TECHNICAL GUIDANCE DOCUMENT

INDIANA DEPARTMENT OF ENVIRONMENTAL MANAGEMENT

Investigation of Manmade Preferential Pathways for Contaminant Transport

www.idem.IN.gov

Mitchell E. Daniels, Jr. — **Governor**

Thomas W. Easterly — **Commissioner**

100 N. Senate Ave., Indianapolis, IN 46204

Toll Free: (800) 451-6027

Guidance Created/Revised: *September 30, 2011*

Background

The following facts, observations, and examples are based on multiple scenarios encountered by IDEM in which manmade conduits have greatly influenced the ground water hydraulics and/or the distribution and extent of subsurface contamination. This listing does not cover every potential scenario or investigative technique. It is intended for informative purposes only.

> Preferential Pathway: The route of least resistance for fluid flow, or a more permeable feature than the surrounding materials. The pathway may extend vertically or horizontally and be derived naturally or by human activities. The feature may also be oriented such that fluid flow could go in an unexpected direction. Generally, they are limited in width from microscopic to a few tens of feet but are often extensive in length. Examples include sediment grain size changes from fine to coarse; buried stream channels; fractured or dissolved bedrock; desiccation fractures in sediments; improperly sealed wells; field tiles; buried utility lines; and building foundations.

Variability exists in all natural materials. Perfectly regular grain size, distribution, and shape rarely occur in naturally deposited sediments. Thus paths of lesser resistance for movement of fluids naturally exist in almost every geological environment. These pathways range from the intuitively obvious to the very subtle. Well known natural preferential pathways include such features as karst, fractured bedrock, and lithologic changes. More subtle kinds of pathways include vertical fractures in clay soils, angled bedding planes in sands, and millimeter thick silts in clay-rich glacial tills. Natural pathways can range in size from tens of feet (abandoned stream channels), to less than an inch (fractures in clay tills), to microscopic (changes in grain orientation or shape). Most of these heterogeneities can be addressed with a clear conceptual geologic site model and/or a well-designed remedial strategy. If the regional and local geology is known, then the potential effects of these natural pathways can be explained during site investigation and compensated for in remedial action.

Unfortunately, most remediation sites are also located in developed areas where the original subsurface environment has been altered. Even areas that do not appear to be developed have often been changed by human activity. Soils in these areas may have been disturbed by drainage improvements, subsurface utilities, leveling of the ground surface, or excavation for building. Often these features are completely unknown to the investigator.

Why are Manmade Preferential Pathways Important?

Once subsurface materials have been disturbed, they are usually more permeable than naturally deposited sediments, regardless of their composition and grain size. For example, sand used for fill is more permeable than naturally-deposited sand because fill is simply poured into a void rather than sorted by water or compacted by glaciation. Textbook porosity and permeability values assume that materials are uniform and compacted, and these values cannot be used to estimate the nature of backfill.

Manmade preferential pathways can transmit contaminants tens to hundreds of feet away from the release point as pure product, in a vapor phase, or dissolved in water. This movement can often be in directions up-gradient or cross-gradient of a release. Manmade pathways can be an issue regardless of depth to ground water. In areas where ground water is deeper than a pathway, vapors may move great distances through porous conduits and backfill. Where shallow ground water is present, product and dissolved phase plumes can travel quickly and without attenuation beyond the property boundary. In addition, preferential pathways can provide a vertical migration route to deeper levels in the aquifer by intersecting and breaching so-called confining layers.

Manmade preferential pathways can act as both a conduit and a barrier to migration. For example: Borings are placed on both sides of a conduit. The up-gradient area is contaminated but the down-gradient area is not. The initial conclusion is that the site characterization is complete. This is not necessarily accurate. If the backfill is transmissive, the contaminant may have just taken a turn and becomes a very long, narrow plume moving along the conduit. If the backfill is finer grained than the surrounding soils (which can happen) or a subsurface structure is present, the obstacle may deflect or be a barrier to contaminant transport, and contaminants may pool behind the barrier until they find a release point.

As part of the conceptual site model, it is not enough to know only that manmade preferential pathways may exist. It is also imperative to know where they are located horizontally, vertically, and with respect to the release area. The conceptual site model should also seek to understand how preferential pathways may affect the hydraulic properties of the subsurface. This preferential pathway survey typically involves a more comprehensive view of the site layout, the site's surroundings, the local and regional geology and topography, and the degree and age of urbanization in the area.

Identification of Preferential Pathways

Identification and evaluation of preferential pathways should begin before or run concurrently with the investigation of a release. Often, an investigation proceeds forward with delineation from a 'source' but considers neither the mechanism of the release nor the property's characteristics or prior history. This can lead to wasted effort by misinterpreting the distribution of contamination. In order to prevent this from happening, the investigator should step back from examination of the release, and view the site as a whole.

The purpose of this section is to present a list of the common, subsurface elements which can influence soil source geometry, vapor intrusion, and contaminated ground water flow. One or more of these elements are present at nearly every site.

1. Storm/Sanitary Sewers: These are the most common preferential pathways associated with subsurface releases of contaminants. Sometimes, they are the actual source area, because wastes have been poured down a drain or the storm sewer has received run-off from a surface spill. Storm sewers and some older sanitary lines are designed to allow leakage into the subsurface as they move water away. Lines installed prior to the 1980s are usually vitrified clay tile and are prone to breakage and cracking. Sewers should always be at least initially assessed, as they are present at nearly all sites. Not only should the main line(s) be identified, but the lateral(s) into the site buildings need to be located. If there are floor drains within buildings, they need to be diagrammed as well.

   Even if the overall ground water table is below the sewer lines, the sewer may still be influencing contaminant distribution. Vapors can travel along conduits and create indoor air issues. Additionally, localized perched aquifers may be associated with the lines, and in some areas sewer main lines can be as much as 30 feet deep. So, it is not enough to know where the sewer is located; the depth is also vitally important. The sewer should be shown, to scale, on cross sections. In addition, it is very important to understand what direction the sewer flows and if it flows constantly or intermittently (i.e. near a lift station) as the conduit can move contaminants in directions different from the ground water gradient.

Although sewers are the feature most commonly associated with manmade preferential pathway flow, there are other kinds of subsurface conduits which may affect contaminant distribution:

2. Energized subsurface utility lines (Gas, Water, Electric, Fiber Optic, etc.): These subsurface features are usually not primary pathways because they are usually not as large, not buried as deeply, and are not designed to leak as sewers are. However, they are still surrounded by porous backfill which can intercept contaminants. Sometimes they are located in the same trench as the sewer lines, which can complicate an investigation. Depending on the size, depth, and location of the lines, they may explain contaminant distribution. The investigator

should determine the locations of energized or pressurized lines in order to safely drill at a location (or use a water or air knife, see below).

3. Septic Systems and other localized wastewater management systems: These have many names including “concrete vaults”, “dry wells”, “oil/water separators” or “water distribution pits.” Much like sewer lines in urban areas, these are common pathways noted in rural or semi-rural areas. At most sites which have these, the researcher can assume that they are at least a partial source of contamination. Recently urbanized or suburban areas may still have the structure in place even if it is not currently being used for wastewater management. They are handy locations to pour other wastes, especially waste oil and waste solvent.

4. Field Tiles and French Drains: These are a system of clay pipes (tiles) or gravel-filled trenches (drains) typically installed from the late 1700s to present day that are intended to lower the water table of an area to make it amenable for development or farming. In many cases, these intercept or directly connect to the existing storm sewer lines or nearby streams. Tank vaults and other structures can also intersect these features. In older buildings, floor drains may be connected into these instead of a sewer or septic system. These are usually not a factor at small sites or in heavily urbanized areas but historical drainage improvements can cause problems at large urban, suburban, or rural facilities that do not realize the history of the area.

   Almost all soils of glacial origin in Indiana have been extensively field-tiled or ditched to allow drainage for building. In rural and suburban areas, the county surveyor’s office might be able to provide some information on the type and density of tiles. A review of the county soil surveys will also list the natural depth to saturation, and thus the probability of drainage lines.

5. Large Areas of Fill: Almost all sites have been cut or filled to make a level surface. All disturbed areas tend to transmit water, vapors, and contamination more readily than natural soils. Large areas of fill can be a source of contamination or control ground water hydraulics. Estimating the distribution and nature of fill around a site takes a more wide-ranging investigation. Boring logs are sometimes not enough. A thorough Phase I investigation can be invaluable. Reviewing the topographic maps for the area can be a great help, as can current and historical aerial photographs. If they are available, Sanborn maps provide an excellent description of historical structures and property usage. Sometimes intermittent drainage ways have been filled in. Sometimes, perennial streams have been channelized under urban development and there is no surface expression. Slopes along creek valleys might have been filled to grade. Many cities in Indiana were originally connected by a canal system. Research may find that the “Water Street” next to the site used to actually be the canal.

   How much fill material affects the contaminant plume depends mostly on the following:

   a. The contrast between the fill and the native materials. If there is sand fill adjacent to coarse-grained or poorly sorted sand, the pathway is less

pronounced. However, well- sorted, fine-grained sands (i.e. dunes) are much more resistant to flow than poured-in backfill. The interface between sandy fill and clayey soils is often an obvious, primary pathway. There can be a large amount of source material present in the gravel sub-base of parking lots, storage areas, and buildings.

b. The location of the sources of contamination with respect to the fill. Contamination released into the fill tends to want to stay in the fill. Surface releases are much more susceptible to this. Contamination released into natural soil may then collect in areas of fill down-gradient of the source.
c. The distribution and thickness of fill across the site. If the whole site is covered with fill, the investigation is simpler than if only portions of the site are covered with fill. Typically, if only portions of the site are covered, it is to fill in low spots or to make high spots, and these create pools and drainage pathways for contaminants.

6. Existing Foundations: Existing subsurface structures are typically affected by contamination in the fill material surrounding the walls and floor. Most commonly the sub-base is contaminated by seepage through concrete floors in process and storage areas. Thorough site investigation can characterize their effect on contaminant distribution. The existing foundation sub-base, often in concert with interconnected utility lines, is a primary source of vapor intrusion in commercial facilities.

7. Abandoned Foundations, Basements, and Cisterns: These can act as pathways or barriers to migration.

    a. As a barrier: Outside the source area, abandoned basements and subsurface structures can act as islands of clean(er) soil/ground water. Borings placed within or directly down-gradient of these areas may lead to misidentifying the extent of contamination.
    b. As a pathway: These can act as pools of continuing source from a process or disposal area which has been long abandoned.

8. Improperly abandoned or installed wells (water, oil, or gas): This includes monitoring wells. Improperly abandoned or installed wells are usually discovered when contamination shows up in a deeper zone unexpectedly. If an investigator is lucky, historical research and a thorough site walk through may turn up such information as an abandoned pump house, neighbors with wells, or pipes present at the surface. The Department of Natural Resources should be notified when abandoned wells are found (312 IAC 13-10-2).

Investigation of Preferential Pathways

General Subsurface Characterization

As described in the identification section, every developed site may contain manmade alterations which could influence the distribution and migration of contamination.

However, not every site needs to evaluate their property beyond basic identification and mapping of subsurface utilities (including the depth).

> *At the majority of sites with subsurface contamination, a properly completed preferential pathway survey would likely consist only of on-site utility location, a thorough site and vicinity walk through, and (potentially) a telephone call to the municipal department of public works.*

Basic preferential pathway information should be presented on site maps and discussed briefly in the characterization report as a part of the elimination of potential exposure pathways for closure.

The need for further study is initially based these factors:

- <u>The location of the source with respect to known sewer main lines and laterals:</u> Active sewer lines and laterals are usually obvious, but their hydrologic effects are often ignored. If the contaminant source is adjacent to the sewer or directly discharges to the sewer, an investigation of the lines and backfill for source material (regardless of the depth to ground water) is needed. If heavily contaminated ground water flows toward a sewer line which is below the water table, the backfill around the sewer trench should be investigated to determine if it is directing dissolved or vapor phase contaminants off-site.

- <u>Irregular distribution of contamination:</u> Contaminant transport through a porous media creates a plume of a generally predictable size, shape, and concentration gradient based on the hydraulic conductivity and ground water gradient. If contamination is much more widespread than the known geology would tend to allow, contamination suddenly “disappears”, the magnitude of contamination is disproportionate to known source, or heavily contaminated soil, ground water, or vapors are detected in unexpected places, there is a possibility that a preferential pathway could be influencing contaminant travel.

- <u>The development and operational history of the site:</u> If the property has changed usage, added and/or removed buildings, or relocated process areas, it is possible that the historic subsurface alterations and drainage may still be in place. For example, sites which were originally residential may still have sewer laterals, cisterns, and water wells left in place. There may have been pre-development dumping at the site. The site may lie in an area of historic sand and gravel mining where pits were filled back in with waste. Additionally, if the site operations historically used contaminants in solution or had to store and dispose of chemicals once they were “spent,” the sewer or other on-site wastewater management areas need to be fully investigated.

Most of the listed preferential pathways are not obvious in the field and may be nearly impossible to detect with a traditional investigation consisting of soil boring methods. A thorough site walkthrough can sometimes find evidence of septic systems, drainage tiles, old foundations, and wells.

Sometimes there is simply no obvious surface expression at all. The site may be completely paved or altered beyond recognition, but areas of fill are found by chance

during investigation or a pre-development clay tile is penetrated during boring. The development history of the site and the vicinity become very important at this point in the investigation.

Historical research is the key to finding abandoned subsurface structures. Careful review of aerial photographs and historic maps of the property can be very helpful. An assessment of the building construction may find built-on areas and added parcels. These features are common at industrial facilities where processes have changed or moved and in areas which were previously residential prior to commercial development. A telephone call to the department of public works may provide both historic and current utility locations. If those desktop methods are not sufficient, or they cannot satisfactorily explain what is happening, then a non-invasive investigation of the subsurface may help determine whether there are manmade disturbances influencing contaminant travel.

Geophysical surveys are generally the most reliable way to find disturbed areas and subsurface pathways without excavating the entire site. Two types of surveys are commonly used to find and map non-metallic subsurface features.

- Ground Penetrating Radar (GPR): This technique is better for finding subsurface structures such as tanks, wells, and foundations but can find most features. It is also more suited to smaller areas and locations with surface obstructions.
- Resistivity/Conductivity: This technique is better for finding changes in soil structure and composition such as trenches and filled areas but can find most features. This method is better suited to large open areas.

If large areas of the site are covered by concrete with rebar, most geophysical methods are unlikely to be successful.

If unexpected pipes or tiles are found during the investigation, there are several methods available to determine if these features need further investigation.

- Smoke Tests: Smoke testing will show where air flows through a pipe. It is especially useful for finding open drain traps and near-surface breaks. Usually the fire department and nearby neighbors need to be informed before completing a smoke test.
- Vacuum Tests: Vacuum tests are useful if there are multiple conduits which may or may not be connected to a nearby source or receptor.
- Dye Traces: Dyes can determine if water entering a drain is connected to sanitary or storm sewers.
- Sewer cameras: These are useful if the line is completely filled with water, a break in the line is a suspected source, or if trying to precisely locate where an active or inactive line goes.

Invasive Site Investigation *

*This discussion is limited to active utility lines because the most difficult part about investigating the other kinds of preferential pathways is actually *finding* them!

Typically, a well-researched site conceptual model, combined with thoughtfully placed soil borings and monitoring wells, can indirectly explain how a manmade preferential pathway affects contaminant distribution. However, it is sometimes necessary to physically sample the subsurface vapors, soils, and ground water adjacent to active utility lines. When this becomes necessary depends on the nature of the release, the objectives of the investigation, and the closure strategy. Common reasons to directly sample within an active conduit include:

- Determination of source area concentrations for site characterization and risk assessment.
- Determination of soil and ground water quality to complete a pathway elimination assessment.
- Measurement of soil gas concentrations moving along a conduit.

Investigating around sewer lines is complicated by the slight risk of encountering an active line. Often, multiple utilities are located in the same trench. If there are known active water, sewer, or gas line trenches that need to be investigated, the municipality will need to be informed. City utility workers can be an excellent source of information about location and construction of active utilities. Private utility locators will show only the location of subsurface lines, but tell nothing about depth, construction, or quality of the conduits.

Options which pose little risk to the lines themselves are readily available. The methods listed below are not typically part of a standard drilling program. Common tools include:

- Hand auguring: This drilling tool is turned into the ground by muscle power. They have a maximum depth of about 20 feet, depending on soil type. They may not be effective if the utility backfill is very coarse or heterogeneous.

The other two methods require a mobilization with a separate drilling machine. This nearly guarantees that the lines will not be harmed. If there are multiple areas that need to be investigated, this is often the fastest way to investigate and requires the least physical effort.

- Water knife: This machine is similar to a power washer and uses high pressure water to remove unconsolidated material. However, the addition of water can leach adsorbed contamination into the ground water. For this reason, these tools are not very commonly used at contaminated sites.
- Air knife: This machine works almost exactly like a water knife, but uses high pressure air to remove soil. The loose sediment is collected with a vacuum on the back of the truck. However, they might not be as effective in tightly compacted or heterogeneous backfill. Also, they may not be effective in cold weather when shallow sediments or fill material may be frozen. There is a large amount of waste soil generated by an air knife, and this may be a consideration if the corridor is suspected to be highly contaminated. The investigator also needs to account for potential VOC loss due to the high pressure air.

Occasionally, it is simply not possible to directly sample due to factors such as fragile water lines, high pressure gas lines, high voltage lines, or interstate pipelines. It may be difficult or impossible to acquire a right of way access permit from a municipality or individual. Situations like this are handled on a case by case basis.

Examples of the Influence of Preferential Pathways on Contaminant Transport

Contamination source in sewer pipe or utility trench backfill: This scenario occurs at sites where wastes were poured down the drain either as pure product disposal or as a result of poor housekeeping. Sewer disposal often leads to disconnected, high concentration contaminant source areas with very small source footprints. Once on-site investigation has shown there is source material in and around drains, the evaluation needs to continue in the flow direction of the pipe. Pure product can travel some distance through competent pipes, so common disconnected source locations are at T and L junctions, nearby lift stations, and any saddles in the gradient. Once dissolved or adsorbed contamination has been found in the conduit, an investigation of potential ground water receptors and the potential for vapor intrusion is needed in the vicinity of each source area.

Dissolved contamination intercepted by utility trench: This scenario occurs when a release into the subsurface travels down-gradient with ground water flow until it intercepts disturbed soils in contact with the water. This situation leads to plumes which apparently 'end' on-site despite having high concentrations near the property line. In order to confirm the extent of contamination, the investigator may need to drill directly adjacent to the trench in the down-gradient direction of flow *within the preferential pathway* (this is not necessarily the same direction as ground water flow). If investigation shows that contamination is traveling along the trench, there is the potential for discharge of contaminated ground water or vapor intrusion at nearby receptors.

Utilities that control ground water hydraulics: This scenario is probable in urban areas with shallow ground water, low ground water gradient and large diameter sewer lines. It is particularly notable in areas with fine-grained subsurface materials. Common indicators of utility-influenced hydrology include unexplained low or high water levels in wells next to the utility trench, and wells off-site and outside the utility corridor that dramatically change on-site ground water flow direction.

Fill creates ephemeral water table for contaminant movement: Although the perennial water table may be well below filled areas, the contrast in materials' permeability tends to allow for horizontal fluid transport until there is sufficient head pressure to drive it downwards. If there is an above ground release, this mechanism spreads the source material outward and increases the footprint of the contamination. This is a probable cause when there is a very small contaminant source (i.e. sink sized degreaser) but a horizontally extensive shallow soil source. In this scenario, depending on the contrast between native and manmade materials, ground water contaminant concentrations may be low to moderate, while vapor contamination is extremely high. This is a primary concern in buildings with large areas of interconnected, coarse grained sub-base.

Contamination source or transport in drain tiles: Unlike other pathways, drainage tiles usually discharge to nearby perennial or ephemeral surface water features. Once contaminated drainage tiles are found on a site, there needs to be an evaluation of surface drainage areas for contaminated sediments or contamination discharging into surface waters.

Cross-contamination due to wells: This scenario usually occurs at large industrial facilities with multiple production wells. Typical cross-contamination problems come from wells installed prior to current DNR grouting and abandonment requirements outlined in 312 IAC 13. Properly installed wells will not allow cross-contamination.

Closure Strategies

This guide is not intended to be a comprehensive discussion of remedial or closure methods. Not every site will need a specific remedy to remove the risk from contamination in preferential pathways. However, if preferential pathways are significantly affecting the ground water hydraulics or vapor flow, they can create difficulties for both active and passive closure strategies. A good investigation using the principles noted above should determine if and how pathways might be affecting the contaminants. Sometimes, the pathways can make remediation easier, because contamination has been contained within a structure or is being funneled to a single discharge point. Some of the more common difficulties with remediation of preferential pathways are listed below:

How do contaminated pathways affect cleanup and closure strategy?

- Overestimation of radius of influence: This is one of the most common issues caused by preferential pathway flow and is a typical reason active remedial systems can fail. Things to monitor during pilot testing are:
    - One or more distant observation points show a much greater effect than points nearby.
    - All extraction influence is concentrated in one direction.
    - Testing is performed only in areas of disturbed soil or backfill rather than native materials.
- Short circuiting: This will show up as nearly instant vacuum or drawdown in a well. Also, unusually rapid arrival of injectate in distant wells for in-situ remedies is a sign of a conduit.
- Underestimation of source area:
    - Removal of a known source such as USTs or a septic tank is planned. During excavation, contaminated clay tiles or a building foundation are discovered and have to be removed.
    - A remediation system is installed, without understanding the distribution of high contaminant levels in the on-site sewers. After several years of operations, contaminant levels remain much higher than predicted because the source has not been effectively treated. Additional operation and possibly a different corrective action are necessary.

Both these scenarios equate to a large, unexpected expense. It is much less costly to know what is going on before starting remediation.

- Vapor intrusion: The existence of a direct conduit into a building invalidates vapor intrusion models or attenuation factors which assume that contaminants rise through a porous media. Borings around a site can indicate low conductivity soils but do not account for manmade alterations. A common way which vapors can affect buildings is through sewer lines and drains. The presence of coarse-grained fill under and around buildings can also lead to underestimation of risk.
- Plume stability: Continued flow of water through a conduit can destabilize contamination. The presence of conduits can also influence the accuracy of perimeter of compliance wells. If the contamination is leaving the site through a preferential pathway rather than through down-gradient flow, then the pathway is where monitoring needs to be concentrated.
- Fate and transport models: The assumptions for uniform, homogenous subsurface conditions rapidly break down in the presence of conduit flow. If they are not taken into account, the risk can be underestimated.

How is remediation of a preferential pathway accomplished?

As previously noted, many times specific remediation of a preferential pathway is not necessary to achieve closure. The conduit may be simply directing residual ground water contamination, and once the source is addressed, it will attenuate without additional measures. However, if the conduit is allowing contamination to discharge to a receptor at an unacceptable risk level, it needs to be included in the remedial strategy. As an example, at a site where the tail of a contaminant plume intersects a sewer, the sewer would not specifically need to be addressed unless vapors above acceptable risk levels were present in nearby structures or contaminated water was discharging to the surface. The remediation of pathways can be as simple as adjusting the location of a few extraction wells/injection points or as complex as a separate, specifically designed remediation system for the conduits. Usually, contaminated pathways not associated with active utility systems are most effectively remediated by targeted removal.

Resources

IDNR Well Rule 312 IAC 13 http://www.in.gov/legislative/iac/T03120/A00130.PDF?

State Coalition for the Remediation of Dry Cleaners, 2010: Conducting Contamination Assessment at Drycleaning Sites;
http://www.drycleancoalition.org/download/assessment.pdf

Sewer Smoke Testing:
http://ci.santa-rosa.ca.us/departments/utilities/sewer_wastewater/Pages/testing.aspx

Video Sewer Inspections: www.fairfield-city.org/utilities/videoinspections.cfm
www.ci.sunnyside.we.us/services/public_works/sewer_abc/video_inspect.php

Wisconsin Department of Natural Resources, 2000: Guidance for Documenting the Investigation of Utility Corridors; PUBL-RR-649, 9 pages.

USEPA, 1997: Expedited Site Assessment Tools For Underground Storage Tank Sites: A Guide For Regulators: Chapter 3 Surface Geophysical Methods, (EPA 510-B-97-001).
http://www.epa.gov/OUST/pubs/esa-ch3.pdf

Further Information

If you have any additional information regarding this technology or any questions about the evaluation, please contact Geological Services at (317) 234-0991. This technical guidance document will be updated periodically or if new information is acquired.