

Final Report

I-66-02-01-NSS

Karst Impact Study
Somerset Northern Bypass
(I-66 Project Corridor)

I-66 Special Project



OVR, NSS

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I-66 Special Project

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Introduction

In 1999 the I-66 Special Project (I-66 SP) of the National Speleological Society was formed within the Ohio Valley Region as a group to study and document the potential and real impacts of the possible construction of an interstate across the karstlands of Southern Kentucky. In May of 2001, the I-66 SP was awarded three grants to continue research in the Somerset to London segment of this project. The National Speleological Society awarded \$250 dollars through the Sara Corrie Memorial Exploration Fund and \$500 dollars from the Conservation Fund to continue the fieldwork associated with this project. The Environmental Systems Research Institute (ESRI) awarded a Software Conservation Grant with an estimated worth of \$7,000 dollars to provide software used for data reduction, analysis, and presentation associated with this study. These grant awards were applied to the Somerset Northern Bypass segment of the proposed I-66 corridor. This report (I-66-02-01-NSS) serves as a final report on the progress of these grants, summarizes acquired data, reports on potential impacts resulting from highway construction within the corridor, provides recommendations for reducing or eliminating these impacts, and outlines requests for future research and funding.

History of Project

The Southern Kentucky Corridor (I-66) is a proposed interstate corridor between crossing the southern one-third of Kentucky. This project focuses on one segment of this proposed interstate, an independent utility bypass of Somerset, KY.

Legislation

In 1991, the Intermodal Surface Transportation Efficiency Act (ISTEA) identified several high priority corridors on the National Highway System. The East–West Transamerica Corridor (I-66) was one of these high priority corridors, generally located between and parallel to I-70 and I-40 with an eastern terminus in Virginia and a western terminus in southern California. This Federal transportation legislation mandated that the portion of the corridor through Kentucky must pass within 25 miles of each of the following cities: Pikeville, Jenkins, Hazard, London, Somerset, Columbia, Bowling Green, Hopkinsville, Benton and Paducah.

The Transportation Equity Act for the 21st Century (TEA-21) also established funding for the Somerset to London segment of the I-66 corridor as a high priority corridor. Part of the high priority corridor initiative involves the improvement of depressed or impoverished regions by increasing access and mobilization. The southeastern region of Kentucky has been traditionally associated with below-average income rates.

Studies

As a result of the ISTEA legislation, consultants Wilbur Smith Associates (WSA) and Howard, Needles, Tammen and Bergendoff (HNTB) were selected in 1992 to conduct a national East-West Transamerica Corridor Feasibility Study.

A Steering Committee consisting of representatives of eleven states and the Federal Highway Administration (FHWA) was created to provide technical direction to the study. This study, titled the “Transamerica Transportation Corridor Feasibility Study,” was completed in 1994. This study concluded that the entire coast-to-coast corridor did not meet established economic feasibility criteria for the study. However, the study did conclude that further analysis could find some segments of the corridor feasible from a state or regional perspective.

In 1997, the Kentucky Transportation Center (KTC) completed a study for the Kentucky Transportation Cabinet (KYTC), concluding that the Southern Kentucky Corridor (I-66) through Kentucky was indeed feasible. Titled the “Southern Kentucky Corridor (I-66) Economic Justification and Financial Feasibility Final Report,” it identified the Somerset to London segment of the I-66 corridor as a priority segment.

Somerset – London Corridor

In May of 1999, the Kentucky Transportation Cabinet (KYTC) unveiled possible routes for the section of I-66 between London and Somerset, KY. Of the alternatives presented, the KYTC seemingly chose the most environmentally damaging route (the southern route) as the preferred alternative (Florea, 1999; Florea et. al, 1999; Florea, 2000A; KYTC, 1999 and 2000) (Figure 1).

The land between Somerset and London contains portions of the Daniel Boone National Forest with rugged hills and valleys of the Cumberland Escarpment. This forest land contains undeveloped woodlands and gorges along the Rockcastle River, listed as a Kentucky Wild and Scenic River (SSI, 1979) – and Buck Creek, recently becoming a Watershed Bioreserve run jointly by the Nature Conservancy, USDA, and other state and non-governmental agencies (Sole, 2000). The region is highly karstified with a tremendous bio-diversity (SSI 1979; KGS, 1985; Crawford 1987; Florea et. al, 1999; Florea, 2000C and E; Florea 2001A and B; KICK 66, 2000; Sole 2000; Ewers, 2001; Greb et. al, 2001).

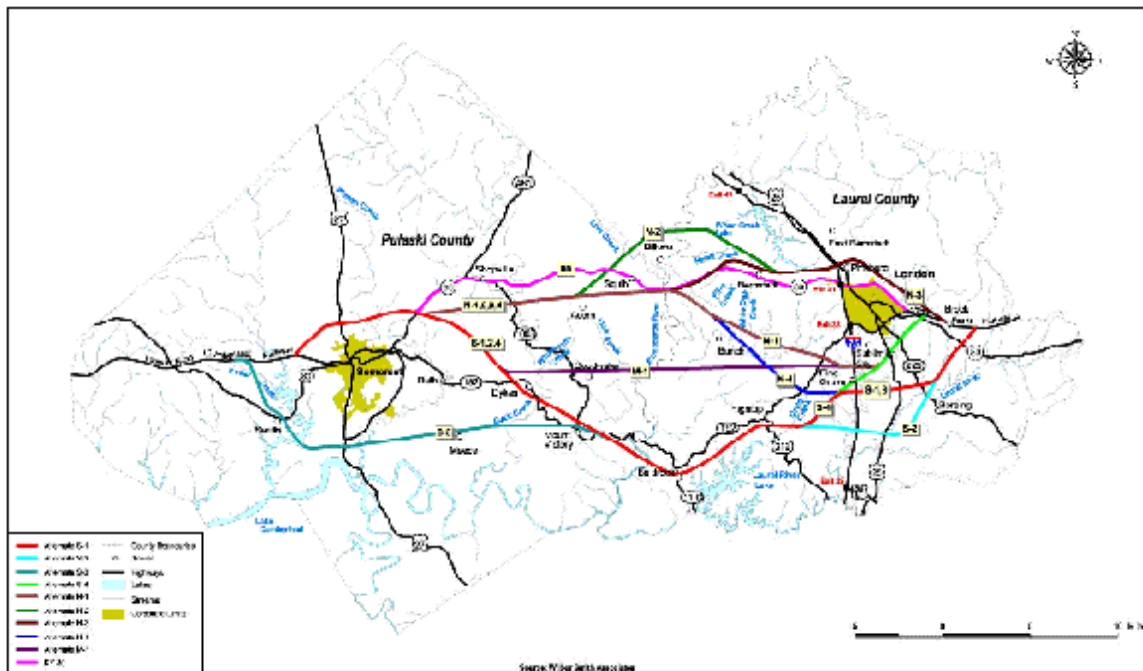


Figure 1: Somerset-London I-66 corridor alternatives in 1999. Original preferred alternative is the southern alternative S3 (red) (KYTC, 1999).

Since releasing their original preferred alternative, the KYTC has retracted from their position amid overwhelming public opposition (KICK 66, 2000). The new preferred alternative is further to the north, away from the areas of previous concern (KYTC, 2000) (Figure 2). The ultimate construction of this corridor along any alignment will have serious consequences to the regional socioeconomic structure and environmental integrity (Moskowitz, 2000). Though closer to regions of development and near existing highways, this new alternative is environmentally deficient for several reasons including:

Parkway and Highway 80 corridor as a disjoint component. The corridor is narrow in the west in order to connect to the planned Southwest Somerset Bypass, and it gradually widens to the east, providing several potential connection points to Highway 80 (Figure 3).

In April of 2002, the KYTC presented the 5 potential alternatives for the bypass corridor. The first is the “no build” option where only routine maintenance is preformed on existing highways. The second option is a reconstruction of existing Highway 80 through Somerset to interstate standards. The remaining three options are new corridors located to the north of the city and consist of a south, a middle and a north alignments. The general location of these alignments is presented in Plate 1.

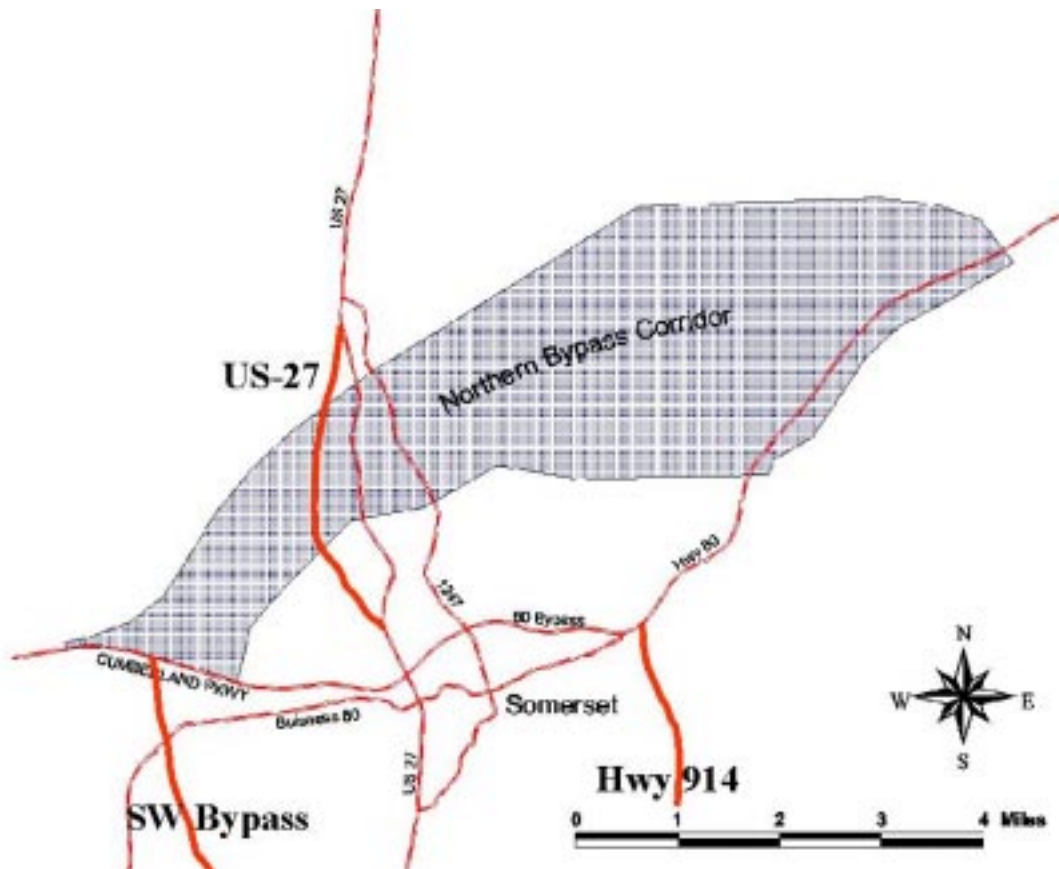


Figure 3: Somerset Northern Bypass corridor.

Natural Resources

Geography and Demographics

The Somerset area in Pulaski County, Kentucky is a region undergoing expansion and development. A large portion of the population of Pulaski County, near 40,000 live

within a few miles of the city limits. Because of its rapid growth, there is a blend of urban and rural settings. Recent trends in development have paralleled those typical of cities in the Midwest where expansion or sprawl is preferred over consolidation. This method of development is cheap and effective, but lends itself to infrastructure problems. Highways, constructed originally as bypasses, become development corridors preferred by minimum wage service jobs.

Somerset is a focal point for tourists passing through on their way to Lake Cumberland for boating, skiing, and fishing. As a passing through point, most evidence of tourism is seen by the proliferation of fast foods, and gas stations. Very few attractions for tourist exits in Somerset to keep tourists nearby. Most arrive from Ohio and points north via I-75 to Highway 461 and Highway 80. Highway 914 has been constructed to the southeast of Somerset to help divert this traffic around town.

New highways are being planned to alleviate the current traffic problems in Somerset. A southwest bypass is undergoing planning, and US 27 is being relocated and expanded. New bridges are being constructed over Lake Cumberland on US 27 and Highway 90. Little is being accomplished to address the three root causes of these traffic concerns: a dependence upon automobile transportation between nearby points, sprawl and poor infrastructure, and a lack of planning and zoning regulations.

Geology and Hydrology

The area of study in Pulaski County, Kentucky is located along the Cumberland Escarpment. This escarpment is a widespread geologic and topographic feature separating the Cumberland Plateau to the east from the Mississippian Plateau, or Highland Rim, to the west. The plateau surface is capped by near horizontal Pennsylvanian clastics underlain by Mississippian age carbonates (Greb et. al, 2001). These units have a slight regional dip to the southeast.

Regional stratigraphy at is quite simple, composed of near horizontal bedded clastics. The lowermost is the **St. Louis Limestone**, a light-grey, fine grained, thin-bedded limestone. The **Ste. Genevieve Limestone** lies above the St. Louis and is a very light-gray limestone with numerous chert nodules. Above the Ste. Genevieve lies the **Kidder Limestone**, a light-grey, variable bedding, oolitic to crystalline, fossiliferous limestone. The Ste. Genevieve and the Kidder limestones are collectively called the **Monteagle Limestone**. The **Hartsell Formation** is a thin, soft, green layer of shale that ranges from six inches to a foot thick in the region. Toward the south, the Hartsell becomes thicker and contains copious sand. Above the Hartsell Formation lie units composing the **Paragon Formation** including the **Bangor Limestone**, a dark-grey, medium-grained limestone, and the **Pennington Shale**, the upper most Mississippian age unit composed of mostly shales with interbedded lenses of silt, sand, and limestone. Numerous sandstones and shales of the Pennsylvanian age, including the **Lee Formation** of the **Breathitt Group**, create an effective caprock prohibiting downward dissolution in the surrounding ridges. Within these Pennsylvanian strata are several coal beds that have been extensively mined along the escarpment. Most of the mining has been either to the south in the Sterns and Beaver

Creek seams or to the north and east in the Halsey Rough seam. More detail on the regional lithology can be found in Greb et. al (2001).

Several surface streams cross the corridor area including Pitman Creek, a fifth order tributary of the Cumberland River. Most blue line streams have their sources at springs. These springs issue from karst aquifers at the contact between the karstic St. Louis Limestone and the low karstic Salem-Warsaw Formation. Wetlands bound these spring reaches and are an important component of the Pitman Creek floodplain.

Karst

The Cumberland Plateau of Southeast Kentucky is a prime location for karst. Over 300 feet of high-quality Mississippian limestones grace the region. The humid climate and forested landscapes provide the water and carbon dioxide necessary to formulate carbonic acid that slowly dissolves away the rock strata. Prominent joint sets, pressure release fractures, small faults, and bedding planes provide routes for water to flow through the rock. Over 500-900 feet of elevation relief drive water downhill toward base level. Finally, millions of years of erosion have given enough time for large-scale conduit systems to develop.

Groundwater zones are vaguely defined in karst aquifers of the Cumberland Plateau. Rather than vadose and phreatic, epiphreatic or “flood phreatic” is better nomenclature. In Cumberland Plateau karst, most recharge to the aquifer is allogenic via stream transport from the caprock plateau. Therefore, water is transmitted at a high rate over a considerable elevation difference. Little water remains within the conduits during times of low flow.

Most caves in the region follow a typical sinking stream, spring model. Water enters the karst aquifer via sinking streams or swallets and flows through canyons to base level master conduits. From here, the water is transmitted to the spring through partially water filled passages. The karst aquifers in the uplands generally fit a Cumberland Style karst model proposed by Sasowski (1994). In this model, master conduits are sinuous and tend to mimic the topography of large surface valleys, in part due to the influence of stress release fracturing.

The influence of topography and structure, in combination with the restricted number of inputs, forces most caves in region to follow an overall branchwork, or tree-like pattern (Palmer, 1991). Pits are common throughout the karst of Southeast Kentucky and play an important role in the development of cave systems (Brucker et. al, 1972). They form when water flows from the caprock plateau across the contact and seeps into fractures in the limestones. This water is highly unsaturated and rapidly enlarges the fractures through dissolution.

Biology

The lands of the corridor are diverse in vegetation, including mixed hardwood forests, pine uplands with scattered ridgetop wetlands, temperate river channels, and karst aquifers.

No mature stands of forest exist in the corridor due to previous logging operations. Some parcels of land have seen little disturbance by humans due to the rugged terrain. Rafinesque's big-eared bat (*Corynorhinus rafinesquii*), small-footed myotis (*Myotis subulatus leibii*) and White Fringeless Orchid (*Plantathera integrilabia*, globally rare), as well as a wealth of other terrestrial species may be present in these woodlands.

Aquatic diversity in the region is well documented, including the rare Ashy Darter (*Etheostoma cinereum*). Rare and endangered mussel species may exist in the sand and gravel riffles of Pitman Creek. Cumberland Combshell (*Epioblasma brevidens*, federally endangered), Oyster Mussel (*Epioblasma capsaeformis*, federally endangered), and Cumberland Bean (*Villosa trabalis*, federally endangered) are among those possible.

Caves in the area also host several rare and sensitive species. These have already declined in numbers due to human impact through pollution and habitat destruction. Several species of bat including the Rafinesque's Big-Eared (*Corynorhinus Rafinesquii*), and Indiana bats (*myotis sodalis*, federally endangered) are documented in the region. Species of blind crayfish, blind fish, and numerous invertebrates (carabid beetles, springtails, millipedes, pseudoscorpions, isopods, amphipods, crickets, etc.) have been documented, in several area caves (White, 2000).

Previous Study

Despite the dominant karst geology along all proposed alternatives, the original KYTC planning study in 1999 made little or no mention concerning karst. "The region around Somerset does exhibit some karst topography where sinkholes and depressions are quite common (KYTC, 1999)."

Through extensive coordinated research with several regional caving organizations, large volumes of information were collected and provided to the KYTC to include for consideration in the next planning study (Florea, 2000E). This information was included and used to help the KYTC make a decision that was much more well informed (KYTC, 2000).

In addition to data collection, research has been ongoing in the areas affected by the I-66 corridors. Studies of regional caves have been produced (Florea, 2000C and D; Florea, 2001B). Regional analysis have been preformed (Florea, 2000E and 2001A). Ongoing biological research is being conducted (White, 2000). Several miles of cave passage have been surveyed.

The present corridor is highly karstified, but little is known about the extent and morphology of the conduit systems. The Somerset-London corridor crosses Sinking Valley, the largest karst aquifer in Pulaski County, with several large mapped caves and

dye traces that extend for several miles (Florea 2001A; Ewers, 2001). Exploration via cave diving technology is currently underway in Sinking Valley to link up individual mapped caves through sumps. Over 2000 feet of passage have been mapped and potential exists for much more. The passage dimensions of this underwater conduit are amazing, up to 130 feet wide by 15 feet tall. Reconnaissance trips have been made into other watersheds potentially affected by this development. Several karst features have been documented for further investigation.

Scope and Method of Study

Work on this project occurred in tandem with the initial EIS phase of this segment of the I-66 project. Primary exploration and research took place during the winter of 2001 and spring of 2002. During the course of the project, participation was on a voluntary basis by members of regional caving communities. Lodging was at Squalid Manor, a farmhouse rented by members of the Dayton Area Speleological Society.

In the spring of 2002, acquired data was reduced and analyzed. Maps were produced for this and other reports of investigations. Versions of these results were also be presented to the KYTC to aid in the completion of their Environmental Impact Statement and to KICK 66 to aid their cause and to support their stance against the I-66 project. All data, reports and maps from this project will be submitted to the Kentucky Speleological Survey (KSS) to include in their database and archives. The KSS is a non-profit corporation dedicated to the gathering and archiving of cave and karst data in Kentucky to further the study of cave and karst resources for conservation, research and scientific exploration (Florea 2000B and 2001C).

Primary emphasis of study was in four locations: Vaught Branch, Sugar Hill, Coleman Road, and Big Spring (Figure 4). These locations were chosen because of high karst potential, and because they were likely places for interchanges or points of connectivity. Fieldwork consisted of ridgewalking, spring inventorying, landowner communications, and cave exploration and survey. All data obtained was included in a database of the corridor.

A GIS was created of the corridor using ArcView 3.2A software provided by a grant from the Environmental Systems Research Institute (ESRI). This software was used to produce maps presented in this study. Vector files used in GIS analysis include: Corridor and alternates, urban areas, suburban areas, woodlands, streams, rivers, wetlands, sinkholes, cave entrances, springs, conduit probability polygons, flowpaths, karst occurrence. Raster images used in the GIS included USGS 7.5-minute topographic and geologic maps, and Digital Orthographic Quarter Quadrangle (DOQQ) aerial photography.

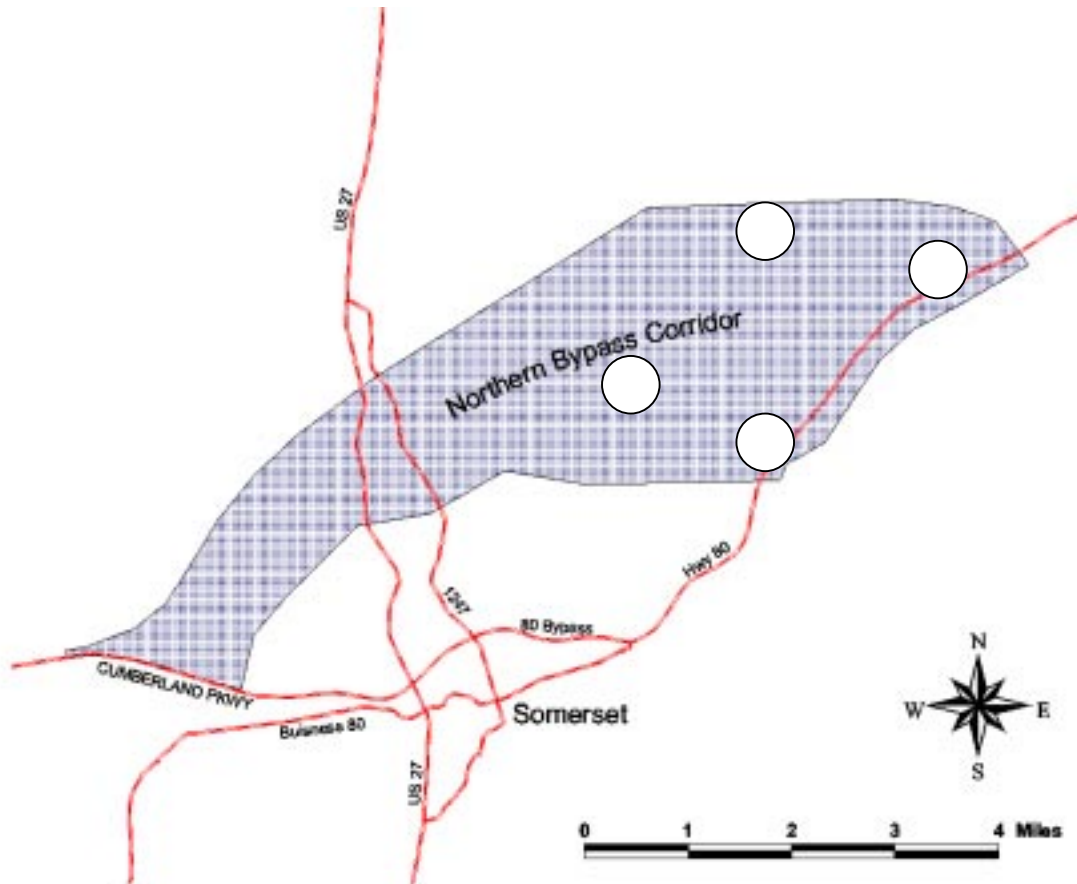


Figure 4: Areas of primary emphasis of study within the corridor (white circles). Clockwise from top: Coleman Road, Big Spring, Sugar Hill, Vaught Branch.

Outcomes

At the completion of the study, investigators had developed a full GIS of the proposed corridor. This GIS contained all information gathered during the study and additional information collected from other geographic information sources.

Forty-eight (48) karst features were documented during the study within 13 karst aquifers contained in 10 surface watersheds in, or directly adjacent to, the corridor. Of these karst features 28 were springs, none of which had been documented in the state spring inventory. Four of these spring zones have significant discharges and serve as the headwaters of major streams. See **Narrative 1** for more information.

Much of the conduit networks in these karst aquifers are inaccessible due to natural collapses or fills. Others had been modified or filled by humans. Several sites were off limits due to landowner restrictions. Groundwater flowpaths were hypothesized within these karst aquifers based upon regional karst hydrogeology. Future dye tracing is planned for the region. Zones of high conduit probability were identified between sinkpoints and springs. The size and distribution of these zones are based upon regional

experience and published works on caves of the area. See **Narrative 2** for more information.

A karst occurrence coverage was developed subdividing the corridor into 10 zones, 8 of which are karstic. See **Narrative 3** for more information about each of these zones and their distribution. The corridor consists of approximately 492.63 million square feet of land surface, 390.03 million square feet of which (79.2%) is karstic. Of this karstic land, 238.23 million square feet (48.4%) is sinkhole plain.

The I-66 SP was an environmental member of the Citizens Advisory Council (CAC) put together by the KYTC for the project. This council was charged with notifying the public of meetings and asking for public input on the direction of the corridor studies. One primary goal of the CAC was the development of core criteria for assessing impacts and the design of weighting factors to measure these potential impacts. The I-66 SP designed its own set of weighting factors for the criteria designed by the CAC. This work is presented in **Appendix 1 – 5**.

The first two criteria from appendix 1 (ecosystem and karst impacts) were applied to the GIS developed for each alternative in the corridor. Buffers were created for each alternative and areas of impact were defined (Appendix 6). All data were normalized to the total for each category in appendix 2 and the weighting formulas were applied from appendix 4 (Table1). No mature forest stands exist in the corridor, therefore their value was recorded as 0. No lakes exist in the corridor, therefore their value was also recorded as 0. A coverage of ponds in the corridor was not available at the time of the project. No data was available to perform analyses on criteria 3 and 4.

Alternative	Criteria 1												
	a					b					c		
	1	2	3	4	5	1	2	3	4	5	1	2	
80	0.79	0.22	0.30	0.15	0.00	0.00	0.00	0.28	0.59	0.20	0.25	0.18	
South	0.04	0.18	0.25	0.15	0.00	0.00	0.00	0.50	0.69	0.17	0.15	0.25	
Middle	0.03	0.22	0.24	0.16	0.00	0.00	0.00	0.35	0.69	0.14	0.14	0.25	
North	0.04	0.19	0.35	0.20	0.00	0.00	0.00	0.31	0.74	0.14	0.20	0.28	
	Criteria 2												
	a				b		c						
	1	2	3	1	2	1	2	3	4	5	6	7	8
80	0.37	0.25	0.21	0.49	0.47	0.17	0.10	0.21	0.31	0.33	0.19	0.18	0.22
South	0.17	0.20	0.00	0.27	0.21	0.26	0.24	0.14	0.19	0.14	0.07	0.07	0.02
Middle	0.02	0.00	0.04	0.21	0.20	0.26	0.40	0.13	0.13	0.10	0.07	0.07	0.02
North	0.15	0.20	0.18	0.50	0.41	0.28	0.09	0.25	0.20	0.10	0.15	0.02	0.26

Table 1: Summary of weighted category scores for Criteria 1 and 2 for bypass alternatives.

Weighting formulas were applied to each division from appendix 3. These represented the raw total score for each criteria out of a total possible of three. Scores from both

categories added together and divided by six represents the percent impact for each alternative. The higher the percent, the greater the potential impacts to ecosystems and karst (Table 2).

Criteria 1 totals						
A	b	C	total			
0.085094	0.308072	0.25	0.614303	80		
0.076862	0.382491	0.15	0.648858	South		
0.079052	0.337565	0.14	0.58964	Middle		
0.101231	0.339426	0.20	0.651077	North		
Criteria 2 totals					Subtotal Criteria 1 and 2	
A	b	C	Total		Raw (out of 6)	Percent
0.547946	0.483336	0.246499	1.428504	80	2.0428	0.34
0.47	0.243691	0.148453	1.022917	South	1.6718	0.28
0.355661	0.201695	0.138135	0.804254	Middle	1.3939	0.23
0.463987	0.462974	0.167876	1.242892	North	1.8940	0.32

Table 2: Summary of weighted division and criteria scores for Criteria 1 and 2 of bypass alternatives.

Recommendations

It is clear from the results of the study, that the Somerset Northern Bypass is being planned in a highly karstic area. We feel that in any karst area, highway construction should proceed warily and extremely conscious of the underground landscape. Many lessons have been learned by poor choices and these do not need to be repeated. In any karst region, development should proceed with an aquifer scale approach. Using this methodology, impacts to the karst aquifer may occur both upstream and downstream of the proposed development (Figure 5). Environmental studies should proceed using ecosystem style measurement criteria with all species interactions and movements considered.

The I-66 Special Project feels very strongly that this interstate corridor (of which the bypass is part) is unnecessary and the byproduct of political promises and pressure from developers. We concede that roads in this day and age are necessary, but argue that building roads for the sake of creating corridors for development and satisfying political whims is wrong. We use for example I-64 (an east-west interstate corridor between Charleston, WV and Lexington, KY). This highway is sparsely traveled in many sections. We feel that an additional east-west corridor passing between similar endpoints is an unjustified use of federal and state money. We feel therefore that the “no-build” option is the only possible means to meet environmental and social justice obligations to the region.

Of the four alternatives other than the “no-build” option presented for the bypass corridor, a redesign of State Highway 80 makes the most environmental and economic

sense. The scores in Table 2 show that 80 has the lowest ecosystem impacts, but the highest karst impacts, thus giving it the highest total impact score. If we acknowledge that these karst aquifers have been already impacted from the construction of 80 and development around Somerset, then the potential impact is much lower. By using this alternative, the highway would be placed over and already established corridor with a well-known environmental footprint. Karst along this alternative is already impacted by prior construction and continuing development. We feel this option provides the best connectivity to the Southeast Bypass (914). This option would help spur revitalization of downtown, as opposed to creating additional sprawl developed along a northerly alignment.

Of the three remaining alternates, we feel that the northern alignment is the most environmentally damaging. This alternate would impact the greatest amount of non-impacted karst landscape, including known cave systems within the highlands to the north and east of Somerset. This alternative is the furthest away from Somerset and therefore presents the highest potential for sprawl at proposed interchanges. Since this alternate is the furthest from Somerset, this also impacts the largest amount of greenspace and rural agriculture. The scores from Table 2 justify this by giving it the highest impact scores for the ecosystems criteria and the second highest for the karst criteria.

Highway Impacts to Karst Aquifers

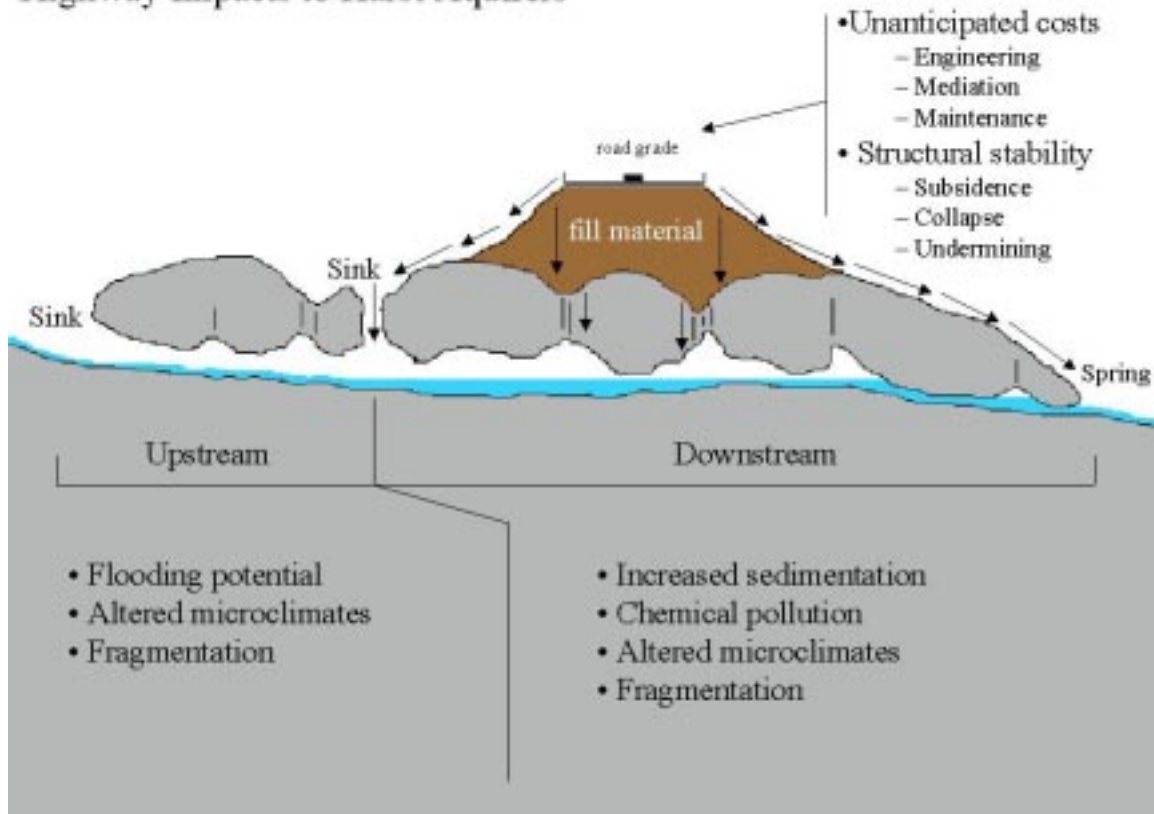


Figure 5: Potential impacts to karst aquifers as a result of highway construction. Arrows indicate direction of water flow.

Future research

Continued work will be conducted within the Northern Bypass Corridor following the Environmental Assessment by the KYTC. Dye tracing in the major aquifers is being planned in collaboration with the Kentucky Division of Water.

The remaining segments of the Somerset-London corridor are now beginning the planning phase. Preliminary work has been conducted in the karst aquifers in these segments, but considerable more is necessary. A key component of this will be a greater understanding of the morphology and dynamics of the Sinking Valley karst aquifer (the largest in Pulaski County).

Request for additional funding

This study was just a single component of a much larger project. Just as the KYTC has divided up the work, the I-66 SP has also divided the project into segments. This report fulfils the obligations of the 2001 NSS grants. Further work is required on the remaining Somerset-London segments. This work will require additional time and money for travel, and field equipment. Consideration for additional funding is requested an amounts equivalent to that already awarded.

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- Kentucky Transportation Cabinet
- Blue Grass Grotto, NSS
- Central Ohio Grotto, NSS
- Kentucky Heartwood
- Kentucky Speleological Survey
- KICK 66
- Ohio Valley Region, NSS
- Sierra Club, Cumberland Chapter
- Sloans Valley Conservation Task Force
- Somerset Pulaski County Concerned Citizens
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Appendix 1: Environmental Criteria

As provided by the constituency of the Environmental Sub-group of the Somerset Northern Bypass Citizens Advisory Council.

- 1) Minimize impacts on ecosystems.
- 2) Avoid construction over caves, cave systems, and other karst formations and minimize sedimentation of sinkholes and underground conduits.
- 3) Minimize impacts on aquatic, subterranean and terrestrial plant and animal species, including habitat loss and disruption of wildlife movements.
- 4) Minimize impacts on air, water (surface and groundwater including karst) quality and noise.

Appendix 2: Criteria subdivisions

This section presents the views of the I-66 Special Project concerning the components necessary to gauge the impacts a corridor will have upon each of the four working criteria. These subdivisions will be used for scoring and weighing of each of the proposed alternatives as presented in following sections.

Format:

N) Criteria.

- x. Division (Further clarification)[Topological expression]
 - r. Category (Further clarification)[Topological expression]
 - N. Factor (Further clarification)[Topological expression]
- 1) Minimize impacts on ecosystems
 - a. Surface [polygon coverage]
 - i. Urban
 - ii. Sub-urban
 - iii. Open land (Prairie, Pasture, Hay fields)
 - iv. Woodland, scrub
 - v. Forest
 - b. Aquatic
 - i. Lakes (>2 acres) [polygon coverage]
 - ii. Ponds (<2 acres) [polygon coverage]
 - iii. Streams [line coverage]
 - iv. Rivers [line coverage]
 - v. Wetlands [polygon coverage]
 - c. Karst [polygon coverage]
 - i. Present
 - ii. Not-present
 - 2) Avoid construction over caves, cave systems, and other karst formations and minimize sedimentation of sinkholes and underground conduits.
 - a. Surface (descriptions of features and list of potential impacts are included in the **Surface expression of karst** narrative)
 - i. Sinkholes [polygon coverage]
 - ii. Entrances (Pits, Sink-points, Collapses, Spring conduits) [point coverage]
 - iii. Springs [point coverage]
 - b. Sub-surface (descriptions of features and list of potential impacts are included in the **Sub-surface expression of karst** narrative)
 - i. Conduit probability [polygon coverage]
 - ii. Groundwater flow paths (karst) [line coverage]
 - c. Occurrence (descriptions of zones and list of potential impacts are included in the **Occurrence** narrative) [polygon coverage]
 - i. Little or no karst (Stream bottom area included)
 - ii. Residual karst

- iii. Sinkhole plain karst
 - iv. Valley karst
 - v. Hillslope karst
 - vi. Contact karst (Residual contact karst area included)
 - vii. Shaly karst
 - viii. Caprock
- 3) Minimize impacts on aquatic, subterranean and terrestrial plant and animal species, including habitat loss and disruption of wildlife movements.
- a. Troglophobic (Surface dependant lifecycle)
 - i. Species (a, b, c, etc.)
 - 1. Habitat [polygon coverage]
 - 2. Occurrence [point coverage]
 - 3. Migration paths [line coverage]
 - 4. Range requirements [polygon coverage]
 - 5. Sensitivities
 - b. Troglophilic (Sub-surface/surface bimodal lifecycle)
 - i. Species (a, b, c, etc.)
 - 1. Habitat [point coverage]
 - 2. Occurrence [polygon coverage]
 - 3. Migration paths [line coverage]
 - 4. Range requirements [polygon coverage]
 - 5. Sensitivities
 - c. Troglotic (Sub-surface dependant lifecycle)
 - i. Species (a, b, c, etc.)
 - 1. Habitat [polygon coverage]
 - 2. Occurrence [point coverage]
 - 3. Migration paths [line coverage]
 - 4. Range requirements [polygon coverage]
 - 5. Sensitivities
- 4) Minimize impacts on air, water (surface and groundwater including karst) quality and noise.
- a. Air
 - i. Particulate [polygon coverage]
 - ii. Ozone (O₃) [polygon coverage]
 - iii. Oxides (SO₂, NO, CO₂) [polygon coverage]
 - iv. Thermal [polygon coverage]
 - b. Water
 - i. Bedload [line coverage]
 - ii. Suspended sediment [line coverage]
 - iii. pH [line coverage]
 - iv. Conductivity [line coverage]
 - v. Dissolved Oxygen
 - vi. Principal anions (Cl, HCO₃, NO₃, PO₄, SO₄) [line coverage]
 - vii. Principal cations (Na, Ca, Mg) [line coverage]

- viii. Heavy metals (Fe, Mn, As, Cr, etc.) [line coverage]
 - ix. Hydrocarbons (alkanes, alkenes, ketones, etc.) [line coverage]
 - x. Complex organics (pesticides, herbicides, etc.) [line coverage]
 - xi. Pathogenic (e-coli, fecal coliform, etc.) [line coverage]
- c. Noise
- i. Decibel contour plot [polygon coverage]

Appendix 3: Methods of Measure

Definitions:

Normalization__ A method by which a set is compared as a fraction of the total.

Examples__ The normalized area of ponds impacted by a certain category in the corridor would be the area of impacted ponds divided by the total area of all ponds in the corridor. The normalized length of streams impacted by a particular category is the length of stream impacted divided by the total length of streams in the corridor. The normalized number of springs impacted by a specific category is the number of springs impacted divided by the total number of springs in the corridor.

- 1) Minimize impacts on ecosystems.
 - a. Surface: Impacts are calculated as area of each category impacted as defined by the corridor plus additional right-a-way buffer.
 - b. Aquatic: If a lake, pond, or wetland is crossed, then the entire feature is impacted. Therefore impacts for the categories are considered as the total normalized area all lakes, ponds, and wetlands crossed by corridor plus additional right-a-way buffer. If a stream or river is crossed then the section downstream of the crossing point has been impacted. Therefore, impact is defined by the normalized cumulative length of stream/river impacted downstream.
 - c. Karst: The impact in this section is merely calculated as the normalized area of the corridor plus additional right-a-way buffer underlain by each category. Further clarification is outlined in criteria 2.

- 2) Avoid construction over caves, cave systems, and other karst formations and minimize sedimentation of sinkholes and underground conduits.
 - a. Surface: Impacts for sinkholes are calculated as normalized area crossed by the corridor plus additional right-a-way buffer. Impacts for entrance and spring categories are calculated as normalized number of features crossed by the corridor plus additional right-a-way buffer.
 - b. Sub-surface: If a conduit is crossed, then the entire feature is impacted. Therefore the impact is defined by the total area of all high conduit probability zones crossed by the corridor plus additional right-a-way buffer. If a groundwater flow path is crossed, then the entire feature is impacted. Therefore, impact is the normalized cumulative length of groundwater flow paths crossed by the corridor plus additional right-a-way buffer.
 - c. Occurrence: Impacts are calculated as normalized area of each category impacted as defined by the corridor plus additional right-a-way buffer. Further specific potential impacts are described in the occurrence narrative.

- 3) Minimize impacts on aquatic, subterranean and terrestrial plant and animal species, including habitat loss and disruption of wildlife movements.

- a. Troglophobic: Calculations are completed for each species. Impacts to habitats are calculated as normalized area crossed by the corridor plus additional right-a-way buffer. Occurrence impacts are calculated as normalized number of occurrence sites crossed by the corridor plus additional right-a-way buffer. Impacts to migration paths are defined by the normalized number crossed by the corridor plus additional right-a-way buffer. The minimal range requirements for each site occurrence will be calculated and if the corridor plus additional right-a-way buffer decreases any of these areas, it will be considered impacted. Therefore, the impact is defined by the normalized number of these minimal ranges that are reduced. Further species-specific sensitivities will be incorporated into the consideration.
 - b. Troglphilic: Same as above.
 - c. Troglobitic: Same as above.
- 4) Minimize impacts on air, water (surface and groundwater including karst) quality and noise.
- a. Air: Impacts are defined by specified changes from baseline (pre-highway) levels of each category. Substantial baseline data will be gathered to use in accepted models to pattern resultant data due to additional input from changes within the corridor. Impact will be measured by the total normalized area with categories elevated a specified amount above baseline.
 - b. Water: Impacts are defined by specified changes from baseline (pre-highway) levels of each category. Substantial baseline data will be gathered from each stream and spring crossed upstream by the corridor. This baseline data will be used in accepted models to pattern resultant data due to additional input from changes within the corridor. Impact will be measured by the total normalized length of streams/rivers/groundwater flow paths with categories elevated a specified amount above baseline.
 - c. Noise: Impacts are defined by specified changes from baseline (pre-highway) decibel levels. Substantial baseline data will be gathered to use in accepted models to pattern resultant data due to additional input from changes within the corridor. Impact will be measured by the total normalized area with categories elevated a specified amount above baseline.

Appendix 4: Scoring and Weighting

Definitions:

$\sum_0^N i$ __ A mathematical method in which a grouping is summed. The values of variable i are added for the case when $i = 0$ through the case where $i = N$.

Examples __ Three species (i) have values of $a=0.2$, $b=0.3$, $c=0.5$. The result of the calculation $\sum_0^N i$ would be $(a + b + c)$ or 1.0.

Format:

N) Criteria $\langle X = \text{Total possible points summed from weighted divisions} \rangle$

x. Division $\langle \text{Total possible points from weighted categories. Sum of category weights} = 1 \rangle$

r. Categories $\langle \text{Weighting factor. Sum of factor weights} = 1 \rangle$

N. Factors $\langle \text{Weighting factor} \rangle$

1) Minimize impacts on ecosystems.

$\langle X = 1.25a + 1.25b + 0.5c \rangle$

b. Surface $\langle a = 1 \rangle$

ii. Urban $\langle 0 \rangle$

iii. Sub-urban $\langle 0.05 \rangle$

iv. Open land $\langle 0.15 \rangle$

v. Woodland, scrub $\langle 0.2 \rangle$

vi. Forest $\langle 0.6 \rangle$

b. Aquatic $\langle b = 1 \rangle$

vii. Lakes (>2 acres) $\langle 0.1 \rangle$

viii. Ponds (<2 acres) $\langle 0.05 \rangle$

ix. Streams $\langle 0.25 \rangle$

x. Rivers $\langle 0.3 \rangle$

xi. Wetlands $\langle 0.3 \rangle$

c. Karst $\langle c = 1 \rangle$

xii. Present $\langle 1 \rangle$

xiii. Not-present $\langle 0 \rangle$

Justification __ The criteria weighting formula $X = 1.25a + 1.25b + 0.5c$ reflects the fact that surface and aquatic ecosystems are judged to be equally important, whereas karst ecosystems are given less weighting due to further consideration in other criteria. In surface ecosystems in the south central Kentucky, forests are the ancestral and most ecologically diverse ecosystem and are therefore given the most weighting. Urban areas are principally impacted and ecologically bottle-necked, therefore they are given a zero weighting. In aquatic ecosystems, wetlands have the highest potential for bio-diversity, followed by rivers and streams respectively. Lakes and ponds are in many man-made and not as essential to the regional bio-diversity. They are therefore given a lower weighting factor.

- 2) Avoid construction over caves, cave systems, and other karst formations and minimize sedimentation of sinkholes and underground conduits.

$$\langle X = 1.5a + b + 0.5c \rangle$$

- a. Surface $\langle a = 1 \rangle$
 - i. Sinkholes $\langle 0.3 \rangle$
 - ii. Entrances $\langle 0.35 \rangle$
 - iii. Springs $\langle 0.35 \rangle$
- b. Sub-surface $\langle b = 1 \rangle$
 - i. Conduit probability $\langle 0.6 \rangle$
 - ii. Groundwater flow paths $\langle 0.4 \rangle$
- c. Occurrence $\langle c = 1 \rangle$
 - i. Little or no karst $\langle 0 \rangle$ (Stream bottom area included)
 - ii. Residual karst $\langle 0.1 \rangle$
 - iii. Sinkhole plain karst $\langle 0.2 \rangle$
 - iv. Valley karst $\langle 0.325 \rangle$
 - v. Hillslope karst $\langle 0.15 \rangle$
 - vi. Contact karst $\langle 0.15 \rangle$ (Residual contact karst area included)
 - vii. Shaly karst $\langle 0.05 \rangle$
 - viii. Caprock $\langle 0.025 \rangle$

Justification__ The criteria weighting formula $X = 1.5a + b + 0.5c$ reflects a progression from the real to the abstract. Surface karst features are easily documented; whereas sub-surface karst features may be mapped, but are often detected by inference methods (geophysics, dye tracing, statistics). Karst occurrence is an abstract method of determining which areas are prone to various karst morphologies; therefore it is given lesser consideration. Surface karst features are point locations of input or output to the karst aquifer, therefore they are given equal weighting. In sub-surface karst conduit probability is more site specific than groundwater flowpaths, therefore it is given more consideration. In karst occurrence, the weighting factors are determined by the potential size and density of karst conduits as defined in the **karst occurrence narrative**.

- 3) Minimize impacts on aquatic, subterranean and terrestrial plant and animal species, including habitat loss and disruption of wildlife movements.

$$\langle X = 0.5a + b + 1.5c \rangle$$

- a. Troglomorphic $\langle a = \sum_0^N i$ where category $i =$ sum of weighted factors 1-5 divided by N where $N =$ number of species in division \rangle
 - i. Species $\langle i = 1 \rangle$
 1. Habitat $\langle 0.3 \rangle$
 2. Occurrence $\langle 0.2 \rangle$
 3. Migration paths $\langle 0.2 \rangle$
 4. Range requirements $\langle 0.3 \rangle$
 5. Sensitivities
- b. Troglophilic $\langle b = \sum_0^N i$ where category $i =$ sum of weighted factors 1-5 divided by N where $N =$ number of species in division \rangle

- i. Species $\langle i = 1 \rangle$
 - 1. Habitat $\langle 0.3 \rangle$
 - 2. Occurrence $\langle 0.3 \rangle$
 - 3. Migration paths $\langle 0.1 \rangle$
 - 4. Range requirements $\langle 0.3 \rangle$
 - 5. Sensitivities
- c. Troglobitic $\langle c = \sum_0^N i$ where category $i =$ sum of weighted factors 1-5 divided by N where $N =$ number of species in division \rangle
 - i. Species $\langle i = 1 \rangle$
 - 1. Habitat $\langle 0.4 \rangle$
 - 2. Occurrence $\langle 0.4 \rangle$
 - 3. Migration paths $\langle 0.1 \rangle$
 - 4. Range requirements $\langle 0.1 \rangle$
 - 5. Sensitivities

Justification__ The criteria weighting formula $X = 0.5a + b + 1.5c$ reflects the energy requirements and sensitivity of each biologic classification. Troglaphobs, because of their surface lifestyle live in a higher energy environment, therefore they have higher adaptation potential and can move to adjacent habitats more readily than either Troglaphiles or Troglaphites. This makes them less sensitive to environmental change. Troglaphites, due to low energy and restricted movement lifestyle imposed by their sub-surface environment, have much lower adaptation potential and lower ability to move to adjacent habitat. This makes them more susceptible to environmental change. In Troglaphobs, habitat and range are considered equally, whereas actual occurrence and migration are considered equal but somewhat less important. In Troglaphiles, habitat, occurrence, and range are considered equally, while migration is considered much less because many of these species live year round within their home range residing in the constant cavern environment during the cold winter months. In Troglaphites, habitat and actual occurrence are considered essential since little is known about the true distribution of many of these species. Migration and range are considered much less since these species life in a constant environment and therefore may move throughout their habitat at any time, thus making their range their entire habitat.

- 4) Minimize impacts on air, water (surface and groundwater including karst) quality and noise. $\langle X = 0.75a + b + 0.25c \rangle$
 - a. Air $\langle a = 1 \rangle$
 - i. Particulate $\langle 0.2 \rangle$
 - ii. Ozone $\langle 0.3 \rangle$
 - iii. Oxides $\langle 0.4 \rangle$
 - iv. Thermal $\langle 0.1 \rangle$
 - b. Water $\langle b = 1 \rangle$
 - i. Bedload $\langle 0.1 \rangle$
 - ii. Suspended sediment $\langle 0.1 \rangle$
 - iii. pH $\langle 0.05 \rangle$
 - iv. Conductivity $\langle 0.05 \rangle$

- v. Dissolved Oxygen <0.125>
- vi. Principal anions <0.075>
- vii. Principal cations <0.05>
- viii. Heavy metals <0.2>
- ix. Hydrocarbons <0.2>
- x. Complex organics <0.025>
- xi. Pathogenic <0.025>
- c. Noise <c = 1>
 - i. Decibel contour plot <1>

Justification__ The criteria weighting formula $X = 0.75a + b + 0.25c$ reflects the potential lasting impact to the corridor. Both air and noise impacts dissipate rapidly with distance and time, whereas water impacts may persist for greater durations. In air, oxides are considered to be the chemicals with the greatest potential for impacts as they promote the development of acidic byproducts, and global warming. Ozone ranked second due to its smog development potential. Particulates from highways are less than for other types of developments, but are important to those with allergies or asthma. In water, principal impacts are heavily weighted to runoff products (heavy metals, and hydrocarbons) and increased sedimentation (bedload, suspended sediment). Dissolved oxygen, due to its use as a measure of water ecosystem health is also considered very important. Other factors are ranked according to decreasing impact due to highway construction. Noise levels depend essentially upon changes from baseline decibel levels in the corridor.

Scoring summary__ Presented in tabular format.

	Upgrade 80	South Alternate	North Alternate	Crossover Alt.
Criteria 1	a=1.25, b=1.25, c=0.5, Total = 3	a=1.25, b=1.25, c=0.5, Total = 3	a=1.25, b=1.25, c=0.5, Total = 3	A=1.25, b=1.25, c=0.5, Total = 3
Criteria 2	a=1.5, b=1, c=0.5, Total = 3	a=1.5, b=1, c=0.5, Total = 3	a=1.5, b=1, c=0.5, Total = 3	A=1.5, b=1, c=0.5, Total = 3
Criteria 3	a=0.5, b=1, c=1.5, Total = 3	a=0.5, b=1, c=1.5, Total = 3	a=0.5, b=1, c=1.5, Total = 3	A=0.5, b=1, c=1.5, Total = 3
Criteria 4	a=0.75, b=1, c=0.25, Total = 3	a=0.75, b=1, c=0.25, Total = 3	a=0.75, b=1, c=0.25, Total = 3	A=0.75, b=1, c=0.25, Total = 3
Total	12	12	12	12

Interpretation__ A lower score indicates a lesser environmental impact based upon the considered variables and the information included in the scoring process.

Appendix 5: Example

Corridor A has two alternates I and II.

The total area of the corridor is 10,000 acres, and consists of the following ecosystems:

Surface:

Urban (1000ac), Sub-urban (2000ac), Open land (2000ac), Woodland, scrub (2000ac), Forest (3000ac)

Aquatic:

Lakes (>2 acres) (200ac), Ponds (<2 acres) (300ac), Streams (35 miles), Rivers (2 miles), Wetlands (400ac)

Karst:

Present (3000ac), Not-present (7000ac)

Alternate I crosses the following ecosystems:

Surface:

Urban (200ac), Sub-urban (300ac), Open land (50ac), Woodland, scrub (100), Forest (50)

Aquatic:

Lakes (>2 acres)(0ac), Ponds (<2 acres)(10ac), Streams (3miles), Rivers (0 miles), Wetlands (20ac)

Karst:

Present (300ac), Not-present (400ac)

Alternate II crosses the following ecosystems:

Surface:

Urban (100ac), Sub-urban (200ac), Open land (100ac), Woodland, scrub (150), Forest (150)

Aquatic:

Lakes (>2 acres)(0ac), Ponds (<2 acres)(20ac), Streams (5miles), Rivers (1 miles), Wetlands (100ac)

Karst:

Present (400ac), Not-present (300ac)

Normalized values for each Alternative are as follows:

Alternate I:

Surface:

Urban (0.2), Sub-urban (0.15), Open land (0.025), Woodland, scrub (0.075), Forest (0.017)

Aquatic:

Lakes (>2 acres)(0), Ponds (<2 acres)(0.033), Streams (0.086), Rivers (0), Wetlands (0.05)

Karst:

Present (0.1), Not-present (0.057)

Alternate II:

Surface:

Urban (0.1), Sub-urban (0.1), Open land (0.05), Woodland, scrub (0.05), Forest (0.05)

Aquatic:

Lakes (>2 acres)(0ac), Ponds (<2 acres)(0.067), Streams (0.14), Rivers (0.5), Wetlands (0.25)

Karst:

Present (0.13), Not-present (0.043)

After using the weighing factors the following values result:

Alternate I:

Surface:

Urban (0), Sub-urban (0.0075), Open land (0.00375), Woodland, scrub (0.015), Forest (0.0102)

Aquatic:

Lakes (>2 acres)(0), Ponds (<2 acres)(0.00165), Streams (0.0215), Rivers (0), Wetlands (0.02)

Karst:

Present (0.1), Not-present (0)

Alternate II:

Surface:

Urban (0), Sub-urban (0.005), Open land (0.0075), Woodland, scrub (0.01), Forest (0.03)

Aquatic:

Lakes (>2 acres)(0), Ponds (<2 acres)(0.00335), Streams (0.035), Rivers (0.15), Wetlands (0.1)

Karst:

Present (0.13), Not-present (0)

Summing these values by division:

Alternate I:

Surface = 0.03645

Aquatic = 0.04315

Karst = 0.1

Alternate I:

Surface = 0.0525

Aquatic = 0.3185

Karst = 0.13

After applying the criteria weighting formula of $X = 1.25(\text{surface}) + 1.25(\text{aquatic}) + 0.5(\text{karst})$ we find the following results:

Alternate I: $X = 0.0456 + 0.0539 + 0.05 = 0.149$

Alternate II: $X = 0.0656 + 0.3981 + 0.065 = 0.5287$

From these results for the ecosystem criteria, it is clear that Alternate I has a much lower score, therefore a lesser environmental impact in this criteria for Corridor A.

Similar normalization, summation, and computation processes are completed for each criterion for the values obtained during the study.

Appendix 6: Corridor and alternates data

- 1) Minimize impacts on ecosystems
 - a. Surface [Total area: 492.63 M ft²]
 - i. Urban [Total: 44.23 M ft², 80: 34.87 M ft², S: 1.68 M ft², M: 1.29 M ft², N: 1.68 M ft²]
 - ii. Sub-urban [Total: 107.23 M ft², 80: 23.09 M ft², S: 18.85 M ft², M: 23.62 M ft², N: 20.03 M ft²]
 - iii. Open land (Prairie, Pasture, Hay fields) [Total: 225.33 M ft², 80: 66.83 M ft², S: 56.71 M ft², M: 54.41 M ft², N: 79.09 M ft²]
 - iv. Woodland, scrub [Total: 130.97 M ft², 80: 19.54 M ft², S: 19.86 M ft², M: 20.84 M ft², N: 25.69 M ft²]
 - v. Forest [0]
 - d. Aquatic
 - i. Lakes (>2 acres) [0]
 - ii. Ponds (<2 acres) [no coverage available]
 - iii. Streams [Total: 163,302 ft, 80: 46,290 ft, S: 81,302 ft, M: 57,823 ft, N: 50,681 ft]
 - iv. Rivers [Total: 169,528 ft, 80: 99,886 ft, S: 117,257 ft, M: 117,257 ft, N: 124,883 ft]
 - v. Wetlands [Total: 3.31 M ft², 80: 0.67 M ft², S: 0.56 M ft², M: 0.46 M ft², N: 0.45 M ft²]
 - e. Karst
 - i. Present [Total: 390.03 M ft², 80: 95.83 M ft², S: 58.24 M ft², M: 53.72 M ft², N: 78.21 M ft²]
 - ii. Not-present [Total: 96.46 M ft², 80: 17.00 M ft², S: 23.70 M ft², M: 24.05 M ft², N: 27.30 M ft²]
- 2) Avoid construction over caves, cave systems, and other karst formations and minimize sedimentation of sinkholes and underground conduits.
 - a. Surface
 - i. Sinkholes [Total: 21.27 M ft², 80: 7.83 M ft², S: 3.54 M ft², M: 4.01 M ft², N: 3.12 M ft²]
 - ii. Entrances [Total: 20, 80: 5, S: 4, M: 0, N: 4]
 - iii. Springs [Total: 28, 80: 6, S: 0, M: 1, N: 5]
 - b. Sub-surface
 - i. Conduit probability [Total: 32.71 M ft², 80: 16.09 M ft², S: 8.75 M ft², M: 6.71 M ft², N: 16.36 M ft²]
 - ii. Groundwater flow paths (karst) [Total: 0.12 M ft, 80: 0.05 M ft, S: 0.02 M ft, M: 0.02 M ft, N: 0.04 M ft]
 - c. Occurrence
 - i. Little or no karst (Stream bottom area included) [Total: 91.53 M ft², 80: 15.93 M ft², S: 23.60 M ft², M: 23.95 M ft², N: 26.04 M ft²]
 - ii. Residual karst [Total: 18.34 M ft², 80: 1.80 M ft², S: 4.39 M ft², M: 7.29 M ft², N: 1.72 M ft²]

- iii. Sinkhole plain karst [Total: 238.23 M ft², 80: 50.30 M ft², S: 33.73 M ft², M: 31.93 M ft², N: 59.52 M ft²]
- iv. Valley karst [Total: 29.61 M ft², 80: 9.18 M ft², S: 5.54 M ft², M: 3.86 M ft², N: 5.81 M ft²]
- v. Hillslope karst [Total: 96.02 M ft², 80: 31.89 M ft², S: 13.61 M ft², M: 9.67 M ft², N: 9.89 M ft²]
- vi. Contact karst (Residual contact karst area included) [Total: 7.85 M ft², 80: 1.53 M ft², S: 0.52 M ft², M: 0.52 M ft², N: 1.14 M ft²]
- vii. Shaly karst [Total: 6.14 M ft², 80: 1.13 M ft², S: 0.46 M ft², M: 0.46 M ft², N: 1.27 M ft²]
- viii. Caprock [Total: 4.93 M ft², 80: 1.08 M ft², S: 0.09 M ft², M: 0.09 M ft², N: 1.26 M ft²]