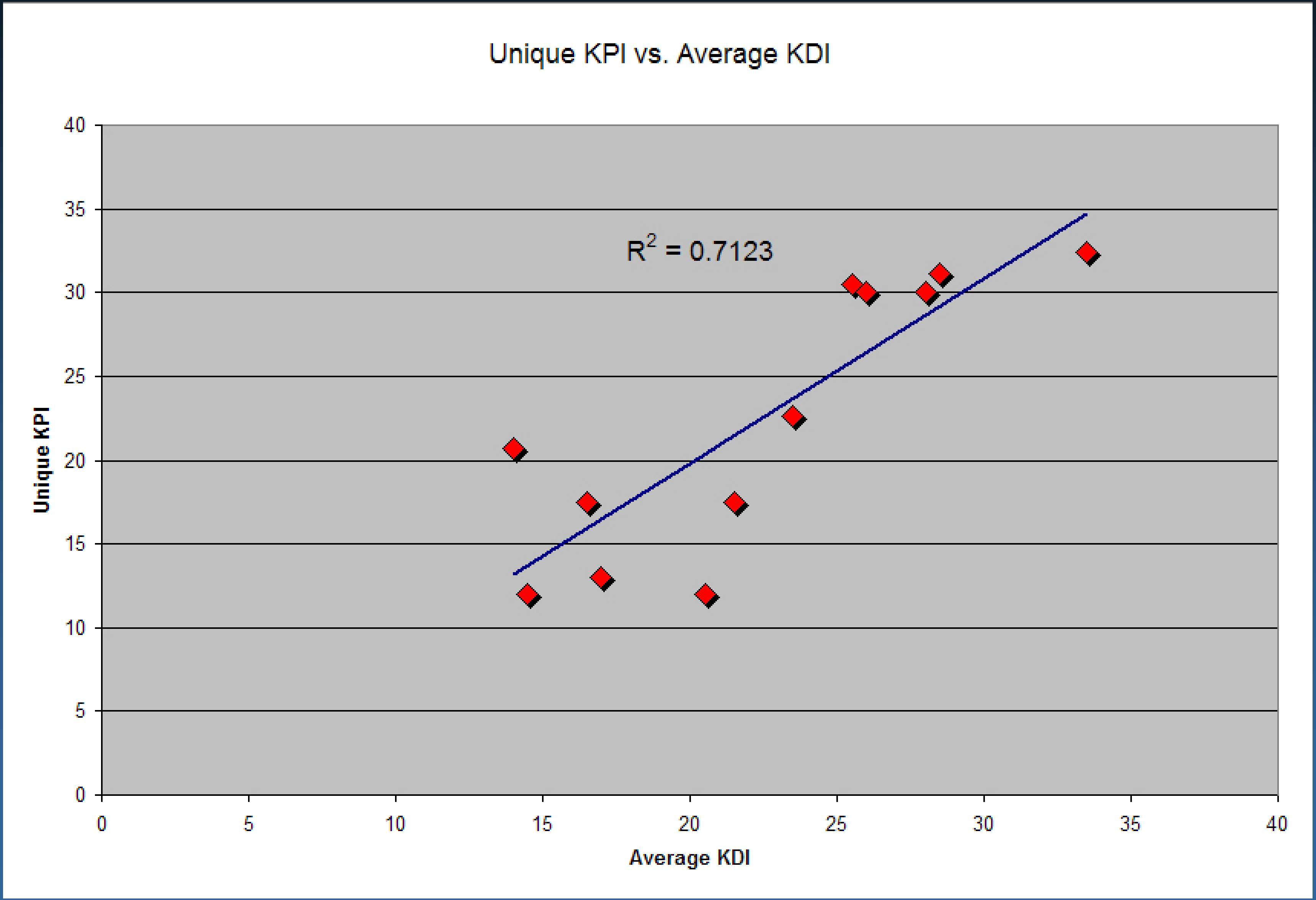
Scoring matrix for evaluating the Karst Potential Index

Percentage of Insoluble Rocks and Minerals in the Stratigraphic Unit W = 4 ⇒		4	3	2	1	Carbonate rock bedding thickness W = 2 ⇓	
		<5%	5 to 15%	15 to 30%	30% to 50%		
4	100% to 90% Calcium Carbonate (Limestone)	**Very High Potential**				Very Thick >100cm	4
3	90% to 50% Calcium Carbonate (Dolomitic Limestone)		**High Potential**			Thick 30-100cm	3
2	50% to 10% Calcium Carbonate (Calcitic Dolostone)			**Moderate Potential**		Medium 10-30cm	2
1	<10% Calcium Carbonate (Dolostone)				**Low Potential***	Very Thin <10cm	1
⇑ Percentage of calcite in the carbonate rock W = 3		Calcilutite (Micrite)	Calcisiltite	Calcarenite	Calcirudites (Bioclastic)	Carbonate grain size ⇐ W = 1	
		4	3	2	1		

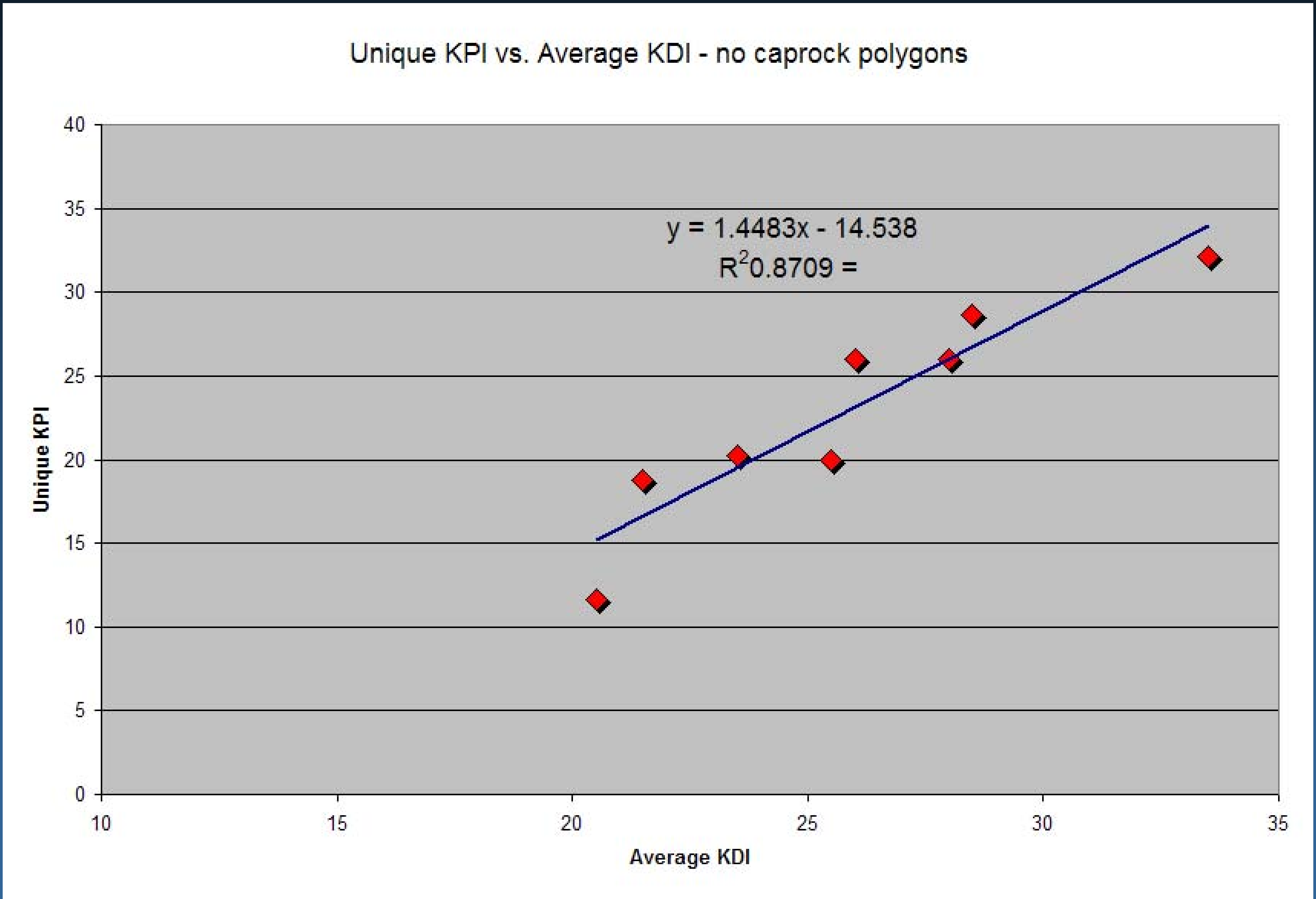
Karst Index Calibration

SINKHOLE AREA /POLYGON AREA (%)	CAVE & SPRING DENSITY (POINTS/KM2)	AVG DEPTH TO BEDROCK, Meters	NORMALIZED CONDUIT LENGTH (KM/KM^2)	KDI: Sc quartile	KDI: EkS quartile	KDI: S&C quartile Direct	KDI: Cd quartile	KDI Score	KPI Score	Unique KPI	Average KDI
0.12	0.083515	1.81	0.010482	1	1	1	1	10	14.5		
0.00	0.112392	3.76	0.044452	1	3	2	1	14	14.5	14.5	0
0.05	0.041216	6.02	0.030237	1	4	1	1	13	14.0		
1.00	0.081879	8.63	0.874431	1	4	1	4	22	14.0		
1.03	0.124755	3.55	0.491486	2	3	2	4	27	14.0	14	0
0.17	0.066029	9.17	0.070735	1	4	1	1	13	17.0	17	0
0.04	0.152415	2.23	0.179324	1	1	2	2	15	16.5		
0.10	0.370315	2.80	0.131177	1	2	4	2	20	16.5	16.5	0
0.32	0.075969	3.42	0.016604	1	2	1	1	11	20.5		
0.14	0.086947	4.67	0.028991	1	3	1	1	12	20.5		
0.40	0.112823	3.08	0.025729	1	2	2	1	13	20.5	20.5	12
0.55	0.158736	6.22	0.006412	1	4	2	1	15	21.5		
5.99	0.398339	6.71	0.080054	3	4	4	2	30	21.5	21.5	17.5
0.04	0.193158	2.73	0.024558	1	2	2	1	13	21.5		
1.32	0.351281	1.99	0.274397	2	1	4	3	26	21.5		
1.15	0.189637	3.42	0.077104	2	2	2	1	17	25.5		
2.07	0.189592	2.52	0.015681	2	1	2	1	16	23.5		
1.13	0.056525	2.41	0.135949	2	1	1	2	17	23.5		
1.25	0.268117	2.29	0.002915	2	1	3	1	18	23.5		
1.76	0.160746	1.32	0.103990	2	1	2	2	19	23.5		
1.94	0.233550	2.05	0.143605	2	1	3	2	21	23.5		
1.89	0.683615	2.41	0.292682	2	1	4	3	26	23.5		
2.69	0.247343	4.15	0.283996	3	3	3	3	30	23.5		
2.66	0.729368	2.91	0.388464	3	2	4	4	34	23.5	23.5	22.625
2.05	0.288092	1.87	0.481575	2	1	3	4	27	25.5	25.5	30.5
3.11	0.622030	1.98	0.276532	3	1	4	3	30	28.0	28	30
6.91	0.025357	14.28	0.140428	3	4	1	2	24	28.5		
26.67	0.019424	10.70	0.276536	4	4	1	3	31	28.5		
7.22	0.324935	6.59	0.139919	4	4	3	2	32	28.5		
7.64	0.210805	5.88	0.182354	4	4	3	2	32	28.5		
10.33	0.444630	4.27	0.128469	4	3	4	2	33	28.5		

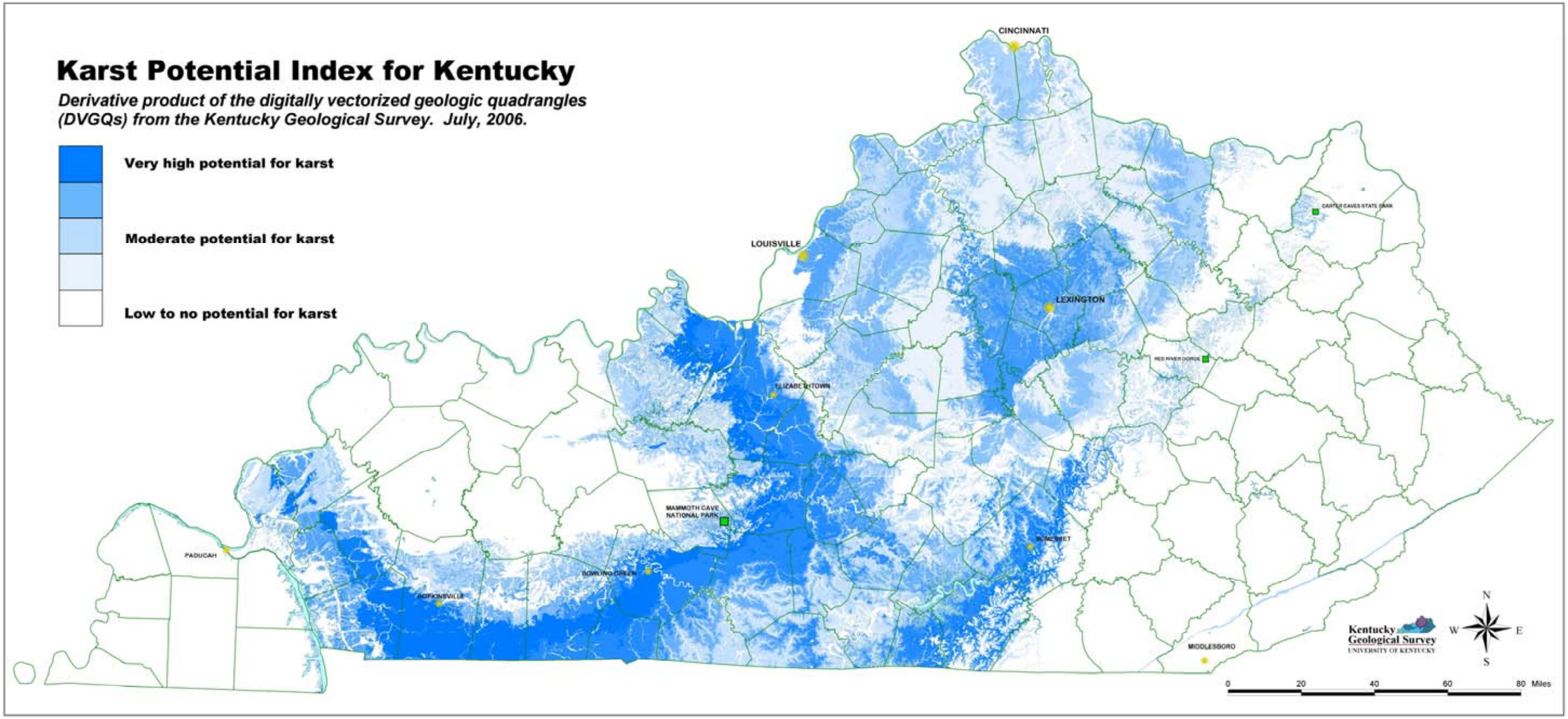
Karst Index Calibration



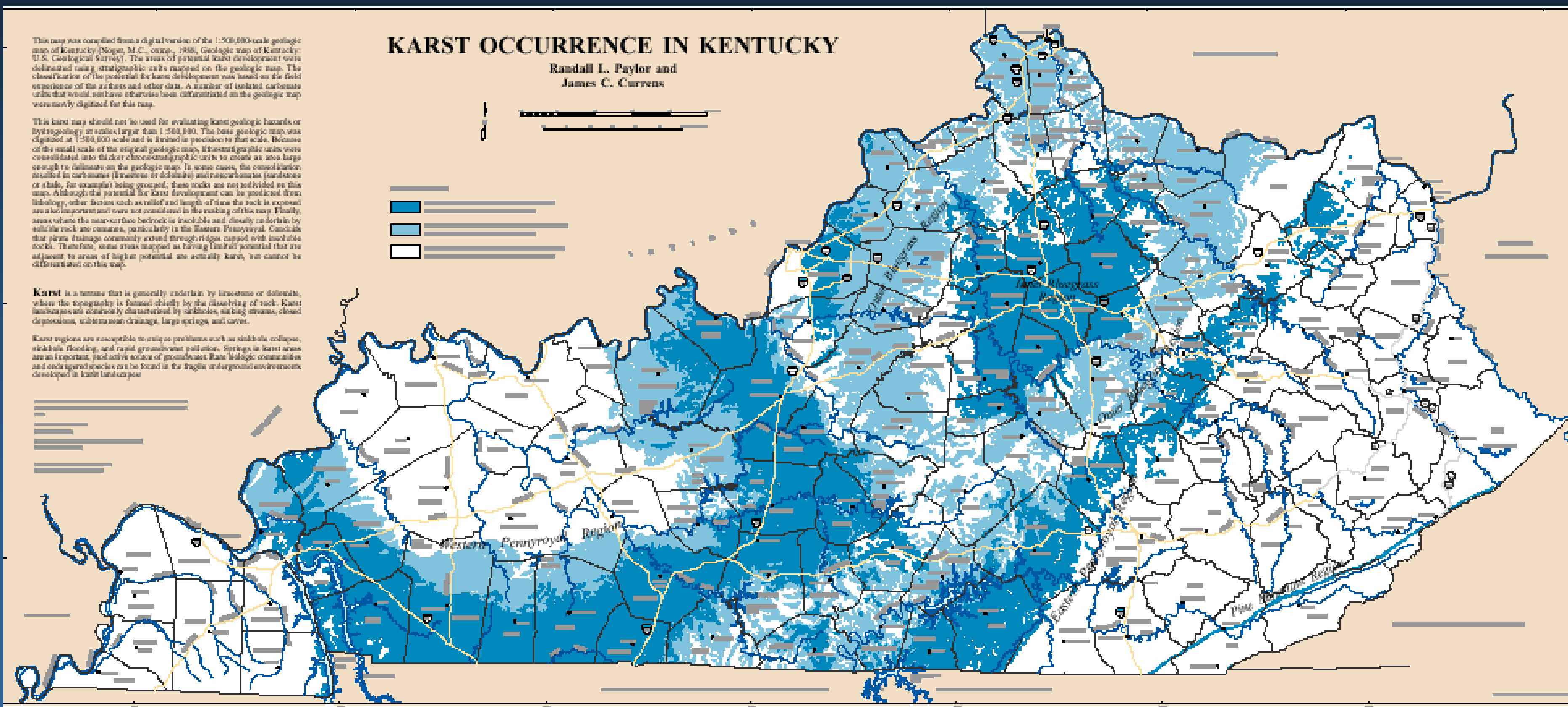
Karst Index Calibration



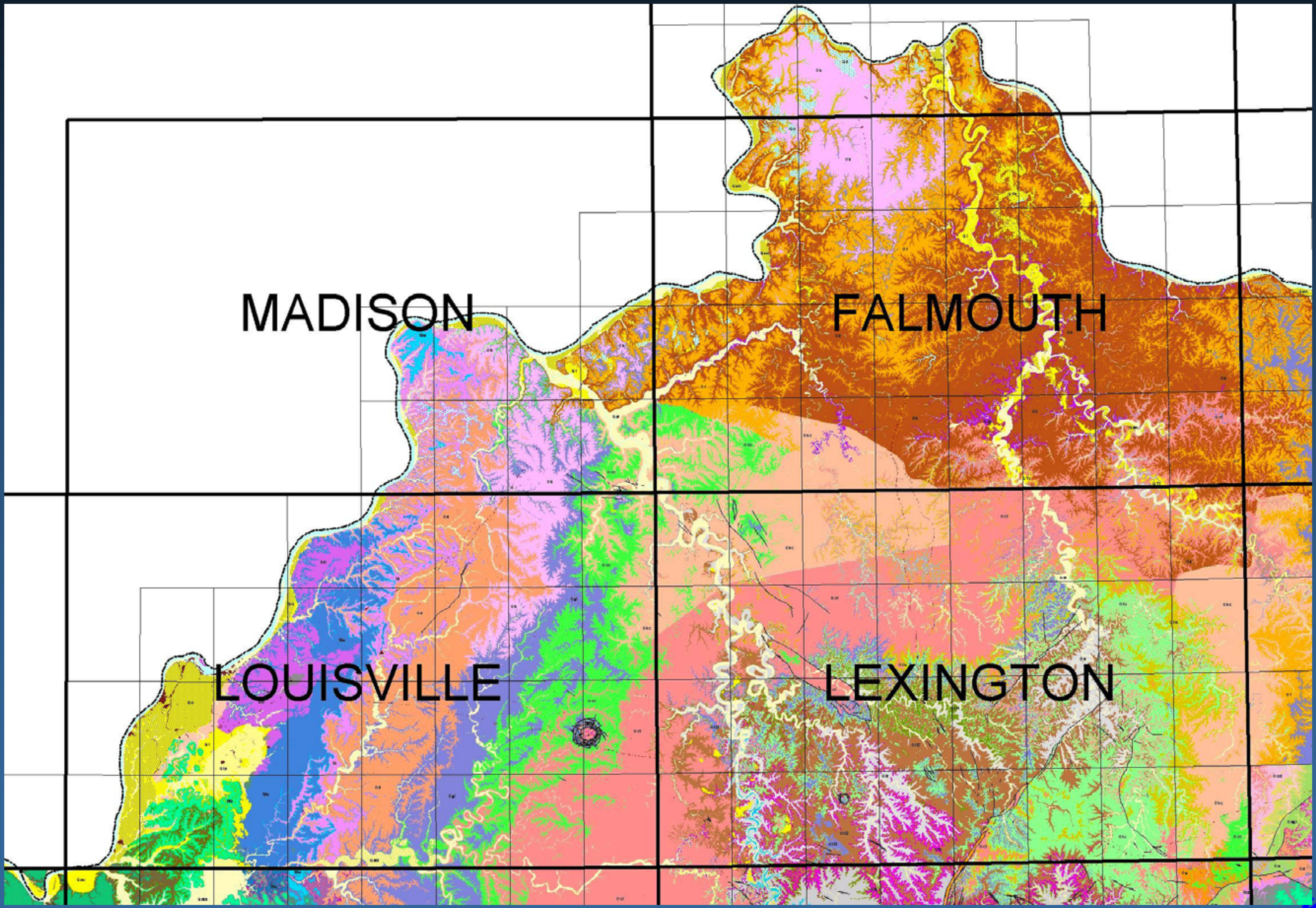
Final Karst Index applied to DVGQs



Comparison with 500k map



Final Karst Index applied to DVGQs - Original Data



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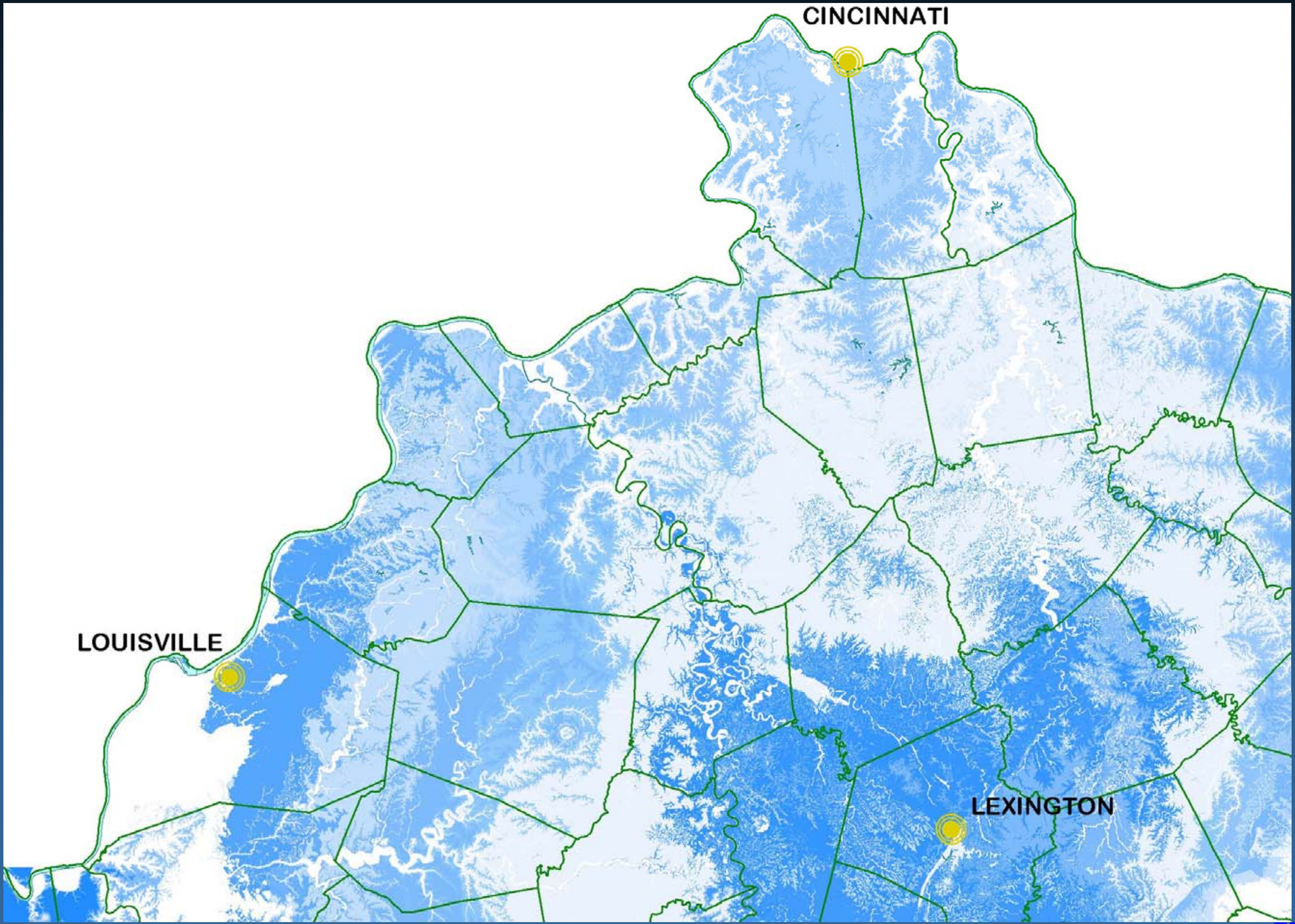

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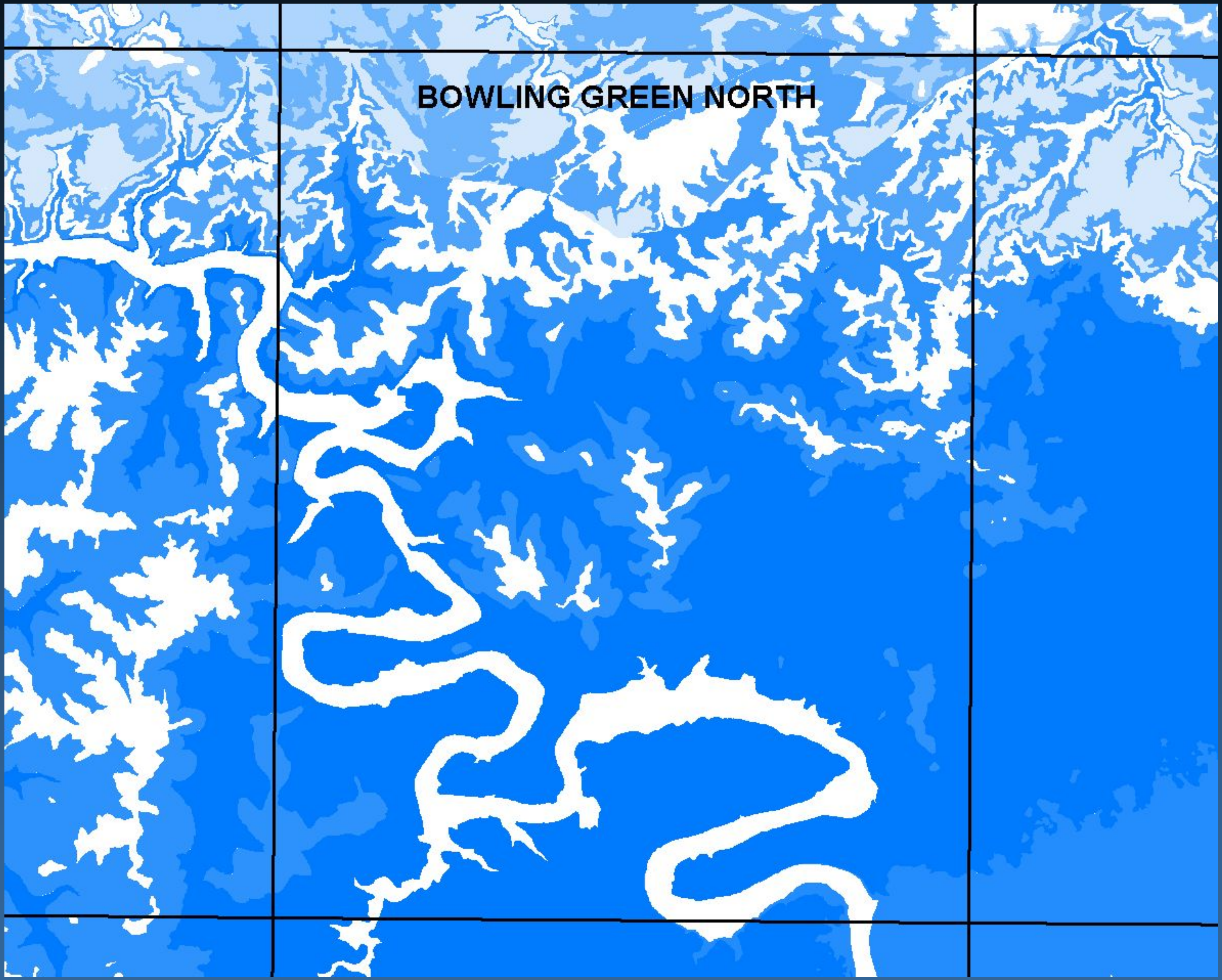


DISCUSSION

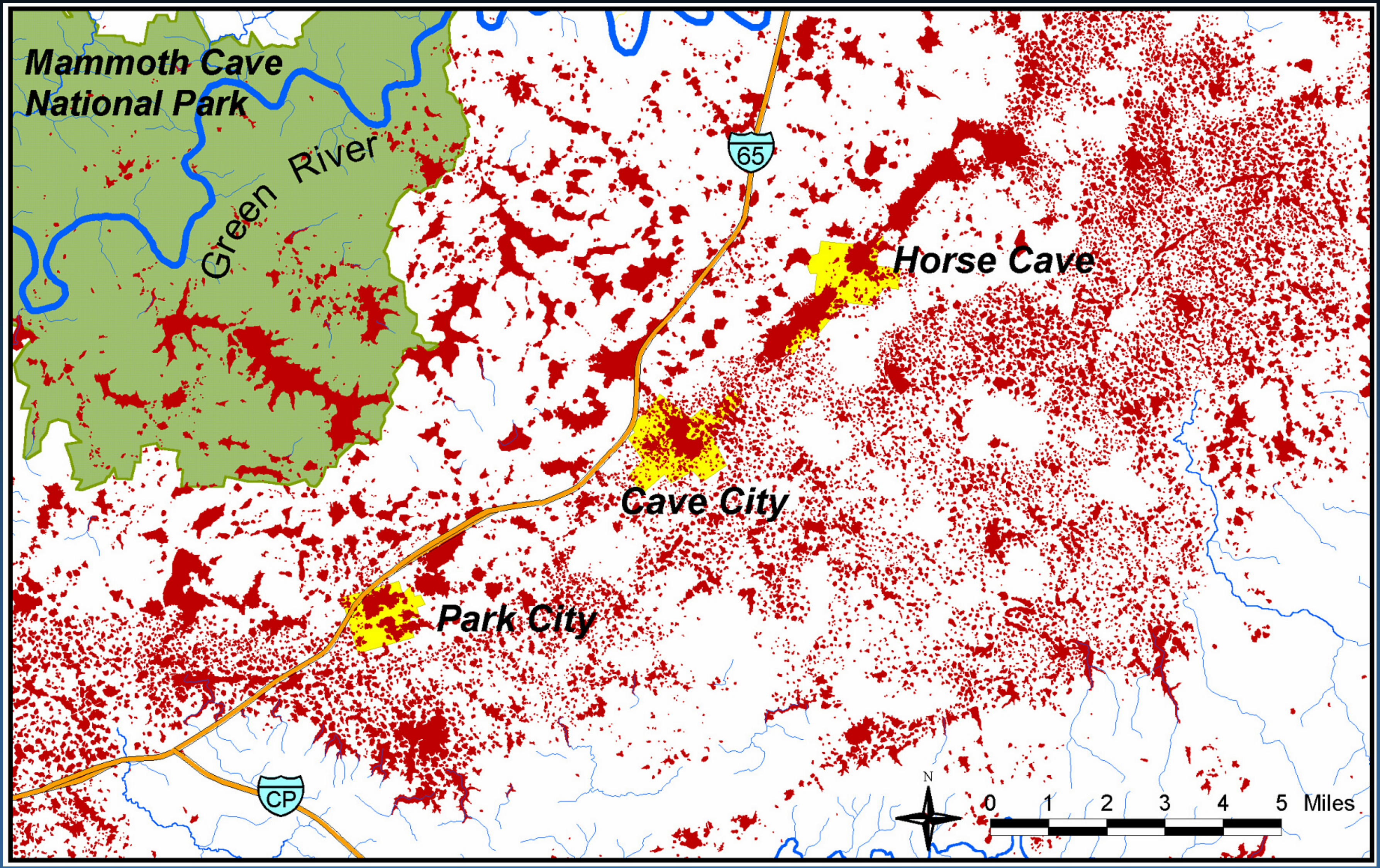
- The KDI/KPI project has developed a regional karst classification method that is more appropriate for Kentucky and the Interior Plateaus province than previously used methods.

- 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.

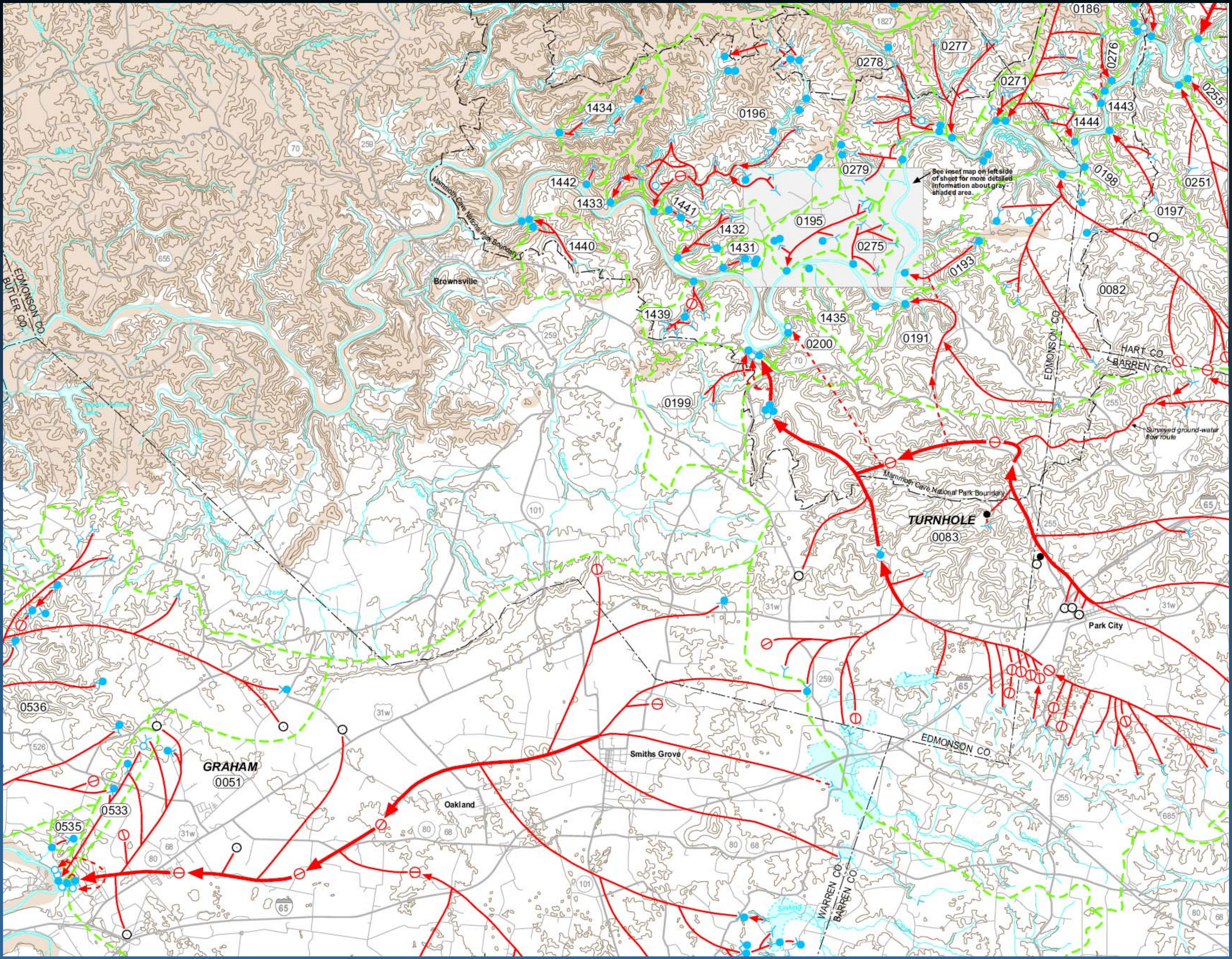
- Groundwater issues are not directly addressed using the KDI/KPI classification, but it can be used to augment karst groundwater classification methods. Does not currently address non-karst catchments draining onto karst areas.

- The classification system proposed here does not remove the necessity for field investigations when evaluating site specific karst issues.



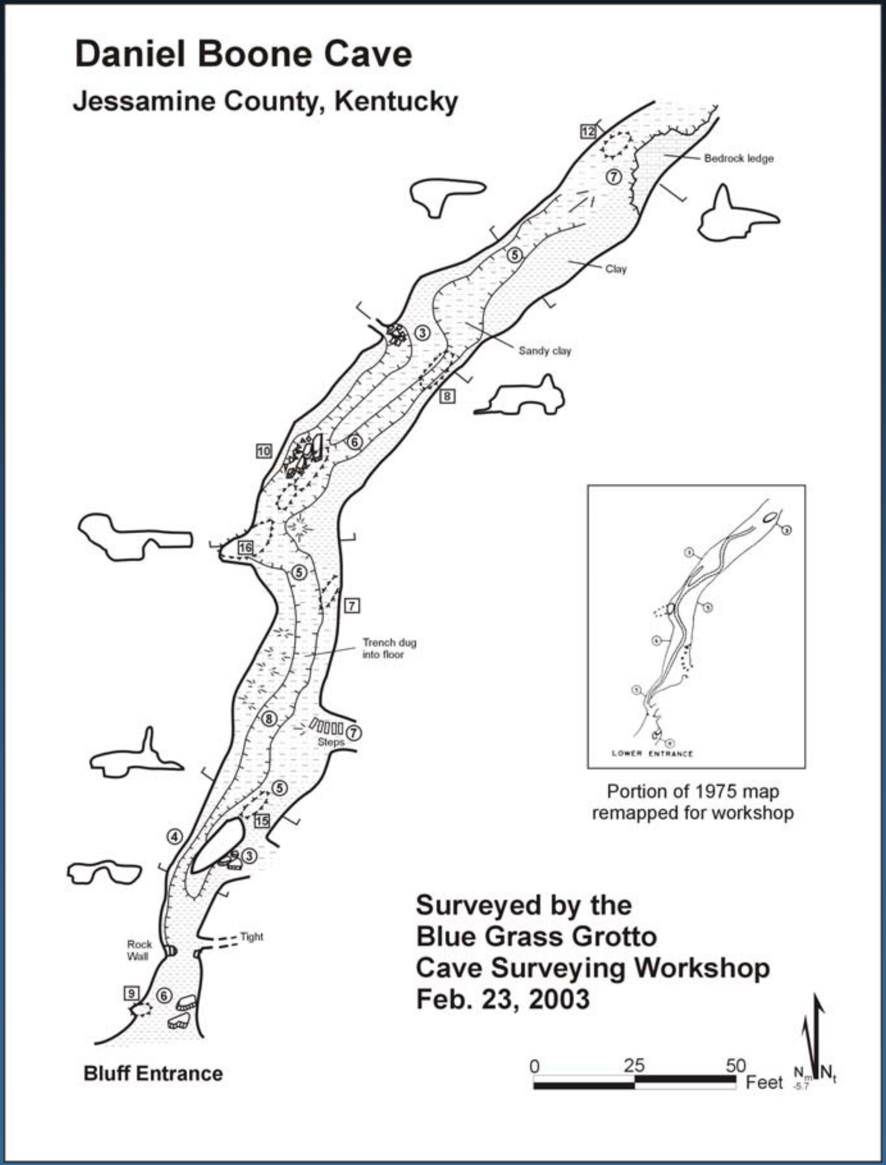
http://www.uky.edu/KGS/gis/sinkpick.htm

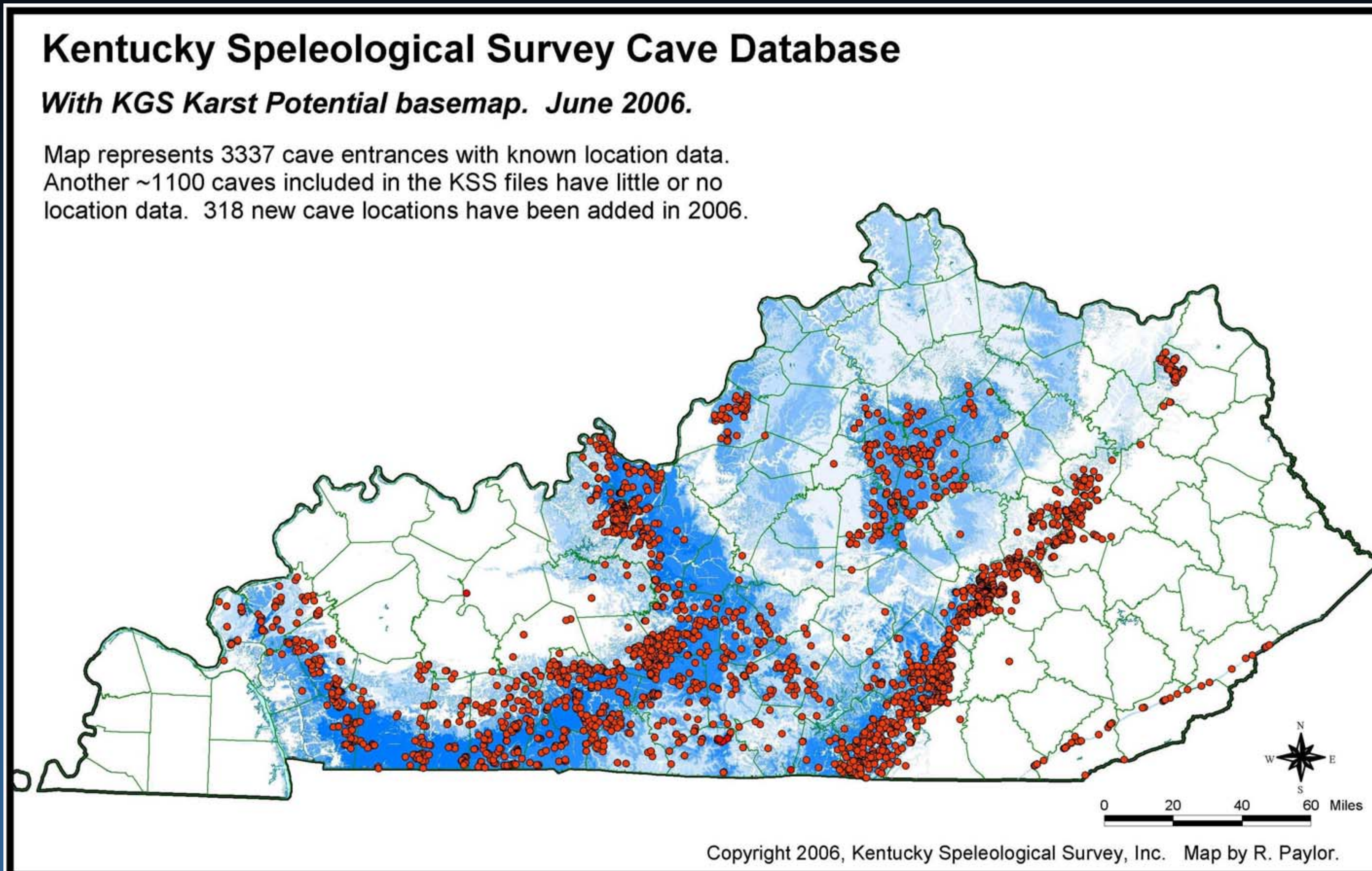
Groundwater dye tracing can delineate drainage basins and identify general conduit flow routes



http://kgsweb.uky.edu/findpubsmain.asp search:karst

Surveys by cavers directly reveal karst porosity and groundwater flow routes





http://www.ksscaves.org/

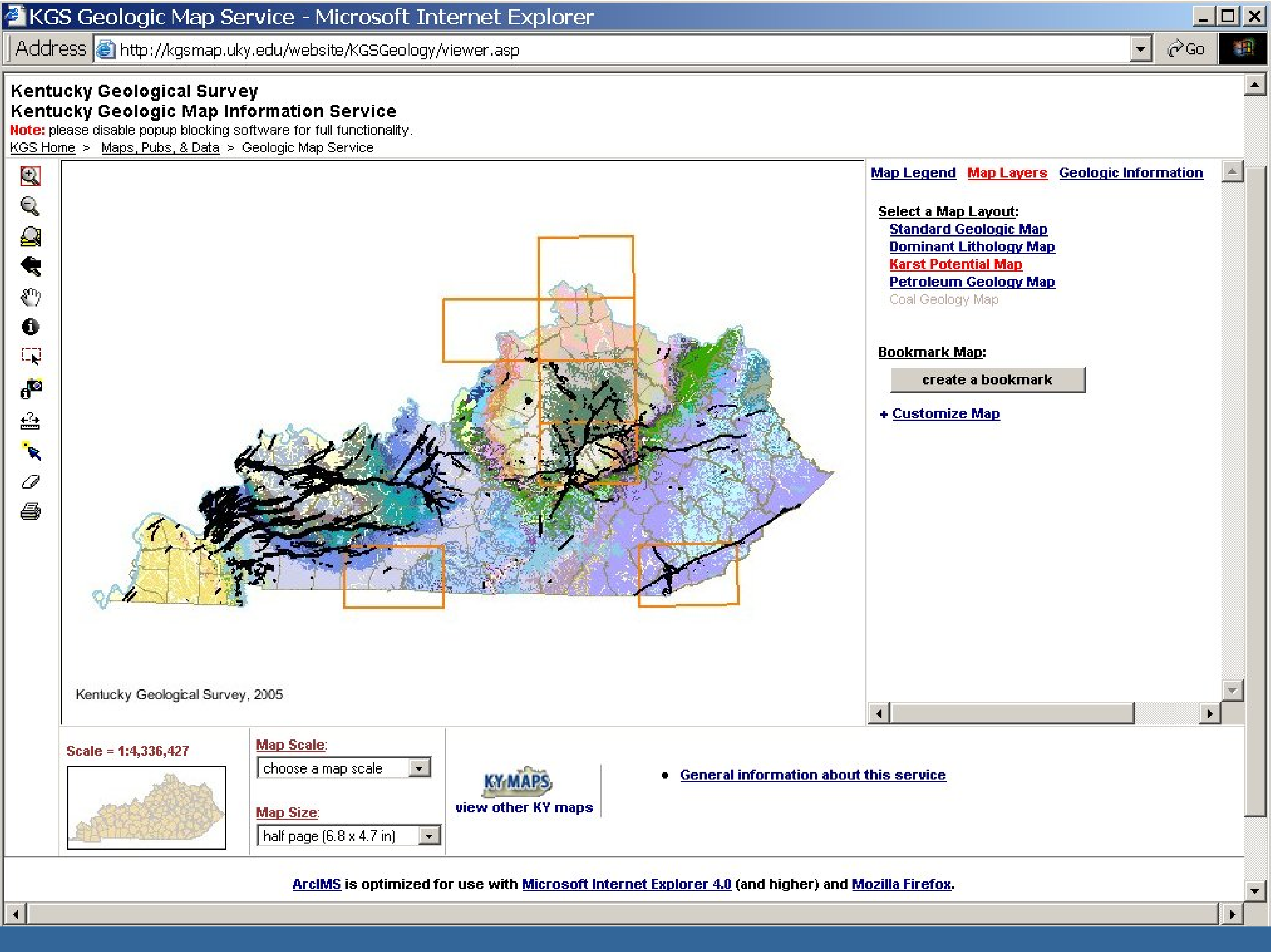
Further Work

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


KGS Geologic Map Service - Microsoft Internet Explorer
Address
http://kgsmap.uky.edu/website/KGSGeology/viewer.asp
Go
Kentucky Geological Survey
Kentucky Geologic Map Information Service
Note: please disable popup blocking software for full functionality.
KGS Home > Maps, Pubs, & Data > Geologic Map Service
Map Legend
Map Layers
Geologic Information
Select a Map Layout:
Standard Geologic Map
Dominant Lithology Map
Karst Potential Map
Petroleum Geology Map
Coal Geology Map
Bookmark Map:
create a bookmark
+ Customize Map
Kentucky Geological Survey, 2005
Scale = 1:4,336,427
Map Scale:
choose a map scale
Map Size:
half page (6.8 x 4.7 in)
KY MAPS
view other KY maps
General information about this service
ArcIMS is optimized for use with Microsoft Internet Explorer 4.0 (and higher) and Mozilla Firefox.

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