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5.8 Lessons Learned

Characterizing and remediating contaminated fractured rock sites is difficult. Common mistakes made at these sites are summarized in Table 5-4. This table is based on field experiences of members of the authoring team regarding fractured rock sites. These common mistakes should also be considered in unconsolidated systems.

Table 5-5 Common mistakes when characterizing a fractured rock system

Common Mistake	Consequence	Remedy
Using an equivalent porous medium (EPM) CSM to investigate a fractured rock system. Scenario: The most upgradient portion of the source area has achieved contaminant reduction goals (PCE, TCE, DCE, and VC) through groundwater extraction after 10 years of operation. Other areas of the source and down gradient areas remain above cleanup criteria. Being unaware of the differences between equivalent porous medium (EPM) and discrete fracture network (DFN) conceptual models and the scale, site conditions, and data quality objectives to which they apply.	Ignores heterogeneous internal structure of bedrock aquifer system and cannot provide a reliable basis for effective delineation or remediation.	Identify a CSM that is appropriate to the site location (fractured sedimentary bedrock, igneous, metamorphic, karst) and refine through appropriate characterization. The EPM model may be sufficient if contamination is limited to shallow weathered bedrock. See Modeling.
Installing monitoring wells at equal, predetermined, or arbitrary depths from surface	Fails to recognize that transmissive fractures are not likely to be oriented parallel to ground surface. Installation of wells at equal depths often results in wells that do not intersect the same water-bearing fracture, frustrating characterization, and delineation efforts. These wells may miss the transmissive fracture zone entirely and may be open to an aquitard unit that is a poor producer of water. The upgradient portion of the source area continues to be pumped from multiple wells at a rate of 70 gpm that appears to no longer be necessary, while other contiguous areas warrant continued groundwater extraction.	The internal structure/architecture of the fracture/aquifer system must be recognized and appropriate tools used to locate transmissive fractures that control groundwater flow at the site. Surface geochemical and geophysical tools can help locate transmissive fractures and, therefore, guide monitoring well installation.
Cross-connecting distinct fracture/water-bearing zones	Distinct fracture/water-bearing zones are sometimes cross-connected (particularly when long open boreholes are present, as in production wells) allowing contamination to vertically migrate through the borehole and contaminating deeper portions of the bedrock aquifer system.	Recognize that vertical cross-flows in an open borehole occur wherever transmissive fractures with different heads are penetrated. At DNAPL sites, an outside-in approach (USEPA 1992) should be used that requires that no borehole is drilled into the known or suspected source area until the site-specific hydrostratigraphy and source impacts on groundwater are well understood.

Common Mistake	Consequence	Remedy
Preparing isoconcentration plume maps as if contamination were in unconsolidated media, without representation of fracture zones	Determine remaining uncertainty in cessation of pumping in this area to enable termination of groundwater extraction while establishing criteria for monitoring the efficacy of terminating extraction in this area. Results in inaccurate and irregular groundwater flow directions. Findings regarding groundwater flow cannot be used to support an accurate delineation of the contaminant plume.	Use only wells intersecting the same fracture/water-bearing zone to determine groundwater flow direction and assess groundwater contamination in that zone. Discrete groundwater level measurements tools such as packers to isolate each fracture to determine their head levels.
Attempted remediation prior to proper characterization of the fractured rock system. Significant data gaps.	Inadequate understanding of the internal structure/architecture of the fracture/aquifer system leads to misdiagnosis of the contamination problem which frustrates and prolongs groundwater remediation efforts. • The potential for back-diffusion from bedrock is not understood. • The contaminant data from the extraction wells may represent a composite sample and concentrations above cleanup criteria may remain in discrete fractures. • The effect of terminating pumping in this area on the overall containment system is not understood.	Proper characterization by an experienced investigator is essential to the design of an effective remediation.
Misinterpretation of vertical hydraulic gradients in a saline fractured rock setting.	Potentially developing a CSM and remedial strategy based on incorrect understanding of the vertical flow gradient.	Adjust water level measurements for salinity/density effects.
Not determining if there is vertical hydraulic flow and if it displays seasonal fluctuation.	Misunderstanding contaminant transport.	Prepare time-series plots of vertical hydraulic gradients. Use transducers to graph relationships over time to further define the system.
Only collecting HPFM data under ambient conditions. Unclear or inadequate data collection requirements.	• Potentially misinterpreting the number of discrete samples from fractures • Fracture orientation • Fracture interconnectivity • Hydraulic conditions in a borehole, the absence of pumping	Collect data under both ambient and stressed conditions.
Disregarding historical water level data when preparing groundwater elevation contour figures.	Potentially demonstrating incorrect lateral groundwater flow directions as a result of including anomalous data.	Prepare time series plots showing historical and new water level data for each well for identifying, and evaluating/excluding, anomalous data points.
Incomplete upgradient delineation of contaminants.	May result in treatment or assumed responsibility for contamination from an upgradient/regional plume.	Perform detailed data analysis of the laboratory analytical results to confirm on-site origin.
Not investigating chemical speciation of individual plumes in a fractured rock system.	Potentially delineating the contaminant footprint as one large plume, when in fact there may be several separated plumes.	Illustrate the contaminant ratios for sampled locations and focus on the distribution of “tracer compounds”, which are low concentration constituents that would otherwise go unnoticed.

Common Mistake	Consequence	Remedy
Incomplete vertical delineation of contamination as a result of only sampling fractures with the highest transmissivity.	Collecting water samples that are biased low (diluted) when there may be fractures with less flow but higher concentrations.	Use geophysical logs or other transmissivity data to select multiple sample depths. Use discrete sampling methodology to determine the most transmissive zones and properly determine contaminant concentrations in each zone. Go to the tools/techniques table for: • Discrete sampling • Orientation • Connectivity
Not recognizing that the water level in an open borehole is often not the water table, but instead is either: 1) the head of a single confined fracture, or 2) the composite head of multiple confined fractures.	Incorrect interpretation of head distribution, gradient and flow.	Use borehole logging to identify transmissive fractures and packers (or equivalent) to quantify discrete fracture heads. Conduct testing to verify if it is a concern, packing and temperature and downhole conductivity monitoring can help to define active gain and loss fractures as well as to map the most dominant flow zones.
Not understanding how/where to sample an open borehole with inflowing and outflowing fractures.	Samples will likely underestimate the maximum concentration in a fracture.	Target transmissive fractures for sampling. Conduct testing to verify concerns; packing and temperature and downhole conductivity monitoring can help to define active gain and loss fractures as well as to map the most dominant flow zones.
Not taking full advantage of outcrops for observing and measuring fractures.	Missed opportunity for Free data. The Structural component of the CSM will be less thorough. May miss vertical or near vertical fractures, which are underrepresented in vertical boreholes.	The right cell should include: Included a qualified field geologist on the team.
Drilling deep, open boreholes through contamination; especially in areas with difficult to predict fracturing.	Cross-contaminating previously clean zones.	Assemble an experienced team of a driller/assistant and geologist who communicate and work well together. Stop at the first water-bearing fracture and sample with rapid turnaround (consider an on-site lab). Build flexibility into the plan. Be prepared to grout the hole. If the well is deep, be prepared to drill through a grouted hole. A vertical aquifer sampling program is highly recommended starting from top to bottom with a drilling program that prevents fluid movement between zones during collection of the samples. Casing advancement, grouting, packers, and a combination of techniques may need to be applied to properly characterize contaminant distribution on a newly investigated site
Not accounting for the effect of active supply wells on changing the gradients and contaminant transport.	Mischaracterization of a plume, putting sensitive receptors at risk.	Look beyond the boundaries of the site for pumping wells. Install pressure transducers as necessary to understand induced flow conditions.
Failure to use natural groundwater chemistry parameters to help understand groundwater flow direction.	Missed opportunity for relatively inexpensive data to improve CSM.	Include a person knowledgeable in groundwater geochemistry on the team.

Common Mistake	Consequence	Remedy
Not effectively or correctly collecting or using geophysical data from boreholes.	Missed opportunity to collect valuable information on: fracture locations and orientations; relations of fractures to stratigraphy; zones of inflows and outflows; borehole conditions such as rugosity and breakouts; and profiles of hydraulic conductivity. If information is improperly used or misinterpreted (generally due to an untrained or inexperienced person working with the data), inconsistencies with other data sets or incorrect input to the CSM could result.	Include professionals who are knowledgeable about borehole geophysical and hydrogeophysical logging and testing in the site characterization team from the beginning.