# Underground Tank Technology Update

**Vol. 12, No. 1**
**January/February 1998**

**Department of Engineering Professional Development The College of Engineering University of Wisconsin–Madison**

*Underground Tank Technology Update* is published bimonthly by the University of Wisconsin–Madison, Department of Engineering Professional Development. *UTTU* supplies useful information to federal, state, and local officials working with groundwater technology and to other interested technical specialists. For new subscriptions or address corrections, use the form on inside back page.

*UTTU* is funded by the U.S. EPA under Cooperative Agreement No. L005924-01 to the University of Wisconsin–Madison, which is responsible for its preparation. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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SPECIAL ISSUE ON

## Karst Terranes

### *Article summaries*



This article describes the fundamentals of karst aquifers. Karst aquifers differ from the usual granular aquifers because these aquifers have hydrogeologic features that cannot be characterized by the usual porous media approximations.



Researchers who study karst terranes know that released contaminants usually travel very rapidly to discharge locations, which could be several kilometers away. Problems associated with transport, storage and attenuation of contaminants in a karst aquifer will depend on the aquifer's characteristics.



This is a continuation of the checklist published in the July/August and September/October 1997 issues of *UTTU*.



Oklahoma's successful implementation of e-mail as the means of communication for a discussion group on RBCA is the subject of this article.



Information sources give phone numbers or addresses of recent publications and provide other relevant information.



This article describes an EPA reimbursement policy.

***UTTU*'s home page, http://epdwww.engr.wisc.edu/uttu/, contains an index of UTTU articles from 1987 to 1997.**

# Karst aquifers

This article describes the fundamentals of karst aquifers, which differ from granular aquifers in that karst aquifers have hydrogeologic features that cannot be characterized by the usual porous media approximations *(ASTM, 1995)*. This article, abstracted from ASTM's "Standard Guide for Design of Groundwater Monitoring Systems in Karst and Fractured-Rock Aquifers," focuses on "unconfined karst systems where dissolution has increased secondary porosity, and on other geologic settings where unconfined groundwater flow in fractures is a significant component of total groundwater flow."

### The essence of fractures

A fracture is "a general term for any break in rock, whether or not it causes displacement, due to mechanical failure by stress. Fractures include cracks, joints and faults" *(ASTM, 1995).* To properly characterize an aquifer as granular, fractured rock, or karst (see Table 1), an investigator needs to understand the following aquifer properties:

- porosity
- isotropy
- homogeneity
- flow
- storage
- recharge

*Porosity.* The most important difference between these three aquifer types (granular, fractured, karst) is porosity. "In a granular aquifer, effective porosity is primarily a consequence of depositional setting, diagenetic processes, texture and mineral composition. In fractured-rock and karst aquifers, effective porosity is a secondary result of fractures, faults and bedding planes. Secondary features modified by dissolution comprise tertiary porosity" *(ASTM, 1995).*

*Isotropy.* "Fractured-rock and karst aquifers are typically anisotropic in three dimensions. Hydraulic conductivity can frequently range over several orders of magnitude, depending upon measurement direction. Groundwater in anisotropic media does not usually move perpendicular to hydraulic gradient, but at some angle to it."

*Homogeneity*. "Variations of aquifer characteristics within the spatial limits of the aquifer are frequently large in fractured-rock and karst aquifers. Hydraulic conductivity differences of several orders of magnitude can occur over very short horizontal and vertical distances."

*Flow*. Flow in fractured rocks that are not significantly soluble depends on the number of fractures per unit volume, their apertures, fracture distribution, and degree of interconnection. Darcy's law may or may not apply. In karst aquifers, groundwater movement is predominantly through conduits formed by dissolution and fractures enlarged by dissolution. These features occupy a small percentage of the total rock mass. "Groundwater flow in the rock mass is both intergranular and through fractures that have not been significantly modified by dissolution. Such flow is usually only a small percentage of the volume of water discharging from the aquifer, though it provides most of the storage."

| **Aquifer characteristics** | **Granular** | **Fractured rock** | **Karst** |
|---|---|---|---|
| Effective porosity | Mostly primary through intergranular pores | Mostly secondary through joints, fractures, bedding plane partings | Mostly tertiary (secondary porosity modified by dissolution through pores, bedding planes, fractures, conduits, caves) |
| Isotropy | More isotropic | Probably anisotropic | Highly anisotropic |
| Homogeneity | More homogeneous | Less homogeneous | Non-homogeneous |
| Flow | Slow, laminar | Possibly rapid and possibly turbulent | Likely rapid and likely turbulent |
| Flow predictions | Darcy's law usually applies | Darcy's law may not apply | Darcy's law rarely applies |
| Storage | Within saturated zone | Within saturated zone | Within both saturated zone and epikarst |
| Recharge | Dispersed | Primarily dispersed; with some point recharge | Ranges from almost completely dispersed to almost completely point-recharged |
| Temporal head variation | Minimal variation | Moderate variation | Moderate to extreme variation |
| Temporal water chemistry variation | Minimal variation | Minimal to moderate variation | Moderate to extreme variation |

*Table 1. Granular, fractured-rock and karst aquifers compared (from ASTM, 1995, page 3).*

Researchers originally believed that “conduit flow was dominant in some aquifers, and diffuse flow dominant in others. The diffuse-flow-dominated regime was thought to be characterized by low variation in hardness, turbidity, and discharge—as measured at a spring. Researchers now recognize that the variations of these parameters are due to aquifer boundary conditions, such as the number of sinking stream inputs or whether the spring is an underflow or overflow spring.”

Rapid flow and slow flow are preferred terms, rather than conduit flow and diffuse flow. “The latter terms are ambiguous when used in reference to karst aquifers because they have been used to describe flow types within an aquifer, types of recharge, and types of spring-flow as affected by recharge events, as well as flow hydraulics and water chemistry. Rapid flow takes place in conduits > 5 to 10 mm in diameter where velocities generally exceed 0.001 m/s. The swallet-flow component of karst aquifers typically yields flow in conduits > 0.001 m/s. Such rapid flow can also occur in open fractures. Flow in the rock matrix and through fractures that have not been significantly modified by dissolution is typically slow (<0.001 m/s). However, flow in conduits and fractures can also be slow” *(ASTM, 1995).*

*Storage*. “In most aquifers, groundwater is stored within the zone of saturation (phreatic zone); karst aquifers, however, can store large volumes of groundwater in a part of the unsaturated (vadose) zone known as the epikarst (subcutaneous zone). The epikarst, the uppermost portion of carbonate rock, about 10-15 m thick, consists of highly fractured and dissolved bedrock. Highly permeable vertical pathways are formed along intersections of isolated vertical fractures. The epikarst behaves as a locally saturated, sometimes perennial storage zone that functions similarly to a leaky capillary barrier or a perched aquifer, but it is commonly not perched on a lithologic discontinuity. Flow into this zone is more rapid than flow out of it, as only limited vertical pathways transmit water downward.”

*Recharge*. Recharge in “karst and fractured-rock aquifers with minimal unlithified overburden tends to be rapid; water levels may rise within minutes of a storm onset and watertable fluctuations may range up to many tens of meters. Karst and fractured-rock aquifers with thick unlithified overburden may have a long temporal lag similar to that of granular aquifers. Recharge may be distributed through an areally extensive network of fractures or through soil (dispersed recharge) or it may be concentrated at points that connect directly to the aquifer (point recharge).”

### Definitions

The following definitions will help the reader better understand the discussion on karst terranes *(ASTM, 1995; American Geological Institute, 1976).*

*Conduit*—pipe-like opening formed and enlarged by dissolution of bedrock that has dimensions sufficient to sustain turbulent flow under ordinary hydraulic gradients.

*Darcy’s law*—a derived formula for fluid flow based on the assumption that flow is laminar and that inertia can be ignored.

*Dissolution zone*—a zone where extensive dissolution of bedrock has occurred; void size may range over several orders of magnitude.

*Epikarst*—a zone of enhanced bedrock-dissolution immediately beneath the soil zone; characterized by storage of water in dissolution-enlarged fractures and bedding planes, it may be separated from the phreatic zone by a relatively waterless interval locally breached by vertical vadose flow.

*Fractured-rock aquifer*—an aquifer in which all or most water flow is through one or more of the following: joints, faults or bedding planes that have not been significantly enlarged by bedrock dissolution.

*Karst aquifer*—an aquifer in which all or most water flow is through one or more of the following: joints, faults, bedding planes, pores, cavities, conduits and caves, any or all of which have been significantly enlarged by bedrock dissolution.

*Karst terrane*—a landscape and its subsurface characterized by flow through dissolution-modified bedrock and characterized by a variable suite of surface landforms and subsurface features, not all of which may be present or obvious. These include sinkholes, springs, caves, sinking streams, dissolution-enlarged joints or bedding planes or both, and other dissolution features. Most karsts develop in limestone or dolomite, or both, but they may also develop in gypsum, salt, carbonate-cemented sandstones and other soluble rock.

*Overflow spring*—a spring that discharges generally intermittently at a groundwater stage above base flow (compare with underflow spring).

*Rapid flow*—groundwater flow with a velocity > 0.001 m/s.

*Secondary porosity*—joints, fissures or faults that develop after the rock was originally lithified; these features have not been modified by dissolution.

*Sinkhole*—a topographic depression formed as a result of karst-related processes such as dissolution of bedrock, collapse of a cave roof, or flushing or collapse of soil and other sediment into a subjacent void.

*Slow flow*—groundwater flow with a velocity < 0.001 m/s

*Swallet*—the hole into which a surface stream sinks.

*Tertiary porosity*—porosity caused by dissolution enlargement of secondary porosity.

*Tracer*—a substance added to a medium, typically water, to give it a distinctive signature that makes the medium recognizable elsewhere.

*Underflow spring*—a spring that is at or near the lowest discharge point of a groundwater basin; such a spring usually flows perennially.

## Groundwater flow conceptual models

Three conceptual models characterize fractured-rock and karst aquifer flow:

- continuum
- discrete
- dual porosity

*The continuum model* assumes that the aquifer approximates a porous medium at some working scale. In this approach

- the properties of individual fractures or conduits are not as important as the properties of large regions or large volumes of aquifer material
- the porous-medium approximation implies that the classical equations of groundwater movement hold at the problem scale; knowledge of hydraulic properties of individual fractures is not important
- aquifer properties can be characterized by field and laboratory techniques developed for porous media

*The discrete model* assumes that

- most groundwater moves through discrete fractures or conduits
- the hydraulic properties of the matrix portion of the aquifer are unimportant
- measurements of hydraulic characteristics of individual fractures or conduits are used to characterize groundwater movement

*The dual porosity model*

- lies between the continuum and discrete model
- attempts to characterize groundwater flow in individual conduits or fractures as well as in the aquifer's matrix portion

Theoretical tools are useful, but the site groundwater monitoring design must be based on the site's empirical data. Standard hydrogeologic field techniques, based on the continuum model, may not be valid in fractured-rock and karst aquifers. Applicability of a conceptual model can be a question of scale. For instance, "implicit in the porous-medium approximation is the idea that aquifer properties such as hydraulic conductivity, porosity, and storativity can be measured for some representative elementary volume (REV) of aquifer material and that these values are representative over a given portion of the aquifer. For granular aquifers and some densely fractured aquifers, the REV is likely to be encompassed by standard field-monitoring devices such as monitoring wells. In such aquifers, the continuum approach is appropriate for site-specific investigations, provided aquifer heterogeneity is adequately characterized. The porous-medium approximation is not a valid conceptual model for those fractured-rock and karst aquifers where flow is primarily through widely spaced discrete fractures or conduits."

The discrete approach is most appropriate for aquifers whose contact between matrix and fracture or conduit hydraulic conductivity is great.

The dual-porosity approach is most appropriate for aquifers whose matrix is "relatively permeable and yet there are discrete zones of higher conductivity such as dissolution zones, fractures or conduits."

Model applicability requires that the investigator determine the influence of fractures and conduits on the flow system. The following criteria can help.

*Ratio of fracture scale to site scale*: for porous-medium aquifers,

- the observed vertical and horizontal fractures should be numerous
- the distance between the fractures should be orders of magnitude smaller than the size of the site
- fractures should show appreciable interconnection

*Hydraulic conductivity distribution*: for porous media aquifers, distribution of hydraulic conductivity (estimated from piezometer slug tests or from specific capacity analyses) tends to be approximately log normal. Where hydraulic conductivity distribution is strongly bimodal or polymodal, the porous-medium approximation is probably not valid. "It is also possible to obtain a log-normal distribution of hydraulic conductivity for wells in those aquifers that do not fit the porous-medium approximation because most wells are preferentially completed in high-yielding zones. In addition, hydraulic conductivity values vary with measurement scale, and slug tests completed in open boreholes will yield averaged hydraulic conductivities that do not represent the full variability in hydraulic conductivity."

*Water table configuration*: for porous medium aquifers, the water table map should be smooth and continuous without areas of rapidly changing or anomalous water levels. The map should not have the "stair-step" appearance; contours should not "V" upgradient. In addition, only sufficient data can ensure that these features do not exist.

*Pumping test responses:* for porous-medium aquifers,

- observation well drawdown should increase linearly with increases in discharge rate of the pumping well
- time-drawdown curves for observation wells located in two or more different directions from the pumped well should be similar in shape and should not show sharp inflections
- distance drawdown profiles should not be highly variable
- a plotted drawdown cone from a pumping test using multiple observation wells should be either circular or near-circular (elliptical); linear, highly elongated, or very irregular cones in areas where no obvious hydraulic boundaries are present indicate a non-porous medium

*Variations in water chemistry*: water chemistry varies spatially and temporally because of rapid water movement through discrete fractures or solution conduits. Generally the coefficient of variation of specific conductance of water is a function of the percentage of rapid versus slow recharge to an aquifer. To determine validity of the porous-medium approximation, investigators should measure at least two of the following, and preferably all:

- spring discharge or hydraulic head
- turbidity
- specific conductance
- temperature a day before, during, and for several days or weeks after several major recharge events

If water becomes turbid and other parameters show rapid and flashy responses to the recharge event, the porous-medium approximation is most likely not valid. A bimodal or polymodal distribution of daily or continuous measurements of specific conductance also indicates that the porous-medium approximation may not be valid.

*Presence of karst features:* the porous medium approach may be invalidated by the presence of sinkholes, sinking streams, blind valleys, caves, dissolution-enlarged joints or a carbonate aquifer with a total hardness less than 500 mg/L.

*Variations in hydraulic head*: variations may not be readily evident because most flow occurs in discrete channels, whereas wells set in the rock matrix may not intersect the channels. The porous medium approach is probably not valid where a high contrast in hydraulic conductivity over short distances exists and exhibits non-coincident water levels in closely spaced wells that are screened or open over the same vertical interval.

*Borehole logging:* for non-porous medium aquifers,

- the caliper log, borehole television logs or acoustic televiewer indicate presence of open fractures or dissolution features
- borehole logs indicate significant variation in specific conductance or temperature
- flow meters indicate significant variations in borehole fluid movement
- porosity log (such as a neutron-neutron log) indicates increase in porosity
- density (gamma-gamma) log indicates significant decrease in density

## Hydrogeologic setting

The ASTM document contains a section describing the importance of understanding hydrogeologic setting and unique features in a karst aquifer. Included in this section are the following:

- regional geology and structure
- data sources
- integrating geologic data with flow-system characteristics
- stratigraphy
- structure
- field mapping and site reconnaissance
- determination of groundwater flow directions, velocities and basin boundaries
- variation of hydraulic head
  - – potentiometric-surface mapping
  - – vertical distribution of hydraulic head
  - – temporal changes in hydraulic head
- determination of directions and rates of groundwater flow
- use of tracer tests

## Geophysical techniques

Geophysical techniques consist of

- surface geophysical techniques
- borehole logging techniques

*Surface geophysical techniques*, reconnaissance tools, usually measure some acoustical or electrical property at the surface, and can give information on

- depth to rock
- water table depth
- buried channel location
- mapping and location of large structural features
- fracture orientation
- areal variation in water quality

*Borehole logging techniques* can help the investigator identify strata type, water bearing zones and hydraulic properties. The common logs that field investigators use include

- natural gamma
- gamma-gamma
- resistivity (conductivity)
- spontaneous potential
- video
- temperature
- caliper
- acoustic televiewer
- flow meter
- borehole fluid logging
- cross-hole tomography

ASTM recommends using video logging to determine fractures and conduits and aid in placement of monitoring well screens when budgets preclude use of multiple logging techniques. (*UTTU* Vol. 7 No. 4 and Vol. 5 No. 4 contain articles on geophysics.)

## Karst aquifers

Monitoring in fractured-rock or karst aquifers can be difficult because aquifer characteristics such as thickness, porosity, hydraulic conductivity and storativity can be difficult to quantify.

*Aquifer thickness* can frequently be defined by lithologic or stratigraphic boundaries in aquifers with primary porosity. However, “karstification may decrease with depth or be confined to very specific zones or beds within the carbonate rock.”

*Porosity*: "primary porosity can be measured on the scale of a hand sample or a core sample; secondary and tertiary porosity need to be measured at a scale that statistically represents the distribution of the aquifer heterogeneities."

*Hydraulic conductivity and storativity* values will also vary with measurement scale. Single or multiple well pumping tests to measure hydraulic conductivity "should be interpreted with respect to the portion of the aquifer that responds and the measurement scale effects. . . measurements of transmissivity and storativity averaged over a groundwater basin in karst aquifers can be estimated from discharge rates at springs." *(Editor's comment: "Hydraulic conductivity for a conduit is infinity and nearly zero in the rock matrix so it has little or no meaning for most karst aquifers.")*

### Development of a groundwater monitoring system

If the actual aquifer deviates significantly from the porous-medium approximation, monitoring wells probably will not yield representative groundwater samples; tracer studies and hydraulic tests, however, may be able to demonstrate that the monitoring points represent site conditions. To test the applicability of monitoring point locations, investigators can use tracer tests. Tracer tests can provide information on

- optimum monitoring frequency
- additional mass-balance data (when tracer concentrations and discharges are measured) to make the design or modify a monitoring system

In general, the cost of measuring both tracer concentration and discharge rises as the number of potential monitoring points rise, but the cost-benefit ratio may improve.

Investigators can use hydraulic tests to determine the relative "connectedness" of an individual monitoring point to the fracture-flow system, that is, connections between monitoring wells and the site. Ideally, monitoring wells should intersect contaminant zones.

"Packer tests and borehole logging techniques can help locate both high-conductivity and low conductivity zones within the aquifer. Pumping tests can then be designed to test the connections between various parts of the system."

Monitoring well placement, construction and development will be similar to that for granular aquifers if the aquifer is uniformly and densely fractured; however, this will not apply to aquifers with discrete high-permeability zones. *(Editor's comment: "How densely? This is usually assumed but rarely occurs.")* "In settings where the matrix blocks have appreciable porosity, it may also be important to monitor the blocks as well as the high-permeability zones because the blocks may function as storage reservoirs for pollutants."

In addition, the ASTM document contains the following sections on monitoring wells:

- construction
- development and maintenance
- alternative monitoring points
- sampling frequency
- hydrographs and chemographs
- conventional parameters
- determining sampling frequency for target compounds
- meeting regulatory goals

### Reference

ASTM, "Standard Guide for Design of Groundwater Monitoring Systems in Karst and Fractured-Rock Aquifers," D 5717-95, American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428, phone 610-832-9585, fax 610-832-9555, e-mail service@astm.org.

## Chemical transport in karst terranes

Researchers who study contaminants in karst terranes know that contaminants usually travel very rapidly to discharge locations, which could be several kilometers away. The aquifers in these terranes—karst aquifers— can store contaminants for long periods of time. The specific problems associated with transport, storage and attenuation of contaminants in a karst aquifer are a consequence of the specific attributes of the karst terranes *(Field, 1990).*

Researchers who worked in karst terranes once believed that little could be done to track or remove released contaminants. In the past 15 years, however, researchers have redefined contaminant hydrogeology in karst terranes. Specifically, investigators have developed

- better contaminant investigation methods
- better understanding of contaminant behavior in the subsurface
- better computer models to enable more accurate prediction of contaminant migration *(see Field and Nash, 1997; Field, 1997 and Field, et al, 1997)*.
- more effective aquifer remediation techniques

Still, contaminants that reach an aquifer in karst terranes "do not behave like those in granular or highly fractured aquifers. The basic hydrogeological assumptions . . . concerning flow regimes are not valid when applied to karst terranes." Groundwater flow in most karst terranes

- is turbulent
- is convergent in the upper drainage reaches
- is dispersive in the lower reaches
- occurs in large passages at very high velocities with nearly insignificant hydraulic gradients

"Releases in most karst terranes are stored and transported, in both the vadose and the phreatic (saturated) zones, across very large distances (e.g. kilometers) . . . and groundwater movement here can be on the order of hundreds of kilometers a day. Actual contaminant transport in the phreatic zone can be expected to be extremely rapid and highly concentrated at eventual discharge points, but it cannot be tracked successfully by methods currently used in other aquifers. Karst aquifers characterized by "diffuse-flow" are not always characterized by the slow-moving laminar flow that Darcy's law describes. Rather, the flow is often fast-moving and turbulent, violating Darcy's law. The situation is perhaps akin to a giant sponge with water flowing uniformly through it. Thus, most karst aquifers characterized by "diffuse-flow" and all those characterized by conduit-flow **cannot** be described by the usual flow and transport equations" *(Field, 1990)*.

"In general, the slow, dispersive laminar flow defined by Darcy's law is **rare** in karst terranes; groundwater flow in most karst terranes is likely to be very rapid, convergent and turbulent within discrete conduits" *(Field, 1993)*.

## Movement to the epikarstic zone

When a release occurs, the contaminant moves from the surface into a soil zone where the contaminant may be retarded; however, in the absence of a thick soil zone and/or small spill, the contaminant will usually reach the water table. Movement may be enhanced by flow through soil macropores. "Sorption of chemical constituents to micro-particles cannot be expected to prevent the downward (or lateral) migration of contaminants because the micro-particles are themselves readily transported through the soil zone either by eluviation or through macropores. . . . highly sorbing chemical constituents may actually be very mobile because of the natural mobility of soil particles. Eluviation is the movement of soil material from one place to another in solution or in suspension by natural soil-forming process."

## Movement in the epikarstic zone

Beneath the soil zone is the epikarstic or subcutaneous zone (Figure 1). "This zone consists of the uppermost portion of the unsaturated rock where significant fracturing, weathering, solutional enlargement and storage may occur. It is approximately 3 to 10 m thick and is separated from the water table by a relatively unfractured, unweathered, waterless zone of rock that is sporadically breached by subcutaneous drains and vadose shafts. Vadose shafts are solutionally produced vertical tubes ranging in size from a few centimeters to several meters across. They often occur in complexes and contain a drain hole at their bottom" *(Field, 1990)*. Subcutaneous drains, the main discharge points for flow within the epikarstic zone, allow for almost uninterrupted vertical transport.

Within the first 10 m from the surface, 50 to 80 percent of carbonate rock dissolution occurs, leaving this upper rock layer heavily corroded. "Most dissolution occurs within 3 m, where fissuring has a uniformly high density and may even exhibit a rubbly nature. Fissures are widened by dissolution at shallow depths but close rapidly with increasing depth because of overburden pressure and reduced dissolution, except for a few isolated preferential vertical flow paths termed subcutaneous drains" *(Field, 1993).*

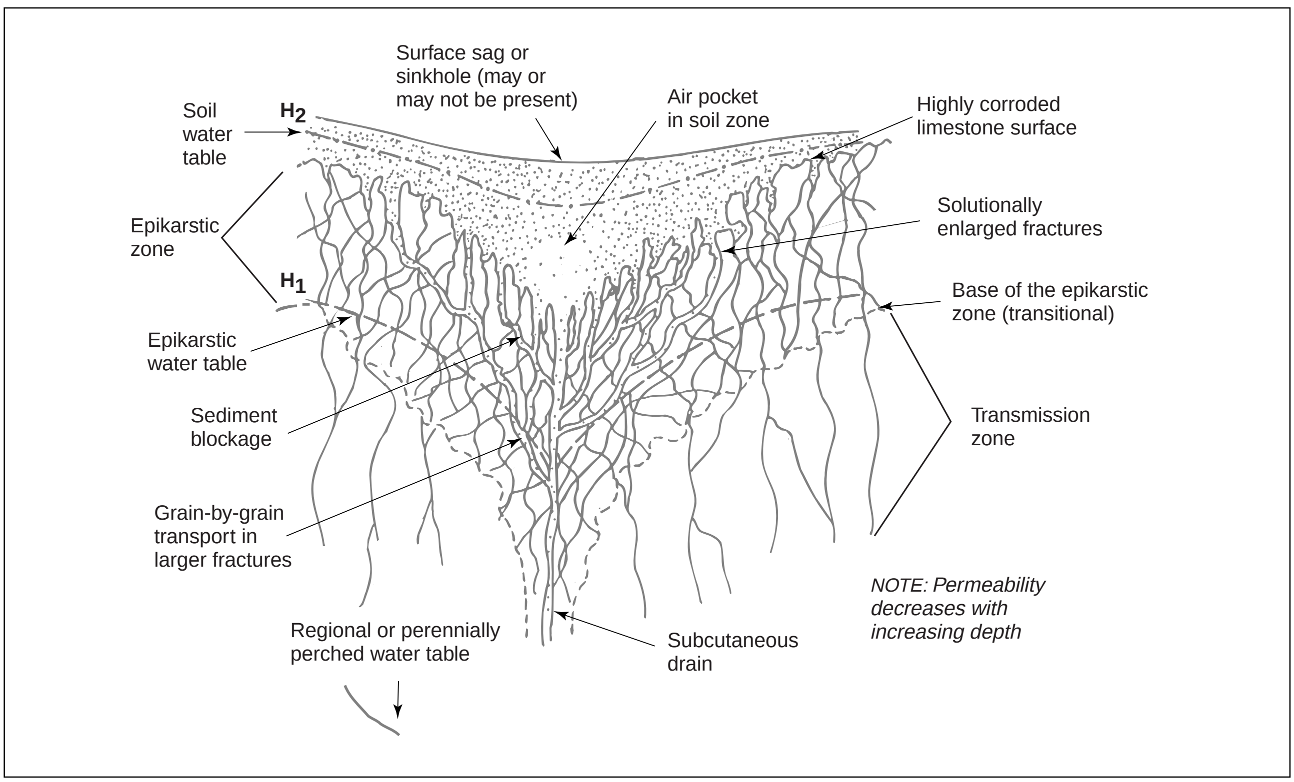


*Figure 1. Elements of a karst terrane (from Field, 1990).*

Electromolecular forces that exist between soil particles, water and contaminants facilitate contaminant retention in the epikarstic zone's minute fractures. "If contaminants have not entered directly into a subcutaneous drain, they are likely to flow both vertically and laterally through this zone, always taking the easiest, most direct path downward. **Substantial storage within this zone can be expected, thus allowing for the slow release of chemical constituents to the underlying aquifer for many years "** *(Field, 1990).* Researchers believe subcutaneous drains are the main avenues for most aquifer recharge. The greater corrosion and enhanced vertical permeability of this area also encourage "redirection of soil water to the subcutaneous drain, commonly causing a catastrophic collapse of the overlying soil" *(Field, 1993).*

## Movement beyond the epikarstic zone

"Release of contaminants from the epikarstic zone occurs primarily during large storm events that tend to flush out the chemicals and temporarily perch local water tables. Such perching occurs as the volume of water entering the epikarstic zone begins to exceed the drainage capacity of the zone; this leads to the development of a hydraulic gradient that commonly has the form of an elongated cone of depression with a subcutaneous drain acting as the lowest point of hydraulic head, similar to a pumping well. Lateral flow and transport to subcutaneous drains may exceed several hundred meters and allow for very rapid flow rates" *(Field, 1990).* Flow can be as high as 600 m/hr (violating Darcy's law), whereas "in the smaller, less developed fissures, flow can be as low as 2 m/hr" *(Field, 1993).*

Contaminant flow "in the vadoze zone of bedrock occurs along major vertical joints, faults and bedding plane partings. Divergent flow readily occurs in the vadose zone as shown by the large number of diversion passages for vadose cave streams. Water and contaminants are always moving progressively downward to lower-flow routes where they may feed larger conduits extending over long distances *(Field, 1993).*" Often, however, flow occurs in vadose conduits that are typically oriented down dip. A series of vadose conduits tend to form at different cave levels; these conduits may reflect the region's geomorphic history.

"Between the epikarstic zone and the water table, subsurface water and contaminants percolate downward, generally via vadose shafts. Vadose zone shafts are cylindrical openings ranging in diameter from a few millimeters to many meters. They are produced by vertically descending water. Often, however, flow occurs in vadose conduits which are typically oriented down the dip of the rock" *(Field, 1993).* A series of vadose conduits tend to form at different cave levels that may reflect the region's geomorphic history. Flow and transport are primarily vertical, but vadose conduits can intercept this vertical flow in lateral directions that may exceed several kilometers.

## Flow and transport in the phreatic (saturated) zone

In the saturated zone, flow and transport will depend on proximity of conduits, hydraulic gradient and strike of bedrock. Intergranular and micro-fracture flow

- is usually diffuse flow leading to a phreatic conduit
- will often be laminar and obey Darcy's law
- exhibits strong anisotropy, which may invalidate the assumption of flow lines normal to equipotential lines

Groundwater flow in karst aquifers usually ranges between conduit and diffuse flow; that is, most flow is mixed. Conduit flow predominates in large passages with relatively high flow velocities. Here, flow is turbulent and the hydraulic gradient may be almost insignificant. The orientation of passageways will depend on local stratigraphy and structure. Water discharge through carbonate rock will be more dependent upon variations in channel size than upon variations in hydraulic gradients.

Significant amounts of storage, evidenced by high contaminant concentrations appearing during springs at high flow, occur within the microfractures.

Flow and transport within a conduit is turbulent, as in a sewer line, with velocities of meters/day to several thousand meters/day. A phreatic conduit, unlike a sewer line, however, will

- be rough
- contain many sharp bends and turns
- be subject to temporary or permanent blockages

Water movement in a phreatic conduit can flow vertically upwards. On a groundwater basin flow net, phreatic conduits are an aquifer's true flow lines.

The conduit floor can be lined with insoluble sediment, including clay, which can attract and absorb contaminants and significantly affect contaminant retardation. Conduits are excellent sediment traps. A cave's backwater zones can store and concentrate contaminants. "Collapse of a cave roof to form breakdown may also result in the temporary storage and concentration of contaminants" *(Field, 1993).*

## Storm events and storage

Storm events can flush contaminants through or around the breakdown; but such events do not flush out all residual contaminants. Storms tend to create a "bank storage" driving contaminants up into older and higher cave levels and into the rock matrix. Once there, drainage and chemical reactions may occur slowly. Thus, chemical contaminants reaching phreatic conduits are not necessarily flushed out freely, and they may be retained for long periods.

Five areas of storage exist in karst terranes:

- overburden (soil zone)
- epikarstic zone
- transmission zone
- phreatic conduits
- saturated rock mass

"The significance of these zones relative to each other varies from one karst terrane to the next" *(Field, 1993).*

### Relationship between a sinkhole and a phreatic conduit

Springs that are discharge points for conduits can release large quantities of water, especially during storm events. Contamination can be stored in portions of a conduit until a water level rise drives out the contaminant. Estavelles (reversing spring) may be important influences on contaminant transport and discharge. They can either dilute or discharge contaminants. "Initially during low flow events, a contaminant is likely to be transported along the subsurface conduit. During a large storm event, however, an increase in hydraulic head may be so great that the piezometric surface will actually rise above land surface, and water can be forced out of the ground" *(Field, 1993).* Contaminants could be

- forced into the surrounding rock matrix
- forced back up the subsurface conduit
- discharged from the estavelle
- back upgradient of the sinkhole; in dye tracing experiments a pollutant was once driven over 300 meters up a regional gradient

### Conduits as monitoring points

"Conduits are rarely intercepted by wells;" conduits, if intercepted, can serve as monitoring points; however, "the probability of a randomly drilled well doing this is commonly less than 0.04 percent. Obviously, this probability is low and is an uneconomical goal, but on the slight chance that an intersection does occur, existing wells are highly desirable for monitoring sites. Such sites can be valuable for tracing studies, which are necessary prerequisites for design of a monitoring system in a karst terrane . . . Commonly, the convergent nature of conduit flow that occurs in the upper reaches of a karst groundwater system gives way to a divergent system at the lower reaches; this is evident from the number of adjacent springs shown by the dye tracing studies and similarity in water chemistry to be connected to the same cave system" *(Field, 1993, 1990).*

### Immiscible contaminants

Because neither light nonaqueous phase liquids (LNAPLs) nor dense nonaqueous phase liquids (DNAPLs) are readily miscible with water, these chemical types slowly "bleed" into the water over an extended period of time. LNAPLs in karst terranes are not easily affected by dispersion and can concentrate in major active conduits. The sudden flooding of a system may cause localized decreases in flow velocity and force contaminant globules into the rock matrix and up into older, higher levels. These globules may adhere onto cave walls or be caught in tight fractures for long periods. Light volatile contaminants tend to rise up and flow through cave passages as gases, which can create hazards in basements.

DNAPLs tend to sink rapidly to aquifer bases, where they form sludges in deep pools and adsorb to microparticles. These sludges will not usually respond to groundwater flow hydraulics but instead flow as a bulk density phase. In a conduit system with very high velocities, bulk mass transport can occur. "If low flow conditions persist for long periods and allow the water table to drop below the sludge pool level, a sudden influx of water during a storm event may possess sufficient force to rip out and entrain much of this sludge along the conduit . . . small portions of this contaminant slowly become miscible with the water and are advected through the system, thus providing a continuous source of contamination to discharge points."

### Natural attenuation of contaminants

Karst aquifers are excellent contaminant transporters, but they are not effective at attenuating subsurface contaminants. Natural attenuation of contaminants is limited in karst aquifers because of the following:

- a significant lack of available surface area for
  - adsorption
  - ion exchange
  - colonization by microorganisms
- rapid infiltration of water and contaminants, which restricts the ability of highly volatile chemicals to evaporate
- typically thin soil cover and relatively large secondary voids, which allow for rapid contaminant transport
- assistance in contaminant transmission by turbulent flow regime typical of conduit flow
- reduction in adsorption-desorption processes and microbiological activities because of the rapid flow-through rates in conduits

"A popular misconception is that a karst aquifer will rapidly flush chemical contaminants out and thus cleanse itself. Large portions of chemical spills will typically be rapidly transported from an input point to a discharge point (on the order of several meters per day to several meters per hour), but this is not always true. Very large quantities of the chemical may be stored in the subsurface" *(Field, 1993).*

### Remediation

With current technology, remediation of contaminated karst aquifers is nearly impossible. The most effective spill response in karst terranes is "don't use the water". In summary:

- traditional aquifer remediation techniques such as groundwater extraction, containment and biorestoration have little or no known value in conduit-flow-dominated karst aquifers
- extraction wells seldom intersect subsurface conduits, preventing significant contaminant withdrawal
- even if extraction wells do intersect conduits, their effectiveness would be minimal because of the wells' inability to remove sufficient quantities of water from conduits, and their inability to significantly affect water stores in rock matrix
- the flow of a conduit-contaminated system does not lend itself to remediation by conventional techniques

"A detailed hydrological and geological investigation of a contaminated area may provide sufficient insight into the karst hydrogeology to allow some form of aquifer remediation to be effectively implemented. Evidence for remediation does exist for some sites (one contaminated karst aquifer was remediated by source removal and waiting for the conduit to flush out remaining contaminants), but the actual remediation of a contaminated karst aquifer will always face certain limitations that are uniquely inherent to karst terranes" *(Field, 1993).*

### References

Field, M.S., "Transport of Chemical Contaminants in Karst Terranes: Outline and Summary," 1990, in *Selected Papers on Hydrogeology*, edited by E. S. Sharp and J.M. Sharp, Jr. Vol. 1, p. 17-27.

Field, M.S, "Karst Hydrology and Chemical Contamination," *Journal of Environmental Systems*, Vol. 22(1) 1993; 800-638-7819.

See also the following papers:

"Risk Assessment Methodology for Karst Aquifers: (1) Estimating Karst Conduit-Flow Parameters," Field, M.S. and S. Nash, 1997, *Environmental Monitoring and Assessment*, Vol. 47, No. 1, p. 1-21.

"Risk Assessment Methodology for Karst Aquifers: (2) Solute-Transport Modeling," 1997, Field, M.S., *Environmental Monitoring and Assessment*, Vol. 47, No. 1, p. 23-37.

"Estimating Karst Conduit Transport Parameters Using a Two-Region Nonequilibrium Model," Field, M.S., Pinske, P. and G. Davies, submitted to *Water Resources Research*.

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***UTTU thanks Dr. Malcolm Field, U.S. EPA, National Center for Environmental Assessment, Washington D.C. 20460, for sending us his papers and for his other contributions to this special issue on karst terranes. Contact Dr. Field at 202-260-8921 or field.malcolm@epamail.epa.gov.***

# Inspector's guide for sacrificial-anode-type cathodic protection—

# Checklist: Part 3

*By Dr. James Myers*

This is a continuation of the checklist published in the July/August and September/October 1997 issues of *UTTU*. The first article contained a checklist for electrical continuity and electrical isolation; the second one described components/material delivered to the job site. Part 3 contains a description of the installation of components/materials.

Figure 2 shows a typical installation where a sacrificial anode is directly connected to an underground pipe. Figure 3 shows a representative installation where a sacrificial anode is connected to an underground pipe through a test station. With regard to the installation of this CP system, the inspector should record answers to the following questions:

1. Were anodes installed at each of the sites and within +/- one foot of the site locations identified on the engineering drawings?

   ☐ Yes ☐ No

2. Were the hole diameters and depths for the anodes within +/- 10 percent of the dimensions specified on the engineering drawings?

   ☐ Yes ☐ No Hole depth ____ Hole diameter ____

3. Was the waterproof container for each prepackaged anode removed before the anode was installed?

   ☐ Yes ☐ No

4. How were the anodes installed?

   ☐ Vertically ☐ Horizontally

5. Were any anodes supported by the anode cables when they were lowered into the hole?

   ☐ Yes ☐ No

6. Were the cables for the anodes installed at a minimum depth of 18 inches below grade except where they surfaced at a test station?

   ☐ Yes ☐ No

7. Did the ancillary cables to the test stations have the proper color coding?

   ☐ Yes ☐ No

8. Were the ancillary cables to the test stations installed at a minimum depth of 18 inches below grade except where they surfaced at a test station?

   ☐ Yes ☐ No

9. Did the anode cables and the ancillary cables to the test stations have sufficient “slack” such that they would not be broken during backfilling?

☐ Yes ☐ No

10. If the copper conductors on the anodes and the ancillary cables to the test stations were exothermically welded to the structure, was the proper weld-metal part number and the mold-part number used for the conductor and structure involved?

☐ Yes ☐ No

11. Did the molds used to make the exothermic welds appear to be excessively worn?

☐ Yes ☐ No

12. Was each exothermic weld tested for integrity and subsequently cleaned?

☐ Yes ☐ No

13. Was the coating damage at each copper-conductor attachment site on the structure suitably repaired prior to backfilling?

☐ Yes ☐ No

14. If required, were weld caps installed at the copper-conductor attachment sites on the structure?

☐ Yes ☐ No

15. Was fine soil properly tamped into annulus between each anode and its respective hole without damage to the anode cable?

☐ Yes ☐ No

16. Were each of the test stations installed within +/- two feet of the sites identified on the engineering drawings?

☐ Yes ☐ No

17. Was the specified type of test station installed at each of the sites identified on the engineering drawings?

☐ Yes ☐ No

18. Were the test stations installed in accordance with the engineering drawings and/or the manufacturer’s recommendations?

☐ Yes ☐ No

19. If shunts were to be installed in the test stations, did the shunts actually installed have the specified resistance (s)?

☐ Yes ☐ No

20. Were the connections in the test stations made in accordance with the engineering drawings?

☐ Yes ☐ No

21. If required, were the permanently installed, reference electrodes installed in strict accordance with the engineering drawings?

☐ Yes ☐ No

22. If the anodes were not prepackaged, was the backfill installed in strict accordance with the engineering drawings?

☐ Yes ☐ No

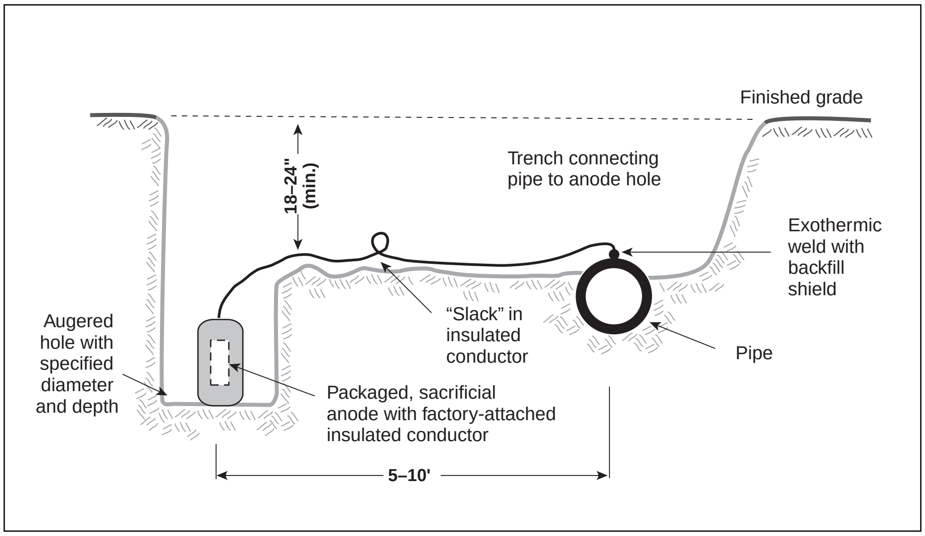


*Figure 2. Sacrificial anode installation (from Myers, 1996).*

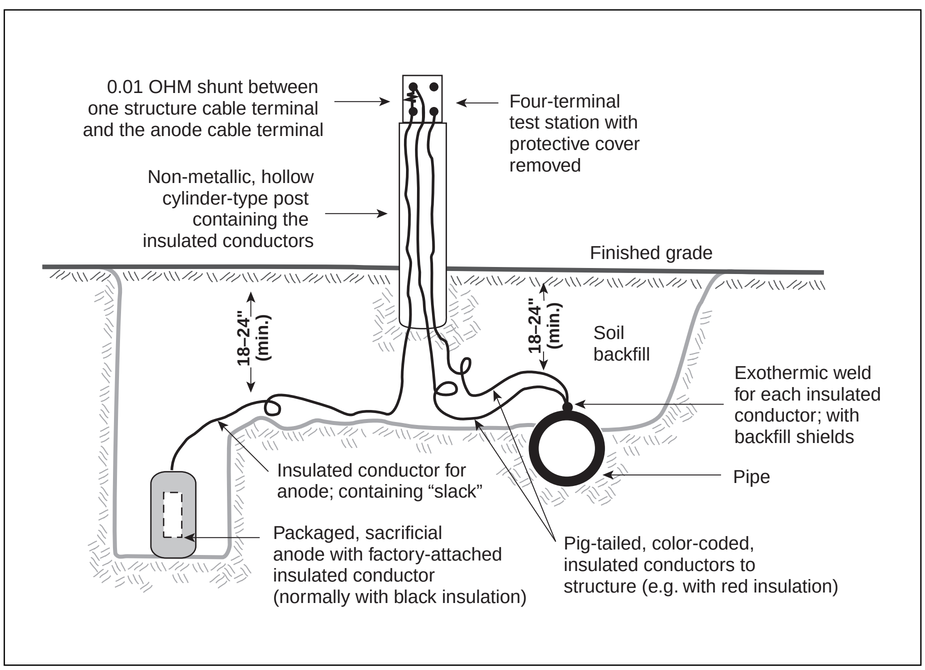


*Figure 3. Sacrificial anode installation connected to an underground pipe (from Myers, 1996).*

23. If the anodes were to be installed without backfill, were they installed in strict accordance with the engineering drawings?

☐ Yes ☐ No

24. Was the construction area returned to its natural status after the cathodic protection system was installed?

☐ Yes ☐ No

## Commissioning the cathodic protection system

During commissioning of the cathodic protection system, time is normally required for polarization to take place on the structure surface. Structure-to-environment potential and anode current output measurements should not be made until the system has been installed at least two months. During commissioning, the inspector should record answers to the following questions:

1. Was a structure-to-environment potential survey conducted after the cathodic protection system had been installed at least two months?

☐ Yes ☐ No

2. If a structure-to-environment potential survey was conducted, use method (a) or (b) to record the results.

(a) On separate sheet(s) of paper use the following format and identify the reference electrode used. (Include units, e.g., milliamperes, on data sheet.)

| *Test Location* | *Structure-to-Environment Potential, Volt* |
| --- | --- |
| ___________ | ________________________________ |
| ___________ | ________________________________ |
| ___________ | ________________________________ |

(b) Alternatively, place the structure-to-environment potentials on a graph or a drawing of the structure.

3. Did the results of the structure-to-environment potential survey reveal that adequate corrosion mitigation had been achieved, according to at least one of the National Association of Corrosion Engineers Criteria for Cathodic Protection? For example, if the protected structure was steel, cast iron, ductile iron, or stainless steel, was it polarized to at least -0.85 volt and no more than -1.3 volts relative to a copper-copper sulfate reference electrode at all locations? Alternatively, was the ferrous-base material polarized in the negative reaction at least 100 millivolts and no more than 500 millivolts at all locations with regard to the natural, structure-to-environment potentials at these locations?

☐ Yes ☐ No

4. Were the anode current outputs measured at the test stations?

☐ Yes ☐ No

5. Record any anode current outputs measured at the test stations (including units, e.g., milliamperes) on separate sheet(s) of paper using this format:

| *Test Location* | *Structure-to-Environment Potential, Volt* |
| --- | --- |
| ___________ | ________________________________ |
| ___________ | ________________________________ |
| ___________ | ________________________________ |

6. If two ancillary cables were connected to the structure at a test station, did both of these give the same results when measuring the anode current output and the structure-to-environment potential?

☐ Yes ☐ No

7. Was there any reason to believe that any of the cables to either the structure or the anode had been broken during the backfilling?

☐ Yes ☐ No

8. If broken cables existed at any of the test stations, were these suitably repaired?

☐ Yes ☐ No

9. If the cathodic protection system involved an underground pipe system when the pipe was cased (e.g., at a road or railroad crossing), were tests conducted to ensure that the casing was not shorted to the pipe?

☐ Yes ☐ No

10. Did any shorted casings exist where an underground pipe system was cased?

☐ Yes ☐ No

## Reference

Myers, J., "Acceptance Criteria for Sacrificial-Anode-Type Cathodic Protection Systems: An Inspector's Guide/ Checklist for Components and Their Installation," 1996, J. Myers, 4198 Merlyn Drive, Franklin, OH 45005.

***UTTU thanks Dr. Myers for sending us this article.***

# E-mail forum: Oklahoma's RBCA

In October 1996, the Fuel Storage Division of the Oklahoma Corporation Commission (OCC) adopted ASTM's risk based corrective action (RBCA) methodology. Neil Garrett, a hydrogeologist at OCC, decided to e-mail the results of any ensuing discussion and decisions—as well as blind reviews of consultants' ORBCA-formatted reports—to anyone who wanted to participate. "These are real sites and each site presents a different risk scenario and learning opportunity," Garrett said in a September 1996 e-mail. "If you want to take a front-row seat and watch the trials and tribulations as a governmental agency implements a methodology that EPA will probably eventually adopt for RCRA and Superfund, send me your e-mail address. . . . There are lots of bugs, questions, decisions and interpretations that will have to be made or clarified about this new system. I want this to be an open forum for you to submit questions or opinions. As we cross this new terrain, we in the regulatory area, will have to make decisions that affect your work . . . E-mail can bridge the gap toward speedier communication."

### Naphthalene

The case of naphthalene analyses can demonstrate some features of Garrett's e-mail system. His first e-mail, September 29, 1996, listed some of OCC's issues of concern:

- First, a new Oklahoma standard for GRO analysis involved calibrating for naphthalene
- labs could offer an EPA method 8020 modified that included a quantification of naphthalene concentrations
- if dissolved naphthalene concentrations exceeded 0.630 mg/L then a full PAH scan was required
- the less expensive EPA method 8310 met the above requirement, but many state labs did not have the hardware to run EPA method 8310
- an alternate method was 8270
- regarding soil, an individual stated you'd probably have to pour the free product off before seeing a naphthalene concentration of 200 mg/kg

At this point, OCC did not want to make a decision on how to proceed with naphthalene analyses until they had more history of the analyses.

### Naphthalene query, September 30, 1996

In response to a query, Garrett wrote:

- naphthalene analyses generally are not required for cases that have met specific OCC rules
- groundwater naphthalene concentrations may be required at "old" gasoline release sites where a drinking water well is threatened; it would be wise to check with your regulatory specialist if you have any drilling or monitor sampling planned for an "old" gasoline-release case; in the delineation stage, naphthalene samples are still probably not required
- a fully completed Tier 1/1A evaluation report is required for all old cases unless a previously submitted risk assessment report has been approved or is awaiting review

### Naphthalene update, November 3, 1996

"If concentrations of naphthalene exceed 200 mg/kg for soil and 0.630 mg/L for groundwater, then you must run a full PAH scan," Garrett said in this e-mail. "The only acceptable analytical method is EPA method 8310. Methods 8270 and 8100 are not acceptable because their detection levels are not low enough."

### Naphthalene update, November 10, 1996

"Many phone calls came in concerning our policy that a full PAH scan had to be run with EPA method 8310 at the exclusion of all other methods, including 8270," Garrett said. "None of our guidance policy is set in stone and an abundance of testimony from people in the know could change that policy. While you are talking with your lab reps, ask them about methods for total organic carbon. Bently Environmental has suggested that 415.1 may be a better method than the ones listed in our guidance document."

### Naphthalene update, December 17, 1996

"The OCC has recently revised what EPA analytical tests it will accept for PAH scans," Garrett said. "Currently we will accept EPA methods 8100, 8270 and 8310. We will collect a history on the analyses and compare them with risk-based goals. Based on that history, things may change in the future."

### Naphthalene question, February 3, 1997

A reader wanted to know what the two action concentrations for naphthalene were based on. Garrett replied, "I used the Tier 1 tables in our guidance document to arrive at these action levels for naphthalene. Oklahoma has not adopted any action levels for naphthalene in its rules. I went through all the possible exposure routes looking for the lowest risk-based screening level for naphthalene and used that as the action level.

"Every state when implementing RBCA must adopt conservative input parameters to base the Tier 1 RBSLs on. Some may ask, 'Are they conservative enough for every situation?' Probably not, and that is why Oklahoma requires every site to be taken to a higher level of evaluation, Tier 1A. At this level the consultant must incorporate fate and transport she or he has required and which may be more conservative than Tier I. Therefore the site will have lower cleanup levels than the action levels unless a Tier II evaluation shows otherwise.

"States implementing RBCA will find they have a few sites with cleanup levels lower than the action levels published in their rules. An interesting situation to deal with."

### Naphthalene update, September 21, 1997

"As of August 1, 1997, the OCC Fuel Storage Division is requiring only one naphthalene analysis each for the "hottest" soil and groundwater sample obtained from the first four borings/wells drilled at the site," Garrett said. "If it is not obvious from field vapor measurements which sample is the "hottest," then you need to make arrangements with your laboratory to rapidly analyze the most likely candidates so you do not exceed holding times. If the naphthalene sample exceeds 200 mg/kg for soil or 0.63 mg/L for groundwater, then you need to analyze that sample for the full set of PAHs."

### Other questions

One reader (e-mail April 27, 1997) posed the question of a receptor changing in the future. How could this be incorporated into the RBCA process, and what would the legal implications be? Garrett responded: "If the risk scenario changed significantly, we would examine the original RBCA evaluation and if necessary reopen the case and require further cleanup. This opens up a whole new set of difficult questions. Who is responsible for informing the OCC about the change in risk? If the site was cleaned up with a pay-for-performance contract, what further obligation does the Indemnity Fund have? If someone's health suffers due to this new exposure, who is responsible? What happens if a property owner intentionally changes the risk scenario to manipulate the RBCA process? Is the OCC Regulatory's mandate to be protective of human health. . . any less important at this site?"

### Other comments

This method of e-mail communication allows ORBCA to send out guidance communications efficiently and promptly. It helps the regulators and consultants to work out inconsistencies and promote policies that are economical and protective of human health and the environment. The e-mails also provided readers with

- a description of RBCA
- a list of errors that commonly occur in ORBCA reports submitted by consultants
- description of ORBCA's worksheets
- notices of proposed rule making and documents
- list of OCC contacts
- description of software (for instance, the Air Force's and EPA's Ada Lab's BIOSCREEN, which can be downloaded from Ada Lab's webpage (http://www.epa.gov/ada/kerrlab.html)
- discussion of ongoing cases, often very detailed, such as a comment that a consultant needed to limit the window of time over which data were collected
- discussion of topics of current interest (i.e., the nonpurge dilemma, UST certification, volumetric water content)
- symposium and meeting announcements

Other helpful information listed in Garrett's e-mails includes an interactive database that contains RBCA policy decisions for various states: http://www.gsi-net.com/RBCAPOL. To download a copy of OCC's rules, see their webpage (http://www.occ.state.ok.us) and click on "rules" in the paragraph for General Counsel.

Presently, Garrett is sending out his e-mails to about 380 addresses including those in 44 states and 15 countries. To get on his mail list and obtain e-mails of previously mailed e-mails, e-mail Neil Garrett at: Neil.Russell.a.Garrett@worldnet.att.net. Let him know your name, affiliation, city, state, country and field of specialty.

### Reference

Garrett, N. e-mails; contact him at above e-mail address for further information.

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***UTTU thanks Kate Becker, EPAOUST, and Neil Garrett, Oklahoma Corporation Commission, for their help on this article.***

# Information sources

### Publications

New publications from CRC Press include:

*Soil Processes and the Carbon Cycle*

*Management of Carbon Sequestration in Soil*

*Selections in Soil Science*

*Earthworm Ecology*

*Method for Assessment of Soil Degradation*

For more information call CRC Press at 1-800-272-7737, fax them at 1-800-374-3401, or visit their website (http://www.crcpress.com) or e-mail them at orders@crcpress.com.

*Conceptual Framework for Groundwater Quality Monitoring* is available at http://h2o.usgs.gov/public/WICP/rept.html

*Biodegradation Kinetics: Generation and Use of Data for Regulatory Decision Making*, 1997. Contact Setac Europe, Brussels, phone 32-2-772-7281 or fax 32-2-770-5386.

### Software

Supermodel, the ground water modeling CD-ROM put together by the National Ground Water Association, contains more than 125 models and sells for $250.
To order, call 800-551-7379.

### Websites

http://www.groundwatermodels.com, contains information on aquifer and slug test analysis

http://www.mindspring.corn/~rbwinston/NewMOD.html, contains new packages for MODFLOW

http://www.100folhas.pt/software/, contains freeware, shareware and demos

http://www.env-sol.com/solutions/EPAW.HTML for information on more than 300 U.S. EPA drinking water and wastewater test methods

http://www.dows.com.cn, Dow's investment, trading and environmental equipment and engineering site

http://www.gnet.org, technology cost guide from Los Alamos Laboratories

http://www.epa.gov/ada/models.html, download free models such as hydrocarbon spill screening model

http://www.osha.igs.net/~gaea, free demos for Win LOG, POLLUTEv6, MIGRATEv9

http://www.pardalis.com/resource.htm, to see text of Federal Register publication on Exxon Valdez Oil Spill; select "Laws and Regulations" then click on "Federal Register Online via Government Printing Office Access"

http://www.flowpath.com, Waterloo Hydrogeologic, Inc., for fracture flow modeling software packages (FRAC3DVS, FRACTRAN and FRACDENS) and other information

http://internet.ocii.com/~dalden/index.html, Public Health Inspector home page includes environmental health links

http://www.cfe.cornell.edu, Cornell Waste Management site

http://www.epa.gov/r10earth/offices/water/gwpu.htm, EPA Region 10 Ground Water Protection Unit home page

http://www.vanessen.com, environmental monitoring instruments

http://www.seispulse.com, geophysical applications

http://www.us.net/adept/links.html contains approximately 200 environmentally related links for government, industry and academia

http://www.gwrtac.org/, Groundwater Remediation Technologies Center

http://www.epa.gov/ada/kerrlab.html, EPA Kerr Lab

http://www.usgs.gov, U.S. Geological Survey home page

http://www.tradeshows-online.com, Environmental Tradeshow Online

http://www.ctech.com
Environmental Visualization System (EVS)

http://www.dnr.state.wi.us/eg/errhw/, Wisconsin DNR

### Listservs

To subscribe to the U.S. Geological Survey's listservs, send mail to listproc@listserver.usgs.gov. In the message's body, write subscribe (name of listserv) (your name). Example: subscribe water-pr Mary Doe. Individuals may subscribe to more than one list, but each request must be listed on a separate line. The listservs presently available include:

| | |
|---|---|
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| geological-hazards-pr | products-pr |
| biological-pr | lecture-pr |

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Many of these websites were obtained from the Bannister Research & Consulting GROUNDWATER Listserv (kenbannister@groundwater.com).

# The view from U.S. EPA: pay-for-performance cleanup agreements

A pay-for-performance (PFP) cleanup means that the overall price of a cleanup is fixed: the contractor receives payments as he/she reaches contaminant-reduction milestones. Paying for cleanups through PFP agreements rewards contractors for quickly and efficiently reaching cleanup goals. The contractor's profit comes from the difference between the actual internal cost of the cleanup and the price that had been set for the cleanup.

Four states—Florida, Georgia, Oklahoma and South Carolina—now have pay-for-performance UST cleanups underway, and more states are developing PFP initiatives. Utah recently held a PFP workshop to begin designing its PFP program.

The states' PFP initiatives differ. For example, Florida and Oklahoma estimate, then negotiate the price that is fixed for a cleanup. South Carolina requests competitive bidding, then gives all qualified contractors access to the site assessment and selects the lowest bid.

When PFP was first proposed, it was envisioned as applying primarily to relatively simple cleanups; however, states are now applying PFP to some complicated sites. For example, Oklahoma has awarded a PFP cleanup agreement for a site at which previous efforts failed despite $600,000 spent over several years. The PFP contractor has already significantly reduced contamination, and so the contractor has received the first performance payment. PFP states and contractors are also giving increasing attention to measuring and monitoring contaminant levels because lower levels can trigger a contractor payment.

More information about the details of PFP can be found via the PFP section of OUST's website at http://www.epa.gov./OUST/pfp/. In early 1998, OUST will offer an additional website where PFP cleanup contractors can post information about their sites including price, technology used, contaminant reductions and performance payments received. Individuals wanting more information about specific PFP cleanups/contractors will be able to obtain this information from the website. For instance, an overview on PFP measurement strategy and issues by Florida's Brian Dougherty has recently been posted on OUST's PFP webpages. In addition, individuals who want general information about PFP cleanups can download or order, from the website, OUST's "Pay-For-Performance Cleanups: Effectively Managing Underground Storage Tank Cleanups".

*For more information about PFP, please e-mail OUST's Bill Foskett at foskett.william@epamail.epa.gov.*

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