INDIANA DEPARTMENT OF TRANSPORTATION

Protection of Karst Features during Project Development and Construction

Ecology and Waterway Permitting Office
Environmental Services Division

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A. Karst

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 allows it to move rapidly through the system. In addition, these systems are complex and may disperse contamination unpredictably and rapidly. The contaminants may also get trapped in pools, sediments, and minor fractures. In addition, 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. 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. When sinkholes are clogged by surface runoff or other materials, they are not able to drain surface waters. In addition, the increase of impermeable surface water flow may also overwhelm the sinkholes. This alteration of drainage patterns may result in increased surface flooding.

This photo shows an area of karst flooding near Bellevue, Ohio. Surface and near-surface geologic conditions, combined with increased precipitation, resulted in the groundwater rising to the surface, flowing from existing sinkholes, and filling closed basins and sinkholes, caverns, and underground drainage passageways.
Source Indiana Geological Survey, Photo credit Douglas Aden

This sinkhole developed in Mississippian carbonate rock in Lawrence County, Indiana. Source Indiana Geological Survey, Photo credit Samuel Frushour

Sinkholes develop through bedrock dissolution, rock collapse, soil down-washing and soil collapse. They work individually or in various combinations to create sinkholes. The two most common types found in Indiana are solution sinkholes and collapse sinkholes. A solution sinkhole 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. Three other types are less common – dropout, suffusion and buried. Dropout sinkholes are formed by soil collapse into a soil void formed over a bedrock fissure. The overlying soil is cohesive clay soils. A suffusion sinkhole is formed by the down-washing of soil into fissures in bedrock. The overlying soil is non-cohesive soils such as sandy loams. Caprock sinkholes are created by the failure of insoluble rock into a cave in soluble rock below. (Waltham, 2010) See Appendix D for more information.

B. Impacts to Karst from Transportation Activity

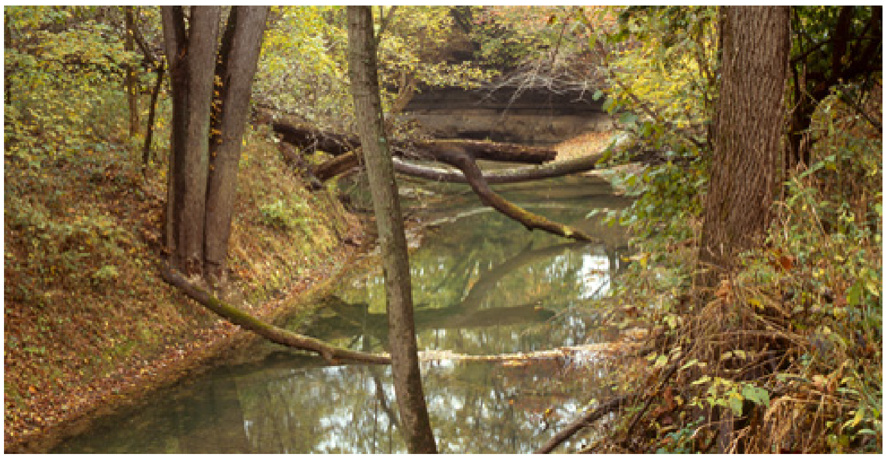
There a many ways transportation activity can impact karst. Physical alteration can result in flooding or desiccation. It can also change the physical environment to include new sinkholes, new or cut-off water or air pathways, dried up springs, collapsed or filled sinkholes or cave passages. Impermeable 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. Unlined retention structures (such as median ditches) can increase localized water pressure or head which can collapse adjacent sinkholes.

Surface and groundwater quality can be impacted through conveyance of pollutants. Pollutants 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 to 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 1 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 the NEPA because of the other related resources tied to the features. Section 7 consultation with the U.S. Fish and Wildlife Service (USFWS) would be required if there was the potential for federally protected species 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 was 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.

Orangeville Rise, Orange County, Indiana Photo credit The Nature Conservancy



Coordination or consultation with the USFWS is required under the Endangered Species Act (ESA) where a listed species was 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 well that requires submittal of inventory information to the EPA. A Class V well may all 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 and the Safe Drinking Water Act. IDEM's Office of Land Quality has oversight 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 they have 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/.

They may also be involved where 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. Currently, Monroe County is the only county with this type of ordinance. The Monroe County Zoning Ordinance Chapter 829 provides Karst and Sinkhole Development Standards. The ordinance establishes review procedures, use limitations, design standards and performance standards related to site development that may impact sinkholes or other karst features. The chapter prohibits development in those areas unless it has been demonstrated that the development would have "no significant detrimental impact on storm water management or ground water quality." Sinkhole conservancy areas must be established in all sinkhole areas that require a sinkhole evaluation and plan. New construction of streets and highways is prohibited without a determination by the County Highway Engineer and Drainage Engineer that "traffic safety considerations outweigh storm water and water quality considerations." This requires the completion of a sinkhole evaluation and plan, submittal, and approval of an improvement location permit. The ordinance also provides guidance on the evaluation of the sinkhole flooding area and sinkhole watershed.

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, the U.S. 50 North Vernon East Bypass has the potential to contaminate North Vernon's drinking water source through karst features located in the project area. Modifications were 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.

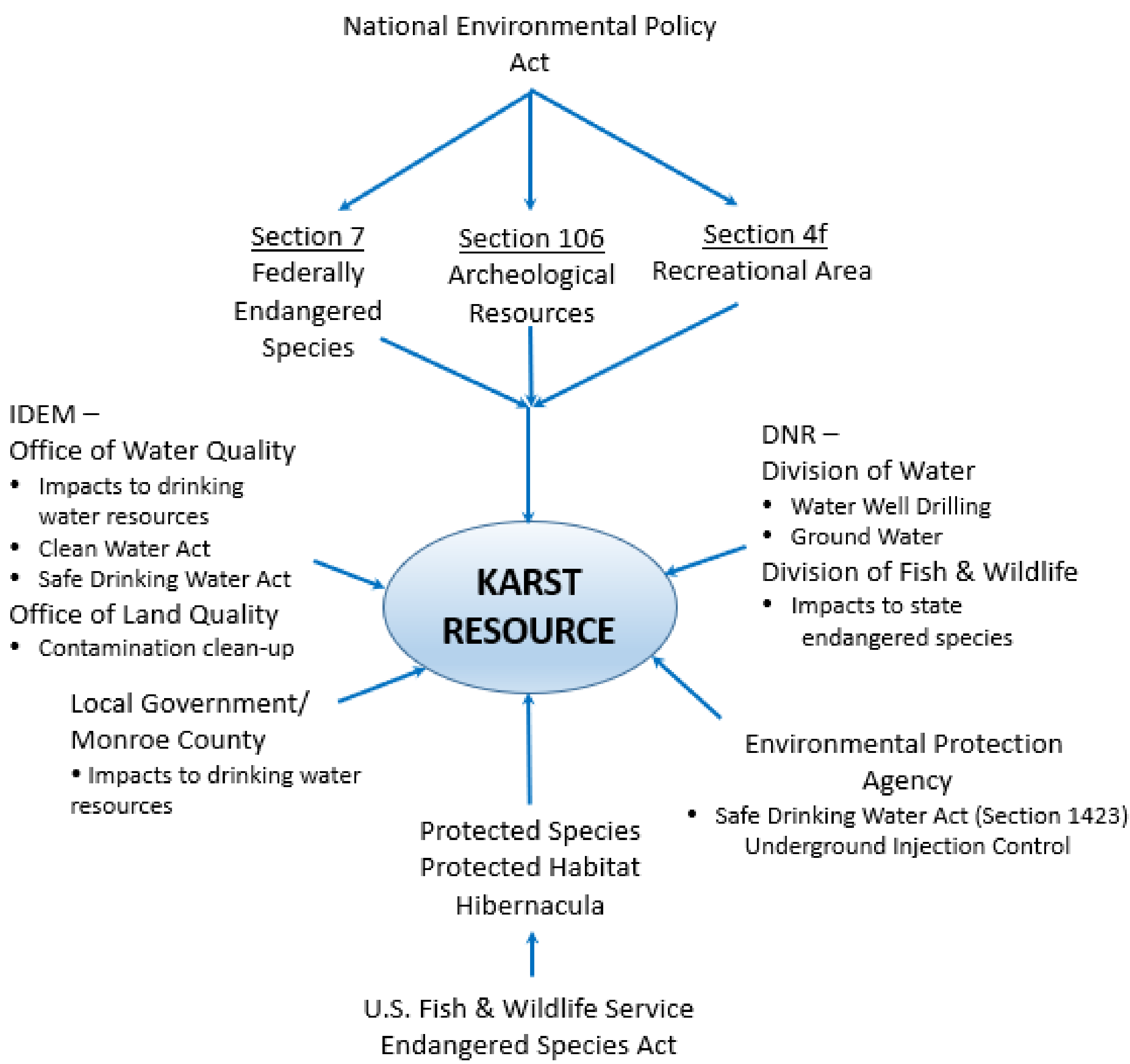


Figure 1. Legal protection of karst resources
Source INDOT

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, monitoring reports, agreements and any other documents required, and participate in field checks.

This procedure replaces the Memorandum of Understanding (MOU) between INDOT, the Indiana Department of Natural Resources (DNR), IDEM and USFWS that was signed in 1993. This procedure adds the United States Environmental Protection Agency (EPA) and the Indiana Geological and Water Survey (IGWS) as participants. IGWS is a non-regulatory research institute that should be consulted.

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.

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 the National Environmental Policy Act (NEPA), Endangered Species Act (ESA) and the Clean Water Act (CWA). In addition, INDOT must comply with the State Environmental Policy Act (SEPA), state water quality and other laws and regulations.

The Indiana Karst Region is defined as the area south of the Wisconsin Glacial Limit. This is depicted in Figure 2 and in Appendix A. 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 to but are strongly encouraged to comply with the 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 mile (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 2011, Karst Springs, and sinking stream basin. If no karst features are located within 0.5 mile, no further action is required. Record

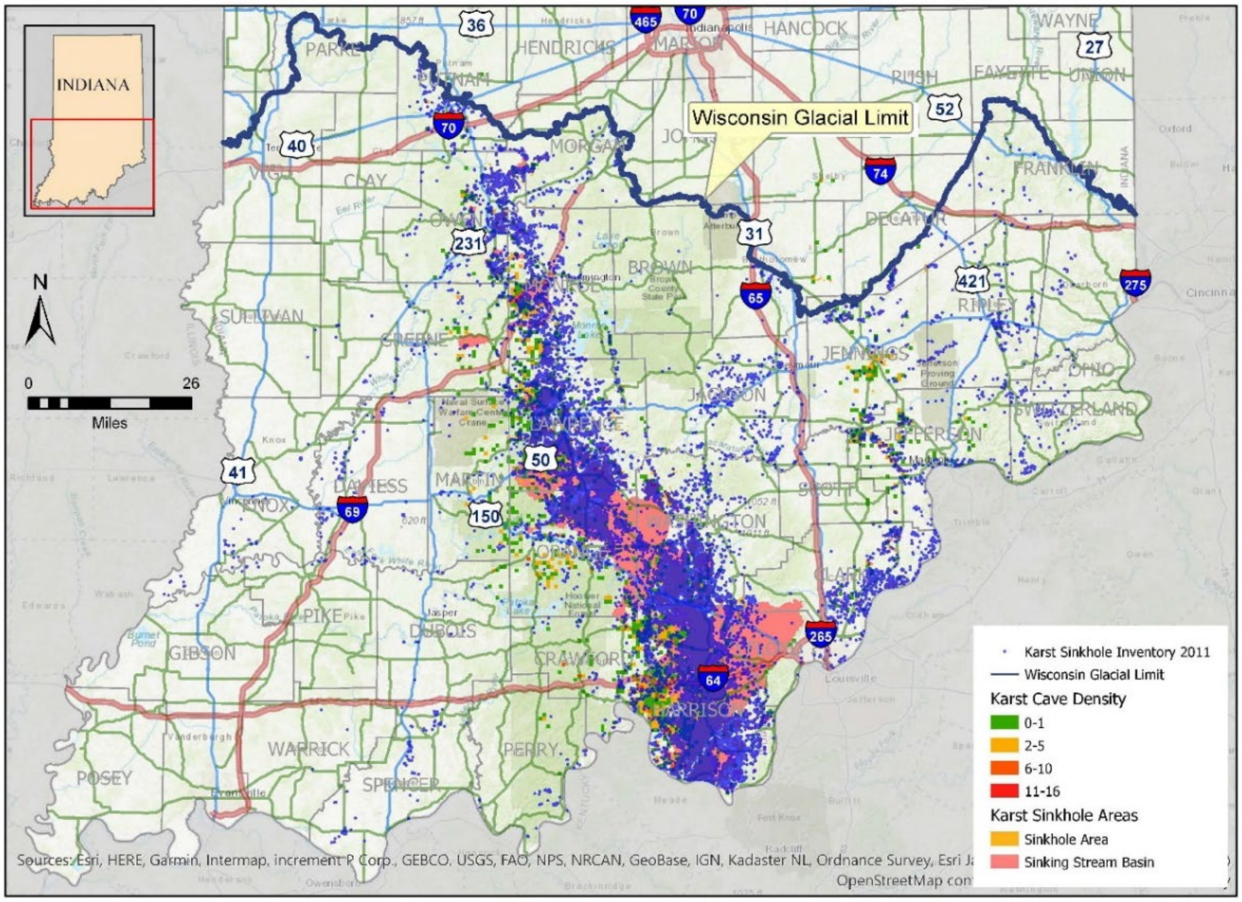


Figure 2. Indiana Karst Region

the finding in the NEPA document. If there is a karst feature located within 0.5 mile, further analysis is required.

The level of NEPA document is affected by the proposed project's potential impacts to karst features. Federally funded projects that are low impact enough to qualify for a Programmatic Categorical Exclusion (PCE) do not require a RFI and therefore will not be evaluated for karst features. Other federally funded projects that require a CE, EA, or 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. Agencies on the early coordination list that have an interest in karst features include USFWS, IDEM Groundwater Section (when 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.

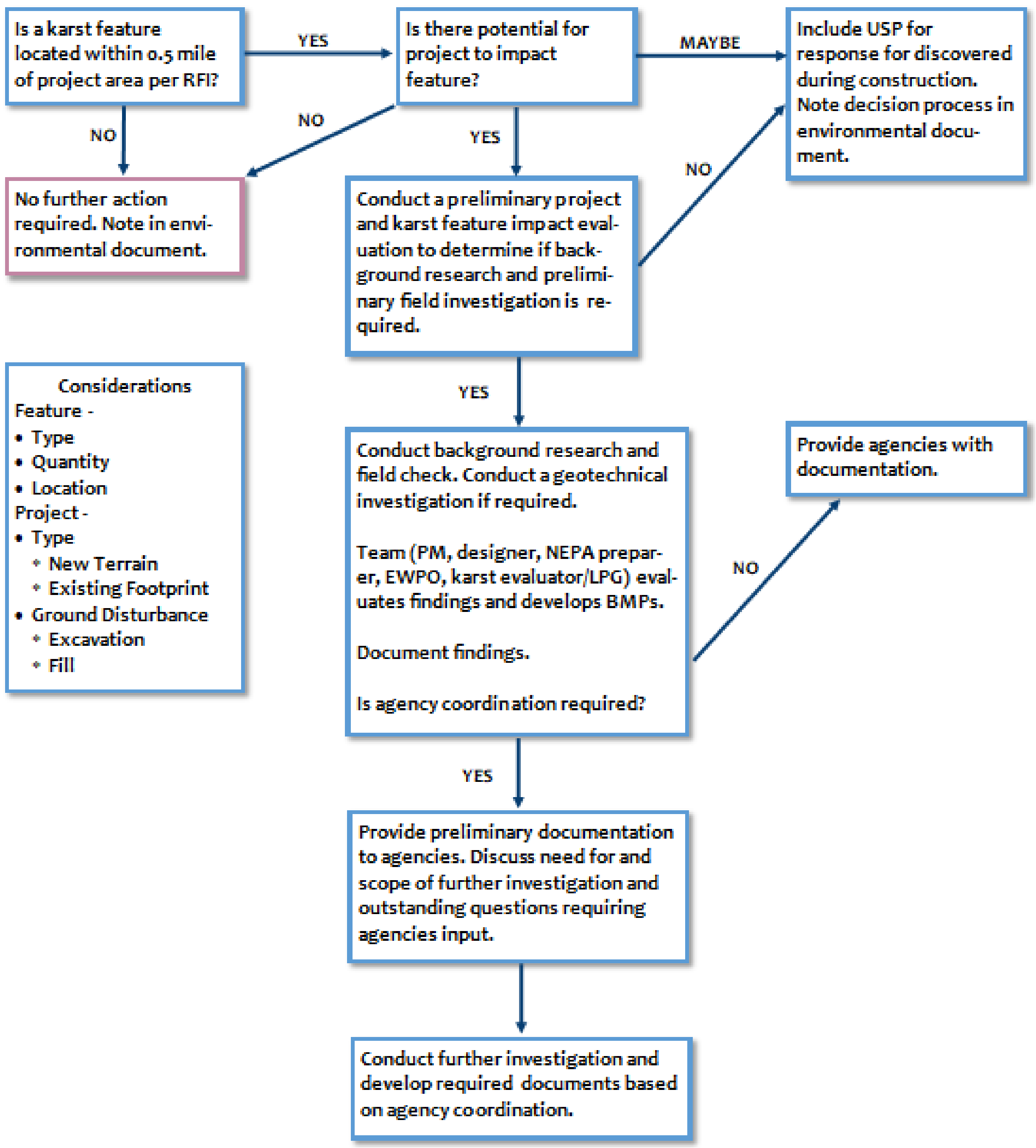


Figure 3. Karst Evaluation for Project Planning

3. Evaluate Potential Impact of Proposed Project

Evaluate whether there is potential for the project to 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 unique special provision (USP) for "Discovery of Karst Features" during construction in the contract documents. For example: a project included the replacement of a box culvert and installation of storm sewer lines through a 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 USP was sufficient.

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

USP

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DISCOVERY OF KARST FEATURES

If unknown karst features are
discovered during construction, all
work within 100 feet of the feature
shall stop and the Engineer shall be
notified immediately. Karst features
include, but are not limited to, voids,
caves, sinking streams, springs, seeps,
and sinkholes. The Department will
provide the treatment measures to be
incorporated for the feature. The karst
feature shall be protected from
sedimentation runoff. Work shall not
resume in the area until directed by
the Engineer.
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4. Conduct a Preliminary Impact Evaluation

Conduct a preliminary project and karst feature impact evaluation to determine if background research and preliminary field investigation is required. Consider the type, quantity, and location of the karst features during the evaluation. Also, consider the potential impacts based on the project type. For example: 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" USP in the contract documents. Verify the decision with the EWPO karst specialist and document decision process in the NEPA document and, if necessary, provide details in a memorandum and attach it as an appendix to the NEPA document.

Considerations

Feature(s) -
- **Type**
- **Quantity**
- **Location**

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

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) that is pre-qualified under 5.12 Karst Studies.

Preliminary investigation includes research of public and private sources for information related to the karst features in the project area. Background research should include review of available:

- Geological and topographic maps
- Aerial photography
- Geological literature

- Soil borings
- Well driller log data

The field check should include:

- 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 rains to identify and map natural drainage patterns

Discuss 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, karst consultant (an LPG) and INDOT Ecology and Waterway Permitting (EWPO) to include Permit Specialist, karst specialist and Manager. The karst team reviews BMPs 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 would include the use of borings or observation wells and would expand until there is sufficient understanding of the site. Geophysical data collection techniques that may be used to include seismic refraction, electric resistivity, gravity/micro-gravity, and down-hole methods. Dye tracing can be used to trace flow patterns from surface points to sampling wells or to trace subsurface flow patterns.

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 EWPO Permit Specialist or karst specialist 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 inject well concern. The written findings of the karst investigation should include:

- Background information (road number, 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, Indiana Map 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

Provide IGWS shape files of the identified features for review and addition to ArcGIS layers. Agency coordination should include findings, recommended course 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.

8. Water Quality Sampling Plan

A water quality sampling plan should only be developed 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 plan are:

- 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

INDOT compliance with IDEM's Construction Storm Water program during project construction will protect karst features from the discharge of sediment and other construction related pollutants. Compliance with INDOT's Rule 13 general storm water permit issued by IDEM will protect karst resources from changes in surface water quality.

B. Best Management Practices (BMPs)

A best management practice (BMP) is 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, 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. Without filtration, the runoff will pass quickly through the subsurface and increase the risk of groundwater contamination. BMPs can also include using 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. Figure 4 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.

Rock ring protecting a large karst feature on the U.S. 50 North Vernon Bypass
Photo credit INDOT

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 peat/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. As permanent features, they will require an asset number, maintenance plan, and periodic monitoring and maintenance.

Karst features are mitigated during construction to maintain water flow or to 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

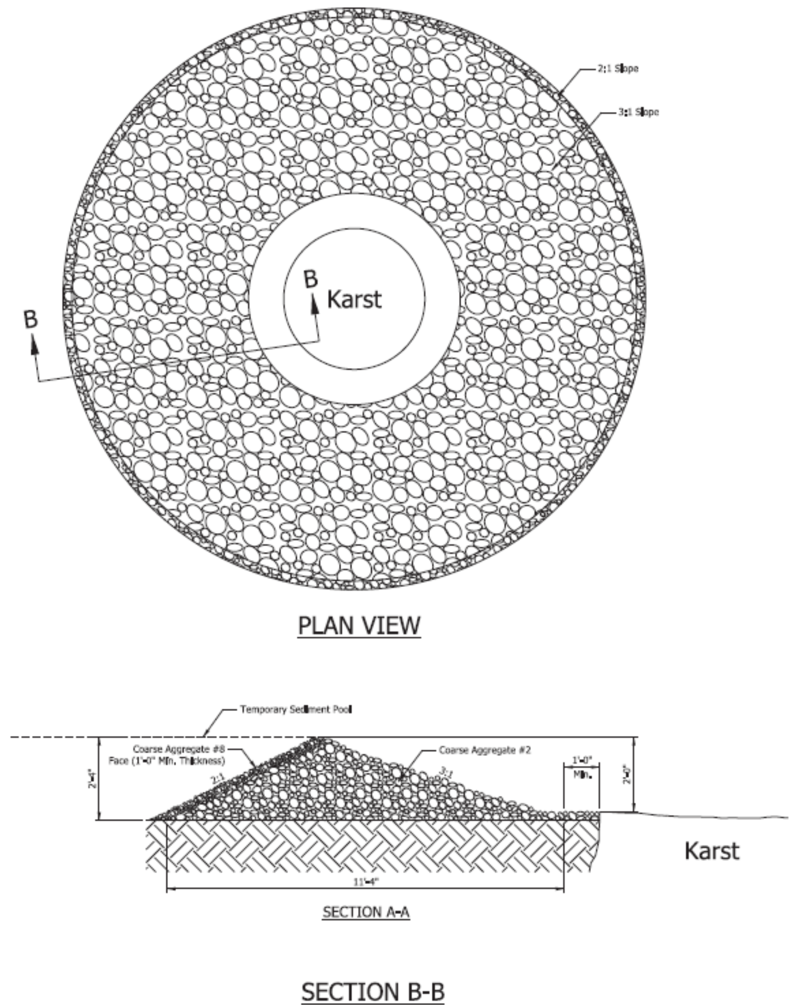


Figure 4. Rock ring, typical design for U.S. 50 North Vernon Bypass
Source INDOT

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. 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 qualified karst specialist.

- 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 5.
- 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 is removed from within the 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 will be located under the roadbed to provide a permanent seal. Figure 6 is a typical example of excavation and plugging.

- 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 filed. 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.

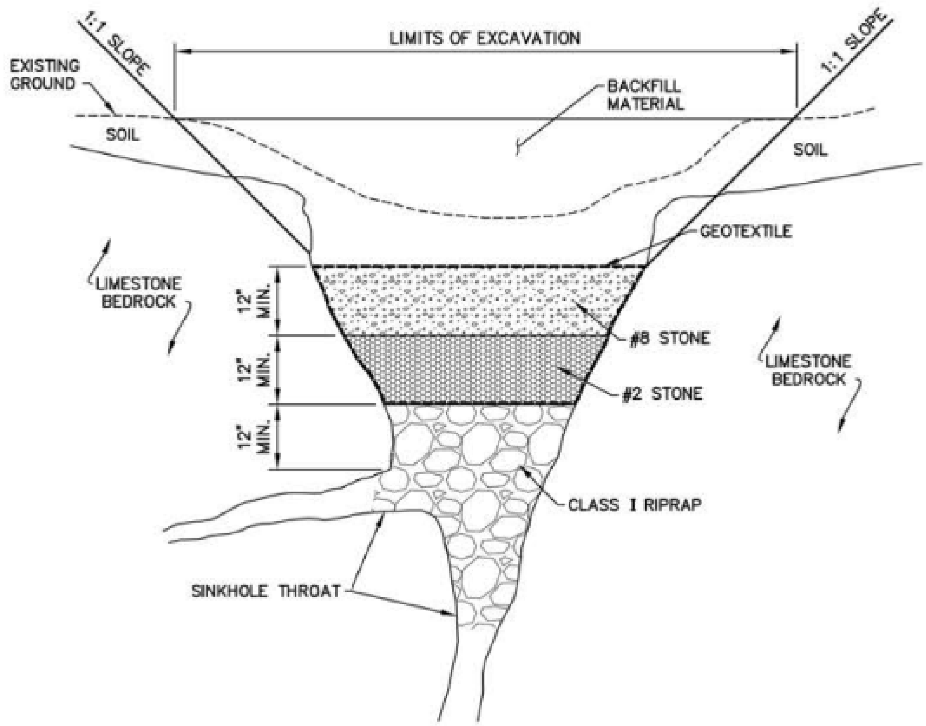


Figure 5. Typical aggregate cap sinkhole treatment
Source INDOT

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. Prior to placing concrete, all rock surfaces shall be free of soil and organic material.

- 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 can't pass.
- 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 storm water 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 7.

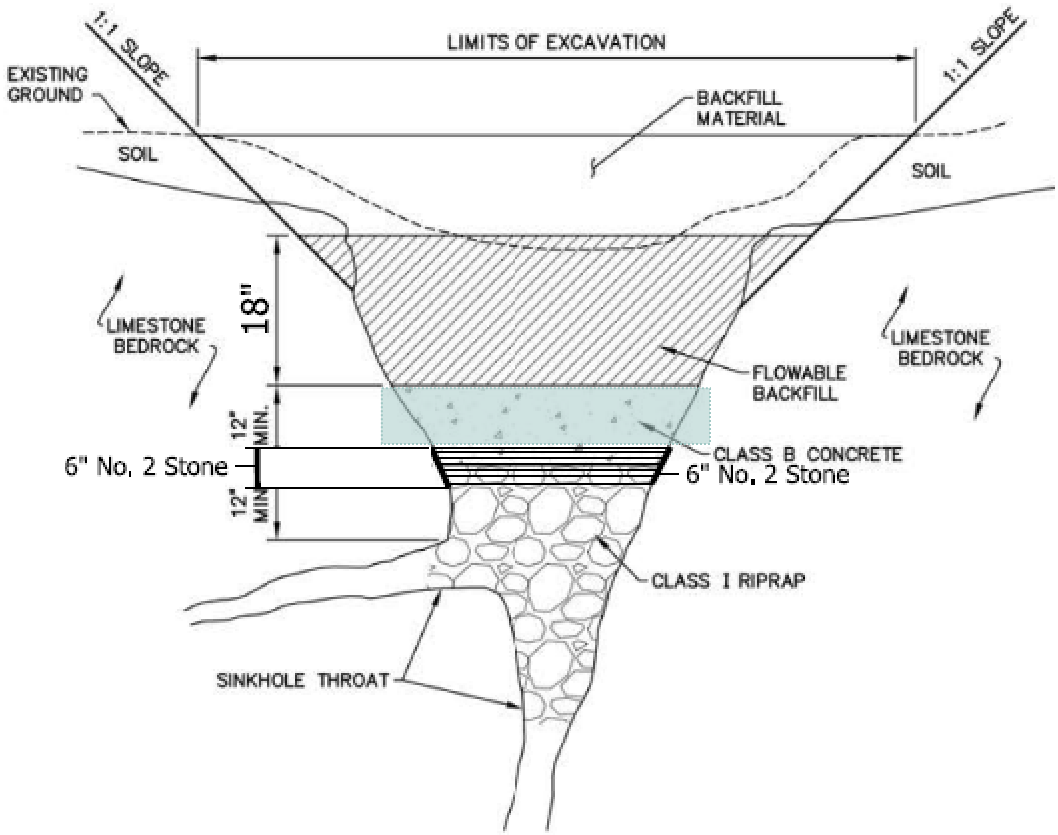


Figure 6. Typical sinkhole treatment concrete cap
Source INDOT

NOTE – The slope at the concrete cap should be keyed to allow the cap to rest on the bedrock as illustrated by the orange shaded area. This would limit future collapse of the cap into the feature.

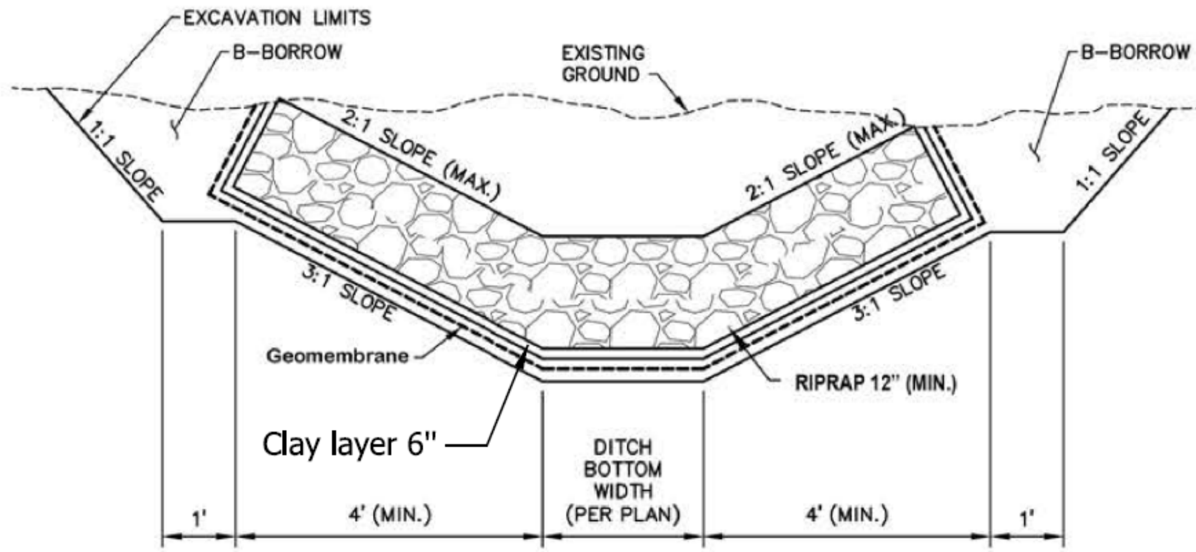


Figure 7. Typical lined drainage ditch with clay layer protection (not to scale)
Source INDOT

- 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 towards 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.

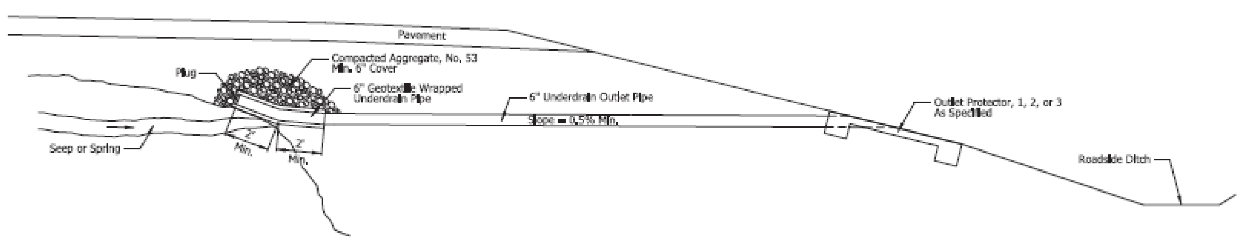


Figure 8. Karst seep or spring outlet
Source INDOT

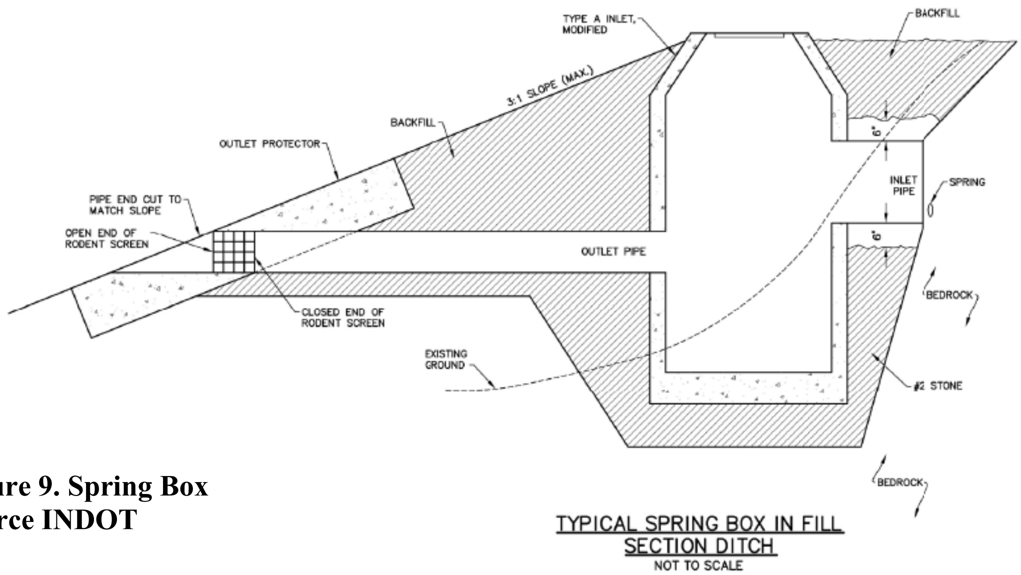


Figure 9. Spring Box
Source INDOT

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.

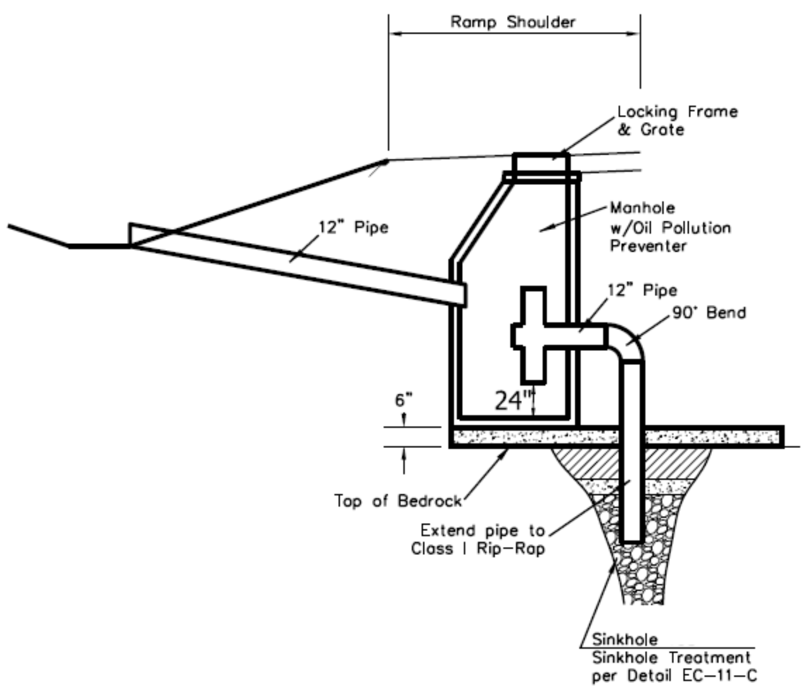


Figure 10. Offset Structure
Source INDOT

- 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.

D. Accidental Karst 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 the 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 it 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 karst specialists and/or a licensed geologist is required.

The sinkhole in this photo was found along U.S. 150 near French Link near a slide correction project. 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 it will need treatment in the future.

IV. Karst and INDOT Maintenance

Two maintenance activities that have the potential to impact karst features are road salting activities and vegetation management. IDEM's *2016 Indiana Integrated Water Monitoring and Assessment Report* listed contamination from salt storage and road salting activities as a high priority risk factor. The risk factors associated with contamination from salinity/brine includes human health and/or environmental risk (toxicity), location of the source relative to the drinking water source, the number and/or size of contaminant sources, hydrogeologic sensitivity, and documented findings of contamination. Mitigation features along INDOT roadways are designed to keep contamination from salinity/brine out of adjacent karst features. This includes designation of no/low salt zones.

Winter snow and ice control follows Operations Memorandum 08-01 Snow and Ice Control. 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. The use of chemicals in or near karst will have as a priority motorist safety. This precludes the use of a "no-salt" strategy. 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 is 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.

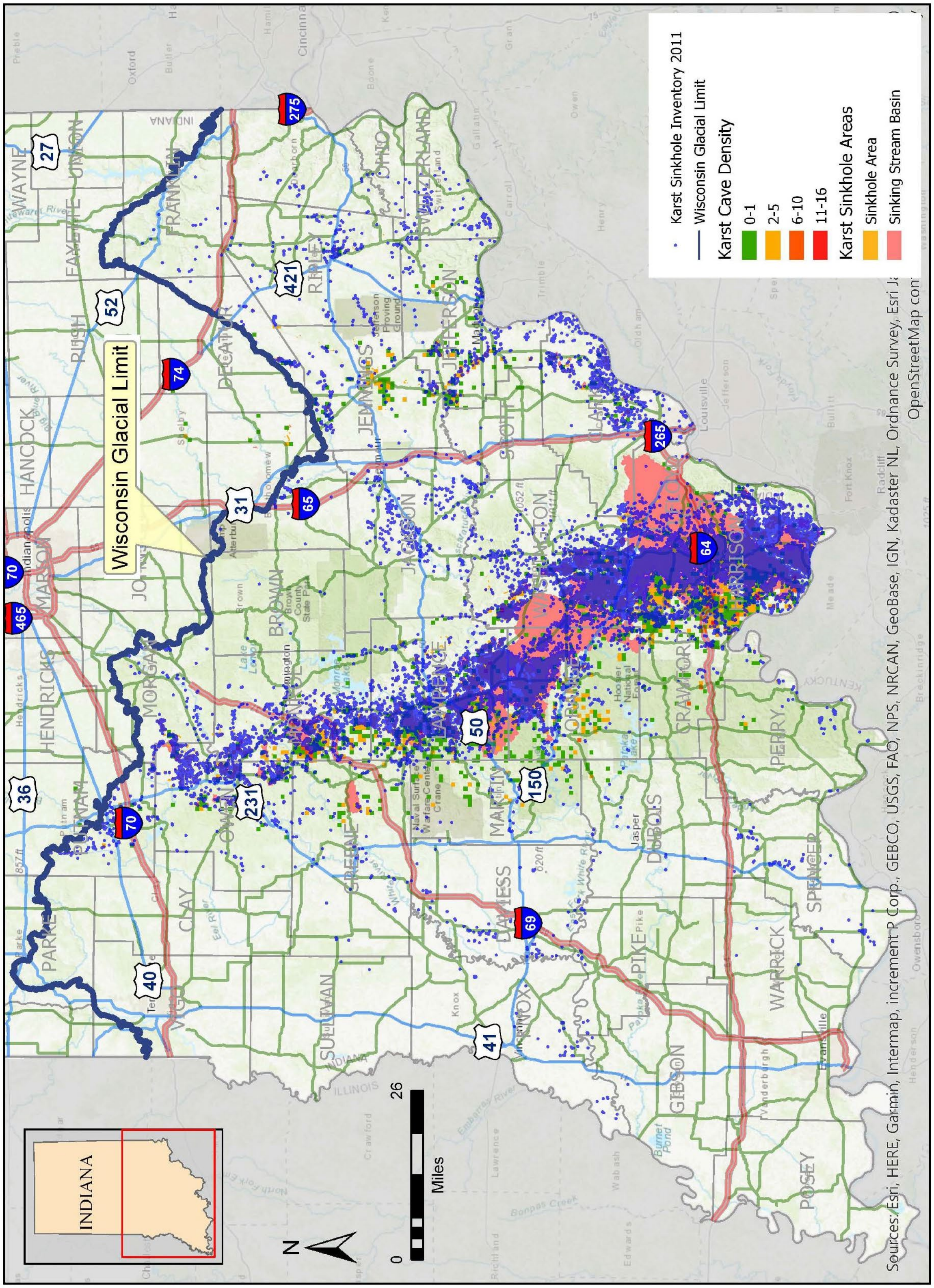
The use of signs to mark karst areas or features will be minimized to reduce negative impacts to vegetation management and maintenance activities. The signs will follow the designs included in Appendix C Karst Area Signage. The key points to consider during design are:

- 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"

Erosion is an impact to the stability of the roadway and is monitored as part of maintenance activities. Karst features will benefit from this monitoring and maintenance activity. The minimization of signs in karst areas will reduce erosion associated with mowing around the signs.

Appendix A Indiana Karst Region Map

INDIANA KARST REGION



Appendix B Glossary of Terms

Aquifer – A formation, group of formations, or part of a formation that contains enough saturated permeable material, or voids or fractures to yield significant quantities of water to wells and springs.

Bedding plane – A primary depositional lamination in sedimentary rocks separating two strata of differing characteristics.

Best management practice (BMP) – The methods or practices determined to be the most effective, practical means of accomplishing the desired state. BMPs can be practices implemented during or post-construction.

Contaminant (drinking water) – Includes any physical, chemical, biological, or radiological substance in water, including constituents that may not be harmful.

Dark zone – Begins where the cave becomes completely dark and extends throughout the rest of the cave.

Dissolution – The process of dissolving material in a fluid, while that fluid is in solution.

Drainage basin – The land area drained by a river and its tributaries, or a karst sink; also called watershed or drainage area.

Entrance zone – The area just inside the cave opening. This area receives sunlight that allows some plant growth and an exchange of animals that might also be seen living above ground.

Epikarst (subcutaneous) zone – A relatively thick (50 to 100 feet) portion of bedrock that extends from the base of the soil zone and is characterized by extreme fracturing and enhanced solution. It is the link between precipitation and transport of water to deep aquifers.

Graded filter – 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.

Groundwater basin – The area throughout which groundwater drains toward the same point. It can be larger than the associated surface-water drainage basin if permeable layers extend outside of the topographical divide.

Karst – A geologic setting, generally underlain by limestone or dolomite, formed chiefly by the dissolving of rock, and characterized by sinkholes, sinking streams, other closed depressions, subterranean drainage, and caves.

Karst valley – A compound sinkhole, sinking valley, or other large karst depression from 300 feet to 60 miles in size.

Karst window – An unroofed section of a subterranean stream; a sinkhole at the bottom of which can be seen a subterranean stream.

Natural bridge – An intact segment of an otherwise collapsed cave.

Pirated/captured (basin, watershed, flow) – The process by which one stream or cave enlarges its drainage basin area by expanding into a neighboring drainage basin.

Seep – An area, generally small, where water percolates slowly to the land surface through small openings of a porous material.

Sinkhole – A basin- or funnel-shaped hollow in limestone, ranging in a diameter from a few feet up to 300 feet and in depth from a few to several hundred feet.

Sinkhole plain – Topographic plain on which most of the local relief is due to sinkholes and nearly all drainage is underground.

Sinking/losing stream – A surface-flowing stream that disappears underground.

Spring – Any natural discharge of water from rock or soil onto the surface of the land or into a body of surface water.

Stygobites – Water-based cave fauna adapted to live their entire life in the cave, cannot survive above ground, and have adaptations to help them survive in the darkness of the caves. Examples include blind crayfish, blind cavefish, blind cave salamanders and cave shrimp.

Stygophiles – Water-based cave fauna they are preadapted to survive their entire life in a cave but can also live in suitable above ground habitat. Examples include springfish and some salamanders.

Stygoxenes – Water-based cave fauna that spend much of their time above ground. They use the caves for a specific part of their life cycle. This fauna includes surface dwelling stream animals such as fish, crayfish, and freshwater mussels.

Subterranean systems cave entrance – Includes the surface openings and reaching as far as the natural light can penetrate (entrance and twilight zones).

Subterranean systems caves – Includes the connected underground rooms and passages beyond natural light penetration (dark zone).

Swallow hole/swallet – A place where water disappears underground into a hole in a stream bed or sinkhole.

Topographic divide – The boundary between two surface watersheds.

Troglobites – Cave fauna that are adapted to live their entire life in a cave. They cannot survive above ground and have adaptations to help them survive in total darkness. Examples include cave millipedes, some beetles, and cave spiders.

Troglophiles – Cave fauna found in the space above the water table that are preadapted to survive their entire life in a cave but can also live in suitable above ground habitat. Examples include beetles, terrestrial crayfish, pigmented earthworms, millipedes, and centipedes.

Trogloxene – Cave fauna found in the space above the water table. They use the cave for a specific part of their life cycle, such as hibernation, nesting, or giving birth. Examples include bats, bears, crickets, foxes, pack rats, snakes, raccoons, moths, swallows, vultures, and groundhogs.

Twilight zone – The area farther from the entrance where the light begins to diminish.

Water table – The surface at the top of the groundwater, below which water completely fills the pore spaces of the rock.

Appendix C 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	1	.	5	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.

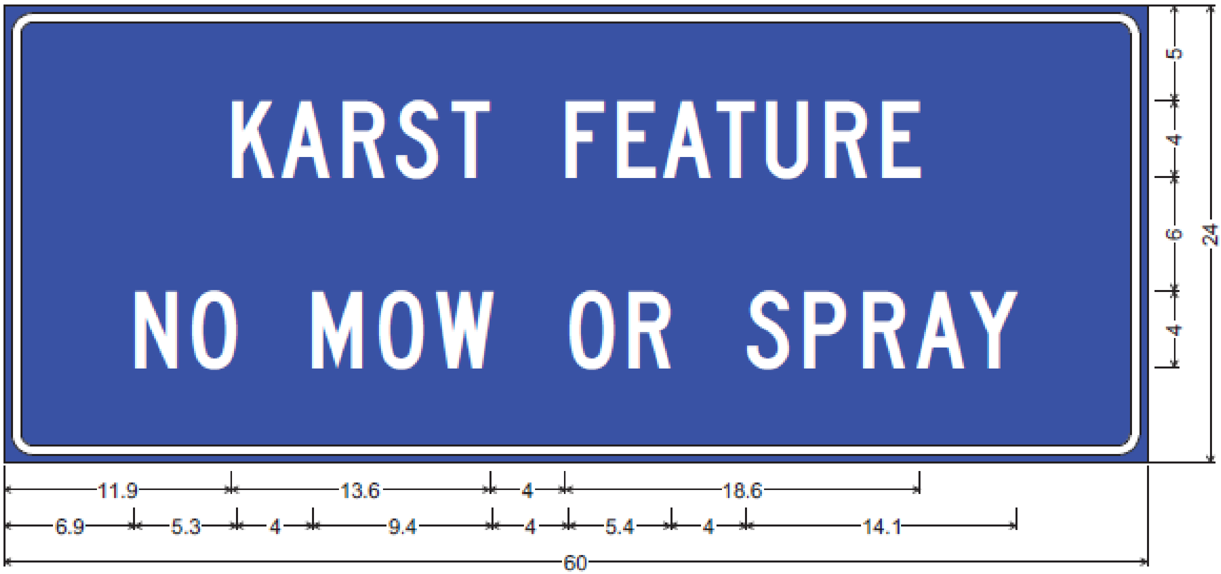
	R	E	P	O	R	T	A	L	L	
6.8	3.0	2.7	2.8	3.2	2.9	6.0	3.1	2.7	2.0	6.8

	S	P	I	L	L	S	T	O	
9.0	3.0	3.1	1.4	2.6	2.7	6.2	2.7	2.3	9.0

	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	3.0

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.

	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

	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 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 (CO_2) as it moves through the subsurface, forming carbonic acid ($CO_2 + H_2O \rightleftharpoons H_2CO_3$). 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 does not have a strong influence on location, design, or construction. In most areas it also 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.

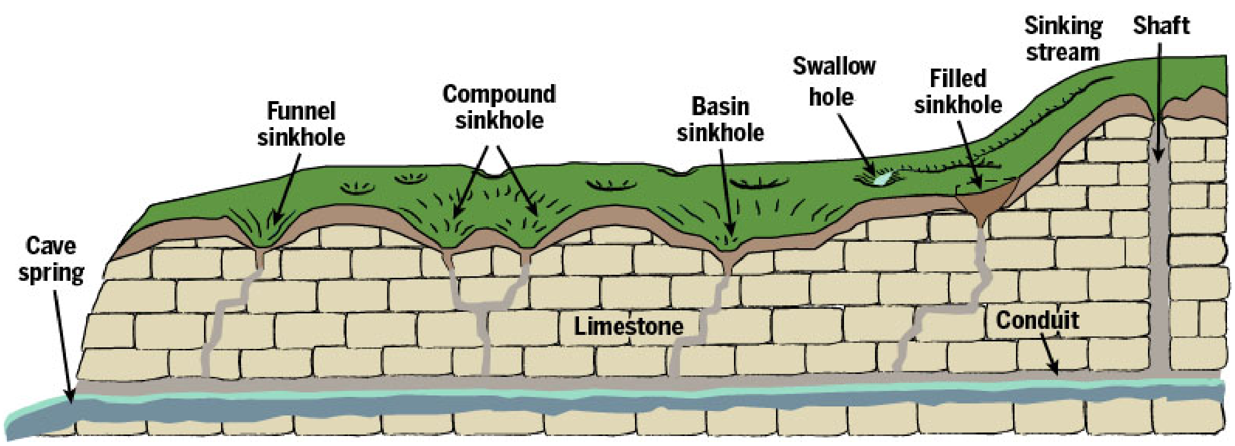


Figure 11. Solution features characteristic of karst terrains
Hasenmueller and Powell, 2005, as found on the Indiana Geological and Water Survey website

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 has a short length 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
Photo credit Lochmueller Group

Cave mouth
Photo credit Parsons

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

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

This small spring located in limestone has diminished and variable flow.
Photo credit 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 the upward raveling (or undoing) of soil over a cavity in the bedrock and the development of a soil arch. Chemical dissolution of the bedrock in conjunction with the mechanical weathering of the overlying soil results in a sinkhole. This is illustrated in Figure 12. The dissolution of the bedrock starts with the movement of surface water through the overburden into the bedrock (A), the development of a soil arch as the bedrock collapses and the overburden begins to fall into developing hole (B and C) and the final collapse of the overburden and the creation of the sinkhole (D).

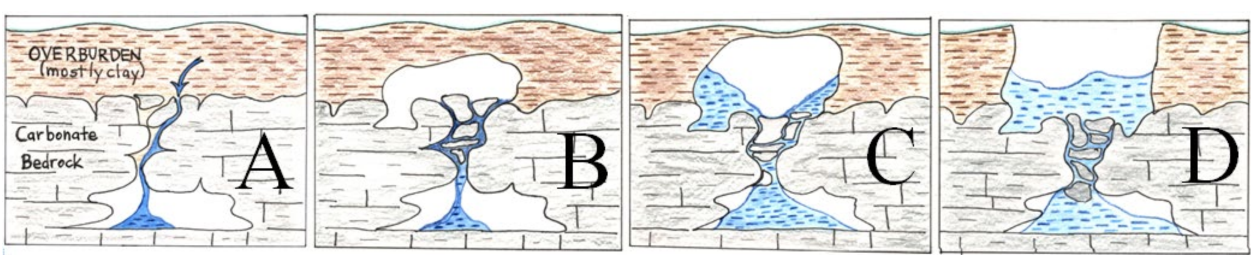


Figure 12. Bedrock dissolution process
Adapted from USGS

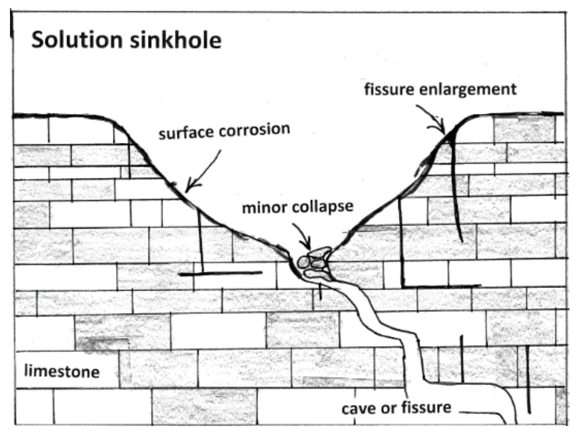
The second mechanism occurs as the result of water table variability. Soil strength is based on water content. The soil strength is low when there is insufficient water to interlock the soil particles. Soil strength increases as water content increases. There is a point where the weight of the water 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.

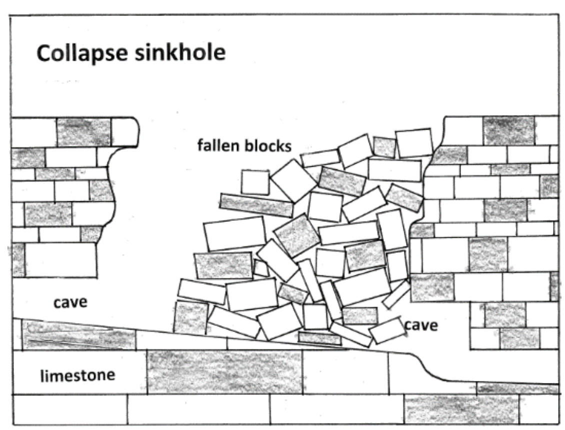
The hydrologic characteristics associated with the presence of karst include:

- Internal drainage of surface runoff through sinkholes.
- Underground diversion or partial subsurface piracy of surface streams (sinking and losing streams).
- Temporary storage of ground water 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, 2008)

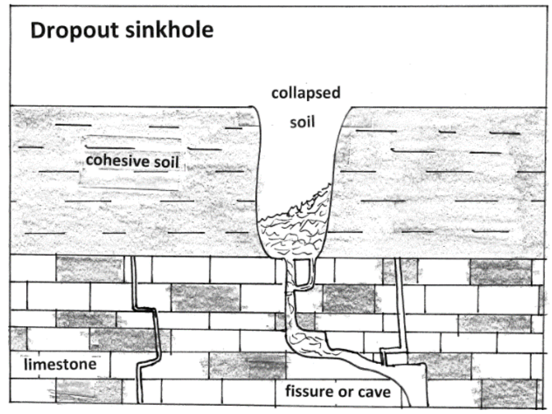
Five types of sinkholes were discussed in Section 1.B. – solution, collapse, caprock, dropout, and suffusion. Solution and collapse sinkholes are the most common types found in Indiana. A solution sinkhole is formed by the dissolutional lowering of the surface. Dissolution is the process of dissolving material in a fluid, while that fluid is in solution. A solution sinkhole occurs in limestone, dolomite, gypsum, and salt. They can be found in stable landforms and evolve over 20,000 years or more.



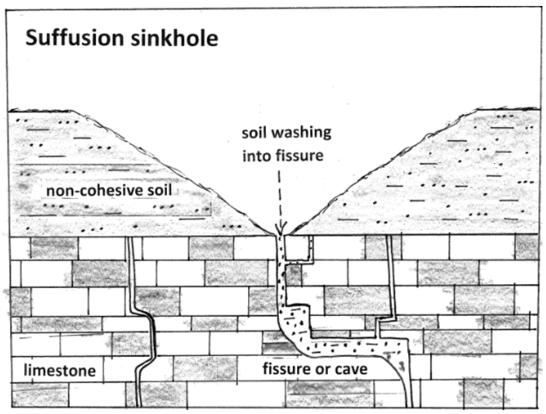
A collapse sinkhole is the failure of a rock roof into an underlying cave. It occurs in limestone, dolomite, gypsum, and basalt. It is an extremely rare, rapid failure event into an old cave.



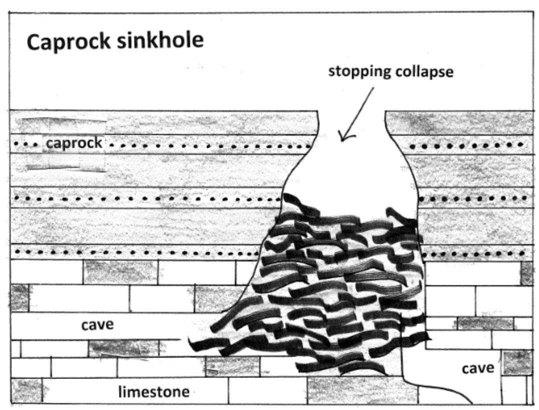
Subsidence, suffusion, and dropout sinkholes are similar in that the underlying bedrock cavities are stable while the material above is unstable. A dropout sinkhole is formed by soil collapse into a soil void formed over a bedrock fissure. It occurs where there is cohesive soil, such as clay, over limestone, dolomite, and gypsum. Formation occurs in minutes, into a soil void that evolved over months or years.



A suffusion sinkhole is formed by the down-washing of soil into fissures in bedrock. It occurs where there are non-cohesive soils, such as sandy loams, over limestone, dolomite, and gypsum. Formation occurs over a period of months or years. Dropout and suffusion sinkholes have similar formation mechanisms but have different overlying soil types.



A caprock sinkhole is formed by the failure of insoluble rock into a cave in solution rock below. It occurs in any rock overlying limestone, dolomite, or gypsum. It is a rare failure event and evolves over 10,000 years. These types of sinkholes may occur in southeast Indiana in the shale/siltstones found in the Knobstone Escarpment. It is the least common of the five sinkhole types found in Indiana. All sinkhole type drawings adapted from Waltham, 2010.



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 13). 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. 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 types of 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 water containing depressions. A sinkhole swamp is a depression that is dominated by tree or shrub species. Both can be found in the Mitchell Karst Plain.

Figure 14 illustrates a physiographic cross section of southern Indiana.

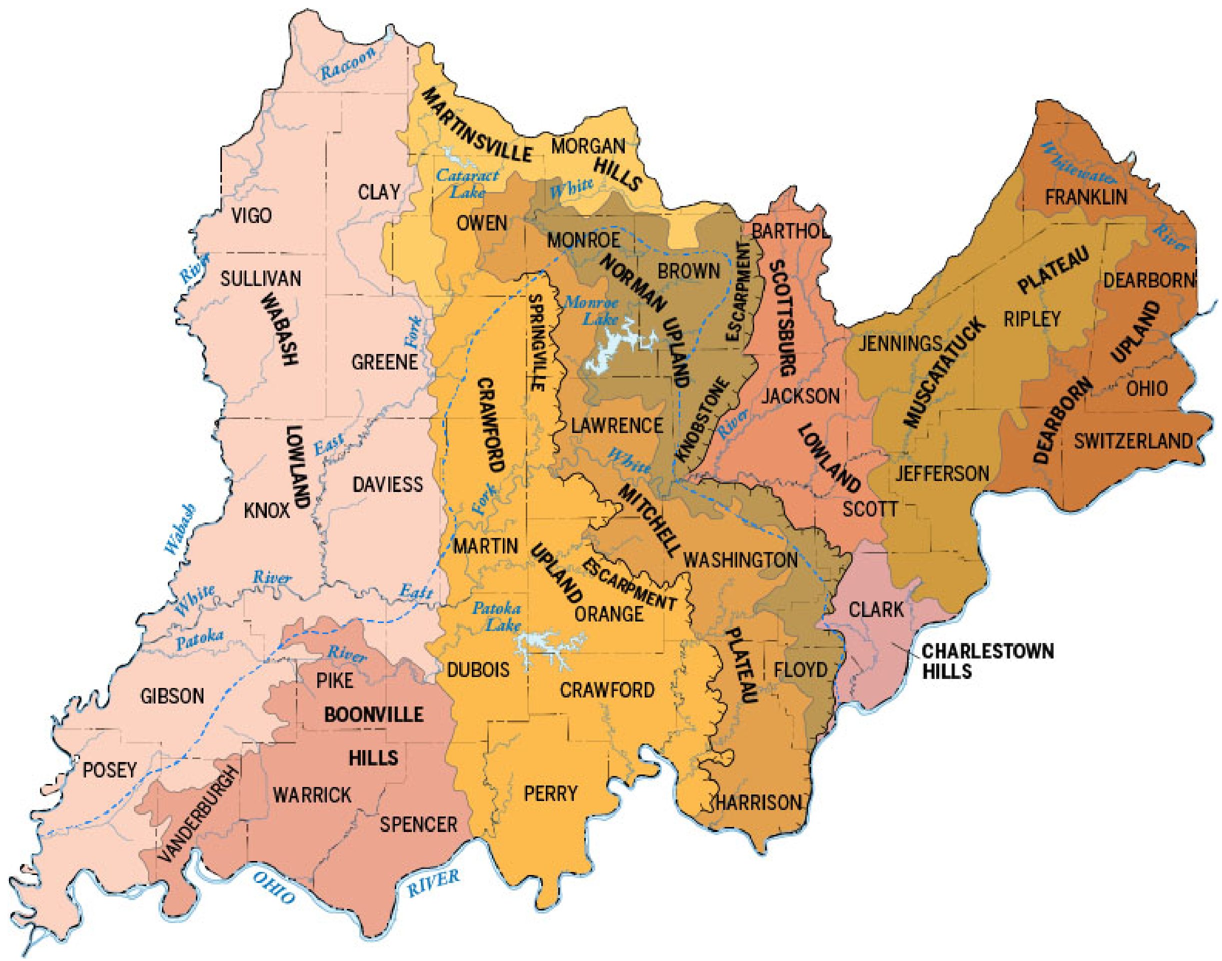


Figure 13. Physiographic divisions of southern Indiana
Source Indiana Geological Survey

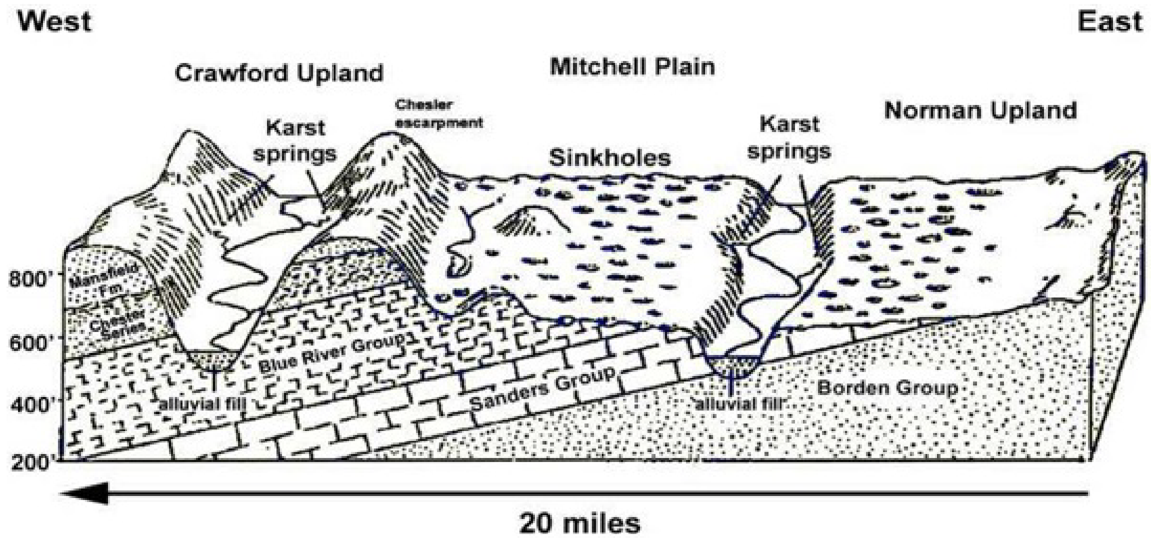


Figure 14. Generalized physiographic cross section of southern Indiana From Palmer, 1969, as found on the Indiana Geological Survey website

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 harvestman. Aquatic animals include cave fish, amphipods, crayfish, and salamanders.

Cave habitats can be divided by light zone. The entrance zone is the area just inside the cave opening. This area receives sunlight that allows 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 where 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 includes the surface openings and reaching as far as the natural light can penetrate (entrance and twilight zones). The Subterranean Systems Caves includes 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 live 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 cycles through the cave inhabitants as illustrated in the following cave food pyramid.

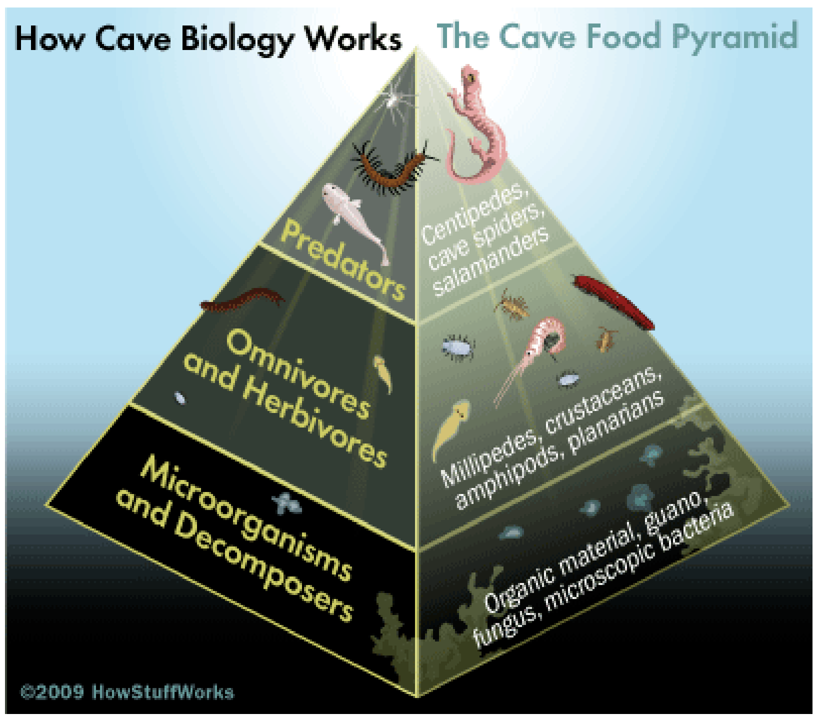


Figure 15. Cave food pyramid Source HowStuffWorks

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*).

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

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 (troglofauna) or aquatic (stygofauna) based. Some animals find temporary shelter, a resting place, or hunting ground in a cave. These trogloxenes 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 trogloxenes include bats, bears, foxes, raccoons, snakes, crickets, moths, and swallows. Stygoxenes are surface-dwelling stream animals, such as fish, crayfish, and freshwater mussels.

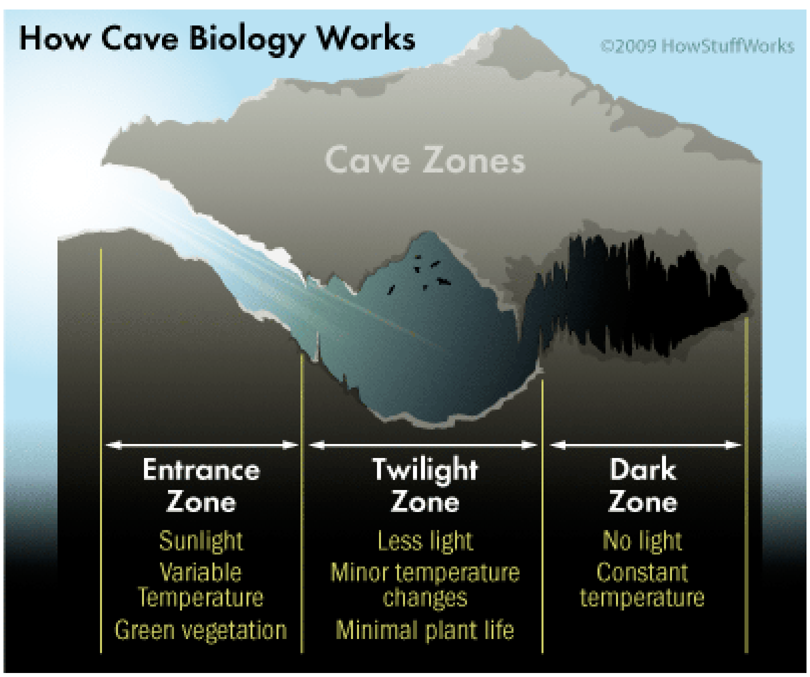


Figure 16. Cave zones
Source HowStuffWorks

Animals that can complete their life cycle either above or below ground are called troglophiles 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 troglophiles include beetles, terrestrial crayfish, pigmented earthworms, millipedes, and centipedes. Examples of stygophiles are springfish and some salamanders.

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

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

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.

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

Appendix F Best Management Practices in Karst Terrain

Adapted from I-69 Evansville to Indianapolis Tier 2 Studies, Chapter 5.21 – Karst Impacts

Best Management Practice (BMP)	Description	INDOT Standard Specification Reference Number (if available)
Ditch Lining		
Compacted clay liner	Lined ditches can be used to prevent erosion. Hydraulic analysis will determine water flow and velocity needed to size lining. This will reduce erosion and limit sediment transport into a feature.	205 describes storm water management measures.
Geosynthetic clay liner	Use to protect groundwater penetration along a roadside ditch.	205 describes storm water management measures.
Flexible membrane liner	Conforms to undulating topography.	205 describes storm water management measures.
Concrete, Portland cement, or asphalt	Possible use, but not aesthetically pleasing.	607 describes paved side ditch construction for concrete and asphalt work.
Sinkhole - Bridging		
Culvert or bridges	Use the INDOT Drainage Design Manual to size openings of bridges or culverts. Evaluate the unique backwater conditions created by 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 bedrock. Cuts into bedrock should be minimized.	714, 715, 723 describe concrete boxes, culverts, 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.	215 describes chemical modification of soil.
Geopier with cap	Can be installed quicker than traditional piers or piles; will provide strength to wide range of soils.	Not addressed specifically, 701 gives requirements for driven piling.
Piles with cap	Traditional method for vertical reinforcement of soils.	701 gives requirements for driven piling.

Best Management Practice (BMP)	Description	INDOT Standard Specification Reference Number (if available)
Sinkhole - Filling		
Rock pads	Effective where the velocity of the storm water needs to be decreased to prevent erosion.	205 describes storm water management measures.
Large rock fill	Effective for slope stability issues.	203 describes excavation and embankment, 207 subgrade and 211 structure backfill.
Compaction grouting	Useful 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.	206 describes process for grout injection.
Dynamic compaction	Will increase the density of the soil, to include soil below the groundwater. Best for granular soils.	203 describes excavation and embankment and 215 describes chemical modification of soil.
Excavation, overlapping geotextiles, soil backfill	If a sinkhole is located within new right-of-way (ROW), but has a small drainage area, capping is more appropriate than installing a catch basin and standpipe.	203 describes excavation and embankment and 215 describes chemical modification of soil.
Excavation, concrete cap, soil backfill	If a sinkhole is located within new right-of-way (ROW), but has a small drainage area, capping is more appropriate than installing a catch basin and standpipe.	203 describes excavation and embankment and 215 describes chemical modification of soil.
Permanent Treatments		
Earth berm	Provides natural look to erosion control	205 describes storm water management measures
Gabion berm	May be appropriate at very steep slopes (>10%)	See recurring special provision 625-R-194.
Open standpipe	A chimney (standpipe), catch basin, and rock filter are common BMPs for sinkholes	No standard available

Best Management Practice (BMP)	Description	INDOT Standard Specification Reference Number (if 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 (HMT).	720 describes catch basins and installation
Natural vegetative buffers	Used to detain/treat runoff prior to discharge	621 describes installation of vegetative cover, as well as installation timeline and method
Peat/sand/gravel filter	Used to detain/treat runoff prior to discharge	205 describes storm water management measures
Spring boxes	Used to protect discharge from springs.	205 describes storm water management measures
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, design follows the INDOT Drainage Design Manual	616 describes riprap placement and type for energy dissipation and scour protection
Geogrid or geotextile layers	Use in lower reaches of embankments, embankment foundations, or roadway subgrades	214 describes geosynthetics
Other		
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, 107 describes requirement for contractor to follow laws and permits, and responsibility to the public
Avoidance	Occurs after the project area has been screened for karst features that may be affected. Design will provide further details on road cross section and alignment at each feature. Consider avoidance if cost effective and within design criteria.	

Best Management Practice (BMP)	Description	INDOT Standard Specification Reference Number (if available)
Alternative drainage	Use of 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	Requires reoccurring special provision, 107 describes requirement for contractor to follow laws and permits, and responsibility to the public
Operation/Maintenance		
Discovery of a new or previously unknown feature	Monitoring of areas that receive roadway runoff to identify soil piping or new karst features.	Follow maintenance procedure.
No-mowing, low salt, or no spray zone	Provides increased vegetative ground cover and runoff filtering prior entering feature.	Follow procedure in Appendix C.
Scheduled inspection and maintenance of measures	Verify capacity, integrity, and operational efficiency of measure.	Follow maintenance procedure.

Appendix G References

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Indiana Department of Transportation, Division of Maintenance, Work Performance Standards https://www.in.gov/indot/files/INDOT-Work-Performance-Standards.pdf
2230 Herbicide Spot Treatment
2231 Herbicide Broadcast Treatment
2630 Snow and Ice Removal

Indiana Geological and Water Survey website https://igws.indiana.edu/Bedrock/Karst
The mission of the Indiana Geological and Water Survey is to provide geological information and counsel that contribute to the wise stewardship of the energy, mineral, and water resources of the state. Since 1837, the health, safety, and welfare of Indiana's citizenry have benefited through a combination of Indiana Geological and Water Survey activities.

Indiana Karst Conservancy website https://ikc.caves.org/

The Indiana Karst Conservancy (IKC) is a 501(c)(3) non-profit organization dedicated to the preservation and conservation of Indiana's unique karst features. The IKC was formed by concerned individuals when it became apparent that no similar group was actively protecting such features for their inherent geological, biological, and historical importance.

The purposes of the IKC are the management, protection, and acquisition of the karst areas in southern Indiana. The IKC also supports research and promotes education related to karst and its appropriate use. Many of today's abuses in karst areas arise from lack of understanding and knowledge.

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