



STANDARD OPERATING PROCEDURES

SOP No.: ERT-PROC-2048-20

PAGE: 1 of 18

REV: 1.0

EFFECTIVE DATE: 04/25/20

GROUNDWATER MONITORING WELL INSTALLATION

CONTENTS

DISCLAIMERS

1.0 SCOPE AND APPLICATION

2.0 METHOD SUMMARY

2.1 Hollow-Stem Augering

2.2 Cable Tool Drilling

2.3 Rotary Drilling

2.3.1 Mud Rotary Method

2.3.2 Air Rotary Method

2.4 Sonic Drilling

3.0 SAMPLE PRESERVATION, CONTAINERS, HANDLING, AND STORAGE

4.0 INTERFERENCES AND POTENTIAL PROBLEMS

4.1 Auger Drilling

4.2 Cable Tool Drilling

4.3 Rotary Drilling

4.3.1 Mud Rotary Drilling

4.3.2 Air Rotary Drilling

4.4 Sonic Drilling

5.0 EQUIPMENT/APPARATUS

6.0 REAGENTS

7.0 PROCEDURES

7.1 Preparation

7.2 Field Preparation

7.3 Well Construction

7.3.1 Bedrock Wells

7.3.2 Overburden Well Construction

7.4 Well Development

7.5 Investigation-Derived Waste Management

8.0 CALCULATIONS

9.0 QUALITY ASSURANCE/QUALITY CONTROL



STANDARD OPERATING PROCEDURES

SOP No.: ERT-PROC-2048-20

PAGE: 2 of 18

REV: 1.0

EFFECTIVE DATE: 04/25/20

GROUNDWATER MONITORING WELL INSTALLATION

CONTENTS (cont'd)

- 10.0 DATA VALIDATION
- 11.0 HEALTH AND SAFETY
- 12.0 REFERENCES
- 13.0 APPENDICES
 - A - Figures



STANDARD OPERATING PROCEDURES

SOP No.: ERT-PROC-2048-20

PAGE: 3 of 18

REV: 1.0

EFFECTIVE DATE: 04/25/20

GROUNDWATER MONITORING WELL INSTALLATION

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STANDARD OPERATING PROCEDURES

SOP No.: ERT-PROC-2048-20

PAGE: 4 of 18

REV: 1.0

EFFECTIVE DATE: 04/25/20

GROUNDWATER MONITORING WELL INSTALLATION

1.0 SCOPE AND APPLICATION

The purpose of this Standard Operating Procedure (SOP) is to provide an overview of the methods used for the installation of conventional groundwater monitoring wells. Groundwater monitoring well installation creates a permanent access for the collection of samples to assess groundwater quality and the hydrogeologic properties of the aquifer in which contaminants may exist. Such wells should not alter the medium that is being monitored.

The most commonly used drilling methods are hollow-stem auger, cable tool, hydraulic rotary and sonic. Rotary drilling can utilize mud rotary or air rotary methods.

Additional technical guidance and information pertaining to drilling, subsurface sampling, and design-installation of monitoring wells can be found in the following: American Society for Testing and Materials (ASTM), 2010; Environmental Protection Agency (EPA), 2013; and Ohio EPA, 2007 and 2008.

A Quality Assurance Project Plan (QAPP) in Uniform Federal Policy (UFP) format describing the project objectives must be prepared prior to deploying for a sampling event. The sampler needs to ensure that the methods used are adequate to satisfy the data quality objectives listed in the UFP-QAPP for a particular site.

The procedures in this SOP may be modified, dependent on site conditions, equipment limitations or other procedural limitations. In all instances, changes in the procedures employed must be documented on a Field Change Form and attached to the UFP-QAPP. These changes must be documented in the final deliverable.

2.0 METHOD SUMMARY

There is no ideal monitoring well installation method for all conditions; therefore, hydrogeologic conditions at the site, as well as project objectives, must be considered before deciding which drilling method is the most appropriate. Boreholes should be drilled and constructed to allow the proper construction of a monitoring well and must allow for the proper placement of a well screen so that chemical and physical parameters can be monitored.

2.1 Hollow-Stem Auguring

Successive 5-foot flights of hollow-stem augers, with outside diameters (O.D.) of 6.25 inches to 22 inches and corresponding inner diameters (I.D.) ranging from 2.25 inches to 13 inches are rotated into the ground to create a borehole. Auger lengths of 10 or 20 feet may be used for deeper holes drilled with machines capable of handling the extended lengths. Formation samples can be taken in a number of ways, depending on the accuracy required. Cuttings are brought to the surface by the rotation of the auger flights and may suffice for shallow depths but become less representative with depth, particularly below the water table. The most accurate samples are obtained with various coring devices, such as split spoons or Shelby tubes, which can be attached to center rods inside the augers. Cores may also be taken with a thin-walled tube sampler that is inserted into the lowest auger and locked in place. The tube is retracted with a wire line and hoist after the hole has been advanced the length of the auger. A bottom plug in the cutting head or bit prevents cuttings from entering the augers until the first core sample is taken and the plug is knocked out.

In unconsolidated material, the augers serve as a temporary casing. Filter-packed wells can be constructed inside the augers as the augers are retrieved from the borehole. Well development is usually less difficult than with wells drilled by the mud rotary method because a bentonite drilling



STANDARD OPERATING PROCEDURES

SOP No.: ERT-PROC-2048-20

PAGE: 5 of 18

REV: 1.0

EFFECTIVE DATE: 04/25/20

GROUNDWATER MONITORING WELL INSTALLATION

fluid is not typically used.

2.2 Cable Tool Drilling

Cable tool drilling is a percussion method in which a bit, attached to a weighted drilling string, is alternately lifted and dropped. The drilling string, consists (bottom to top) of the drill bit, drill stem, drilling jars, socket, and wire cable. A walking beam on the drilling rig provides the lifting and dropping motion to the wire cable and hence to the drilling string. The repeated action breaks or loosens the formation material, which mixes with formation water, or water can be added to the borehole by the operator, forming a slurry mixture. The slurry facilitates the removal of the cuttings, which are periodically removed from the borehole with a bailer. In unconsolidated formations, steel casing must be driven or pushed into the ground as the drilling progresses to maintain the wall of the borehole and prevent collapse. A hardened steel drive shoe on the bottom end of the casing prevents damage during drilling. A well may then be constructed inside the steel casing before the casing is pulled back. In consolidated formations, the casing may be driven through the weathered zone and seated in solid rock. The hole below the casing may remain open or may be fitted with a smaller diameter inner casing and screen, depending on the sampling requirements. Depending on formation material, extensive well development may often not be necessary.

2.3 Rotary Drilling

2.3.1 Mud Rotary Method

In the mud rotary method, the drill bit is rotated rapidly to cut the formation material and advance the borehole. The drill bit is attached to hollow drilling rods, which transfer power from the rig to the bit. In conventional mud rotary drilling, cuttings are removed by pumping drilling fluid (water, or water mixed with bentonite or other additives) down through the drill rods and bit, and up the annulus between the borehole and the drill rods. The drilling fluid flows into a mud pit where the cuttings settle out, and the "fluid" is pumped back down the drilling rods. The drilling fluid cools and lubricates the bit and prevents the borehole from collapsing in unconsolidated formations.

Sampling may be done from the cuttings, but these types of samples are generally mixed and the amount of fine material may not be accurately represented. Coring may be done through the drill rods and bit, if a coring bit (with a center opening big enough to allow passage of the coring tube) is used. When drilling unconsolidated formations, a temporary surface or shallow casing may have to be installed to prevent cross-contamination, borehole collapse, or wall erosion by the drilling fluid. Casing (riser pipe), screen, and filter pack are usually installed in the open hole or through the surface casing. Once the well is constructed, extensive well development may be necessary to remove drilling fluid from the formation.

2.3.2 Air Rotary Method

In the conventional air rotary method, the drill string operates in a manner similar to that described for the mud rotary system. In a "hammer" air rotary method, the bit is pneumatically driven rapidly against the rock in short strokes while the drilling string slowly rotates and uses air as the drilling fluid. Air is forced down the drill rods by an air compressor, escapes out of the bit and returns to the surface in the annular space between



STANDARD OPERATING PROCEDURES

SOP No.: ERT-PROC-2048-20

PAGE: 6 of 18

REV: 1.0

EFFECTIVE DATE: 04/25/20

GROUNDWATER MONITORING WELL INSTALLATION

the borehole wall and the drill string. Cuttings are moved out of the borehole by the ascending air and collect around the rig. Cuttings are mixed and may not always be representative of the depth currently being drilled. Air rotary methods are generally limited to consolidated and semi-consolidated formations. Casing is often used in semi-consolidated formations and through the weathered portion of consolidated formations to prevent borehole collapse or “caving in”. In environmental investigations, the air supply must be filtered to prevent introduction of any contamination into the borehole.

2.4 Sonic Drilling

A sonic drill is a rotary-vibratory drill capable of high drilling speeds as well as continuous coring that uses an adjustable high-frequency mechanical vibration to take continuous core samples of overburden soils and most hard rocks. The drill rig looks very much like a conventional air or mud rotary drill rig. The biggest difference is in the drill head, which is slightly larger than a standard rotary head. The head contains the mechanism necessary for rotary motion, as well as an oscillator, which causes an adjustable high frequency force to be superimposed on the drill string. The drill bit is physically vibrated up and down in addition to being pushed down and rotated. The amount of power applied is also adjustable in order to achieve optimal drilling conditions.

In overburden, the vibratory action causes the surrounding soil to fluidize. In rock, the drill bit causes fractures at the rock face, creating rock dust and small rock particles, which facilitates advancement of the drill bit. In many instances the drilling and coring of rock can be accomplished without the use of a drilling fluid.

Soil sampling can be performed using a 10-foot long core barrel that is rotated, advanced, and retrieved within the inner casing. Cores are then resonated from the core barrel into plastic sleeves, which are placed on aluminum trays. The cores are generally less disturbed than those obtained using a split-spoon sampler.

3.0 SAMPLE PRESERVATION, CONTAINERS, HANDLING, AND STORAGE

Often, a primary objective of the drilling program is to obtain representative lithologic or environmental samples. The most common techniques for retrieving samples are:

In unconsolidated formations:

- Shelby tube sampling, when an undisturbed sample is required from clay or silt soils, especially for geotechnical evaluation or chemical analysis
- Split spoon sampling when a reasonably undisturbed sample is required for geotechnical evaluation or chemical analysis
- Cutting collection, when a general lithologic description and approximate depths are sufficient

In consolidated formations:

- Rock coring at continuous or discrete intervals
- Cutting collection, when a general lithologic description and approximate depths are sufficient

Samples should, however, be cooled to less than or equal to (\leq) 6 degrees Celsius ($^{\circ}\text{C}$) and protected from sunlight to minimize degradation and any potential reaction due to the light sensitivity of the sample. The amount of sample to be collected, the proper sample container (i.e. glass, plastic), chemical preservation, and



STANDARD OPERATING PROCEDURES

SOP No.: ERT-PROC-2048-20

PAGE: 7 of 18

REV: 1.0

EFFECTIVE DATE: 04/25/20

GROUNDWATER MONITORING WELL INSTALLATION

storage requirements are dependent on the matrix being sampled and the parameter(s) of interest which are discussed in Environmental Response Team (ERT) SOP, *Sample Storage, Preservation and Handling*.

4.0 INTERFERENCES AND POTENTIAL PROBLEMS

The advantages and disadvantages of the various drilling methods are listed and summarized below:

4.1 Auger Drilling

The advantages of auger drilling are:

- Relatively fast and inexpensive
- Because augers act as temporary casing, drilling fluids are not used, resulting in reduced well development
- Allows collection of split spoon samples

The disadvantages of auger drilling are:

- Very slow or impossible to use in coarse materials such as cobble or boulders
- Cannot be used in unweathered consolidated formations and is generally limited to depths of approximately 100 feet below ground surface in order to be efficient

4.2 Cable Tool Drilling

The advantages of cable tool drilling are:

- Relatively inexpensive with minimum labor requirements
- Water table and water bearing zones are easily identified
- Driven casing stabilizes the open borehole and minimizes potential for cross-contamination
- Especially successful in caving formations or formations containing boulders (unconsolidated and consolidated medium hard to hard rock)
- Accurate formation samples can usually be obtained from cuttings

The disadvantages of cable tool drilling are:

- Extremely slow rate of drilling
- Necessity to drive casing may limit depth in large diameter holes

4.3 Rotary Drilling

4.3.1 Mud Rotary Drilling

The advantages of mud rotary drilling are:

- Fast, typically more than 100 feet of borehole advancement per day
- Provides an open borehole, necessary for some types of geophysical logging and other tests

The disadvantages of mud rotary drilling are:

- Potential for cross-contamination of water-bearing zones
- Drill cuttings may be mixed and not accurately represent lithologies at a given drilling depth
- Drilling mud may alter the groundwater chemistry/geochemistry
- Water levels can only be determined by constructing wells



STANDARD OPERATING PROCEDURES

SOP No.: ERT-PROC-2048-20

PAGE: 8 of 18

REV: 1.0

EFFECTIVE DATE: 04/25/20

GROUNDWATER MONITORING WELL INSTALLATION

- Drilling mud may change local permeability of the formation and may not be entirely removed during well development
- Disposal of large volumes of drilling fluid and cuttings may be necessary if they are contaminated

4.3.2 Air Rotary Drilling

The advantages of air rotary drilling are:

- Very fast, typically more than 100 feet of borehole advancement a day
- Preliminary estimates of well yields and water levels are often possible
- No drilling mud to plug the borehole
- Economical for deep water wells

The disadvantages of air rotary drilling are:

- Generally cannot be used in unconsolidated formations
- In contaminated zones, the use of high-pressure air may pose a significant hazard to the drill crew because of transport of contaminated material up the hole
- Introduction of air to the groundwater could reduce concentration of volatile organic compounds (VOCs)

4.4 Sonic Drilling

The advantages of sonic drilling are:

- Very fast drilling, more than 100 feet of borehole advancement a day
- Drilling can be done in almost all types of lithology
- Generally, no need to use a drilling fluid other than potable water

The disadvantages of sonic drilling are:

- Expensive method

5.0 EQUIPMENT/APPARATUS

The following equipment is necessary for the site geologist/hydrogeologist:

- Metal clipboard box case
- Ruler
- Depth sounder
- Water level indicator
- Water/phase probe indicator
- Bailer
- Rope
- Knife (with locking blade)
- Personal Protective Equipment (PPE)
- Sample collection jars (i.e. glass, plastic, etc.)
- Aluminum trays
- Soil description aids such as Munsell® color and grain-size charts
- Field Logbook or Field Data Sheets

Drilling equipment, tools, and construction materials required for well installation are usually provided by



STANDARD OPERATING PROCEDURES

SOP No.: ERT-PROC-2048-20

PAGE: 9 of 18

REV: 1.0

EFFECTIVE DATE: 04/25/20

GROUNDWATER MONITORING WELL INSTALLATION

the drilling contractor.

6.0 REAGENTS

Reagents are generally not required for preservation of soil samples. Decontamination solutions are specified in the ERT SOP, *Sampling Equipment Decontamination*, and the site-specific UFP-QAPP.

7.0 PROCEDURES

7.1 Preparation

All drilling and monitoring well installation programs must be planned and supervised by a licensed professional geologist/hydrogeologist.

The planning, selection and implementation of any monitoring well installation program should include the following:

- Review of existing data on site geology and hydrogeology including publications, aerial photographs, water quality data, and existing maps. These may be obtained from local, state and federal agencies.
- Ensure the drilling subcontractor has obtained all local, state, and federal licenses and/or permits required to drill and install monitoring wells.
- Assess the site to determine potential access problems (i.e. overhead obstructions) for drill rig, locate water supply sources, establish equipment storage area, and observe outcrops.
- Perform utilities check, note location of underground and aboveground utility lines and obstructions.
- Prepare a site-specific Health and Safety Plan (HASP).
- Select drilling, sampling and well development methods.
- Determine the well construction specifications (i.e., casing and screen materials; casing and screen diameter; screen length and screen interval; filter pack and screen slot size; etc.).
- Determine the need for containing drill cuttings and fluids and their method of disposal.
- Prepare the site-specific UFP-QAPP including all of the above.
- Prepare and execute the drilling contract as written.

7.2 Field Preparation

Prior to mobilization, the drill rig and all associated equipment must be thoroughly decontaminated by a steam/pressure washer to remove all soil and residue materials. Prior to drilling each boring, all drilling equipment is required to be steam cleaned and rinsed with potable water to prevent cross-contamination. It is required that all drilling equipment be steam-cleaned at completion of the



STANDARD OPERATING PROCEDURES

SOP No.: ERT-PROC-2048-20

PAGE: 10 of 18

REV: 1.0

EFFECTIVE DATE: 04/25/20

GROUNDWATER MONITORING WELL INSTALLATION

project to ensure that no contamination is transported from the site.

7.3 Well Construction

The well casing material must not interact with the groundwater. Well casing for environmental projects is usually constructed of polyvinyl chloride (PVC) or stainless steel. Details of the construction methods are given in Sections 7.3.1 and 7.3.2.

7.3.1 Bedrock Well Construction

Wells installed in bedrock will be drilled using the air or mud rotary or sonic methods. Crystalline rock wells are usually drilled most efficiently with the air rotary method while consolidated sedimentary formations are drilled using either the air rotary or mud rotary method. The compressed air supply will be filtered prior to introduction into the borehole to remove oil or other contaminants. Bedrock wells may be completed as an open-hole, providing that borehole “cave-in” is not a possibility.

Bedrock wells will be advanced with air or mud rotary methods until a minimum of 5 feet of competent rock has been drilled. The minimum borehole diameter will be at least 2 inches greater than the well diameter. The drill string will then be pulled from the borehole followed by insertion of an appropriate diameter Schedule 40 or Schedule 80 PVC casing. Portland cement/bentonite grout will be pumped through a tremie pipe (placed at the bottom of the borehole) into the annular space outside the casing. After the cement grout has cured (minimum of 24 hours), it will be drilled-out (if needed) and then the borehole will be advanced to the final desired depth. Figure 1, Appendix A depicts typical construction details for an open-hole bedrock well.

The preferred method of well completion for the bedrock wells will be open-hole. However, if the open borehole is subject to “cave-in”, the well will be completed as a screened and cased filter-packed well. For completion details, see Section 7.3.2.

7.3.2 Overburden Well Construction

Any of the drilling methods discussed in this SOP can be used to drill or set a well in the overburden. Hollow-stem auguring method is the preferred choice for shallow (less than [$<$] 100 feet total depth) overburden wells because the well can be constructed inside of the augers. Details of the well construction are provided below and are shown in Figure 2, Appendix A.

1. The screen slot size will be determined by the site geologist/hydrogeologist, based on the filter-pack size. The length of screen used will be site-dependent. Casing sections will be flush-threaded. Screw-threaded bottom plugs will be used. To prevent introduction of contaminants into the well, no glue-connected fittings will be used. Each piece of PVC pipe, screen, and the bottom plug will be steam-cleaned or certified-clean by the manufacturer before lowering into the borehole. The site geologist/hydrogeologist is responsible for supervising all steam cleaning procedures.
2. The annular space between the well screen and the borehole wall will be filled with a uniform gravel/sand to serve as a filter pack. For wells deeper than 50 feet or when



STANDARD OPERATING PROCEDURES

SOP No.: ERT-PROC-2048-20

PAGE: 11 of 18

REV: 1.0

EFFECTIVE DATE: 04/25/20

GROUNDWATER MONITORING WELL INSTALLATION

recommended by the site geologist, the filter pack will be emplaced using a tremie pipe. A sand-slurry composed of sand and potable water will be pumped through the tremie pipe into the annulus throughout the entire screened interval, and over the top of the screen. Allowance must be made for settlement of the sand pack. This may be accomplished by gently surging the filter pack prior to installing the annular seal. Additional sand may need to be added to compensate for settlement.

3. Depth to the top of the sand will be determined using the tremie pipe and a weighted measuring tape, thus verifying the thickness of the sand pack. Additional sand will be added to bring the top of the sand pack to approximately 2 to 3 feet above the top of the well screen.

Under no circumstances should the sand pack extend into any aquifer other than the one to be monitored. In most cases, the well design can be modified to allow for a sufficient sand pack without a threat of cross-flow between producing zones through the filter pack.

4. For materials that will not maintain an open borehole, the temporary or outer casing will be withdrawn gradually during placement of the filter pack/grout. For example, after filling 2 feet with sand pack, the outer casing should be withdrawn 2 feet. The procedure of placing more sand and withdrawing the outer casing should be repeated until the level of the sand pack is approximately 3 feet above the top of the well screen. This ensures there is no locking of the inner casing within the outer casing.
5. A bentonite seal of a minimum 2-foot vertical thickness will be placed in the annular space above the sand pack to separate the sand pack from the cement surface seal. The bentonite will be placed through a tremie pipe or poured directly into the annular space, depending upon the depth and site conditions. The bentonite will be pourable pellets. The geologist/hydrogeologist will record the start and stop times of the bentonite seal emplacement, the interval of the seal, the amount of bentonite used, and any problems that arise. The type of bentonite and the supplier will also be recorded.

A cap placed over the top of the well casing, before pouring the bentonite pellets, will prevent pellets from entering the well casing.

6. If a slurry mixture of bentonite is used as an annular seal, it is prepared by mixing powdered or granular bentonite with potable water. The slurry must be of sufficiently high specific gravity and viscosity to prevent its displacement by the grout to be emplaced above it. As a precaution (regardless of depth) and depending on fluid viscosity, a few handfuls of bentonite pellets may be added to solidify the bentonite slurry surface.
7. Cement and/or bentonite grout is placed from the top of the bentonite seal to the ground surface.

Only Type I (normal) or II (sulfate resistant) cement without accelerator additives should be used. An approved source of potable water must be used for mixing grout materials. The following mixes are acceptable:



STANDARD OPERATING PROCEDURES

SOP No.: ERT-PROC-2048-20

PAGE: 12 of 18

REV: 1.0

EFFECTIVE DATE: 04/25/20

GROUNDWATER MONITORING WELL INSTALLATION

- Neat cement, a maximum of 6 gallons of water per 94 pound bag of cement
 - Granular bentonite, 1.5 pounds of bentonite per 1 gallon of water
 - Cement-bentonite, 5 pounds of pure bentonite per 94 pound bag of cement with 7-8 gallons of water
 - Cement-bentonite, 6 to 8 pounds of pure bentonite per 94 pound bag of cement with 8-10 gallons of water, if water mixed
 - Non-expandable cement, mixed at 7.5 gallons of water to ½ teaspoon of Aluminum Hydroxide, 94 pounds of cement (Type I) and 4 pounds of bentonite
 - Non-expandable cement, mixed at 7 gallons of water to ½ teaspoon of Aluminum Hydroxide, and 94 pounds of cement (Type I and Type II)
8. Grout is pumped through a tremie pipe (usually a 1.25-inch PVC or steel pipe) to the bottom of the annulus until undiluted grout flows from the annulus at the ground surface.
 9. In materials that will not maintain an open hole, the temporary steel casing should be withdrawn in a manner that prevents the level of grout from dropping below the bottom of the casing.
 10. Additional grout may be added to compensate for the removal of the temporary casing and the tremie pipe to ensure that the top of the grout is at or above ground surface. After the grout has set (about 24 hours), any depression due to settlement is filled with a grout mix similar to the one described above.
 11. The protective casing should be set at this time. The casing may be a 5-foot minimum length of black iron or galvanized pipe extending about 1.5 to 3 feet above the ground surface, and set in concrete or cement grout. The protective casing diameter should be at least 2 inches greater than the well casing. A 0.5-inch drain hole may be installed near ground level. A flush-mount protective casing may also be used in areas of high traffic or where access to other areas would be limited by a well stick-up.
 12. A protective steel cap, secured to the protective casing by a padlock, should be installed.
 13. Steel guard posts should be installed around the protective casing in areas where vehicle traffic may be a safety hazard. Posts should have a minimum diameter of 3 inches and be a minimum of 4 feet high.
 14. All monitoring wells must be labeled and dated with permanent paint or steel tags.

7.4 Well Development

Well development is the process by which the aquifer's hydraulic conductivity is restored by removing drilling fluids, and fine-grained formation material from newly installed wells. Two methods of well development that are commonly used are surging and bailing, and over-pumping. A well is considered developed when the pH and conductivity of the groundwater stabilizes and the measured turbidity is <50 nephelometric turbidity units (NTUs).



STANDARD OPERATING PROCEDURES

SOP No.: ERT-PROC-2048-20

PAGE: 13 of 18

REV: 1.0

EFFECTIVE DATE: 04/25/20

GROUNDWATER MONITORING WELL INSTALLATION

Surging and bailing will be performed as follows:

1. Measure the total depth (TD) of the well and depth to water (DTW).
2. Using an appropriately-sized surge block, surge 5-foot sections of well screen, using 10-20 up/down cycles per section. Periodically remove the surge block and bail accumulated sediment from the well, as required.
3. For open-hole wells, a 6-inch surge block will be used inside the cased portion of the well. Sediments will be bailed periodically, as required. Over-pumping may be used in combination with surging and bailing for development of bedrock wells. The method (s) used will be based on field conditions encountered, and will be determined by the site geologist/hydrogeologist. However, sediment will initially be removed from the wells by bailing to minimize the volume of development water generated.

The pump used must be rated to achieve the desired yield at a given depth. The pump system should include the following:

- A check valve to prevent water from running back into the well when the pump is shut off
- Flexible discharge hose
- Safety cable or rope to remove the pump from the well
- Flow meter (measuring bucket or inline flow meter)
- Generator
- Amp meter to measure electrical current (load)

The amp meter is used to monitor pump performance. If the pump becomes clogged, the amperage will increase due to stress on the pump. If the water level drops below the intake ports, the current will drop due to decreased resistance on the pump. Please refer to ERT SOP, *Monitoring Well Development* for more details.

7.5 Investigation-Derived Waste Management

The drilling and development of groundwater monitoring wells will generate solid and liquid investigation-derived waste (IDW). The IDW will need to be contained, properly stored, and adequately characterized, and transported by a licensed hauler for disposal. Manifests documenting the ultimate disposition of the IDW should be retained by the responsible party installing the groundwater monitoring wells.

8.0 CALCULATIONS

To maintain an open borehole during rotary drilling, the drilling fluid must exert a pressure greater than the formation pore pressure. Typical pore pressures for unconfined and confined aquifers are 0.433 pounds per square inch per foot (psi/ft) and 0.465 psi/ft, respectively.

The relationship for determining the hydrostatic pressure of the drilling fluid is:

$$\text{Hydrostatic Pressure (psi)} = \text{Fluid Density (lb/gal)} \times \text{Height of Fluid Column (ft)} \times 0.052 \text{ (Equation 1)}$$

The minimum grout volume necessary to grout a well can be calculated using:



STANDARD OPERATING PROCEDURES

SOP No.: ERT-PROC-2048-20

PAGE: 14 of 18

REV: 1.0

EFFECTIVE DATE: 04/25/20

GROUNDWATER MONITORING WELL INSTALLATION

$$\text{Grout Volume (ft}^3\text{)} = \text{Volume of Borehole (ft}^3\text{)} - \text{Volume of Casing (ft}^3\text{)} = \pi L (r_B^2 - r_C^2) \text{ (Equation 2)}$$

Where,

- L = length of borehole to be grouted (ft)
- r_B = radius of boring (ft)
- r_C = radius of casing (ft)

9.0 QUALITY ASSURANCE/QUALITY CONTROL

There are no specific quality assurance activities that apply to the implementation of these procedures. However, the following general Quality Assurance (QA) procedures apply:

1. All data must be documented on standard well completion forms, field data sheets or within field/site logbooks.
2. All instrumentation must be operated in accordance with the operating instructions as provided by the manufacturer, unless otherwise specified in the UFP-QAPP. Equipment checkout and calibration activities must occur prior to sampling/operation and must be documented.

10.0 DATA VALIDATION

Data verification (completeness checks) must be conducted to ensure that all data inputs are present for ensuring the availability of sufficient information. This may include but is not limited to well identification; identifications of driller installing the well and geologist supervising the construction; top of casing elevation and horizontal coordinates; depth and diameter of boring; protective wellhead completion (vault or monument); diameter and type of surface and isolation casing, if present; well cap type; screen type, slot size, and interval; annular materials such as sand pack, choke sand, and grout type; and dates the well construction started and ended. These data are essential to providing an accurate and complete final deliverable. The contractor's Task Leader (TL) is responsible for completing the UFP-QAPP verification checklist for each project.

11.0 HEALTH AND SAFETY

Based on Occupational Safety and Health Administration (OSHA) requirements, a site-specific health and safety plan (HASP) must be prepared for response operations under the Hazardous Waste Operations and Emergency Response (HAZWOPER) standard, [29 CFR 1910.120](https://www.ecfr.gov/current/title-29/chapter-I/subchapter-B/part-1910/section-1910.120). Field personnel working for EPA's ERT should consult the Emergency Responder Health and Safety Manual currently located at <https://response.epa.gov/HealthSafetyManual/manual-index.htm> for the development of the HASP, required personal protective equipment (PPE) and respiratory protection.

12.0 REFERENCES

American Society for Testing and Materials (ASTM). 2010. Standard Practice for Design and Installation of Ground Water Monitoring Wells. ASTM D5092-04 (Reapproved 2010).

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STANDARD OPERATING PROCEDURES

SOP No.: ERT-PROC-2048-20

PAGE: 15 of 18

REV: 1.0

EFFECTIVE DATE: 04/25/20

GROUNDWATER MONITORING WELL INSTALLATION

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13.0 APPENDICES

A - Figures



STANDARD OPERATING PROCEDURES

SOP No.: ERT-PROC-2048-20

PAGE: 16 of 18

REV: 1.0

EFFECTIVE DATE: 04/25/20

GROUNDWATER MONITORING WELL INSTALLATION

APPENDIX A

Figures

SOP: ERT-PROC-2048-20

April 2020



STANDARD OPERATING PROCEDURES

SOP No.: ERT-PROC-2048-20

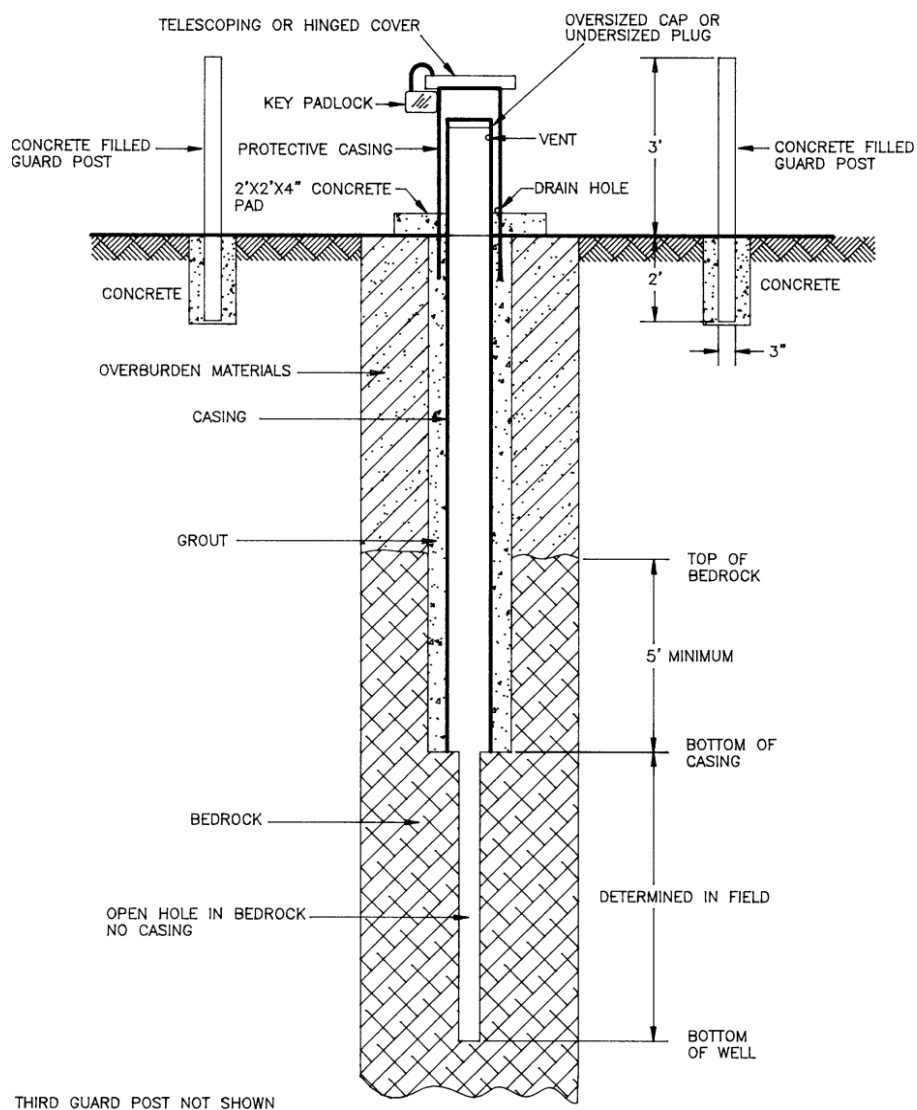
PAGE: 17 of 18

REV: 1.0

EFFECTIVE DATE: 04/25/20

GROUNDWATER MONITORING WELL INSTALLATION

FIGURE 1. Typical Bedrock Well Construction





STANDARD OPERATING PROCEDURES

SOP No.: ERT-PROC-2048-20

PAGE: 18 of 18

REV: 1.0

EFFECTIVE DATE: 04/25/20

GROUNDWATER MONITORING WELL INSTALLATION

FIGURE 2. Typical Overburden Well Construction

