



Appendix C. Drilling

Choosing a drilling method to install a well for site characterization and remediation at a fractured rock site is based on the following considerations:

- an understanding of the relative advantages and disadvantages of various drilling methods
- the site conceptual flow model
- the monitoring and remediation program objectives
- the drilling and borehole data collection process
- monitoring or remedial well design

An overarching principle guiding the use of any drilling method at a fractured rock site is the prevention vertical cross contamination through the simple act of drilling a borehole. A contamination source is typically at the surface or in the shallow subsurface. An open borehole in bedrock is an unnatural condition whereby zones with different water level elevation, which are normally separated by rock, are interconnected thereby allowing water and contaminants, to flow vertically downward. The drilling process must be conducted in such a way as to prevent, or limit, the potential for the borehole to act as a vertical conduit for contamination to move from shallow to deeper zones in the fractured rock and thereby spread contamination and make characterization and remediation more difficult.

C.1. Drilling Methods

The drilling methods typically used at fractured rock sites include: [air rotary](#), [rock core](#), [water or mud rotary](#) (using a tricone bit), and [sonic](#). All drilling methods use a drilling fluid to cool and lubricate the drill bit and, if necessary, to maintain borehole stability and carry cuttings from the bottom of the borehole to the surface. When drilling in unconsolidated sediments, water-based drilling fluid or casing advance methods are typically used to keep the borehole open by countering hydrostatic forces in the formation.

Water-based drilling fluid is prepared by mixing water with an additive, typically powdered bentonite, a polymer, or both to increase the weight and viscosity of the fluid to facilitate cuttings removal. If a well is to be installed in the weathered bedrock zone (saprolite, the transition between the overburden and bedrock), then a water-based drilling fluid or a casing advance method typically must be used to maintain borehole stability. A casing may be advanced while drilling using either a rotary or sonic drilling method. In bedrock, the borehole stays open without the support of a water-based drilling fluid or a casing. Consequently, drilling methods which use air or water without additives as the drilling fluid are preferred because they facilitate using borehole for data collection prior to well construction and make well development more efficient, ensuring better communication between the well and formation.

The air rotary method uses air, often with some water added to control dust, as the drilling fluid. The air rotary method is relatively fast compared to other methods and is therefore often the most cost effective. Rock coring uses water as a drilling fluid and produces rock core suitable for logging and characterization, but is relatively expensive. The rotary drilling method can be conducted using water alone as the drilling fluid. However, use of drilling mud is often required to ensure adequate removal of cuttings. Likewise, the sonic method uses water, often with some bentonite added, as the drilling fluid to cool and lubricate the bit (cuttings are pushed to the side and rock ahead of the casing is removed with a core barrel). Because the drill bit is attached to the bottom of the casing, the sonic method also advances a casing as the borehole is advanced. The sonic drilling method provides a rock core as the borehole is advanced however the core is often broken up so rock coring using a diamond core bit is preferred if rock core is required for logging, sampling, or other characterization work. The [cable tool method](#) may also be used. This method uses drilling mud, but has the advantage of being able to advance a borehole under the most difficult drilling conditions.

Finally, the source of water used during drilling must be carefully selected and must be analyzed for all site related contaminants prior to use.

C-2. Site Conceptual Model and Well Location

The site conceptual model provides valuable information required to plan the drilling program such as overburden and

saprolite thickness, the type of rock underlying the drilling location, and the physical properties of the rock including the orientation of features such as joints and bedding. In addition, the target depth of the borehole is based on the conceptual flow model. Conversely, data collected during the drilling program is used to update, refine, and expand the conceptual flow model.

C.3. Monitoring and Remediation Program Objectives

Monitoring and remediation program objectives must be taken into consideration when selecting a drilling method for a given well. The first consideration is whether samples will be collected as the borehole is advanced and if data will be collected as the borehole is advanced or after the borehole is completed, but before the well is installed. This step is often necessary to achieve project objectives such as determining the extent and nature of contamination, collecting data on borehole transmissivity and feature orientation, and, at a minimum, data needed to design the well such as the location of transmissive zones. Borehole diameter is an important factor for project objectives. For example, most borehole geophysical methods work best in borehole between about 4 inches and 8 inches in diameter.

C.4. Drilling and Borehole Data Collection Process

The borehole drilling and well installation process must be conducted to meet project objectives, as follows:

- preventing unconsolidated or weathered bedrock (saprolite) from collapsing into the borehole
- preventing vertical migration of contaminants, including DNAPL, from the overburden, or shallow bedrock, deeper into the bedrock
- collecting data needed for site characterization and well design from the rock core or open hole
- completing the well successfully

For example, if the site is underlain by overburden, this region is typically cased off by advancing a borehole three to five feet into competent rock, installing a steel casing into the borehole, grouting the casing in place, and then allowing the grout to set before the borehole is advanced into bedrock. Because a well will not be installed in the overburden or weathered bedrock section of the borehole the full range of drilling methods may be used to install the casing, including those which use water/bentonite drilling fluid. The critical decision is the diameter of the casing because this distance controls the diameter of the borehole and well which can be installed in the fractured rock. For example, if a Westbay multilevel system or a 2-inch diameter screened well is being installed then a 4-inch casing may be sufficient because it will allow a 3 7/8-inch borehole to be drilled into bedrock. On the other hand, if a 4-inch diameter screened well or Water FLUTE is being installed, then a 6-inch diameter or 8-inch diameter casing would be required. Steel casing is typically used. If there are contaminants such as DNAPL present in the shallow bedrock, then this region may also be cased off before the borehole is advanced deeper into fractured rock.

Once the overburden and weathered rock are cased off, a borehole maybe advanced to depth using rock core to characterize rock lithology and to obtain samples for analysis of physical and chemical properties of the rock matrix and contaminants in the rock matrix. Alternatively, well screen or sampling zone placement may be determined by the depth to a specific lithologic unit best identified in rock core. At other locations where rock sampling is not required and logging from cuttings is sufficient to meet project objectives (precise lithologic control is not required), the borehole may be advanced to depth using air or water rotary methods.

C.5. Monitoring or Remedial Well Design

Using the results of the data collected during the drilling project, monitoring or remedial well designs are completed and the wells are installed. Three types of wells are commonly used for monitoring and site remediation at fractured rock sites: multilevel wells, screened wells, and open-hole wells. The design of each type of well influences the choice of drilling method. For example, if a multilevel well is selected for installation then rock coring should be considered as the drilling method because it provides a smooth borehole wall, compared to the air rotary method. A smooth borehole well facilitates a good packer or liner seal. If a conventional screened well or open-hole well is required, then the air rotary or water rotary method is typically used because it is less expensive than rock coring. Finally, wells must be constructed in accordance with any state or local regulatory requirements including but not limited to materials (such as grout recipe), borehole diameter, annular space, and maximum open or screened interval length.

In some cases, such as the installation of a screened monitoring well, the design may be completed or finalized in the field and the well installed immediately after (the same day) drilling is completed. In contrast, if multilevel wells are installed, data collected from the borehole must be compiled and analyzed, the design completed, the well fabricated, and then the

materials, equipment, and personnel must be mobilized to the site so that well construction can be completed. This process takes weeks to complete and during this time it is important the borehole be lined to prevent vertical fluid movement in the borehole.

C.6. Equipment Decontamination

Before first use at a site and after drilling and well installation at each location is completed, all downhole equipment and equipment in contact with groundwater must be thoroughly decontaminated to remove contaminants in accordance with the approved project plan.