



## INDIANA DEPARTMENT OF TRANSPORTATION

# Protection of Karst Features During Project Development, Construction, and Post-Construction



Ecology, Waterway Permitting, and Stormwater Office  
Environmental Services Division

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# INDIANA DEPARTMENT OF TRANSPORTATION

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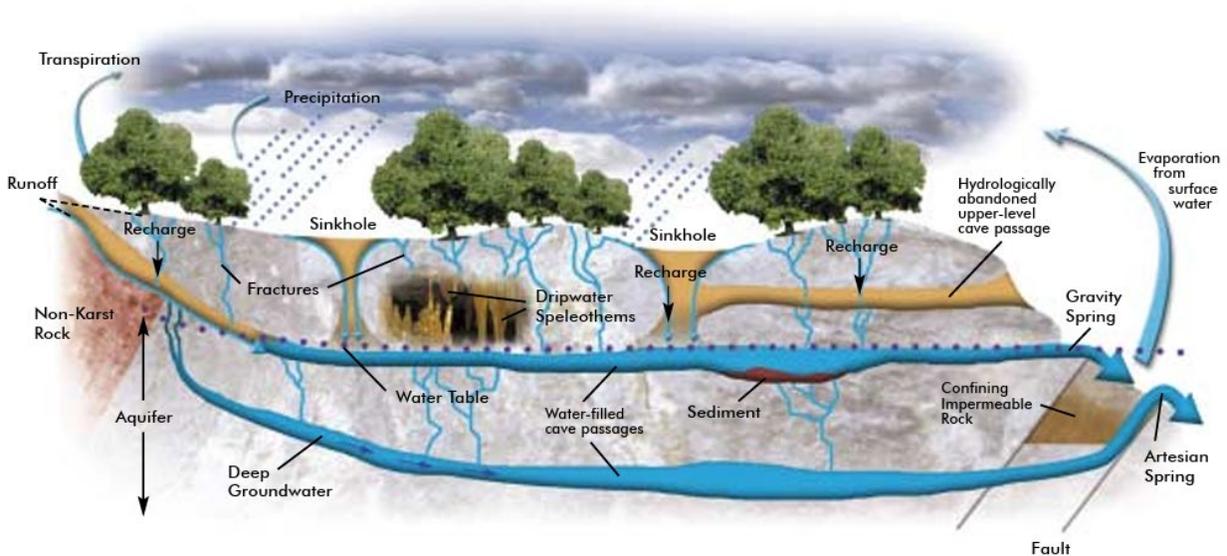
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## I. Protection of Karst Resources

### A. Background

Karst is a landscape feature that is formed by the dissolution of a layer or layers of soluble rock by acidic water. The two types of soluble rock found in the Indiana karst region are limestone and dolomite. Karst features are formed as acidic water dissolves the subsurface rock, forming cracks and fissures. The water moves sideways along horizontal cracks between rock layers and fractures or joints in the rock. In many karst areas, there is little surface water because most of it has entered the subsurface water flow of the karst system.

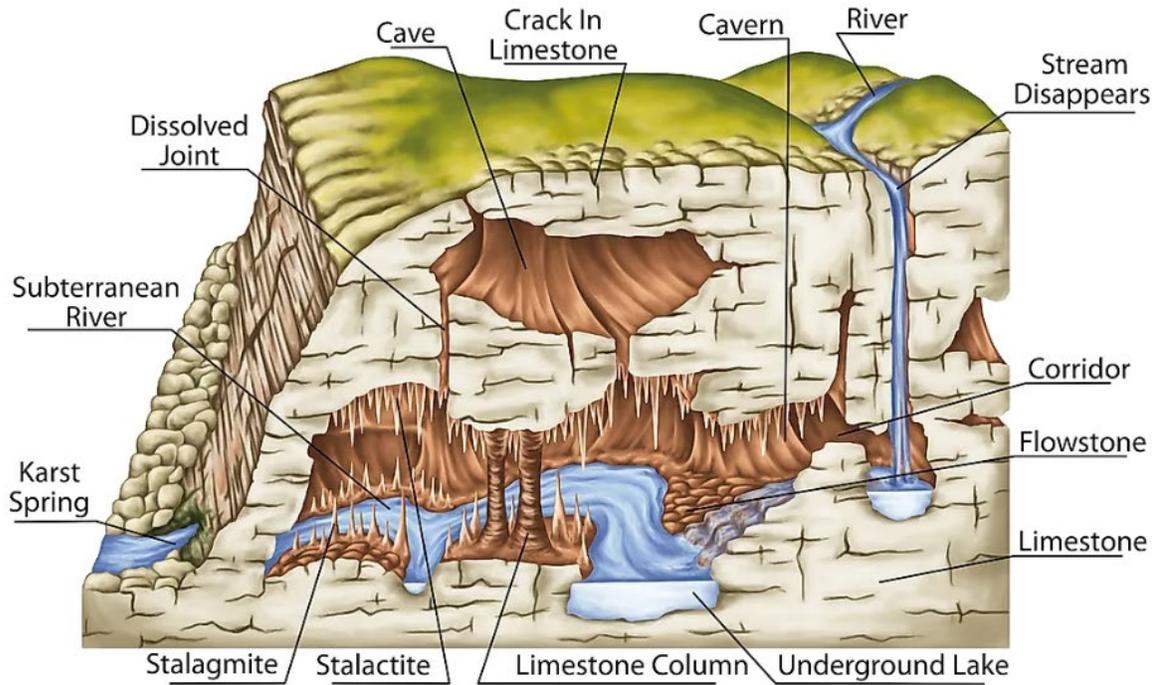
Understanding the geology of a project area includes understanding the type of bedrock that lies below the surface, the surface landforms, and the materials above the bedrock, including soils. An understanding of the hydrologic cycle in karst areas is also important. The source of groundwater for all aquifers is precipitation.



**Figure 1. The hydrologic cycle in karst areas**

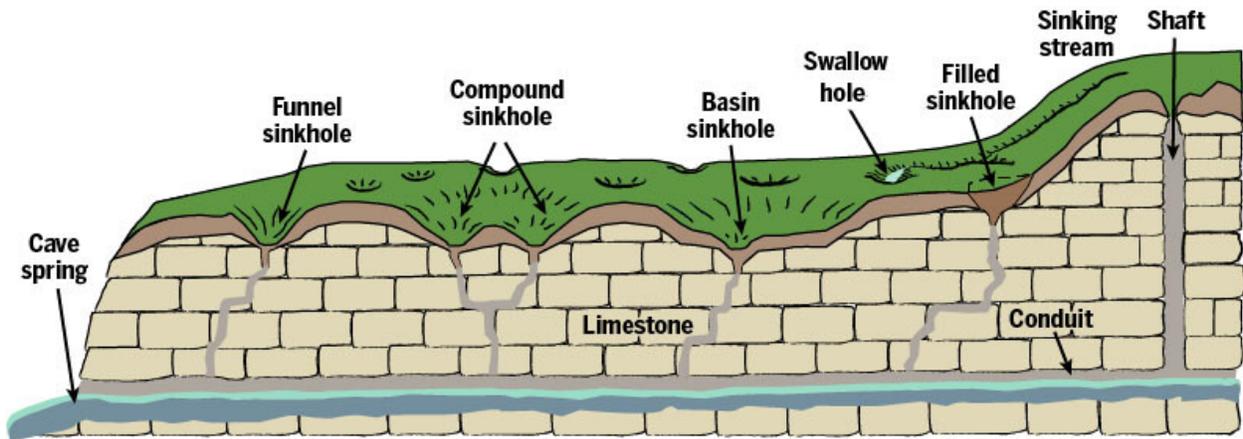
American Geological Institute, *Living with Karst: A Fragile Foundation*, 15

Projects located in karst areas may require special consideration of karst features in site evaluation, selection, project design, and environmental impact avoidance.



**Figure 2. How karst forms**

<https://www.worldatlas.com/articles/what-is-karst.html>



**Figure 3. Solution features characteristic of karst terrains**

Hasenmueller and Powell, 2016, Indiana Geological and Water Survey,  
<https://data.igws.indiana.edu/pages/search.php?search=%21collection644343#>

Sinkholes develop through bedrock dissolution, rock collapse, soil down-washing, and soil collapse. These mechanisms work individually or in various

combinations to create sinkholes. The U.S. Geological Survey (USGS) identifies three types: dissolution, cover-subsidence, and cover collapse. The common types found in Indiana are the dissolution or solution sinkhole that is formed by a dissolutional lowering of the surface in limestone and dolomite. A collapse sinkhole is formed by the failure of a rock roof into an underlying cave. See Appendix E for more information.

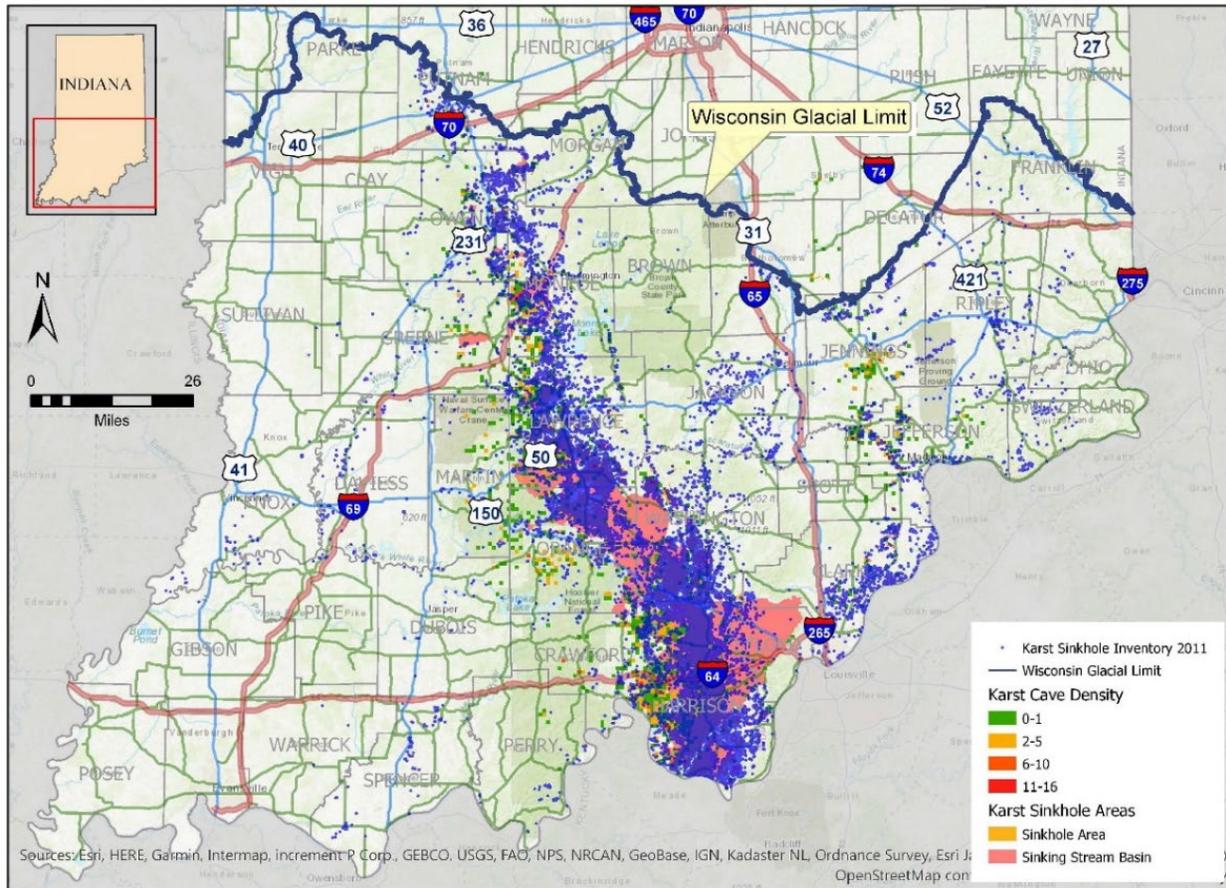
Karst terrain is environmentally sensitive. It is geologically and ecologically vulnerable to contamination because of the unpredictability of contaminant transport mechanisms, the exceptional value of the resource, and the human or ecological risks that may result from contamination. Contamination enters karst through the openings and conduits formed by the dissolution of rock, which enables it to move rapidly through the system. These systems are complex and may disperse contamination unpredictably and rapidly. The contaminants may also get trapped in pools, sediments, and minor fractures. Organisms that have adapted to the karst environment may be impacted by minor changes in water quality.

Point source contamination of karst features can come from spills, leaking underground storage tanks, and household septic systems. Non-point source contamination can come from road salts, vehicle emissions, pesticides, and fertilizers. Contaminants can also be introduced through other human activity such as the use of the feature as a disposal site for solid waste and organic matter, including lawn waste, animal waste, and sewage.

Groundwater contamination in karst areas is a serious concern that promotes chain reactions of ecological degradation. The opportunity for the contaminants to be filtered by soil and bedrock or exposed to sunlight is limited. Decomposing organic matter will lower the oxygen content of the water and, in sufficient quantities, kill cave-dwelling aquatic animals. The organic matter will also promote the transport of other contaminants.

The structural stability of the bedrock may also be modified by changes in the flow of surface water into karst features. When sinkholes are clogged by surface runoff or other materials, they cannot drain surface waters. In addition, the increase of impermeable surface water flow or land disturbance may also overwhelm the sinkholes. This alteration of drainage patterns may result in increased surface flooding.

The Indiana Karst Region for INDOT planning purposes is defined as the area south of the Wisconsin Glacial Limit. This is depicted in Figure 4 and in Appendix C. It incorporates the known karst features in the Indiana Maps ArcGIS data.



**Figure 4. Indiana karst region**

INDOT

**B. Impacts on Karst from Transportation Activity**

There are many ways transportation activity can impact karst. Physical alteration can result in flooding or desiccation (moisture removal). It can also change the physical environment to include new sinkholes, new or cut-off water or air pathways, dried-up springs, and collapsed or filled sinkholes or cave passages. Impermeable surfaces will alter natural runoff patterns such as the concentration or redirection of runoff into sinkholes (open or with no surface expression) or result in collapse or blockage.

Surface and groundwater quality can be impacted through conveyance of pollutants, such as solid materials like trash and liquids that may not be filtered. Once pollutants enter the system, they have long residence times. The lack of exposure to sunlight or soil microbes prevents or slows breakdown. There may also be impacts on organisms and animals in the cave systems because of changes to the water regime, air movement, and temperature.

## C. Legal Protection of Karst Resources

Karst features are indirectly protected through federal and state laws because they provide a conduit between surface and groundwater or provide habitat for protected species. The Federal Cave Resources Protection Act of 1988 provides protection to significant caves located on federal lands. Indirect protection is provided through the Endangered Species Act (ESA), Section 106 of the National Environmental Policy Act (NEPA), and other federal and state laws. Figure 5 provides a diagram of the federal, state, and local government agencies, their areas of concern and source of legal authority. Karst resources could result in higher level scrutiny under NEPA because of the other related resources tied to the features such as endangered species, historical sites, and drinking water.

Section 7 consultation with the U.S. Fish and Wildlife Service (USFWS) would be required if federally protected species potential were within or near the resource. An example would be the presence of a cave used by endangered bat or fish species. Section 106 consultation would be required if there were the potential for archeological resources in the area, such as evidence of use by Native Americans or early settlers. Indiana does have one directly protected feature. The Orangeville Rise, located in Orange County, is designated as a National Natural Landmark and provides a headwater for the Lost River system. The Lost River is a large sinking and subterranean stream.

Coordination or consultation with USFWS is required under the ESA when a listed species is connected to the karst feature. The prime example of this is the use of caves by the Indiana bat as hibernacula. The cave would be designated as a protected habitat under the ESA.

The Environmental Protection Agency (EPA) considers some karst features (sinkholes and swallow holes) to be Class V injection wells if alterations are made to the drainage system that increase the amount or type of runoff received by the feature. If a project impacts a feature, the project sponsor must provide the EPA with inventory information about the feature and implement measures that will protect underground sources of drinking water that are connected to the feature. Improved sinkholes are a Class V injection well that requires submitting inventory information to the EPA. A Class V injection well may require an individual permit from the EPA if it has the potential to endanger an underground source of drinking water. For more information see <https://www.epa.gov/uic/class-v-wells-injection-non-hazardous-fluids-or-above-underground-sources-drinking-water>

Potential impacts to karst resources resulting from Indiana Department of Transportation (INDOT) projects would more frequently fall under the jurisdiction of state agencies. The Indiana Department of Environmental Management (IDEM) Office of Water Quality Ground Water Section addresses potential impacts to karst features from the perspective of the protection of surface water and drinking water resources under the Clean Water Act (CWA) and the Safe Drinking Water Act. IDEM's Office of

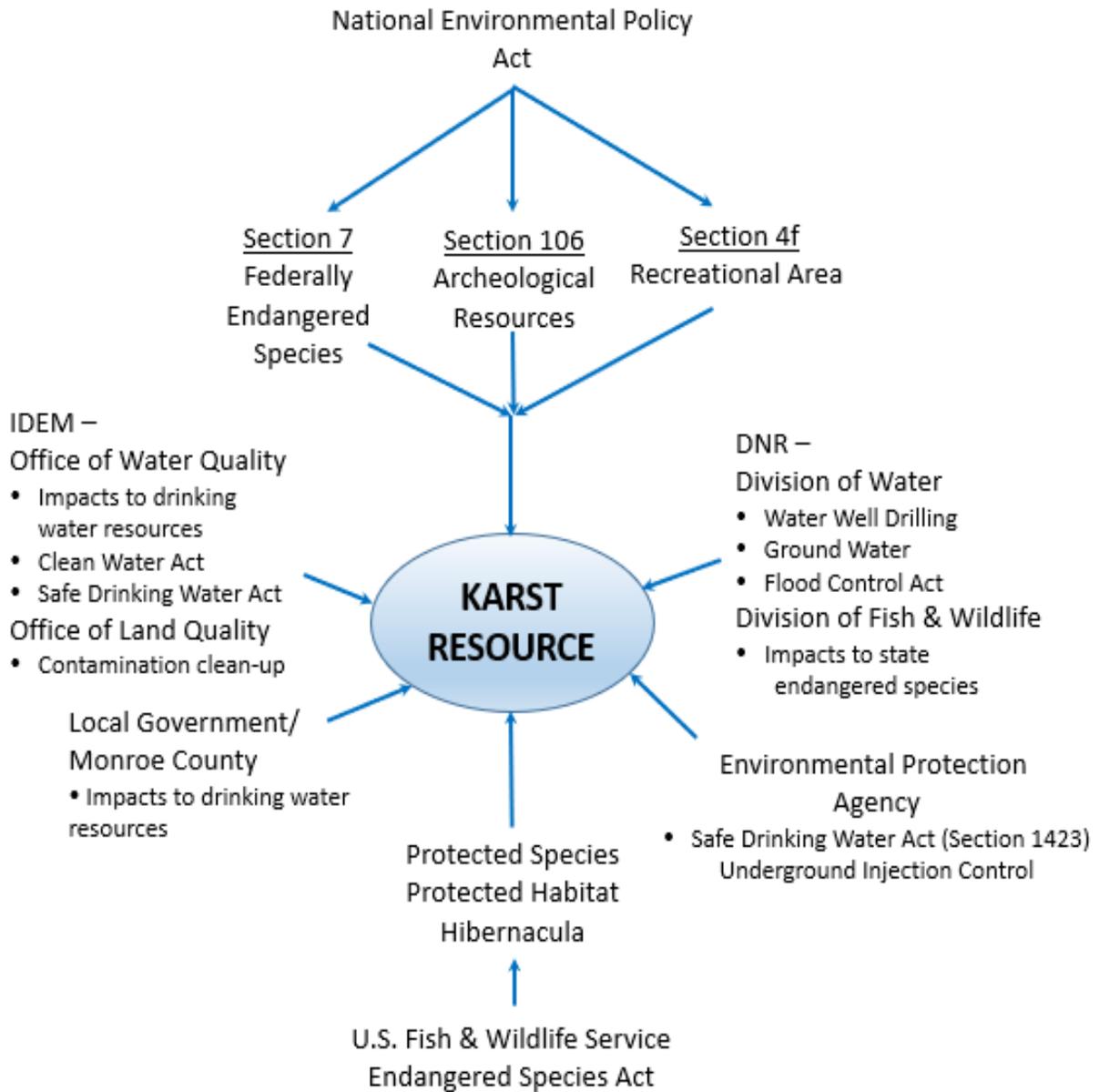
Land Quality oversees over potential contamination of a feature or the cleanup of a feature that has been contaminated. The Ground Water Section will contact the Office of Land Quality if it has any concerns.

The Indiana Department of Natural Resources (DNR) Division of Water regulates the drilling, casing, operating, plugging, and abandoning of wells and any related fluid storage. The drilling or boring logs from wells maintained by the agency are a useful tool in mapping karst resources. For more information, see <https://www.in.gov/dnr/water/> Another reference is the INDOT Geotechnical Services Division's [Aquifer Protection Guidelines](#).

The DNR may be involved when a project may impact groundwater resources. The DNR Division of Fish and Wildlife would be involved if the project had the potential to impact state-listed species. The DNR will provide a biological review of projects located in karst areas.

Karst topography may also be covered under other local government ordinances. Monroe County is the only Indiana county with this type of ordinance. The Monroe County Development Ordinance Chapter 826 provides Karst and Sinkhole Development requirements. The ordinance establishes review procedures, use limitations, and design and performance standards related to site development that may affect karst features.

Coordination with local government organizations in the project area will occur as part of NEPA compliance. Concerns regarding the impact of the project on local water resources may be presented at that time. For example, a spill on the U.S. 50 North Vernon East Bypass potentially could contaminate North Vernon's drinking water source through karst features located in the project area. In such a case, modifications would be made to address those concerns to include installation of hazardous material traps and the purchase of an old quarry as a new reserve water source.



**Figure 5. Legal protection of karst resources**

INDOT

## II. Site Investigation and Documentation Procedure

### A. Introduction

INDOT compliance with federal and state environmental requirements will ensure consideration of the impact of INDOT projects to karst features during project development and construction. This procedure documents the process that will be

followed. The procedure will be updated as required to accommodate changes to federal and state laws and regulations. Karst features will be identified during project development and treatment measures incorporated to avoid and minimize impacts from construction.

Regulatory agencies may be requested to provide early coordination comments, review draft reports, monitoring plans and reports, agreements, and any other required documents, and participate in field checks.

This procedure, originally published online by INDOT in 2017 as “Karst Geological Resources and INDOT Construction,” replaced the Memorandum of Understanding (MOU) between INDOT, the DNR, IDEM, and USFWS that was signed in 1993. The procedure added the EPA and the Indiana Geological and Water Survey (IGWS) as participants. IGWS is a non-regulatory research institute that should be consulted during early coordination.

The purposes of this procedure are:

- Provide guidelines for the construction and maintenance of transportation facilities in karst regions of the state.
- Cooperate in the identification, study, and treatment of drainage in karst regions related to the construction and maintenance of transportation projects.
- Ensure the transportation needs of Indiana are met in an environmentally sensitive manner that protects the habitat of all species.
- Support use of design and construction practices that protect groundwater quality, public health and safety, and the environment from degradation.
- Ensure post-construction best management practices created to protect karst features are designed, documented, inspected, and maintained appropriately.

## **B. Background**

INDOT must comply with federal and state laws. The procedures that are in place to guarantee compliance with these laws ensure that potential impacts to karst features are considered during project development. The federal laws include NEPA, ESA, and CWA. In addition, INDOT must comply with the State Environmental Policy Act (SEPA), state water quality, flood control, and other laws and regulations.

Karst best management practices may also be required as part of INDOT’s compliance with its separate storm sewer system permit and the project Construction Stormwater General Permit.

INDOT uses the term Indiana Karst Region and to include the area south of the Wisconsin Glacial Limit. This is depicted in Figure 4 and in Appendix C. It incorporates the known karst features in the Indiana Maps ArcGIS data.

## **C. Applicability**

This procedure applies to INDOT federal and state-funded projects. Local Public Agency (LPA) projects are not required, but are strongly encouraged to, comply with this procedure.

## **D. Process**

### **1. Red Flag Investigation**

The INDOT Red Flag Investigation (RFI) is the first step in the process. The RFI identifies karst features within 0.5 miles (one-half mile) of a project area on the Water Resources map. The GIS layers included are karst cave density, karst sinkhole areas, karst sinkhole inventory, karst springs, and sinking stream basin from IGWS inventory. If there are no karst features located within 0.5 mile, no further action is required. Record the findings in the NEPA document. If there is a karst feature located within 0.5 mile, further analysis is required. Karst resources could result in higher scrutiny under NEPA because of other related resources tied to the feature.

The level of NEPA document is affected by the proposed project's potential impacts to karst features. Federally funded projects that qualify for a Programmatic Categorical Exclusion (PCE) may not always require an RFI and therefore will not always be evaluated for karst features. Other federally funded projects that require a Categorical Exclusion (CE), Environmental Assessment (EA), or Environmental Impact Statement (EIS) will require evaluation of karst features in the analysis of involvement with resources. State-funded projects that are major state actions must follow the state environmental assessment process found at IC 13-12-4 Environmental Impact Statements and 327 IAC 11 State Environmental Policy.

### **2. Early Coordination**

Early coordination is required for all projects that require a CE, EA, or EIS. Agencies on the early coordination list that have an interest in karst features include USFWS, IDEM Groundwater Section (when a project is near or within a wellhead protection area), and the DNR Division of Fish and Wildlife. IGWS, Indiana Cave Survey, and the Indiana Karst Coalition, non-agency organizations, should also be coordinated with. Project specific karst background information and questions in which their input is required can be provided if known or follow-up coordination can occur later.

### **3. Evaluate the Potential Impact of Project**

Evaluate whether the project could potentially impact karst features. If the answer is no, then no further action is required. Record the determination in the environmental document.

If the proximity and type of features in the area could result in accidental discovery of karst features during construction, include the Recurring Special Provision (RSP) 203-R-744 [Discovery of Karst Features within the Construction Limits](#). For example, a project included the replacement of a box culvert and installation of storm sewer lines through the town. The cave features of concern were in the hills above the project site. Since the culvert replacement was not going outside of the existing footprint and the storm sewer lines were below the area with the karst features, it was determined that including the RSP was sufficient. The RSP directs treatment measures to follow INDOT Standard Specifications Section 205 – Stormwater Management. EWPSO will coordinate with IDEM, DNR, and USFWS if required.

If the project has the potential to directly impact karst features, further evaluation is required.

#### **4. Conduct a Preliminary Impact Evaluation**

Conduct a preliminary project and karst feature impact evaluation to determine if background research and preliminary field investigation are required. Consider the type, quantity, and location of the karst features during the evaluation. Evaluate the changes to water drainage that may result from the project. Also, consider the potential impacts based on the project type such as will the project be over new terrain or be on a previously disturbed existing footprint? Consider the amount and depth of ground disturbance or excavation and the requirement to place fill in the disturbed area. If the evaluation determines that no further investigation is required, include the Discovery of Karst Features RSP in the contract documents. Verify the decision with EWPSO's Ecologist and Team Lead and document the decision process in the NEPA document and, if necessary, provide details in a memorandum and attach it as an appendix to the NEPA document.

#### **5. Conduct Background Research and Field Check**

At this point in the process the project karst lead must be an Indiana Licensed Professional Geologist (LPG) who is pre-qualified under 5.12 Karst Studies. See [Consultants Prequalification](#) for more information.

## RSP 203-R-744

### DISCOVERY OF KARST FEATURES WITHIN THE CONSTRUCTION LIMITS

Karst features include, but are not limited to, voids in the ground, caves, sinking streams, springs, seeps, and sinkholes.

If a potential karst feature is discovered during construction, all work within 100 ft of the feature shall immediately stop and the Engineer shall be notified. The Engineer will suspend all work in this area in accordance with 104.02(b). The Engineer will notify the Department's Geotechnical Engineering Division and the Ecology and Waterway Permitting Group.

The Department will provide the treatment measures to address the karst feature. The karst feature shall be protected from sedimentation runoff in accordance with 205. Work shall not resume in the area until directed by the Engineer. Work shall not resume in the area until directed by the Engineer.

**Figure 6. INDOT RSP 203-R-744**

### INDOT

The design consultant, LPG, and EWPSO Ecologist and Team Lead shall determine the extent of the investigation and potential documentation needs. Preliminary investigation includes research of public and private sources for information related to the karst features in the project area. Background research should include the review of:

- Geological and topographic maps
- Aerial photography
- Geological literature
- Soil boring logs
- Well driller log data
- Spring data (perennial and ephemeral)

The field check should include:

### Considerations

#### Feature(s) -

- Type
- Quantity
- Location

#### Project -

- Type
  - \* New Terrain
  - \* Existing Footprint
- Ground Disturbance
  - \* Excavation
  - \* Fill

- Investigation for visual indicators of karst features, such as subsurface voids, cavities, fractures, or other features
- Feature documentation to include location, photographs, and description
- If possible, the site should be investigated during heavy rainfall to identify and map natural drainage patterns

The LPG karst consultant may recommend additional field investigation of any features to include video analysis. Dye tracing can be used to trace flow patterns from surface points to sampling wells or to trace subsurface flow patterns. Dye tracing of all features that will be capped by the project should occur to determine if it contributes to the recharge of a perennial spring

Discuss the findings and proposed avoidance and minimization measures (AMMs) with the karst team. Members of the team include the Project Manager (INDOT and designer), design engineer, NEPA document preparer, LPG, and EWPSO Ecologist and Team Lead. The karst team will review best management practices and design plans.

## **6. Geotechnical Investigation**

A detailed geotechnical investigation should be conducted based on the size and type of the project and the complications posed by the karst geology. The investigation must be performed by an INDOT 7.1 prequalified consultant. The investigation would include the use of soil borings or observation wells and would expand until there is sufficient understanding of the site. Geophysical data collection techniques that may be used include seismic refraction, electric resistivity, gravity/micro-gravity, and down-hole methods.

The information collected should include:

- Bedrock characteristics (type, geologic contacts, faults, geologic structure, and rock surface configuration)
- Depth to water table and depth to bedrock
- Soil characteristics such as type, thickness, and mapped unit
- Bedrock outcrop areas
- Sinkholes, springs, seeps, or other closed depressions
- Flow rates at different precipitation conditions
- Perennial or intermittent streams and their flow behavior

## **7. Documentation and Agency Coordination**

The EWPSO Ecologist/Consultant will provide a copy of the written findings to USFWS, IDEM Groundwater Section, DNR Division of Fish and Wildlife and IGWS. EPA should be included if there is a Class V injection well concern. The written findings

of the karst investigation may include information based on earlier coordination with EWPSO:

- Background information (road number, designation (DES) number, and county)
- Narrative (project scope and setting, investigation methods, site geology and physiography, soils, surface drainage, water features, description of type and location of karst features, feature relationship, etc.)
- Maps (location, site layout, IndianaMap karst data, karst feature identification, and photo orientation)
- Photos
- Potential impacts, risks, design concerns, avoidance, minimization, and mitigation measures
- Preliminary design plan or concept if available (include installation of protective resource fence and best management practices around features prior to earth-disturbing activity)
- References

Modification to an approved mitigation design or documents may be required based on agency comments.

Provide IGWS shapefiles of the identified features for review and addition to ArcGIS layers. Agency coordination should include findings, recommended courses of action and outstanding questions requiring their input. Update the karst investigation document as appropriate.

Prior to release to the public, all sensitive information, such as feature location and presence of endangered species, must be removed from the report. The location of karst features, hazardous material measures, and drainage patterns should be provided to area emergency response authorities.

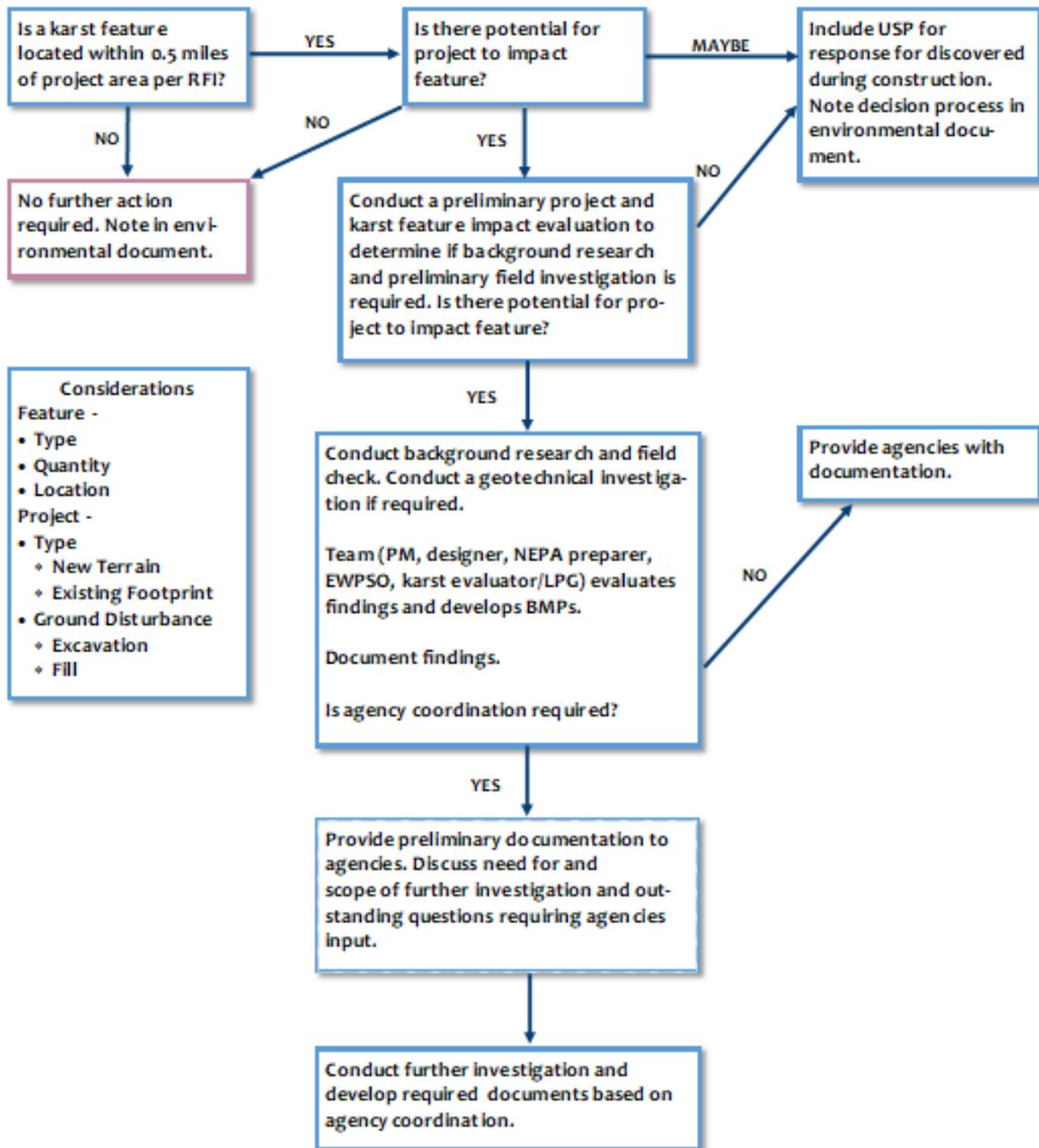


Figure 7. Karst evaluation for project planning

INDOT

## 8. Karst Best Management Practices as Post-Construction Assets

All features designed to protect karst resources will be selected and managed like post-construction best management practices and will be a managed asset. Their design will be like the designs in the Post-Construction Stormwater Management (PCSM) guidance. This guidance includes PCSM selection and design requirements. Like post-construction best management practices (PCBMPs), feature sizing is based on the total percent impervious area, but it is not limited to new impervious area. Infeasibility exceptions will not be allowed for PCBMPs associated with karst features. Each feature must be labeled with a Post-Construction BMP identification number following the PCSM numbering system. A project specific USP will be required for each project .

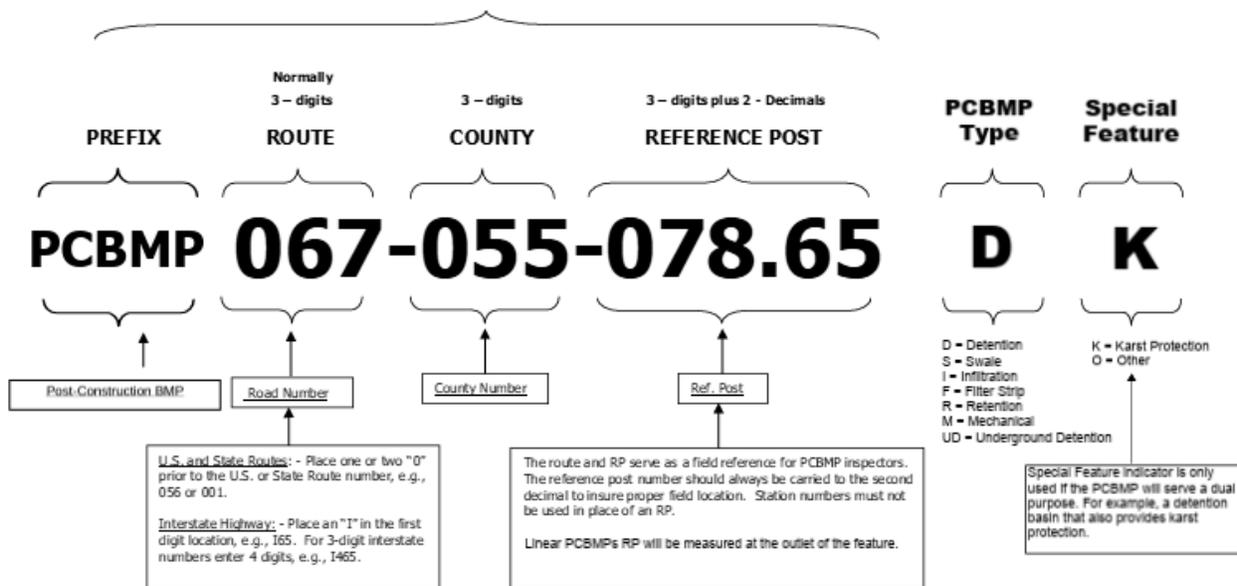


Figure 8. Post-construction stormwater management karst numbering system

INDOT

## 9. Water Quality Sampling Plan

A water quality sampling plan should be developed only when requested by the agencies during coordination. The purpose of the plan is to document the project water quality sampling program. Information to be included in the typical plan is:

- Sampling goals and objectives
- Location, description, and selection criteria for the features to be sampled
- Water quality sampling parameters (chemical and biological)

- Sampling methodology, frequency (baseline, during, and post construction), and duration
- Sampling at base and storm flow
- Location map
- Reporting requirements
- Remediation (during and post-discussion if required)

### **III. Karst and INDOT Construction**

#### **A. Regulatory Compliance**

Karst features will be protected from the discharge of sediment and other construction related pollutants throughout construction by erosion and sediment control protection measures.

#### **B. Best Management Practices**

Best management practices (BMPs) are a method or practice determined to be the most effective, practical means of accomplishing the desired state. Implementation can occur before, during, or after construction. BMPs include treatments such as lining ditches with clay, sinkhole bridging, sinkhole filling (based on location), avoidance, redirecting road runoff, and feature specific treatment. They can be temporary or permanent structures that filter storm water runoff or seal a feature from future runoff. BMPs can also include use of a low-salt/low-spray strategy, developing an emergency response plan, and using a stop work plan if any potentially federal and/or state listed species are encountered during construction. Features may also be sealed to prevent continued erosion of bedrock underneath or adjacent to a roadway. Measures such as protective buffers and run-off management should be considered with the goal of no effect to existing recharge or discharge.

Karst features must be protected from sediment and other contaminants during construction. The common method of protecting features during the initial construction phase is by encircling the feature with a rock ring. The following photo shows a typical design for a rock ring used on the U.S. 50 North Vernon Bypass. It consists of a band of coarse aggregate #2 (at a 3:1 slope) with the outside edge covered with coarse aggregate #3 (at a 2:1 slope). The rock ring retains the surface flow and filters sediments prior to entering the feature. As with any BMP, monitoring and maintenance must occur throughout construction for the BMP to be effective in protecting the karst feature.

#### **C. Impact Mitigation**

Karst mitigation is focused on maintaining the quality and quantity of water entering the feature. It includes permanent measures designed to reduce impacts

resulting from the project. Mitigation measures include installing sand/gravel filters, vegetative buffers, and lined spill/runoff containment structures, to detain or treat highway runoff prior to discharge. Mitigation measures are developed as part of the design process and may require coordination with federal, state, and local governments.



**Figure 9. Rock ring**

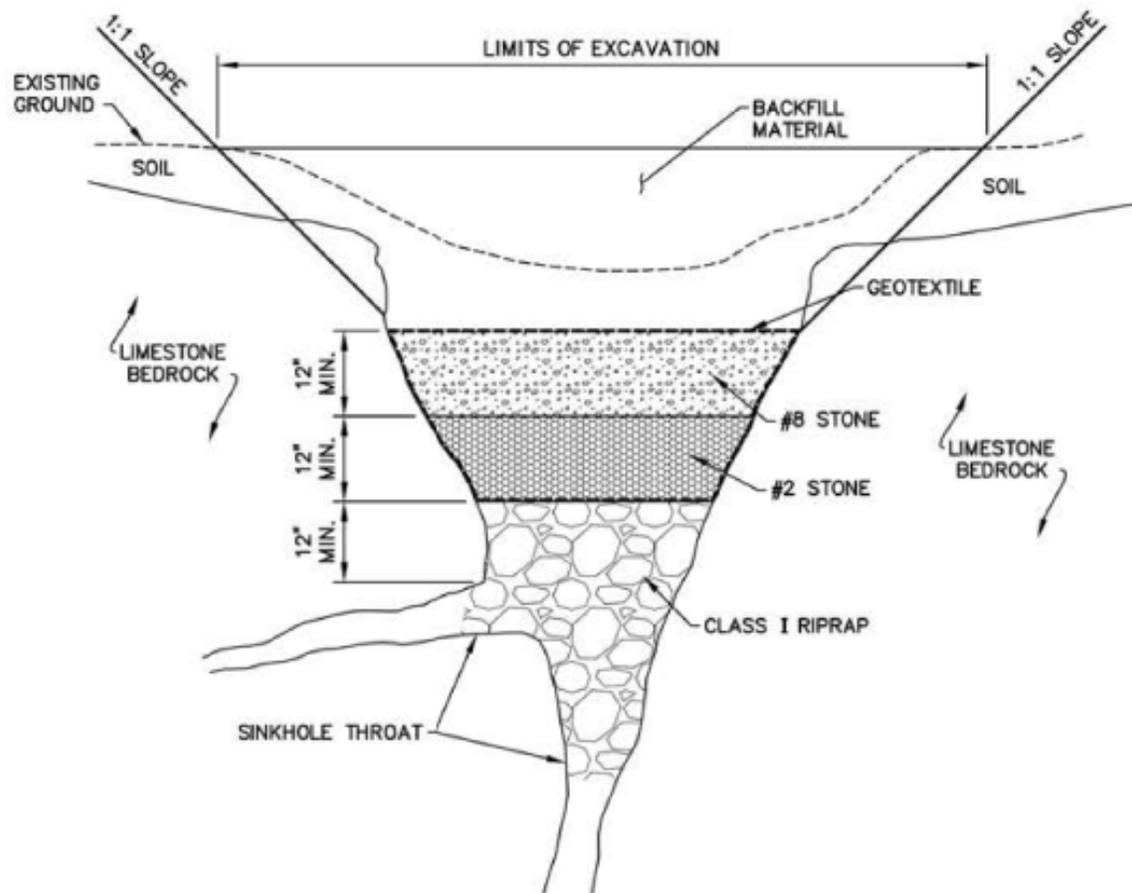
protecting a karst feature on the U.S. 50 North Vernon Bypass  
INDOT

Each permanent post-construction stormwater BMP must comply with the agency Post-Construction Stormwater Management guidance. The features included in the guidance are dry or wet swales, vegetated filter strips, dry or wet detention, infiltration, and hydrodynamic separators. They will require an asset number, maintenance plan, and periodic monitoring and maintenance. One of the criteria for the recommended measures is ease of maintenance. Therefore, the use of designs that include components that require frequent replacement such as peat filters or other materials that break down easily should not be used.

Karst features are mitigated during construction to maintain water flow or provide structural integrity for the overlying roadway. The location of the feature and direction of water flow will determine the appropriate mitigation measure. If the location is in the proposed roadway and the water flows through the feature into the underlying karst, it will be capped. If the feature located in the proposed roadway is a spring or seep, the mitigation method will maintain the flow of water from the underlying karst to the surface. The design of roadside ditches and other conveyances must ensure that the surface runoff has received adequate filtration prior to entering karst features located

along the roadway. These examples will require modification to suit the site conditions. There are many methods used to mitigate karst features, and a combination of techniques may be required. Mitigation measures must be developed by the project team, which must include the project designer, geotechnical engineer, and an LPG.

- Excavation and aggregate cap – When existing recharge into the sinkhole can be maintained, remove all soil, rock, and debris from within the weak zones. The throat of the soil void is “capped” with a rock fill plug and backfilled or compacted to the desired density. Geotextile fabric is placed between the layers of stone and soil of an aggregate cap to prevent fine grained soil from entering the feature. See Figure 9.
- Excavation and plugging – This is the most common mitigation method used to permanently seal a feature from surface flows. It is used for shallow sinkholes with a depth of 15 feet or less. All soil, rock and debris are removed from within weak zones. The throat of the soil void is “capped” with concrete, grout, or a rock fill plug and backfilled or compacted to the desired density. Geotextile fabric is placed between the layers of stone and soil of an aggregate cap to prevent fine grained soil from entering the feature. A concrete cap is used when the sinkhole is located under the roadbed to provide a permanent seal. Figure 10 is a typical example of excavation and plugging. The slope at the concrete cap should be keyed to allow the cap to rest on the bedrock as illustrated by the green shaded area. This would limit future collapse of the cap into the feature.
- High/low mobility grouting – This method is used to permanently seal a feature. High or low mobility grout (HMG/LMG) is pumped into the karst void until the desired pressure is reached, the pump is raised, and void is continued to be filled. This can be applied in a grid pattern over the site or larger voids as isolated sinkholes. High mobility, or cement slurry, grouting is normally done in fissured rock to reduce the flow of water along the joints and discontinuities in the rock. Cement grout may also be injected into the void space within coarse granular soils. Low mobility grouting densifies loose granular soils, reinforces fine grained soils, and stabilizes subsurface voids or sinkholes by the staged injection of low-slump, low mobility aggregate grout.
- Void-bridging – This method places high-strength geotextile material over potential voids to increase the load carrying capacity. On embankments, this allows for higher construction and steeper side slopes. It can also be used under lightweight structures to create a barrier through which a top layer of sand and other soils is filtered.

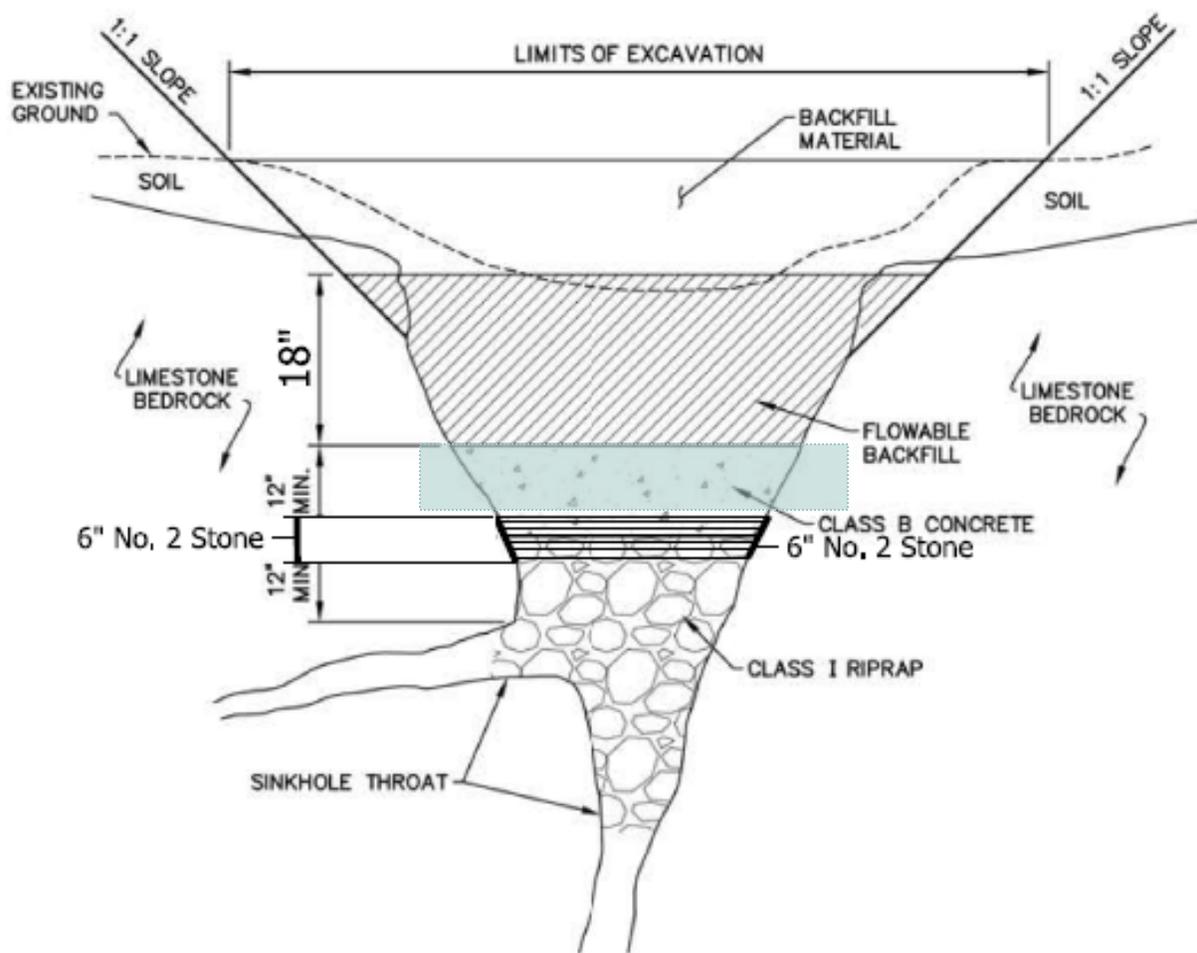


**Figure 10. Typical sinkhole treatment aggregate cap**

INDOT

This design included the following notes:

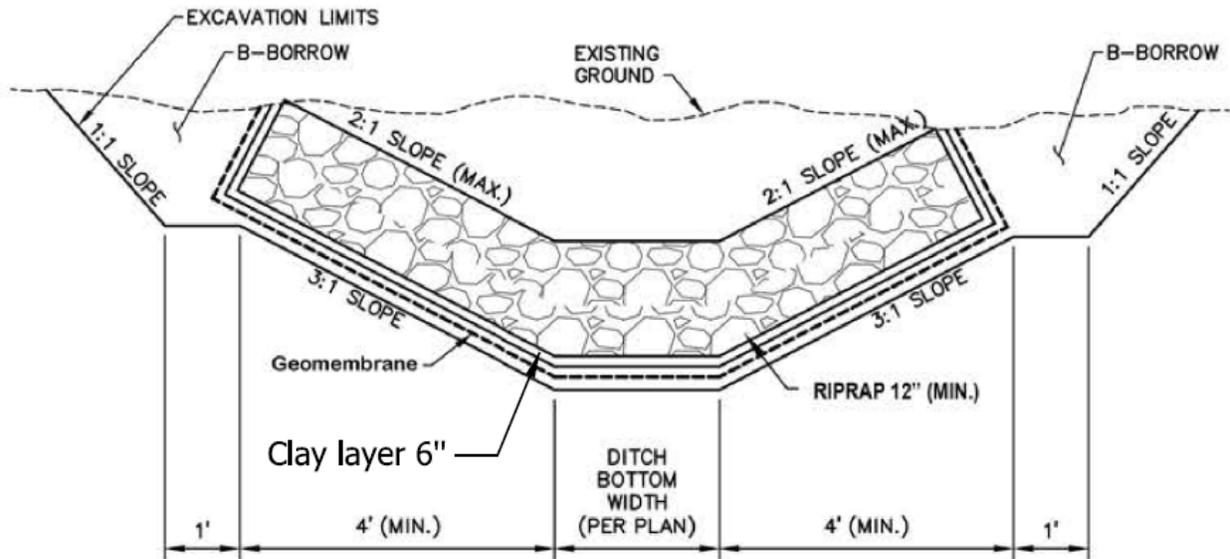
1. Contractor shall perform exploratory excavations to determine extent of the sinkhole throat prior to installing the treatment.
2. All loose and fragmented rock, soil, trash, and debris shall be removed from the excavation, down to the stable rock walls/surfaces at the sinkhole throat.
3. If, during exploratory excavation, the sinkhole throat is determined to be greater than 36", Class II Riprap shall be used in lieu of Class I Riprap.
4. Contractor shall overlap the ends of the geotextile material a minimum of 24 inches.
5. For treatments requiring a concrete cap (see Figure 11), all rock surfaces shall be free of soil and organic material prior to placing concrete.



**Figure 11. Typical sinkhole treatment concrete cap**

INDOT

- Drainage control – Infiltration of surface water can lead to soil voids, collapse, and potential sinkhole formation. The features are protected during and post-construction with lined drainage routes and stormwater detention areas. The primary goal is to control entry points of surface runoff and divert subsurface water from known sinkholes. A concrete lined ditch that is cracked would allow water and potential contaminants into a feature and the increased water flow would lead to the collapse of the feature. See Figure 11 and the Post-Construction Stormwater Management Guidance.



**Figure 12. Typical lined drainage ditch with clay layer protection**

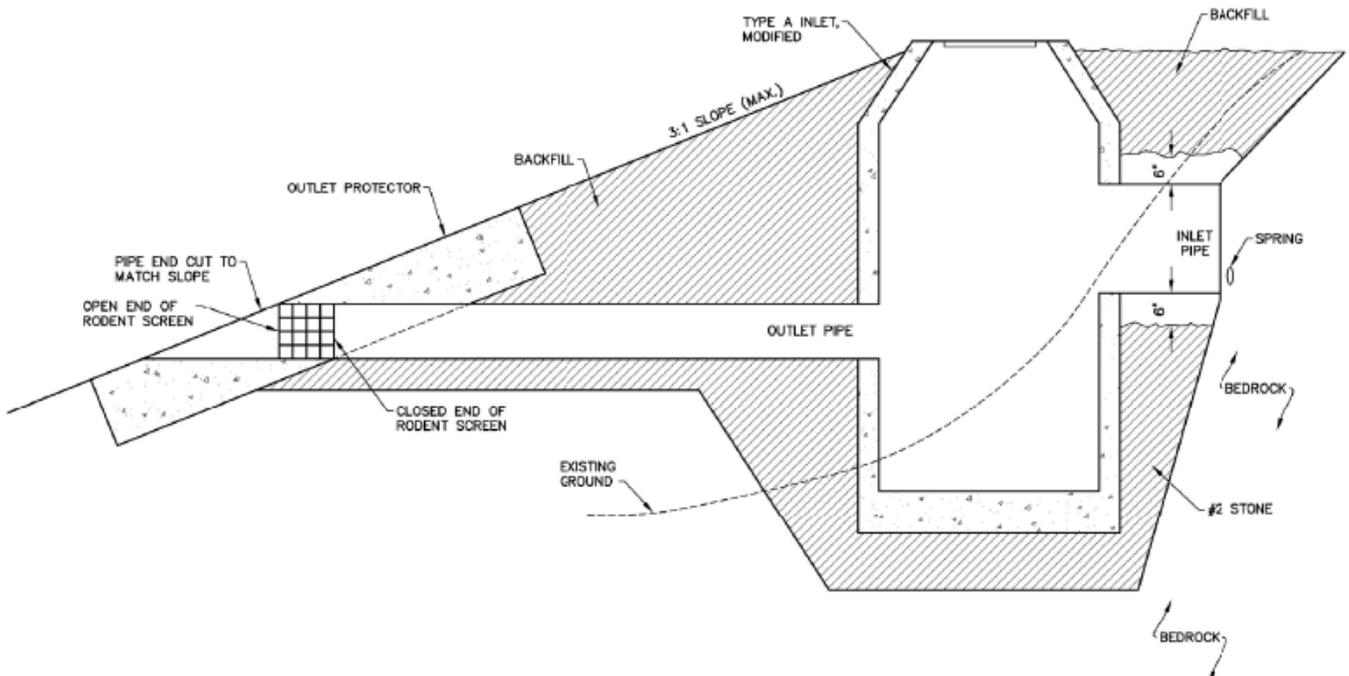
INDOT

- Spring or seep protection – Springs and seeps require special treatment to reduce impacts to the road and the water resources. The outlet below is designed to capture the flow from a seep located under a roadway and direct it toward its normal flow path. Springs or seeps will continue to flow and cannot be treated by capping. Failure to direct the flow from under the roadway will result in instability of the fill under the roadbed. See Figure 8.

A spring box is designed to capture flow from a spring or seep located under fill and direct it toward the bottom of the slope.

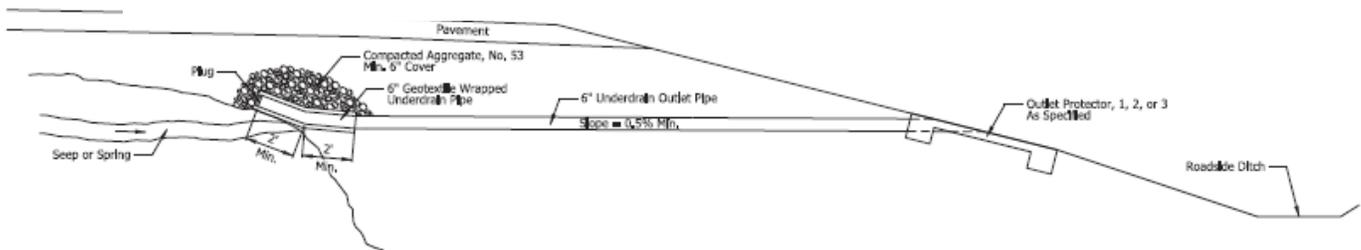
An offset structure is designed to allow water from the roadside ditch to flow into a sinkhole located under the embankment. The sinkhole is stabilized prior to installing the structure. The grate provides access for maintenance.

- Bridge pier construction – The construction of bridge piers within karst terrain requires that the pier footing be designed to the terrain. For example, spread footings are appropriate for locations with stable overburdens. Driven piles and caissons may also be used.



**Figure 13. Karst seep or spring outlet**

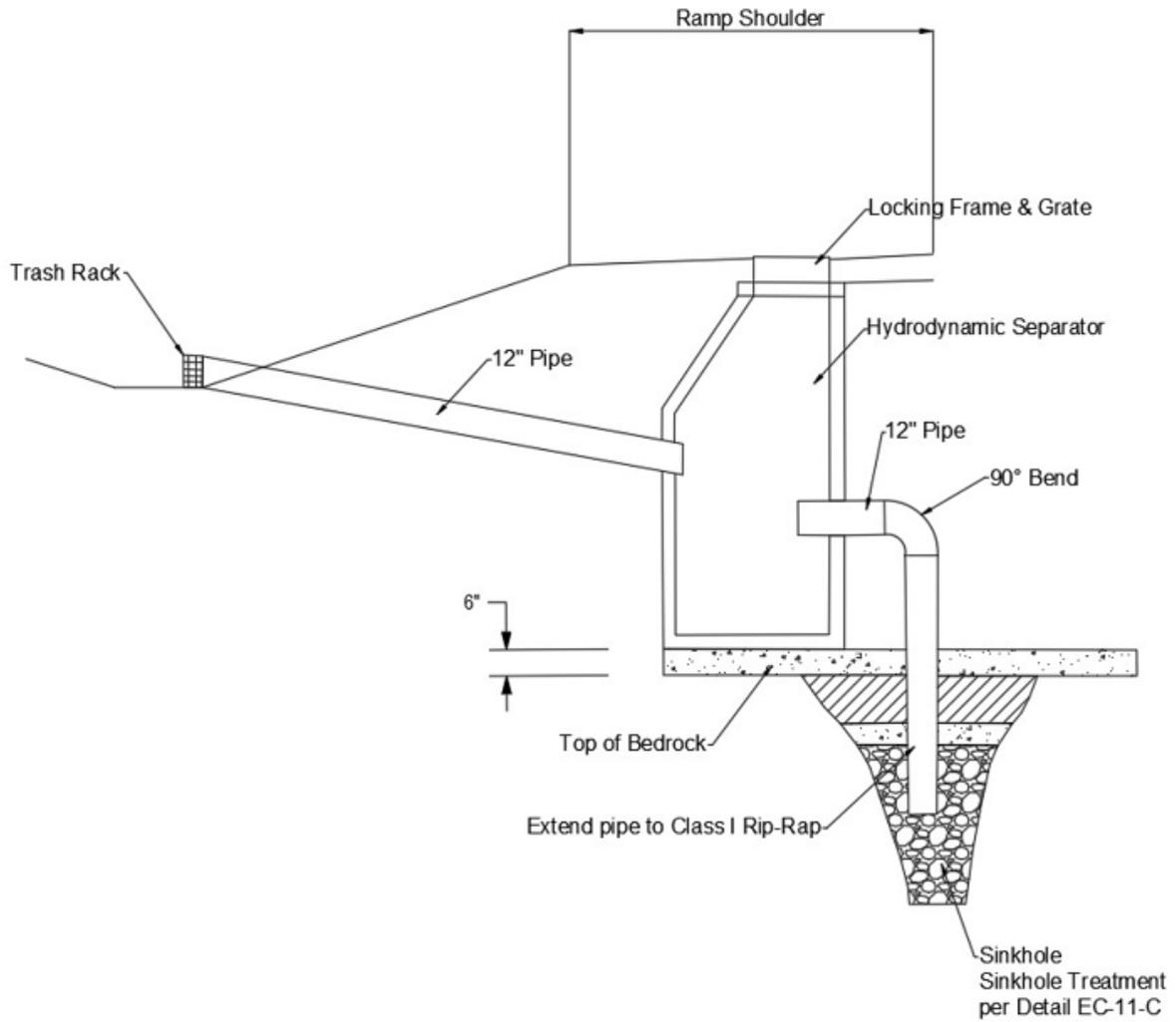
INDOT



**Figure 14. Spring box in fill section ditch**

INDOT

A graded filter is a method for filling sinkholes in which the sinkhole's throat in the bedrock is covered with large pieces of stone. The layer of large stones is covered with a second layer of stones that are large enough to bridge the openings between the underlying stones. Layers of stone are laid down in courses until a final layer of fine gravel can be covered with soil and the surface can be graded.



**Figure 15. Offset structure**

INDOT

## D. Accidental Discovery

If a karst feature is discovered within existing right-of-way or near an active construction project, it should be evaluated to determine if protection measures are necessary. The USP for Discovery of Karst Features during construction should be followed:

1. All work within 100 feet of the feature shall stop, and the Project Engineer or Supervisor shall be notified immediately.
2. INDOT will provide treatment measures to be incorporated for the feature.
3. The karst feature shall be protected from sedimentation runoff.
4. Work shall not resume in the area until directed by the Engineer.

If the feature is a hazard to the roadway and has the potential to undermine the roadway or make it unstable, it should be stabilized. Measures that may be required to protect the feature may include installation of an aggregate cap to prevent unfiltered runoff water from entering the feature or installation of a permanent cap if impacts to the roadway are possible. Consultation with INDOT Area Engineer, EWPSO Ecologist and Team Lead, district environmental staff, project designer, a licensed geologist, and/or the regulatory agencies is required.

Figure 16 shows a sinkhole found during a slide correction project along U.S. 150 near French Link in Orange County. The feature was located outside of the construction limits and approximately 10 feet off the roadway. It continued to erode since identification the previous year. It was determined that the feature did not need to be addressed under the current contract but will need treatment in the future.

### Figure 16. Karst feature

found along U.S. 150  
near French Lick,  
Orange County, IN  
INDOT



#### IV. Karst and INDOT Maintenance

Two maintenance activities that have the potential to impact karst features are winter operations and vegetation management. Mitigation features along INDOT roadways are designed to keep contamination from winter operations out of adjacent karst features.

Winter snow and ice control follows Operations Memorandum 08-01 Snow and Ice Control and the INDOT Maintenance Work Performance Standards. INDOT roadways are divided into three classes based on road volume or nearby high-priority activities, such as hospitals or emergency services. Service objectives are based on class with the goal of achieving bare pavement conditions. The amount of deicing and anti-icing chemicals used will be appropriate to maintain and/or restore bare pavement condition before, during, and after winter storm events. Motorist safety will be prioritized. The designation of “low salt zones” should be minimized to allow treatment based on pavement condition. New technologies are being used that will reduce the amount of salt required to meet the service objectives. Salt storage facilities are monitored, repaired, or replaced to reduce the contamination from chemicals outside of winter operations. Maintenance Work Performance Standard 2630, Snow and Ice Removal, provides additional details on INDOT procedures.

Vegetation management in karst areas includes the use of pesticides and mowing. The procedures for vegetation management in karst areas are as follows:

- Establish “no mow or spray” buffers of 100 feet or less to limit impacts to a sensitive karst feature.
- Pesticide application:
  - Restricted-use pesticides are prohibited.
  - Applied in accordance with the product label.
  - Applied by licensed applicator.

The use of signs to mark karst areas or features will be minimized to reduce negative impacts on vegetation management and maintenance activities. The signs will follow the designs included in Appendix A Karst Area Signage. The key points to consider during design are:

- The quantity of signposts should be minimized by combining signs on a post, (for example, “low salt zones” and “report spills”) or including with reference post/mile marker signs
- Signs should state “begin,” “end,” or “next XX miles”

## Appendix A Karst Area Signage



1.5" Radius, 0.6" Border, 0.4" Indent, White on Blue;

"LOW SALT ZONE" C; "NEXT 1.5 MILES" C;

Table of distances between letter and object lefts.

L	O	W	S	A	L	T	Z	O	N	E			
5.0	2.7	3.0	7.0	2.8	3.2	2.2	6.0	2.9	3.2	3.0	2.0	5.0	
N	E	X	T	I	.	S	M	I	L	E	S		
6.1	3.0	2.7	2.8	6.0	1.5	1.2	6.2	3.5	1.4	2.6	2.7	2.2	6.1

Sign placement –

1. Beginning of zone – “Begin Low Salt Zone Next \_\_\_\_ Miles.”
2. If required, repeat every five miles until end of zone.
3. At end of zone – “End Low Salt Zone.”

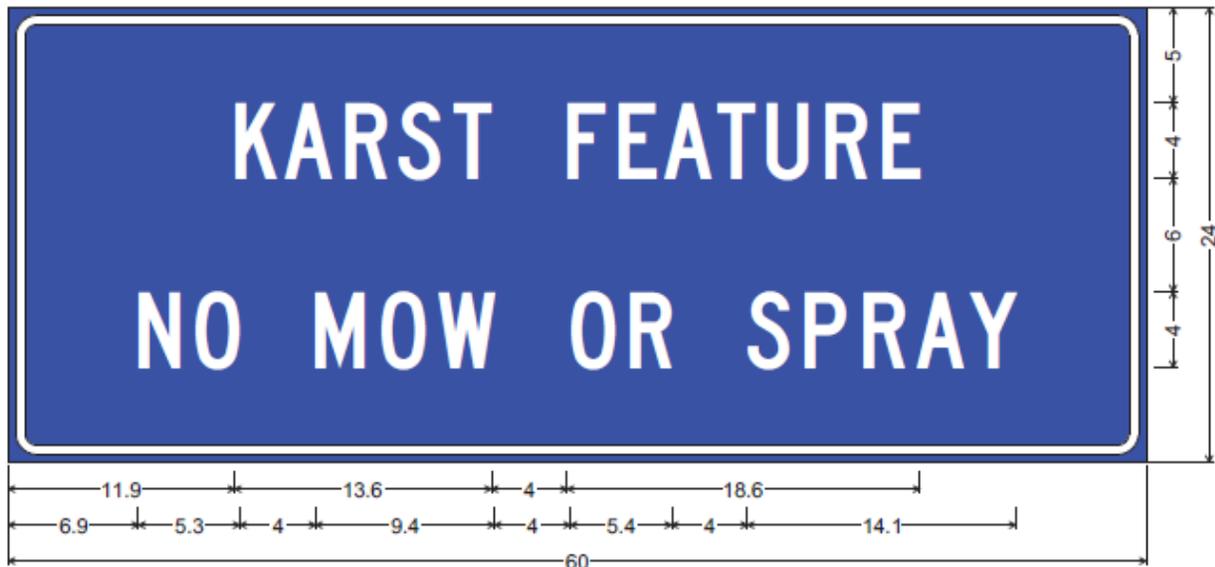


1.5" Radius, 0.6" Border, 0.4" Indent, White on Blue;  
 "REPORT ALL" C; "SPILLS TO" C; "1-888-233-7745" C;  
 Table of distances between letter and object lefts.

6.8	R	E	P	O	R	T	A	L	L	6.8					
3.0	3.0	2.7	2.8	3.2	2.9	6.0	3.1	2.7	2.0						
9.0	S	P	I	L	L	S	T	O	9.0						
3.0	3.0	3.1	1.4	2.6	2.7	6.2	2.7	2.3							
3.0	1	-	8	8	8	-	2	3	3	-	7	7	4	5	3.0
	1.6	2.5	2.8	2.9	2.8	2.5	2.9	2.8	2.9	2.2	2.4	2.4	3.2	2.1	

Sign placement –

At each feature or group of features if in proximity. Attached on post below “Karst Feature No Mow or Spray” sign.



1.5" Radius, 0.5" Border, 0.4" Indent, White on Blue;

"KARST FEATURE" C; "NO MOW OR SPRAY" C;

Table of distances between letter and object lefts.

11.9	K	A	R	S	T	F	E	A	T	U	R	E	11.9
2.7	3.1	2.9	2.9	6.0	2.7	2.4	2.7	2.7	3.0	3.1	2.0	11.9	
6.9	N	O	M	O	W	O	R	S	P	R	A	Y	6.9
3.0	6.3	3.4	3.0	7.0	3.2	6.2	3.0	3.0	2.9	2.7	2.5	6.9	

Sign placement –

At each feature or group of features if in proximity. Attached on post above “Report All Spills to 1-888-233-7745” sign.

## Appendix B Best Management Practices in Karst Terrain

Adapted from I-69 Evansville to Indianapolis, Ind., Tier 2 Draft Environmental Impact Statement, Section 5: Bloomington to Martinsville, Volume I, Part B, October 2022.  
Chapter 5.21 – Karst Impacts

Best Management Practice (BMP)	Description	INDOT Standard Specification Reference Number (if available)
<b>Ditch Lining</b>		
Compacted clay liner	Lined ditches are used to prevent erosion. Hydraulic analysis evaluates water flow and velocity required to size lining. This reduces erosion and sediment transport into a feature.	Section 205 – Stormwater Management
Geosynthetic clay liner	It is used to protect groundwater penetration along a roadside ditch.	Section 205 – Stormwater Management
Flexible membrane liner	Conforms to undulating topography.	Section 205 – Stormwater Management
Concrete, Portland cement, or asphalt	Possible use if feature is not regulated but is not aesthetically pleasing.	Section 607 – Paved Side Ditch or Concrete Gutter
<b>Sinkhole – Bridging</b>		
Culvert or bridges	Use INDOT Drainage Design Manual to size bridge or culvert openings. Evaluate the backwater conditions created by the karst features in design to ensure proper detention storage. If karst features cannot be avoided, filled, or capped, the roadway should span the feature and be anchored (reinforced) into competent	Section 714 – Reinforced Concrete Box Structures Section 715 – Pipe Culverts, and Storm and Sanitary Sewers Section 723 – Reinforced Concrete Three-Sided Structures

Best Management Practice (BMP)	Description	INDOT Standard Specification Reference Number (if available)
<b>Sinkhole – Bridging (cont.)</b>		
	bedrock. Minimize cuts into bedrock.	
Reinforcement of cave	Mortar used to coat and strengthen the cave walls.	Section 708 – Pneumatically Placed Mortar
Ground modification	Strengthen soils by injecting concrete or lime.	Section 215 – Chemical Modification of Soils
Geopier with cap	Installed quicker than traditional piers or piles and will provide strength to a wide range of soils.	Section 701 – Driven Piling
Piles with cap	Traditional method for vertical reinforcement of soils.	Section 701
<b>Sinkhole - Filling</b>		
Rock pads	Effective where the velocity of the storm water needs to be decreased to prevent erosion.	Section 205 – Stormwater Management
Large rock fill	Effective for slope stability issues.	Section 203 - Excavation and Embankment Section 207 – Subgrade Section 211 - Structure Backfill
Compaction grouting	Use where soil is loose or soft and does not need a large area for installation.	No standard available.
Cement grouting	Effective where there are significant voids and cracks in load bearing rock.	Section 616 – Riprap and Slopewall
Dynamic compaction	Will increase the density of the soil, to include soil below the groundwater. Best for granular soils.	Sections 203 and 215

Best Management Practice (BMP)	Description	INDOT Standard Specification Reference Number (if available)
<b>Sinkhole – Filling (cont.)</b>		
Excavation, overlapping geotextiles, soil backfill	If a sinkhole is located within new right-of-way, but has a small drainage area, capping is more appropriate than installing a catch basin and standpipe.	Sections 203 and 215
Excavation, concrete cap, soil backfill	If a sinkhole is located within new right-of-way, but has a small drainage area, capping is more appropriate than installing a catch basin and standpipe.	Section 203 and 215
<b>Permanent Treatments</b>		
Earth berm	Provides erosion control feature a natural look	Section 205
Gabion berm	May be appropriate at very steep slopes (>10%)	RSP 625-R-194 Gabions
Open standpipe	A chimney (standpipe), catch basin, and rock filter are common BMPs for sinkholes	No standard available
Concrete catch basin	A chimney (standpipe), catch basin, and rock filter are common BMPs for sinkholes. Can be enhanced with a basin designed as a hazardous material trap.	Section 720 – Manholes, Inlets, and Catch Basins
Natural vegetative buffers	Used to detain/treat runoff prior to discharge	Section 621 – Seeding and Sodding
Sand/gravel filter	Used to detain/treat runoff prior to discharge	Section 205
Spring boxes	Used to protect discharge from springs	Section 205

<b>Best Management Practice (BMP)</b>	<b>Description</b>	<b>INDOT Standard Specification Reference Number (if available)</b>
<b>Permanent Treatments (cont.)</b>		
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, follow the INDOT Drainage Design Manual	Section 616
Geogrid or geotextile layers	Use in lower reaches of embankments, embankment foundations, or roadway subgrades	Section 214 - Geosynthetics
<b>Other</b>		
Agencies (DNR, IDEM, USFWS) attend field checks/meetings	Agency input regarding treatment proposals to avoid or minimize adverse effects	Requires project specific agency coordination
Notify the USFWS and DNR if a federal or state protected species is observed during construction	Work will stop in the project area and agencies will be notified	Requires project and species specific unique special provision Section 107 – Legal Relations and Responsibility to Public - requirement for contractors to comply with laws and permits
Avoidance	Occurs after the project area has been screened for karst features. Design will provide further details on road cross section and alignment at each feature. Consider avoidance if cost effective and within design criteria.	

<b>Best Management Practice (BMP)</b>	<b>Description</b>	<b>INDOT Standard Specification Reference Number (if available)</b>
<b>Other (cont.)</b>		
Alternative drainage	Use measures to redirect highway runoff away from karst recharge features. Implement where feasible.	
Discovery during construction	Requires coordination with LPG with karst expertise to determine treatment	Section 107 RSP 203-R-744 Discovery of Karst Features within the Construction Limits
<b>Operation/Maintenance</b>		
Discovery of a new or previously unknown feature	Monitoring of areas that receive roadway runoff to identify soil piping or new karst features.	INDOT Maintenance Work Performance Standards
No-mowing, low salt, or no spray zone	Provides increased vegetative ground cover and runoff filtering prior entering feature.	See Appendix C for sign guidance.
Scheduled inspection and maintenance of measures	Verify capacity, integrity, and operational efficiency of measure.	INDOT Maintenance Work Performance Standards



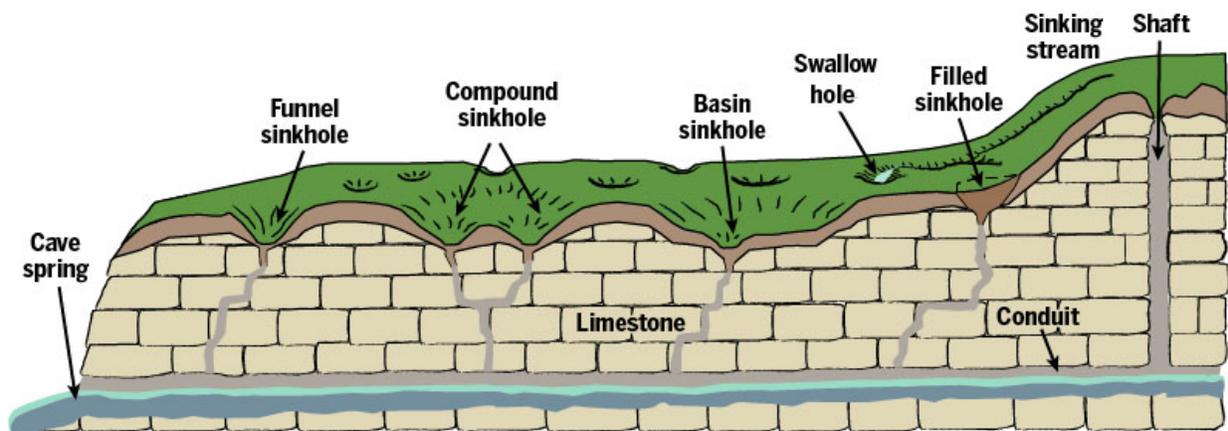
## Appendix D Karst Geology

### A. Development of Karst Features

Karst is a landscape feature that is formed by the dissolution of a layer or layers of soluble rock by acidic water. The two types of soluble rock found in the Indiana karst region are limestone and dolomite. The acidity of rainwater increases as it absorbs carbon dioxide ( $\text{CO}_2$ ) as it moves through the subsurface, forming carbonic acid ( $\text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{CO}_3$ ). Karst features contain sensitive ecological communities that are susceptible to environmental changes that may be caused by construction or use of INDOT roadways.

Understanding the geology of a project area includes understanding the type of bedrock that lies below the surface, the surface landforms, and the materials above the bedrock, including soils. For most roadway projects, the type and depth of bedrock generally do not have a strong influence on location, design, or construction. In most areas, it is not a consideration when evaluating potential environmental impacts. However, projects located in karst areas may require special consideration of karst features in site evaluation, selection, project design, and environmental impact avoidance.

Karst features are formed as acidic water dissolves the subsurface rock, forming cracks and fissures. The water moves sideways along horizontal cracks between rock layers (bedding planes) and fractures or joints in the rock. In many karst areas, there is little surface water because most of it has entered the subsurface water flow of the karst system.



**Figure 17. Solution features characteristic of karst terrains**

Hasenmueller and Powell, 2005, as found on <https://igws.iu.edu/outreach/karst>

## B. Types of Karst Features

There are many types of karst physiographic features present in Indiana.

- Cave – A cave is an air-filled underground void that is large enough to be entered by a person.
- Sinking/losing stream – A sinking or losing stream has a bed that allows water to flow directly into the groundwater system.
- Natural bridge or tunnel – A natural bridge or tunnel is a void beneath standing bedrock. It is short but will be large enough to allow human passage. A natural bridge is shorter than a tunnel and is, more often, air-filled rather than water filled.
- Spring – A spring is a natural resurgence of groundwater from a karst groundwater system to the surface. Springs are usually located along a hillside or on a valley floor.
- Seep – An area, generally small, where water percolates slowly to the land surface through small openings of a porous material.
- Swallet/swallow hole – A swallet or swallow hole is an area where a stream sinks into the subsurface.
- Sinkhole or sink – A sinkhole or sink is a collapsed portion of bedrock above a void. It creates a basin- or funnel-shaped surface depression ranging from a few feet to several hundred feet in diameter and from a few feet to several hundred feet in depth.



Cave entrance  
Lochmueller Group



Cave mouth  
Parsons

Rock column collapse through  
sandstone into limestone cave  
system.  
Lochmueller Group



This small spring located in  
limestone has diminished and  
variable flow.  
Lochmueller Group



This spring has artesian flow from  
a submerged cave.  
Lochmueller Group





Sinkholes  
Photo Credit Parsons

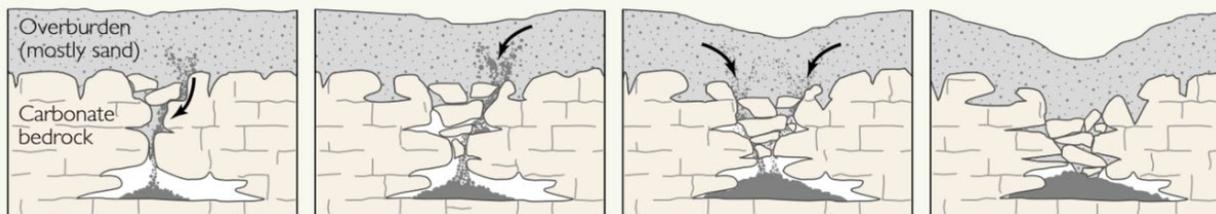
The development of karst features is illustrated by the two mechanisms that can create sinkholes. The first mechanism is where granular sediments spill into secondary openings in the underlying carbonate bedrock. The overlying sediment settles into (piping) the vacant spaces. Chemical dissolution of the bedrock in conjunction with the mechanical weathering of the overlying soil results in a sinkhole.

Granular sediments spill into secondary openings in the underlying carbonate rocks.

A column of overlying sediments settles into the vacated spaces (a process termed "piping").

Dissolution and infilling continue, forming a noticeable depression in the land surface.

The slow downward erosion eventually forms small surface depressions 1 inch to several feet in depth and diameter.



**Figure 18. Bedrock dissolution process**

Land Subsidence in the United States. USGS.

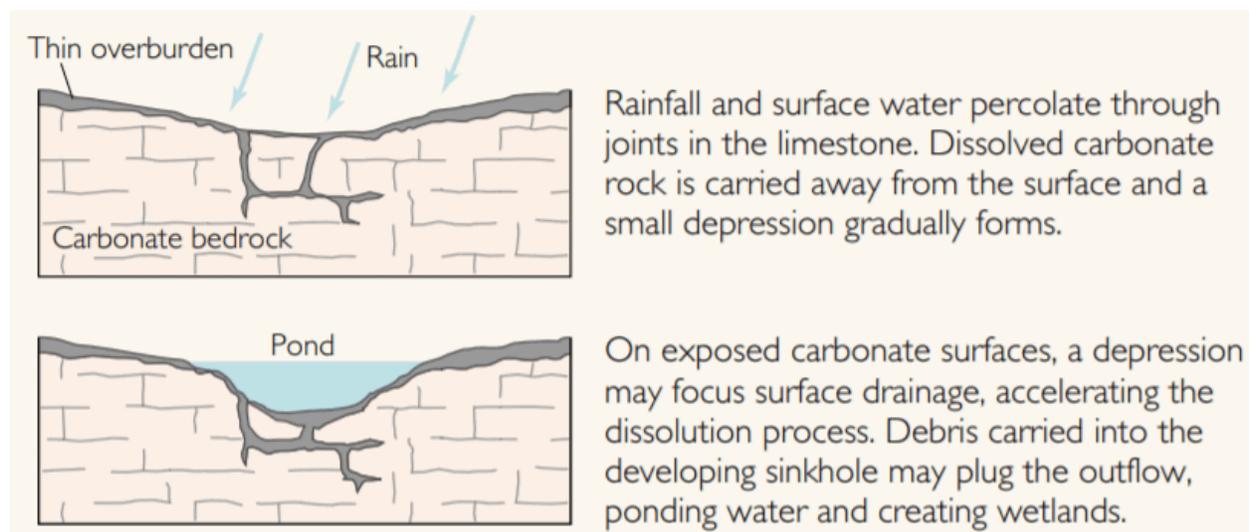
The second mechanism occurs as the result of water table variability. Soil strength is based on water content. The soil strength is low when there is insufficient water to interlock the soil particles. Soil strength increases as water content increases. There is a point where the weight of the water will overcome the soil strength, and the soil will collapse. When there is a rapid increase or fluctuation in water content, changes in the effective stress load (the force that keeps a collection of particles rigid) will lead to failure.

The epikarst zone is the interface between soil and rock in karst landscape. It is characterized by fracturing and solution pockets that can be filled with water. It stores and directs percolation water toward the vertical drains or springs in the karst.

The hydrologic characteristics associated with the presence of karst include:

- Internal drainage of surface runoff through sinkholes.
- Underground diversion or partial subsurface piracy of surface streams (sinking and losing streams).
- Temporary storage of groundwater within a shallow, perched epikarst zone.
- Rapid, turbulent flow through subsurface pipelike or channel like solutional openings called conduits.
- Discharge of subsurface water from conduits by way of one or more large perennial springs. (Taylor and Nelson, 2008)

The USGS classifies three types of sinkholes: dissolution, cover-subsidence, and cover-collapse. Dissolution of the limestone or dolomite is most extensive where the water first contacts the rock surface. Where there are preexisting openings in the rock, such as along joints, fractures, and bedding planes and in the zone of water-table fluctuation, the dissolution is more aggressive.



**Figure 19. Dissolution sinkhole**

Land Subsidence in the United States, USGS

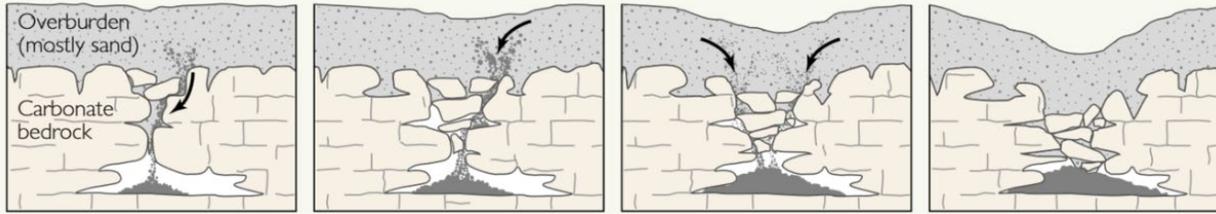
Cover-subsidence sinkholes develop gradually where the covering sediments are permeable and contain sand.

Granular sediments spall into secondary openings in the underlying carbonate rocks.

A column of overlying sediments settles into the vacated spaces (a process termed "piping").

Dissolution and infilling continue, forming a noticeable depression in the land surface.

The slow downward erosion eventually forms small surface depressions 1 inch to several feet in depth and diameter.



**Figure 7. Cover-subsidence sinkhole**

Land Subsidence in the United States, USGS

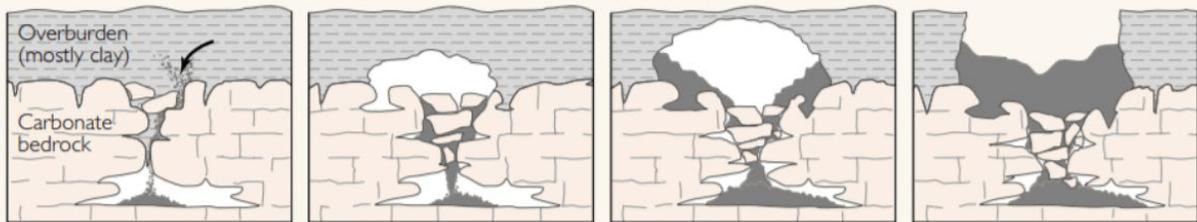
Cover-collapse sinkholes may develop abruptly and occur where the covering sediments contain a significant amount of clay.

Sediments spall into a cavity.

As spalling continues, the cohesive covering sediments form a structural arch.

The cavity migrates upward by progressive roof collapse.

The cavity eventually breaches the ground surface, creating sudden and dramatic sinkholes.



**Figure 21. Cover-collapse sinkhole**

Land Subsidence in the United States, USGS

### C. Karst in Indiana

There are two primary areas of karst landscape located in southern Indiana: the Mitchell Plateau and the Crawford Upland (see Figure 22). The Mitchell Plateau extends from the eastern part of Owen County southward to the Ohio River in Harrison County and into Kentucky. It developed on Mississippian carbonates. The Crawford Upland, located west of the Mitchell Plateau, is characterized by ridges and valleys developed on shale, sandstone, and carbonate strata of Mississippian age. Sinkholes, karst valleys, and caves are common along the border between the two areas. A karst valley is a compound sinkhole, sinking valley, or other large karst depression from 300 feet to 60 miles in size.

Three other areas can be found east of the Norman Upland: the Muscatatuck Plateau, Charleston Hills, and the Dearborn Upland. The northern two-thirds of Indiana are covered with thick unconsolidated glacial material that covers potentially karstic rock layers. There are also areas along the Wabash River, outside of the typical karst areas, where the karst features are exposed due to thin or absent glacial materials.

Two rare and ecologically important wetland types can be found in karst topography: sinkhole ponds and sinkhole swamps (see 327 IAC 17-1-3(3)(B)). Sinkhole ponds are depressions containing water. A sinkhole swamp is a depression that is dominated by trees or shrub species. Both can be found on the Mitchell Plateau.

Figure 23 illustrates a physiographic cross section of southern Indiana.

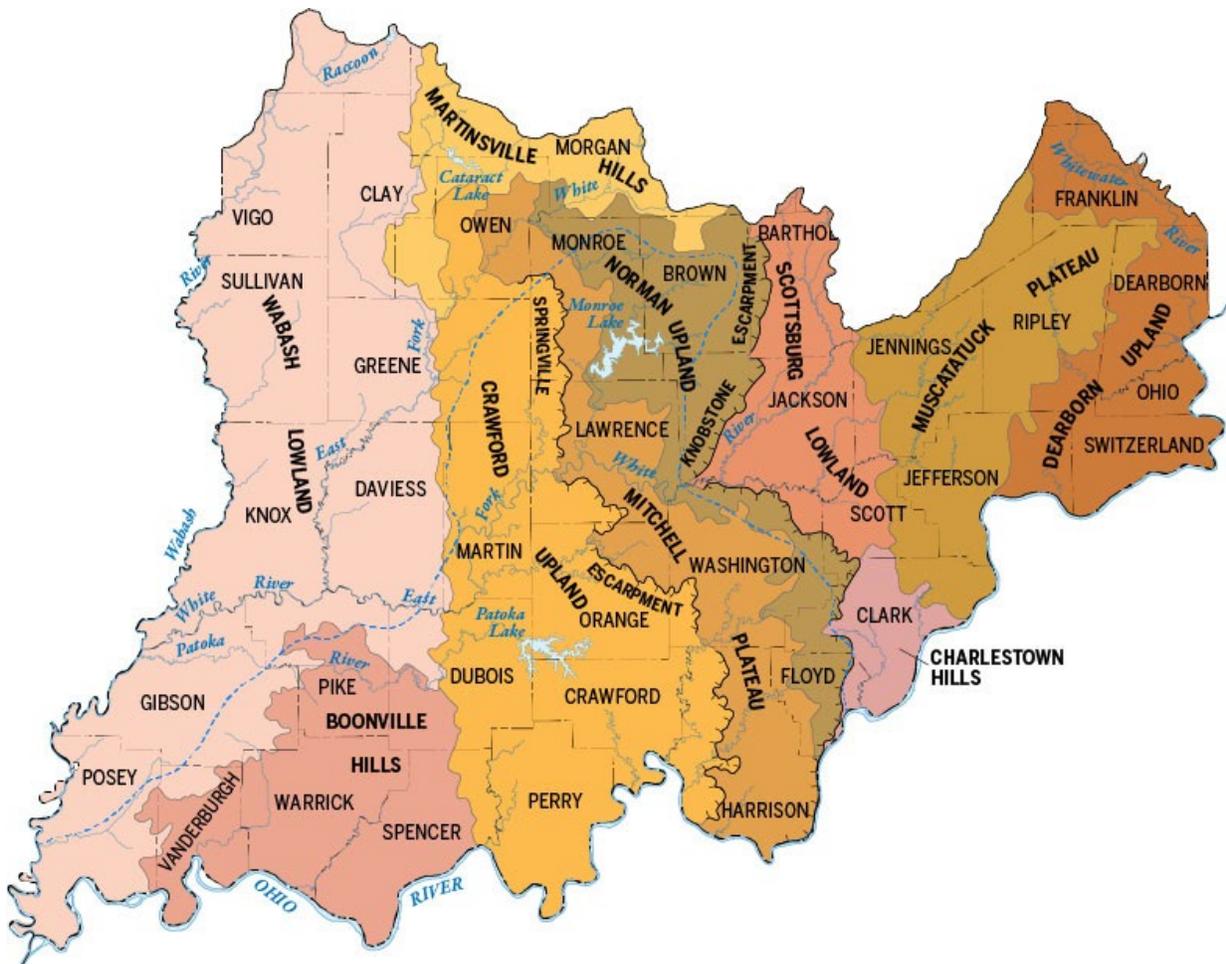
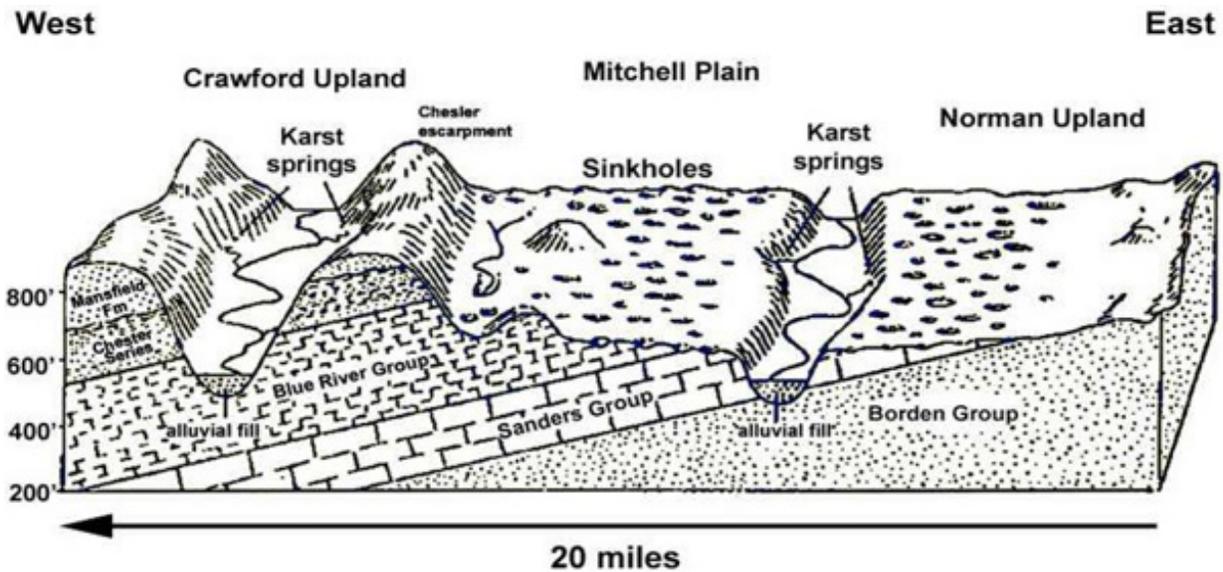


Figure 8. Physiographic divisions of southern Indiana

From Gray, 2000



**Figure 23. Generalized physiographic cross section of southern Indiana**

From Palmer, 1969

#### **D. Karst Aquifers**

An aquifer is a body of bedrock, or other earth material, from which useable quantities of groundwater can be produced by a well or spring. An aquifer can be composed of granular materials such as loose sand and gravel or weakly cemented bedrock. The groundwater flows very slowly through these aquifers between the grains of sand or gravel, or through narrow fractures in the bedrock. The small openings in the surface soil layer act as a filter and physically or chemically remove bacteria, viruses, and polluting chemicals. Sinking streams, swallow holes and other features with a limited or absent surface soil layer provide limited filtration and may result in contamination from fecal bacteria and other pollutants.

Unlike a typical aquifer, the drainage pattern of a karst aquifer resembles the branching pattern formed by streams flowing above ground. Water will enter a karst aquifer either directly, through swallow holes and sinkholes, or indirectly, through the pores in the soil overlying the limestone bedrock. As the volume of water increases in response to surface rainfall in the enclosed channel, the pressure will increase. Water will move through the channel in a manner like water going through a hose.

The flow of water on the surface will follow the topography, creating drainage basins. A groundwater basin boundary will have little relationship to surface drainage patterns and may cross surface watershed boundaries. This creates challenges in mapping water flow through the karst features.

## Appendix E Karst Biology

### A. Cave Zones

Caves and karst areas contain unusual organisms that have adapted to the specialized and fragile habitat. Cave habitats can be classified into two groups – terrestrial and aquatic. Terrestrial animals include bats, crickets, and harvestmen. Aquatic animals include cave fish, amphipods, crayfish, and salamanders.

Cave habitats can be divided by light zones. The entrance zone is the area just inside the cave opening. This area receives sunlight that enables some plant growth and an exchange of animals that might also be seen living above ground. The twilight zone is the area farther from the entrance where the light begins to diminish. The dark zone begins when the cave becomes completely dark and extends throughout the rest of the cave.

The caves can also be divided into two habitats. The Subterranean Systems Cave Entrances include the surface openings and reaching as far as the natural light can penetrate (entrance and twilight zones). The Subterranean Systems Caves include the connected underground rooms and passages beyond natural light penetration (dark zone). For more detail see the DNR [Subterranean Systems Habitat Summary](#).

### B. Cave Food Pyramid

In addition to adaptation to living in low to no-light where there is limited primary production, karst species have adapted to live on a limited food supply. The nutrients are brought into the cave from outside in the form of organic debris, seeds, and nuts carried in on flowing water. Organic matter is also introduced by eggs, feces, dead insects, and other animals, which cycle through the cave inhabitants as illustrated in the following cave food pyramid.

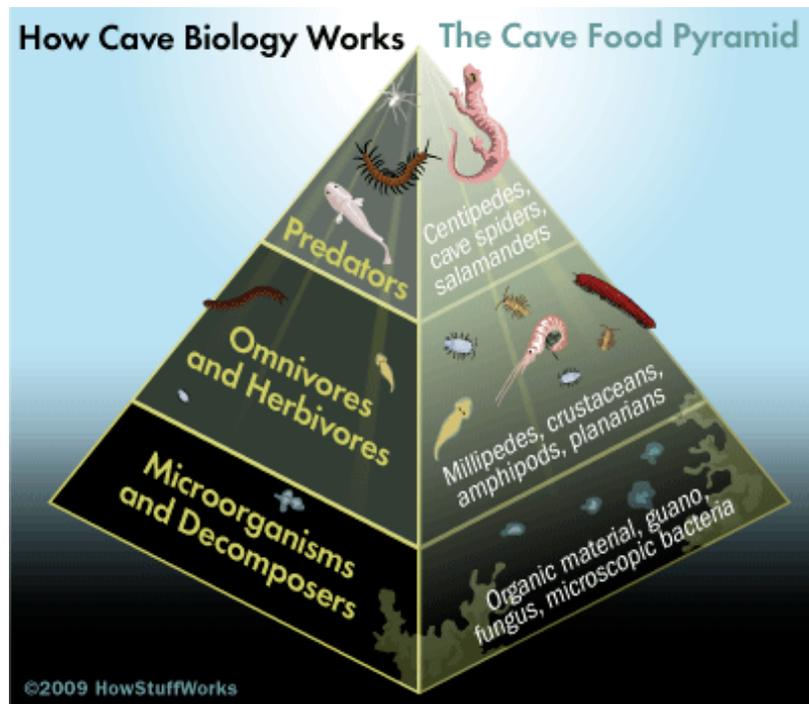


Figure 24. Cave food pyramid

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### C. Cave Fauna

Caves serve important roles. For example, caves serve as bat hibernacula for the endangered Indiana bat (*Myotis sodalis*) and northern long-eared bat (*Myotis septentrionalis*) and the tricolored bat/eastern Pipistrelle (*Pipistrellus subflavus*) that has been proposed for listing.

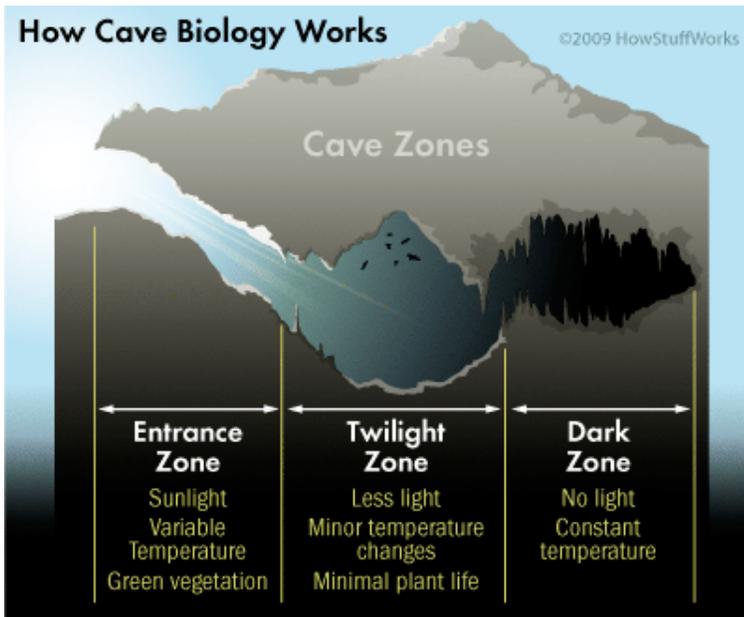
Cave fauna can be classified by the amount of their life cycle spent in or adapting to the cave environment and whether they are terrestrial (troglifauna) or aquatic (stygofauna) based. Some animals find temporary shelter, a resting place, or hunting ground in a cave. These troglonexes and stygoxenes spend much of their time above ground. They use the caves for a specific part of their life cycle, such as hibernation, nesting or giving birth, but they must go above ground for other parts of their life cycle, such as foraging for food or to mate. Examples of troglonexes include bats, bears, foxes, raccoons, snakes, crickets, moths, and swallows. Stygoxenes are surface-dwelling stream animals, such as fish, crayfish, and freshwater mussels.



Indiana bats (*Myotis sodalis*) drinking from water that has condensed on the cave wall.  
Photo credit USFWS; Andrew King

Animals that can complete their life cycle either above or below ground are called troglaphiles and stygophiles. These animals are adapted to survive their entire life in a cave, but they can also live in a suitable habitat above ground. Examples of troglaphiles include beetles, terrestrial crayfish, pigmented earthworms, millipedes, and centipedes. Examples of stygophiles are springfish and some salamanders.

Animals adapted to live entirely in caves are called troglobites and stygobites. They cannot survive above ground and have adaptations to help them find food, avoid predators, and complete their life cycles in the total darkness of the caves. These adaptations include long antennae and vibration sensory organs, a good sense of smell, long fins or legs, smaller bodies than surface species, low metabolic rates, few eggs, and a long lifespan. Some have little or no pigmentation and smaller or no eyes in the adult stages. Examples of troglobites include cave millipedes, some beetles, and cave spiders. Stygobites include blind crayfish, blind cavefish, blind cave salamanders, and cave shrimp.



**Figure 9. Cave zones**

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Ortmann's Mudbug (*Cambarus ortmani*)  
Photo credit DNR



Cave salamander (*Eurycea lucifuga*)  
Photo credit asih.org



Banded sculpin (*Cottus carolinae*)  
Photo credit cape.k12.mo.us

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