Appendix D

Geological Overview & Geotechnical Overview

Summary of the Geology and Hydrology of the Bowling Green Area Related to Planning of Interstate 66 Construction

April 10, 2003

Dr. G.A. Weisenfluh

Kentucky Geological Survey

Dr. Kenneth W. Kuehn

Department of Geography and Geology, Western Kentucky University

1.0 Summary

Geologic issues that impact the development of transportation corridors in the Bowling Green region (Plate 1) relate primarily to the protection of sensitive karst groundwater systems. Most of the region is underlain by limestone, but different geologic units are more or less susceptible to karst development. Differences in limestone solubility and presence of impediments to solution processes has resulted in various degrees of formation of karst features such as sinkholes and caves. Maps accompanying this report show the distribution of geologic and topographic units and their associated hydrologic characteristics.

Areas with low topographic relief that are desirable as corridor locations also contain large numbers of karst features. A pronounced escarpment presents an obstacle for northerly routes, and the adjacent plateau is also underlain by numerous caves and vertical shafts.

Karst groundwater basin boundaries have been approximately delineated through dye tracing and show the probable routes for drainage of subsurface water. These routes do not show the accurate locations of underground caves or conduits, but represent vectors that connect dye insertion locations to dye detection points. Because the rate of water movement in underground karst systems is very high, extra precautions must be made to protect these systems from contamination.

Other geologic concerns are present in the area, including faults, expanding shales, and asphalt-bearing sandstone, but these are minor relative to karst issues and do not immediately affect the proposed corridors.

2.0 Topograpic and geologic regions

The study area encompasses four topographically and geologically distinct regions (Plate 2). The topographically-low southern area is separated from the topographically higher northern part by the Dripping Springs Escarpment. The escarpment marks the southern edge of a regional plateau that lies as much as 350 ft above the plain. Two geologic regions are north of the escarpment and two are south of the escarpment.

2.1 **Caseyville Hills**. The northernmost part of the study area is underlain by Pennsylvanian-age coal-bearing sandstone and shale. These rocks form narrow, steep ridges and broad alluvial valleys.

2.2 **Mammoth Cave Plateau**. The region immediately north of the Dripping Springs Escarpment is underlain by interbedded limestone, sandstone and shale of Mississippian age. It is characterized by high relief, narrowly incised stream valleys, broad flat ridge tops, and wide karstic valleys that are underlain by extensive cave systems.

2.3 **Western Pennyroyal** (Sinkhole plain). Immediately south of the Dripping Springs Escarpment is a very low-relief plain underlain by relatively pure limestone of Mississippian age. The northern half of this area has lower relief than the southern half.

2.4 **Central Pennyroyal**. The southernmost part of the study area is underlain by impure limestone of Mississippian age. These rocks are associated with moderate to high relief and incised, narrow valleys.

3.0 General Geologic Conditions

3.1 **Geologic structure and age**. The geologic strata in the study area dip generally to the north exposing progressively younger rocks in that direction (Figure 1). Limestone units that are exposed at the surface within the sinkhole plain occur in the near subsurface under the Mammoth Cave Plateau. The youngest rocks in the study area are the Pennsylvanian sandstones in the Caseyville Hills.

3.2 **Susceptibility to karst**. Most of the study area is underlain by carbonate-rich rocks that have developed a variety of karst features including sinkholes, caves, and karst valleys (Figure 2). The degree of karst development is related to a number of factors, among which are the solubility of the limestone and its exposure to chemically agresssive waters. Plate 3 is a simplified geologic map that classifies the geologic units on the basis of solubility (potential for karst development) and shows two kinds of features that inhibit karst development. (1). In the south, the older limestone units are rich in chert and insoluble silica, and therefore little karst is present in that area. (2). Under the Mammoth Cave Plateau, some limestones are interbedded with shale layers, and these impermiable lithologies may inhibit development of some surface karst (e.g., sinkholes) in rocks that would otherwise be susceptible. However, these thin limestone units are equally susceptible to dissolution by subsurface water flow.

3.3 **Leitchfield Formation**. A formation of red and green shale (Plate 4) is found near the boundary of the Mammoth Cave Plateau and Caseyville Hills regions. These shales are highly slaking, susceptible to moisture, and difficult to vegetate. Existing new construction in the area applies limestone rock cover to very low-sloping cuts to stabilize this formation.

3.4 **Tar Springs ashphalts**. A sandstone formation that occurs on the Mammoth Cave Plateau (Plate 4) contains solid asphalt in pore space, dikes, and veins. This material may be a local source for construction material but may also increase land acquisition costs.

3.5 **Western Kentucky coal field**. The Caseyville Hills region contains a number of minor coal beds. These are unlikely to represent a significant resource, but may have been locally surface mined in the past. Shale beds that occur with the coals may be susceptible to landslides and slumps.

3.6 **Faults**. There are a number of faults that occur in the Mammoth Cave Plateau along the northwest border of the study area (Plate 4). Faults are unlikely to be undergoing active movement but are associated with deformed strata that are susceptible to slumping or landslides in road cuts.

4.0 Karst features

The study area lies within one of the most highly developed karst regions in the state. Mammoth Cave National Park lies immediately northeast of the proposed transportation corridors. Karst is environmentally sensitive because of the potential for contaminants associated with transportation routes entering the groundwater system and because of the possibility of intersecting cave systems and collapse structures during road construction. Rates of contaminant movement in karst systems are high compared to granular aquifer groundwater systems. Building roads in karst terrains requires additional geotechnical assessment and more costly design engineering. A number of different kinds of karst features are present in the study area (Figure 2, Plate 5).

4.1 **Sinkholes**. Simple closed depressions, usually circular in form, are found in abundance within the low-relief Western Pennyroyal region. These sinkholes collect water from surface drainage and funnel it into the groundwater system of caves and conduits. Sinkholes may be shallow (5-10 ft) to deep (40-50 ft) depending on local groundwater and geologic conditions. Sinkholes are classified according to how they form. Dissolution sinkholes form by near-surface solution of limestone substrate and may have various amounts of unconsolidated sediment infill. Collapse sinkholes form by subsidence related to failure of underlying cave or conduit caprock or overlying soils. Most sinkhole collapses occur when covering soils are weakened through repeated water saturation. A much smaller number of collapse sinkholes are related to failure of bedrock caps overlying shallow caves. The latter type requires more extensive engineering in order to protect the associated cave passages. There is no complete inventory of sinkhole features according to genesis within the area and assessment and this would be required during preconstruction design. The primary design objective is to disperse water drainage to avoid concentrated recharge into karst features.

4.2 **Karst valleys and compound sinkholes**. These are larger depressions that have no surface outlet for drainage. They contain numerous individual sinkholes that funnel water into the subsurface. Karst valleys are common where surface streams sink into a swallet and along the margin of the Mammoth Cave Plateau. Large complex sinkholes are prevalent at the base of the Dripping Springs Escarpment. Both kinds of features are more prone to sinkhole flooding during high rainfall conditions.

4.3 **Lost River Chert**. Highly soluble limestones that occur in the sinkhole plain exhibit different amounts and types of karst development. One reason for this difference is a distinct chert layer that separates two limestone units. The overlying limestone has many fewer distinct sinkholes, but where the chert bed is eroded, the underlying limestone is more susceptible to sinkhole development (Plate 5). The chert bed acts as an aquitard and results in an irregular perched water table where it is present (north of the magenta line on Plate 5). This area was more susceptible to formation of broad, complex sinkholes. It is important to note that the degree of karstification is not necessarily reflected by the number of sinkholes expressed at the surface. Some sinkholes may be concealed by infilling of sediment, and areas with fewer sinkholes may still have extensive subsurface karst development.

4.4 **Vertical shafts**. Vertical karst conduits that drain water into underlying caves are present throughout the study area, but particularly common at the edge of the Mammoth Cave Plateau. These features are not well documented, and are therefore difficult to plan for prior to construction. Frequency of vertical shafts along the escarpment may be as high as 80%. Shaft size ranges from 3 ft diameter and 12 ft deep to 60 ft diameter and 120 ft deep.

4.5 **Intermittent lakes**. Some sinkholes (or other low-lying areas) may back up with water that cannot be accommodated in underlying passages during periods of high rainfall. The resulting lakes can create flooding conditions for short periods of time (hours to days). Intermittent lakes are typically associated with surface runoff into karst valleys or groundwater rise into compound sinkholes. Hydrologic conditions that result in sinkhole flooding vary according to site conditions (conduit geometry and cachement area), as well as soil conditions and rainfall distribution.

4.6 **Subjacent karst**. Some rock units that have low solubility and occur as cap rock on the Mammoth Cave Plateau develop karst depressions due to dissolution of underlying limestone units.

4.7 **Springs**. Springs occur at the location where the groundwater carrying passage discharges to the surface. Base level springs along major streams and rivers are important discharge points for karst groundwater drainage. Because these springs are the terminus of related tributary karst conduits, they are critical monitoring locations for groundwater contamination. Turnhole Spring on the Green River and Graham Spring on the Barren River are two of several major spring locations in the region that drain most of the study area.

4.8 **Caves**. Cave systems are prevalent in the near subsurface throughout the study area. Those within the Mammoth Cave Plateau are well known and explored, but others are present throughout the sinkhole plain. At least two levels (representing different ages of development) of cave passages are present under the sinkhole plain. The older cave systems are generally only intermittently flooded or abandoned and occur at depths as shallow as ten ft. The younger cave systems carry most of the active groundwater and occur at depths as great as 100 ft. Caves are sensitive ecosystems that can be affected by contaminants in groundwater and can be compromised during construction of cuts. Cave passages that underlie roadways may also be susceptible to collapse (see section 4.1).

5.0 Hydrology

5.1 **Major rivers**. Two major river systems are found within the study area (Plate 6). The Barren River and its tributaries flow to the northwest, crossing the sinkhole plain. The Green River flows west across the Mammoth Cave Plateau and joins the Barren River at the northwest corner of the study area. Alluvial valleys composed of unconsolidated sand and clay are typically 1,000 to 2,500 ft wide in the area, but widen to 3,000 to 5,000 ft where the rivers cross the soft sedimentary rocks of the Caseyville Hills region. Alluvial valleys require additional geotechnical evaluation because they are sources of drinking water and are potential locations for archeological sites.

5.2 **Streams**. Small tributary streams are present overlying geologic units that are relatively insoluble. Streams along the southern margin of the sinkhole plain sink into swallet holes where the water travels into the subsurface groundwater system (Plate 5). There are few surface streams within the main portion of the sinkhole plain—groundwater is recharged across the entire area but especially where it is collected into the numerous sinkholes.

5.3 **Karst groundwater basins**. Unlike surface streams, karst groundwater may travel in unpredictable paths in the subsurface. Because there is often more than one level to cave systems, water can rise into higher passages and flow in different directions under certain hydrologic conditions. Hydrologic conditions that result in groundwater overflow vary according to conduit geometry and depth, as well as local soil conditions and rainfall distribution at the time of high rainfall events. Karst scientists perform dye tracing to model the underground flow of water. Dye is injected into sinking streams and detected at springs in the vicinity. Networks of interconnected underground flow paths have been used to delineate karst groundwater basins (Ray and Currens, 1998, 2000). Two large basins have been designated within the study area that impact the planning project—the Turnhole Spring Basin and the Graham Spring Basin. Plate 7 shows the approximate boundary of the individual basins and their inferred flow paths in the subsurface. The Graham Spring Basin collects water from streams on the southern edge of the sinkhole plain, and drains westward toward Bowling Green. The Graham Spring itself is one of the largest in Kentucky, and a potential future water source for Bowling Green and Warren County. The Turnhole Spring Basin collects water from streams on its southern boundary and surface sinkholes and flow paths are northward through Mammoth Cave National Park and into the Green River. It is known that under very high rainfall conditions, water from one basin can rise into higher (older) cave passages that may flow into an adjacent basin. No dye traces to date are known to have detected this behavior in these two basins although this possibility is currently under investigation. In addition to the possibility of interconnectivity, there is also some uncertainty about the precise position of the boundary between adjacent basins. Additional groundwater dye-tracing experiments can be used to improve the accuracy of these boundaries.

6.0 **Recommendations**

Alternative corridor locations proposed for this study area are shown on Plate 8. Corridors for Interstate 66 are numbered on the diagram, while Bowling Green outer beltway locations are given letters. Portions of corridors are coincident with those of others in some locations. Proposed corridors are grouped according to whether they primarily utilize existing I-65 (central route) or are north or south of I-65.

6.1 **Southern route (Corridor 23)**. The best locations for new road construction that would minimize impacts to the groundwater environment are in the south of the study area. Alignments along the southern edge of the Graham Springs groundwater basin, or in the Central Pennyroyal region are preferred. Such routes should exit the Nunn Parkway prior to entering the Turnhole Springs groundwater basin that flows through Mammoth Cave National Park. This placement would have the added advantage of reducing existing traffic at the western terminus of the Nunn Parkway which is situated in the Turnhole Springs Basin.

6.2 **Central route (Corridor 12)**. This route will be primarily located in the sinkhole plain that is environmentally sensitive. However, reconstruction of existing I-65 may minimize additional environmental impacts to the study area. Extensive geotechnical evaluation will be required in order to minimize impacts to karst features.

6.3 **Northern routes (Corridors 2, 4, 5, 10, 11)**. Northern routes require crossing the sinkhole plain, the Dripping Springs Escarpment, and the Mammoth Cave Plateau with new construction. Such routes should minimize exposure to the Turnhole Spring groundwater basin and maximize use of the relatively flat-lying sandstone caprock on the Mammoth Cave Plateau. Portions of corridors along the edge of the escarpment are likely to encounter numerous vertical karst conduits during construction. Northern routes cross the steepest, most rugged topography.

6.4 **Outer Beltway**. Bowling Green outer beltway routes are primarily located within the sinkhole plain and have the same conditions as those discussed about. None of the alternatives are preferred on the basis of geology.

7.0 References Cited

Ray, J.A., and Currens, J.C., 1998, Mapped karst ground-water basins in the Beaver Dam 30 x 60 minute quadrangle: Kentucky Geological Survey, Map and Chart 19, ser 11, one sheet.

Ray, J.A., and Currens, J.C., 2000, Mapped karst ground-water basins in the Bowling Green 30 x 60 minute quadrangle: Kentucky Geological Survey, Map and Chart 22, ser 12, one sheet.

Plate 1

Location of the I-66 Study Area

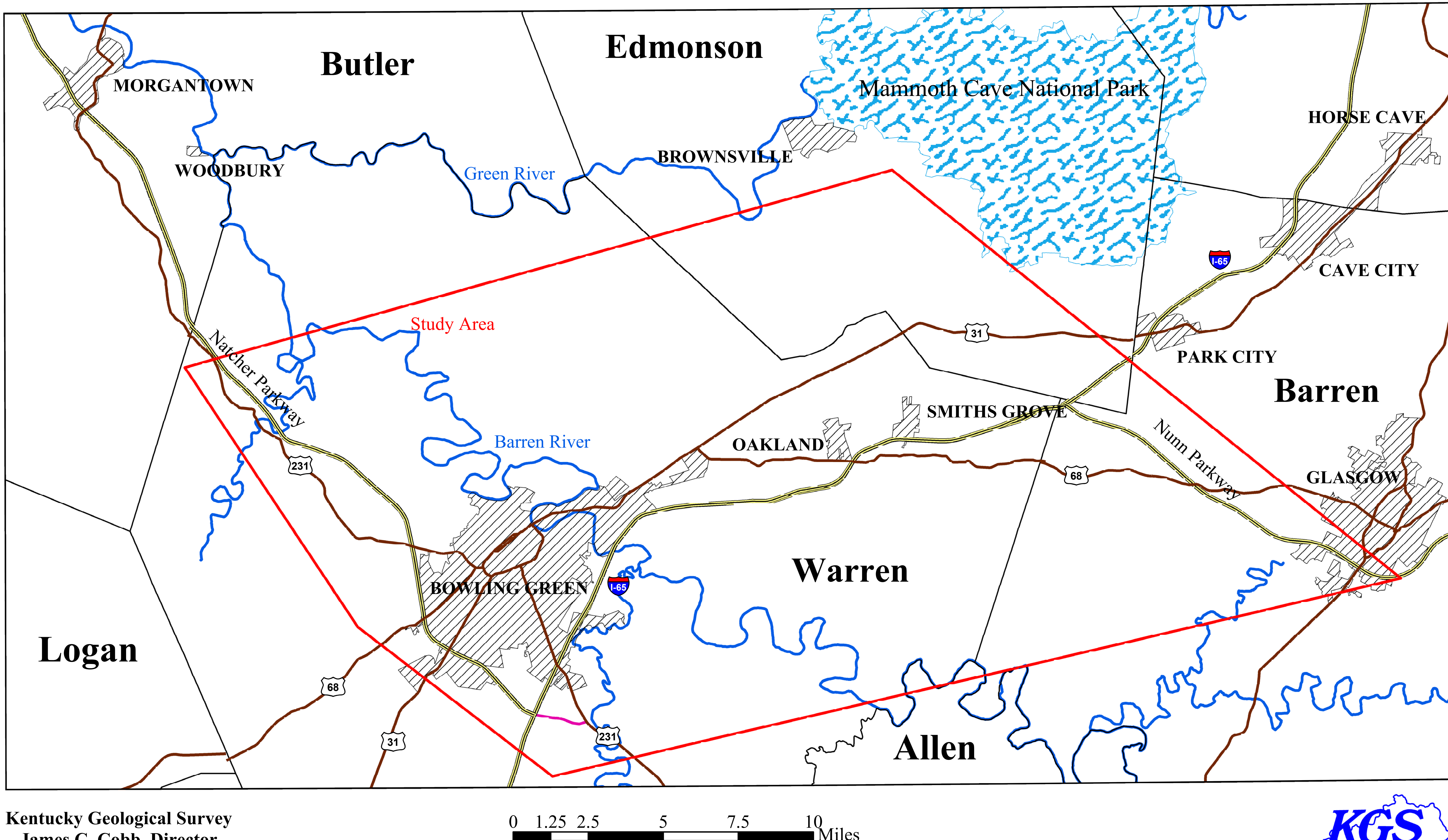

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Plate 2

Topography and Geologic Regions of the I-66 Study Area

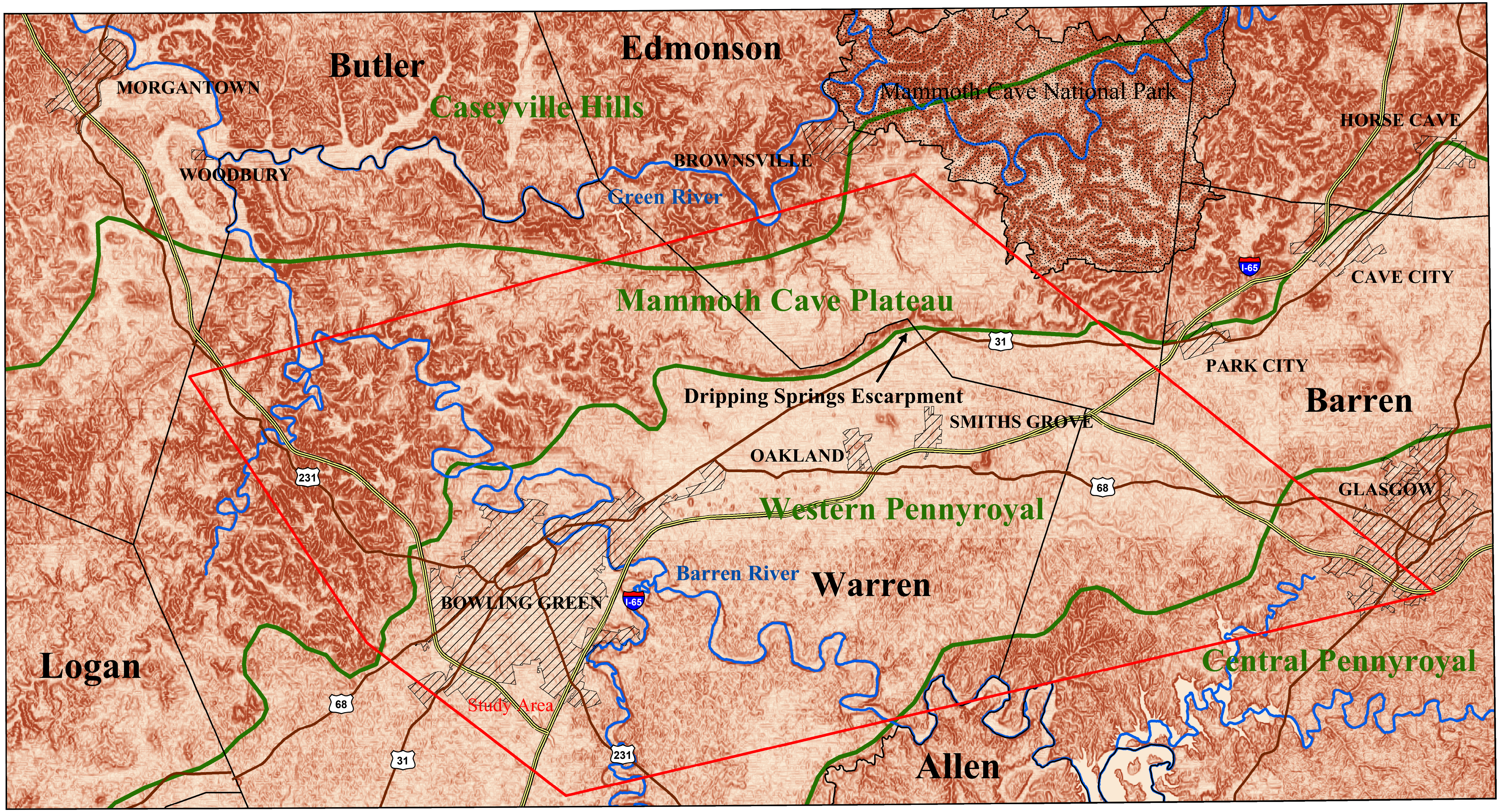

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Plate 3

Susceptibility to Karst Development

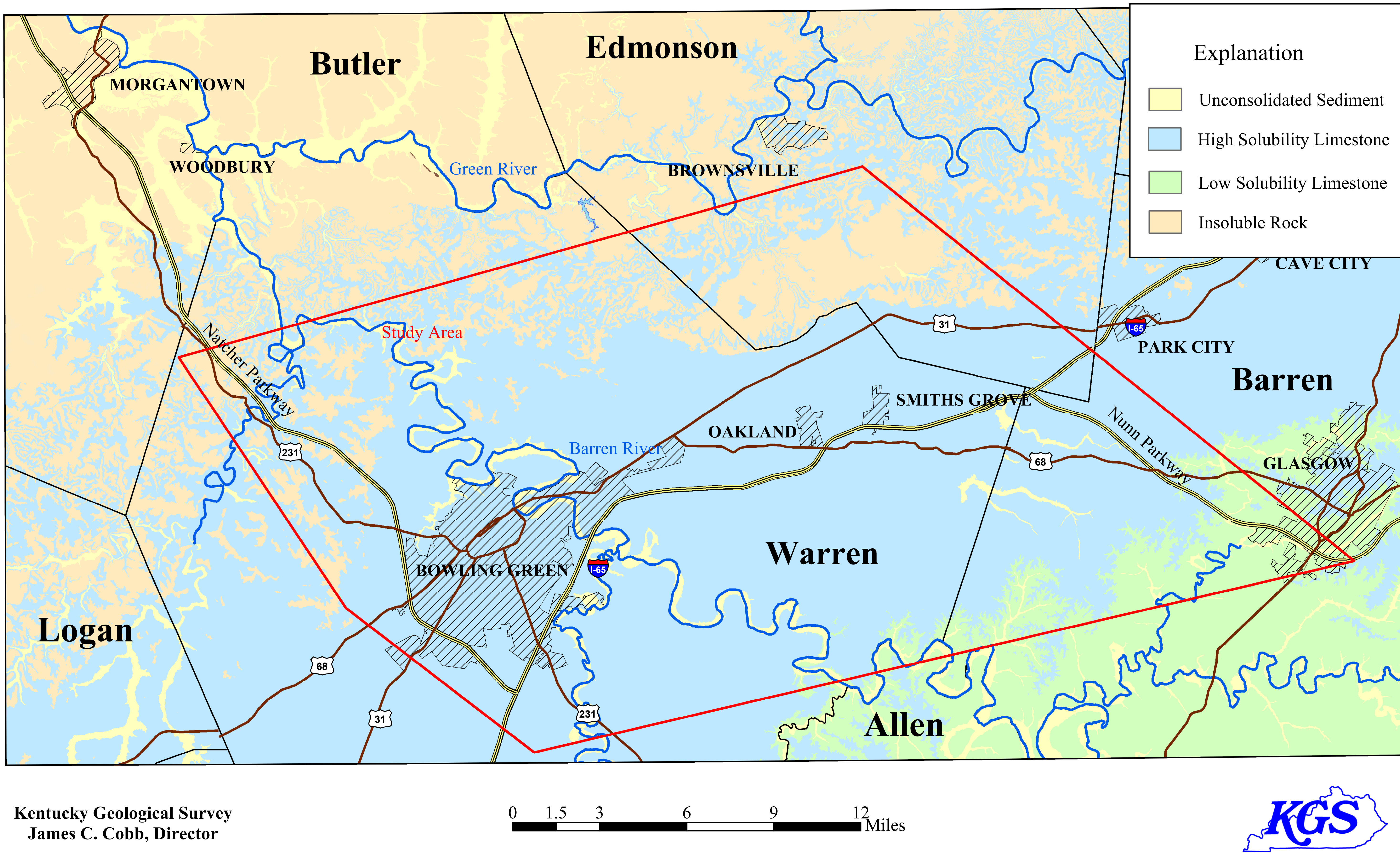

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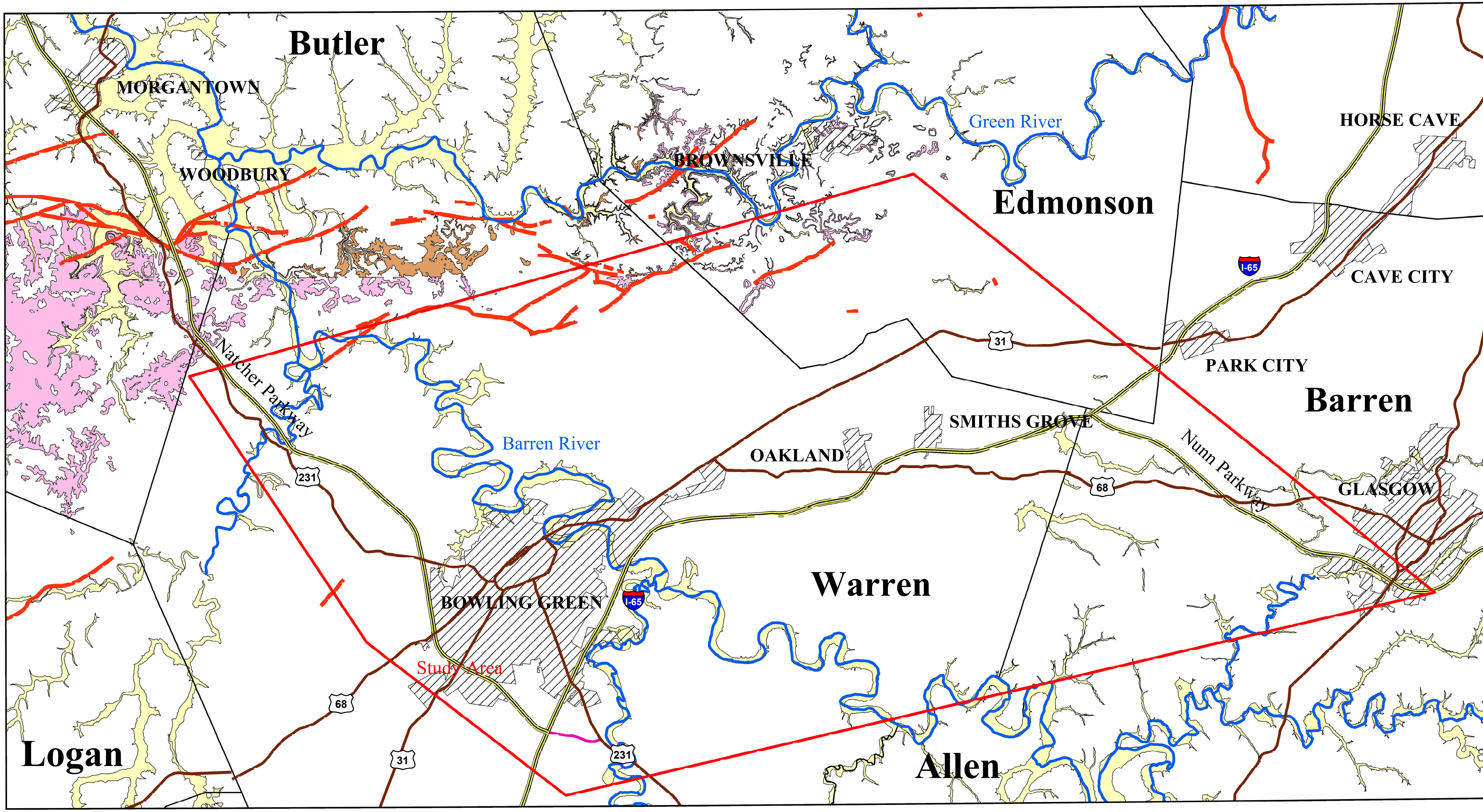
Plate 4

Non-karst Geologic Issues in the I-66 Study Area



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0 1.5 3 6 9 12 Miles

Alluvial Sediment
Red and Green Shales
Asphalt-bearing Sandstone
Faults

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Plate 5

Surface Karst Features in the I-66 Study Area

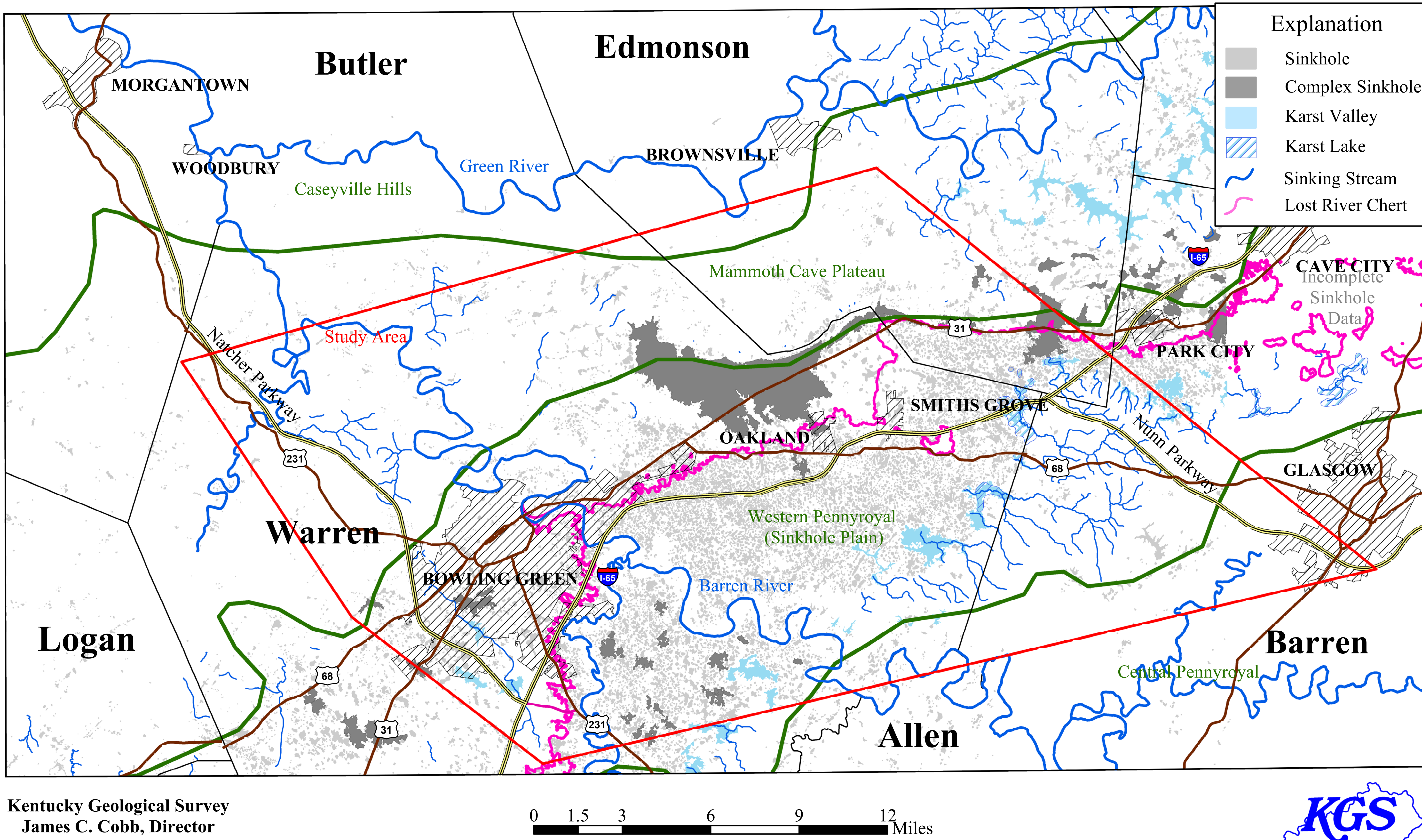

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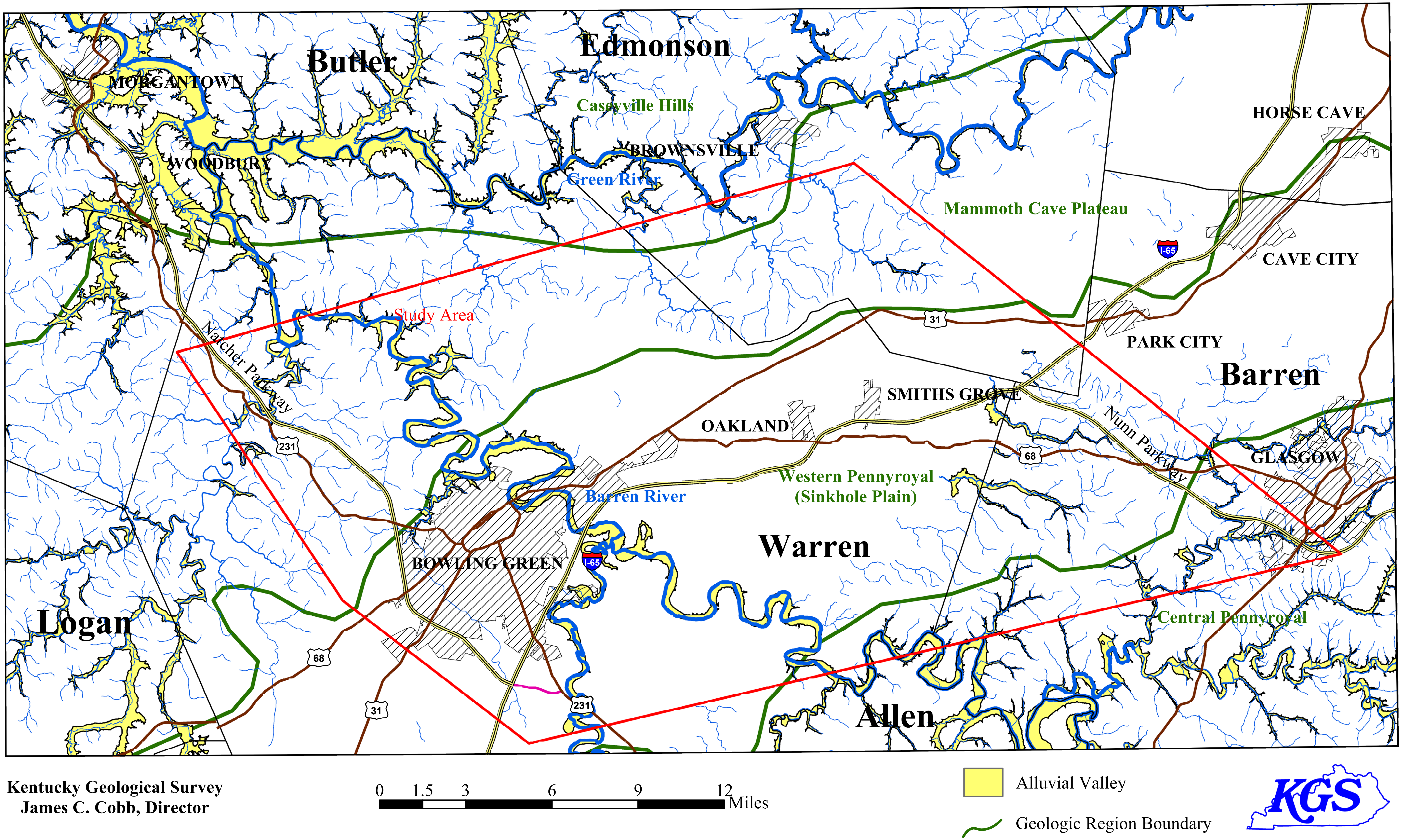
Plate 6

Surface Streams in the I-66 Study Area



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0 1.5 3 6 9 12 Miles

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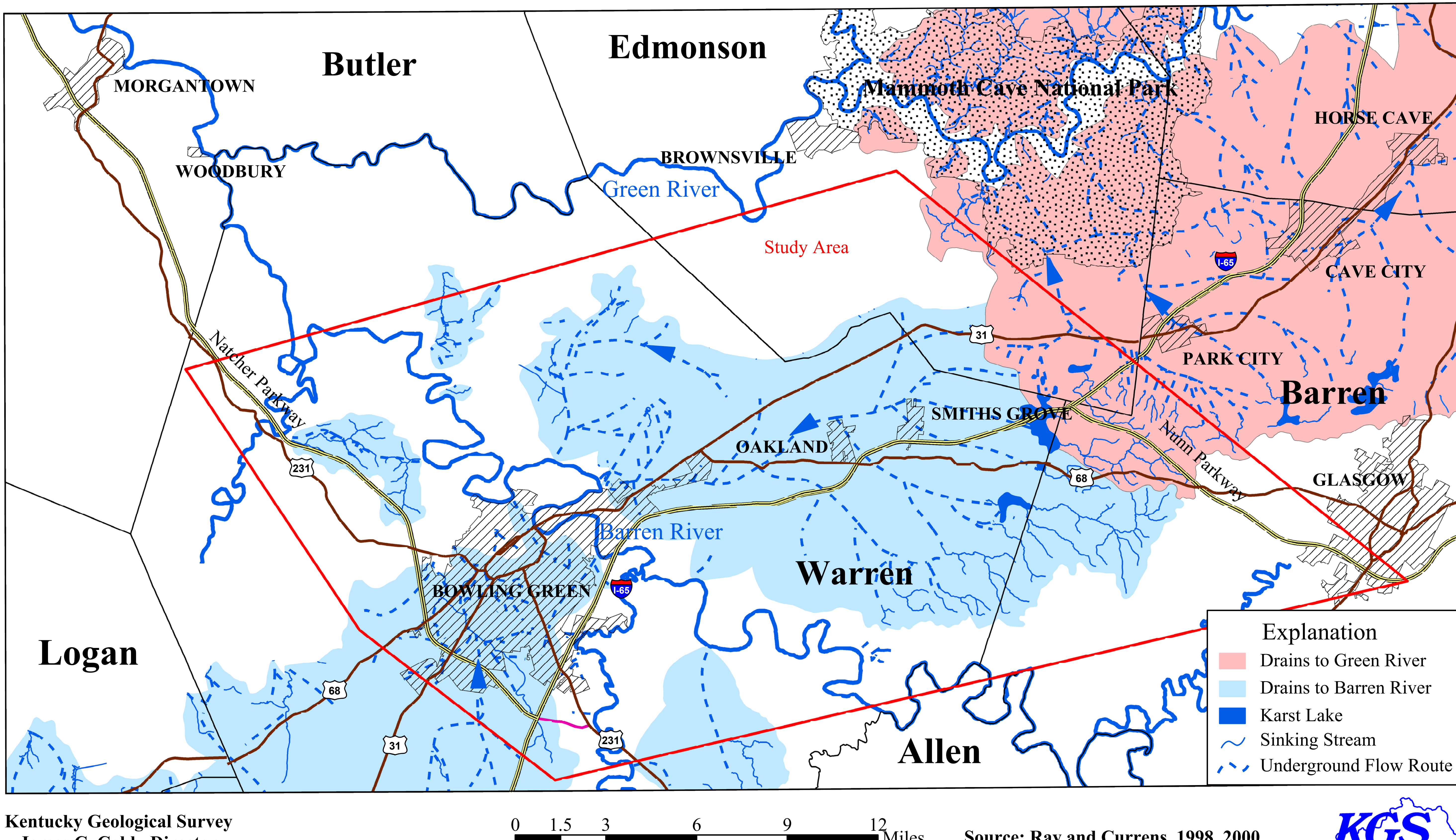
Plate 7

Karst Groundwater Basins of the I-66 Study Area



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Source: Ray and Currens, 1998, 2000

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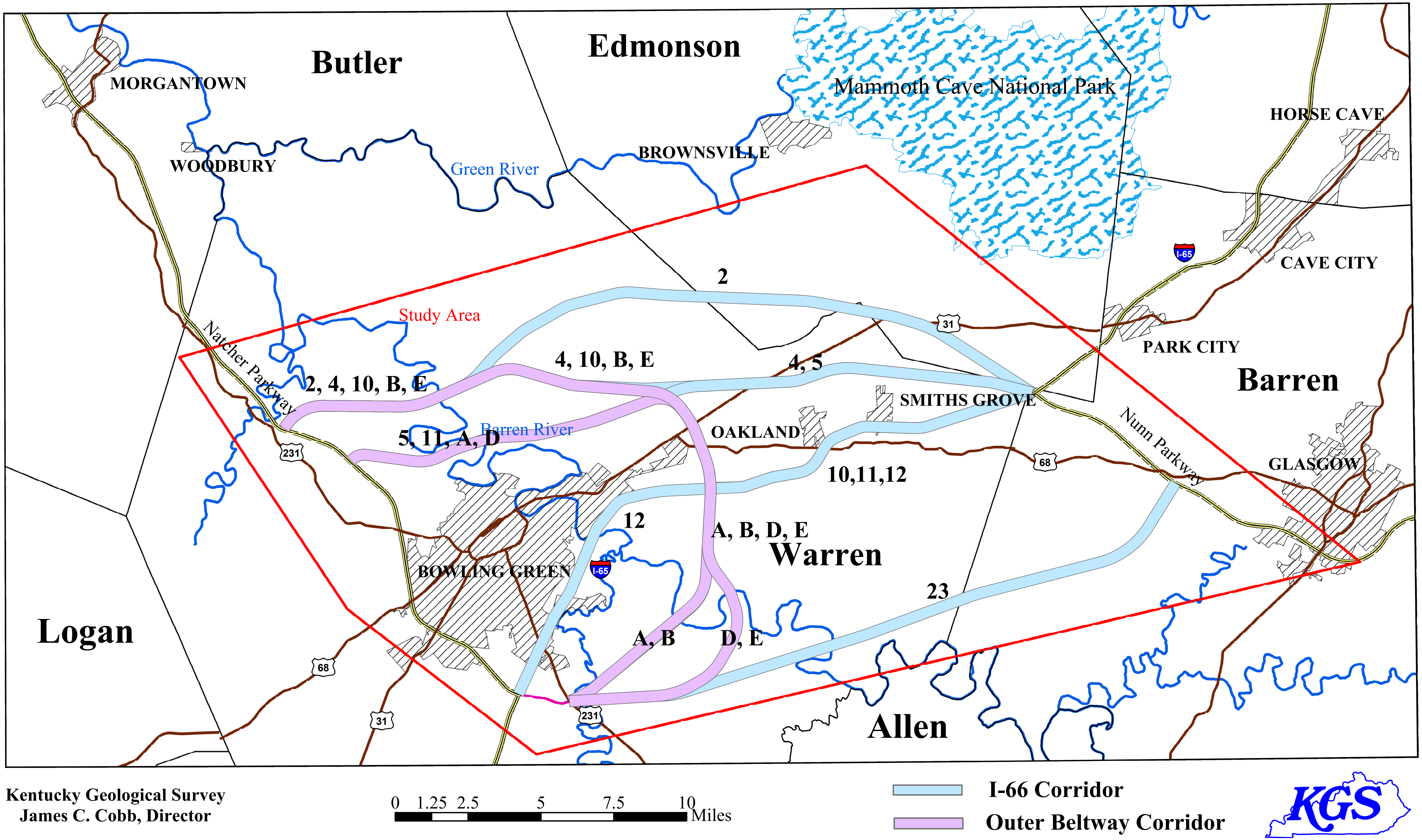
Proposed I-66 and Bowling Green Outer Beltway Corridor Alternatives



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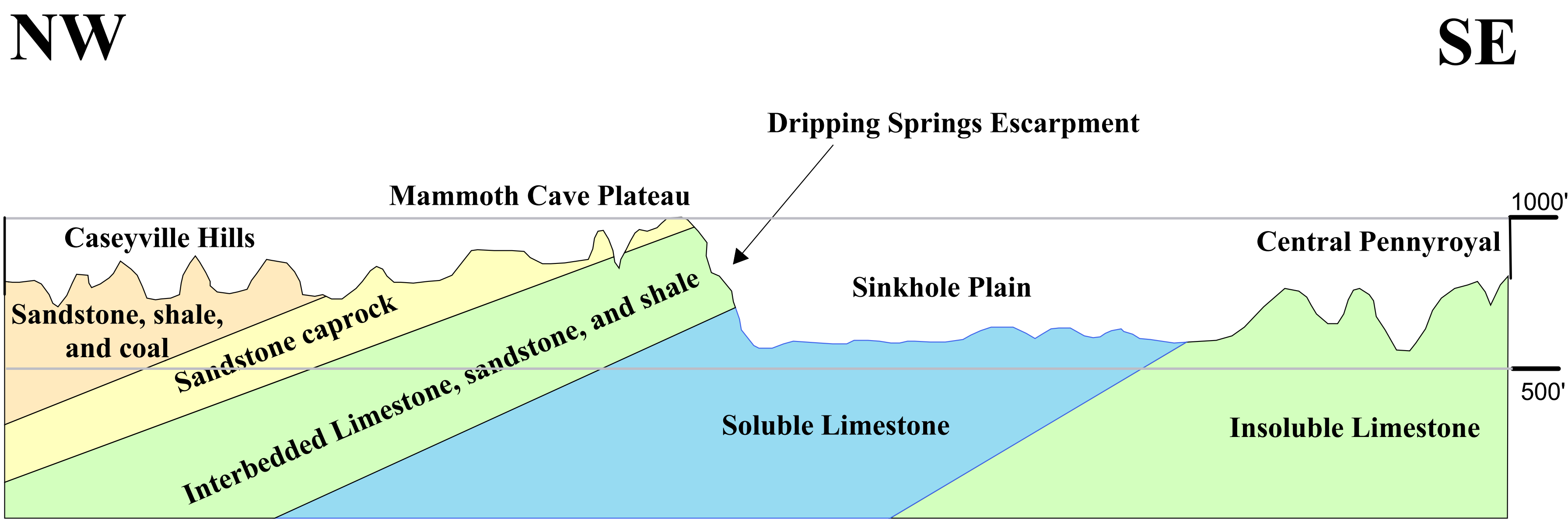


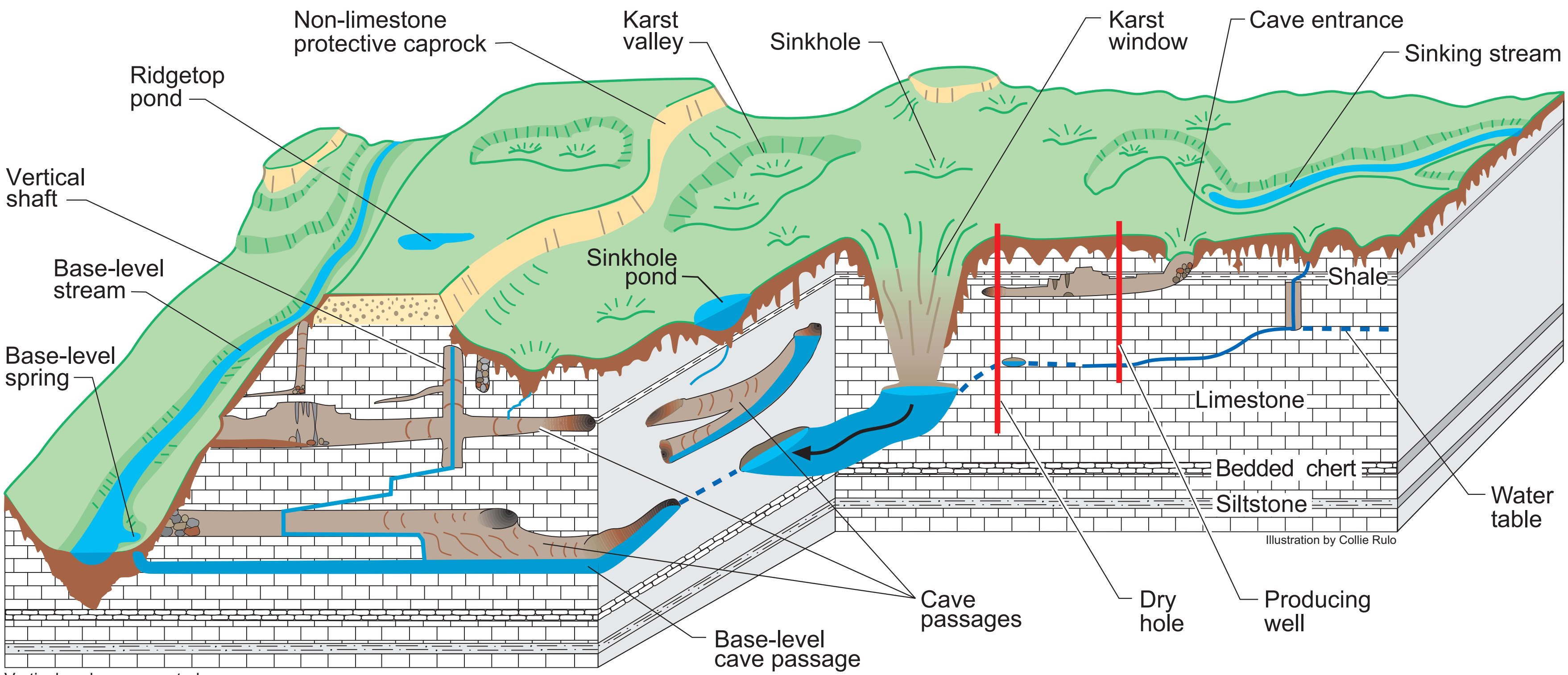
Figure 1. Diagramatic representation of the geologic structure and topography of the Bowlling Green region. Elevations in feet about sea level.

Kentucky Geological Survey
James C. Cobb, State Geologist and Director
UNIVERSITY OF KENTUCKY, LEXINGTON

MAP AND CHART 16
Series XII, 2001

Generalized Block Diagram of the Western Pennyroyal Karst

James C. Currens



Western Pennyroyal karst:

Karst occurs where limestone or other soluble bedrock is near the earth's surface, and fractures in the rock become enlarged when the rock dissolves. Sinkholes and sinking streams are two surface features that indicate karst development. In karst areas most rainfall sinks underground, resulting in fewer streams flowing on the surface than in non-karst settings. Instead of flowing on the surface, the water flows underground through caves, sometimes reemerging at karst windows, then sinks again to eventually discharge at a base-level spring along a major stream or at the top of an impermeable strata. The development of karst features is influenced by the type of soluble rock and how it has been broken or folded by geologic forces. There are four major karst regions in Kentucky: the Inner Bluegrass, Western Pennyroyal, Eastern Pennyroyal, and Pine Mountain. This diagram depicts the Western Pennyroyal karst.

Many of the conditions needed for long cave systems occur in the Western Pennyroyal. These include a thick block of pure limestone, a high rainfall rate, higher elevation areas draining toward a major stream, rocks dipping toward the stream, and large areas of the limestone protected from erosion at the surface by overlying insoluble rocks. In the Mammoth Cave area, all of these conditions are found together, which resulted in Mammoth Cave, the longest known cave system in the world at 350 miles! As erosion on the surface continues over geologic time, the major stream draining a karst terrane cuts its channel deeper. In response, deeper conduits increase their flow to the major stream and new springs develop at lower elevations along the stream's banks. Older, higher flow routes are left as dry cave passages, some of which become sediment filled. To produce significant amounts of water, wells drilled into karst aquifers must intersect a set of enlarged fractures, a dissolution conduit, or a cave passage with an underground stream.

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GEOTECHNICAL OVERVIEW

EDMONSON, WARREN, AND BARREN COUNTIES, KENTUCKY

I-66

FROM WILLIAM NATCHER PARKWAY TO I-65 AND NUNN (CUMBERLAND) PARKWAY

ITEM NO. 3-66.00

FOR

KENTUCKY TRANSPORTATION CABINET
FRANKFORT, KENTUCKY

APRIL 2003

H. C. NUTTING COMPANY

EMPLOYEE OWNED

HCN H. C. NUTTING COMPANY
EMPLOYEE OWNED
GEOTECHNICAL, ENVIRONMENTAL AND TESTING ENGINEERS
SINCE 1921

CORPORATE CENTER
611 LUNKEN PARK DRIVE
CINCINNATI, OHIO 45226
(513) 321-5816
FAX (513) 321-0294

April 24, 2003

W.O. 71566.002

Mr. Carl Dixon
Bernardin Lochmueller & Associates
975 River Bend Road #2
Frankfort, Kentucky 40601

Re: Geotechnical Overview
Edmonson, Warren, and Barren Counties
I-66 and Outer Beltlines
Item No. 3-66.00

Dear Mr. Dixon:

Enclosed you will find a **Submittal Draft** for the Geotechnical Overview to be included in your scoping study for the subject project. Please review and provide us with your comments. We will be glad to meet with you to discuss it. If you desire any additional information, please advise. Thanks for the opportunity to provide you with our services.

Respectfully submitted,
H. C. NUTTING COMPANY

Robert A. Thomson, Jr.

Robert A. Thomson, Jr., E.I.
Staff Geotechnical Engineer

Doug Smith / Dew

Doug Smith, P.G.
Senior Geologist

Henry Mathis / CRK

Henry Mathis, P.E.
Senior Consultant

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SUBMITTAL DRAFT

INTRODUCTION

The H. C. Nutting Company is pleased to team with Bernardin Lochmueller to provide the Geotechnical Overview on the I-66 corridor and interchange study between the existing Natcher and Nunn (Cumberland) Parkways for the Kentucky Transportation Cabinet (KYTC). Additionally, beltline corridors around the city of Bowling Green, Kentucky were to be evaluated. Henry Mathis, P.E., Senior Consultant, Doug Smith, P.G., Senior Geologist, and Robert Thomson, E.I., Staff Geotechnical Engineer, and others in the H. C. Nutting Company assisted in the preparation of this overview. Seven corridors and four beltline locations have currently been proposed for the I-66 connection between the Natcher and Nunn (Cumberland) Parkways.

The report format and outline are in general accordance with requirements described in the KYTC's Geotechnical Manual, section GT-801, page 1, and scope of work as suggested by Daryl Greer, KYTC, Division of Planning. The primary focus on this study is to identify geological conditions that could adversely affect the design and construction of this project. General recommendations were provided concerning geotechnical issues related to this site.

In preparation of this report, Doug Smith and Robert Thomson reviewed the corridors in the field on January 29 and 30, 2003. Information was gathered from ten (10) United States Geologic Survey (USGS) 7.5 minute geologic and topographic quadrangles, including the Hadley, Rockfield, Bowling Green North, Bowling Green South, Bristow, Polkville, Smith's Grove, Meador, Park City, and Lucas quadrangles. Information was reviewed from the geotechnical reports (R-3-01 and R-03-2003) that were prepared by the KYTC Geotechnical Branch for roadway design in the area. Discussions were held with several of the KYTC

District 3 engineering staff, including Greg Meredith, Chief District Engineer, Daryl Price, Construction Engineer, and Tim Eaton, Office Engineer. These discussions were held concerning construction issues associated with the current I-65 widening in progress. Discussions were also held with Dr. Ken W. Kuehn, Professor of Geology at Western Kentucky University concerning geologic and environmental features of the project area.

This Geotechnical Overview includes a description of each corridor and beltline and the geotechnical and geological issues associated with them, as well as general recommendations for the corridors.

The following table summarizes the geotechnical and geological issues associated with each corridor and beltline proposed at the project site. It should be noted that caves and oil well listings are not all-inclusive and should be considered as a general guide.

Corridor / Beltline	Topography	Significant Cave Systems	Oil Well Locations*
Corridor 2	Rough to rolling terrain with flat plateaus	Gift Horse Cave Complex Haney Limestone Sinkhole Plain Pruitt's Cave Garret Hollow Cave System	8
Corridor 4	Rough to rolling terrain with flat areas	Cave Spring Caverns	13
Corridor 5	Rough to rolling terrain with flat areas	Cave Spring Caverns	9
Corridor 10	Rough to rolling terrain	--	8
Corridor 11	Rough to rolling terrain	--	5
Corridor 12	Rolling to flat terrain	--	1
Corridor 23	Flat to rolling terrain	Steep Hollow Cave System	4
Beltline A	Rough to rolling terrain	--	4
Beltline B	Rough to rolling terrain	--	8
Beltline D	Rough to rolling terrain	--	5
Beltline E	Rough to rolling terrain	--	9

*** Denotes the number of locations that oil wells were identified in the field within the corridor, not the actual number of oil wells.**

The proposed corridors form an integrated network of overlapping corridor and beltline segments. The following is a detailed description of each segment of the corridor system.

Nunn Parkway

The western end of the existing parkway (including portions of Corridors 2, 4, 5, 10, 11, and 12) is located in the Western Pennyroyal (Sinkhole Plain) geologic region. This region is typically a low relief area underlain by highly soluble limestone formations. Extensive sinkhole development and underground stream drainage is prevalent along this corridor segment. Shallow cuts and fills in this area would likely be in soil.

As the corridors continue along Nunn Parkway in a northwestern direction, they traverse the southwestern corner of the Turnhole Spring Basin (as located per our discussions with Dr. Ken W. Kuehn, Department of Geography and Geology, Western Kentucky University), which is part of the Mammoth Caves drainage basin.

North Corridor (Eastern End of Project)

The eastern end of this corridor segment (which includes Corridor 2) traverses through the Western Pennyroyal (Sinkhole Plain) and Mammoth Cave Plateau geographic regions. The Mammoth Cave Plateau geographic region is an area of high relief underlain by highly soluble limestone formations that are capped by sandstone. Extensive cave systems and vertical conduits are common in this area. The corridor traverses the Dripping Springs Escarpment (also known as "The Knobs") just east of the proposed KY 101 interchange (see Edmonson-Warren County KYTC report R-3-01 for detailed geotechnical information at KY 101), through Girkin Formation and Big Clifty sandstone bedrock. West of this proposed interchange, the corridor crosses a plateau that is characterized by relatively flat to gently rolling terrain, which transitions to rougher terrain as the corridor continues to the west. The corridor has two major creek crossings, including Alexander Creek and Little Beaver Creek.

Oil wells were observed near intersections with KY 259, Beaver Creek Road, and KY 185. Cemeteries were noted at intersections with KY 1339, KY 1659, and KY 1320.

This corridor would result in additional roadway within the Turnhole Spring Basin. Additionally, some portions of the proposed corridor lie within karstic limestone plains that form the Graham Spring drainage basin. Significant cave systems that may be impacted by Corridor 2 include the Gift Horse Cave Complex, the Haney Limestone Sinkhole Plain, Pruitt's Cave, and the Garrett Hollow Cave System. The Gift Horse Cave Complex and Pruitt's Cave are of particular significance due to the presence of endangered wildlife species and archeological artifacts.

<u>Corridors 4 & 5 (Eastern End of Project)</u>

This corridor segment traverses through the Western Pennyroyal (Sinkhole Plain) and Mammoth Cave Plateau geographic regions, as previously discussed.

Oil wells were observed near intersections with Rocky Hill School Road, Stoney Point Church Road, KY 101, and KY 743.

These corridors would result in additional roadway within the Turnhole Spring Basin. Additionally, much of the proposed corridors lie within karstic limestone plains that form the Graham Spring drainage basin. One significant cave system that may be impacted by Corridors 4 and 5 is the Cave Spring Caverns, located near the intersection with Upper Smith Grove Road. This system is of particular significance because of the presence of endangered wildlife species and archeological artifacts.

I-65 Corridors

Corridors 10 and 11 follow existing I-65 from Nunn Parkway to Sunnyside, and Corridor 12 continues along I-65 from Nunn Parkway to the existing interchange with Natcher Parkway at Three Springs (see Warren County KYTC reports R-49-98 and R-50-98 for detailed geotechnical information along I-65). This corridor segment travels through the Western Pennyroyal (Sinkhole Plain) geographic region, as previously discussed. Construction issues associated with the current I-65 widening in progress include numerous sinkhole repairs, with sinkhole sizes ranging between 5 and 20 ft. in diameter. At times, sinkholes have not formed within the roadway until after pavement had been placed. Per our discussions with engineers at the KYTC District 3 office, significant sinkhole repairs have occurred along I-65 near mileposts 25.7, 27.2, 31.7, 33.5, and 35.2.

Rinker's Quarry was also noted within the corridors near McGinnis Quarry Road.

The existing interstate and Corridor 12 cross the Barren River east of the city of Bowling Green. Alluvial bottom lands were observed on the southern bank at the crossing, and bedrock outcrops should be expected on the northern bank.

The eastern portion of this corridor segment traverses the southwest region of the Turnhole Spring Basin. Additionally, much of the proposed corridor lies within karstic limestone plains that form the Graham Spring drainage basin along I-65.

North Corridors (Western End of Project)

This corridor segment, which includes corridors 2, 4, and 10 to the north and corridors 5 and 11 to the south, are located within the Mammoth Cave Plateau geographic region, as previously discussed. Terrain becomes increasingly rough in a western direction along these routes, where St. Louis and Ste. Genevieve limestone bedrock can be found in deep cuts at lower elevations, and Girkin Formation and Big Clifty sandstone bedrock can be found at higher elevations. Cave entrances are abundant in this region. Both corridor routes cross the Barren River in primarily alluvial plains, with possible bedrock outcrops along the western bank at the northern route crossing and the eastern bank at the southern route crossing.

Along the northern route, oil wells were observed near intersections with Mount Olivet Girken Road, Garrett Hollow Road, KY 526, Cambel Road, Slim Island Road, Koostra Road, KY 1435, and Westbrook Road. Along the southern route, oil wells were noted near intersections with KY 526, Plum Springs Road, KY 2665, and Natcher Parkway.

South Corridor (Eastern End of Project)

This corridor segment, which includes Corridor 23, lies within the Western Pennyroyal (Sinkhole Plain) and Central Pennyroyal geographic regions. The Central Pennyroyal geographic region is an area of moderately high relief underlain by low solubility limestone. This region is drained by surface streams with little karst development. Sinkholes and depressions were noted at the northeastern and southwestern ends of this portion of the corridor. The Steep Hollow Cave system has also been mapped in the northern edge of the corridor east of the Barren River. Additionally, a cave entrance was noted near Buck Creek.

The topography of this region is typically gently rolling, with larger hill sizes between Steam Mill Road and Lawrence Road in the southeastern region of the corridor, where surface drainage is more prevalent. Stream and river crossings along of the corridor include, from east to west, Buck Creek, Barren River, and

Drakes Fork Creek. Alluvial bottomlands were observed along the western bank of the Barren River and the eastern bank of Drakes Fork Creek. Bedrock outcrops of Salem, Warsaw, and St. Louis limestone are expected along the east bank of Barren River, and St. Louis limestone outcrops are expected along the west bank of Drakes Fork Creek.

Oil wells were observed near intersections with KY 255, Mt. Union Church Road, and Motley Lane. A pipeline was noted near the intersection with KY 255. Communication towers were noted near Iron Bridge Road.

Unlike the other corridor options, Corridor 23 will not result in further encroachment of the Turnhole Spring Basin. This region has a northward drainage and is potentially within the Graham Spring drainage basin

Natcher Parkway

The corridors that follow the existing parkway, including Corridors 12 and 23, as well as Corridors 5 and 11 to the west, traverse through the Western Pennyroyal (Sinkhole Plain) and Mammoth Cave Plateau geographic regions, as previously discussed. This sinkhole plain has a northward subsurface drainage, draining to the Barren River.

Toward the northwestern end of this corridor route, the parkway traverses increasingly rough terrain, with several deep cuts and fills. Girkin Formation and Big Clifty sandstone bedrock can be found at higher elevations. Cave entrances are abundant in this region, and oil wells were observed along the existing parkway.

Beltlines

The beltline corridors traverse through the Western Pennyroyal (Sinkhole Plain) and Mammoth Cave Plateau geographic regions, as previously discussed. The beltlines first cross the Barren River north of the proposed interchange with KY 234. Within Beltlines A and B, alluvial bottomlands were found along the northern bank at this crossing, and bedrock outcrops are expected along the southern bank. Within Beltlines D and E, alluvial bottomlands were found along the southern bank at this crossing, and bedrock outcrops are expected along the northern bank.

Oil wells along the southern portions of Beltlines D and E were observed near an intersection with South Hewitt Road. Each of the beltlines crosses a portion of the Barren River and Graham Spring drainage basin near the interchange with I-65.

RECOMMENDED SOLUTIONS FOR POTENTIAL GEOTECHNICAL PROBLEMS

1. Sinkholes and basins located within the embankments and existing solution channels in cut limits are to be treated in accordance with the KYTC standard procedures. In cases where a sinkhole is to be used for drainage purposes, a minimum of 150 ft. of grass-lined ditch or swale with silt checks appropriately positioned should be designed to filter the flow draining from the roadway. If this cannot be achieved, a detention area should be utilized to capture pollutants prior to discharging the flow into the sinkhole.

2. The soils at subgrade will typically have a very low CBR value. Chemical stabilization is an option to increase these anticipated low values. In areas where rock is plentiful, rock roadbed subgrade construction should be considered.

3. Typically, in areas where soils are used for embankment construction, (under 40 ft.), a 2 horizontal to 1 vertical slope will be anticipated. For embankment heights greater than 40 ft., embankment slopes of 3 horizontal to 1 vertical or flatter may be necessary depending upon the foundation geotechnical investigation result.

4. Cuts in soils will typically be stable on slopes of 2 horizontal to 1 vertical or flatter. In cut areas where limestone rock is encountered, cut slopes will typically be stable on ½ horizontal to 1 vertical slopes with 15 to 18 ft. horizontal benches at 30 to 45 foot height intervals.

5. Non-durable shales will typically be encountered in the northern corridors. These shales are subject to weathering, and therefore, flatter cut slopes (1H:1V to 1-½H:1V) are anticipated in the cut areas. Special compaction efforts during construction operations, as specified in the KYTC specifications, will be required for non-durable shales utilized for embankment construction. Embankments greater than 30 ft. in height constructed of these materials may require side slopes flatter than the normal 2 horizontal to 1 vertical slope. The results of the geotechnical foundation investigation will determine the side slope configurations.

6. Drilled shafts are suggested for structures (wet and dry) located within any of these proposed corridors due to the possibility of sinkholes and the irregular rock line located beneath the proposed foundations. The drilled shafts will provide a means to inspect the hole before the steel and concrete is placed for the structure foundation.

7. Stone columns and/or wick drains may be necessary at the wet bridge crossings because of possible excessive settlements and resulting drag

down loads on the piles or drilled shafts. Select granular embankments may be utilized at these crossings to prevent flatter slopes at the abutments and decrease the settlement in the embankments. These special operations will be determined as a result of the foundation geotechnical investigation.

8. In the areas where side hill embankments are to be constructed over unstable hillsides, the unstable material shall be removed to rock or stable material and embankment benches with drainage blankets and perforated pipe under drains are suggested in accordance with the KYTC specifications.

7. Numerous oil wells were noted at several locations throughout the corridors. During the alignment phase, these oil wells should be avoided if possible by modifying the corridor.

8. The project is located in Seismic Risk Zone VIII, which is defined as an area of slight damage to structures due to earthquake activity. This information is from the "Estimated Maximum Regional Seismic Intensities" by S.T. Algermissen and Margaret G. Hopper, 1984 published by the USGS.

SUMMARY

Much of the study area lies within karst plains. Over time, subsurface solution channels have formed within the St. Louis and St. Genevieve limestone bedrock, forming a complex system of sinkholes and caves. Though these solution channels may develop over long periods of time, a sinkhole basin can open or collapse almost instantaneously. Experience with the current construction widening of I-65 has shown that though it is helpful to identify as many sinkholes along the corridors as possible, encountering additional sinkholes during and after construction should be anticipated. For example, per our discussions with engineers from the KYTC District 3 office, more than twice as many sinkholes have been mitigated as originally budgeted on one portion of the interstate widening. Some sinkholes may not develop until after final pavement of the roadway, and in some cases, well after project completion.

At least a portion of each corridor and beltline passes through a karst plain. Basins and sinkholes should be expected, regardless of the chosen corridor. Complex cave systems are also abundant throughout the study area. Significant cave systems, containing archeological artifacts and endangered wildlife habitats, include the Gift Horse Cave Complex, the Cave Spring Caverns, and Pruitt's Cave. These cave systems would be directly affected by the northern corridors, particularly Corridors 2, 4, and 5.

Much of the karst plains within the study area have subsurface drainage either towards Mammoth Caves in the northeast or Graham Spring in the west (in Plum Springs). The Turnhole Spring Basin, with a direct subsurface drainage connection to Mammoth Caves, would be further encroached by each of the northern corridors (Corridors 2, 4, and 5), as well as by each of the corridors that follows existing I-65 in the eastern region (Corridors 10, 11, and 12). The Graham Spring drainage basin will also be encroached by each of these corridors, as well as each of the proposed beltline locations (Beltlines A, B, D, and E). Though Corridor 23 is the only corridor that does not encroach the Turnhole Spring Basin, it does traverse a sinkhole plain south of the city of Bowling Green that may also be part of the Graham Spring drainage basin.

Rough terrain was encountered in the northwestern region of the study area. Numerous deep cuts and fills should be anticipated for corridors traversing this region, including Corridors 2, 4, and 10, as well as Beltlines B and E. To a lesser extent, rough terrain was also encountered along Corridors 5 and 11 and Beltlines A and D.

Corridor 23 will likely result in the least encroachment of significant subsurface drainage basins. Particularly, this corridor does not result in further encroachment of the Turnhole Spring Basin, as located per our discussion Dr. Ken Kuehn. Encroachment of the Steep Hollow Cave System can likely be avoided with some corridor modification. A greater number of surface drainage crossing structures, such as bridges and culverts, may be required along this corridor.

As mentioned above, most of the corridors are located within karst plains. Therefore, sinkhole basins, open-throated sinkholes, and caves will likely be encountered during construction regardless of which corridor is chosen. However, it is our understanding that I-65 has been constructed successfully with only minor problems and no reported negative impact to the environment.