TECHNICAL GUIDANCE DOCUMENT

INDIANA DEPARTMENT OF ENVIRONMENTAL MANAGEMENT

Proper Investigative Techniques for Fractured and Shallow, Non-Karst Bedrock

Office of Land Quality

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INTRODUCTION

Several standard assumptions are commonly used to predict contaminant behavior in porous media:

1) Subsurface materials are relatively flat and continuous across the study area;
2) Groundwater flows in predictable directions;
3) Perched groundwater is not directly connected to the water table;
4) Groundwater flows toward the nearest stream;
5) Contamination travels down-gradient with the ground water; and.
6) Unconsolidated sediments allow contamination to attenuate.

These assumptions are not applicable when contamination is in shallow and/or fractured bedrock. Direct transport of contaminated materials (i.e. no retardation or attenuation) should be included in the conceptual site model (CSM). This document addresses the data collection and investigations necessary to evaluate contaminant fate and transport in shallow and/or fractured bedrock.

Deep Bedrock

Deep bedrock contamination is usually limited to a specific contaminant set; e.g. chlorinated solvents and manufactured gas plant (MGP) residuals. Deep bedrock presents special considerations and challenges. Please consult with Geological Services for a site specific analysis of these situations.

Karst Bedrock

Contamination in karst does not follow many fate and transport assumptions presented in this document. Please consult with Geological Services for a site specific analysis of these situations. Additional guidance is found at:

http://www.in.gov/idem/files/remediation_tech_guidance_karst.doc

WATER TRANSPORT IN BEDROCK

Water flow through fractures and along surfaces in consolidated material is fundamentally different than transport though an unconsolidated porous media. Water transport (as well as contaminant transport) through bedrock will usually be along discreet natural pathways. The following features are primary pathways of ground water flow in shallow or fractured bedrock. These features should be described during the investigation and considered in the CSM:

Bedding Planes

Bedding planes are in unconsolidated materials and bedrock. Bedding is defined as a noticeable change in the horizontal appearance and characteristics of the material such as an abrupt change in grain size. These features have different characteristics in the bedrock than unconsolidated material. In unconsolidated materials bedding planes can deflect, retard, or increase the transport of contaminants. In bedrock, bedding planes are also identified by a change in the characteristics of the material; however, there may also be void spaces between the “blocks” of bedrock. Bedding planes are in all bedrock types found in Indiana.

Fractures

Most bedrock fracturing in Indiana is in response to the formation of the Illinois Basin (to the west), the Cincinnati Arch (to the east), the Michigan Basin (to the north), and the Kankakee Arch (to the northwest). There are several localized structural features that may influence fracturing, but the features listed above are the major features, therefore local scale published studies should be reviewed.

The evaluation of the patterns made by fractures is called a fracture trace analysis. When fractures are examined they will form predictable patterns that can be mapped. Once these patterns are mapped proper monitoring well locations can be determined.

Topography of bedrock surface

Mapping the bedrock topography is important because water and/or contaminants may follow that surface.

The following are secondary, not as important, to the development of a CSM.

Grain Size Changes

A change in grain size can be due to bedding planes; however, grain size can change within a stratigraphic unit. This can have several effects on ground water flow or contaminant transport (i.e. deflect, retard, or increase the contaminant movement). There are two major types of changes in grain sizes in most sediments:

- A fining downward sequence, and
- A coarsening downward sequence.

An understanding of the geometry and distribution of differing grain sizes is needed to design a remedial measure for contamination in bedrock.

Cross-Bedding

Cross-beds can form in sediments deposited by wind or water (can be both sandstone or limestone). Cross-beds can create a preferential flow direction because of the way the grains are sorted and oriented during deposition. This allows discrete zones of enhanced porosity to develop and, if interconnected, increased permeability. Cross beds can occur in both unconsolidated granular materials (fine sands through gravels) and bedrock (limestone and sandstone).

Bedrock Geometry

Bedrock in Indiana is not always flat or of uniform thickness. Bedrock in Indiana was deposited in one of three ways:

a) Particle settlement (shales, siltstones, and sands),
b) Chemical precipitation (limestones and dolomites), and
c) Biological activity (limestones and dolomites).

How to Investigate Bedrock

Bedrock is very close to the surface in some areas of Indiana. Most investigators will stop drilling when bedrock is encountered. They will note refusal, take samples, and set a well. Thus, they may overlook an important preferential pathway for contaminant migration.

The zone where unconsolidated materials and bedrock meet is usually a zone of enhanced porosity. Ground water will flow within the weathered bedrock surface until deeper un-weathered material is encountered or the water table intersects the land surface (seeps).

Once shallow bedrock is identified, the contact between the soil and bedrock is investigated using a three step process to determine if the interface could be a preferential pathway:

Step 1: Bedrock surface mapping.

Bedrock surface mapping is a simple way to determine how water drains through subsurface materials. Geophysics can provide data to both locate potential "problem areas" where boring programs should be focused, and allow accurate extrapolation of data between borings. Examples of land-based geophysical methods include:

- **Electromagnetics (EM) and Electric Imaging (EI)** are used to detect variations in subsurface electrical properties related to anomalously thick or wet soils (which will produce an electrical conductivity high response), or voids in the electrically conductive clay soil (which will produce an electrical conductivity low response).

- **Spontaneous Potential (SP)** is used to detect naturally occurring minute electrical currents/potentials commonly associated with concentrated infiltration or subsurface movement of water.

- **Microgravity** is used to map minute variations in gravity that may be due to soil voids or bedrock fractures where "missing" subsurface mass results in measurably lower gravity.

- **Seismic Refraction, Reflection, and Surface Wave Analysis** can provide top-of-rock profiles which may represent fractures, bedding planes, or other lineaments. Seismic rock depths are also used to calibrate microgravity results where no boring data are available. The latter two methods (microgravity and seismic profiling) are also often used to discern the difference between EM or EI conductive anomalies (which could represent wet, saturated soils), or between EM or EI resistive anomalies (which could be caused by either dry, competent rock or air filled voids).

- **Ground Penetrating Radar (GPR)** uses high frequency electromagnetic energy to acquire subsurface information. Energy is radiated downward into the ground from a transmitter and reflected back to a receiving antenna. Reflections of the radar wave occur where there is a change in the dielectric constant between two materials. The reflected signals are recorded and produce a continuous cross-sectional image of shallow subsurface conditions.

These techniques work best when there is little near-surface interference (sometimes called cultural or anthropogenic interference). Types of near-surface interference can include, but are not limited to:

- Utility corridors,
- Fill materials,
- Reinforced concrete, and
- Above ground metallic objects (i.e. fences, rail roads, power lines).

If there is significant near surface interference, geophysical investigation results can be misleading and soil boring data will produce better results.

Once the area where the borings will be placed is known, a series of probe points are advanced (on a grid pattern) until refusal. The depths of refusal and the contaminant levels are mapped and, if possible, the "low spot" on the bedrock surface is located. If high levels of soil contamination are identified in the "low spot", there is a high probability that contamination is flowing along the bedrock surface. However, prior to investigating the bedrock aquifer, confirm if water draining from the site is contaminated (i.e. sample the water flowing along the soil bedrock interface).

Step 2 Soil Sampling:

Soil sampling in areas with shallow bedrock should be conducted both above and below the water table. Since soils along the bedrock surface can become entrained in water flowing along this surface, contaminated soil particle migration is a concern. Soil samples should be collected from a subset of the borings used for determining bedrock depth.

Step 3: Ground Water Sampling:

Once the bedrock mapping is complete, and "low spots" are identified; several monitoring wells are installed so that the screens intersect the interface between the unconsolidated materials and the bedrock surface. At least one monitoring well should be installed in each "low spot" identified on the bedrock surface map. These wells are installed to monitor water flowing along the bedrock surface. One of the most difficult aspects of sampling this type of ground water is knowing when to sample. Water flowing through a fractured bedrock system is dependent on rainfall. Samples need to be collected during non-storm flow conditions (termed base flow conditions) and during storm flow conditions. A storm event is considered any precipitation event over ¾ of an inch of rain in a 24 hour period.

Monitoring Well Placement

Monitoring wells first need to be installed across the soil/bedrock interface. The first step to investigate fractured bedrock is determining if contamination is migrating along the soil bedrock interface. If contamination is present, additional investigation of the fracture system will be needed. By utilizing the results from the earlier steps in the investigation, wells can provide information about contaminant transport through the fractured bedrock system.

Regional Fracture Pattern Map

Further analysis of the bedrock geometry is warranted if contamination in bedrock fractures extends beyond the site boundaries, or a receptor is nearby. A fracture trace analysis can be a simple way to characterize ground water flow in bedrock beneath a site. In many cases the analysis can be conducted using topographic and geologic maps or other published materials. When possible, fracture patterns should be field verified.

Remediation Methods

Ground water remediation in fractured bedrock areas is difficult. The best way to remediate ground water is to address contamination before it enters fractured bedrock. If contamination is in fractured bedrock, the most effective way to control risk is to treat it at the point of use or where ground water discharges to the surface.

Soil remediation is a good method for controlling exposures where bedrock is shallow and a permanent water table is lacking. Remediation can either be ex-situ or in-situ:

Ex-situ Methods:

- Excavation,
- Soil washing,
- Soil pulverizing (dependant on type of contamination),
- Chemical treatment,
- Landfarms (ex-situ form of bioremediation),
- Soil piles (ex-situ form of bioremediation), and
- Additional methods can be proposed and are evaluated on a case by case basis.

Bedrock typically needs to be less than 15 feet deep for these methods to be cost effective. Any deeper would need shoring and benching.

In-situ methods:

- Chemical treatment,
- Soil Vapor Extraction (SVE),
- Bioremediation,
- Thermal desorption,
- Soil stabilization (usually for metals), and
- Additional methods can be proposed and are evaluated on a case by case basis.

Information on the nature of bedrock is needed for these methods to be effective. This information usually will include:

- An investigation of the bedrock surface.
- An analysis of the degree of bedrock fracturing.
- Detailed groundwater flow information.

It is important to know the direction of ground water flow in the bedrock so that a suitable monitoring network can be installed prior to the in-situ treatment.

Contamination can be treated in the same way as ground water flowing along the top of an aquitard if bedrock is shallow and not fractured. However, it can be challenging to determine all of the points where ground water exits the site.

Special Cases

Pinnacle Reefs of Northeastern Indiana

These structures can add an element of uncertainty to investigations conducted in this region. These bedrock structures can be very porous and should generally be investigated like karst (see the Karst Investigation Technical Document for more information).

Devonian Shales of Indiana

These are investigated in the same manner as other shallow bedrock except for contaminant sampling. The Devonian Shales (very common in southern Indiana) are organic rich shales. Geologists refer to these as oil shales that can provide anomalous SVOC and metals sampling values. Investigators need to know if the site under investigation is in an area where Devonian shales are present. The unconsolidated materials directly above these shales may also have a high organic content.

Summary and Conclusions

Staff assembled the information contained in this document from sites in Indiana and staff experiences. This document provides a basic outline for investigating shallow or fractured bedrock. More in-depth evaluations should be discussed on a site specific basis. Understanding the nature of not only the materials associated with shallow or fractured bedrock, but also how ground water interacts with those materials is needed to develop an accurate CSM. When shallow or fractured bedrock is present a successful remedial approach may involve a combination of remediation methods. Elements of a remedial measure can include, but are not limited to, excavation, in-situ chemical oxidation, vapor extraction, bioremediation, pump & treat, or source removal (free phase contamination).

Further Information

If you have any additional information regarding these investigative techniques or any questions about the evaluation, please contact the Office of Land Quality Science Services Branch at (317) 232-3215. This technical guidance document will be updated periodically or if new information is acquired.

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