INDIANA DEPARTMENT OF ENVIRONMENTAL MANAGEMENT

Aquitard and Fine Grained Sediment Characterization

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PURPOSE

The purpose of this document is to provide guidance for evaluation of aquitards and fine grained sediments for revising the CSM and assess the use of appropriate attenuation factors of the vapor intrusion exposure pathway.

INTRODUCTION

An **aquitard**, for the purpose of this technical guidance document, is a geological unit of low conductivity that can store groundwater and contamination and transmit them slowly from one aquifer or media (fine grained sediments can act as a secondary source) to another.

A **fine grained sediment**, for the purpose of this technical guidance document, is a geological unit of low conductivity that can inhibit the upward migration of vapors into occupied structures.

Further investigation of site aquitards (groundwater contaminant transfer) or fine grained sediments (vapor migration) is needed to revise the CSM only if:

- The aquitard is a key component influencing the plume behavior (in this case the aquitard restricts vertical plume movement or can be a secondary source for plume migration),
- The aquitard limits contamination reaching groundwater or VI receptors (exposure pathway),
- The aquitard is part of the long-term fate and transport of the plume, or
- The fine grained material is used as evidence for a site-specific attenuation factor for vapor intrusion.

Conceptual Framework for Revising the CSM

When low permeability layers are present locally or regionally, they can greatly affect the groundwater flow path and contaminant migration. Aquitards are often mischaracterized as homogeneous and massive, and interpretations about how these units affect groundwater flow are often incorrect. Some key concepts to keep in mind when developing a conceptual site model (CSM) that involves an aquitard or fine grained sediments include:

- Groundwater is not static and will flow through aquitards,

- Aquitards can have sufficient areal extent, thickness, and geometry to impede or deflect groundwater flow from or into aquifers,
- Fine grained sediments can have sufficient areal extent, thickness, and geometry to impede or deflect vapor migration to the surface,
- Aquitards can determine flow paths and serve as storage units for both water and contaminants,
- Groundwater often spends more time in aquitards than in aquifers, and
- Hydraulic properties can cause very long response times to water levels and changes in groundwater flow.

If a clay unit of sufficient thickness is encountered in a boring, the investigator often assumes contamination will not migrate any deeper or vapors will not migrate into overlying structures. However, if these clays are fractured or are not continuous, contamination may migrate through the unit. Fine-grained materials similarly can impede the migration of vapors upward to the surface unless there are fractures or are not continuous.

The same characteristics that inhibit groundwater flow will also hinder vapors, therefore the method of investigation is similar. When characterizing aquitards and fine grained materials for ground water contaminant and vapor migration, the following information is needed to develop a CSM:

- **Aquitard Surface Flow**: Contaminants can flow preferentially along the surface of an aquitard rather than horizontally and with groundwater flow. Since glacially deposited aquitards are not flat lying and extend laterally in all directions, the surface of the aquitard needs to be investigated to understand how aquitards affect groundwater flow and contaminant transport.

- **Sediment Type and Hydraulic Conductivity**: The degree to which an aquitard protects inhibits vertical migration of dissolved and vapor phase contamination depends on the vertical hydraulic conductivity, which is largely controlled by the type of sediment. The classification of the sediment composing the aquitard (e.g., shales, clays, silty clays) can be determined by visual observation of geologic borings samples, tests pits, trenches or through laboratory analyses of soil or rock samples. Vertical hydraulic conductivity (Kv) is generally determined by laboratory analysis of undisturbed samples (i.e., Shelby tube) or by *in-situ* techniques, such as pumping tests. Horizontal hydraulic conductivity may affect the Kv in an aquitard as it may influence the transport of water through fractures. The number of borings and laboratory samples needed depends on the geologic heterogeneity of the aquitard.

  In general, clays and silty clays with low vertical hydraulic conductivity (e.g., Kv $>1\times 10^{-07}$ cm/sec) will more effectively protect underlying groundwater than sands and gravels (Kv $\geq\times 10^{-04}$ cm/sec). Competent shale or some other relatively impermeable bedrock may also effectively isolate underlying groundwater.

- **Aquitards and Natural Preferential Pathways**: Looking at the sediment without evaluating the macroscopic features may cause an over estimation of the aquitard's resistance to flow. Once the lateral extent of the aquitard is known, an evaluation of it as an effective barrier to contaminant migration is needed. Both thickness and areal extent are factors to consider when evaluating an aquitard. In addition to these factors, an evaluation of both natural and man-made preferential pathways is needed. A copy of the Geological Services *Investigation of Manmade Preferential Pathways* can be found at: https://www.in.gov/idem/cleanups/resources/technical-guidance-for-cleanups/site-characterization-and-sampling-guidance/. This document provides information needed to understand common natural preferential pathways encountered when investigating aquitards.

- **Thickness of an Aquitard**: In order to be an effective barrier to vertical flow for both dissolved and vapor contamination, an aquitard has to have sufficient known thickness. A 30-feet thick clay zone is often considered sufficient to protect underlying groundwater (Ohio EPA 2009). However, evaluating the degree of protection should not be based solely on thickness. Other criteria, such as sediment type, vertical and lateral discontinuities, presence/absence of hydraulically active fractures, and contaminant characteristics and concentrations should also be considered.

- **Lateral Extent**: Aquitards that are laterally continuous generally provide better protection from both dissolved and vapor contamination. Lateral continuity of an aquitard may be compromised by permeable zones formed by variations in sediment (e.g., silty clay with interbedded sand layers) or by structural discontinuities where the aquitard was not deposited or has been eroded, joint systems/fractures, or breaks caused by man-made structures such as water supply wells.

  Lateral continuity is determined from a sufficient number of geologic borings. Geophysical methods may also be useful. The presence of discontinuous interbedded sands or permeable zones or fractures may provide conditions for contaminant migration. Regional hydrogeologic data and information from adjacent sites may provide helpful information as to the scale of the aquitard's lateral continuity.

  For the use in evaluating vapor intrusion, laterally extensive is defined as sufficiently covering the area of the defined extent of the plume. In the case of **chlorinated solvents (since these COCs do not bio-attenuate)**, this should include the **100-foot buffer** beyond the defined extent of the plume.

- **Contaminant Migration Through an Aquitard**: Localized aquitards are not true barriers to groundwater flow. There are instances where aquitards can deflect or temporarily hold groundwater. These smaller units can affect local groundwater flow and contaminant transport.

  If contamination is in contact with a low permeability layer for a sufficient length of time, the contaminant will penetrate and fill the pore spaces of the unit. Once a compound has replaced water in the pores, it will continue slowly to transmit contamination into the surrounding geologic sediments. Thus, as a plume travels down-gradient, the source of contamination changes from vadose zone leaching to saturated zone diffusion. Refer to Bradbury, et al. (2006) and Cherry, et al (2006) for a detailed discussion of the hydraulics controlling this process.

To determine if an aquitard is a continuing source of contamination, groundwater samples should be collected from the zone immediately above and from within the aquitard. Should groundwater contamination be confirmed, soil samples from the aquitard will be needed for further characterization.

Once it is confirmed that the aquitard may be a potential secondary source for back diffusion into the overlying aquifer, the natural and manmade preferential pathways should be evaluated to determine if contamination could breach the aquitard. If an evaluation of the preferential pathways reveals there is a potential for contamination to breach the aquitard. Data is needed to determine if the aquitard is of sufficient thickness to compensate for the identified preferential pathways. If all of these tests and evaluations show there is potential for a breach, the next deepest water bearing unit should be investigated.

- **Secondary Porosity Features**: Secondary porosity features include, but are not limited to, bedding planes, fractures, macro pores, tree roots, and animal burrows. An evaluation of these breaks is especially important when the groundwater zone is shallow. However, such features can also be associated with ancient soil/weathering zones found deeper in the stratigraphic sequence. Fractures and other natural breaks can be identified through observation of soil/rock cores or excavations (tests pits and trenches).

  In unconsolidated sediments, a bedding plane is identified as a change in the characteristics of the sediment (i.e. change in grain size). In unconsolidated sediments, bedding plains can deflect, retard, or increase either volume or speed of transport of contaminants. Bedding thickness and composition are important to know when investigating the effectiveness of an aquitard. For example, millimeter thick silt beds within a generally dense, low permeability unit can be the primary contaminant transport mechanism. The more homogeneous the clay or low permeability sediment the more effective the aquitard is at retarding flow. However, for an aquitard to be effective it needs not only sufficient thickness, but it also needs to be laterally extensive.

  For an aquitard to be effective the degree of fracturing should be low, otherwise the aquitard would not be considered a barrier to vertical migration of contaminants. The presence of fractured clays and glacial till in Indiana is well documented. See: http://igs.indiana.edu/MarionCounty/PoroAndPerme.cfm for additional information.

  Macro pores are void spaces in a sediment that are larger than the spaces between the grains of the sediment. Most sediments testing methods will not identify these features. Most macro pores are identified in the field. A detailed field evaluation of the borings is needed to identify macro pores. If these observations are not made in the field, valuable information may be lost. Pump tests can also identify the presence of macro pores.

  In instances where an aquitard is shallow, plant roots can breach the aquitard (usually the plant roots are seeking the water table) and allow contamination to migrate deeper into the subsurface. If the site has a shallow clay layer and well developed vegetation, the roots of the larger plants have probably breached the aquitard. In addition, if part of the aquitard is made up of a paleosol, there could be relic plant root and animal casts that could create preferential pathways.

- **Shallow Aquitards and Manmade Preferential Pathways**: Shallow low permeability units are typically cut or breached by either natural or anthropogenic (man-made) actions. Low permeability units less than 20 feet deep should not considered effective barriers to contaminant migration due to potential human alterations without additional lines of evidence (LOEs).

Land Form of an Aquitard

The shape and extent of the aquitard needs to be determined. In most cases, the depositional environment of the aquitard sediment did not leave behind continuous units. Aquitards can be:

- Truncated or “pinch-out” into an aquifer,
- Discontinuous,
- Incised (eroded),
- Layered with thin permeable zones,
- Contain discontinuous layers of higher conductive zones, or
- Truncated by or in contact with bedrock aquifers.

INVESTIGATIVE STRATEGIES

Investigation of an aquitard is similar to the initial investigation steps taken when investigating karst, shallow bedrock or fractured bedrock. Once the contaminant is found in an area where an aquitard is affecting its distribution, an investigation of the interface between the porous sediments and the suspected aquitard is needed, to determine if the interface itself could be affecting contaminant transport. There are several tests to determine if the surface needs further study:

Mapping the surface of the aquitard

Mapping the surface of an aquitard is a simple way of determining how water is draining through, and in the case of an aquitard alone, the subsurface sediments beneath the site. Geophysics can provide data both to locate potential “problem areas” where boring programs should be focused, and allow accurate interpretation of data between borings. Some of these methods can also provide information regarding the thickness of the aquitard. Examples of land-based geophysical methods include:

- Electromagnetics (EM) and electric imaging (EI) surveys,
- Spontaneous potential (SP) survey,
- Microgravity survey,
- Seismic refraction, reflection, and surface wave analysis, and
- Ground penetrating radar (GPR).

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

- Utility corridors;
- Fill materials;
- Buildings, fences, and
- Reinforced concrete.

If there is significant near surface interference, geophysical investigation results can be misleading and soil borings will produce better results. Also, it may be necessary to examine the manmade preferential pathways. Typically, at least a few borings are needed to verify the interpretations of geophysical investigations.

Sampling the soil and groundwater

Once the area where the borings will be placed is determined, a series of probe points are advanced (on a grid pattern) until the top of the aquitard is encountered (collect soil samples in a subset of these "borings"). The depth to the top of the aquitard and the contaminant levels are mapped and, if possible, the "low spot" on the aquitard 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 surface of the aquitard. However, prior to investigating the units beneath the aquitard, confirm if water draining from the site is contaminated (i.e. sample the water flowing along the surface of the aquitard).

- **Soil Sampling:** Soil sampling in areas where an aquitard is present should be conducted in both the overlying unit and the top portion of the aquitard. The top of the aquitard is investigated as there is a potential for the aquitard (provided it has been in contact with contamination for a long time) to store contamination and act as a source.

- **Groundwater Sampling:** Once the surface of the aquitard has been mapped, and "low spots" have been identified; several monitoring wells are installed so that the screens intersect the interface between the base of the aquifer and the aquitard. At least one monitoring well should be installed in each of the identified "low spots". These wells are installed to monitor water flowing along the surface of the aquitard.

Fine Grained Attenuation Factor Adjustment

Additional information about the nature of the sediment is needed when evaluating VI pathways. In accordance with the Unified Soil Classification System (USCS), a fine-grained soil is when more than 50% of the soil sample passes through the number 200 sieve size. Site-specific field sampling will be needed to show this. For this reason, ASTM grain size analysis (ASTM, 2009) results from samples collected in representative areas of the site should accompany proposals to employ the 0.0005 attenuation factor.

However, IDEM expects that laterally extensive fine-grained soils will often act as aquitards, and that the uppermost water bearing unit is likely to lie *above* such soil layers. Given that the groundwater to vapor migration exposure pathway evaluation should be applied to the uppermost water bearing unit, IDEM does not expect to see many instances where use of the 0.0005 attenuation factor is appropriate. Nevertheless, IDEM will evaluate proposals to use the 0.0005 attenuation factor based on their merits.

In some cases, geologic layers can form partial or complete barriers to upward vapor transport toward overlying buildings, particularly laterally continuous, fine grained soil layers that retain sufficient moisture to be saturated or nearly saturated. Should preferential pathways cut through the fine grained sediment, the fine grained sediment would no longer be used to adjust the attenuation factor for vapor intrusion.

Summary and Conclusions

Staff assembled the information contained in this document from sites in Indiana, the references provided, and staff training and experiences. This document provides a basic outline for investigating aquitards. More in-depth evaluations should be determined on a site by site basis. An understanding of the nature of not only the sediments associated with aquitards, but also how groundwater interacts with those sediments is needed to develop an accurate CSM. When an aquitard is present, a successful remedial approach may involve a combination of remediation methods.

Further Information

If you have any additional information regarding this technical process or any questions about the evaluation of the plume behavior, please contact the Office of Land Quality, Science Services Branch at (317) 232-3215. IDEM TEG will update this technical guidance document periodically or on receipt of new information.

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