APPENDIX Y
FINAL KARST REPORT (REDACTED)

TECHNICAL REPORT APPENDICES

I-69 EVANSVILLE TO INDIANAPOLIS

Tier 2 Studies

Final Karst Feature and Groundwater Flow Investigation Report

Section 5, SR 37 south of Bloomington to SR 39

April 2013

CONFIDENTIAL MATERIAL ENCLOSED

Prepared for

Federal Highway Administration and
Indiana Department of Transportation

INTERSTATE 69

EXECUTIVE SUMMARY

This study was conducted to support the I-69 Tier 2, Section 5 Environmental Impact Statement (EIS) and address Items 1 through 4 of the 1993 Memorandum of Understanding (MOU) as entered into by the Indiana Department of Transportation (INDOT), the Indiana Department of Natural Resources (IDNR), the Indiana Department of Environmental Management (IDEM), and the U.S. Fish and Wildlife Service (USFWS) to delineate guidelines for construction of transportation projects in karst regions of the state. A copy of the 1993 MOU is presented in **Appendix A**. The study was prepared by Ozark Underground Laboratory (OUL) of Protem, Missouri and Philip Moss, PG of Waterloo, Illinois with additional data provided by Michael Baker, Jr. Inc. (Baker) of Indianapolis, Indiana, and Lewis and Associates, LLC of Borden, Indiana.

This study focused on characterizing karst features and related groundwater flowpaths relevant to Section 5, and identifying caves, springs, sinkholes, and other karst features that could be impacted by construction and use of the proposed interstate highway.

This Final Report is an update to and replacement of the July 2006 I-69 Tier 2 Studies Section 5 Draft Karst Feature and Groundwater Flow Investigation Report (2006 Draft Karst Report) and October 2012 Draft Karst Feature and Groundwater Flow Investigation Report (2012 Draft Karst Report). Updates to the 2006 and 2012 Karst Reports include:

- The 2006 Karst Report was provided to the Karst MOU signatory agencies and the U.S. Environmental Protection Agency (USEPA) for review and comment on September 22, 2006, and comments received were incorporated into an updated 2012 Karst Report that was included as Appendix Y – *Draft Karst Report* of the October 2012, Section 5: Bloomington to Martinsville Tier 2 Draft Environmental Impact Statement (DEIS).

- Additional field reconnaissance and dye tracing was conducted to determine the approximate recharge area for two overlapping cave systems (known as Cave and Cave) in the vicinity of the Section 5 corridor, based on agreement between INDOT, FHWA, and USEPA.

- Updated land cover, land use, population growth, planned development, and setting as part of the Section 5 DEIS evaluations, subsequent to the 2006 Draft Karst Report.

- Monroe County geographic information system (GIS) files such as the 2010 aerial photography and 2-foot contours were reviewed to identify potential additional or adjust 2006 Section 5 karst features. The Monroe County data included topography from Light Detection And Ranging (LiDAR) that can measure beneath leaf canopy, increase reproducibility between surveys, and provide increased precision over standard aerial photography based mapping. Karst feature additions and adjustments from this data were incorporated following field check confirmations.

- Geologic mapping and descriptions were updated with publications by the Indiana Geological Survey such as the Monroe and Bloomington quadrangle bedrock mapping

(Thompson 2007) and Bedrock Geologic Map of Monroe County, Indiana (Hasenmueller 2008).

- Data from the I-69 Tier 2 Studies Section 4 Survey of Karst Features Report (2010) and Addendum No. 1 (2011) was reviewed and incorporated where appropriate.

- The 2012 Karst Report was provided to the Karst MOU signatory agencies and the USEPA for review and comment on October 26, 2012, and comments received were incorporated into this 2013 Final Karst Report to be included in the subsequent Final Environmental Impact Statement /Record of Decision.

These updates, additional field data, and evaluations resulted in increases in the number of identified karst features and flowpaths included in the 2012 Draft Karst Report and this 2013 Final Karst Report.

Section 5 Karst Setting

- The Section 5 EIS Study Corridor is a 2,000-foot wide area centered on State Road 37 (SR 37) from southwest of Bloomington in Monroe County, Indiana to just south of Martinsville in Morgan County, Indiana. The karst study area included both the I-69 Tier 1 and Tier 2 karst data that was determined to be relevant to Section 5, and extended from the southern terminus of Section 5 north along SR 37 to roughly Chambers Pike. The study area for karst included the 2,000-foot corridor and appropriate areas outside the corridor based on geologic information and mapping for the area. Relevant karst is the portion of karst within the 21-mile length of Section 5 Corridor and associated areas outside of the corridor that has been demonstrated to have corridor derived water passing through it; or, is linked by logical inference based on the best available geographic, geologic, and hydrologic data, including the Tier 2 investigation. It does not necessarily include areas outside the corridor that contribute water to the corridor. Three distinctive karst areas were recognized based on bedrock substrate, sinkhole characteristics, and drainage features.

- Karst Areas:

    - Bloomington Karst extends from approximately Clear Creek along SR 37, south of the Section 5 corridor, northward along SR 37 to approximately Arlington Road. It is primarily developed in the lower St. Louis Limestone above the contact with the underlying Salem Limestone.

    - Bloomington North Karst extends from about Arlington Road north to the approximately Kinser Pike on the southern slope of the Beanblossom Creek Valley and is developed in the Ramp Creek and Harrodsburg Limestones.

    - Simpson Chapel Karst extends from approximately Wayport Road on the northern slope of the Beanblossom Creek Valley and continues north to just south of Chambers Pike and is developed in the Ramp Creek and Harrodsburg Limestones.

- Land Use: Land use within the Bloomington area has been affected by both historic and recent development. Approximately 53.8% of land use within the relevant karst area - as mapped inside the karst study corridor and including associated areas outside the corridor - is currently developed, while 46.2% remains undeveloped (e.g., 35.9% upland/wetland habitat, 9.9% agricultural, and, 0.4% water), based on field reviews and updates of a GIS land use layer provided by the Monroe County Planning Department. Local planners anticipate development of an additional 21% of the karst area by 2035, based on only those specific areas of development identified by the local planning staffs (City of Bloomington and Monroe County tax increment financing [TIF] Districts); this development is anticipated to occur independent of the proposed Section 5 project.

- The Section 5 physiography consists of limestone plateaus dissected by many deeply entrenched stream systems, areas of karst development, and generally rugged topography with relatively flat uplands. Both the Bloomington and Bloomington North Karst are located within the Mitchell Plateau while the Simpson Chapel Karst is located in the Norman Upland portion of the of the Southern Hills and Lowlands Physiographic Region (Gray, 2000).

- The non-karst portion of the Section 5 corridor extends from Chambers Pike to the northern terminus with Section 5 just south of Martinsville. Historical data and field checks for karst features were conducted in this area without the identification of any karst features.

- The bedrock in Section 5 is typically shallow with thin overlying soils, except in some of the larger stream valleys. The study area is within the Illinois Basin structure, with the bedrock gently dipping to the southwest and west, younger formations to the south and west, and older formations to the north and east.

- Monroe County mining has been limited mainly to limestone and includes dimension stone (Salem Limestone), high calcium-rich limestone, crushed stone for construction, agricultural lime and livestock feed. A natural gas storage dome is located under SR 37 in the Simpson Chapel Karst area.

- Groundwater supplies are limited in the karst portion of Section 5 with the majority of the local water supply coming from man-made surface water reservoirs (such as Lake Monroe Reservoir). Well production is typically low, generally ranging from less than 10 gallons per hour (gph) to 10 gallons per minute (gpm).

- The main hydrogeologic unit in the Bloomington Karst is the St. Louis Limestone, while the Ramp Creek and Harrodsburg Limestones act as a single hydrogeologic formation in the Bloomington North and Simpson Chapel Karst areas.

Methodology

The karst investigations reported herein are consistent with the requirements for such investigations from the 1993 MOU, Items 1 through 4, and included:

- Public and private research sources.

  The Project Team compiled existing information on local karst features from a number of sources. These sources included: the Indiana Geological Survey, Indiana Cave Survey, and karst experts knowledgeable about the area. Specific karst studies and mapping for the Section 4 corridor examined and field checked for this study included I-69 Tier 1 and Tier 2 public comments, including cave maps and other karst feature data and mapping, as well as all previous I-69 related karst study data. Additional resources included high resolution aerial photography, planimetric and topographic mapping in the corridor as well as USGS topographic maps.

- Karst feature field check (sinkholes, springs, karst flowpaths, caves, and others).

  Field checks were conducted to verify and map previously recorded karst features along the length of the Section 5 corridor. In addition, a field reconnaissance was conducted to determine the presence of, and map previously unrecorded karst features within the 11.5-mile length of karst crossed by the Section 5 corridor and appropriate areas outside of the corridor to identify potentially related karst features that may be associated with the corridor via karst groundwater flowpaths or surface run-off. Cave entrance research and field surveys were conducted concurrently by Indiana Geological Survey personnel for cave accessibility and potential bat habitat research.

- Dye tracing/drainage patterns.

  Drainage areas, drainage patterns, and land use specifically related to the karst features were determined and mapped. Additionally, dye tracing tests were conducted on selected karst features within the karst study area in order to determine and map the subsurface flow from recharge features (caves, sinkholes, swallets, and sinking streams) to discharge features (springs and gaining streams) and establish groundwater flow patterns within the study area.

- Annual pollutant load estimates.

  The pollutant loads were calculated for each karst feature within the right-of-way (ROW) but outside (or with portions outside) the construction limits of the I-69 preferred alternative. Pollutant loads were calculated for pre- and post-construction conditions. The calculation procedures are based upon models developed to predict pollutant loads without field measurements presented in a Federal Highway Administration (FHWA) training course.

- Biological survey of caves.

  Accessible caves and related springs with hydraulic or physical connection with the alternatives being advanced were surveyed for biological fauna. During the study, coordination was maintained among the Project Team to review and exchange new information discovered by other project related studies. These included ongoing studies regarding caves as potential Indiana bat habitat, as well as karst studies and other field evaluations being conducted for the I-69 corridor within adjacent sections and within Section 5. This included cross referencing all previous mapping collected with the field investigations and the IGS cave entrance surveys conducted in support of the Project Team's Section 7 Consultation with the USFWS for this project.

- Agency coordination and mitigation measures.

  The Project Team has conducted ongoing coordination with the Karst MOU signatory agencies and USEPA. The karst survey methodology and updates on survey results were discussed with resource agencies during the karst studies. Any future agency concerns or questions relating to the findings or recommendations presented in this report, or any other karst related issues will be addressed through ongoing coordination relative to addressing the Karst MOU.

Results

The Section 5 karst investigation produced the following results (2006 data and 2012 updates[1]), specific to conditions identified in the Section 5 study area:

- Three distinct areas of karst (Bloomington Karst, Bloomington North Karst, and Simpson Chapel Karst) were identified for a total of approximately 11.5 linear miles of karst along SR 37.
- 446 sinkholes, five losing/sinking stream basins, and 21 filled or appreciably modified sinkholes were documented within or adjacent to the 2,000-foot karst study corridor.
- The drainage area and land use corresponding to each feature was determined.
- Field investigations revealed 169 springs, 143 had not been previously reported; 131 were individually determined to be relevant to Section 5.
- Fourteen karst flowpaths were shown to cross under at least one lane of SR 37.
- One previously unreported cave was found.
- Three karst windows relevant to the Section 5 Corridor were identified and documented.

[1] Updates to the 2006 Karst Report include: MOU signatory agencies and USEPA 2006 Karst Report comments, additional field reconnaissance and dye tracing for and Cave recharge area(s), data from the Tier 2 Studies Section 4 Survey of Karst Features Report (2010) and Addendum No. 1 (2011), and post 2006 Section 5 DEIS updates (such as land cover, land use, population growth, planned development, setting, bedrock, Monroe County 2010 aerial photography and 2-foot contours) (see page i). These updates, additional field data, and evaluations resulted in increases in the number of identified karst features and flowpaths included in the 2012 Karst Report and this 2013 Karst Report.

- The karst relevant to the Section 5 EIS study area was determined. The relevant karst is the portion of karst within the I-69 Section 5 corridor, and associated areas outside of the corridor, that has been demonstrated to have corridor-derived water passing through it, or is linked by logical inference based on the best available geographic, geologic, and hydrologic data, including the Tier 2 investigation. It does not include areas outside the corridor that contribute water to the corridor.

- Dye Tracing:

  - A total of 205 dye trace sampling stations were established, and over 3,800 samples were analyzed. Forty-one dye introductions were made that demonstrated 59 karst groundwater flowpaths, and 20 relevant dye traces from other sources were included for a total of 83 groundwater flowpaths evaluated in this report.

  - Groundwater flow was characterized in the Section 5 relevant karst areas; flow velocities ranged from 10 feet per day (0.42 feet per hour) to over 48,000 feet per day (2,000 feet per hour), and flowpaths ranged from 243 feet to over one mile in length. The flowpath data presented in this report are diagrammatic; the lines representing the flowpaths are *not* meant to represent the actual location or distribution of the conduits.

  - Fourteen groundwater flowpaths illustrated transfer across sub-watershed boundaries.

- The Spring recharge area was revised and the recharge area for the Cave system was delineated.

- No federally listed species were identified in Section 5 caves; however, two state listed threatened/endangered species were identified from cave biological surveys at and caves.

- Four areas of special concern for Section 5 were identified: Lemon Lane and Bennett's Dump Superfund sites, SR 45/2nd Street Interchange, and Cave.

- Annual Pollutant Load Estimates for pre- and post-construction were completed for the preferred alternative.

- Potential measures to offset impacts to karst include the 1993 MOU preferences for avoidance, alternative drainage, mitigation/treatment, and operations and maintenance.

Summary and Conclusions

The report study results are specific to conditions identified within the Section 5 study area. Land use within the Bloomington area has been affected by both historic and recent development. Approximately 53.8% of land use within the relevant karst area is currently developed, while 46.2% remains undeveloped (e.g., 35.9% upland/wetland habitat, 9.9% agricultural, and 0.4% water), based on field reviews and updates of a GIS land use layer provided by the Monroe County Planning Department. Local planners anticipate development of an additional 21% of the karst area by 2035, based on only those specific areas of development identified by the local planning staffs (City of Bloomington and Monroe County tax increment financing TIF Districts).

Although some particular karst features may be avoided, since Section 5 is essentially the upgrade of the existing four-lane divided highway SR 37 to a new four- to six-lane divided interstate I-69, karst geology cannot be avoided within the Section 5 corridor. Therefore, the focus of alignment and design should be on minimizing impacts via alternative drainage, mitigation/treatment, and operations and maintenance.

Only three of the dye traces demonstrated discrete recharge from insurgence features without surface expression and where no buried sinks have been identified. Some rapid movement of water into karst groundwater systems could also occur in areas where the landscape has been modified, or where sinkholes have been filled or altered.

In general terms, existing SR 37 is situated near both the topographic drainage and groundwater divides; thus, the general trend is for water to flow away from SR 37 through relatively short pathways (from hundreds of feet to about one mile) to springs on either side of the roadway. While karst flowpaths cross under SR 37, it was generally the headwaters of these systems that passed under SR 37.

The Section 5 karst groundwater systems tend to be small and relatively isolated; therefore, a single spill along the roadway, even if uncontained, would generally impact a single, relatively small groundwater system. The only significant cave system linked hydrologically to the Section 5 corridor is the Cave System that receives water from a relatively small part of the corridor. South of the Cave recharge area to the Section 5 southern terminus with Section 4, the flowpaths are longer and shared recharge areas become more common.

About 80% of the springs in Section 5 were found at or near geologic contacts. Spring discharges varied by at least two orders of magnitude. During the study, the mean daily discharge at the was 257 gpm, but ranged from 18 to 3,916 gpm; two orders of magnitude variation in discharge appears to be representative of springs in Section 5. Hydrologic characteristics by area are as follows:

- *Bloomington Karst*: Recharge to springs generally includes the grade of SR 37, and springs were being impacted from road use, maintenance, and development along SR 37. The Bloomington Karst has longer and slower groundwater flowpaths than the other karst areas, with velocities ranging from hundreds to thousands of feet per day. Water tended to go from the surface to a spring in one to two days.

- *Bloomington North Karst*: About half of the insurgence features and some of the springs in the corridor were at higher elevations than the SR 37 grade. Sinkholes and springs were smaller on average than those found in the other two karst areas and reflected the thin nature of the karst that terminated at the edge of the ridge tops.

- *Simpson Chapel Karst:* Most insurgence features were above the SR 37 grade; therefore, many springs were not receiving road runoff. SR 37 was cut into the limestone through most of this area and essentially has been redirecting runoff to other, lower elevation karst features or off the karst entirely.

The flowpaths in the Bloomington North Karst and Simpson Chapel Karst tended to be relatively short and faster than those in the Bloomington Karst, with velocities over 48,000 feet per day (9.1 miles/day) and typical travel times ranging from minutes to a single day for water to runoff the surface and discharge at the springs.

Areas of Special Concern

- The <u>Lemon Lane Landfill Superfund site</u> is approximately 1,000 feet from existing SR 37 pavement and adjacent to the eastside of the Section 5 corridor. Drainage from the site is treated at the facility. Peak flows have historically exceeded the treatment and storage capacities and have the highest concentrations of contaminants. Parties involved in the ongoing treatment operations for the site requested that planning and design of I-69 find ways to prevent additional water above existing SR 37 levels from entering the recharge area along I-69. The revised recharge area shows that minimal amounts of SR 37 are located in the recharge area.

- The <u>Bennett's Dump Superfund site</u> is located approximately 1,000 feet from existing SR 37 pavement and adjacent to the Section 5 corridor in the northwest corner of the interchange of SR 37 and SR 46. While it is not hydrologically connected to SR 37 or Section 5, parties involved in ongoing remedial design and mitigation measures at the site have requested that the planning and design of I-69 prevent additional highway drainage above existing SR 37 levels from entering the northwest quadrant of the SR 46 and SR 37 (I-69) interchange .

- The <u>intersection of SR 45/2nd Street and SR 37</u> is an area of special concern due to the presence of a reported former cave and numerous sinkholes that were filled as part of SR 37 construction and other local development. Many of these sinkholes have had roadway and development runoff culverts installed in or nearby and since have reopened, resulting in the potential to destabilize the roadbed and adjacent lands.

- Cave and nearby Cave are areas of special concern due to the biological significance of diverse troglobitic (obligate cave dwelling) fauna, and state-listed threatened and endangered species.
  - No federally listed species were identified.
  - The cave's biological community appeared to be in relatively good health at the time of the field investigation despite historical and current aquatic impacts from

SR 37. However, there is ongoing development in the recharge area unrelated to this I-69.

- The mapped cave passage extends under SR 37, and the recharge area of the cave extends across SR 37 and the Section 5 corridor. Since the cave passages are at relatively shallow depths, there also may be a problem of bedrock competency over the cave passage.

- While Cave (Cave B) has been linked by dye tracing to the existing SR 37, the Cave recharge area is over 800 feet south of the Section 5 corridor and is more accurately termed a karst window with limited access to a water filled cave passage.

General Environmental Concerns

- Karst systems are capable of transporting sediment and contaminants quickly into caves and to springs that may be relatively far from their source.

- Interbasin transfer of water is common in karst and in Section 5. If a spill containment failure were to occur, the location for an effective response might not be obvious.

- Redirection of runoff may be perceived as aggravating existing flooding downstream of SR 37.

General Engineering Concerns

- Collapse of filled sinkholes can threaten adjacent or overlying structures. These failures can result without surface expression prior to the collapse in areas where loess-derived soils overlie karst. There are sinkholes that have been filled or otherwise modified by people or natural processes throughout Section 5.

- Impervious surfaces, such as roads, can change patterns of runoff and infiltration. Concentrated or redirected water can destabilize sinkholes (with or without current surface expression) as they equilibrate with the new water input conditions. Unlined water detention or retention structures can increase the hydraulic head (i.e., saturate) in the supporting earthen materials and possibly lead to failure of such structures.

- Impervious surfaces, such as roads, can sever recharge features from the groundwater system. This can result in decreased spring discharges and alteration of habitat for any biological communities within the karst system

- Potential alteration of existing groundwater flow/quality and bedrock competency concerns are associated with groundwater flow within the Section 5 karst. The flowpaths demonstrated in this investigation are naturally occurring conduits in bedrock and are not meant to represent the actual location or distribution of the conduits. While these conduits are large enough to have turbulent flow, they are unlikely to have spans of more than a few feet, based on the relatively small groundwater systems of which they are components.

- There are hydrologically active drainage systems (such as culverts) to sinkholes and from springs under SR 37. Roadways can be eroded by passing over a spring with drainage and structural fill that is not properly engineered.

- Numerous instances of reopening sinkholes and soil piping were observed that had formed under concrete-lined ditches along SR 37. Many of these instances had been caused by wheel ruts from vehicles accidentally leaving the roadway, or by tractor tire ruts resulting from mowing the right-of-way when the ground was soft.

Recommendations

Best Management Practices

- Construction within the karst areas should be planned with effective erosion and sediment control measures. Procedures to reduce the impacts to karst will be implemented in accordance with applicable but not karst specific INDOT's *Standard Specifications* and other BMPs identified in the Section 5 FEIS/ROD, Final Karst Feature and Groundwater Flow Investigations Report, and the 1993 Karst MOU between the INDOT, IDNR, IDEM and the USFWS. Stormwater runoff protection measures will be installed at all karst features in the right-of-way at the initiation of construction and maintained until all stormwater drainage has been diverted away from the feature, or final permanent stormwater treatment measures are in place. Erosion control measures will be put in place as a first step in construction and maintained throughout construction. Temporary erosion control devices such as silt fencing, check dams, sediment basins, inlet protection, sodding and other appropriate BMPs will be used to minimize sediment and debris in tributaries within the project area. Timely re-vegetation after soil disturbance will be implemented and monitored. Any riprap used will be of a large diameter in order to allow space for habitat for aquatic species after placement. Prior to construction, heavy equipment parking and turning areas will be located outside the construction limits but within the right-of-way to minimize soil erosion. Soil bioengineering techniques for bank stabilization will be considered where appropriate.

- A Low salt/No spray zone for Section 5 will be established along the I-69 mainline and interchanges that extends from the Section 4 interchange to approximately 200 feet north of Chambers Pike. Further coordination with the Karst MOU agencies will occur during the design phase of the project regarding low-salt/no spray zones. Road maintenance should follow plan and posted low salt/no spray areas to prevent contaminants from entering karst systems. Mowing should be restricted to appropriate times, and repairing damaged vegetation and drainages should be required.

- It is anticipated that the Blasting Operations Specifications utilized during the Section 4 construction in karst areas will be utilized for the Section 5 activities. The specification was developed to protect karst and limestone resources.

- Because this project will require a Rule 5 Permit issued by IDEM, INDOT has make a mitigation commitment requiring the designer to abide by Rule 5, Item B1 of the Erosion Control Plan.

- There are locations along existing SR 37 where runoff water is directed to karst features (i.e. sinkholes). While the specific karst features requiring a Class V injection well are not known at the EIS stage of the Section 5 project, they are likely to be related to sinkholes if they are modified to receive Section 5 stormwater drainage as part of final design, and mitigation commitments. Most of the Class V well permits anticipated within Section 5 would be authorized by rule because there will be measures in place to prevent contamination as part of sinkhole mitigation under the Karst MOU.

- The staging of equipment and materials should occur outside of karst areas or at a minimum on impervious material with drainage controlled. Same-season re-vegetation of disturbed land during construction, repairs and maintenance should be used, when feasible.

- Some of the channels that cross the corridor may be under-drained in karst areas and appear to transmit water infrequently. Culverts and bridge openings must be sized to accommodate the required rainfall events as defined by the INDOT Drainage Design Manual. Unique backwater conditions created by sinking streams and other insurgence features will require further evaluation during final design to assure that adequate detention storage volume is available.

- The roadway project needs to convey surface water runoff with as much natural treatment for water quality as is feasible. This treatment is best accomplished by dispersing the runoff through at least 100 feet of vegetation filter swale or passing it through an engineered treatment system (sediment basin) before it reaches the invert elevation for a sinkhole.

- Where possible, the road prism (structures, base, and pavement) should not restrict flow into a sinkhole or other insurgence feature. Use of filters, buffers, containment structures, reinforced soil, void grouting, compaction grouting, concrete caps, reinforced bridging slabs (land bridges), deep foundations, etc. are potentially effective mitigation measures, but will not be determined until final design.

- Utilization of lined ditches designed to prevent erosion to the outfall discharge points are recommended within the karst areas. Water flow within the roadway ditches will need an analysis for lining requirements. Culvert outlets should be designed to discharge water to at grade terrain. This design will reduce erosion scour and sediment transport into the karst and other environments. Design of ditches and culverts should be based on INDOT's Drainage Design Manual and be appropriate to the specific karst feature.

- The drainage design for I-69 should provide for proper energy dissipation devices at the culvert and storm sewer system outlet locations to prevent erosion to existing channels. Energy dissipater devices include such items as scour holes, riprap linings and stilling basins. Design of energy dissipater devices and ditch linings should be based on INDOT's Drainage Design Manual.

- The roadway drainage system should be incorporated into the Operations and Maintenance Plan for inspection and repair to prevent disturbance of karst drainage patterns and undercutting observed along SR 37. The karst areas will require monitoring to identify roadway slopes and ditches and repair of off-road disturbances. Mowing should be restricted to periods of dry weather/firm soil conditions to avoid rutting from vehicles. Reseeding/drainage repair should be required following accidents that disrupt vegetative cover. Installation of guardrails could be utilized to prevent vehicles from leaving paved roadway surfaces. Roadway maintenance should include posted low salt/no spray areas to prevent chemicals from entering the karst system.

- Excavation into bedrock below the current SR 37 roadway grade, which could potentially expose cave passages and other karst conduits, should be avoided where possible. Roadway grading constructed with embankment fill is preferable to cuts in bedrock.

- Implementation of hazardous waste traps will conducted by INDOT (or their designated contractors) to protect karst features against hazardous materials spills per Step 7 of the Karst MOU. Spill response equipment should be readily available during construction and subsequent use of the road. Due to the high flow rate within karst systems, response times are critical for prevention/reduction of impacts to karst ecologic communities, groundwater resources, and surface water. The first priority must be to prevent contaminants from entering the karst groundwater system at the location of the release, or at the location of overflow where treatment/mitigation measures are present. Once contaminants have entered the karst system, use of preventive or mitigation measures at appropriate resurgence points for both surface water and sediment are time critical due to the high water velocities (depending on the particular conduit system), precipitation, and other flow conditions.

- In the event that a sinkhole disturbance cannot be avoided, the sinkhole should be capped. A special design of the roadway subgrade and pavement structure should be considered in these areas to avoid the hazards of sinkhole instability and reallocated water runoff. The special design may include special subgrade treatment and/or increased structural design of roadway pavement and anchoring of pavement slabs crossing the sinkhole area(s) to underlining bedrock.

- In the event that disturbance of a spring cannot be avoided, a spring box and culvert should be constructed to discharge the flow to an appropriately designed outfall to prevent undercutting of the pavement and/or subgrade. A special design of the roadway subgrade and pavement structure should address potential undermining of the roadbed due to excess pressure head discharging from the spring or potential water leakage from the spring boxes and culverts over time. The special design may include special subgrade treatment and/or increased structural design of roadway pavement and an anchoring of pavement slabs crossing the spring areas to underlining bedrock.

- In the event that disturbance to a karst flowpath cannot be avoided, the top of the karst flowpath should be capped, but still allow for natural flow within the flowpath. A special design of the roadway subgrade and pavement structure should be considered in these areas to ensure that the natural conduit does not collapse and threaten the integrity of the roadbed. The special design could include special subgrade treatment and/or increased structural design of roadway pavement and an anchoring of pavement slabs crossing the karst conduits to underlining bedrock.

- If caves are exposed during construction, karst experts should be consulted to determine their project significance. Drainage and treatment alternatives will be considered concurrently so as to not impede drainage in recharge areas and having potentially harmful impacts to cave biota.

- Per the 1993 MOU, in the event that Federal and/or State listed species are encountered during construction that were not previously reported/evaluated, construction should be halted in that area until an evaluation can be performed.

Areas of Special Concern

- INDOT has made a mitigation commitment to prevent drainage from increasing above the existing SR 37 levels extending along the eastern side of SR 37 that is within the Lane Landfill recharge area to address USEPA and IDEM concerns regarding changes in existing groundwater flow. Coordination with USEPA and IDEM has occurred throughout the Section 5 study and will continue through the design phase. Blasting is not anticipated and will not be allowed adjacent to the site to prevent damage to the monitoring system. Design plans for construction in this area will be provided to USEPA and IDEM for review with a requested two-week turnaround time for comment.

- INDOT has made a mitigation commitment to prevent drainage from increasing above the existing SR 37 levels extending along the northwest quadrant of the SR 37/SR 46 interchange area to address USEPA and IDEM concerns regarding changes in existing drainage. Blasting is not anticipated and will not be allowed adjacent to the site to prevent damage to the monitoring system. Design plans for construction in this area will be provided to USEPA and IDEM for review with a requested two week turnaround time for comment.

- Design and Construction of the SR 45/2nd Street interchange will require karst feature engineering to mitigate impacts on buried sinkholes.

- Impacts to the Simpson Chapel Karst area may be reduced where SR 37 generally follows the karst groundwater divide and numerous nearby valley heads drain below the karst bedrock.

- The Cave and Cave recharge areas are of special concern due to the presence of State listed threatened and endangered species. Additional measures may be required or installation of alternative drainage at Cave and Cave. In order to maintain the existing base flow levels in the system, surface treatment of runoff water may be required. Treatment options include:

    - Engineered wetland sediment and contaminant reduction systems.

    - Linear peat sand filters and/or vegetated swales along the roadway or at the terminus of lined storm water control structures.

    - Sinkhole sediment and contaminant traps.

- Runoff and storm water detention/retention systems, treatment, and infiltration galleries.
- Control of "first flush" volumes with designed overflow into natural drainage system.

TABLE OF CONTENTS

TABLES

FIGURES

APPENDICES

GLOSSARY OF KEY TERMS
(As defined for this report)

General Terms

Corridor	A 2,000-foot wide area centered on existing SR 37. The I-69 Tier 2 Section 5 Corridor extends from just south of Bloomington in Monroe County, Indiana, to the southern edge of Martinsville in Morgan County, Indiana.
Section 4	The study area south of Section 5, where the proposed I-69 corridor departs from SR 37 and heads to the southwest on new alignment to US 231.
Section 6	The study area to the north of Section 5. This study area extends along SR 37 from south of Martinsville north to Indianapolis, Indiana.

Biological Terms

Commensal	A species that benefits from the association with a host species, which is substantially unaffected.
Troglobite	An obligate cave dweller.
Stygobite	An aqueous obligate subterranean dweller.

Karst Terms

Bioclastic	Derived from shell fragments or similar organic remains.
Bloomington Karst	The portion of relevant karst from just south of Bloomington to the SR 37/SR 46 interchange.
Bloomington North Karst	The portion of relevant karst from the SR 37/SR 46 interchange to the south side of the Beanblossom Creek valley.
Calcarenite	Sedimentary rock formed of calcareous particles ranging in diameter from 0.002- to 0.08-inch that have been deposited mechanically and consist of fossil materials, pebbles and granules of carbonate rock, and oolites (spherical nodules with concentric structure).
Calcareous	Descriptive – of, containing, or like calcium carbonate; chalky.

Cave	A naturally occurring void in earth materials that can be entered by a human for an appreciable distance.
Cave System	An assemblage of karst features that may contain multiple caves, water inlets, and springs that are all related. For management purposes, the cave system is generally the category of interest since fauna and water movement in a cave system are rarely restricted in areas where humans cannot enter.
Drainage Area	Drainage area (as informally used in the MOU) is used in this report synonymously with recharge area (i.e., "the land surface that contributes at least some water under some flow conditions to a particular karst feature.")
Dye Trace	A dye trace for this project consisted of the following actions: 1) the introduction of dye into an insurgence feature with either existing water flow and/or with potable water; 2) travel of the dye through the karst groundwater system; and, 3) detection of the dye in the elutant from an activated carbon sampler or from a grab sample of water.
Epikarst	The weathered upper surface of karst consisting of a network of fissures and cavities that can store and redistribute water into the main karst conduits.
Insurgence Feature	A surface feature that directs surface water into the karst groundwater system (i.e. sinkholes, swallet, losing and sinking streams).
Interference peak	A peak from a fluorescent dye or other compound, detected at sampling stations that is not associated with dye introduced as part of the Section 5 studies.
Karst	A three-dimensional landscape underlain by soluble rocks and having appreciable groundwater flow through solutionally enlarged openings (internal drainage) in the rock.
Karst Conduit	A tubular opening created by dissolution of the bedrock, which carries, can carry, or has carried water flow.
Karst Groundwater System	Includes water in both the saturated and unsaturated zones, the conduits through which the water flows and the springs at which groundwater is discharged.

Karst Valley	A valley that is like an ordinary valley on the upper slopes, but has sinkholes in the bottom draining it. The sinkholes are often aligned along the valley bottom.
Karst Window	For this study, a karst window is a sinkhole that provided limited access to a submerged karst conduit.
Loess	Calcareous silt associated with windblown dust of Pleistocene age.
Losing Stream	A surface stream from which a portion of the flow enters into a subterranean groundwater system.
Micritic	Descriptive – a fine grained material formed from carbonate mud with very small crystals (less than 4 micrometer (μm) diameter).
Pellatal	Descriptive - of, relating to, or resembling a pellet.
Recharge Area	The land surface that contributes at least some water under some flow conditions to a particular karst feature.
Resurgence Feature	Discrete opening(s) in the bedrock where water is discharged to the earth's surface (i.e. springs, seeps, and gaining streams).
Relevant Karst	The relevant karst is the portion of karst within the I-69 Section 5 corridor and associated areas outside of the corridor; that has been demonstrated to have corridor-derived water passing through it; or, is linked by logical inference based on the best available geographic, geologic, and hydrologic data, including the Tier 2 investigation. It does not include areas outside the corridor that contribute water to the corridor.
Sampling Station	Sampling stations for this project generally consisted of two anchored carbon packets in water flow at a spring, stream or pool. GPS locations were obtained and the station marked with identifying flagging. Grab samples of water would generally be collected at the sampling stations.
Simpson Chapel Karst	The portion of relevant karst from the north side of the Beanblossom Creek valley to just south of Chambers Pike in Monroe County, Indiana.
Sinking Stream	A stream that leaves the surface and enters into a subterranean groundwater system.

Sinkhole	A natural, closed depression in the surface of the earth which recharges groundwater (internal drainage). All land draining into a sinkhole is part of the sinkhole. The boundaries of sinkholes with surface expression in Section 5 were mapped based on 2-foot contour data which were derived from 2010 LiDAR data along with field checking of sink points (swallets).
Spring	A discrete point for water discharging from a karst groundwater system. Springs have discernable channels that may carry perennial flow or only flow as storm response.
Swallet	The location where a stream sinks underground, often associated with a stream flowing into a sinkhole or cave entrance.
Karst Flowpath	Groundwater flow through a karst conduit within a karst groundwater system.

Land Use Terms

The following land use terms used for relevance to karst within Section 5 and are based upon a consolidation of the land use terms used in other Tier 2 documents.

Agricultural	Includes row crops, pasture, orchards, groves, nurseries, specialty crops, and agricultural operations.
Nonresidential/Industrial	Includes commercial and industrial developments.
Planned Development	Ranges from parcels with approved site plans to areas targeted by local comprehensive plans to absorb future residential or commercial growth. Specific sites of planned development were identified during the coordination process with planners from the City of Bloomington and Monroe County and placed in the project GIS database. This development is anticipated to occur independent of the proposed project.
Public and Institutional	Public use and institutional land uses include schools, libraries, soccer fields, parks, hospitals, fire and police stations, churches, cemeteries, communally owned civic facilities (Masonic lodges, rotary clubs, etc.) or other public facilities.
Mines/Quarries	Includes areas of extractive mining activities (but not reclaimed mine areas).

Residential	Includes single-family, multi-family, and mobile home parks.
Water	Includes surface hydrologic features such as streams, rivers, lakes, reservoirs, and ponds.
Transportation, Utilities, and Communications	Includes infrastructure such as roads, road right-of-ways, railroads, utility right-of-ways, and power substations.
Upland/Wetland Habitat	Includes wetland and upland habitat ranging from forested to herbaceous cover.

1.0 INTRODUCTION

1.1 Purpose of the Study

This study was conducted to support the I-69 Tier 2, Section 5 Environmental Impact Statement (EIS) and address Items 1 through 4 of the 1993 Karst Memorandum of Understanding (MOU) as entered into by the Indiana Department of Transportation (INDOT), the Indiana Department of Natural Resources (IDNR), the Indiana Department of Environmental Management (IDEM), and the U.S. Fish and Wildlife Service (USFWS) (INDOT et al., 1993) to delineate guidelines for construction of transportation projects in karst regions of the state. A copy of the 1993 MOU is presented in **Appendix A**.

This report documents reviews of karst information relevant to the Section 5 study corridor, field checks of previously recorded karst features, field investigations to identify previously unrecorded karst features, dye tracing of karst features, and recommendations for karst feature avoidance, impact minimization, and mitigation of unavoidable impacts. The study was prepared by Ozark Underground Laboratory, Inc. (OUL), Protem, Missouri and Philip Moss, PG of Waterloo, Illinois with additional data provided by Michael Baker, Jr. Inc. (Baker), Indianapolis, Indiana.

This 2013 Final Karst Report is an update to and replacement of the July 2006 I-69 Tier 2 Studies Section 5 Draft Karst Feature and Groundwater Flow Investigation Report (2006 Draft Karst Report) and 2012 Draft Karst Feature and Groundwater Flow Investigation Report (2012 Draft Karst Report). Updates to the 2006 and 2012 Karst Reports include:

- The 2006 Karst Report was provided to the Karst MOU signatory agencies and the U.S. Environmental Protection Agency (USEPA) for review and comment on September 22, 2006, and comments received were incorporated into an updated October 2012 Karst Report that was included as Appendix Y – *Karst Report* of the October 2012, Section 5: Bloomington to Martinsville Tier 2 Draft Environmental Impact Statement (DEIS).

- Additional field reconnaissance and dye tracing was conducted to determine the approximate recharge area for two overlapping cave systems (known as Cave and Cave) in the vicinity of the Section 5 corridor, based on agreement between INDOT, FHWA, and USEPA.

- Updated land cover, land use, population growth, planned development, and setting as part of the Section 5 DEIS evaluations, subsequent to the 2006 Draft Karst Report.

- Monroe County geographic information system (GIS) files such as the 2010 aerial photography and 2-foot contours were reviewed to identify potential additional or adjust 2006 Section 5 karst features. The Monroe County data included topography from Light Detection And Ranging (LiDAR) that can measure beneath leaf canopy, increase reproducibility between surveys, and provide increased precision over standard aerial photography based mapping. Karst feature additions and adjustments from this data were incorporated following field check confirmations.

- Geologic mapping and descriptions were updated with publications by the Indiana Geological Survey such as the Monroe and Bloomington quadrangle bedrock mapping (Thompson 2007) and Bedrock Geologic Map of Monroe County, Indiana (Hasenmueller 2008).

  Data from the I-69 Tier 2 Studies Section 4 Survey of Karst Features Report (2010) and Addendum No. 1 (2011) was reviewed and incorporated where appropriate.

- The 2012 Karst Report was provided to the Karst MOU signatory agencies and the USEPA for review and comment on October 26, 2012, and comments received were incorporated into this 2013 Final Karst Report to be included in the subsequent Final Environmental Impact Statement /Record of Decision.

These updates, additional field data, and evaluations resulted in increases in the number of identified karst features and flowpaths included in the Draft 2012 Karst Report and this 2013 Final Karst Report.

Items 1 through 4 of the 1993 MOU are quoted as follows:

1. *INDOT in cooperation with the IDNR, IDEM and USFWS shall determine the location of sinkholes, caves, underground streams and other related karst features and their relationship prior to proposed alterations or construction in karst regions of the State. A consultant with expertise in karst geology/hydrology may assist in the identification and characterization of the karst features. The choice of the consultant retained by INDOT will be subject to the review of IDNR, USFWS and IDEM.*

2. *Tasks to accomplish this work will include:*

    - *Research available from public and private sources for information relative to karst features.*

The Project Team compiled existing information on local karst features from a number of sources. These sources included: the Indiana Geological Survey, Indiana Cave Survey, and karst experts knowledgeable about the area. Specific karst studies and mapping for the Section 4 corridor examined and field checked for this study included I-69 Tier I and Tier II public comments, including cave maps and other karst feature data and mapping, as well as all previous I-69 related karst study data. Additional resources included high resolution aerial photography, planimetric and topographic mapping in the corridor as well as USGS topographic maps.

During the study, coordination was maintained among the Project Team to review and exchange new information discovered by other project-related studies. These included ongoing studies regarding caves as potential Indiana bat habitat, as well as karst studies and other field evaluations being conducted for the I-69 corridor within adjacent sections and within Section 5. This included cross referencing all previous mapping collected with the field investigations and the IGS cave entrance surveys conducted in support of the Project Team’s Section 7 Consultation with the USFWS for this project. Accessible caves related springs with hydraulic or physical connection with the alternatives being advanced were surveyed for biological fauna.

- *Field check karst and cave features that appear from the first task and identify any additional karst features.*

Field checks were conducted to verify and map previously recorded karst features along the length of the Section 5 corridor. In addition, a field reconnaissance was conducted to determine the presence of, and map previously unrecorded karst features within the 11.5-mile length of karst crossed by the Section 5 corridor and appropriate areas outside of the corridor to identify potentially related karst features that may be associated with the corridor via karst groundwater flowpaths or surface run-off.

- *Prepare a draft report with photographs and maps, drainage areas, and land use of that drainage area for each sinkhole or karst feature. Dye-tracing and/or other geotechnical information to determine subsurface flow of water in the project area and surface water drainage patterns of the area. Calculations of estimates of annual pollutant loads from the highway and drainage within the right-of-way will be made, including prior to, during and post construction estimates. The design of the treatment of the karst features will take into consideration treatments necessary to meet the standards of the monitoring and maintenance plan.*

Drainage areas, drainage patterns, and land use specifically related to the karst features were determined and mapped. Additionally, dye tracing tests were conducted on selected karst features within the karst study area in order to determine and map the subsurface flow from recharge features (caves, sinkholes, swallets, and sinking streams) to discharge features (springs and gaining streams) and establish groundwater flow patterns within the study area.

- *That report will be used as a tool to assist in determining the proposed highway alignment. The intent of INDOT is to avoid karst areas and use alternate drainage where possible.*

3. *IDNR, IDEM and USFWS will be requested to review and comment on the findings at the early coordination phase of project development.*

The Project Team has conducted ongoing coordination with the agencies signatory to the Karst MOU (signatory agencies). The karst survey methodology and updates on survey results were discussed with resource agencies during the karst studies. Any future agency concerns or questions relating to the findings or recommendations presented in this report, or any other karst related issues will be addressed through ongoing coordination relative to addressing the Karst MOU. In addition, the 2012 Draft Karst Report was distributed to the signatory agencies, USEPA, and other appropriate review agencies for their review and comments as part of the DEIS. A Resource Agency webcast/conference call was conducted to review Section 5's response to agency comments on the DEIS and its appendices (such as the 2012 Karst Report).

4. *INDOT, using the input for IDNR, IDEM, and USFWS, will begin to formulate appropriate measures to offset unavoidable impacts to the karst features. It is understood by all parties that some of the methods proposed at this time will be generic and could be applied throughout the length of the corridor. Other methods may be specific to a particular cave or karst feature. Some of the approaches may require additional investigations to determine their necessity and/or their feasibility. A revised draft report will be prepared by INDOT'S consultant and provided to the IDNR, IDEM and the USFWS as part of the design review process.*

The Project Team will determine the appropriate measures to offset unavoidable impacts to karst features through coordination with the signatory agencies and any other appropriate review agencies. Any future agency concerns or questions relating to the findings or recommendations presented in this report, or any other karst related issues will be addressed by the Project Team through ongoing coordination relative to addressing the Karst MOU. Agencies were provided the opportunity to review and comment on the 2012 Draft Section 5 Karst Report. These comments were evaluated and, where applicable, have been included as part of this Final Karst Report.

1.2 The Study Area

The Section 5 Corridor (**Figure 1**) is a 2,000-foot wide area centered on State Route 37 (SR 37) from southwest of Bloomington in Monroe County, Indiana approximately 21 miles north to just south of the SR 39 interchange in Martinsville, located in Morgan County, Indiana. The karst study area encompasses the I-69 Tier 1 and Tier 2 karst feature data, and extends from Clear Creek, south of Section 5, northward along SR 37 to roughly Chambers Pike. Relevant karst is the portion of karst within the 21-mile length of Section 5 Corridor and associated areas outside of the Corridor that has been demonstrated to have Corridor derived water passing through it; or, is linked by logical inference based on the best available geographic, geologic, and hydrologic data, including the Tier 2 investigation (2006 data and 2012 updates[2]). It does not necessarily include areas outside the Corridor that contribute water to the Corridor. The relevant karst is shown on **Figure 2** and was divided into three areas as follows:

- Bloomington Karst – begins at the southern terminus at approximately That Road (just north of the Section 4 SR 37 interchange) and continues north to approximately Arlington Road (old SR 46) within the Mitchell Plateau Physiographic Region.

- Bloomington North Karst - the relevant karst begins at approximately Arlington Road and continues to Kinser Pike at the southern slope of the Beanblossom Creek Valley within the Mitchell Plateau Physiographic Region.

[2] Updates to the 2006 Karst Report include: MOU signatory agencies and USEPA 2006 Karst Report comments;, additional field reconnaissance and dye tracing for and Cave recharge area(s),); data from the Tier 2 Studies Section 4 Survey of Karst Features Report (2010) and Addendum No. 1 (2011),); and, post 2006 Section 5 DEIS updates (such as land cover, land use, population growth, planned development, setting, bedrock, Monroe County 2010 aerial photography and 2-foot contours) (see page i). These updates, additional field data, and evaluations resulted in increases in the number of identified karst features and flowpaths included in this 2012 Karst Report and this 2013 Karst Report.

- Simpson Chapel Karst - the relevant karst begins approximately Wayport Road at the northern slope of the Beanblossom Creek Valley and continues north to just south of Chambers Pike within the Norman Upland physiography.

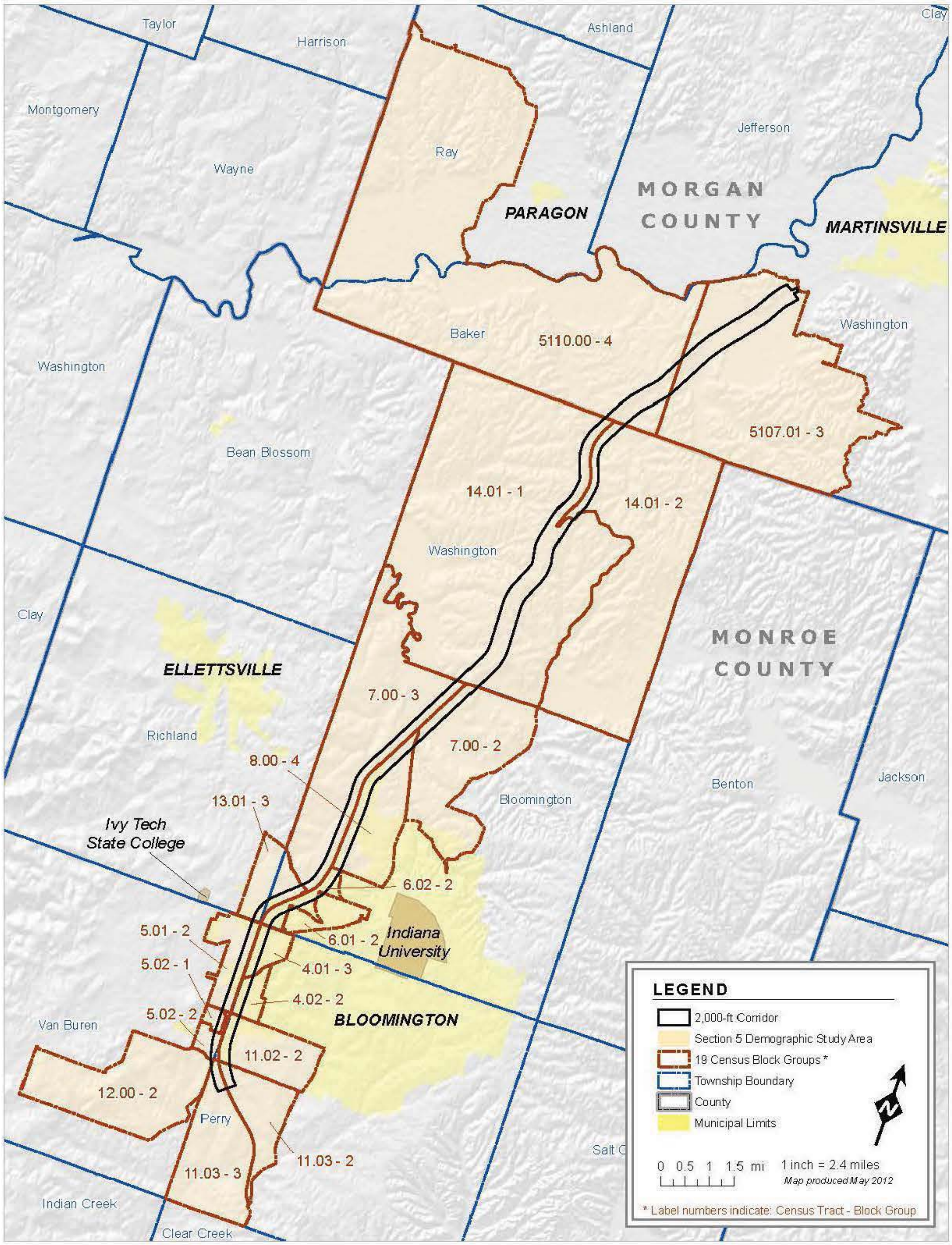

Figure 1 Section 5 Location Map

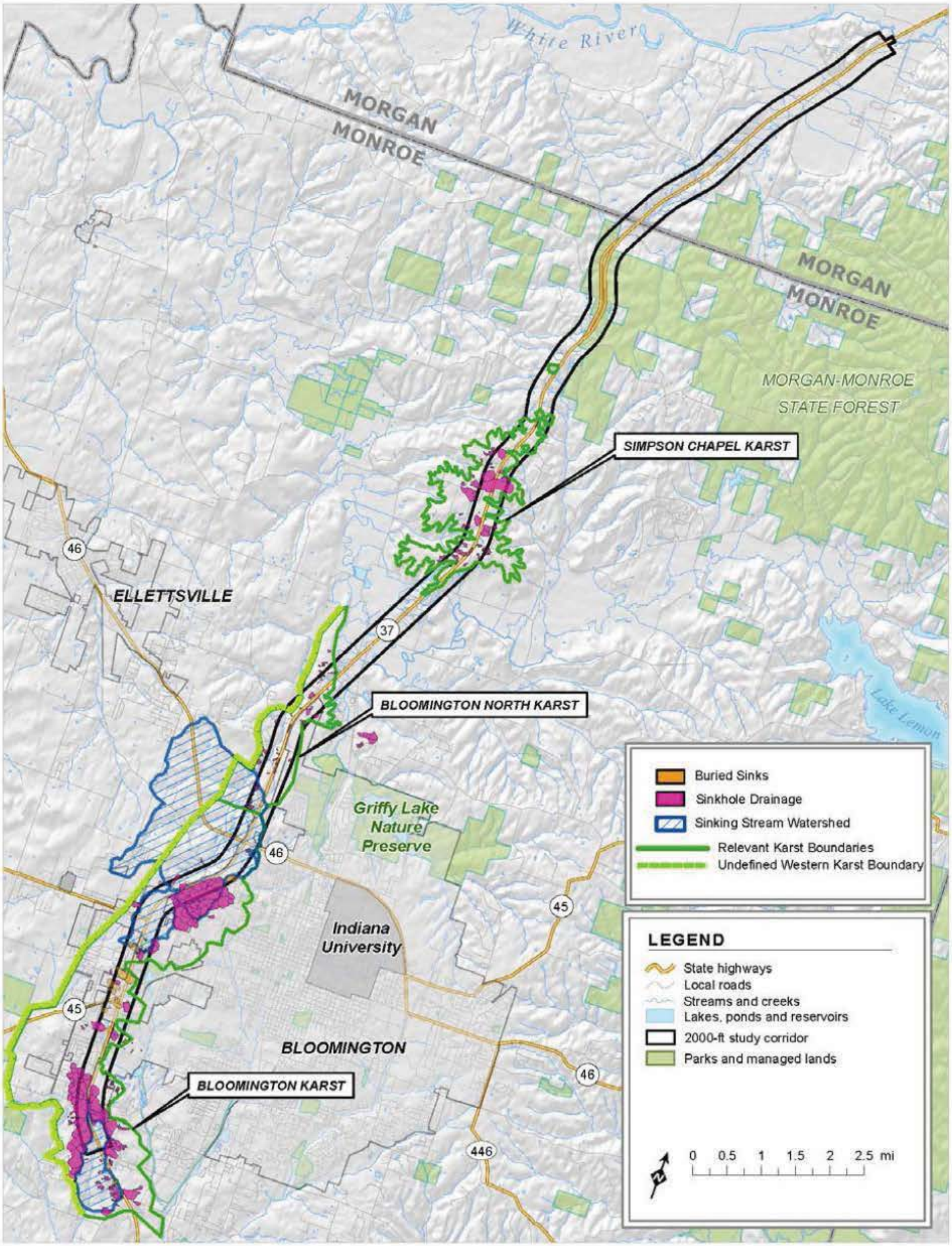

Figure 2 Location of Section 5 Karst Areas

1.3 Land Use Setting

The relevant karst portion of Section 5 is located within the Bloomington area of Monroe County. Like most of Indiana, agriculture was the primary early source of development in Monroe County and continues to play a vital role outside the greater Bloomington area. Bloomington itself has been a commercial and residential center since the 1830's. Much of the city's development has been, and is currently, based on Indiana University and the national and international demand for the high quality limestone available from local quarrying operations. Concurrent commercial, industrial, and residential growth has expanded to urban and suburban land use patterns now prevalent in the relevant karst areas.[3]

Generally, the City of Bloomington has more urbanized land uses at higher densities than surrounding areas of Monroe County, which display a mix of suburban and rural land uses. However, Monroe County on the whole has experienced, and is projected to continue to experience, steady population growth. The 2010 Population Density for relevant karst areas (compiled from 2010 U.S. Census block data, see **Figure 1**) and Monroe County Population Density Trend (**Figure 3a and Figure 3b**) illustrate the overall densities that have resulted from residential and other non-residential uses (i.e., commercial and industrial land uses) and the density increase projected for the area.

The 2010 land use (based on field reviews and updates of a GIS land use layer provided by the Monroe County Planning Department (2006 data and 2012 updates[4]) in the relevant karst portions of Section 5 included the following:

- Agricultural — 3,747 acres or 9.9%
- Nonresidential/ Industrial — 110 acres or 2.9%
- Public Use and Institutional — 471 acres or 12.4%
- Mines and Quarries — 45 acres or 1.2%
- Residential — 669 acres or 17.6%
- Water — 15 acres or 0.4%
- Transportation, Communication and Utilities — 750 acres or 19.7%
- Upland and Wetland Habitat — 1,365 acres or 35.9%
- Planned Development[5] (by 2035) — 796 acres or 21.0%

---

3 Include post 2006 Section 5 DEIS updates (such as land cover, land use, population growth, planned development, setting, bedrock, Monroe County 2010 aerial photography and 2-foot contours (see page 1).

4 Specific sites of planned development were identified during the coordination process with planners from the City of Bloomington and Monroe County and placed in the project GIS database. This development is anticipated to occur independent of the proposed project.

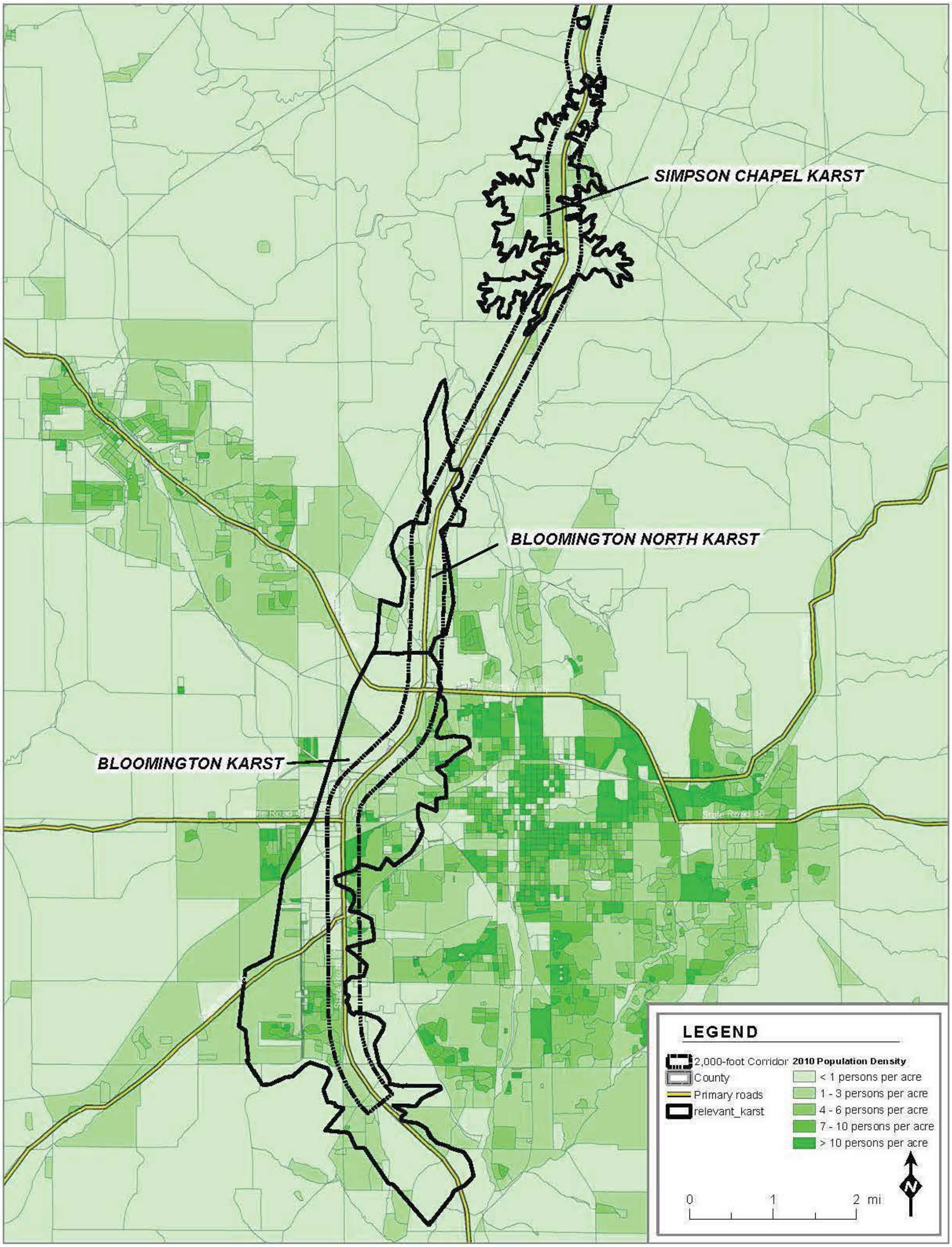

Figure 3a 2010 Population Density for Relevant Karst Areas

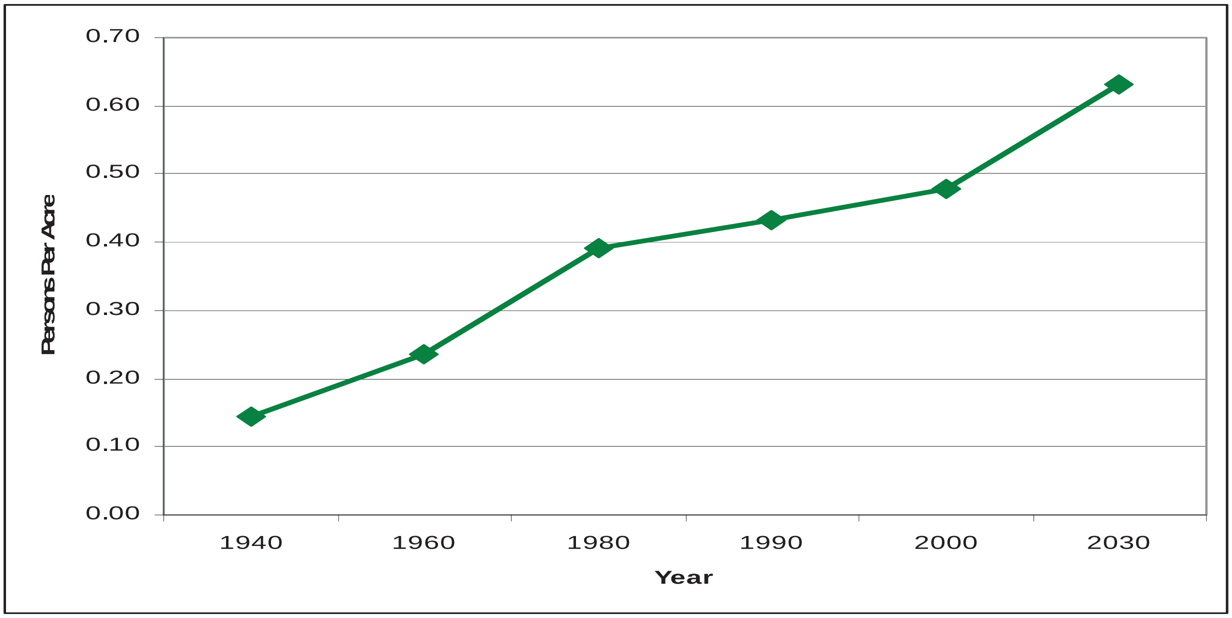

Figure 3b Monroe County Population Density Trend

Different land use types result in different hydrological and ecological implications for karst environments. To assess this impact, existing (2010) land uses were identified based on field reviews and updates of a GIS land use layer provided by the Monroe County Planning Department received to date (2006 data and 2012 updates[6]). According to a GIS analysis of this layer, 53.8% of existing land use within the relevant karst areas was classified as developed (e.g., residential, non-residential/industrial, public use/institutional, mines/quarries, and/or transportation/communication/utilities), 35.9% was upland/wetland habitat, 9.9% was agricultural, and 0.4% was water.

Additional development is likely to occur within the Bloomington region by 2035. Over time, this development would result in the conversion of undeveloped land uses such as agricultural and upland/wetland habitat to developed land uses. For the purposes of this analysis, only those specific areas of development identified by the local planning staffs and the Expert Land-Use Panel (City of Bloomington and Monroe County) are being considered. The Project Team created a GIS layer based on the sites identified by the local planning staffs. These sites are primarily based upon tax increment financing (TIF) districts, and additional information for developments with preliminary or approved site plans, and consistency with the local comprehensive plan. Based on this GIS analysis, an additional 21% of the relevant karst area is planned for development by 2035.

Historically, much of the development in Section 5 has been linked to the presence of karst, including: limestone quarries, cutting mills, abandoned quarries, use of sinkholes as drainage, historical landfills/dumps in sinkholes and quarries, springs used as water supply for both human and livestock consumption, and disposal of lawn cuttings or trash in sinkholes. Incidental

[6] Updates to the 2006 Karst Report include data from the Tier 2 Section 5 DEIS updates (such as land cover, land use, population growth, planned development, setting, bedrock, Monroe County 2010 aerial photography and 2-foot contours) (see page 1) are were included in the 2012 Draft Karst Report and 2013 Final Karst Report.

relationships with the relevant karst areas include hazardous waste spills, over-fertilization, herbicide releases, sewage leaks from both septic and sanitary sewers, disruption of natural flow by ongoing development, and pavement runoff. **Table 1** describes specific implications of different land use types to karst areas. The table was derived from a variety of sources, including: "Living with Karst, a Fragile Foundation" (Veni et al. 2001).

Table 1 Karst Effects by Land Use

Land Use	Impervious Surface	Potential Runoff Contaminants	Other concerns or benefits
Agricultural	Low	Sediment, animal waste, fertilizers, pesticides	The lack of consistent vegetation/ground cover, presence of animal waste, and use of fertilizers and pesticides have a greater potential to increase the sediment load, pH, and biological oxygen demand (BOD) than other land use through both chronic releases and acute episodes .
Nonresidential/ Industrial	High	Salt, petroleum based contaminants and some heavy metals	Nonresidential/industrial land uses pose elevated risks due to the potential for releases of materials used or stored on site including a wide range of chemicals, raw materials, byproducts, and wastes.
Public Use and Institutional	Varies	Salt, petroleum based contaminants and some heavy metals.	NA
Mines and Quarries	Varies	Suspended solids and petroleum based products	Elevated sediment load, pH and temperature impacts and potential direct impact to the karst formations and groundwater flow patterns.
Residential	Low Moderate	Pesticides and fertilizers	While residential uses have lower runoff/impervious surface than other developed uses, sewage/septic system and water service leaks are endemic to human occupation in a karst area, and such conditions were observed during the field studies.
Water	Low	NA	Lakes and ponds may provide natural attenuation of runoff contaminants, storm water storage, and trapping of suspended matter. Streams, lakes, and ponds may act as suspended load catchments and contaminant sinks.
Transportation, Communication and Utilities	Varies	Heavy metals, petroleum products, PCBs, chemicals, and wood preservatives	Transportation and communication land uses are characterized by high levels of impervious surface coverage; however, impacts related to these land uses are less frequent and more diffuse than those related to other developed land uses.
Upland and Wetland Habitat	Low	NA	Forest, shrub, and herbaceous cover serve to attenuate storm events and trap sediment and other particulate matter. Wetlands provide natural attenuation of runoff contaminants, storm water storage, and trapping of suspended matter.

Monroe and Morgan Counties have not specifically adopted "Enhanced Septic System Regulations" as recommended in the I-69 Planning Toolbox for those areas with karst geology. Nevertheless, Monroe County has detailed septic system regulations, some of which pertain specifically to karst-sensitive areas and sinkholes. In addition, both Monroe and Morgan County implement Indiana State Statute Rule 410 IAC 6-8.3 pertaining to residential onsite sewage systems.

These considerations are important in the context of I-69 development because human activity and pollution of karst landscapes can have a detrimental impact on water quality in areas with karst features, as well as and communities and biological systems relying on them. Failing septic systems are a potential hazard in these landscapes, and enhanced regulation of these systems is a measure outlined in the I-69 Planning Toolbox. Typically, enhanced regulations include increased minimum setbacks from sinkholes and caves, increased separation distance between septic system drainage fields and bedrock, mandatory periodic maintenance, and the reservation of an additional drainage field.

1.4 Physiographic Setting

The physiographic setting consists of the geographic area with similar geologic structure, climate and geomorphology, and is usually part of a larger region of similar characteristics. Section 5 is located in the Southern Hills and Lowlands Physiographic Region, a portion of Indiana that was not glaciated during the Wisconsin Glacial Episode and is characterized by hills and valleys in bedrock formations. Although a significant portion of the study area was glaciated during the Pre-Wisconsin glacial events, the area was not significantly altered. The Section 5 study area crosses three of the 10 Southern Hills and Lowlands Physiographic Region divisions. These include from south to north: the Mitchell Plateau, the Norman Upland, and the non-karst terrain Martinsville Hills (Gray, 2000; 2001).

- The Mitchell Plateau extends from south of Section 5 to the Beanblossom Creek valley. It is comprised of a limestone plateau dissected by many deeply entrenched major stream systems, and exhibits extensive karst features.

- The Norman Upland begins at the Beanblossom Creek valley and continues north to about the Morgan/Monroe County line. It is characterized by high relief and generally rugged topography with relatively flat uplands (such as the Simpson Chapel Karst area) among a maze of dendritic ridges.

- The Martinsville Hills start at about the Morgan/Monroe County line and extend northward through Section 5 to Martinsville. They are distinguished from the other divisions due to modification by pre-Wisconsin glaciations and the presence of a relatively thin layer of pre-Wisconsin glacial drift.

1.5 Geologic Setting

The bedrock in Section 5 is typically fairly shallow with thin overlying soils, except in some of the larger stream valleys (Thomas et al., 1981). Structurally, the study area is within the Illinois Basin, with the bedrock dipping to the southwest and west (at approximately 30 feet per mile) with younger formations to the south and west and older bedrock formations located to the north and east (Melhorn, 1959; Rupp, 1991). The divisions occur as follows:

Table 2 Bedrock and Karst Area Groupings

Bedrock Group	Geologic Formations	Outcrop Area
Blue River Group	Paoli	South and west of Section 5
	Ste. Genevieve	
	St. Louis	Bloomington Karst
Sanders Group	Salem	
	Harrodsburg	Bloomington North and Simpson Chapel Karst
	Ramp Creek	
Borden Group	Edwardsville	North of Simpson Chapel Karst to north of Section 5
	Spickert Knob Formation (or Carwood and Locust Point)	
	New Providence Shale	

The karst in Section 5 is formed on and in Mississippian age limestones, which are shown on **Figure 2**. The eastern and western edges are not necessarily the limits of karst development, but are often simply the limits of the existing karst studies (Shaver, 1986).

1.5.1 Bloomington Karst

The Bloomington Karst area consists of St. Louis Limestone as the dominant karst-forming limestone, with some karst development in the underlying Salem Limestone. Formations below the Salem Limestone are not relevant to this investigation, since they are well below the water table and are not part of the karst groundwater system(s) associated with caves and springs of the study area.

The St. Louis Limestone, at the base of the Blue River Group, can be subdivided into upper and lower formations. The upper portion consists of largely thin beds of medium to dark gray-brown micritic, pellatal, and skeletal limestone with very thin beds of gray shale. The lower portion is predominantly composed of pellet-micritic limestone, calcareous shale, and silty dolomite. The thickness of the St. Louis Limestone is approximately 250 feet (Rupp, 1991; Gates, 1962).

Under the St. Louis Limestone and at the top of the Sanders Group, is the Salem Limestone, a medium to coarse grained crossbedded calcarenite that occurs in exceptionally thick beds and is used as building stone (dimension stone). The Sanders Group is predominantly composed of carbonate rocks with an occasional shale and siltstone layer typically ranging from 50 to 85 feet in thickness (Gates, 1962).

1.5.2 Bloomington North and Simpson Chapel Karst

The Bloomington North and Simpson Chapel Karst consist of the Ramp Creek and Harrodsburg Limestones with the divide between these members occurring roughly at Arlington Road. The rock immediately below the Ramp Creek Limestone is insoluble shale (Edwardsville) that provides a barrier to the downward formation of karst. Much of the Harrodsburg Limestone and all of the formations above it have been removed by erosion (Rupp, 1991).

The Ramp Creek Formation is at the base of the Sanders Group. It predominantly consists of a carbonate unit formed from interbedded very fine grained dolomite and limestone with small amounts of siltstone and shale. In addition, chert and geodes are common, especially in the dolomite. The Ramp Creek formation is fairly uniform and generally ranges from 20 to 25 feet in thickness. Above the Ramp Creek is the Harrodsburg Limestone, a dominantly well-cemented and, at times, bioclastic limestone that includes some dolomite, shale, very argillaceous limestone, and minor amounts of chert (Gates, 1962). The top of the Group (Salem Limestone) has been eroded in this area and is no longer present (Thompson, 2007; Hasenmueller, 2008).

Underlying and to the north of the Bloomington North and Simpson Chapel Karst is the Borden Group, comprised of gray argillaceous siltstone and shale commonly with fine-grained sandstone and the occasional limestone formation. The New Providence Shale is dominantly a greenish gray, blue gray or dark lead gray shale bordering on claystone, with minor amounts of sandstone, ironstone, limestone, and silty dolomite. The Borden Group is approximately 600 to 800 feet thick (Rupp, 1991).

Overlying the karst-forming rocks is a wind-deposited silt called loess. The loess was deposited during the Pleistocene Age (Gates, 1962) and is highly erodible and subject to soil piping or soil migration.

1.5.3 Mining/Quarry Operations

Mining in the study area is largely limited to limestone and includes dimension stone, high calcium-rich limestone, crushed stone for construction, agricultural lime and livestock feed. With the famous Salem Limestone at or near the surface, Monroe County has become well known for dimension stone. In addition to being used for building material, dimension stone has a high calcareous content and its waste limestone may be used for chemical limestone. From the Blue River group, primarily Paoli and Salem Limestone have been quarried for crushed stone or gravel. In addition to dimension stone, high calcium limestone including the Harrodsburg, Salem, Paoli and Ste. Genevieve have been quarried for use primarily as flux in steel production, agricultural lime and glass manufacturing (Gates, 1962). See **Figure 4a** for Limestone Reserves.

Other mineral sources include shale, quartz sand, clay, sandstone, gypsum, anhydrite and gas producing/storage domes along the Leesville Anticline. The most northern of these is the Hindustan Dome, which is located in the study area and used for storage of natural gas. Although minor oil and coal fields are present in Monroe County, they are of limited economic importance and do not exist in the study area (Droste Bulletin 63). See **Figure 4b** for Section 5 abandoned quarries, sand/gravel deposits, natural gas wells and the storage dome.

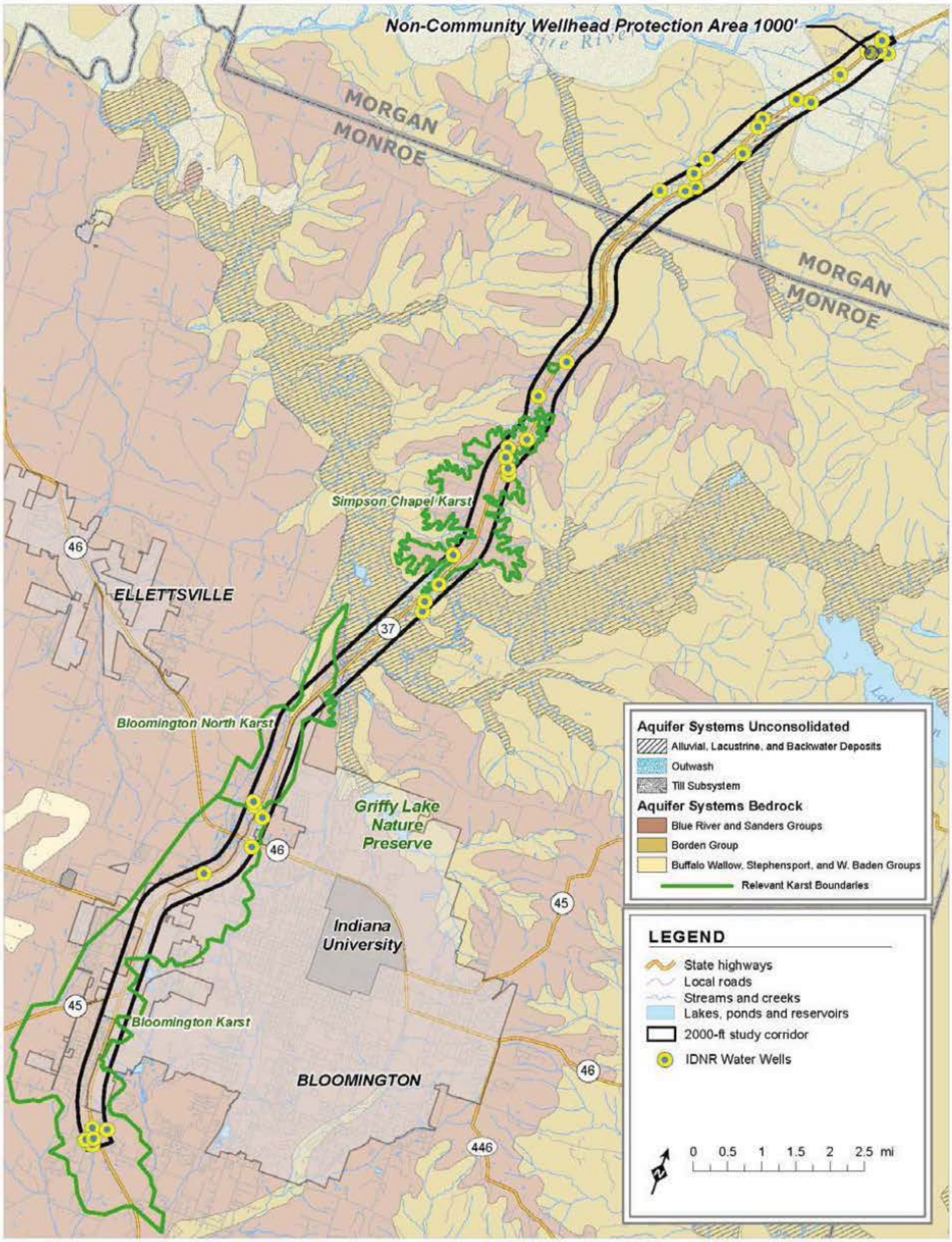

Figure 4a **Section 5 Mineral Resources – Limestone Reserves and IDNR Water Wells**

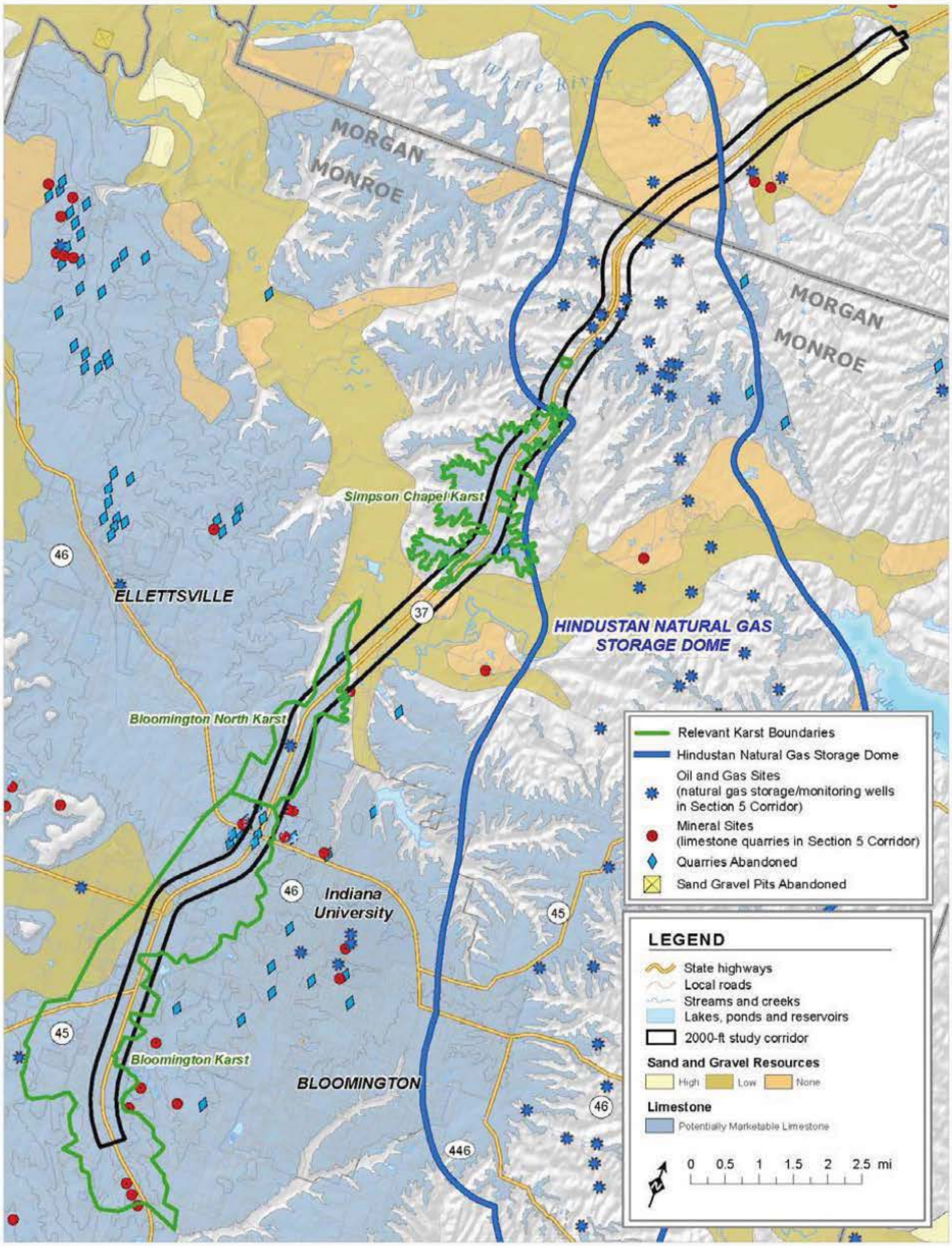

Figure 4b Section 5 Mineral Resources – Abandoned Quarries, Sand/Gravel Deposits, Natural Gas Wells and Storage Dome

1.5.4 Hydrogeologic Setting

Groundwater supplies are limited in the karst portion of Section 5 with the majority of the local water supply coming from man-made surface water reservoirs (such as Lake Monroe Reservoir). Public water services that utilize these sources in Section 5 karst areas include the following:

- The City of Bloomington Utilities Department
- Town of Ellettsville Utilities
- Van Buren Water Inc.
- Southern Monroe Water Company
- Washington Township Water Corporation

Water wells installed in unconsolidated materials are typically limited to the larger valley fill and terrace areas. Bedrock wells are installed in the Salem, Harrodsburg, St. Louis and Ste. Genevieve limestone formations, primarily along joints, fractures and bedding planes (Gates, 1962). Well production is typically low, ranging from less than 10 gallons per hour (gph) to 10 gallons per minute (gpm) and small areas of greater than 10 gpm (Harke and Gray, 1998). See **Figure 4a** for IDNR water well locations included in **Appendix M**.

Karst groundwater movement within the limestones includes both slow-flow and fast-flow regimes. Slow flow groundwater velocities are typically on the order of 0.00001 centimeter per second, and have uniform flow directions known as laminar flow (Freeze and Cherry, 1979). Fast flow velocities, typically greater than 1,000 meters per day, are in the turbulent flow regime, and have a greater potential to transport material into and through the karst groundwater system.

The main hydrogeologic unit in the Bloomington Karst is the St. Louis Limestone. The underlying Salem Limestone appears to support its own hydrogeologic unit. The springs draining the St. Louis Limestone are at or very near the contact with the underlying Salem Limestone, indicating that there is a hydrogeologic boundary near the contact. An exception to this association between Bloomington Karst springs and the Salem Limestone contact is Spring, which discharges from the Salem Limestone and is a relatively large spring (for this study area).

In both the Bloomington North and Simpson Chapel Karst, the Ramp Creek and Harrodsburg Limestones act as a single hydrogeologic formation. The springs draining these formations are usually above a thick, fossiliferous limestone bed that is underlain by non-karst forming Edwardsville Shale. The basal limestone bed also seems to act as an aquitard in addition to the underlying shale aquitard.

2.0 METHODOLOGY

The karst study was conducted to support the Tier 2 EIS and address Items 1 through 4 of the 1993 MOU for the I-69 Section 5 Corridor and Relevant Karst.

2.1 Public and Private Research Sources

Documents regarding previous karst investigation in and around Bloomington were gathered, including: general mapping of spring and cave locations and karst areas from the Indiana Geological Survey (IGS); development or hazardous waste mitigation documents conducted by various consultants; and, academic research studies and identification of significant numbers of karst features by cavers, as recorded by the nongovernmental Indiana Cave Survey (ICS).

Interviews were conducted with knowledgeable local karst professionals, including the late Dr. Noel Krothe (principal with Hydrogeology, Inc.), Sam Frushour (IGS at the time and data custodian for the ICS), John Bassett (Earth Tech), Mike McCann (Viacom; now CBS), and several cavers and state and federal agency employees.

INDOT supplied GIS data, INDOT personal communications, related reports (Earth Tech 1996, 2002), and “as-built” files and City of Bloomington drainage infrastructure files along existing SR 37, which were reviewed and incorporated into the data set and utilized during the karst evaluations.

Indiana University, IGS, and Bloomington repositories/libraries were researched for relevant local literature, master and doctorial theses, USEPA documents, and karst feature studies. The ICS database showing relevant cave entrances, City of Bloomington two-foot contour and 2010 Monroe County two-foot contours derived from LiDAR data, and storm water management mapping, six-inch resolution aerial photography, 1939 and 1980 stereo pair aerial photographs from the USDA, and previous INDOT studies were obtained and incorporated as part of the data set.

2.2 Karst Feature Field Check Methodology

Karst features include sinkholes, springs, karst flowpaths, caves, and other landforms (e.g., losing streams and sinking streams) (see Glossary of Key Terms). In accordance with the 1993 MOU, the location, type, area, and significant characteristics of karst features were researched, field checked, documented and imported into a GIS database for evaluation relative to SR 37 and Section 5.

The field checks included walking the Study Corridor and adjacent areas of interest for karst features not noted in the pre-screening information sources. Multiple field checks were conducted during periods when the vegetation was reduced (late fall, winter, and early spring). Field checks were conducted by teams of 1 to 3 professional geologists utilizing a Trimble® global positioning systems (GPS) capable of sub-meter accuracy. Features and springs that were encountered at any time during the field work were documented and mapped regardless of the time of year. In areas where a feature was not accessible (due to landowner objection, locked facilities, buried or too expansive features, etc.), the location was determined via the best available data source (e.g., 6-inch resolution aerial photographs).

The results were imported into GIS, displayed on project mapping/aerial photographs and checked by the field personnel in comparison to one or more of the following: 6-inch resolution aerial photographs, USGS quadrangle mapping, and two-foot contour mapping. The areas that were field checked were also tracked/planned utilizing the GIS database. Insurgence boundaries were adjusted to encompass the drainage area, based upon contour mapping (two-foot interval) and best professional judgment, for use in alternative evaluations, annual pollutant loading calculations, avoidance, alternative drainage, and treatment/mitigation planning.

The field checks also included walking the Corridor and adjacent areas of interest for karst features not noted in the above information sources. Field checks consisted of the following steps:

1. The locations, types of feature, photographs (of select features or areas), estimates of flow (if present) and other significant characteristics were inventoried.

2. Locations were determined. In areas where a feature was not accessible (due to landowner objection, locked facilities, buried or too expansive features, etc.), the location was determined via the best available data source (e.g., 6-inch resolution aerial photographs).

3. Field checked data was imported into GIS and displayed on project mapping and aerial photographs. Quality control consisted of review by the field personnel and comparison to one or more of the following: 6-inch resolution aerial photographs, USGS quadrangle mapping, and two-foot contour mapping.

4. Insurgence boundaries were adjusted to encompass the drainage area, based upon two-foot contour mapping and best professional judgment, for use in alternative evaluations, annual pollutant loading calculations, avoidance, alternative drainage, and treatment/mitigation planning.

2.2.1 Sinkholes

Potential sinkhole and other insurgence feature locations were determined based on the following screening methods (from sources gathered throughout the duration of the study):

- IGS state and county geologic and karst feature maps were reviewed for areas and bedrock units prone to formation of karst.

- Current USGS topographic maps were examined for sinkholes and other insurgence features.

- Historic USGS topographic maps were examined for insurgence features that might not be represented on current USGS topographic maps or may have been obscured or buried by development in the study area.

- Two-foot contour interval topographic mapping along the Section 5 Corridor was compared to the USGS mapping to look for features that were not apparent on the larger contour intervals.

- Stereo photography from flight lines flown in 1980 and 1939 were examined to locate insurgence features as a check on the USGS topographic mapping and as an additional source of data on historically modified or filled sinkholes.

- Six-inch resolution aerial photography of the Section 5 Corridor was examined for indications of potential insurgence features.

- Information provided by local karst professionals and volunteered by local residents was compiled and included in field checks.

- I-69 Tier 1 comments were reviewed.

Potential sinkholes were field checked to verify the accuracy of reported locations and interpretations. The relevant karst areas may include small/buried sinkholes that did not have surface expression at the time of the field checks due to the dynamic nature of these systems, especially as related to development, tree clearing, and earthmoving in the Bloomington area that may cover, alter or expose features, as compared to the conditions at the time of the field checks. In addition, some very small features may have been obstructed by vegetation even during leaf off conditions of reduced vegetation. This does not mean that karst features or potential karst areas were omitted or not identified but rather that a small feature may have been included in larger features/areas or groups of features or via identification based on additional sources such as historical stereo paired aerials photographs, two-foot topographic mapping, previous karst mapping, or interpretation by the karst professional.

Future investigations may reveal somewhat different sinkhole distribution than documented at the time of this study. Determinations of areas in which sinkholes are present versus areas with no sinkholes were used to differentiate hydrology and evaluate potential engineering hazards. A bias was placed upon the presence of karst, rather than its absence.

2.2.2 Springs

Springs (or resurgence features) are often the first point accessible to groundwater flow in karst terrain and are natural sampling points for tracer dyes and groundwater quality assessments. Spring locations were determined from the following sources:

- Review of the I-69 Tier 1 database.

- Review of I-69 Tier 1 comments.

- IGS database research.

- Literature search.

- Interviews of local karst professionals.

Potential springs were field checked to verify the accuracy of reported locations and interpretations. The field checks included walking local creeks and geologic formation contacts for springs not noted in the above information sources. Field checks were conducted in as detailed in **Section 2.2** with the addition of the following:

1. Features were assigned names and serial numbers, and labeled flagging was placed to ensure accurate sample collection.

2. Sampling stations were established, carbon packet anchors were secured, and photographs were taken of the station areas (for springs determined to be relevant to the study).

3. Discharge rates were estimated: the volume of water discharged is roughly proportionate to the area recharging a given spring, assuming that the geologic setting and climatic conditions are comparable.

2.2.3 Karst Flowpaths

Karst flowpaths (or conduits) are the links between insurgence features (i.e., sinkholes and losing/sinking streams) and resurgence features (springs). Karst flowpaths are difficult to locate unless the passage is large enough to be considered a cave (defined as large enough for human traverse) and has an entrance. Karst flowpath locations for this study were approximated by connecting each dye introduction point with each spring at which the associated dye was detected.

2.2.4 Caves

Potential cave and cave entrances were determined based on the following sources:

- ICS and IGS databases.

- Cave entrance research and field survey was conducted concurrently by IGS personnel for cave accessibility and potential bat habitat research.

- Interviews with local cavers and knowledgeable individuals.

- Review of I-69 Tier 1 comments.

Potential caves and cave entrances were field checked to verify the accuracy of reported locations and interpretations. The field checks included walking the Corridor and adjacent areas of interest for caves not noted in the above information sources. Field checks were conducted as detailed in **Section 2.2** with the addition of the following:

1. Cave entrance locations were determined via GPS except in instances where an entrance was no longer open and therefore could not be field checked and a GPS location

obtained, the location was determined via the best available data source (for example, ICS records).

2. Research and field check data were imported into the CONFIDENTIAL GIS layer for use in alternative evaluations, annual pollutant loading calculations, avoidance, alternative drainage, and treatment/mitigation planning.

Cave entrances were field checked and included as part of the sinkhole and spring field checks, since cave entrances are typically located in sinkholes or at springs. IGS reported several historic cave entrances that had been filled or buried.

2.2.5 Others

The majority of karst features to fall into the "Others" category in this study are losing and sinking streams. Losing streams are streams where a portion of the flow enters the subsurface drainage system, and under low flow conditions may disappear from the surface. Sinking streams are those streams that flow directly into a swallet (or sink point). Losing streams, as well as some sinking streams, often have the same general geomorphology as streams that are not in karst, which can make them difficult to identify during field checks. Sinking or losing streams are important to the karst studies since they can transport significant amounts of water and other material directly into the karst groundwater system.

Because of their lack of distinctive geomorphology, seasonally sinking or losing streams seldom appear as such on topographic maps or aerial photography. Sinking streams were identified in this study by multiple observations of streams and dry channels downstream of flowing water during various flow events (high, base, and low). While potential losing streams also were identified by these limited field checks, confirmation was made via evaluation of dye trace results. Dye introduced into streams at the surface, but detected at springs, demonstrated that some or all of the water from the surface stream was "lost" into the karst groundwater system. The difference between a sinking stream and a losing stream is often solely dependent on the volume of water flowing at the time of observation. That is, a stream that loses some of its flow at high stream stages may lose all of its flow at low stream stages.

Another karst feature of importance that falls into the "Others" category is a karst window. Karst windows are unroofed sections of caves that give access to karst flowpaths. These features are important as potential biological sampling sites and as potential dye introduction points. Karst windows tend to have perennial flow and similar habitat to caves. Karst windows were identified during the field check of sinkholes and springs discussed previously and were included in the CONFIDENTIAL GIS layers.

2.3 Dye Trace Methodology

The dye traces focused on fast-flow pathways in karst-forming rocks relevant to the Section 5 Corridor and were conducted as follows:

- Results of the karst feature field checks, research, and field checks of accessible sites where karst groundwater systems return to the surface (e.g., springs or streams feed by springs) were used to develop a dye trace program.

- The program was developed to provide coverage of the relevant karst portions of Section 5, with incorporation of previous dye trace data from local sources.

- A network of sampling stations was established to provide coverage of potential dye detection and background sites.

- Background sampling and analysis were conducted to evaluate the potential for interference from fluorescent compounds if present within the study area.

- Potential dye introduction locations were identified where waters sink from the surface into the groundwater system (e.g., sinkholes or sinking streams).

- Appropriate tracer dyes selected from four different dyes were used in the Section 5 studies: fluorescein, eosine, rhodamine WT, and sulforhodamine B. All of these dyes are environmentally safe (Smart 1984; Field et al., 1995). These dyes pose no risk to humans or to aquatic life in the concentrations used in professionally directed groundwater tracing work, and are appropriate for the work that was conducted (Aley, 2002). More detailed discussion of the performance characteristics and properties of the four dyes used in this study are included in **Appendix C**.

- Dye was introduced at selected karst or drainage features.

- Samples were collected at potentially relevant sampling stations and submitted for analysis, data management, quality assurance, and evaluation at OUL (see Section 2.4).

2.3.1 Dye Trace Program

The dye trace program (2006 data and 2012 updates[7]) was designed to account for potential interference fluorescence from sources not associated with the Section 5 studies related to facilities in the study area, including:

- Significant paved surfaces (SR 37, street crossings, roads, parking areas),

- Developed/urban environment with commercial/industrial facilities.

- Two former landfills (Superfund sites).

Groundwater tracing in developed areas, such as Section 5, routinely encounters waters characterized by fluorescence interference peaks/dyes due to man-made compounds. These

[7] Updates to the 2006 Karst Report included additional field reconnaissance and dye tracing for and Cave recharge area(s) in the vicinity of the Section 5 corridor, based on agreement between INDOT, FHWA, and USEPA (see **Section 1.1**).

fluorescent compounds may include tracer dyes or other compounds that could be mistaken for some of the dyes. For example:

- Fluorescein dye is a common coloring agent in most automotive coolants. Vehicles that leak coolants onto paved surfaces can introduce sufficient fluorescein into runoff waters that concentrations of the dye can be detected at sampling stations.

- Rhodamine-based dyes are common coloring agents in hydraulic fluids and some coolants; leaks and spills of these fluids may result in fluorescence peaks at sampling stations. In these cases, the fluorescence peaks are commonly in or near the acceptable wavelength ranges of rhodamine WT and sulforhodamine B used in dye traces.

Due to the urbanized/industrial nature of significant portions of the Section 5 study area and the two former Superfund sites, numerous dye trace studies have been conducted or are ongoing within the study area by various entities. These have the potential to cause interference based on fluorescent compounds that were not introduced as part of the Section 5 dye-tracing program. These interference peaks are most commonly detected in carbon samplers, which accumulate (and thus concentrate) the fluorescent compounds and are continuously sampling the passing water such that they do not miss short duration pulses of fluorescent compounds.

Separating fluorescence peaks from appropriate Section 5 dyes from interference peaks/dyes was accomplished using a combination of the following four protocols:

- The fluorescence background at key individual sampling stations was routinely characterized prior to introducing dyes. Fluorescence peaks that were in or near the acceptable wavelength range for each of the tracer dyes were quantified as though they were the particular dye (**Appendix C**). Most of these fluorescence peaks were footnoted because they did not meet all of the criteria for positive dye detections (**Appendix C**). The data resulting from the background sampling permitted selection of a dye for a particular trace that was likely to experience minimal fluorescence interference at the detection sites.

- Sufficient dye was used for each trace to ensure clear results in activated carbon samplers, but not enough to expect visibly colored water. The use of excessive amounts of dye was avoided because it lengthens the period during which the dye is detectable at sampling stations, which in turn lengthens the period until another trace with the same dye can be used in that area. In many cases, the amount of dye used was sufficient to produce detectable fluorescence peaks in at least a few associated water samples.

- Activated carbon sampling was used to continuously sample water prior to introduction and post introduction of dye to ensure that pulses of Sections 5 dyes were not missed and that background fluorescence at the sampling stations were adequately characterized (**Appendix C**).

- Control stations and confirmation stations were established in a number of stream sampling stations. A control station would be located at a point where it would be likely to detect fluorescent compounds moving into the study area from outside sources. For example, Station 44 (Clear Creek at First Street) revealed dye being used by maintenance personnel at Indiana University as part of their sewer line repairs. Confirmation stations were located downstream of springs where the discharge of dye was likely. These stations served to detect any dye that might discharge from a spring that had not been discovered, and to confirm the passage of dye derived from an upstream location.

2.3.1.1 Quality Assurance/Quality Control

OUL's "Procedures and Criteria" document (**Appendix C**) contains a number of quality control and quality assurance (QA/QC) methods used during the Section 5 studies. QA/QC samples were collected throughout the dye trace program and were indicated by a letter designation following the sample number according to the following method (**Appendix B**):

- "D" indicated a duplicate sample analysis. With activated carbon samplers, duplicate samples were from the second of two activated carbon samplers placed at the sampling station for the same sampling interval.

- "R" indicated a replicate sample analysis. Replicate sample analyses were either a second analysis of the charcoal sampler elutant; or, in the case of water samples, an analysis of a second aliquot of water from the sample vial collected at the station. As a QA/QC step, the laboratory routinely analyzed a duplicate charcoal sampler or a replicate water sample for every sample where the last two digits of the sample number ended with 00, 20, 40, 60, or 80; this represented about 5% of the collected samples.

- "V" indicated a verification sample analysis. These were essentially identical to duplicate samples except that the sample number did not end with the digits 00, 20, 40, 60, or 80. Verification samples were typically analyzed if one of the tracer dyes appeared to be in the sample and the person conducting the analysis work determined that a verification sample was required.

Upon completion of fieldwork and laboratory analysis, all analytical graphs and custody records were individually examined to ensure that all data were complete and correct and that all footnotes and information associated with background fluorescence were correct and consistent. In general, a dye detection was not attributed to a particular trace unless the concentration was at least 10 times greater than the maximum concentration of fluorescent compounds in any background sample from the station. Finally, dye detections at a particular sampling station were not identified as positive traces unless the detection was reasonable in view of all other available data including the proximity of the detection station to other detection stations and the dye introduction location.

2.3.2 Sampling Stations

A comprehensive network of sampling stations was established to:

- Determine individual and regional background fluorescence values (interference peaks).

- Detect dye from Section 5 dye traces.
- Detect dye from traces from other investigations that might interfere with Section 5 investigations.
- Detect dye if any were introduced by outside parties to intentionally cause confusion.

Sampling stations were established by OUL and Baker staff to provide groundwater flowpath data relevant to the investigation. Relevant springs were sampled along with some additional springs that were included to demonstrate a lack of potential impact from the existing SR 37 and Section 5 Project. Some sampling stations were established as control stations to identify the input of fluorescent compounds into the study area that were not derived from dye introductions made by OUL. Surface sampling stations were established in local streams to identify potential groundwater discharges from unknown springs.

Sampling stations were established by:

1. Assigning a serial number.
2. Collecting a grab sample of water.
3. Placing two, independently anchored, activated carbon packets in the spring or stream channel (often obscured to prevent disturbance by curious observers).
4. Estimating flow and describing flow conditions (for springs).
5. Hanging flagging ribbon nearby with the station name and number.
6. Writing a description of the sampling location.
7. Photographing the sampling station.
8. Collecting a Trimble® GPS location that later was downloaded into GIS.

A total of 205 sampling stations were established for this investigation. **Appendix E** includes photographs of each of the sampling stations. The sampling stations were located in the Clear Creek, Bloomington, and Modesto 7.5-minute USGS quadrangles. The locations of the sampling stations are shown on **Figures 5 and 6**. An index to dye sampling locations is presented in **Appendix D** Table D-1 Sampling Station Index.

2.3.3 Dye Introductions

The main dye tracing program was designed to provide a dye trace for approximately every 2.5 miles of Corridor that passed through karst. The supplemental dye tracing program was designed to delineate the Cave recharge area and to determine if it were likely that Cave had hydrological connections with the Cave groundwater system. Selection of dye introduction points was based on:

- Coverage of the relevant karst area.
- Projected ability to identify potential groundwater systems that could be impacted by highway construction and use.
- Proximity to areas of special concern (e.g., Superfund sites).
- Potential to determine whether specific features were karst features.
- Practicality of placement.
- Preference for larger catchment areas (the larger the area, the more area is characterized).

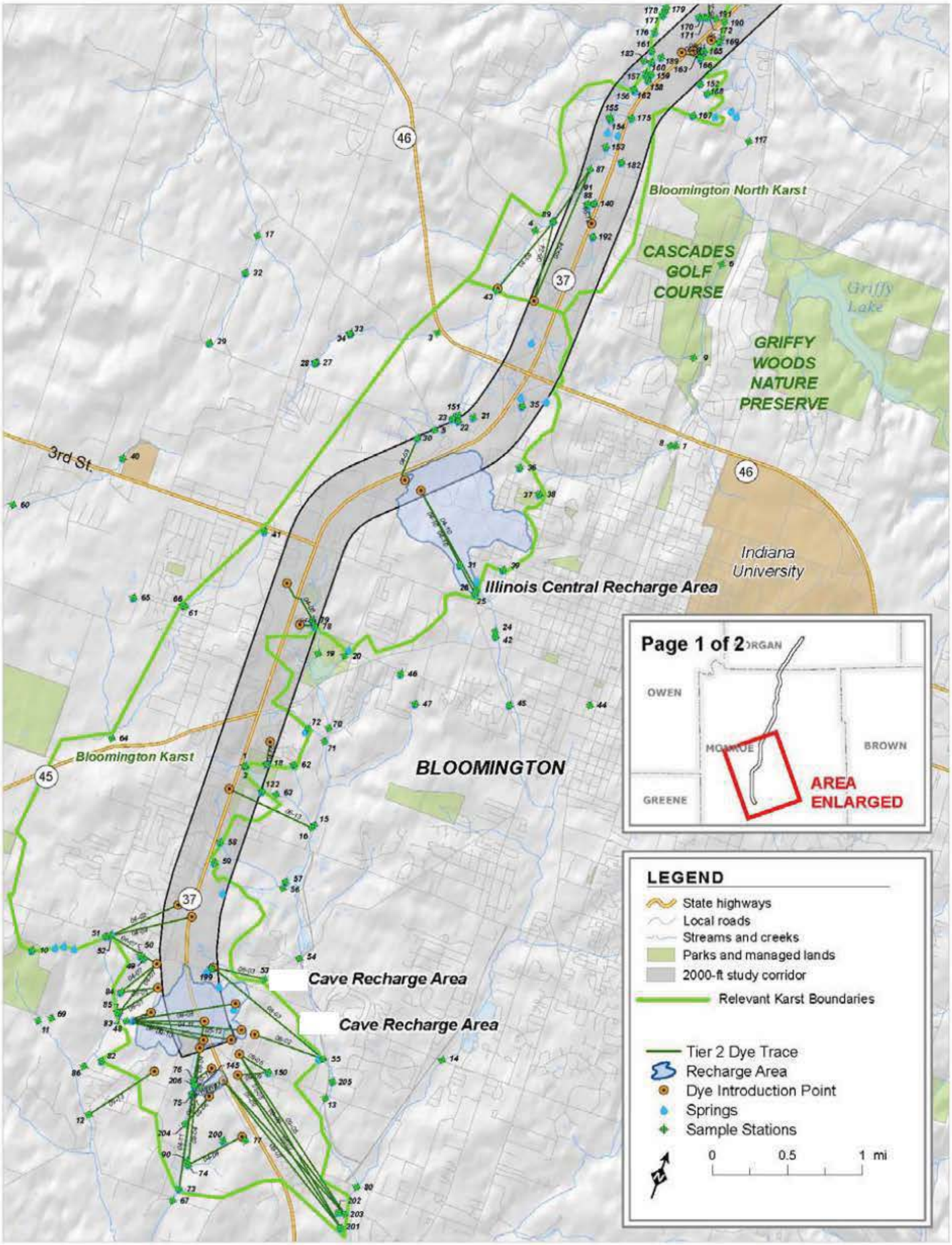

Figure 5 Summary of Dye Tracing - Bloomington and part of Bloomington North Karst

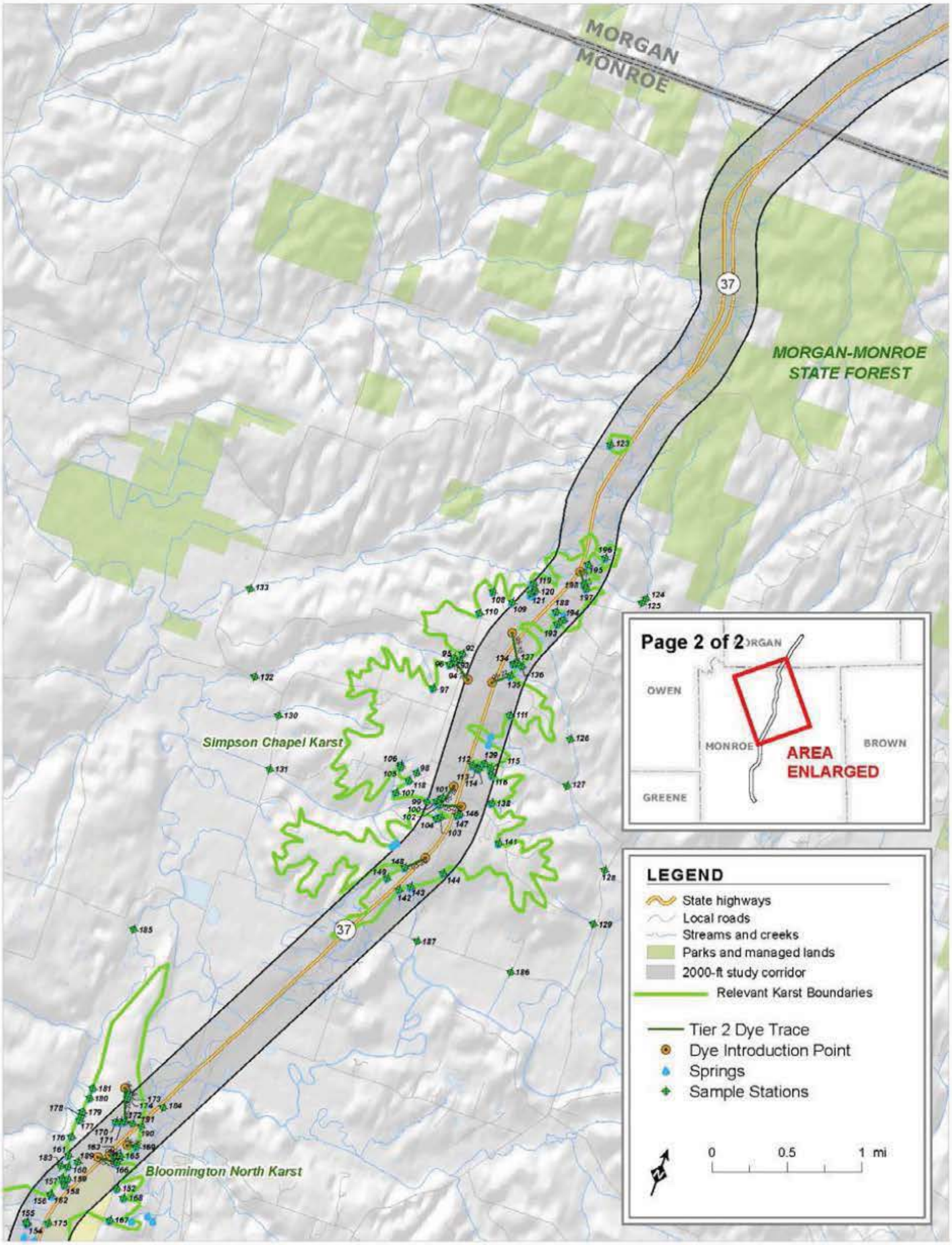

Figure 6 Summary of Dye Tracing – part of Bloomington North and Simpson Chapel Karst

All of the dye introduction points were thought to be potential insurgence features: however, some features were better able to move water and dye into the groundwater system than others. Where it was impractical to wait for natural flow, potable water was used to introduce dye into the groundwater system. Potable water was obtained from nearby fire hydrants or was hauled to the dye introduction point by truck.

Insurgence features with larger catchment areas were preferred since they represent a larger portion of the landscape and have more frequent episodes of runoff entering the groundwater systems. Thus, larger insurgence features are generally more representative of groundwater flow patterns and are easier to utilize.

Dye types and quantities were selected based on relevant background analysis and in coordination with ongoing and planned dye traces to prevent ambiguous results. The dye quantities used were influenced by previous dye tracing in the area, professional experience in other karst areas, and with the intention of minimizing the quantity of dye used while still producing credible data. Smaller quantities of dye were less likely to be noticeable to the public and were more likely to quickly reduce to ambient background levels. Since primary reliance was placed on activated carbon samplers (which are cumulative samplers), the sampling methodology permitted the use of smaller quantities of dye than if the sampling primary relied on water samples.

Dye traces were coordinated with and notification given as necessary to IDEM, the Monroe County Health Department, and Viacom, Inc. (now CBS) has been actively conducting dye traces in the area as part of on-going studies of the Lemon Lane Superfund site).

The dye traces were numbered sequentially with the first two digits indicating the year and the last pair of digits indicating the serial number of the trace. For example, Trace 04-05 was initiated in 2004 and was the fifth trace initiated in the study.

A total of 41 dye introductions that demonstrated 59 groundwater flowpaths were included in the Section 5 studies (see **Appendix F**). Twenty relevant dye traces from previous studies and other sources were included in this investigation.

2.4 Tracer Dyes Sampling and Analysis Methodologies

Sampling for tracer dyes was based primarily on activated carbon samplers with additional data from selected analysis of water grab samples. All analysis was conducted using a Shimadzu RF5301 spectrofluorophotometer operated under a synchronous scan protocol. Details of the analytical approach are presented in OUL's procedures and criteria document (**Appendix C**). The following sections discuss the details of how each type of sample was collected and handled.

2.4.1 Activated Carbon Samples

All four of the dyes used in this investigation (fluorescein, eosine, rhodamine WT, and sulforhodamine B) can be adsorbed onto laboratory grade coconut shell charcoal samplers. The samplers were placed in the water to be sampled and were left for periods which ranged from a few days to two weeks or more based upon project needs in the professional judgment of the onsite geologist.

Activated carbon samplers (samplers or packets) were used as the primary sampling matrix because they sample continuously and accumulate dyes. Two samplers were placed at each sampling station, except for one location that was sampled from a private well. The use of two samplers allowed for analysis of duplicate samples, and provided a redundant sample in case a sampler was lost or damaged.

In the event that one sampler was deemed to be less representative than the other, the preferred sampler was folded and placed in the Whirl-Pak® bag. A note was put on the Sample Collection Data Sheet to indicate that the folded packet was to be analyzed. If both samplers were absent or out of the water, then the grab sample of water was the only sample available for that sampling period at that station.

Sample stations were established in flowing water at springs and surface streams and anchored with wire or rope to sticks, rocks, roots, etc. as appropriate. Only materials free from dye were used, and the anchors were set to maintain contact between the samplers and the water being tested. Samplers were concealed to minimize disturbances from passersby.

Upon collection, activated carbon samplers were placed in a new Whirl-Pak® bag labeled with the station name, number, date and time of collection. Samples collected in the field were placed in a cooler with blue ice and maintained under refrigeration until shipment to OUL for analysis. Throughout the sampling collection, handling and shipping, the samples were accompanied with a chain-of-custody type form called “Sample Collection Data Sheet for Fluorescence Analysis.” The samples were maintained in the custody of the sampler until shipment to the laboratory. The sample station name, number, time of sample placement, time of collection, collector, and sampling comments were documented on the form. Sampler placement and collection was conducted by both OUL and Baker Professional Geologists following training of Baker staff by OUL personnel.

Upon receipt of sampler coolers at the OUL laboratory, samples were immediately refrigerated at 4° C, pending analysis. Prior to analysis, the sample shipment was compared to the Sample Collection Data Sheet to ensure that all samples were received and that there were no discrepancies between the information on the form and the information on the sample containers. All analysis work was conducted by OUL personnel.

2.4.2 Water Samples

Water samples were collected when a station was established and when carbon packets were collected. Water samples were collected with disposable 50 milliliter (ml) vials dipped into the water to be sampled. Water samples were collected downstream of the carbon packets in order to minimize potential cross contamination from other locations and to minimize turbidity in the water sample. The sample handling was performed following the same handling and tracking procedures and described in **Section 2.4.1** above, similar to the activated carbon sample.

Water samples in storage were selected for analysis according to the following criteria:

- As the first sample collected when the sampling station was established (for background fluorescence).
- If dye was detected in the associated carbon sample.
- In the event that the carbon samplers had been lost or damaged.

Following sample selection, approximately 2.5 ml of the water sample was withdrawn with a disposable pipette and placed in a disposable cuvette for analysis in a spectrofluorophotometer operated under a synchronous scan protocol by OUL personnel.

The water samples provided data for the following:

- Indication of the quantities of dyes present at the time of collection.
- Support for the carbon sampler results.
- Comparison of dye concentrations in water to concentrations derived from the associated carbon samplers to aid in characterization of flowpaths.
- Estimation of dye concentration reduction rates to nondetect or background levels.

2.5 Annual Pollutant Load Estimates

2.5.1 Pollutant Loads from Highway and Right-of-Way

Pollutant loading calculation procedures are based upon models developed to predict pollutant loads without field measurements presented in an FHWA training course. The modeling procedure was developed based on a monitoring program conducted in 1976 and 1977 at sites in Milwaukee, Wisconsin; Harrisburg, Pennsylvania; Nashville, Tennessee; and Denver, Colorado. The model uses Total Solids as the carrier pollutant for the model because they showed the highest correlation with the other monitored quality parameters when regression analysis was performed.

The methodology acknowledges some limitations of the model due to the complex interaction of rainfall, runoff and traffic on highways. These limitations include: 1) geographic locations with low intensity, frequent rainfalls (i.e. Pacific Northwest – this is not believed to generally be a concern in Indiana); 2) procedure should be limited to non-winter periods; 3) procedure is better suited to continuous simulation using daily rainfall records covering periods of at least one month; 4) model assumes the highway area to be uniformly characterized by the three site types listed (this project was assumed to be a Type II highway with some curb or barrier, structured drainage, and grassy right-of-way); 5) predicted pounds of total solids washed off during a rainfall event are dependent upon the model prediction of the surface load at the start of the storm, if the surface load is underestimated, the pounds discharged will be low; 6) use of average runoff rate to remove surface pollutants is the quickest and easiest method; 7) long dry periods and overlapping storms present predictive problems in determining the pre-storm surface load; and, 8) construction activities are difficult to simulate unless monitoring data is available.

The pollutant loads were calculated for each karst feature within the right-of-way (ROW) but outside (or with portions outside) the construction limits of the I-69 Refined Preferred Alternative 8. All features inside the construction limits were assumed to be filled and capped. Therefore pollutant loading for those features will be zero. Any springs inside the construction limits will be provided with a “spring box” as well as drainage culvert to perpetuate the natural flow of the stream discharge.

The pollutant loading estimates were modified into concentrations by taking the loadings and dividing by the volume of rain water (for a particular rain event) inside the right-of-way that would drain into the karst feature. Concentrations of pollutants were then compared to Indiana’s Water Quality Standards for aquatic life and drinking water. These standards are from Indiana Administrative Code (327 IAC 2-1-6) and assume a hardness of 250 mg/L. The five pollutants that are exceeded the most often are lead, copper, total nitrogen, cadmium and mercury. The FHWA course materials state that caution must be used when interpreting the pollutant loadings of lead predicted by the model. The reduction in lead in gasoline has resulted in an estimated 50% reduction in lead loadings since the predictive equation was developed.

The pollutant loading calculations represent estimates of pollutant loads. Several assumptions had to be made to conduct this analysis at early stages of the project design. These assumptions overestimated the pollutant loads; for example, it is assumed that the entire length of right-of-way within the feature drainage area drains directly into an opening in the feature. In many cases, this is highly unlikely. For instance, if a karst feature is located on the backslope of a ditch along the southbound lane, there is no guarantee that highway runoff from the median or ditch along the northbound lane would drain to the karst feature. Also, where multiple karst features are located within the same right-of-way drainage area, the pollutant loading calculation for each feature assumed no runoff would drain into the other features. In all likelihood, the karst features would share the runoff volumes. Finally, the roadside and median ditches are designed for conveyance and outlet into streams and creeks, not into karst features such as sinkholes or swallets. Therefore, it is reasonable to assume that runoff would not find its way to a feature, instead traveling along the ditch grades and culverts as designed and constructed. The pollutant loading calculation assumed the entire right-of-way would drain into the karst feature, and not be conveyed elsewhere.

Pollutant loads were calculated for pre- and post-construction conditions. The calculation procedures are based upon models developed to predict pollutant loads without field measurements presented in a Federal Highway Administration (FHWA) training course. The first part of the model calculates pollutant load estimates, developed in the late 1970's using field data from monitoring programs in various states. The second part estimates the pollutant concentrations and compares them to water quality standards. The third part estimates the pollutant loads in the "background", or what occurs before the highway is built. This methodology is included in **Appendix L** of this document.

Since the construction phasing of Section 5 is not yet determined, during-construction load estimates were not performed. As part of the construction and construction oversight, strict adherence to the erosion control measures is essential. Runoff and sediment control will be performed during construction in accordance with Rule 5, Item B1 of the Erosion and Sediment Control plans developed in compliance with the Indiana Handbook for Erosion Control in Developing Areas (Division of Soil Conservation, Indiana Department of Natural Resources). According to the "Results of MOU-Related Karst Studies for Indiana State Road 37, Lawrence County, Indiana (1992-1995)" (EarthTech, 1997), there were elevated levels of Total Suspended Solids (TSS) and Total Recoverable Metals (TRM) to the subsurface associated with the during-construction activities for the SR 37 project. These levels returned to pre-construction conditions about two years after construction.

When discussing the results of the SR 37 Study ("Results of MOU-Related Karst Studies for Indiana State Road 37, Lawrence County, Indiana (1992-1995)", in relation to the I-69 project, it is acknowledged that the determination and installation of karst drainage structures for the SR 37 project was done when construction had already begun, allowing less time for planning and design. Therefore, some drainage structures, and associated detention basins, were not designed to handle the correct amount of runoff capacity. Some additional sinkhole excavation was needed to increase the size of the drainage structure and/or detention basin. This sinkhole excavation, done during the road construction, contributed to higher levels of TSS. The SR 37 Study states, when speaking of the temporary increases in pollutant loadings, "This is not likely to be a problem for future construction projects that are fully carried out within the MOU framework" (SR 37 Study, page 66). The strategy to avoid subsurface contamination of TSS and TRM will be contained in the Erosion Control Plan and fulfillment of the Rule 5 requirements. Erosion Control standards and specifications have changed and improved since the SR 37 project.

2.6 Review of IDNR Water Well Data

In their comment letter dated August 3, 2007, on the Section 5 Draft Karst Report the USEPA suggested that IDNR, Division of Water, water well database should be included in this study to document local water tables and to determine the flow conditions under which the dye traces were conducted.

Because karst groundwater is moving through conduits and flowpaths may intersect within a given karst formation, there may be little correlation between the "water table" as measured in wells and a karst conduit flow system in the vicinity. Many assumptions would need to be made regarding well connectivity to and influence from a karst conduit system versus the consolidated formation system, as well as the status of the seasonal influence on these water levels across the wide ranging timeframe of the IDNR well dataset. The undissolved rock (in which wells are typically placed) usually has several orders of magnitude less hydraulic conductivity than does the turbulent flow regime in the karst conduits; and therefore, response times are quite different. These factors limit the usefulness of IDNR water well data for the analyses recommended. The data were reviewed to identify references to karst voids and for assessment of major structural issues. The data may be reviewed and compared to geotechnical boring data utilized for final design of the project. Water well locations and logs in the vicinity of the Section 5 Corridor are depicted on **Figure 4a** and included in **Appendix M**.

2.7 Cave Biology

Accessible caves and related springs with hydraulic or physical connection with the alternatives being advanced were surveyed for biological fauna. A reconnaissance-grade biological survey was conducted by an OUL Professional Geologist with cave bioinventory experience in each cave demonstrated to have relevance to the Section 5 Corridor. During the reconnaissance, a state-listed crayfish was observed in a cave with mapped passages that cross under SR 37 and a recharge area that crosses the Section 5 Corridor.

Based on this reconnaissance and the relevance to the Section 5 Corridor, an additional task was requested for evaluation of troglobitic species by a cave biologist. The task was approved, and Dr. Julian Lewis of Lewis and Associates was contracted to conduct biological surveys via two entrances into one cave system and a nearby cave/karst window, which are all the caves that have extant entrances that are related to Section 5.

The following information is summarized from the *Interstate 69 Evansville to Indianapolis Tier 2 Studies: Section 5 Cave Fauna Report* dated September 2005 (**Appendix J**). Note in reference to **Appendix J,** the State Listing Status has been updated since the completion of Dr. Lewis' report (Lewis, 2005) for the following:

State Listed Species	2005 Status	2012 Status
• Indian cave springtail	State Endangered	State Watch List
• Packard's groundwater amphipod	State Rare	State Watch List
• Cave crayfish	State Threatened	State Rare
• Barr's cave crayfish	not listed	State Watch List
• Bollman's cave millipede	State Rare	State Watch List

Sample method type, timing, and location selection were based upon the conditions encountered in the caves at the time of sample introduction/collection, methods developed during sampling in numerous similar caves, and the professional judgment of the cave biologist, Dr. Lewis.

The methods of sampling included some or all of the following:

- Manual collection.

- Placing of pitfall traps that consisted of four-ounce glass specimen jars filled with 70% isopropyl alcohol as a preservative and baited with limburger cheese spread.

- Collection of leaf litter for Berlese extraction.

- Placement of shrimp-baited jars in the deeper water of the karst window.

- Extraction of interstitial aquatic fauna via the Karaman-Chappuis method.

The baited jars holding water samples were placed in a cooler and transported to the laboratory where samples were placed in petri dishes and examined for living fauna under a dissecting microscope. Litter taken from the cave was placed in a Berlese funnel (with overhead light/heat) for extraction of the invertebrates into a vial of 40% isopropyl alcohol. Pitfall residues were screened, then transferred into petri dishes for sorting of the fauna under a dissecting microscope. Specimens of each taxon were placed in 3 or 4 dram vials of 40% isopropyl alcohol and labeled per cave of origin, state, county, distance to nearest town, date and collector. The samples were maintained in the custody of the sampler (Dr. Lewis) during collection, transport to the laboratory, and during preparation and examination.

Some taxa required the use of outside taxonomists for specific identification. These taxonomists were part of the Lewis Project Team (**Appendix J**). Samples were prepared as appropriate for taxa specific identification and shipped in accordance with the requirements of the recipient facility and state, federal, and international regulations. The identification of specimens was performed by appropriate taxonomists with familiarity with the taxa to be identified:

- Dr. Thomas C. Barr, Jr. (carabid beetles), professor emeritus, University of Kentucky.

- Dr. J. P. Battigelli (collembolans), consultant, Earthworks Research Group.

- Dr. Lynn Ferguson (diplurans), professor, Longwood University.

- Dr. Robert Hershler (aquatic snails), curator, Department of Invertebrate Zoology, Smithsonian Institution.

- Dr. John R. Holsinger (amphipods),professor, Department of Biological Sciences, Old Dominion University.

- Dr. Pierre Paquin (spiders), post-doctoral fellow, Department of Biological Sciences, San Diego State University.

- Dr. Janet Reid (copepods), research associate, Virginia Museum of Natural History.

3.0 RESULTS

This section summarizes the results of the karst feature mapping, dye tracing, recharge area delineations, and biological surveys of caves.

3.1 Karst Features

Karst features included sinkholes, springs, karst flowpaths, caves, and others (losing streams and sinking streams). In accordance with the 1993 MOU, the location, type, area, and significant characteristics of karst features were researched, field checked, documented and imported into a GIS for evaluation relative to SR 37 and Section 5. The Section 5 Corridor and those areas hydrologically connected through the karst were searched for the presence of these features. The results for each of these features are discussed in the following subsections.

3.1.1 Sinkholes and Other Insurgence Features

The research and field checks identified 446 sinkholes (including sinks within larger sinkholes and some sinkholes outside the Corridor), five losing/sinking stream basins, and 21 filled or appreciably modified sinkholes. Photographs of select karst features are included in **Appendix E**. **Figures 7a and 8a** show the distribution of insurgence features in the Bloomington, Bloomington North, and Simpson Chapel Karst areas with land use, based on consolidated terms from field reviews and updates of a GIS land use layer provided by the Monroe County Planning Department. **Figures 7b, and 8b** show the insurgence features on an aerial photo base.

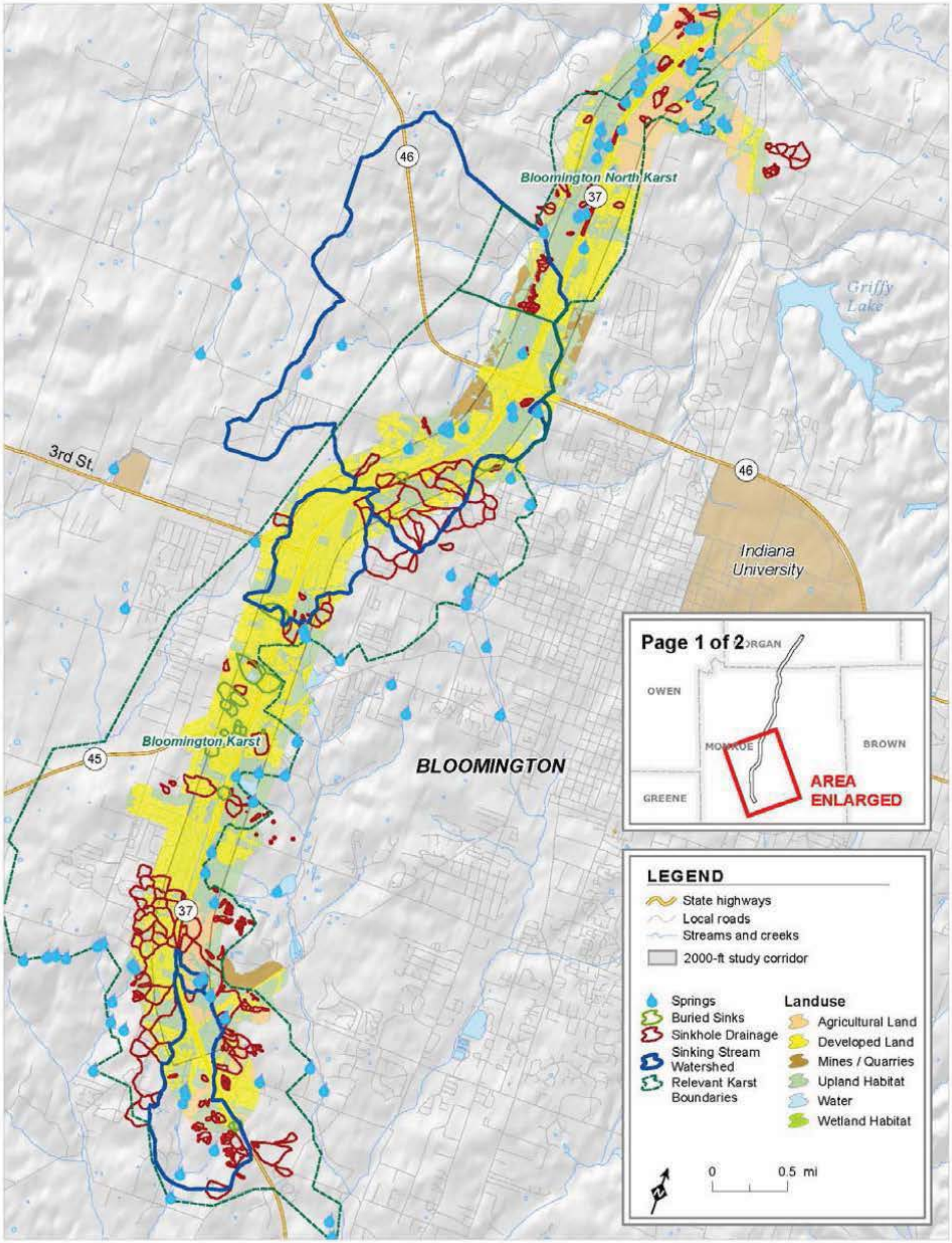

Figure 7a **Sinkholes/Insurgence Features and Land Use – Bloomington and part of Bloomington North Karst**

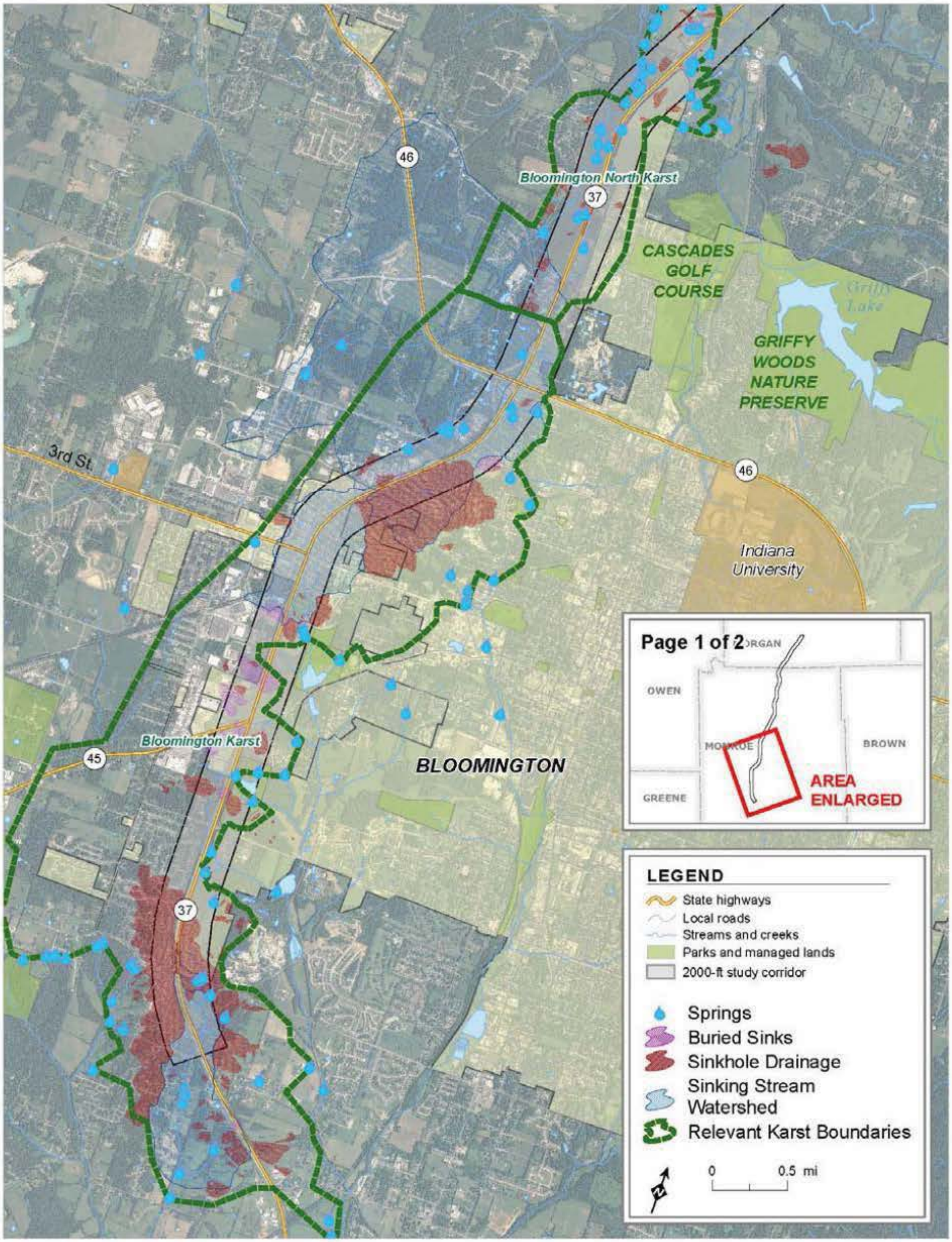

Figure 7b Sinkholes/Insurgence Features on Aerial Background – Bloomington and part of Bloomington North Karst

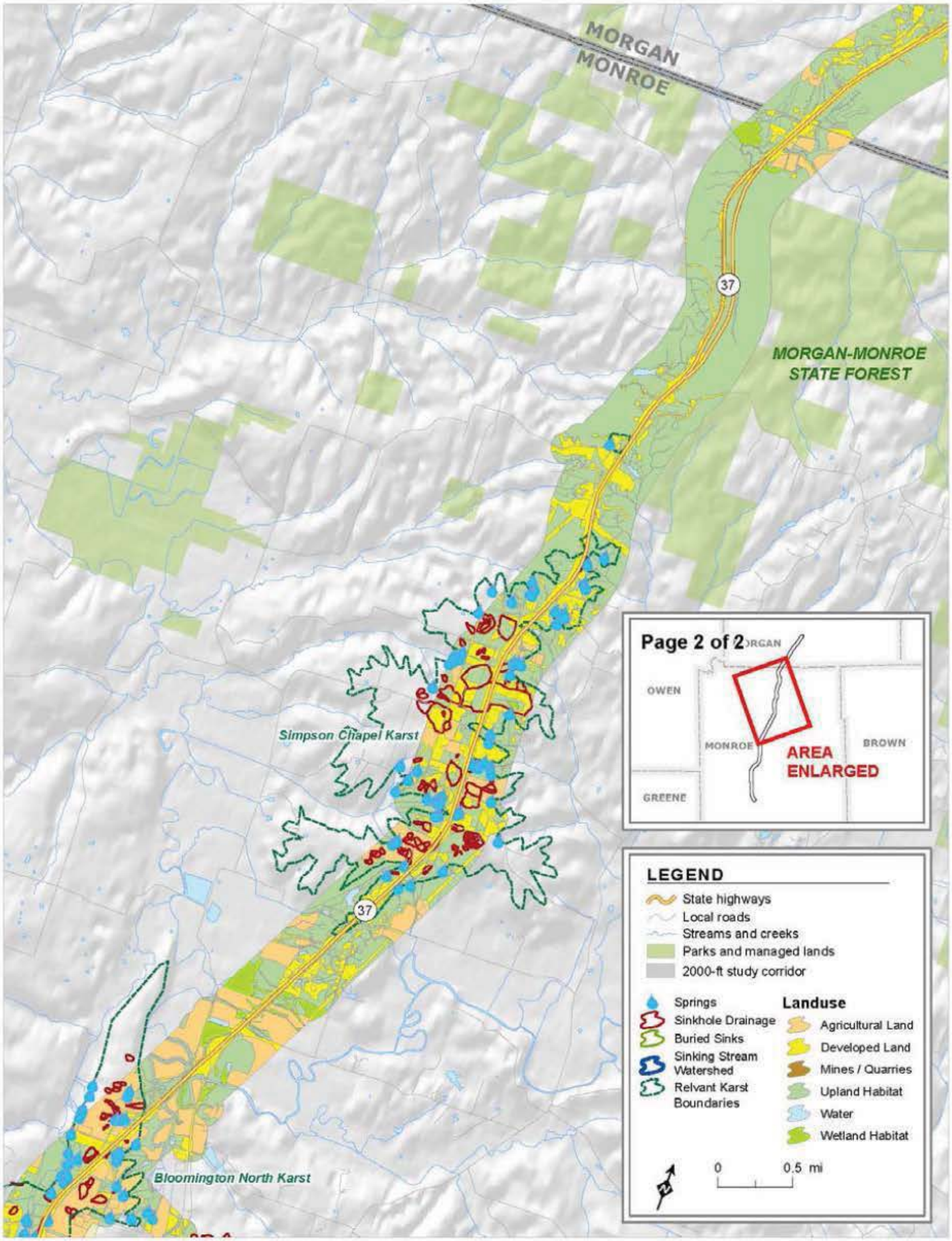

Figure 8a **Sinkholes/Insurgence Features and Land Use – part of Bloomington North and Simpson Chapel Karst**

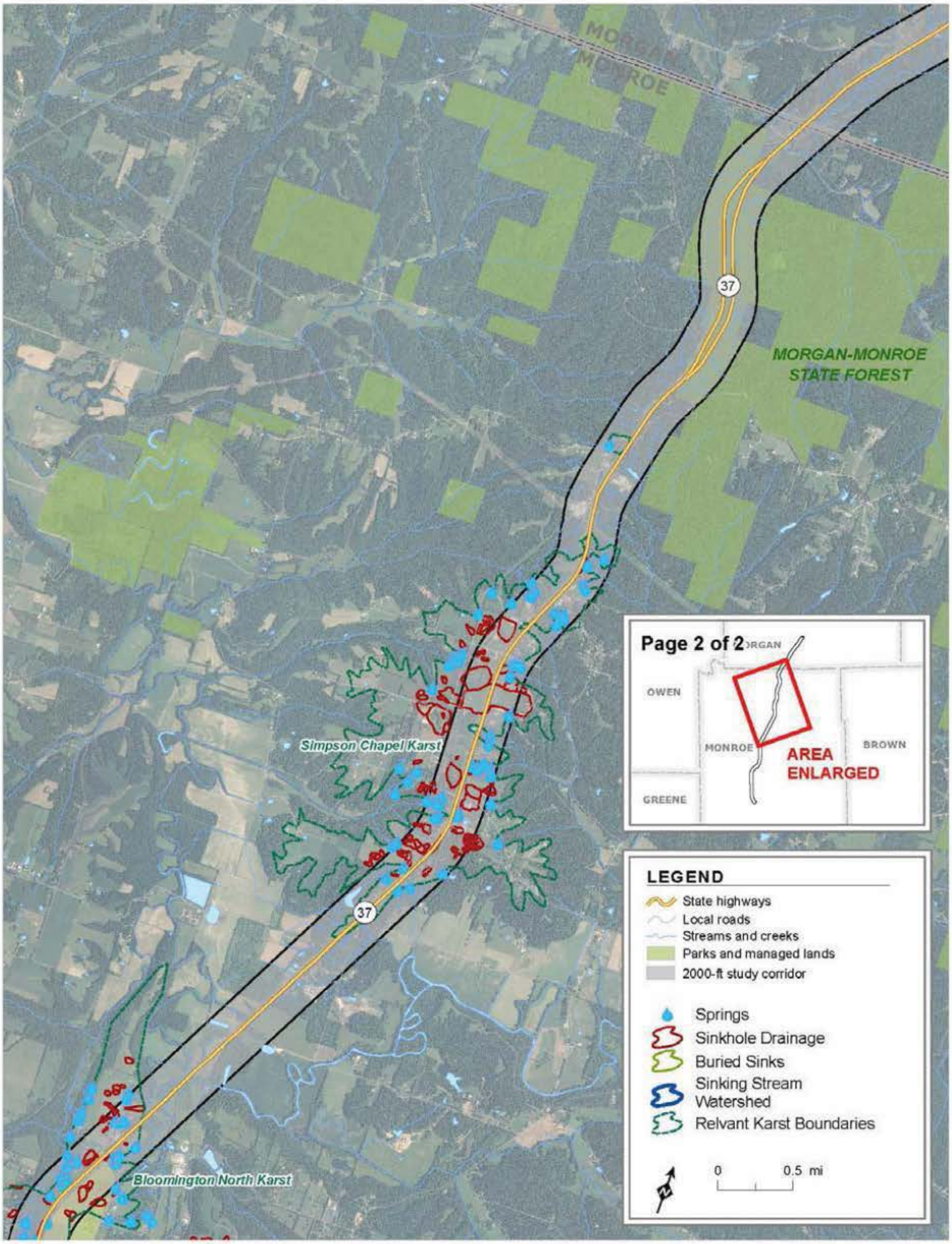

Figure 8b Sinkholes/Insurgence Features on Aerial Background – part of Bloomington North and Simpson Chapel Karst

Several insurgence features were observed capturing runoff from SR 37 through sinks that have formed or reopened in ditches along SR 37 or existing sinks that were used as part of the SR 37 and Bloomington drainage systems.

Three of the five losing or sinking streams had much larger topographic watersheds than sinkholes and were identified from south to north:

- An unnamed tributary of Clear Creek whose headwaters are near the intersection of Rockport Road and SR 37 (**Figure 5**). The tributary flows nearly south from the northernmost reaches that recharge Spring to the southern reaches that recharge (Station 73 on **Figure 5**). The stream loses all of its water at low flows near Spring (Station 74 on **Figure 5**). At higher flows, there is appreciable water throughout its course.

- A sinking stream basin centered near the intersection of 3rd Street and SR 37 and along SR 37 (**Figure 5**). This basin drains to the south through a detention pond and passes under SR 37 to its sink point on the SR 37 ROW. This stream resurges at Stoney Spring West A (Station 79 on **Figure 5**). Its northern topographic basin boundary is shared, in part, with the southern basin boundary of Stout Creek.

- Stout Creek, which, at low flow conditions near Hoadley Quarry between Hunter Lane and Arlington Road, loses all of its water into the karst groundwater system (**Figure 5**). At normal to high flow, there is water throughout the channel. The lost water resurges into the Stout Creek channel at multiple points between Station 89 (Lower Stout Spring) and Acuff Road.

Sinkholes that had been deliberately filled as a part of development projects were relatively obscure karst features and difficult to identify. These sinks were identified from old topographic and roadway mapping, and stereophotography taken in 1939, prior to construction within the Section 5 Corridor. While most of the buried sinkholes drain to their current discharge points through culverts, they contribute little to no water to the karst groundwater system. Some of these filled sinkholes appear to be unstable and presumably in the process of reopening and thus reactivating the historic hydrologic role of the sinkhole.

In addition to sinkholes identified during this study, unidentified bedrock sinkholes likely exist that have been naturally filled with loess. These sinks have no surface expression, but have the potential to reopen catastrophically through internal erosion in the form of soil pipes and stoping (undercutting). This process is speeded up when excess water is directed to them by regrading or other redirection of runoff.

The research and field reconnaissance was appropriate and thorough, however, the presence of karst features beyond those identified in this study is likely, and is partly a function of the dynamic nature of the karst systems as well as historical development in the study area.

3.1.1.1 Drainage Area

The drainage area of each of the karst insurgence features (sinkholes/losing streams) was based on the results of the karst feature research and field checks imported into a GIS database. All land contributing to a specific karst insurgence feature was based on two-foot contour topography and included within the drainage area boundaries. The acreage was calculated in GIS based on these boundaries and summarized (**Appendix D** - Table D-2), and the insurgence features are depicted in **Figures 5 and 6**.

Land uses were identified in GIS based on a field review and update of land use files provided by Monroe County. Land uses represent the developed and undeveloped land cover found within the study area in 2010, based on field reviews and updates of a GIS land use layer provided by the Monroe County Planning Department. Acres of planned development anticipated by 2035 were developed as a GIS layer based on TIF districts in coordination with local planning officials at the City of Bloomington and Monroe County and the Expert Land-Use Panel. Land use within the relevant karst areas are illustrated in **Figures 7a and 8a** and are summarized below.

Table 3 Relevant Karst Land Use for Section 5 Study Area[8]

Land Use in 2010	Bloomington Karst (acres)	Bloomington North Karst (acres)	Simpson Chapel Karst (acres)	Acreage of Land Use in Relevant Karst	Percentage of Land Use in Relevant Karst
Agricultural	101	181	92	374	9.9%
Nonresidential/ Industrial	100		10.	110.	2.9%
Public Use and Institutional	330	59	18	471	12.4%
Mines and Quarries	35	11	0	45	1.2%
Residential	448	74	147	639	17.6%
Water	12	2	1	15	0.4%
Transportation, Communication and Utilities	484	116	150	750	19.71%
Upland and Wetland Habitat	726	269	370	1,365	35.9%
Totals	**2,236**	**738**	**825**	**3,799**	**100%**
Acres of Planned Development anticipated by 2035[9]	*550*	*246*	*0*	*796*	*21%*

8 Updated since the 2006 Karst Report as part of the Section 5 DEIS (such as land cover, land use, population growth, planned development, setting, bedrock, Monroe County 2010 aerial photography and 2-foot contours) (see **Section 1.1**).

9 Specific sites of planned development were identified during the coordination process with planners and the Expert Land-Use Panel from the City of Bloomington and Monroe County and placed in the project GIS. This development is anticipated to occur independent of the proposed project.

Note: the karst areas extend beyond land use data sets, and therefore, the land use acreages above are for only the 2,000-foot Section 5 Corridor.

To summarize, as previously discussed in **Section 1.4**, and illustrated by the data shown above, the relevant karst in the Section 5 study area has been affected by the residential and commercial/industrial development of the Bloomington area. Moreover, this development is projected to continue regardless of upgrading of SR 37 to I-69.

3.1.2 Springs

Springs and other resurgence features located and documented as part of this study included 26 relevant springs from I-69 Tier 1 data, and 143 additional springs (**Figures 9 and 10**). The majority of springs (approximately 80%) were located along geologic formation contacts.

Bloomington Karst springs typically discharge at the base of the St. Louis Limestone while the Bloomington North and Simpson Chapel Karst springs typically discharge on top of a relatively thick bed of fossiliferous limestone at the base of the Ramp Creek formation. These springs tend to be slightly above the limestone-shale contact, but are typically found in valley heads.

Table 4 shows the relevance of the springs to the proposed road alignment. The “springs linked by dye tracing” have had hydrologic linkage to the Section 5 Corridor demonstrated by dye traces initiated in the Section 5 Corridor. Some of these springs are within the Corridor, but most are located outside the Section 5 Corridor. “Springs located in the Corridor” are related to the Section 5 Corridor by their physical location in the Section 5 Corridor. These may or may not receive recharge from the Section 5 Corridor. The “springs linked by logical inference” to the Corridor are springs that are generally: 1) located proximate to the Section 5 Corridor; and, 2) the flow direction of the spring and the surrounding geology indicate that parts of the Section 5 Corridor provide some or most of their recharge. The flow patterns revealed by the dye tracing investigation and the surrounding geology indicate that the springs classified as “not related to the Corridor” would not derive water from the Section 5 Corridor. The final column “springs where relevance was not determined” in **Table 4** are the springs for which the evidence is not clear as to whether they are recharged by water from the Section 5 Corridor.

Table 5 provides estimated discharge rates for most of the springs visited during the study. While there are a relatively high number of springs found in the area, these are generally springs with small baseflow discharges and therefore, have small recharge areas. None of the springs are known to provide water for human consumption. A few of them are used for watering livestock. Photos of the springs (and other sampling stations) are included in **Appendix E**. Photos 1 and 2 are shown below as examples of typical small springs that receive water from the Section 5 Corridor.

Of the 131 relevant springs related to the 2,000-foot Section 5 Corridor, 25 were from 0 to 1 gallons per minute (pm) when observed, 63 were 2 to 10 gpm, 32 were 11-100 gpm and 11 were greater than 100 gpm.

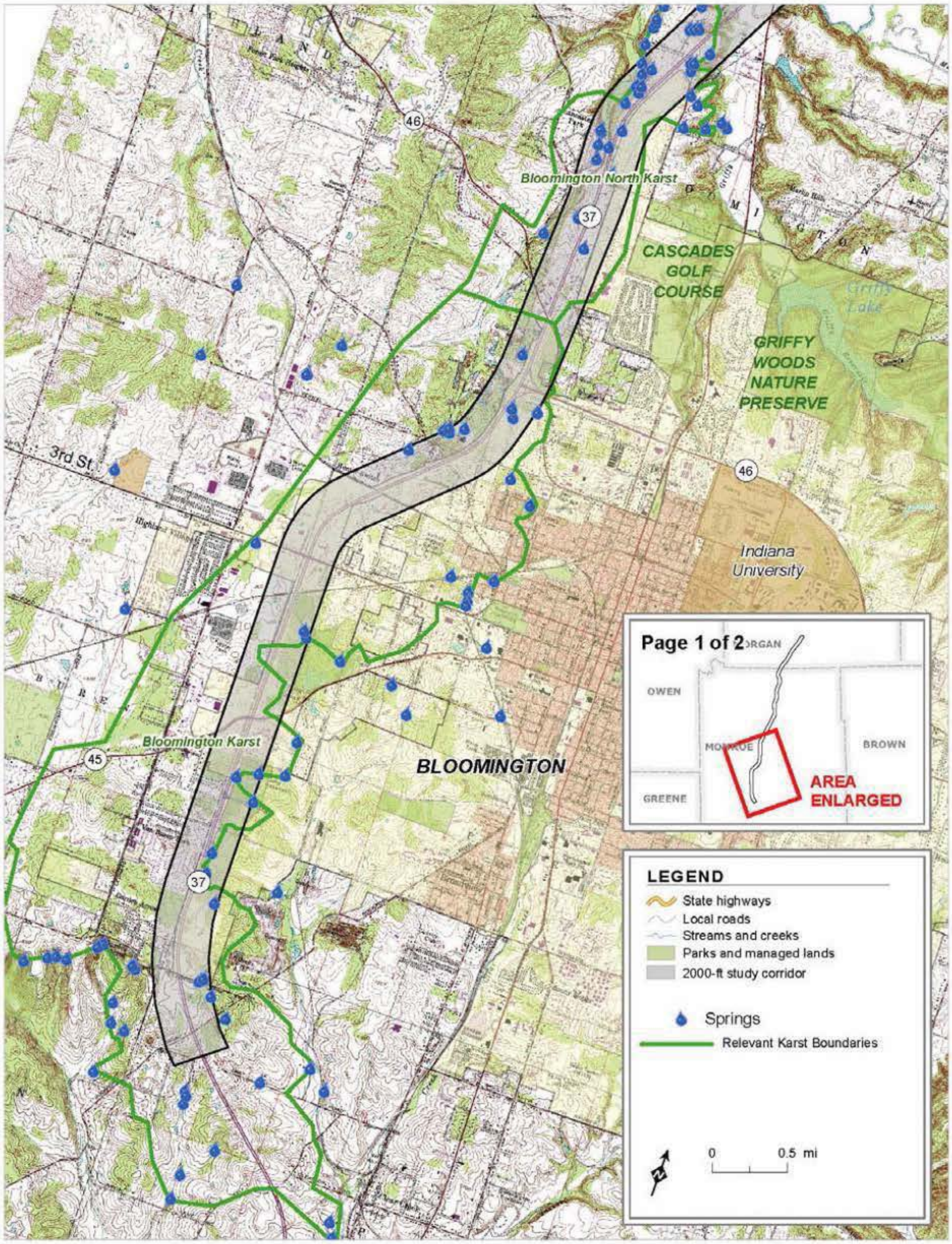

Figure 9 **Locations of Springs – Bloomington and part of Bloomington North Karst**

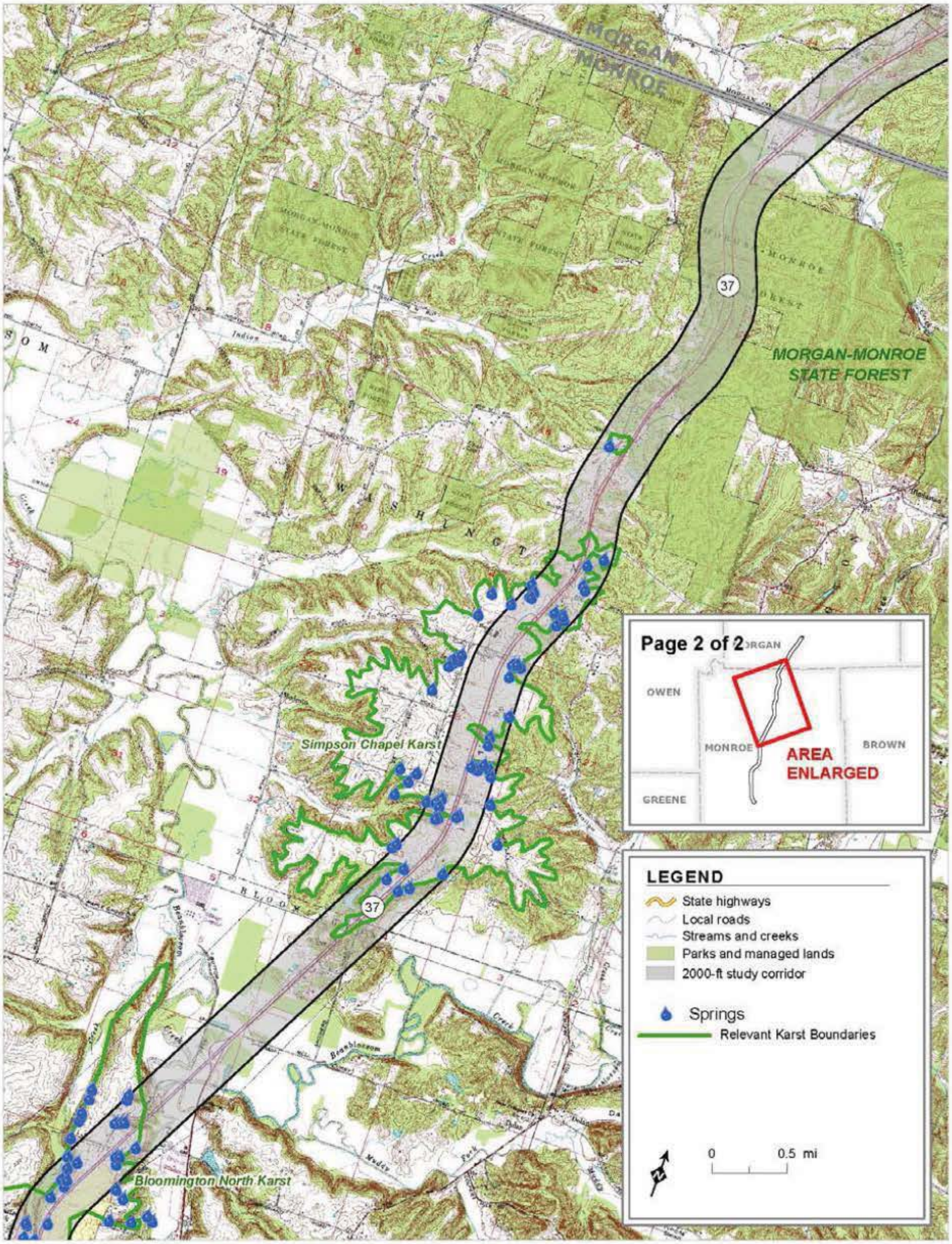

Figure 10 Locations of Springs – part of Bloomington North and Simpson Chapel Karst

Photo 1: **Spring (Station)**

Photo 2: **Spring (Station)**

Table 4 Spring Relevance

37 Springs Linked by Dye Tracing	65 Other Springs in the Corridor	29 Springs Linked by Logical Inference	28 Springs Not Related to the Corridor	12 Springs where Relevance was not Determined

Table 4 Spring Relevance

37 Springs Linked by Dye Tracing	65 Other Springs in the Corridor	29 Springs Linked by Logical Inference	28 Springs Not Related to the Corridor	12 Springs where Relevance was not Determined

Table 5 Estimated Discharge for Relevant Springs

Station Number	Station Name	Date	Estimated Discharge (Gpm)	Flow Conditions (At Time Of Estimate)
	Spring	5/20/04	200	base
	Spring	1/5/05	2,025	storm response
	Spring	5/19/04	2,500	base
	Spring	5/20/04	8	base
	Spring	1/5/05	30	storm response
	Spring	5/20/04	350	base
	Spring	5/20/04	220	base
	Spring	5/21/04	5	base
	Spring	1/5/05	160	storm response
	Spring	5/21/04	3	base
	Spring	1/5/05	100	storm response
	Spring	5/21/04	5	base
	Springs	5/21/04	10	base
	Springs	5/21/04	90	base
	Spring	6/14/05	2	base
	Spring	6/14/04	71	base
	Spring	1/5/05	300	storm response
	Spring	6/9/04	40	base
	Spring	1/5/05	2,200	storm response
	Spring	6/9/04	25	base
	Spring	6/9/04	1	base
	Spring	6/9/04	100	base
	Spring	1/5/05	2,000	storm response
	Spring	6/9/04	75	base
	Spring	1/5/05	2,000	storm response
	Spring	6/9/04	900	base
	Spring	1/5/05	1,200	storm response
	Spring	7/21/04	20	base
	Spring	1/5/05	70	storm response
	Spring	8/31/04	10	base
	Spring	8/31/04	3	base
	Spring	8/31/04	10	base
	U/S Spring	8/31/04	1	base
	Spring	8/24/04	25	base
	Spring	1/5/05	300	storm response
	Spring	8/24/04	600	base
	Spring	1/5/05	4,000	storm response
	Spring	9/3/04	1	base
	Spring	9/28/04	1	low
	Spring	1/5/05	20	storm response
		9/28/04	2	low
	Spring	10/6/04	10	low
	Spring	10/6/04	90	low
	Spring	1/7/05	85	storm response
	Spring	1/7/05	20	storm response
	Spring	1/7/05	45	storm response
	Spring	1/7/05	15	storm response

Table 5 Estimated Discharge for Relevant Springs

Station Number	Station Name	Date	Estimated Discharge (Gpm)	Flow Conditions (At Time Of Estimate)
	Spring	1/7/05	65	storm response
	Spring	1/7/05	50	storm response
	Spring	1/7/05	20	storm response
	Spring	1/7/05	40	storm response
	Spring	4/20/05	3	base
	Spring	1/7/05	8	storm response
	Spring	1/7/05	12	storm response
	Spring	1/7/05	40	storm response
	Spring	1/7/05	15	storm response
		1/7/05	105	storm response
	Spring	1/9/05	10	storm response
	Spring	1/9/05	10	storm response
	Spring	1/9/05	30	storm response
	Spring	1/9/05	8	storm response
	Spring	4/12/05	0	low
	Spring	4/20/05	0	low
	Spring	1/9/05	90	storm response
	Spring	1/9/05	35	storm response
	Spring	1/9/05	15	storm response
	Spring	1/9/05	12	storm response
	Spring	1/9/05	6	storm response
	Spring	1/9/05	10	storm response
	Spring	1/14/05	18	base
	Spring	1/20/05	4	base
	Spring	1/20/05	1	base
	Springs	1/20/05	4	base
	Spring	2/1/05	3	base
	Spring	2/2/05	1	base
		2/2/05	800	base
	Spring	2/3/05	3	base
	Spring	2/3/05	3	base
	Spring	2/4/05	3	base
	Spring	2/4/05	2	base
	Spring	2/4/05	4	base
	Spring	2/4/05	<1	base
	Spring	2/11/05	1	base
	Spring	2/11/05	2	base
	Spring	2/11/05	4	base
	Spring	2/11/05	3	base
	Spring	2/11/05	3	base
	Spring	5/22/05	2	base
	Spring	2/25/05	3	base
	Spring	2/25/05	4	base
	Spring	2/25/05	7	base
	Spring	2/25/05	2	base
		3/25/05	7	base
	Spring	3/16/05	18	base
	Spring	3/25/05	2.5	base

Table 5 Estimated Discharge for Relevant Springs

Station Number	Station Name	Date	Estimated Discharge (Gpm)	Flow Conditions (At Time Of Estimate)
	Spring	3/16/05	5	base
	Spring	3/16/05	30	base
	Spring	3/16/05	25	base
	Spring	3/25/05	3	base
	Spring	3/25/05	4	base
	Spring	3/25/05	8	base
	Spring	3/16/05	20	base
	Spring	3/25/05	8	base
	Spring	3/16/05	0.25	base
	Spring	3/25/05	6	base
	Spring	3/25/05	1.5	base
	Spring	3/25/05	0.5	base
	Spring	3/25/05	6	base
		3/23/05	40	base
	Spring	3/16/05	1	base
	Spring	3/25/05	1.5	base
	Spring	3/25/05	2	base
	Spring	3/25/05	8	base
	Spring	3/25/05	1	base
	Spring	3/25/05	3	base
	Spring	3/25/05	1	base
	Spring	3/25/05	5	base
	Spring	3/25/05	3	base
	Spring	3/25/05	1	base
	Spring	3/25/05	4	base
	Spring	3/25/05	3	base
	Spring	3/25/05	2	base
	Spring	3/25/05	1.5	base
	Spring	3/25/05	10	base
	Spring	3/30/05	1	storm response
	Spring	4/2/05	8	storm response
	Spring	4/3/05	6	storm response
	Spring	4/3/05	10	storm response
	Spring	4/3/05	3	storm response
	Spring	4/3/05	1	storm response
	Spring	4/3/05	15	storm response
	Spring	4/3/05	2	storm response
	Spring	10/7/08	3	base
	Spring	12/4/08	1	base
	Springs	12/4/08	400	
	Spring	1/23/09	1	base
	Spring	3/17/09	200	
	Spring	5/24/06	2	base
	Spring	5/24/06	2	base
	Spring	5/24/06	2	base
	Spring	5/24/06	4	base

3.1.3 Karst Flowpaths

Fifty-nine karst flowpaths have been shown to drain to or from the Section 5 Corridor including dye introduction points that receive surface runoff from the Corridor. An additional eight karst flowpaths were demonstrated, or are included for their use in recharge area delineation. In addition, there are three more karst flowpaths that have been included because of their proximity to the Corridor. All of these flowpaths have been demonstrated by linking a dye introduction location to one or more springs. The dye traces shown on **Figures 12 and 13** are diagrammatic representations of a karst flowpath. The only mapped karst flowpaths in Section 5 are in Cave, which was mapped in the 1950s (Roy and Wells, 1959).

Fourteen karst flowpaths cross under one or both lanes of SR 37, and 131 springs were either within the Corridor, linked by dye tracing, or linked by logical inference(see **Section 3.3**), Each of these springs presumably has an associated karst flowpath.

An appreciable portion of one of these streams was carried under SR 37 via a culvert to a sinkhole, which drains to Spring and may be the location of a covered cave conduit (see **Section 3.1.4**).

3.1.4 Caves

A number of cave entrances that were reported are no longer accessible. These include Cave, Cave (tributary to Cave), Cave, Cave (tributary to Cave), and Cave. Three accessible caves have been linked to the Corridor hydrologically or by logical inference:

- Cave has been mapped under SR 37 (Roy and Wells, 1959) and six Tier 2 and two previous dye traces were detected at its spring. **Figure 15** shows the traces in the Cave area.

- Cave is a tributary to Cave and receives runoff from the Section 5 Corridor.

- While Cave has been linked by dye tracing to the existing SR 37 and Section 4 Corridor, the Cave recharge area is over 800 feet south of the Section 5 corridor (see **Figure 15**). Cave is more accurately termed a karst window with a water filled cave passage.

ICS listed a formerly accessible cave (Cave) just west of the spring; however, IGS and OUL were not able to locate a cave entrance in this area.

An INDOT employee reported that a cave had been encountered during construction in the SR 37 right-of-way. The cave was located south of 3rd Street, south of the Indiana Railroad tracks, and east of the current Menard's store. The opening was large enough to enter, and an open area was found with some writing on its walls. The opening was not filled by the construction crew, but a box was constructed around it with concrete and rebar and the hole was spanned so that water could continue to flow and the structure was covered with fill material and the existing SR

37 system. The span was approximately three feet by three feet. Water near the cave was observed flowing from southwest to northeast (White, 2005). Cross-referencing this report with other data sources indicated this cave was most likely Cave. The cave does not currently have an accessible opening.

The majority of the information regarding caves associated with this study is considered confidential and is presented in **Appendix I**.

3.1.5 Others

Losing/sinking stream features were discussed in **Section 3.1.1** (Sinkholes and Other Insurgence Features).

Three relevant karst windows were identified and documented in Section 5. Cave was discussed in **Section 3.1.4**. The other karst window was found in a sinkhole (GIS insurgence feature No. 423) and used as a dye introduction point (Trace 05-16). Trace 05-16 is discussed in detail in **Section 3.2.2.16**. The base flow was approximately two gpm through the karst window, and both the upstream and downstream openings were too small for human access. The third karst window was found field checking the 2010 LiDAR data (GIS insurgence feature No. 2). This karst window has no accessible passage at its upstream or downstream ends.

3.2 Dye Tracing Results

A total of 41 dye introductions that traced 59 karst groundwater flowpaths were made over approximately 11.5 linear miles of relevant karst in Section 5, or approximately three traces per linear mile, not counting the traces conducted specifically for delineating the Cave recharge area. In addition, 18 traced flowpaths from the Tier 1 dataset were deemed relevant for the Tier 2 study, and two traces from Section 4's Tier 2 investigation were relevant, resulting in a total of 83 groundwater flowpaths for use during alternative evaluation, planning and design.

Dye detections shown in **Appendix B** were attributed either to Section 5 dye traces or to environmental contaminants grouped together as background fluorescence. There were also dye detections attributed to specific dye tracing activities not related to the I-69 Section 5 studies:

- Dye tracing associated with the Lemon Lane Landfill Superfund site is ongoing. Spring, Spring, Spring, and Weddle Creek consistently had significant detections of fluorescein and rhodamine WT dyes. These detections were attributed to Viacom, Inc., the company conducting the dye-tracing program at Lemon Lane Landfill.

- Other detections (such as that at Station 44) were attributed to maintenance operations at Indiana University (IU). After the first detections, IU personnel were interviewed and the results of the detections made during the Section 5 study were found to be consistent with the time and place for dye releases reported by IU personnel.

3.2.1 Previous Dye Tracing Results

The 18 relevant dye traces provided in the Tier 1 dataset are shown on **Figure 11**. Five of the 18 traced flowpaths transfer water across the sub-watershed boundaries. While none of the previous traces were started in the Section 5 Corridor, three of the traced flowpaths cross the Corridor and indicate that there are conduits of unknown dimensions (i.e. karst flowpaths) that are capable of transmitting water across the Corridor.

Additional pre-Tier 1 traces were conducted in previous studies with different dye trace and quality control methods from those performed as part of the Section 5 study. While the low concentration detections reported in a few of these traces were considered marginal, the main flowpaths they traced were reviewed and deemed suitable for inclusion in the Section 5 study.

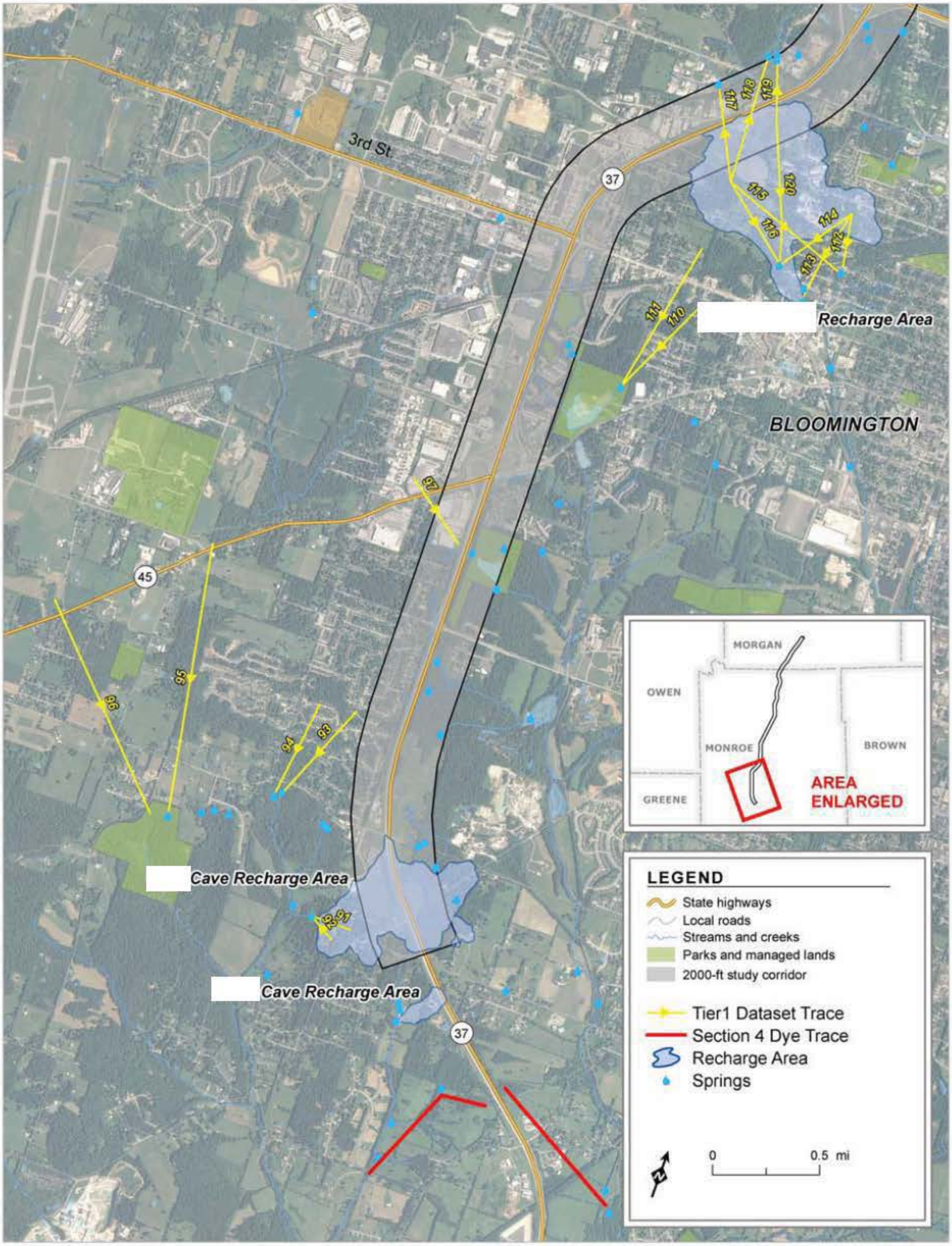

Figure 11 **Previous Relevant Dye Traces and Spring Locations and Cave Recharge Areas**

3.2.2 Groundwater Tracing Results by Individual Traces

A total of 41 dye introductions traced 59 karst groundwater flowpaths as part of the Section 5 dye-tracing program. The flowpath data presented in this report are diagrammatic; the lines representing the flowpaths are not meant to represent the actual location or distribution of the conduits. The sampling station network is shown on **Figures 12 and 13. Appendix D,** Table D-1 Sampling Stations, correlates the dye trace to the station number, the station name, and provides location information. **Appendix B** includes complete results for both activated carbon samplers and water grab samples and contains an analytical results table with columns attributing dye detections to a particular dye trace. Graphs of all analyzed samples are presented in **Appendix G**. OUL's Procedures and Criteria document is provided in **Appendix C**. Detailed descriptions, summary tables, and figures illustrating individual dye traces are presented in **Appendix F** and include:

- Amount and type of dye used.
- Elevation and location of the dye introduction point.
- Date and time of dye introduction.
- Flow conditions at the dye introduction point at the time of dye introduction.
- Locations where dye was detected.
- Elevation difference between introduction and recovery points.
- Mean groundwater flowpath gradient.
- Time of first dye detection.
- Relevance to the project.
- Figure showing the trace and its relation to the Corridor.
- Summary table of dye trace details.
- Other relevant information.

The following factors are pertinent to the individual dye traces and summaries:

- The summaries show the first detection of dye at the primary discharge point.
- The concentrations were reported in parts per billion (ppb) from activated carbon samplers, unless otherwise noted. The water concentrations were only included if they added substantially to the discussion of the results.

- "ND" means no dye was detected and "NS" means that there was no sample collected for the given time interval. Generally, "NS" means that both samplers were lost to floods or animal disturbance.

- The velocity of the dye front was based on the assumption that dye arrived at the end of the sampling period in which dye was first detected (unless there were other data available such as observations of dye discharge or more accurate times associated with grab samples of water). Often dye was detected in the same sampling period at the spring at which the dye was discharged as well as downstream sampling stations. The velocity of the dye front was calculated as the distance to the most distal sampling station that had a sample collection date *no later* than that of the sample collected from the spring. The arrival time at the spring was then calculated based on the mean velocity to the distal station and the distance to the spring.

- In some cases, residual dye was present at a sampling station when a new dye pulse arrived. In such cases, the number of the trace providing the dominant dye concentration was listed as the source.

- Sampling stations (205 total stations) were established as needed or dropped from the sampling routine throughout the investigation.

In addition to the individual trace details provided in **Appendix F**, **Section 3.3** discusses the summary of dye tracing results. **Figure 12** and **Figure 13** show all of the traced groundwater flowpaths. **Table 6** summarizes the dye trace parameters, and **Table 7** lists the dyes introduction and detections for each trace. General statements about individual dye trace results and highlights are presented below:

- 04-01: Basswood Trace - linked a sinkhole that currently receives runoff from SR 37 to Stoney Spring West A, which is also within the Section 5 Corridor. No previous traces were known to have been detected at Stoney Spring West A. Runoff entering the groundwater system near the Basswood sinkhole flows easterly to Stoney Spring West A.

- 04-02: Glenwood Acres Trace - linked a sinkhole in the Section 5 Corridor with a relatively large discharge spring (Sexton Spring East) located approximately from the SR 37 centerline. This trace demonstrated that springs located appreciably outside the Corridor have the potential to be impacted from activities in the Section 5 Corridor. Also, the tested insurgence feature transfers water across the sub-watershed boundary. The section of Corridor near Glenwood Acres drains west and southwest to Sexton Spring East.

- 04-03: Horseshoe Road Trace – linked a sinkhole receiving drainage from SR 37 to Snoddy Spring A. This trace provided data supporting a revision of the Spring recharge area. Fitch (1994) included the catchment area for this dye introduction point as being within the Spring recharge area (**Figure 14**). This trace demonstrated that it was not in the recharge area, and that road activity within the catchment area of the dye introduction point would not impact the quantity or quality of water discharged from Spring and its associated springs. Due to polychlorinated biphenyls (PCBs) contamination, water discharged from Spring is treated prior to accessible surface discharge. Increase of impervious surfaces, such as roadways, can increase the quantity of runoff requiring treatment.

- <u>04-04: Ditch Trace</u> – was the second trace to be detected at Sexton Spring East and the third (including a pre-Tier 2 trace) to transfer water across the sub-watershed boundary to Sexton Spring East. This trace was from a point that currently receives runoff from SR 37 through a reopening sinkhole. The reopening sinkhole apparently had been filled during construction of the adjacent lanes of SR 37. The reopening point was at the downstream end of the concrete ditch liner. This was a point that could readily transmit contaminants from SR 37 to Sexton Spring East. This trace expanded the area known to drain southwest from the Corridor to Sexton Spring East.

- <u>04-05: Wapehani Apartments Trace</u> - linked a sinkhole in the Section 5 Corridor with a spring (Spring) that was also in the Section 5 Corridor. Spring had been undocumented prior to this investigation, and is a relatively small spring that discharges into Weimer Lake in the Wapehani Mountain Bike Park. This trace demonstrated groundwater flow to the south for the tested sinkhole.

- <u>04-06: Retention Pond Trace</u> - demonstrated a flowpath linking a sinking stream basin that was almost entirely within the Section 5 Corridor to a spring (A) that was also in the Corridor. The water discharged from often did not thermally equilibrate with the bedrock environment. It was observed to be relatively warm during high flow events during the summer sampling events. This warming was apparently due to residence in a retention pond prior to passing through the ground to discharge at ; the water moved along this path faster than it could equilibrate with the ambient groundwater temperature. The underground segment of this trace was approximately 800 feet long. The dye front had a velocity of more than 10,000 feet per day and some of the dye was only underground for about two hours.

- <u>04-07: Cintas Trace</u> – linked a sinkhole that received Corridor runoff to three springs: Spring , Spring, and . Neither Spring nor had been documented prior to this investigation. The trace expanded the area known to drain to Spring , demonstrating the complexity of the groundwater system (since Spring only received water from this sinkhole briefly during the trace). In addition, it showed that groundwater flow direction in this area could cover an entire USGS 7.5-minute topographic map quadrant to the south and west.

- <u>Trace 04-08: List Trace</u> – linked a sinkhole in the Corridor to Spring, which had been undocumented prior to this investigation. The flowpath from this part of the Corridor is to the southwest.

- <u>04-09: Stout Creek Trace</u> - demonstrated that the tested reach of Stout Creek sinks under very low flow conditions and would be expected to lose water under base and higher flow conditions. The sinking/losing reach received runoff from SR 37 and was located downstream of the Bennett's Dump Superfund site. Neither Spring nor the gaining reach downstream had been documented prior to this investigation.

- 04-10: Lemon Lane Trace – linked a sinkhole in the Section 5 Corridor to the Spring. This trace also addressed the Spring recharge area refinement, as discussed in Trace 04-03 (Horseshoe Trace). Groundwater flow near the tested sink was to the southeast. The trace also demonstrated interbasin transfer of water from the Stout Creek topographic basin to the Clear Creek Basin.

- 04-11: Rockport Trace – the dye introduction point recharged Spring and Cave, a biologically significant cave. The trace demonstrated that Spring receives runoff from SR 37, that the stream branch was a losing/sinking stream, and that there is complexity in the distribution of recharge in the study area. The flowpath has two components, one generally westward, and the other generally southward.

- 05-12: Pelt Trace - demonstrated that Spring's recharge area crossed the SR 37 Corridor and that at least one-half mile of the Corridor axis was within the Spring recharge area. It also demonstrated the presence of a karst flowpath crossing under SR 37. This stream also crosses the sub-watershed boundary and transfers water from the Jackson Creek topographic basin to the May Creek basin (via interbasin transfer). The flowpath is generally westward.

- 05-13: Hill Crest Trace - demonstrated the presence of an karst flowpath crossing under SR 37. The flowpath is generally eastward.

- 05-14: Triple Failure Trace – linked a sinkhole in the SR 37 median to Spring. Neither Spring nor the overflow spring upstream had been documented prior to this investigation; however, both the dye introduction point and Spring were in the Section 5 Corridor. The flowpath near the sinkhole is generally northwest.

- 05-15: Brown School Trace - linked a sinkhole in the Section 5 Corridor with Spring, which had been undocumented prior to this investigation. The trace was in the Corridor and demonstrated the presence of a karst flowpath crossing beneath SR 37. The flowpath near the sinkhole is generally southeast.

- 05-16: Karst Valley Trace – linked a sinkhole in the Section 5 Corridor to Spring, which had been undocumented prior to this investigation. The flowpath from the karst valley is generally northwest.

- 05-17: Livingston Trace – linked a sinkhole that received runoff from SR 37 to Spring and demonstrated that the Cave recharge area extended farther north than shown by previous studies. Surface runoff from portions of SR 37 contributed to the dye introduction point and to Spring. The flowpath for this trace is generally southwest.

- 05-18: Emerson Trace – linked a sinkhole in the Section 5 Corridor to a spring called Upstream of Spring, which had been undocumented prior to this investigation. The flowpath for this trace is generally southwest.

- 05-19: Spriggs Trace- linked a large sinkhole in the Section 5 Corridor to Spring, a previously undocumented spring located in the Section 5 Corridor. The flowpath from the sinkhole is generally south.

- 05-20: Trace - linked a sinkhole in the median of SR 37 with Spring, a previously undocumented spring located in the Section 5 Corridor. The flowpath from areas near the sinkhole is generally southwest.

- 05-21: Kinser Pike NE Trace - the dye introduction point was in the road ditch of SR 37 and received runoff from the roadway. The trace was detected primarily at Spring and secondarily at Spring in the Section 5 Corridor. Neither of these springs had been previously documented. The flowpaths from the sinkhole demonstrated two different directions, the primary path is generally northeast and the secondary path is generally southeast.

- 05-22: Windsor Trace - linked a reopening sinkhole that received runoff from SR 37 with a previously undocumented spring located in the Section 5 Corridor. Trace 05-22 demonstrated the presence of a karst flowpath crossing under SR 37. The flowpath near the sinkhole is generally northeast.

- 05-23: Wylie Trace - linked one sinkhole in a cluster of sinkholes that was located in the Section 5 Corridor to Spring, which also was located in the Section 5 Corridor. This was the second trace to Spring. The trace demonstrated the presence of an karst flowpath crossing SR 37. The flowpath of this trace is generally southwest.

- 05-24: Hunter Lane Trace – linked a sinkhole in the Section 5 Corridor to springs in Stout Creek. This was the second trace to flow to Stout Creek's previously undocumented springs. The flowpath near the sinkhole is generally north.

- 05-25: Hill Trace - linked a sinkhole in the Section 5 Corridor to Spring, a previously undocumented spring in the Corridor. The trace may have discharged from a road cut along SR 37. The primary groundwater flowpath was generally east, while the possible secondary flowpath is generally north.

- 05-26: Kinser Pike SW Trace - demonstrated the presence of an karst flowpath crossing SR 37. The trace also linked a reopening sinkhole that abuts SR 37 with Spring in the Section 5 Corridor. This was the second trace detected at Spring. The flowpath of this trace is generally east.

- 05-27: Spa Trace - demonstrated that an karst flowpath flows under SR 37. The trace also linked a reopened sinkhole that abuts SR 37 with Spring, an undocumented spring in the Section 5 Corridor. The flowpath of this trace is generally southeast.

- 05-28: Naylor Trace – linked a sinkhole outside the Corridor (but relevant to a potential Kinser Pike interchange) to Spring and Spring in the Section 5 Corridor. Neither of the springs that received water from Trace 05-28 had been documented prior to this investigation. Both flowpaths are generally southeast.

- 08-01: Rothrock Trace – linked a sinkhole that receives runoff from the Corridor to Spring and ; demonstrating two groundwater flowpaths. It also demonstrated that the dye introduction point lies outside the Cave recharge area. The flowpaths are generally southwest.

- 08-02: Elkins Trace – linked a sinkhole outside the Corridor to Spring. This is the first known dye trace detected at Spring and it demonstrates that the sinkhole does not recharge Cave. The flowpath is generally to the southeast.

- 08-03: Stone Trace - linked a sinkhole inside the Corridor to Spring. This is the second known dye trace detected at Spring and it demonstrates that the sinkhole does not recharge Cave. The flowpath is generally to the southeast.

- 09-04: Spring Tributary Trace – helped define the losing reach of this losing stream. Trace 04-11 demonstrated that this stream loses some of its water to Cave and this dye introduction point proved to be downstream of that losing reach. However, the stream did have dye which was detected at Spring and Spring , demonstrating at least two karst flowpaths.

- 09-05: Elkins Drive Trace – linked a sinkhole in the Corridor with three springs: Spring ; Springs; and, Spring. Therefore this trace demonstrated three karst flowpaths, and that the sinkhole does not recharge Cave. The flowpaths are generally to the southeast.

- 09-06: Elgar Trace – linked a sinkhole in the Corridor with an unknown spring upstream of Station ( ), and demonstrated that this sinkhole does not recharge Cave. The flowpath is generally to the southwest.

- 09-07: SR 37 Frontage Trace – linked a roadside ditch with no apparent karst features, including buried sinkholes, with several springs: Spring; Spring; Springs; and, . This is the first known trace detected at Spring. This dye introduction demonstrated flowpaths both southeast and southwest and contributes to two topographic basins.

- 09-08: Glosser Trace – linked a sinkhole on the east side of the Corridor with Cave on the west side of the Corridor. The flowpath is generally to the southwest and demonstrated interbasin transfer from the Jackson Creek basin to the May Creek basin.

- 09-09: Crowder Trace - linked a sinkhole in the Corridor with three springs: Spring ; Springs; and, Spring. Thus, it demonstrated three karst flowpaths and that the sinkhole does not recharge Cave. It also shows that these springs' shared recharge area extends at least from this dye introduction point to that of Trace 09-05. The flowpath are generally to the southeast.

- 09-10: Intermediate Trace - helped define the losing reach of this losing stream. Traces 04-11 and 09-04 had demonstrated some boundaries for the losing reach of interest and this trace defined it further. This trace linked its losing reach with Spring demonstrating that it recharges Cave, as well as . The flowpath is generally to the southwest.

- 09-11: Well Trace – defined the hydrologic relationship between this karst feature and the nearby springs. The farthest upstream point at which this trace was detected was Spring. All the other detections were almost certainly derived from losses in the stream downstream from Spring. The flowpath is generally to the southwest.

- 09-12: Abrams Trace – linked a sinkhole in the Corridor to Cave. The flowpath is generally to the southwest and demonstrated interbasin transfer from the Jackson Creek basin to the May Creek basin.

- 09-13: Schaad Trace – linked a sinkhole outside the Corridor to an unknown spring upstream of Station 12 (Unnamed Tributary in Section 25) demonstrating that this sinkhole lies outside the Cave recharge area. The flowpath is generally to the southwest.

3.3 Summary of Dye Tracing Results

A total of 83 groundwater flowpaths have been traced during pre-Tier 2 and Tier 2 studies in the Section 5 area. Relevant traced groundwater flowpaths for Bloomington and Bloomington North Karst are shown on **Figure 12**, and for Simpson Chapel Karst on **Figure 13**. The Tier 2 Section 5 flowpaths parameters are presented in **Table 6** and **Table 7** summarizes the dyes used, the dates dye was introduced, and the sampling stations at which dye was detected for each trace. The flowpath data presented in this report are diagrammatic; the lines representing the flowpaths are not meant to represent the actual location or distribution of the conduits.

The Tier 2 data indicated relatively rapid to very rapid mean groundwater velocities in all three karst areas:

- Bloomington Karst: 1,561 feet per day with a mean gradient of 194 feet per mile.

- Bloomington North Karst: 7,025 feet per day with a mean gradient of 330 feet per mile.

- Simpson Chapel Karst: 2,017 feet per day with a mean gradient of 251 feet per mile.

Each of the karst areas appeared to retain dye (and by inference, potential contaminants) associated with the upper portion of the karst formations (epikarst). The lower mean gradients in the Bloomington Karst probably resulted from thicker karst aquifers than in the Simpson Chapel and Bloomington North Karst. The thinner karst formations have less potential to develop extensive epikarst because of the lack of room for vertical weathering in the subsurface.

The background sampling indicated impacts from current land use in Section 5, and from stormwater runoff, leaks and spills on and along SR 37. Dye traces routinely showed that the karst groundwater system served to transport water and associated contaminants from their point or points of origin to springs and streams that were fed by the springs. An example of this in Section 5 was the relatively high level of background fluorescence values found for Spring (Station 103, **Appendix B**). The appreciable fluorescence in the range of fluorescein dye was likely associated with runoff from a gas station and convenience store parking lot located across SR 37 from the spring (BP Amoco Station near Sample Road). Other background fluorescence values (or potential runoff leaks/spills) can be found in **Appendix B**. General engineering concerns and Best Management Practices for addressing these impacts are discussed in **Section 5.0** of this report.

Table 6 Summary of Dye Trace Parameters

Trace Number	Trace Name	Sampling Station Linked	Length (ft)	Elevation loss (ft)	Gradient (ft/mile)	Minimum Velocity of Dye Front (ft/day)*	Duration of Dye Detection (days) since dye introduction
Bloomington Karst							
04-01	Basswood Trace	Spring	535	20	197	5,718	>216
04-02	Glenwood Acres Trace	Spring	2,616	88	178	8,710	<33
04-03	Horseshoe Road Trace	Spring	1,617	58	189	2,097	>255
04-04	Ditch Failure Trace	Spring	2,940	90	162	10,462	>176
04-05	Wapehani Apts Trace	Spring	802	40	263	1,813	>176
04-06	Retention Pond Trace	Spring	1,631	59	191	9,910	<98
04-07	Cintas Trace		1,604	105	346	147	>210
04-07	Cintas Trace	Spring	2,155	116	284	120	>210
04-07	Cintas Trace	Spring	1,911	74	204	783	<68
04-08	List Trace	Spring	2,128	83	206	78	>210
04-10	Lemon Lane Trace	Spring	2,968	37	66	1,475	<90
04-10	Lemon Lane Trace	Springs	4,012	63	83	200	<85
04-11	Rockport Trace	Spring	2,760	91	174	214	>122
04-11	Rockport Trace	Spring	5,971	111	98	425	>122
05-12	Pelt Trace	Spring	4,075	92	119	833	<51
05-13	Hill Crest Trace		3,210	99	163	660	>43
05-17	Livingston Trace	Spring	927	92	524	893	>39
05-18	Emerson Trace	Spring	770	52	357	157	>39
08-01	Rothrock Trace	Spring	1,605	108	355	969	>166
08-01	Rothrock Trace		1,306	97	392	352	>166
08-02	Elkins Trace	Spring	2,561	103	212	50	<51
08-03	Stone Trace	Spring	5,041	85	89	1,688	>336
09-04	Spring Tributary Trace	Spring	4,137	69	88	262	>170
09-04	Spring Tributary Trace	Spring	5,014	82	86	1,002	dye overridden
09-05	Elkins Drive Trace	Spring	1,210	49	214	1,076	<106
09-05	Elkins Drive Trace	Springs	7,098	99	74	883	<78
09-05	Elkins Drive Trace	Spring	6,574	101	81	817	<15
09-06	Elgar Trace	Spring	1,280	50	206	594	<77
09-07	SR 37 Frontage Trace	Spring	1,196	65	287	178	dye overridden
09-07	SR 37 Frontage Trace	Spring	869	49	298	10	>177
09-07	SR 37 Frontage Trace	Springs	6,653	123	98	996	>97

Table 6 Summary of Dye Trace Parameters

Trace Number	Trace Name	Sampling Station Linked	Length (ft)	Elevation loss (ft)	Gradient (ft/mile)	Minimum Velocity of Dye Front (ft/day)*	Duration of Dye Detection (days) since dye introduction
09-07	SR 37 Frontage Trace	Spring	6,376	132	109	954	<85
09-08	Glosser Trace	Spring	3,904	90	122	1,186	dye overridden
09-09	Crowder Trace	Spring	1,093	69	333	181	<6
09-09	Crowder Trace	Springs	6,504	119	97	1,082	<84
09-09	Crowder Trace	Spring	6,195	128	109	1,030	<21
09-10	Intermediate Trace	Spring	2,806	76	143	475	<106
09-11	Well Trace	Spring	341	16	248	301	>106
09-12	Abrams Trace	Spring	3,764	102	143	551	>106
09-13	Schaad Trace		2,771	98	187	200	>14
Bloomington North Karst							
04-09	Stout Creek Trace	Spring	3,083	35	60	949	<189
05-14	Triple Failure Trace	Spring	693	40	305	2,371	>92
05-21	Kinser Pike NE Trace	Spring	243	24	521	13,997	>18
05-21	Kinser Pike NE Trace	Spring	365	27	391	20	>18
05-24	Hunter Lane Trace	Spring	2,895	110	201	598	>18
05-24	Hunter Lane Trace	springs	5,052	140	146	3,770	>18
05-25	Hill Trace	Spring	314	31	521	107	>18
05-26	Kinser Pike SW Trace	Spring	687	39	300	71	>16
05-28	Naylor Trace	Spring	268	30	591	48,240	>16
05-28	Naylor Trace	Spring	1,195	55	243	125	>10
Simpson Chapel Karst							
05-15	Brown School Trace	Spring	1,094	24	116	5,276	<68
05-16	Karst Valley Trace	Spring	792	41	273	1,483	>74
05-19	Spriggs Trace	Spring	809	56	365	980	>29
05-20	Trace	Spring	804	28	184	132	>28
05-22	Windsor Trace	Spring	689	27	207	2,866	>17
05-23	Wylie Trace	Spring	758	56	390	3,087	>18
05-27	Spa Trace	Spring	478	20	221	293	>15

* For traces started as dry sets, the date used for velocity calculations is that for the first credible storm event following placement. Minimum velocity may be derived from data from stations other than the spring at which the trace was discharged.

Table 7 Dye Traces and Detection Stations

Trace Number	Trace Name	Dye Type & Dye Quantity	Date Introduced	Detection Stations
04-01	Basswood	1 lb eosine	6/15/04	13,15,19,54,78
04-02	Glenwood Acres	2 lb rhodamine WT	6/15/04	12,52,68
04-03	Horseshoe Rd.	2 lb eosine	6/30/04	4,5,30,43
04-04	Ditch Failure	2 lb eosine	7/26/04	12,52,68,85,86
04-05	Wapehani Apts	1 lb rhodamine WT	7/26/04	16,18,53,54,63
04-06	Retention Pond	1 lb rhodamine WT	8/30/04	13,15,19,54,70,79,80
04-07	Cintas	1/3 lb fluorescein	9/10/04	12,52,83,84,85,86
04-08	List	1 lb rhodamine WT	9/10/04	67,74
04-09	Stout Creek	2 lb rhodamine WT	9/30/04	4,87,89
04-10	Lemon Lane	4 lb eosine	12/1/04	24,25,26,31
04-11	Rockport	3 lb eosine	12/7/04	48,67,73,75,76,90
05-12	Pelt	3 lb SRB	1/5/05	48
05-13	Hill Crest	1/2 lb fluorescein	1/13/05	16
05-14	Triple Failure	2/3 lb fluorescein	1/13/05	87,88,91
05-15	Brown School	1 lb fluorescein	2/3/05	126,128,137
05-16	Karst Valley	1 lb rhodamine WT	2/4/05	94,132
05-17	Livingston	1/2 lb rhodamine WT	2/28/05	48
05-18	Emerson	1/2 lb eosine	2/28/05	75,76,90
05-19	Spriggs	1/2 lb eosine	2/28/05	102,131
05-20		1/2 lb rhodamine WT	3/23/05	148
05-21	Kinser Pike NE	1/4 lb eosine	4/2/05	163,166
05-22	Windsor	1/4 lb eosine	4/2/05	126,128,135
05-23	Wylie	1/2 lb rhodamine WT	4/2/05	102,131
05-24	Hunter Lane	1 lb eosine	4/2/05	87,89,183,185
05-25	Hill	1 oz fluorescein	4/4/05	169
05-26	Kinser Pike SW	1/4 lb SRB	4/4/05	166
05-27	Spa	1/2 lb rhodamine WT	4/4/05	198
05-28	Naylor	1/4 lb rhodamine WT	4/4/05	172,173
08-01	Rothrock	1/4 lb fluorescein	11/19/08	12,83,84,85
08-02	Elkins	3/4 lb rhodamine WT	11/19/08	55
08-03	Stone	1 lb eosine	11/19/08	13,53,55,80
09-04	Spr.Trib.	1 lb eosine	2/1/09	67,68,73,74,75,76,90,204
09-05	Elkins Drive	1/4 lb fluorescein	2/2/09	150,201,202, 203
09-06	Elgar	3/4 lb SRB	2/3/09	67,68.90,204
09-07	SR 37 Frontage	3 lb eosine	4/27/09	75,145.201,203,204
09-08	Glosser	1/2 lb fluorescein	4/27/09	12,48,86
09-09	Crowder	1 lb rhodamine WT	4/28/09	150,201,203
09-10	Intermediate	2 1/2 lb eosine	7/7/09	12,48,67,73,75,76,86,90,204
09-11	Well	1/4 lb SRB	7/7/09	67,73,75,90,145,204
09-12	Abrams	1 lb fluorescein	7/7/09	12,48,86
09-13	Schaad	1/2 lb rhodamine WT	7/7/09	12

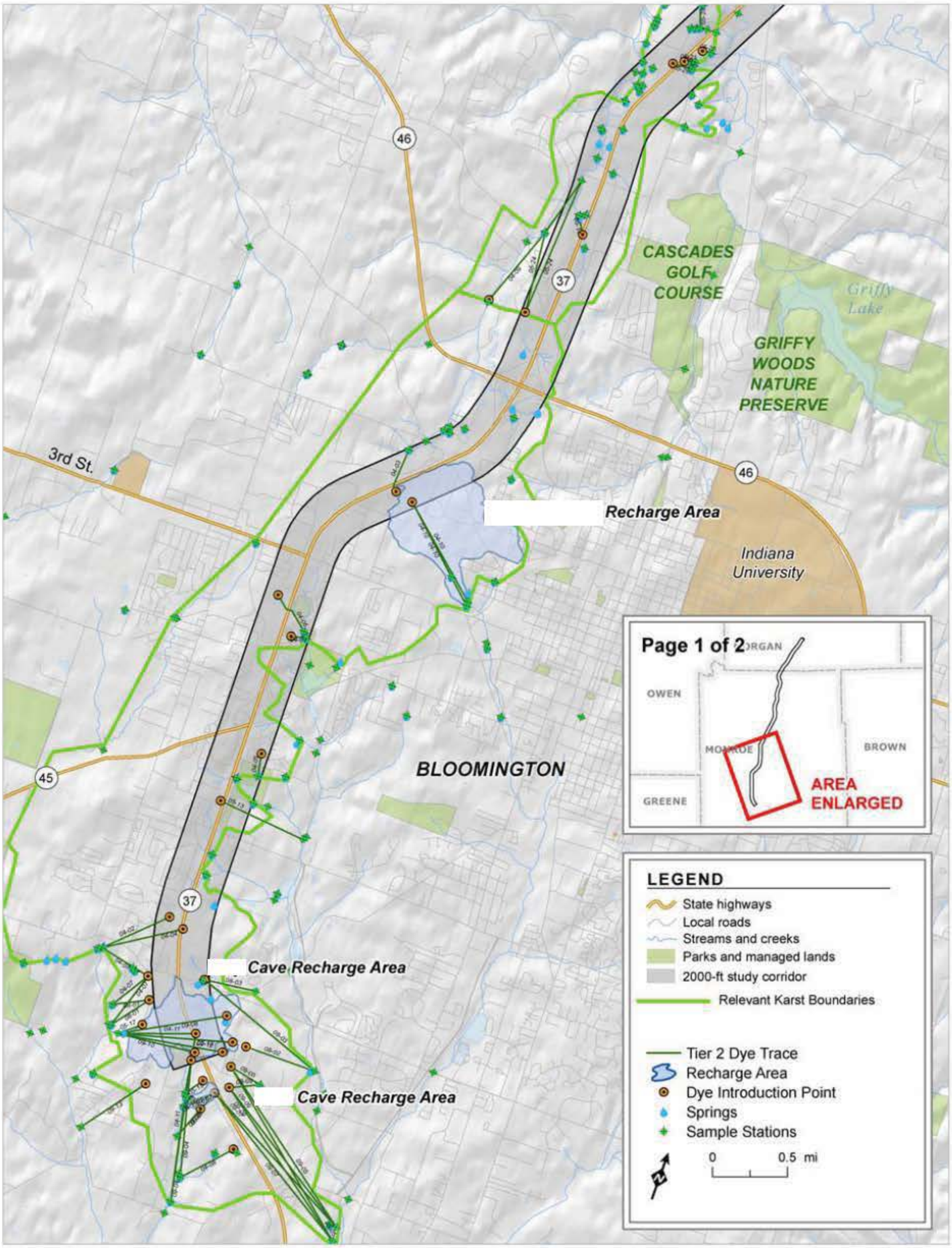

Figure 12 **Summary of Dye Tracing for the Bloomington and part of Bloomington North Karst**

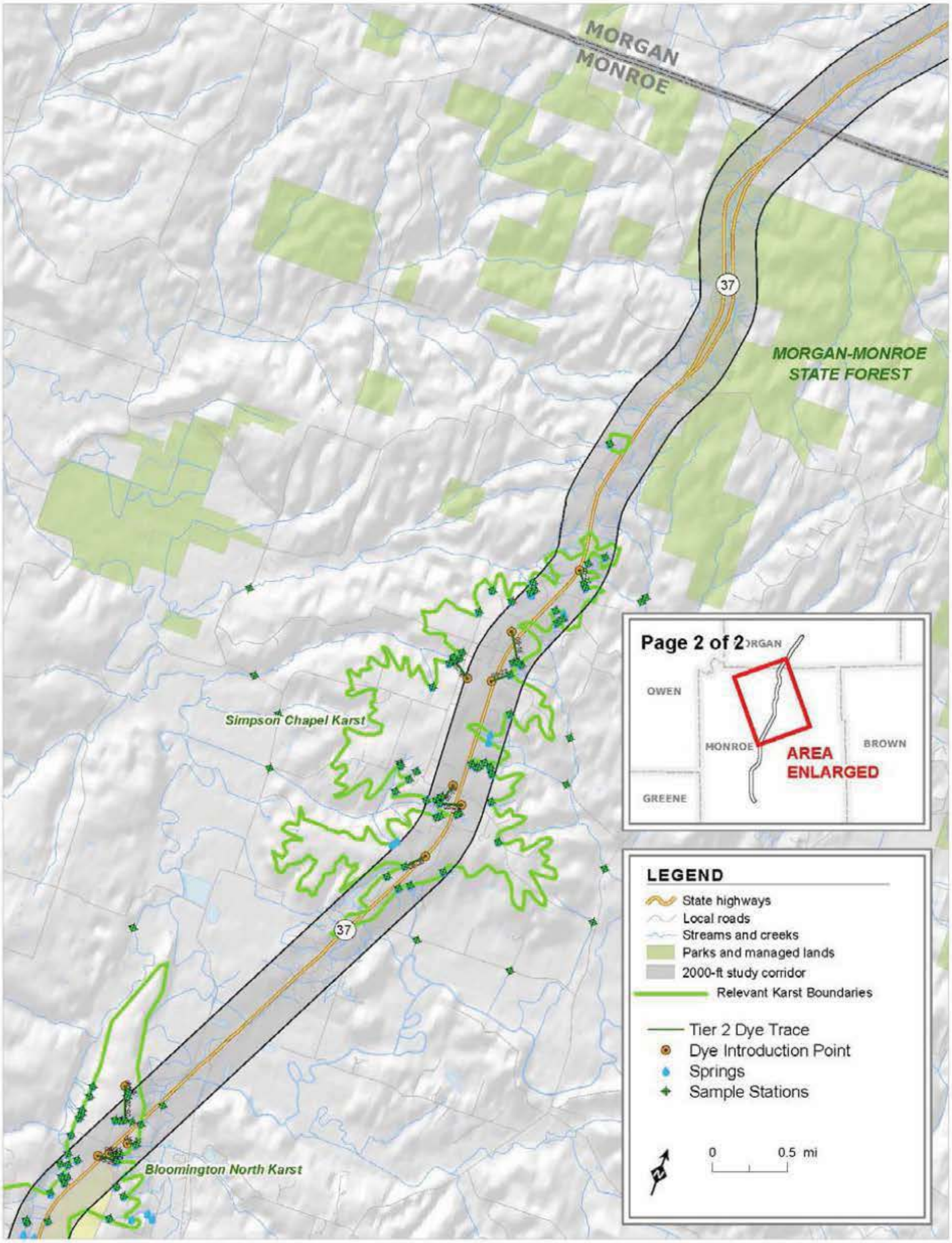

Figure 13 **Summary of Dye Tracing for part of Bloomington North and Simpson Chapel Karst**

3.4 Recharge Area Delineations

A recharge area of a spring consists of those lands which contribute at least some water to the spring under some flow conditions. This includes those lands that contribute to dye introduction points that were traced to the spring. Dye introduction points traced to other locations, and the lands that contributed to these points, were deemed to be outside of the recharge area.

While recharge area delineations were not part of the 1993 MOU Items 1-4, the data collected during the Section 5 study permitted revision of the following recharge areas:

- Spring, which drains the Lemon Lane Landfill Superfund site.
- Spring, which drains the Cave system - a biologically significant cave that receives water from SR 37 and the Section 5 Corridor.

3.4.1 Spring Recharge Area

Water from the is being treated as part of the Lemon Lane Landfill Superfund site remedial action. Changes to the base and peak flow conditions of this spring are potentially significant to the operations of the treatment facility and have financial, engineering, human and ecological risk implications. The research and refinement of the recharge area was used, where possible, as part of this evaluation for potential avoidance and/or alternative drainage options for planning and design of the proposed I-69 roadway. The goal will be to avoid an increase in water entering the recharge area from the proposed I-69, both during and following construction.

A previous recharge delineation of the groundwater system, which includes Quarry and Quarry B Springs, reported in 1994 by J. R. Fitch was reviewed. The original recharge area delineation was based on five dye introductions made primarily by a graduate student to determine where the water from approximately 24 sinkholes flowed. It also relied on USGS 10-foot contour interval topographic mapping to determine the location of sinkhole boundaries. The current investigation looked not just at the reported results, but looked at the reported analytical data.

The Section 5 studies augmented this delineation by conducting additional dye traces and incorporating higher quality two-foot topographic contour data derived from 2010 LiDAR data. The resulting recharge area was found to be appreciably smaller than had been previously reported. This revision is not represented to have tested the Fitch version of the recharge area; only that area crossing the Corridor. At least one of Fitch's trace results was not reproduced; the non-detection at Spring A from GIS insurgence feature No.192, which is the adjacent sinkhole to the west of the sinkhole used by Fitch (GIS insurgence feature No. 203), failed to replicate the detection reported by Fitch from Karst Feature 203. It is possible that professional dye tracing along GIS insurgence feature Nos.198 and 199 might result in additional revisions as no tracing by any party has been done there and the closest trace is about 1,000 feet away from the boundary as drawn.

The majority of the revision came from results of one trace, Trace 04-03, which demonstrated that its sinkhole, which had not been previously traced despite it being the farthest from , does not contribute water to . These empirical data conflict with the interpretation based on assumptions. The remaining revisions are simply the result of better topographic data.

While it is not uncommon in karst areas for recharge area boundaries to fluctuate under differing flow conditions, it is at least as common for them to not vary with changing flow conditions. While the study did not trace under every possible flow condition, there were no data suggesting that the boundaries of the recharge area vary with flow conditions. The Fitch and augmented delineations, and the traces used for both, are shown on **Figure 14**.

3.4.2 Cave Recharge Area

Cave (Cave A) is part of a biologically significant cave system that discharges to the surface at Spring. The Cave system includes Cave, Cave , caves. The recharge areas of the spring and the cave system are nearly equivalent in their geographical boundaries; however, the cave system is underground and consists of relatively small interconnected conduits within this area, and the recharge area is the entire land surface within the defined geographical boundary.

Eighteen dye introductions are relevant to the Cave recharge area. These traces and inclusion of lands that contribute to the dye introduction points were used to delineate the Cave recharge area. Some traces demonstrated lands that recharge Cave, while others demonstrated areas that do not recharge the cave system.

While Cave (Cave B) has shared recharge with springs within the Section 5 Corridor, it is over to the 800 feet south and located outside of the Section 5 Study Corridor. While a general recharge area was determined for Cave during the Cave recharge area investigations, it was found not to be hydrologically connected to the Cave system. Cave is more accurately termed a karst window with limited access to a water filled cave passage.

Figure 15 shows the recharge area and relevant dye traces for Spring and Cave.

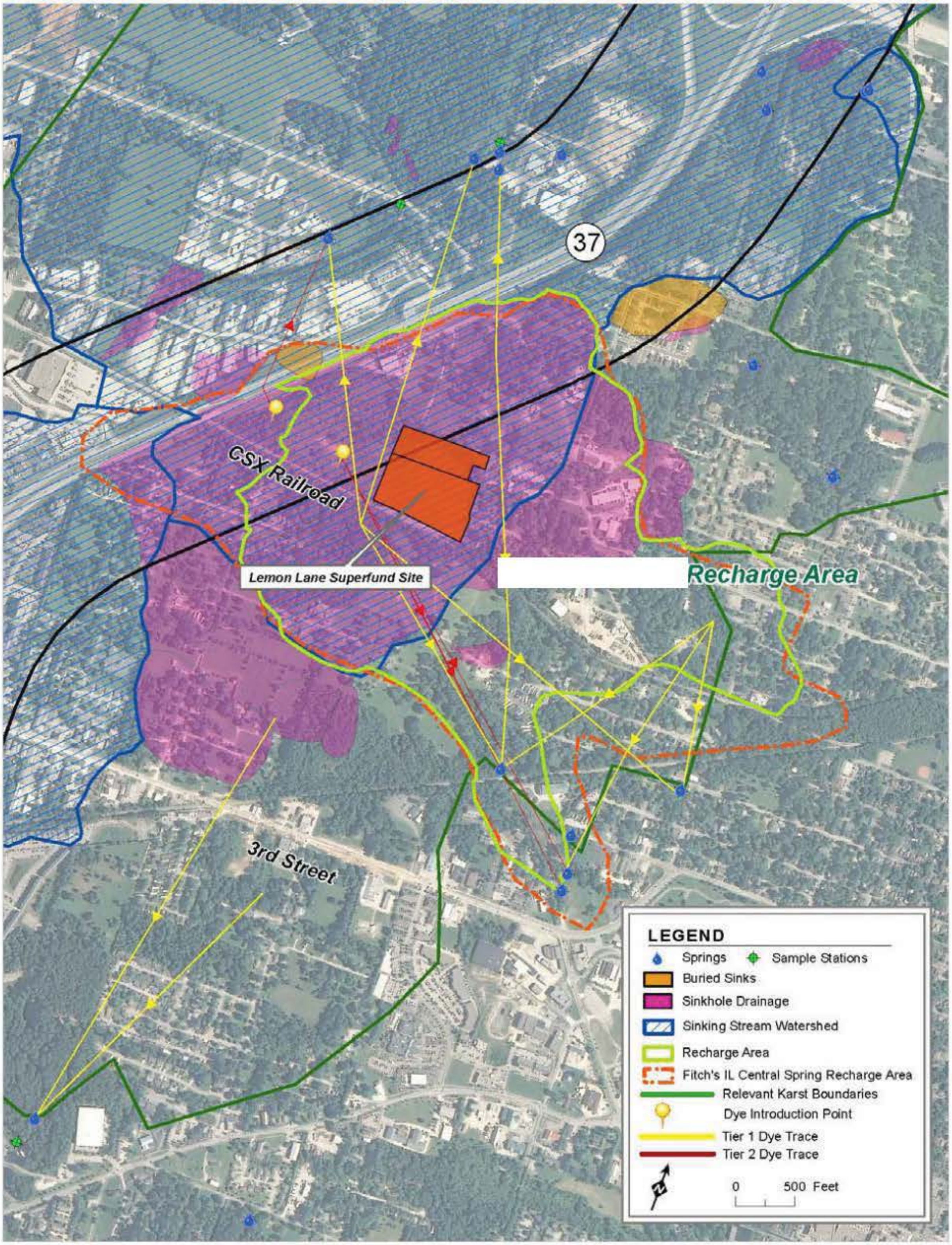

Figure 14 Revised Spring Recharge Area

Figure 15 Recharge Area of Cave

3.5 Cave Biology Results

A biological survey was conducted in Cave, Cave, and Cave, based on a demonstrated connection with SR 37, literature and Section 5 reconnaissance observations, and cave passages and a recharge area that cross SR 37. The specific locations of the cave entrances are part of the confidential data and will not be released (**Appendix I**). The biological survey (**Appendix J**) results are shown on **Table 8** and are as follows:

- There were no federally listed species identified as part of the biological surveys.
- and Caves have not been demonstrated to be related hydrologically; however, they are located fairly near one another.
- Cave has aquatic habitat, but almost no air-filled, enterable passages. Spring has no troglobitic species.

Table 8 Obligate Subterranean Species Summary

Common Name	Scientific Name	Global Rarity Rank*	Listing Status	Ecological Status	Cave	Cave	Cave
Hidden spring snail	*Fontigens cryptica*	G1	State Endangered	Stygobite	X		
Northern cave isopod	*Caecidotea stygia*	G5		Stygobite	X		X
Indiana cave amphipod	*Crangonyx indianensis*	G3		Stygobite	X		X
Packard's groundwater amphipod	*Crangonyx packardi*	G3	State Rare	Stygobite	X		
Barr's cave amphipod	*Crangonyx barri*	G3	State Rare	Stygobite			X
Cave crayfish	*Orconectes inermis testii*	G3	State Threatened	Stygobite	X		X
Barr's cave crayfish ostracod	*Sagittocythere barri*	G3		Stygobite/ Commensal	X		
Subterranean sheet-web spider	*Phanetta subterranea*	G5		Troglobite	X		
Bollman's cave milliped	*Conotyla bollmani*	G3	State Rare	Troglobite	X		
Indiana cave springtail	*Sinella alata*	G3	State Endangered	Troglobite	X		
Mayfield cave beetle	*Pseudanophthalmus shilohensis mayfieldensis*	G1	State Endangered	Troglobite	X		
Cave dung fly	*Spelobia tenebrarum*	G5		Troglobite	X	X	X

* The Global Rarity Rank is as of the 2005 Lewis' report (Lewis 2005 in Appendix J).

Dr. Lewis reported that Cave ranked 9th highest for biological significance out of 484 Indiana caves. The ranking is based on the number of obligate subterranean species (troglobites and stygobites) and species of high global rarity identified from cave bio-inventories in Indiana (Lewis, 2005). Dr. Lewis included caves in Indiana with appreciable data on their biological communities.

The presence of one State-listed Threatened Species in Cave, and two State-listed Endangered Species and one State-listed Threatened in Cave makes these caves and their recharge areas of special concern in Section 5.

Note in reference to **Appendix J**: the State Listing Status has been updated since the generation of Dr. Lewis' report (Lewis, 2005) for the following:

State Listed Species	2005 Status	2012 Status
Indian cave springtail	State Endangered	State Watch List
Packard's groundwater amphipod	State Rare	State Watch List
Cave crayfish	State Threatened	State Rare
Barr's cave crayfish	not listed	State Watch List
Bollman's cave millipede	State Rare	State Watch List

The survey report concluded the following:

- There were no federally listed species identified as part of the biological surveys.
- Five troglobitic species were identified in Cave, two of which are State-listed Rare Species (cave crayfish *Orconectes inermis testii* and Barr's cave amphipod *Crangonyx barri*).
- A spring located down gradient of Cave had no troglobitic species.
- Cave had one troglobitic species (cave dung fly *Spelobia tenebrarum*) that are not designated rare or protected.
- Cave had 11 troglobitic species, eight of which are globally rare. Two are State-listed Rare Species (Barr's cave amphipod *Crangonyx barri* and cave crayfish *Orconectes inermis testii*); four species are on the State Watch List (Barr's cave crayfish ostracod *Sagittocythere barri*, Packard's groundwater amphipod *Crangonyx packardi*, Bollman's cave millipede *Conotyla bollmani*, and Indiana cave springtail *Sinella alata*); and, two are State-listed Endangered Species (hidden spring snail *Fontigens cryptica* and Mayfield cave beetle *Pseudanophthalmus shilohensis mayfieldensis*).

3.6 Annual Pollutant Load Estimates

The Karst MOU delineates guidelines for construction of transportation projects in karst regions of the state. As part of the I-69 project, the USEPA has also been invited to participate in the MOU activities review process. The MOU signatory agencies and the USEPA have been informed that Steps 1-4 of the Karst MOU will be followed as part of the NEPA study for Section 5 of the I-69 project. Step 2 of the Karst MOU states the following "….Calculations of estimates of annual pollutant loads from the highway and drainage within the right-of-way will be made, including prior to, during and post construction estimates. The design of the treatment of the karst features will take into consideration treatments necessary to meet the standards of the monitoring and maintenance plan…."

This section summarizes key points from the research gathered as part of the karst pollutant loading estimations for the Tier 2 EIS of I-69 Section 5 in Monroe County. It also discusses the attempts made and limitations to compute the pollutant loadings as a desktop exercise, without actual field sampling, using a FHWA published process.

3.6.1 INDOT's Previous Karst Study on SR 37

In April 1996, Earth Tech prepared "Results of MOU-Related Karst Studies for Indiana State Road 37, Lawrence County, Indiana (1992-1995)" for INDOT. This document described the Karst MOU and documented the results of the Best Management Practices (BMPs) used both during and after construction. The project was to reconstruct SR 37 from a two-lane highway to four-lane divided highway between SR 60 (Mitchell) to US 50 (Bedford). In general, INDOT used the following steps to fulfill the Karst MOU:

1. Survey all karst features directly or indirectly affected by the project.
2. Delineate sub-surface drainage routes using dye-tracing.
3. Install drainage structures (BMPs) such as settlement basins, peat filters and rock filters to all karst features within the ROW. The size and type of each BMP was estimated based on the drainage area and type of karst feature. By all indication, the choice of the BMP was an estimation with the understanding that monitoring of the BMP was essential to assure its effectiveness.
4. Collect samples of runoff at the BMP's both during and after construction and test for pollutants (e.g. lead, zinc, copper, etc.). These samples were collected during six storm events between February 1993 and August 1995. The concentrations of pollutants were compared to Indiana's Water Quality Standards for aquatic life and drinking water.
5. Observe the BMP effectiveness at conveying stormwater during rain events. Most BMPs proved effective, although some need to be enlarged or their drainage basins enlarged to assure water was not going to pond onto the roadway.

The study concluded that less than two years after construction, the pollutant concentrations in the runoff were reduced to what one would expect prior to construction. As long as the filter systems operate as designed, no long term effects to karst features was expected.

In the short term (within two years after construction), high levels of Total Suspended Solids (TSS) and Total Recoverable Metals (TRM) (copper, lead, zinc, etc.) were found. This was likely due to the fact the BMPs were installed prior to earthwork and grading activities. Therefore, even though the BMP filters and normal erosion control measures were monitored, the filters were typically found to be clogged.

However, When discussing the results of the SR 37 Study ("Results of MOU-Related Karst Studies for Indiana State Road 37, Lawrence County, Indiana (1992-1995)", in relation to the I-69 project, it is acknowledged that the determination and installation of karst drainage structures for the SR 37 project was done when construction had already begun, allowing less time for planning and design. Therefore, some drainage structures, and associated detention basins, were not designed to handle the correct amount of runoff capacity. Some additional sinkhole excavation was needed to increase the size of the drainage structure and/or detention basin. This sinkhole excavation, done during the road construction, contributed to higher levels of TSS. The SR 37 Study states, when speaking of the temporary increases in pollutant loadings, "This is not likely to be a problem for future construction projects that are fully carried out within the MOU framework" (SR 37 Study, page 66). The strategy to avoid subsurface contamination of TSS and TRM will be contained in the Erosion Control Plan and fulfillment of the Rule 5 requirements. Erosion Control standards and specifications have changed and improved since the SR 37 project.

3.6.2 Kentucky's Previous Karst Study on I-65 at Mammoth Cave

As part of the literature research conducted, a report completed by the Kentucky Transportation Center, "Evaluation of Methods to Protect Water Quality in Karst Areas: Phase I" was reviewed. This study, done for the Kentucky Transportation Cabinet in October 2003, analyzed pollutant loads to karst features near an interchange of I-65 and an entrance to Mammoth Cave. The procedures detailed in the study match those of Indiana's Earth Tech report. Field samples were collected to find the pollutant concentrations and those values compared to national standards. Their findings were highway runoff pollutant loadings were minimal. Additional phases of the research report were to study other karst features throughout the state, and report a methodology that could be used for loading calculations and BMP design. One of the authors was contacted to check the status of additional phases to the study; however, none have been completed at this time.

3.6.3 Karst Features to Analyze

The karst survey identified over 672 karst features in the karst study area. About 319 features are located within the 2,000-foot wide Corridor of Section 5; 77 within existing SR 37 ROW, and, 110 inside the total proposed ROW for Refined Preferred Alternative 8. The drainage areas for all these features were estimated using GIS software and are listed in **Appendix L** of this report. It was assumed that any karst feature inside the construction limits would be capped, so its pollutant load estimate is zero. A karst feature had to be outside the construction limits (or with a portion outside the construction limits) yet inside the proposed ROW to be eligible for analysis. The number of features that fit this criteria is 53 Pre-Construction (Existing) and 57 Post-Construction (Proposed).

The calculation of the pollutant loadings into the karst features required some assumptions; primarily when delineating how much of the proposed ROW would drain into the karst feature. Three main assumptions were made, all likely erring on the side of a higher pollutant loading than what will realistically occur after construction:

1. It was assumed that the entire ROW width would drain into the karst feature. In many cases, this is highly unlikely. For instance, if a karst feature is located on the backslope of a ditch along the southbound lane, there is no guarantee that highway runoff from the median or ditch along the northbound lane would drain to the karst feature on the other side of the road. More often than not, the road acts as a barrier, preventing runoff from being conveyed from one ditch to the other. The only exception would be if a cross culvert or median drain would convey drainage to a karst basin.

2. Also, where multiple karst features are located within the same ROW drainage area, the pollutant loading calculation for each feature assumed no runoff would drain into the other features. In all likelihood, the karst features would share the runoff volumes.

3. Finally, the roadside and median ditches are designed for conveyance and outlet into streams and creeks, not into karst features such as sinkholes or swallets. Therefore, it is reasonable to assume runoff may not find its way to a feature, instead traveling along the ditch grades and culverts as designed and constructed. The pollutant loading calculation assumed the entire right-of-way would drain into the karst feature, and not be conveyed elsewhere.

3.6.4 FHWA Highway Runoff Water Quality Training Course

FHWA conducted a class on water quality and storm water runoff from highways. Section 8 of this workshop dealt with models and studies that have been developed to predict pollutant loads without field measurements. The first part of the model calculates pollutant load estimates, developed in the late 1970's using field data from monitoring programs in various states. The second part estimates the pollutant concentrations and compares them to water quality standards. The third part estimates the pollutant loads in the "background", or what occurs before the highway is built. This methodology is included in **Appendix L** of this document.

3.6.4.1 Part 1: Pollutant Loadings from Highway Runoff

In order to estimate the pollutant loading from the highway runoff, the length of the road that would drain into the karst feature must be estimated. This included the area of the karst feature within the existing SR 37 ROW ($\geq$0.3-acre) for existing conditions and the area of the karst feature within the Refined Preferred Alternative 8 ROW for post construction conditions. The pollutant loading calculation assumes the *entire* highway ROW along this length would drain into the karst feature. This is unlikely, given the three drainage ditches (two roadside and the median) are not designed to convey drainage to karst features. For instance, if a karst feature is located inside the roadside ditch along the southbound lanes, there is no guarantee (and in fact is very unlikely) that cross culverts would be installed to convey drainage from the other roadside ditch and the median under the road to the karst feature.

The model estimates the pollutant loading by first determining the load of total solids. Once that load is found, regression equations are used to determine the load for other various pollutants (lead, copper, zinc, etc.). The theory behind this is solids act as "carriers" for other pollutants, so the higher the solids the higher the metals and other pollutants. The estimated pollutant load prior to the rain event is calculated using the daily traffic estimate. It is assumed that the road has not been washed of pollutants in 20 days, which the study's analysis determined to be an adequate length of time for an accurate initial load estimate. The initial pollutant load is then modified to account for the runoff rate. This rate was calculated using National Oceanic and Atmospheric Administration (NOAA) data four design storms:

1. 1-year/1-hour design storm (1.21 inches)
2. 2-year/24-hour design storm (3.16 inches)
3. 5-year/24-hour design storm (3.92 inches)
4. 50-year/10-minute design storm (1.20 inches)

The rate also takes into account the drainage control on the highway, in this case, open median and ditches, and the length of highway within the drainage basin of the particular karst feature. The I-69 Section 5 project was considered a Type II roadway, which is indicative of an urban setting with some curb or barrier, structured drainage, and grassy ROW.

Once the runoff and rain data is taken into account, the pollutant loading of total solids at each karst feature was calculated. Regression models are then used to determine the pollutant load (pounds) for other pollutants. For karst features with very small drainage areas, some of the regression equations produce values in the negative. It should be assumed, for these cases, the load is zero. **Tables 1-1, 1-2, 1-3, and 1-4** included in **Appendix L** summarize the pre-construction (Existing) pollutant mass loadings for each of the four design rainfall events (1-year/1-hour, 2-year/24-hour, 5-year/24-hour, and 50-year/10-min) for Refined Preferred Alternative 8. **Tables 1-5, 1-6, 1-7, and 1-8** show the post-construction (Proposed) pollutant mass loadings for each of the four design rainfall events.

3.6.4.2 Part 2: Pollutant Concentrations from Highway Runoff

The pollutant loadings calculated in Part 1 can then be modified into concentrations. The loadings are divided by the volume of rain water (for a particular rain event) inside the right-of-way that would drain into the karst feature. **Tables 2-1, 2-2, 2-3, and 2-4** in **Appendix L** summarize the pre-construction (Existing) results of the pollutant concentration estimates for each design rainfall event for the Refined Preferred Alternative 8. **Tables 2-5, 2-6, 2-7, and 2-8** show the post-construction (Proposed) pollutant concentration estimates for each of the four design rainfall events.

Concentrations of pollutants are then compared to Indiana's Water Quality Standards for aquatic life and drinking water. These standards are from Indiana Administrative Code (327 IAC 2-1-6) and assume a hardness of 250 mg/L. The five pollutants that are exceeded the most often are lead, copper, total nitrogen, cadmium and mercury. **Table 9** below summarizes the results for those five pollutants for pre-construction (Existing) and post-construction (Proposed) for the four types of rain events analyzed. The more intense the rain event, the more wash-off of the highway will result and the less settling of solids in the ditches, hence the 1-year/1-hour event shows more pollutants exceeding the water quality standards. The FHWA course materials state that caution must be used when interpreting the pollutant loadings of lead predicted by the model. The reduction of lead in gasoline has resulted in an estimated 50% reduction in lead loadings since the predictive equation was developed.

Table 9 Summary of Karst Features Exceeding Water Quality Standards for Refined Preferred Alternative 8[1]

Design Rainfall	No. of Features Exceeding Water Quality Standards[2]					Highest Concentration (mg/L) / Feature ID				
	Lead	Copper	Total Nitrogen	Cadmium	Mercury	Lead	Copper	Total Nitrogen	Cadmium	Mercury
Pre-Construction (Existing)										
1-year/ 1-hour	53	53	53	53	53	2.847 (i020)	1.205 (i020)	9.040 (i082)	0.269 (i082)	0.006 (i020)
2-year/ 24-hour	53	49	53	53	38	0.668 (i020)	0.331 (i020)	3.302 (i182)	0.098 (i182)	0.001 (i020)
5-year/ 24-hour	53	45	53	53	37	0.602 (i020)	0.286 (i020)	2.686 (i182)	0.080 (i182)	0.001 (i020)
50-year/ 10-min	53	53	53	53	53	2.872 (i020)	1.216 (i020)	9.116 (i182)	0.271 (i182)	0.006 (i020)
Post-Construction (Proposed)										
1-year/ 1-hour	57	57	57	57	56	5.197 (i017)	1.946 (i017)	10.932 (i017)	0.338 (i017)	0.012 (i017)
2-year/ 24-hour	57	48	57	57	42	1.187 (i017)	0.496 (i017)	3.327 (i252)	0.099 (i252)	0.003 (i017)
5-year/ 24-hour	57	46	57	57	39	1.077 (i017)	0.437 (i017)	2.719 (i252)	0.083 (i017)	0.002 (i017)
50-year/ 10-min	57	57	57	57	56	5.242 (i017)	1.963 (i017)	11.025 (i017)	0.341 (i017)	0.012 (i017)

[1] The lowest of the three Water Quality Standards listed in the IAC is 0.01 mg/L for lead, 0.026 mg/L for copper, 0.01 mg/L for total nitrogen, 0.0023 mg/L for cadmium and 0.00014 mg/L for mercury.
[2] Total number = 53 Pre-Construction (Existing) features and 57 Post-Construction (Proposed) features.

According to the FHWA estimating calculations included in **Appendix L** and summarized above in **Table 9**, both the existing SR 37 ROW and proposed Refined Preferred Alternative 8 exceed the applicable water quality standards. The increase in the total number of features exceeding water quality standards from Pre-Construction (Existing) conditions to Post-Construction (Proposed) conditions is associated with the increased number of features within existing SR 37 ROW to the proposed Refined Preferred Alternative 8 ROW. In addition, many of the specific features are within existing or planned local development areas that are not related to the Section 5 project such as:

- The northern half of feature i017 is located within an area planned for commercial development as part of the South Monroe Medical Park, while the southern half includes residential development along West Watson Drive and South Rockport Road.

- Most of the i020 feature is covered with local roads, commercial development along West Fullerton Pike, South Monroe Medical Park Boulevard (such as the multi-building Monroe Hospital and Golf Car complexes), and residential development along Judd Avenue and West Jordan Court.

3.6.4.3 Part 3: Pollutant Concentrations from Highway Runoff

The pollutant loading calculations represent estimates of pollutant loads. Several assumptions had to be made to conduct this analysis at early stages of the project design that overestimated the pollutant loads. For example, it is assumed that the entire length of right-of-way within the feature drainage area drains directly into an opening in the feature. In many cases, this is highly unlikely. For instance, if a karst feature is located on the backslope of a ditch along the southbound lane, there is no guarantee that highway runoff from the median or ditch along the northbound lane would drain to the karst feature. Also, where multiple karst features are located within the same right-of-way drainage area, the pollutant loading calculation for each feature assumed no runoff would drain into the other features. In all likelihood, the karst features would share the runoff volumes. Finally, the roadside and median ditches are designed for conveyance and outlet into streams and creeks, not into karst features such as sinkholes or swallets. Therefore, it is reasonable to assume that runoff would not find its way to a feature, instead traveling along the ditch grades and culverts as designed and constructed. The pollutant loading calculation assumed the entire right-of-way would drain into the karst feature, and not be conveyed elsewhere.

As part of the construction and construction oversight, strict adherence to the erosion control measures is essential. Runoff and sediment control are to be performed during construction in accordance with the Erosion and Sediment Control plans developed in compliance with the October, 2007 version of the Indiana Storm Water Quality Manual (IDEM). According to the "Results of MOU-Related Karst Studies for Indiana State Road 37, Lawrence County, Indiana (1992-1995)" (EarthTech, 1997), there were elevated levels of total suspended solids (TSS) and total recoverable metals (TRM) for arsenic, copper, lead, and zinc to the subsurface associated with the during-construction activities for the SR 37 project. These levels returned to pre-construction conditions about two years after construction.

4.0 POTENTIAL MEASURES TO OFFSET IMPACTS TO KARST

The intent of the 1993 MOU is to minimize impacts to karst from road construction and operation via four preferred strategies, listed in order of preference: avoidance, alternative drainage, mitigation/treatment, and operations and maintenance. Each is discussed briefly below.

4.1 Avoidance

The 1993 MOU indicates that avoidance is the best alternative for preventing impacts to karst features. Due to the constraints of the Section 5 Corridor, appreciable development on and along SR 37, and connections to the existing infrastructure, the opportunities to avoid karst features are limited.

4.2 Alternative Drainage

The 1993 MOU indicates that providing alternative drainage is the second measure in order of preference to offset impacts to karst. Alternative drainage entails controlling roadway runoff and redirection of runoff to alternative drains, features or surface water bodies instead of insurgence features (sinkholes and losing streams). Alternative drainage has two potential drawbacks:

- Reduction of existing water quantity where there are aquatic species of concern.
- Potential to increase flooding downstream of the redirected drainage.

These concerns should be considered when evaluating the alternative drainage options. Additional data may need to be collected in order to adequately assess such measures. Hazardous waste, ecologically sensitive populations, and limited potential for flooding at several of the areas of special concern may outweigh other considerations during evaluation of preventive measures. Drainage and treatment alternatives will be considered concurrently so as to not impede drainage in recharge areas and having potentially harmful impacts to cave biota.

4.3 Mitigation/Treatment

The third measure indicated in the 1993 MOU is mitigation or treatment, such as peat-sand filters, gravel filters, vegetative buffers, and lined spill or runoff containment structures. Use of filters, buffers, containment structures, reinforced soil, void grouting, compaction grouting, concrete caps, reinforced bridging slabs (land bridges), deep foundations, etc. are potentially effective mitigation measures, but will not be determined until subsequent detailed design stages. Each of these would be designed to reduce or prevent contaminants from entering the karst groundwater system.

The strategy to avoid subsurface contamination of TSS and TRM will be contained in the Erosion Control Plan and fulfillment of the Rule 5 requirements. A mitigation commitment has been added to FEIS Sections 5.21.4, *Mitigation* and 7.3, *Section 5 Mitigation Measures and*

Commitments, requiring the designer to abide by item B1 of the Erosion Control Plan Development which emphasizes pollutant sources and requires a plan to minimize the danger of pollutants entering storm water.

In addition to karst feature avoidance and runoff treatment, the diversion of road runoff away from sensitive karst groundwater systems is included in the mitigation recommendations. Recommendations to treat runoff that would be directed to an engineered wetland sediment/containment reduction system; linear peat sand filters and or vegetated swales; sinkhole sediment and containment traps; runoff and storm water detention/retention systems, treatment and infiltration galleries; and, control of first flush volumes with designed overflow into natural drainage. These treatment options are not incorporated into the pollutant loading analysis. The methodology assumes no treatment.

Based on up-front planning associated with the Karst MOU and improved erosion control standards and specifications, it is anticipated that TSS levels, and corresponding pollutant levels, will be lower and return faster to preconstruction levels than those experienced during the SR 37 study referenced above.

4.4 Operations and Maintenance

The fourth measure, operations and maintenance, is actually a supplement to alternative drainage and mitigation/treatment and includes the following actions:

- Mowing protocols to minimize the formation of soil pipes and liner failures (such as were frequently observed along SR 37 during this investigation).
- “Low Salt”, “No spray” zones.
- Inspection of drainage systems for leaks or other failure modes.
- Maintenance and routine inspection of containment structures for capacity to contain a spill (i.e., removal of sediment or standing water) and structural integrity.
- Monitoring and testing of treatment systems to meeting system specifications.

5.0 SUMMARY AND CONCLUSIONS

The report study results are specific to conditions identified within the Section 5 study area. Although some particular karst features may be avoided, since Section 5 is essentially the upgrade of the existing four-lane divided highway SR 37 to a new four- to six-lane divided interstate I-69, karst geology cannot be avoided within the Section 5 Corridor. Therefore, the focus of alignment and design should be on minimizing impacts via alternative drainage, mitigation/treatment, and operations and maintenance.

5.1 Karst Settings Description and Distribution

5.1.1 Bloomington Karst

The Bloomington Karst extends from approximately Clear Creek ,south of the Section 5 Corridor northward through Section 5 from That Road to approximately Arlington Road (old SR 46) and is developed in the St. Louis Limestone. The contact with the underlying Salem Limestone generally forms the lower limit of fast-flow groundwater circulation. Springs tend to be located at the contact between the St. Louis Limestone and the Salem Limestone. Springs draining the Bloomington Karst are typically contact springs, but are not limited to valley heads. The St. Louis Limestone has relief developed in excess of 150 feet (see elevation loss in **Table 6**). Recharge areas for springs generally include the grade of SR 37. These springs are being impacted by current road use and maintenance, development along SR 37, and other non-road related activities within their recharge areas.

The Bloomington Karst is the most extensive of the three karst areas investigated, and was crossed by about 36,000 linear feet of Section 5 Corridor. A total of 232 sinkholes and 64 springs were identified and associated with this karst during the study. The largest discharge springs in Section 5 are in the Bloomington Karst.

Spring is the most studied spring associated with Section 5. During the main investigation, mean daily discharge from Spring was 257 gpm and ranged from a daily discharge of 18 gpm to 3,916 gpm. The variation in discharge appeared to be representative of springs in the Section 5 study area.

A total of 27 dye introductions were conducted in the Bloomington Karst. Straight-line distances from the dye introduction points to the resurgent springs had a mean length of 3,023 feet and ranged from 341 to 7,098 feet. The Bloomington Karst mean trace length was longer than that of the Bloomington North Karst and Simpson Chapel Karst to the north.

Three losing streams that recharged karst groundwater systems were determined via dye traces in the Bloomington Karst.

Discrete recharge was not limited to sinkholes and losing streams, as some traces demonstrated discrete recharge from insurgence features without surface expression. Some rapid movement of water into karst groundwater systems can occur from locations where there is no surface expression to indicate the drainage conditions. This would be especially true in areas where the landscape has been modified and resulted in filled or altered sinkholes.

5.1.2 Bloomington North Karst

The Bloomington North Karst extends from about Arlington Road north to Kinser Pike at the southern slope of the Beanblossom Creek Valley and is developed in the Ramp Creek and Harrodsburg Limestones. The karst development is limited by underlying Edwardsville Shale that serves to perch the groundwater in the Ramp Creek Limestone. Karst development extends only 25 to 40 feet below sinkhole bottoms. Springs were typically small, just above the contact, and were generally found in valley heads. About half of the insurgence features and some of the springs in the Corridor were at higher elevations than the SR 37 grade.

Approximately 11,775 feet of the Section 5 Corridor crossed the Bloomington North Karst, the smallest of the three karst areas. A total of 99 sinkholes and 38 springs associated with this karst were identified during this investigation. The sinkholes were smaller on average than those found in the other two karst areas.

Seven dye introductions were conducted in the Bloomington North Karst. Straight-line distances from the dye introduction points to the resurgence springs had a mean length of 1,567 feet and ranged from 243 to 5,052 feet. This reflected the thin nature of the karst and the termination at the edges of the ridge tops.

5.1.3 Simpson Chapel Karst

The Simpson Chapel karst extends from Wayport Road at the northern slope of the Beanblossom Creek Valley and continues north to just south of Chambers Pike. This karst area was known to some local karst experts and appeared on a map produced by the IGS (Harke and Gray, 1998). The geology is similar to the Bloomington North Karst with development from 25 to 60 feet below sinkhole bottoms. Most of the insurgence features are above the SR 37 grade; therefore, many springs are not receiving road runoff. SR 37 was cut into the limestone through most of this area and was essentially redirecting runoff to other lower elevation karst features, or off the karst entirely.

Approximately 17,000 feet of the Section 5 Corridor crossed the Simpson Chapel Karst and was restricted to ridge tops. A total of 112 sinkholes and 57 springs associated with this karst were identified during this investigation. Road cuts on existing SR 37 often cut through karst in this area. In addition, many of the karst features in this area are not visible from roadways.

Seven dye introductions were conducted in the Simpson Chapel Karst. Straight-line distances from the dye introduction points to the resurgence springs had a mean length of 775 feet and ranged from 478 to 1,094 feet. This reflected the thin nature of the karst and the termination at the edges of the ridge tops. All of the dye introductions in this area were in sinkholes because no streams crossed the Simpson Chapel Karst (the stream channels have cut into the underlying shale).

5.2 Drainage Patterns and Land Use

Drainage patterns seem to have evolved quickly in some areas due to changes in land use. Numerous springs that had been used in previous investigations during the past 15 years were observed to have ceased discharging water. Some of these appear to have had sufficient flow since previous investigators had installed weirs to measure discharge.

In general terms, SR 37 was near both the topographic drainage divides as well as near the groundwater divides. **Figures 16 and 17** show the difference between the topographic basin divides and the groundwater drainage divides. These divides do not correspond in all of the tested locations and it should be assumed that not all of the locations that transfer water between topographic basins were identified.

The 2010 land use (based on field reviews and updates of a GIS land use layer provided by the Monroe County Planning Department (2006 data and 2012 updates[10]) in the relevant karst portions of Section 5 included the following:

- Agricultural 3747 acres or 9.9%
- Nonresidential/ Industrial 521 acres or 13.7%
- Public Use and Institutional 61 acres or 1.6%
- Mines and Quarries 45 acres or 1.2%
- Residential 669 acres or 17.6%
- Water 15 acres or 0.4%
- Transportation, Communication and Utilities 750 acres or 19.7%
- Upland and Wetland Habitat 1,365 acres or 35.9%
- Planned Development[11] (by 2035) 796 acres or 21.0%

As shown above, substantial portions of the Bloomington area have been developed. With an additional 796 acres or 21.0% of the relevant karst within the land use area planned for development by 2035 (based on only those specific areas of development identified by the local planning staffs [City of Bloomington and Monroe County]), the trend is for continued development, with corresponding increases in impervious surfaces, utility lines, drainage alterations, and potential sources of contaminants.

The relevant karst in the Section 5 study area has been impacted by residential and commercial/industrial development of the greater Bloomington area. This development is projected to continue regardless of potential interstate highway development.

---

10 Include post 2006 Section 5 DEIS updates (such as land cover, land use, population growth, planned development, setting, bedrock, Monroe County 2010 aerial photography and 2-foot contours (see page 1).

11 Specific sites of planned development were identified during the coordination process with planners from the City of Bloomington and Monroe County and placed in the project GIS. This development is anticipated to occur independent of the proposed project.

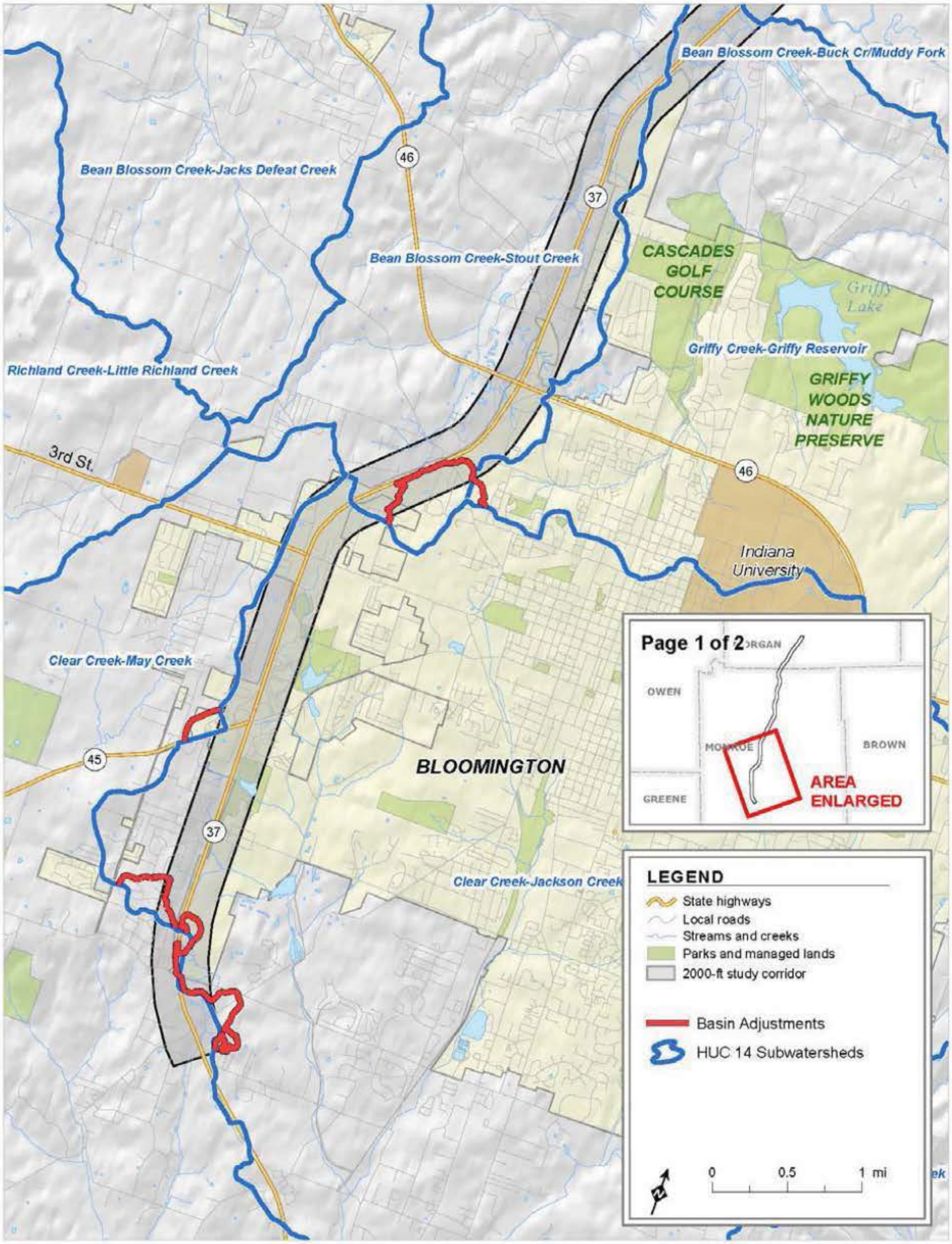

Figure 16 **Adjustment of Sub-Watershed Boundaries Resulting from Dye Tracing - Bloomington and Bloomington North Karst**

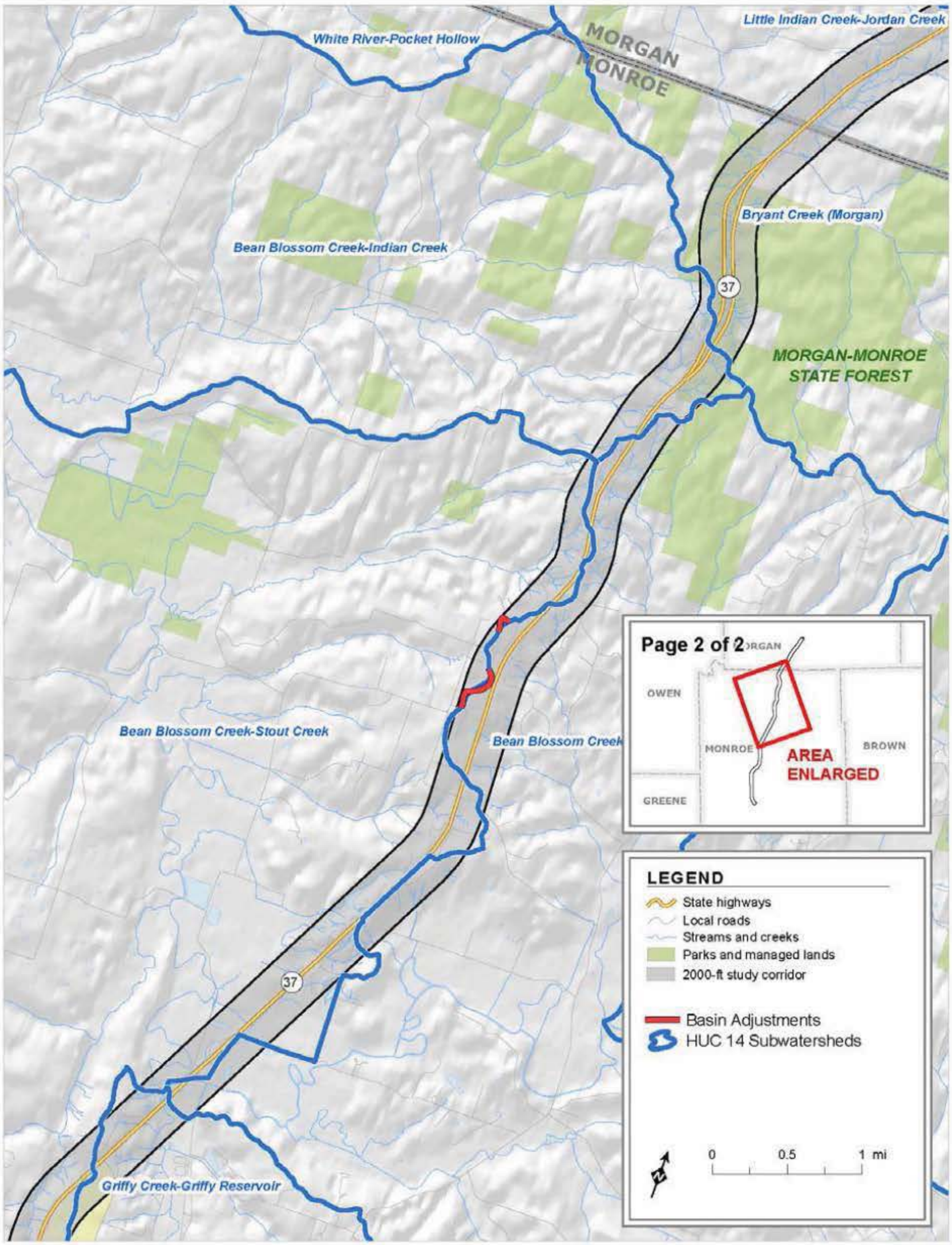

Figure 17 Adjustments of Sub-Watershed Boundaries Resulting from Dye Tracing - Simpson Chapel Karst

5.3 Dye Tracing

Forty-one dye introductions were made during this investigation. These dye introductions demonstrated 59 groundwater flowpaths, many to previously undocumented springs. Eighteen relevant previous dye traces and two Section 4 traces were used in this investigation for a total of 80 traced groundwater flowpaths. A total of 143 previously unreported springs were found in this investigation, over 3,800 samples were analyzed for the presence of fluorescent tracer dyes, and the dye-tracing program demonstrated the existence of three losing/sinking streams and their resurgences.

5.4 Characterization of Karst Groundwater Flowpaths

While the Bloomington Karst has longer and slower groundwater flowpaths than the other karst areas, these relatively slow flowpaths were still faster than those generally found in non-karst areas. Velocity tended to be in the hundreds to thousands of feet per day, and water from the fast-flow regime tended to travel from the surface to a spring in one to two days. The slower velocity is likely due to the lower average groundwater gradients.

The flowpaths in the Bloomington North Karst and Simpson Chapel Karst tended to be relatively shorter and faster than those in the Bloomington Karst, with velocities up to 48,000 feet per day. Travel times in the fast-flow regime typically ranged from minutes to one day for water to leave the surface and discharge at the springs.

The pathways traced are in turbulent flow regimes based on documented travel times and are competent to carry sediment, material adsorbed to sediments, bacteria, and dissolved loads into and through the groundwater system. These streams have most of the characteristics of surface streams, like surface streams, their flow velocity and ability to carry sediment varies dramatically with changes in discharge. The discharge of the springs investigated varied by at least two orders of magnitude. During the investigation, mean daily discharge from the was 257 gpm (**Appendix H)** however, the range for mean daily discharge was 18 gpm to 3,916 gpm. The hydrologic characteristics of the were representative of springs in the study area.

Most of the dye introductions in this area were in sinkholes. Sinkholes were the most common insurgence feature found in Section 5 and the dominant insurgence feature in which traces were initiated. Most of the sinkholes did not have bedrock exposed in them and did not have visible openings draining them. While only three traced insurgence features out of 28 had visibly open drain points, ponded water was observed in two features at the time of dye introduction. These observations indicated that dissolved contaminants would not be detained in the sinkholes, even if the sinkholes did not have obvious openings.

SR 37 tended to follow the sub-watershed boundaries with the groundwater divides fairly close to the topographic divides; thus, water generally flowed away from SR 37 through relatively short pathways (hundreds of feet to about one-half mile) to springs on either side of SR 37. Clearly there were karst flowpaths that crossed under the Corridor (and under SR 37); however, it was generally the headwaters of these systems that passed visibly, or via culverts, under SR 37.

For a karst groundwater system, the study area systems were relatively small and simple. Despite the relatively large number of springs found, the investigation revealed that there were relatively few interconnections among the groundwater systems, although that is less true south of That Road. Most traces were detected at only one spring, and most of the remaining traces showed some minor leakage to a nearby spring. The traces did not reproduce the complex flowpaths in the Bloomington area that appear in the resource literature and were reported as having trace detections of dye (Fitch, 1994).

South of That Road, there is a relatively large shared recharge area that contributes water to Spring, Spring , Spring, Springs, and Spring as demonstrated by Traces 09-05, 09-07, and 09-09. These hydrologically linked groundwater systems have karst groundwater flowpaths that range from generally east to southeast, to southwest, to nearly west.

There is also the hydrologically complex tributary containing Spring (GIS insurgence feature No. ss1) that had three dye introductions made at different locations in it: 04-11, 09-04, and 09-10. This stream has losing reaches, springs, and possibly gaining reaches. Water discharged at the in-channel springs Spring and Spring sinks through the stream channel, at least in part, to later resurge at Spring and Spring . Spring receives water, in part, from Spring. The stream reach between Rockport and That Roads loses water to Cave.

The Section 5 karst groundwater systems tend to be small and relatively isolated; therefore, a single spill along the roadway, even if uncontained, would generally impact a single, relatively small groundwater system. The only significant cave system linked hydrologically to the Section 5 Corridor is the Cave System that receives water from a relatively small part of the Corridor. South of the Cave recharge area to the Section 5 southern terminus with Section 4, the flowpaths are longer and shared recharge areas become more common.

5.5 Cave Biology

Cave and Cave and their associated conduits, groundwater systems and recharge areas were identified for a supplemental biological survey based on their connection to SR 37, and literature and reconnaissance observations conducted as part of the Section 5 investigation. OUL and its subcontractor, Lewis & Associates, conducted the survey (**Appendix J**). Note: the State Listing Status has been updated since the generation of Dr. Lewis' report (Lewis, 2005) for the following:

State Listed Species	2005 Status	2012 Status
• Indian cave springtail	State Endangered	State Watch List
• Packard's groundwater amphipod	State Rare	State Watch List
• Cave crayfish	State Threatened	State Rare
• Barr's cave crayfish	not listed	State Watch List
• Bollman's cave millipede	State Rare	State Watch List

The survey report concluded the following:

- There were no federally listed species identified as part of the biological surveys.
- Five troglobitic species were identified in Cave, one of which was a State-listed Rare Species (cave crayfish [*Orconectes inermis testii*]).
- Spring had no troglobitic species.
- Cave had one troglobitic species that was not designated rare or protected.
- Cave (Cave A) had 11 troglobitic species, of which eight are globally rare. Two are state-listed Rare Species (Barr's cave amphipod *Crangonyx barri* and cave crayfish *Orconectes inermis testii*); four species are on the State Watch List (Barr's cave crayfish ostracod *Sagittocythere barri*, Packard's groundwater amphipod *Crangonyx packardi*, Bollman's cave millipede *Conotyla bollmani*, and Indiana cave springtail *Sinella alata*); and, two are state-listed Endangered Species (hidden spring snail *Fontigens cryptica* and Mayfield cave beetle *Pseudanophthalmus shilohensis mayfieldensis*). Cave was ranked 9th most significant biological community out of 484 caves according to the number of obligate subterranean species (troglobites and stygobites) and species of high global rarity from cave bioinventories in Indiana (Lewis, 2005).
- While Cave (Cave B) has been linked by dye tracing to the existing SR 37 and Section 4 Corridor, the recharge area is over 800 feet south of the Section 5 corridor and is more accurately termed a karst window with limited access to a water filled cave passage.

Cave and Cave were considered biologically significant due to the state-listed species demonstrated to occupy them. Special measures may be required to protect these fauna from potential impacts from road construction, operation, and maintenance.

5.6 Areas of Special Concern

This investigation revealed four areas of special concern: Lemon Lane Landfill, Bennett's Dump, the area around the 2nd Street interchange with SR 37, and Cave. Each is discussed in the following sections.

5.6.1 Lemon Lane Landfill

Lemon Lane Landfill is a Superfund site and is described below in its USEPA Record of Decision Summary:

- *The original remedy for the Lemon Lane Landfill (as described in the Consent Decree and the Enforcement Decision Document) called for the excavation of approximately 196,000 cubic yards of material disposed of after 1958. The 1958 level within the landfill was based upon records which indicated that polychlorinated biphenyls (PCBs) disposal occurred after 1958. The PCB contaminated material was to be treated through the* *construction of a permitted, Toxic Substances Control Act (TSCA) approved municipal solid waste-fired incinerator. The modified remedy for the source control operable unit at the Lemon Lane Landfill consists of the following:*

- *Excavation and removal of selected areas of contamination (referred to as hot spots) contaminated with greater than 50 parts per million (ppm) PCBs on average, and disposal of the excavated soils and materials in a commercial, permitted chemical waste landfill. The estimated volume of material is 38,000 cubic yards.*

- *All PCB oil filled capacitors discovered during the hot spot excavation will be incinerated off-site in a permitted, commercial incinerator capable of meeting a destruction and removal efficiency of 99.9999%.*

- *Construction of a Resource Conservation Recovery Act (RCRA) Subtitle C compliant cap meeting the permeability requirements of 1 x 10-7 centimeters per second (cm/sec) placed over the landfill surface to address the low level threat wastes remaining. To limit surface water from migrating into the landfill, lined drainage ditches will be put in place to control water run on and runoff from the site.*

- *Areas outside the landfill cap to the north, east and west side of the site and outside the site fence line will be remediated to high occupancy/residential standard of 2 ppm PCBs on average. Areas within the fence line not covered by the landfill cap will be remediated to a low occupancy standard/industrial standard of 10 ppm PCBs on average with 10 inches of clean soil cover. Areas on the south side of the site that are outside the final cap, including the railroad berm will be remediated to 20 ppm PCBs on average.*

- *Development of a long-term inspection and maintenance plan for the landfill cap along with groundwater, springs, and surface water monitoring program for governmental parties approval.*

- *Treatment by off-site incineration of PCB oil filled capacitors is included as part of the remedy thereby partially meeting the requirement of reduction in toxicity, mobility, or volume through treatment. Off-site landfilling of PCB contaminated landfill material does not reduce the toxicity or volume through treatment, but does reduce mobility and is justified based upon the large quantities of municipal landfill waste mixed with industrial waste that was disposed of at the site. The court ordered deadline of December 31, 2000, along with community opposition to on-site thermal treatment, was factored into the decision making process. The low level threat waste remaining on-site will be contained under a RCRA Subtitle C compliant cap.*

- *The source control operable unit remedial action selected in the ROD Amendment results in hazardous substances remaining on-site above health-based levels, but these will be contained under a landfill cap. Future remedial decisions will be made regarding* *additional final water treatment and sediment removal. A long-term inspection and maintenance plan along with a groundwater and surface water monitoring plan will be implemented. A Five-Year Review will be conducted after commencement of the remedial action to ensure that residual PCBs do not pose a threat to public health and the environment.*

Lemon Lane Landfill is located southeast of the intersection of SR 37 and Vernal Pike (see **Figure 18**). The site is located adjacent to the 2,000-foot corridor, approximately 1,000 feet from existing SR 37 pavement. However, the current alignment of SR 37 crosses the Spring recharge area from approximately 1,200 feet south to 1,200 feet north of the Vernal Pike intersection. The Second Five-Year Review Report for the Lemon Lane Landfill (USEPA, May 2010) describes the background and actions taken for the Lemon Lane site, located in the City of Bloomington, Indiana. The site is a former 10-acre municipal landfill that accepted both municipal and industrial waste material. The Lemon Lane Landfill was operated as a sanitary landfill from the late 1930s to 1964 and included polychlorinated biphenyl (PCB) contaminated capacitors, materials, and other industrial wastes. Remedial measures at the site included: Phase II Assessment and delineation; and excavation and offsite disposal of 80,087 tons of PCB contaminated material and 4,402 capacitors; consolidation of 40,000 cubic yards of landfill material to an approximately 9 acres area; installation of a landfill cap over this material, perimeter drainage, security fencing, and a stormwater retention pond. The cleanup of areas outside the landfill boundary to high occupancy/residential standard of 2 ppm PCBs (on average) to the north (toward Vernal Pike), east, and west (toward SR 37) side of the site. Coordination with IDEM site managers and the USEPA superfund manager has occurred throughout the Section 5 study and is ongoing.

At the Superfund site, PCB impacted groundwater drains to via conduits developed in the karst (limestone bedrock). The USEPA treatment plant (with the capability to treat up to 1,000 gpm via carbon adsorption) captures the water emanating from the emergence, treats it for PCBs and then discharges the treated water to the stream. While attempts were made to treat all of the PCB impacted water discharged from the , peak flows have exceeded treatment and storage capacities, and the highest concentrations of contaminants are associated with the peak flows. Thus, any change in land use that would increase the volume or frequency of the excess flow could have significant adverse impact on the effectiveness of the site's discharge treatment. PCB impacted water discharging from that originates from the Lemon Lane Landfill is captured and treated prior to release to surface water. Recent additions at the plant have increased the treatment to a goal of 5,000 gpm. The combined treatment systems are expected to treat nearly 100% of the spring water and prevent 99.9% of the PCB mass from from entering the receiving stream.

USEPA and IDEM and site participants (primarily CBS – formerly Westinghouse) involved in the ongoing treatment operations have requested that the Section 5 design and planning processes take into account the overall goal of reducing the volume of water entering the recharge area. Since the treatment system operations directly affect the local surface water and sediment quality, and consequently potential human and ecological receptors, roadway pavement runoff control and redistribution away from the recharge area has been determined to be of specific concern for mitigation planning.

The current alignment of SR 37 crosses the recharge area of as delineated by Fitch (1994). The Section 5 Tier 2 investigation revised the recharge area based on new data, see **Figure 18**. The revised recharge area shows that minimal amounts of SR 37 are currently in the recharge area.

The preferred alignment and design for Section 5 of I-69 should avoid contributing additional water to the recharge area and drainage control during construction should avoid increasing runoff to the site. Ideally, less water would be directed from the pavement, frontage roads, and right-of-ways, and thus reduce the duration and frequency of discharges in excess of treatment and storage capacity at the treatment facility.

All of the alternatives maintain use of the existing SR 37 right-of-way with potential widening, away from Lemon Lane Landfill. A commitment that subsequent I-69 drainage along the western edge of the recharge area will not increase above existing SR 37 levels has been made by INDOT to prevent increased flow into the Lemon Lane Landfill/ system.

The following three measures are recommended for reduction of roadway contribution to the recharge area:

- Maintain the eastern boundary of the SR 37 right-of-way with any required mainline expansion or new access roads to the west, away from the landfill, in all six of the alternatives.

- Shift the proposed Vernal Pike grade crossing north to connect with 17th Street in all of the alternatives and use of an overpass rather than rock cut for use of underpass in Alternative 7, 8, and the Refined Preferred Alternative 8.

- INDOT has made a mitigation commitment to prevent drainage from increasing above the existing SR 37 levels extending along the eastern side of SR 37 that is within the Lane Landfill/ recharge area to address USEPA and IDEM concerns regarding changes in existing groundwater flow. Coordination with USEPA and IDEM has occurred throughout the Section 5 study and will continue through the design phase. Blasting is not anticipated and will not be allowed adjacent to the site to prevent damage to the monitoring system (see **Figure 18**). Design plans for construction this area will be provided to USEPA and IDEM for review with a requested two-week turnaround time for comment.

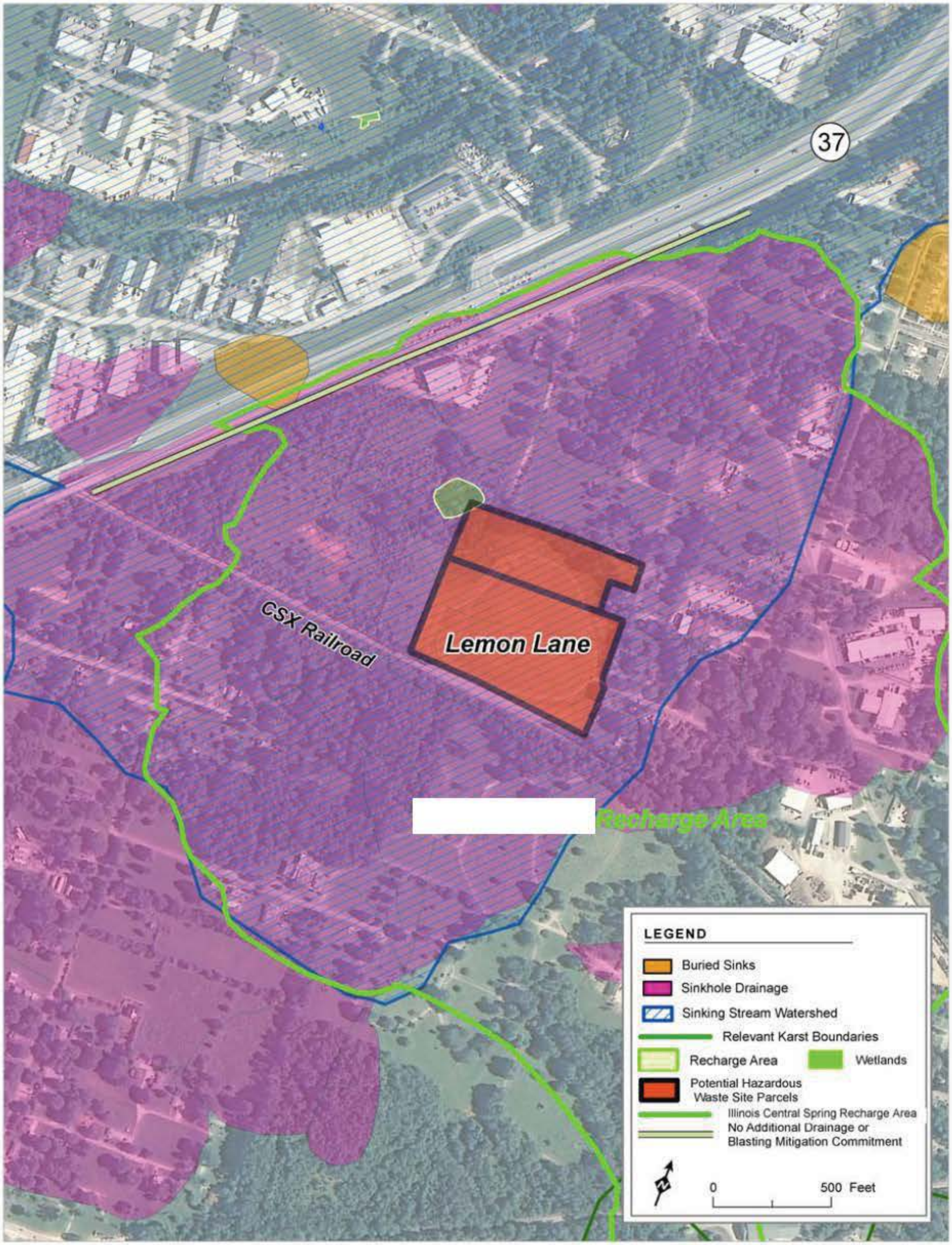

Figure 18 Area of Special Concern: Lemon Lane Landfill

5.6.2 Bennett's Dump

The Bennett's Dump Superfund site is described below in its USEPA Record of Decision Summary:

- *The cleanup remedies for the Bennett site was developed in accordance with the Comprehensive Environmental Response, Compensation, and Liability Act of 1980, as amended by the Superfund Amendments and Reauthorization Act of 1986 (CERCLA), and, to the extent practicable, the National Oil Hazardous Substances Pollution Contingency Plan (NCP) and Agency Policy.*

- *Original remedy called for excavation of 55,000 cubic yards. The excavated soils and materials contaminated with PCBs were to be treated by incineration through the construction of a permitted, municipal solid waste fired incinerator.*

- *The modified remedy for Bennett's Dump consists of the following:*

    - *Excavation of approximately 55,000 cubic yards of PCB contaminated soils and materials and off-site disposal in a permitted, commercial chemical waste/TSCA landfill. Cleanup of PCBs will be to industrial/low occupancy standards of 25 ppm PCBs on average.*

    - *Off-site incineration of large PCB oil filled capacitors. Small capacitors, defined as containing less than three pounds of PCBs, will be disposed of in a TSCA landfill.*

    - *Long-term groundwater monitoring and implementation of deed restrictions.*

- *The selected remedies are protective of human health and the environment, comply with, at a minimum, federal and state requirements that are legally applicable or relevant and appropriate to the remedial action, and are cost effective. Treatment by off-site incineration of large, PCB oil filled capacitors is included as part of the remedy thereby meeting the requirement of reduction of toxicity, mobility, or volume through treatment.*

- *Off-site landfilling of PCB contaminated soil and materials does not reduce the toxicity, mobility, or volume through treatment but is justified based upon the court mandated deadline and community opposition to thermal treatment.*

- *The remedial actions selected in the ROD Amendment do not result in hazardous substances remaining on-site above health-based levels. Groundwater monitoring and a Five-Year Review will be conducted after commencement of the remedial action to ensure that residual PCBs do not pose a threat to public health and the environment. After the completion of the first five-year review for each site, the U.S. EPA will evaluate whether further five-year reviews are necessary and whether groundwater monitoring will continue.*

The Bennett Stone Quarry USEPA National Priority List (Superfund) site (also referred to as Bennett's Dump), is owned by Ledge Wall Quarry, LLC. (formerly Star Quarry Inc.) and covers about four acres of the total parcel. Bennett's Dump is located in the northwest corner of the interchange of SR 37 and SR 46, approximately 1,000 feet from existing SR 37 pavement and adjacent to the Section 5 Corridor.

The Third Five-Year Review Report for Bennett's Dump (USEPA, August 2012) describes the background and actions taken for the site. During the previous SR 46 interchange construction, a series of former quarries were filled and portions of the Stout Creek drainage system were altered. The site has exhibited elevated groundwater levels since construction of SR 46. After soil and material excavation and off-site treatment/disposal activities were completed in 1999, five springs ( ) on the Bennett's Dump site that discharge to Stout Creek showed PCB contamination. To address these springs, a passive drainage system to allow upgradient abandoned quarry pits and waste stone areas to drain directly to Stout Creek, thereby bypassing residual contaminates at the dump site, was installed in 2010. On-site groundwater treatment and potential hydraulic isolation (via installation of a slurry wall/groundwater barrier) treatments are under consideration by the overseeing agencies and site participants (primarily CBS – formerly Viacom and formerly Westinghouse).

The remedy for the source control area has been implemented with confirmation sampling showing residual PCBs in soils below the site cleanup level of 25 ppm. Potential exposure to landfill related soil contamination (in excess of construction worker standards) is minimal based upon the upgradient, higher elevation, and 1,000-foot separation from existing SR 37 and all of the alternatives, and the completion of on-site soil remedial actions to site cleanup standards.

The SR 46 extension was constructed south of the site. During construction, a group of former quarries were filled and portions of the Stout Creek drainage system were altered. The site has exhibited elevated groundwater levels since construction of SR 46.

USEPA and IDEM and site participants involved in ongoing remedial design and mitigation measures at the site have requested that the I-69 Section 5 design and planning processes take into account the overall goal of redirecting runoff around the site. Since mobilization of residual contaminants at the site has the potential to directly affect the local surface water and sediment quality, and consequently potential human and ecological receptors, roadway pavement runoff control and redistribution outside of the recharge area and drainage control during construction should avoid increasing runoff to the site. This has been has been determined to be of specific concern for mitigation planning. Coordination with IDEM site managers has occurred throughout the Section 5 study and is ongoing. IDEM has indicated that it potential additions to groundwater in the SR 46 area would be of concern, rather than surface water flow from diversion of runoff water upstream to Stout Creek.

While none of the six alternatives will impact the Bennett's Dump, the current alignment of SR 37 and all of the six alignments are upgradient of Bennett's Dump. INDOT has made a commitment that the ramp drainage in the northwest quadrant of the SR 37/future I-69 and SR 46 will not increase from existing SR 37 levels (see **Figure 19**).

The remedy for groundwater has not been completely implemented, since low levels of PCBs continue to be detected at onsite springs. Based on recent data by USEPA, the PCB mass discharging into Stout Creek is being reduced by over 80% with the installation of a passive quarry drain. While the passive quarry drain has been constructed and functioning well, PCBs continue to be released from on-site springs into Stout Creek, and further investigation into capturing and treating these releases is ongoing. The installation of a collection trench, on-site water treatment plant, and appropriate institutional controls are also under consideration as part of the completion of the groundwater remedy. A remedial option has not yet been chosen.

The following measures are recommended for reduction of roadway contribution to the Bennett's Dump recharge area during subsequent design phases:

- Limit paving and construction to the existing SR 37 and SR 46 mainline and intersection.
- INDOT has made a mitigation commitment to prevent drainage from increasing above the existing SR 37 levels extending along the eastern side of SR 37 that is within the Lane Landfill/ recharge area to address USEPA and IDEM concerns regarding changes in existing groundwater flow. Coordination with USEPA and IDEM has occurred throughout the Section 5 study and will continue through the design phase. Blasting is not anticipated and will not be allowed adjacent to the site to prevent damage to the monitoring system (see **Figure 19**). Design plans for construction this area will be provided to USEPA and IDEM for review with a requested two-week turnaround time for comment.

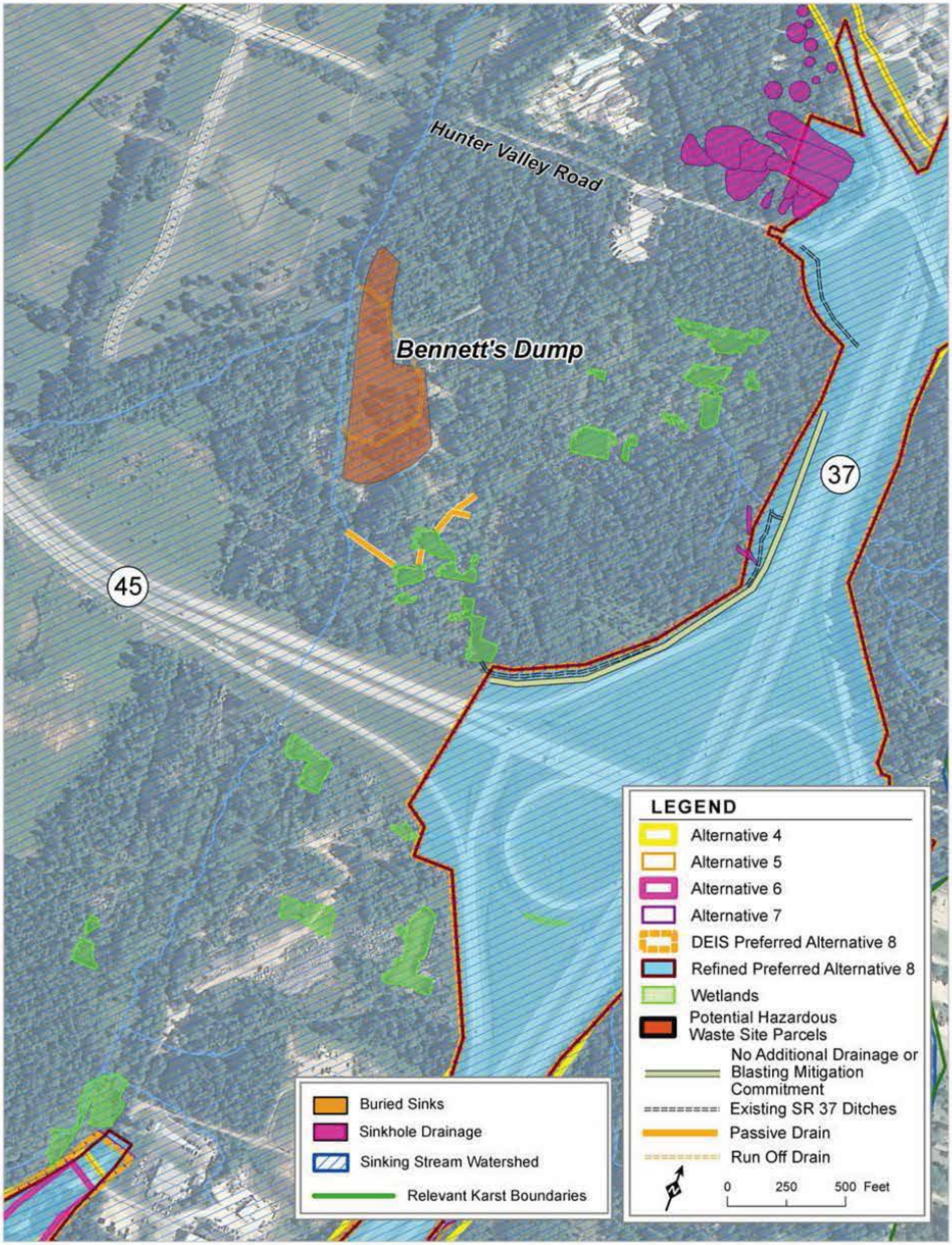

Figure 19 Area of Special Concern: Bennett's Dump

5.6.3 SR 45/2nd Street – SR 37 Interchange

The intersection of SR 45/2nd Street and SR 37 is considered an area of special concern due to the presence of numerous sinkholes and a reported former cave that were filled as part of SR 37 construction, and by various local developments. Many of these sinkholes have had roadway and development runoff culverts installed in or near them. There has been a history of some of these sinkholes reopening. **Figure 20** shows the area of special concern, the associated modified and filled sinkholes, and their historic catchment areas.

The literature search provided numerous examples from across the country of roadbed failures at reopened sinkholes resulting in economic loss, and sometimes loss of life (Waltham et al., 2005). Care should be taken to ensure that the design of I-69 Section 5 consider sinkholes which no longer have the appearance and function of sinkholes, but have the potential to destabilize the roadbed and adjacent lands.

In the Tapp Road and 2nd Street intersections area, the split interchange (Alternatives 5, 7, 8, and the Refined Preferred Alternative 8) has a larger right-of-way for the additional ramps and access lanes. This larger area could cause greater impacts to relevant karst features including sinkholes, increased potential for roadbed subsidence and/or reopened sinkhole(s), and could potentially alter karst recharge patterns more than the less impactful features (overpasses) in Alternatives 4 and 6 and the reuse of the existing 2nd Street interchange in Alternative 6.

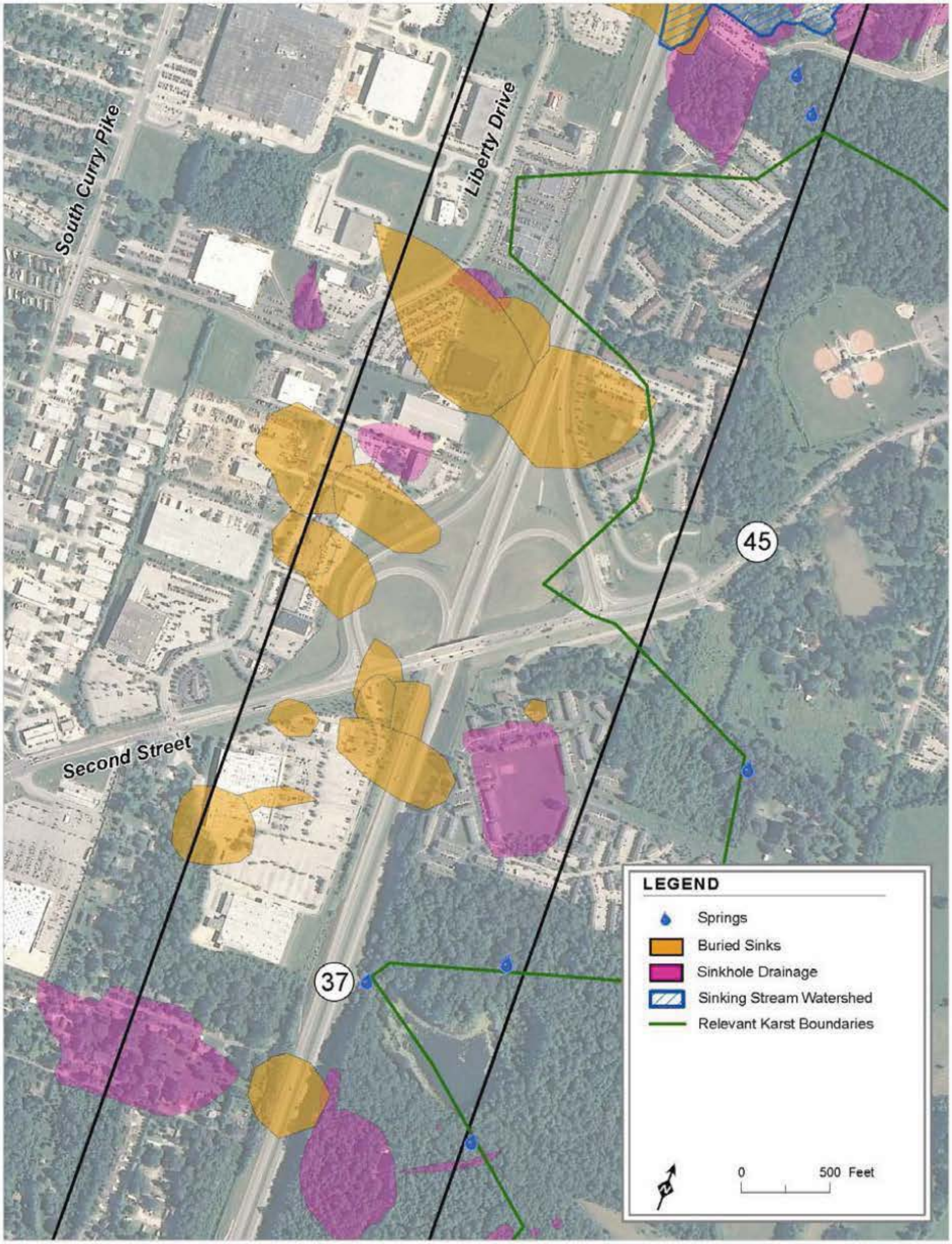

Figure 20 Area of Special Concern: 2nd Street – SR 37 Interchange

5.6.4 Cave Recharge Area

Cave (Cave A) is considered an area of special concern due to its biological significance from diverse troglobitic (obligate cave dwelling) fauna, and state-listed threatened and endangered species (Lewis, 2005). A mapped cave passage extends under SR 37 (Roy and Wells, 1959), and the groundwater recharge area of the cave extends across SR 37 and the Section 5 Corridor.

The Lewis, 2005 investigation indicated that the cave's biological community appears to be in relatively good health despite historical and current runoff from SR 37 and other land uses in its recharge area. No federally listed species were identified.

The I-69 Section 5 planning and design process will attempt to minimize potential additional impacts from water derived from Section 5. While there is little direct data on cave passage depth, based on a comparison of spring and Section 5 Study Corridor elevations, some Cave conduits may be not much more than 20 feet and are no more than 100 feet in depth. While the Cave passage that extends under SR 37 was reported as a narrow, linear feature, if bedrock removal is included in construction designs in this area, geophysical surveying to evaluate the potential for intercepting this conduit will be required.

The Monroe Hospital complex, Medical Park Boulevard, parking lots, electrical sub-station, and two retention basins were constructed on the southwest corner of the Fullerton Pike/SR 37 intersection. Additional medical or commercial development buildings and related parking lots, new access roads, onsite stormwater management, and a helipad are also planned. Most of this complex and new development are within the Cave recharge area, and are expected to alter the recharge patterns for the Cave system (see **Figure 21**).

While Cave has been linked by dye tracing to the existing SR 37 and Section 4 Corridor, the recharge area is over 800 feet south of the Section 5 corridor and is more accurately termed a karst window with limited access to a water filled cave passage (see **Figure 21**).

All of the alternatives are within the Cave recharge area and have similar impact areas. The proposed six-lane I-69 will have similar type of direct impacts to the Cave System as the existing four-lane SR 37, see **Figure 21**.

- The That Road to Rockport Road local access road and the Rockport Road overpass have similar impacts to the Cave recharge area in all six of the Alternatives.
- The eastern shift off of existing SR 37 in Alternatives 4 and 5 have increased impacts to the Cave recharge area when compared to Alternatives 6, 7, 8 and Refined Preferred Alternative 8 that stay on existing SR 37 for both the mainline and the Fullerton Pike interchange.
- The Cave recharge area impacts related to the Fullerton Pike interchange are limited to the southern part of the south side interchange ramps. This change is not considered to be of sufficient magnitude to adversely affect the Cave fauna.

- The Cave recharge area is to the west of the Monroe County Fullerton Pike project that begins at the Fullerton Pike and Rockport Road intersection.

Several treatment options are available for consideration as potential mitigation measures in implementation of the Karst MOU to reduce roadway impacts to the Cave recharge area and maintain the existing base flow levels in the system:

- Engineered wetland sediment and contaminant reduction systems.
- Linear peat sand filters and/or vegetated swales along the roadway or at the terminus of lined storm water control structures.
- Runoff and storm water detention/retention systems, treatment, and infiltration galleries.
- Control of “first flush” (or initial stormwater runoff which typically will have higher contaminant concentrations) volumes with designed overflow into natural drainage systems.

See **Appendix F** - Figure F-42 for a summary of the individual dye traces used for the determination of the Cave Recharge Area. This summary includes historical traces, those conducted for the Section 5 Karst evaluations, and thirteen additional traces conducted specifically for determination of the Cave recharge area:

Trace 08-01: Rothrock Trace
Trace 08-02: Elkins Trace
Trace 08-03: Stone Trace
Trace 09-04: Spring Tributary Trace
Trace 09-05: Elkins Dr Trace
Trace 09-06: Elgar Trace
Trace 09-07: SR 37 Frontage Trace
Trace 09-08: Glosser Trace
Trace 09-09: Crowder Trace
Trace 09-10: Intermediate Trace
Trace 09-11: Well Trace
Trace 09-12: Abrams Trace
Trace 09-13: Schaad Trace

Figure 21 Area of Special Concern: Cave Recharge Area

5.7 General Environmental Concerns

In addition to the previously discussed areas of special concern, there are general environmental concerns when planning road construction in karst. Karst cannot be entirely avoided within the Section 5 Corridor, although some particular karst features may be avoided. Thus, the focus of alignment development and design should be on minimizing impacts to the karst via alternative drainage, mitigation/treatment, and operations and maintenance.

It is characteristic of karst systems to exhibit high groundwater velocities through natural conduits large enough to permit turbulent flow. Turbulent flow is capable of transporting sediment and contaminants quickly into caves and to springs that may be relatively far from their source. In addition, karst systems often transfer water across sub-watershed boundaries (i.e., interbasin transfer). Fourteen traces demonstrated this transfer in Section 5. Consequently, if a hazardous material spill containment failure should occur in the vicinity of the roadway, the location for an effective response might not be obvious. The dye tracing data provided in this report demonstrated certain specific linkages as well as patterns in groundwater flowpaths. These data should be used to plan spill responses in the event that spill containment and/or passive treatment systems fail. Additional dye tracing may be necessary to provide more data for identifying appropriate locations for spill response.

Flooding in the southern portion of the Section 5 study area was a common complaint of residents in the Bloomington area. Sub-watershed boundaries are not the only data required to determine where runoff will flow. While the local flooding was probably not related to karst groundwater flowpaths, redirection of runoff may be perceived as aggravating existing problems. Thus, care should be taken to quantify the amount of redirected water and to minimize overall increases to peak flows.

One characteristic that was favorable to highway construction in this karst area was that groundwater systems tend to be small and relatively isolated. A single spill along the roadway, even if uncontained, should generally impact a single, relatively small groundwater system. In many other karst areas, spills have the potential to impact very large, interconnected groundwater systems. Only a relatively small portion of the Section 5 Corridor is hydrologically linked to significant cave systems, Cave.

Existing road use, maintenance, and adjacent development currently impact Section 5 karst.

5.8 Engineering Concerns

Karst is a distinct landscape in which standard engineering practices are sometimes inappropriate. Consideration should be given to how this landscape functions under given conditions:

- There are sinkholes throughout Section 5 that have been filled or otherwise modified by people or natural processes. In areas where loess-derived soils overlie karst, sinkhole collapse can result with no apparent surface expression prior to collapse. Loess is internally erodible and is susceptible to soil piping and stoping upward from bedrock cavities to the surface.

- Impervious surfaces, such as roads, can inherently change patterns of runoff and infiltration. Concentrated or redirected water can destabilize sinkholes (with or without current surface expression) as they equilibrate with the new water input conditions. Unlined water detention or retention structures can increase the hydraulic head (i.e., saturate) in the supporting earthen materials and possibly lead to failure of such structures.

- Impervious surfaces, such as roads, can sever recharge features. This can result in decrease spring discharges and alteration of habitat for any biological communities within the karst system.

- The flowpaths determined in this investigation are naturally occurring conduits in limestone bedrock (karst flowpaths). Fourteen of these flowpaths have been determined to cross under SR 37, and additional conduits are likely to be discovered. The flowpath data presented in this report are diagrammatic; the lines representing the flowpaths are not meant to represent the actual location or distribution of the conduits. While these conduits are large enough to have turbulent flow, they are unlikely to have spans greater than a few feet, based on the relatively small groundwater systems of which they are components.

- There are hydrologically active insurgence and resurgence features under SR 37. The dye introduction point for Trace 04-03 is a sinkhole under the highway that has a culvert leading into it. Spring (Station 2) is under SR 37 and has a steel culvert installed to allow water to flow out from under the highway. Springs in karst terrain can have a wide range of discharges. If the seal between a culvert and a spring orifice is or becomes imperfect, or if the culvert is undersized (for peak flows that tend to increase over time in urbanizing areas), excess head (pressure) can build up under the road, leading to failure of the highway facility. Road bases can be eroded by an underlying spring that is not properly engineered.

- During the investigation, numerous reopening sinkholes and soil piping were observed, and had formed under concrete-lined and natural grass roadside ditches within the study area, most notably along road ditches on SR 37. Wheel ruts found at the upstream end of concrete paved ditches, or adjacent to the paved linings seemed to have a high correlation with the locations of soil piping. Presumably, these ruts are causing water to pond at the edge of the paved ditches and become a point source for relief of hydraulic head. The excess hydraulic head is relieved by erosion underneath the concrete lining. In other words, the water passes under the concrete linings and causes internal erosion (soil piping). Some of the wheel ruts appeared to result from vehicles accidentally leaving the roadway in wet weather, while others clearly resulted from tractors mowing the ROW grass when the ground was soft.

6.0 RECOMMENDATIONS

The recommendations are divided into: 1) additional studies; 2) BMPs related to highway construction and design; and, 3) Measures in areas of Special Concern.

6.1 Best Management Practices

The following recommendations for BMPs relevant to the design, construction, and maintenance of Section 5 in the relevant karst areas were developed to conform to the 1993 MOU:

- Construction within the karst areas should be planned with effective erosion and sediment control measures. Procedures to reduce the impacts to karst will be implemented in accordance with applicable but not karst specific INDOT's Standard Specifications and other BMPs identified in the Section 5 FEIS/ROD, Final Karst Feature and Groundwater Flow Investigations Report, and the 1993 Karst MOU. Stormwater runoff protection measures will be installed at all karst features in the right-of-way at the initiation of construction and maintained until all stormwater drainage has been diverted away from the feature, or final permanent stormwater treatment measures are in place. Erosion control measures will be put in place as a first step in construction and maintained throughout construction. Temporary erosion control devices such as silt fencing, check dams, sediment basins, inlet protection, sodding and other appropriate BMPs will be used to minimize sediment and debris in tributaries within the project area. Timely re-vegetation after soil disturbance will be implemented and monitored. Any riprap used will be of a large diameter in order to allow space for habitat for aquatic species after placement. Prior to construction, heavy equipment parking and turning areas will be located outside the construction limits but within the right-of-way to minimize soil erosion. Soil bioengineering techniques for bank stabilization will be considered where appropriate. The staging of equipment and materials should occur outside of karst areas, or at a minimum on impervious material with controlled drainage. Same-season re-vegetation of disturbed land during construction, repairs and maintenance should be used when feasible.

- A Low salt/No spray zone for Section 5 will be established along the I-69 mainline and interchanges that extends from the Section 4 interchange to approximately 200 feet north of Chambers Pike. Further coordination with the Karst MOU agencies will occur during the design phase of the project regarding low-salt zones. Road maintenance should include posted low salt/no spray areas to prevent contaminants from entering karst systems. Mowing should be restricted to appropriate times, and repairing damaged vegetation and drainages should be required. Installation of guardrails could be utilized to prevent vehicles from leaving paved roadway surfaces.

- It is anticipated that the Blasting Operations Specifications utilized during the Section 4 construction in karst areas will be utilized for the Section 5 activities. The specification was developed to protect karst and limestone resources.

- Because this project will require a Rule 5 Permit issued by IDEM, INDOT has make a mitigation commitment requiring the designer to abide by Rule 5, Item B1 of the Erosion Control Plan, which states:

  > "This item is included in the rule to place an emphasis on identification of pollutants that are associated with construction activity. In the past, the emphasis has been on sediment reduction; however the rule requires the plan preparer to identify other potential pollutants and their sources. Potential pollutant sources include material and fuel storage areas, fueling locations, exposed soils, leaking vehicles and equipment, etc.
  >
  > To satisfy this item, the plan needs to contain a written description of the expected pollutants that could enter storm water during the construction operation, and where those potential pollutants might be generated. In addition, the plan preparer should include discussion of measures or operational activities that will be initiated to minimize the danger of pollutants entering storm water."

- There are locations along existing SR 37 where runoff water is directed to karst features (i.e. sinkholes). While the specific karst features requiring a Class V injection well are not known at the EIS stage of the Section 5 project, they are likely to be related to sinkholes if they are modified to receive Section 5 stormwater drainage as part of final design, and mitigation commitments. Most of the Class V well permits anticipated within Section 5 would be authorized by rule because there will be measures in place to prevent contamination as part of sinkhole mitigation under the Karst MOU.

- Some of the channels that cross the Corridor may be under-drained in karst areas and may appear to transmit water infrequently. Culverts and bridge openings must be sized to accommodate the required rainfall events as defined by the INDOT Drainage Design Manual and be appropriate to the specific karst feature, where applicable. Unique backwater conditions created by sinking streams and other insurgence features will require further evaluation during subsequent design stages to assure that adequate detention storage volume is available.

- The roadway project needs to convey surface water runoff with as much natural treatment for water quality as is feasible. This treatment is best accomplished by dispersing the runoff through at least 100 feet of vegetation filter swale or passing it through an engineered treatment system (sediment basin) before it reaches the invert elevation for a sinkhole.

- Where possible, the road prism (structures, base and pavement) should not restrict flow into a sinkhole or other insurgence feature. Use of filters, buffers, containment structures, reinforced soil, void grouting, compaction grouting, concrete caps, reinforced bridging slabs (land bridges), deep foundations, etc. are potentially effective mitigation measures, but will not be determined until subsequent detailed design stages.

- Utilization of lined ditches to the outfall discharge points are recommended within the karst areas designed to prevent erosion. Water flow within the roadway ditches will need an analysis for lining requirements. Culvert outlets should be designed to discharge water to at grade terrain. This design will reduce erosion scour and sediment transport into the karst and other environments. Design of ditches and culverts should be based on INDOT's Drainage Design Manual and be appropriate to the specific karst feature.

- The drainage design for I-69 should provide for proper energy dissipation devices at the culvert and storm sewer system outlet locations to prevent erosion to existing channels. Energy dissipater devices include such items as scour holes, riprap linings and stilling basins. Design of energy dissipater devices and ditch linings should be based on INDOT's Drainage Design Manual and be appropriate to the specific karst feature.

- The roadway drainage system should be incorporated into the Operations and Maintenance Plan for inspection and repair to prevent disturbance of karst drainage patterns and undercutting observed along SR 37. The karst areas will require monitoring to evaluate roadway slopes and ditches and repair of off-road disturbances.

- Excavation into bedrock below the current SR 37 roadway grade that could potentially expose cave passages and other karst conduits and should be avoided where feasible. Roadway grading constructed with embankment fill is preferable to cuts in bedrock.

- Implementation of hazardous waste traps will conducted by INDOT (or their designated contractors) to protect karst features against hazardous materials spills per Step 7 of the Karst MOU. Spill response equipment should be readily available during construction and subsequent use of the road. Due to the high flow rate within karst systems, response times are critical for prevention/reduction of impacts to karst ecologic communities, groundwater resources, and surface water. The first priority must be to prevent contaminants from entering the karst groundwater system at the location of the release. Once contaminants have entered the karst system, use of preventive or mitigation measures at appropriate resurgence points for both surface water and sediment are time critical due the high water velocities (depending on the particular conduit system, precipitation, and flow conditions).

- In the event that a sinkhole cannot be avoided, the sinkhole should be capped. A special design of the roadway subgrade and pavement structure should be considered in these areas to avoid the hazards of sinkhole instability and reallocated water runoff. The special design may include increased structural design of roadway pavement and anchoring of pavement slabs crossing the sinkhole area(s) to underlining bedrock.

- In the event that disturbance of a spring cannot be avoided, a spring box and culvert should be constructed to discharge the flow to an appropriately designed outfall. A special design of the roadway subgrade and pavement structure should address potential undermining of the roadbed due to excess pressure (head) discharging from the spring or potential water leakage from the spring boxes and culverts over time. The special design may include increased structural design of roadway pavement and an anchoring of pavement slabs crossing the spring areas to underlining bedrock.

- In the event that disturbance of a karst flowpath (underground steam) cannot be avoided, the top of the karst flowpath should be capped, but still allow for natural flow within the flowpath. A special design of the roadway pavement structure should be considered in these areas to ensure that the natural conduit does not collapse and threaten the integrity of the roadbed. The special design could include increased structural design of roadway pavement and an anchoring of pavement slabs crossing the karst conduits to underlining bedrock.

- If caves are exposed during construction, karst experts should be consulted to determine their project significance. Drainage and treatment alternatives will be considered concurrently so as to not impede drainage in recharge areas and having potentially harmful impacts to cave biota.

- In the event that federal and/or state listed species are encountered during construction that were not previously reported/evaluated (e.g., at and Caves) construction should be halted in that area until an evaluation can be performed.

A listing of karst feature treatment circumstances which may require BMP implementation, BMPs that may be implemented, and a numerical cross-reference to applicable but not karst specific INDOT Standard Specifications, such as Standard Specification 205 pertaining to soil liners, is included in **Table 10**. The INDOT Standard Specifications are available on-line at: http://www.in.gov/dot/div/contracts/standards. This listing is not intended to be all-inclusive. These and other BMPs identified in the Tier 2 Section 5 FEIS/ROD, *Final Karst Feature and Groundwater Flow Investigations Report*, and the 1993 Karst MOU will be considered for implementation on a case by case basis.

Table 10: Best Management Practices (BMPs) in Karst Terrain

Best Management Practice (BMP)	Description	Numerical Reference to INDOT Standard Specification[12] (where applicable)
Ditch Lining		
Compacted clay liner	Lined ditches can be utilized to prevent erosion. The hydraulic analysis in design will determine the water flow and velocity to select the proper lining. This will not only reduce erosion but also limit the sediment transport into karst features.	205 describes the installation of pond liners, synthetic liners, and soil liners and could be adapted to this work.
Geosynthetic clay liner	This is an effective method to protect groundwater penetration along a road side ditch.	205 describes the installation of pond liners, synthetic liners and soil liners and could be adapted to this work.
Flexible membrane liners	Beneficial since these will conform to undulating topography.	205 describes the installation of pond liners, synthetic liners, and soil liners and could be adapted to this work.
Concrete, Portland cement, or asphalt	Can be used, although not as aesthetically pleasing as the other options.	607 describes paved side ditch construction for both concrete and asphalt work.
Sinkhole - Bridging		
Culvert or bridges	The INDOT Drainage Design Manual will be used to size the openings of bridges and culverts. Unique backwater conditions created by karst features will be evaluated further in design to assure proper detention storage. If a karst feature cannot be avoided, filled, or capped, the roadway should span the feature and be anchored (reinforced) into competent bedrock. Cuts into bedrock should be minimized when possible.	714, 715, 723 describe different culverts and concrete boxes and 3-sided structures that can be installed.
Reinforcing within cave	The mortar will coat and strengthen the cave walls.	708 describes pneumatically placed mortar (shotcrete).
Ground modification	Can strengthen soils by injecting concrete or lime.	203 describes soils modification with chemical.
Geopier with cap	Typically installs quicker than traditional piers or piles; will provide strength to wide range of soils	INDOT does not directly address Geopier, but 701 gives requirements for piles and piers.
Piles with cap	Traditional method for vertical reinforcement of soils.	710 addresses pile installation.
Sinkhole - Filling		
Rock pads	Works where the velocity of the storm	205 describes rock splash

[12] INDOT has not developed standard specifications for every conceivable mitigation need which may be encountered. If specific field conditions require a mitigation measure for which INDOT presently has no Standard Specification, then a Unique Special Provision could be developed and approved by INDOT.

Table 10: Best Management Practices (BMPs) in Karst Terrain

Best Management Practice (BMP)	Description	Numerical Reference to INDOT Standard Specification[12] (where applicable)
	water needs to be decreased to prevent erosion.	pads as an erosion control measure.
Large rock fill	Effective for slope stability issues.	203 describes placing large rock fill before backfilling with structure backfill or borrow.
Compaction grouting	Useful where soil is loose or soft and does not need a large area for installation.	A standard would have to be written for this.
Cement grouting	Effective where there are significant voids and cracks in load bearing rock	206 describes the process for grout injection.
Dynamic compaction	Will increase the density of the soil, even soil below the groundwater; best for granular soils.	203 describes excavation and backfilling requirements as well as chemical soil modification.
Excavation, overlapping geotextiles, soil backfill	If a sinkhole is located within the new right-of-way, yet has a very small drainage area, then capping is more appropriate (versus installing a catch basin and standpipe).	203 describes excavation and backfilling requirements as well as chemical soil modification.
Excavation, concrete cap, soil backfill	If a sinkhole is located within the new right-of-way, yet has a very small drainage area, then capping is more appropriate (versus installing a catch basin and standpipe).	203 describes excavation and backfilling requirements as well as chemical soil modification.
Other		
Avoidance	The alternatives have been screened for the number of karst features that may be affected. As design further details the road's cross section and alignment at a particular karst feature, avoidance should continue to be considered if cost effective and within appropriate design criteria.	
Alternative drainage	Redirecting highway runoff away from karst recharge features. Will be implemented where feasible. In some areas, this is not an option due to karst features being distributed across the corridor.	
Earth berm construction	Provides a natural look to the erosion control.	205 describes diversion berms of earth or rock as an erosion control method.
Gabion berm construction	May be appropriate at very steep slopes (>10%).	Recurring provision 625-R-194 describes the requirements and placement of gabions.

Table 10: Best Management Practices (BMPs) in Karst Terrain

Best Management Practice (BMP)	Description	Numerical Reference to INDOT Standard Specification[12] (where applicable)
Open standpipe installation	A chimney (standpipe), catch basin, and rock filter is a common BMP for sinkholes located within the right-of-way of the new road. These were used in the SR 37 project.	A standard would have to be written for this.
Concrete catch basin installation	A chimney (standpipe), catch basin, and rock filter is a common BMP for sinkholes located within the right-of-way of the new road. These were used in the SR 37 project. They can be enhanced to include a special basin to act as a hazardous material trap (HMT) that can be specially drained to avoid the adjacent watershed.	720 describes catch basins and installation.
Natural vegetative buffers	Could be constructed in appropriate locations to detain/treat runoff prior to discharge. Same season re-vegetation should occur when possible.	Section 621 describes installation of vegetative cover, as well as timeline for when they must be installed, and the method for installation.
Peat/sand/gravel filters	Could be constructed in appropriate locations to detain/treat runoff prior to discharge.	205 describes placement of erosion control and filtering devices as an erosion control measure.
Spring boxes	Use to protect spring discharge	205 describes placement of erosion control and filtering devices as an erosion control measure.
Energy dissipation devices (e.g. scour holes, riprap linings, stilling basins)	Use at culvert and storm sewer outlet locations to prevent erosion to existing channels. Will be based on INDOT's Drainage Design Manual.	Section 616 describes riprap placement and type for energy dissipation and scour protection.
Agencies (IDNR, IDEM, USFWS) attend field checks/meetings	Meet during later design in effort to negate/minimize adverse effects.	Would need special standard provision; Indiana Design Manual defines the parties required to attend field checks during design, and Section 105 defines coordination procedures and agencies the contractor much include and coordinate with.
Notify the USFWS & IDNR if a state/federal listed species is observed during construction	Work will stop within the project area and these agencies will be notified.	Would need special standard provision; Section 107 describes contractor's responsibilities to follow permits and laws, responsibility to the public.

Table 10: Best Management Practices (BMPs) in Karst Terrain

Best Management Practice (BMP)	Description	Numerical Reference to INDOT Standard Specification[12] (where applicable)
Newly discovered cave during construction	Karst experts will be consulted to determine the significance of the cave.	Would need special standard provision; Section 107 describes contractor's responsibilities to follow permits and laws, responsibility to the public.
Geogrid or geotextile layers	Could be installed in the lower reaches of embankments, embankment foundations, or roadway subgrades.	214 describes geogrid installation requirements.
Operation/Maintenance		
Discovery of karst features previously not known	Examination of areas that receive runoff from highway to detect soil piping or opening of buried karst features.	A standard would have to be written for this.
No-mowing, low salt, or no-spray zones and associated signage	Implemented in order to increase vegetative groundcover and filter runoff prior to leaving right-of-way.	Section 621 describes "Do Not Spray" and "Do Not Mow" signage and placement.
Routine maintenance and inspection of treatment/containment structures	Verify capacity, integrity, and operational efficiency of structure.	Section 205 describes the type and frequency of inspection of temporary erosion control devices; INDOT to assume responsibility of permanent devices after final acceptance of the project.
Emergency response plan	To be developed post-NEPA, as stated in Step 11 of the Karst MOU.	
Installation of signage alerting public that all spills are potentially hazardous	In order to increase public awareness in sensitive areas.	Would need a special provision; 802 describes sign placement and type for unique sign types.

6.2 Areas of Special Concern

Control of construction water runoff, post construction roadway water, and alternative drainage to either surface water systems or drains, is recommended for portions of the proposed roadways and support structures. Feature specific impact reduction recommendations were made for four karst Areas of Importance in Section 5:

1) Lemon Lane Landfill / Spring Superfund Site

The following three measures are recommended for reduction of roadway contribution to the recharge area:

- Maintain the eastern boundary of the SR 37 right-of-way with any required mainline expansion or new access roads to the west, away from landfill.

- Shifted the proposed Vernal Pike grade crossing north to connect with 17th Street in all Alternatives and use of an overpass rather than rock cut for use of underpass in Alternative7, 8 and the Refined Preferred Alternative 8.

INDOT has made a mitigation commitment to prevent drainage from increasing above the existing SR 37 levels extending along the eastern side of SR 37 that is within the Lane Landfill/ recharge area to address USEPA and IDEM concerns regarding changes in existing groundwater flow. Coordination with USEPA and IDEM has occurred throughout the Section 5 study and will continue through the design phase. Blasting is not anticipated and will not be allowed adjacent to the site to prevent damage to the monitoring system (see **Figure 18**). Design plans for construction this area will be provided to USEPA and IDEM for review with a requested two-week turnaround time for comment.

2) Bennett's Dump Superfund Site

The following measures are recommended for reduction of roadway contribution to the Bennett's Dump recharge area during subsequent design phases:

- Limit paving and construction to the existing SR 37 and SR 46 mainline and intersection.

- INDOT has made a mitigation commitment to prevent drainage from increasing above the existing SR 37 levels extending along the northwest quadrant of the SR 37/SR 46 interchange area to address USEPA and IDEM concerns regarding changes in existing drainage at the Blasting is not anticipated and will not be allowed adjacent to the site to prevent damage to the monitoring system (see **Figure 19**). Design plans for construction in this area will be provided to USEPA and IDEM for review with a requested two-week turnaround time for comment.

3) 2nd Street/SR 45 – SR 37 Interchange Buried Sinks

The following two measures are recommended during design for reduction of roadway contribution to the 2nd Street/SR 45 – SR 37 Interchange Buried Sinks area:

- Limit paving and construction to the existing SR 37 and 2nd Street/SR 45 mainline and intersection.

- Care should be taken to ensure that the final design of SR 37 and 2nd Street/SR 45 consider sinkholes which no longer have the appearance and function of sinkholes, but have the potential to destabilize the roadbed and adjacent lands.

4) Cave Recharge

Several treatment options are available for consideration of potential mitigation measures in implementation of the Karst MOU to reduce roadway impacts to the Cave recharge area and maintain the existing base flow levels in the system:

- Engineered wetland sediment and contaminant reduction systems.
- Linear peat sand filters and/or vegetated swales along the roadway or at the terminus of lined storm water control structures.
- Sinkhole sediment and contaminant traps.
- Runoff and storm water detention/retention systems, treatment, and infiltration galleries.
- Control of "first flush" (or initial stormwater runoff which typically will have higher contaminant concentrations) volumes with designed overflow into natural drainage systems.

7.0 REFERENCES

Aley, Thomas. 2002. The Ozark Underground Laboratory's groundwater tracing handbook. 35 p.

Arroyo, K.J. 2001. A shallow temperature profile, fracture trace and very low frequency investigation to determine locations of lateral inflow beneath a Superfund site in Bloomington, Indiana. Unpublished Master's thesis, Indiana University. 144 p.

Droste, J.B., and S.J. Keller. 1995. Subsurface Stratigraphy and Distribution of Oil Fields of the Buffalo Wallow Group (Mississippian) in Indiana. Indiana Geological Survey Bulletin, B63, 24 p., 18 fig., 1 pl.

Earth Tech. Inventory of Karst Features and a Discussion of Potential Karst-Related Environmental Consequence of State Road 46 Roadway and Interchange Construction, Bloomington, Indiana, prepared for Indiana Department of Transportation, 1996.

Earth Tech. Memo: Karst Inventory of Tapp Road Property, prepared for Smith Neubecker and Associates, 2002.

Eklund, B.A. 1999. An investigation of a PCB contamination point source within a karst terrain using the stable isotopes of sulfur and deuterium to perform a three-part hydrograph separation on a karst spring in Monroe County, Indiana. Unpublished Master's thesis, Indiana University. 89 p.

Field, Malcolm S., Wilhelm, R.G., Quinlan, J.F.. and Aley, T.J. 1995. An assessment of the potential adverse properties of fluorescent tracer dyes used for groundwater tracing. *Environmental Monitoring and Assessment*, Vol. 38, pp. 75-96. Kluwar Academic Publishers.

Fitch, J.R. 1994. A karst groundwater study to delineate the Quarry Spring basin groundwaters near the Lemon Lane Landfill, west-central Bloomington, Indiana. Unpublished Master's thesis, Indiana University. 154 p.

Freeze, R.A. and J.A. Cherry. 1979. *Groundwater*. Prentice-Hall, Inc. 604 p.

Gates, G. R. 1962. Geologic considerations in urban planning for Bloomington, Indiana: Indiana Geological Survey Report of Progress 25.

Gray H. 2000. Physiographic Divisions of Indiana, Indiana Geological Survey Special Report 61.

Gray H., 2001. Map of Physiographic Divisions of Indiana, Indiana Geological Survey.

Harke and Gray. 1998. Geology for Environmental Planning in Monroe County; Published by the Indiana Geologic Survey, 1989, reprinted in 1998.

Hasenmueller, Walter A. “Bedrock Geologic Map of Monroe County, Indiana”. Indiana Geological Survey, 2008.

Indiana Department of Natural Resources, Division of Soil Conservation. 1992. Indiana Handbook for Erosion Control in Developing Areas: Guidelines for Protecting Water Quality through the Control of Sedimentation on Construction Sites.

Keith, J.H., J.L. Bassett, J.A. Duwelius, and B.L. Luther. 1997. Results of 1993 MOU-related karst studies for Indiana State Road 37, Lawrence County, Indiana (1992-1995). Unpublished contract report prepared by Earth Tech for the Indiana Department of Transportation. 72 p. + appendices

Lewis, J.J. 2005. Cave Fauna of the Section 5 Corridor of I-69. Unpublished contract report to the Ozark Underground Laboratory. 22 p.

Melhorn, W.N. and N.M., Smith. 1959. The Mt. Carmel Fault and related structural features in south-central Indiana: Indiana Geological Survey Report of Progress 16.

Moss, Philip L. and Thomas Aley. 2003. Mapping presumptive habitat for subterranean, aquatic species of concern in 16th National Cave and Karst Management Symposium Proceedings. p.70-73

Robinson, W.H. 1986. The study of surface and ground-water interactions in two watersheds. Unpublished Master’s thesis, Indiana University. 107 p.

Roy, S. and S. Wells. 1959. Cave Area. Map archived in the Indiana Cave Survey files. 2 sheets.

Rupp, J.A. 1991. Structure and Isopach Maps of the Paleozoic Rocks of Indiana, Department of Natural Resources Geological Survey Special Report 48, 106 p.

Shaver, R.H., and G. S. Austin. 1986. Compendium of Paleozoic Rock Unit Stratigraphy in Indiana – A Revision of the State of Indiana Department of Natural Resources Geological Survey 59.

Shaver, R.H. and C.H. Ault, et al. 1972. A field guide to the Mt. Carmel Fault of southern Indiana: Indiana Geological Survey Guidebook.

Smart, P.L. 1984. A review of the toxicity of twelve fluorescent dyes used for water tracing. National Speleological Society Bulletin, vol. 46, pp. 21-33.

Talarovich, S.G. 1998. Stable isotopic three-component storm hydrograph separation of Illinois Central Emergence located in Monroe County, Indiana. Unpublished Master’s thesis, Indiana University. 85 p.

Thomas, J.A., R.C. Wingard, and P.A. Kempf. 1981. Soil survey of Monroe County, Indiana. U.S. Department of Agriculture Soil Conservation Service.

Thompson, Todd A., Geologic Map of Bloomington 7.5-Minute Quadrangle. Indiana Geological Survey. 2007. U.S. Geological Survey. 1980a. Bloomington Quadrangle, Indiana-Monroe County: 7.5-minute series (topographic).

U.S. Geological Survey. 1980b. Clear Creek Quadrangle, Indiana-Monroe County: 7.5-minute series (topographic).

Veni, G., H. DuChene, N.C. Crawford, C.G. Groves, G.N. Huppert, E.H. Kastening, R. Olson, and B.J. Wheeler. 2001. Living with karst, a fragile foundation. American Geological Institute Environmental Awareness Series No. 4 64 p.

Waltham, T., F. Bell, and M. Culshaw. 2005. Sinkholes and subsidence: karstand cavernous rocks in engineering and construction. Published by Springer-Verlag, New York. 382 p.

White, B. 2005. Interview. Ben White is an INDOT Construction Project Supervisor for the Seymour District.