STANDARD OPERATING PROCEDURE

THREE

MONITORING WELL DESIGN AND INSTALLATION

Modified from

U.S. Environmental Protection Agency Environmental Response Team

Response Engineering and Analytical Contract

Standard Operating Procedures

Drilling and Monitoring Well Installation

at Hazardous Waste Sites in South Dakota

SOP 2150

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1.0 SCOPE AND APPLICATION

The purpose of monitoring wells is to provide access to ground water and other fluids at specific locations and depths. Fluid elevations, samples for chemical analysis, and other information may be obtained from properly constructed monitoring wells. Monitoring wells must be carefully constructed to provide accurate, representative information and minimally alter the medium which is being monitored.

There is no "ideal" monitoring well design. Monitoring wells should be located and designed according to a comprehensive monitoring plan, based upon an understanding of the hydrogeology of the area. Screen length and placement must be carefully chosen because they may have a profound effect upon the reliability and usability of subsurface data. The physical characteristics of potential or known contaminants (lighter or denser than water, miscible or immiscible in water) may dictate screen placement at the surface or at the base of an aquifer or require specific well equipment or well design. Chemical compatibility of well construction materials and equipment with potential or known contaminants must be considered. Well drilling methods, discussed below, also must be chosen carefully with adequate consideration given to the site geology and hydrogeology, the proposed uses and design of the well, and the nature of the contaminants which may be present.

2.0 METHODS

Monitoring wells in South Dakota must be adapted to a number of purposes in widely varying local geologic and hydrologic conditions. Consequently, there is no ideal monitoring well installation method. 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and hydrogeology including South Dakota Geological Survey (SDGS) and U.S. Geological Survey (USGS) publications and unpublished databases (available at SDGS, Vermillion, South Dakota, and USGS, Rapid City and Huron, South Dakota), county soils surveys (available from the county Soil Conservation Service [SCS] offices), air photos (available from county SCS offices and Earth Resources Observation Systems [EROS] Data Center, Baltic, South Dakota), water- quality data (available at SDGS and the South Dakota Department of Environment and Natural Resources [DENR], Division of Water Rights), and existing maps available from local, state, or federal agencies. Maps and photos showing historical land uses from local city or county planning agencies and historical societies or groups may also be significant. Every effort should be made to collect and review all applicable field and laboratory data from previous investigations of the project area.

A visit to the site to observe field geology and potential access problems for a drilling rig, to secure a water supply for drilling (if needed), and to check for hazards to personnel and equipment (such as utilities on and near the site).

- Preparation of site safety plan in compliance with applicable U.S. Environmental Protection Agency (U.S. EPA) and Occupational Safety and Health Administration (OSHA) guidelines.

- Definition of project objectives, selection of drilling, well development, and sampling methods.

- Selection of well-construction materials including well-construction specifications (i.e., casing and screen materials, casing and screen diameter, screen length and interval, and filter pack and screen size).

- Determine need for containing and disposing of potentially contaminated soil and water generated by the monitoring well installation process.

- Preparation of written work plan including site safety plan, definition of objectives and work methods, listing of material and equipment specifications, and plan for disposal/treatment of contaminated materials.

- Preparation and execution of the drilling contract.

- Field implementation of the drilling program.

- Final report preparation including background data, project objective, field procedure, and well-construction data, including well logs and well-construction information.

All drilling activities must be performed by a contractor licensed by the Division of Water Rights, DENR (phone 605-773-3352). Well-construction standards (Administrative Rules of South Dakota [ARSD] 74:02:04) which govern test-hole drilling, monitoring-well drilling, and other drilling related to water resources are available from the Division of Water Rights. The driller must apply for a variance if the planned monitoring wells will not meet the well-construction standards. All drilling and well-installation programs must be under the supervision of a certified petroleum release assessor or remediator.

2.1 Drilling Methods

Monitoring wells may be constructed in holes drilled by any of several methods. The most commonly used drilling methods are:

- Hollow-stem auger
- Solid-stem auger
- Bucket auger
- Direct-mud rotary
- Reverse-air rotary
- Cable tool

The type of equipment used depends upon the site geology, hydrology, equipment available, and monitoring design. Control of cuttings and other potentially contaminated materials at the drill site may influence drilling method selection. Depending upon equipment availability and site geology, more than one method may be combined to complete a particular monitoring well installation. The reader is referred to the Standard Operating Procedure for Drilling Methods (SOP 9) for a complete discussion of available drilling methods.

3.0 EQUIPMENT

Verify that the drilling contractor will arrive onsite with all proper and operational equipment for the drilling program outlined in the work plan and contract. The consultant should bring at a minimum:

- Well-logging forms
- Ruler and other measuring apparatus for verifying well and hole depths, water levels, and equipment dimensions.
- All required health and safety gear (i.e., a hard hat, steel-toed boots, hearing and eye protection); refer to applicable OSHA and U.S. EPA guidance documents.
- Contaminant-detection equipment appropriate with information derived during the program-planning stage and in the site-safety plan.
- Sample-collection containers, plastic Ziploc® bags (quart and gallon sizes), or other containers, as appropriate.
- Trowels, knives, hammers, chisels, as appropriate.
- Description aids (Munsell-color charts, grain-size charts, etc.) as appropriate.

4.0 REAGENTS

No chemical reagents are used in this procedure. Decontamination of drilling equipment should follow the Standard Operating Procedures on Sampling Equipment Decontamination and a site specific work plan.

5.0 PROCEDURES

5.1 Drilling Equipment Cleaning and Decontamination

Prior to mobilization, the drill rig and all associated equipment should be thoroughly cleaned to remove all oil, grease, mud, etc. Any equipment that is not required at the site should be removed from the rig prior to entering the site. To the greatest extent possible, drilling should proceed from the least to most contaminated sections of the work site.

Before drilling each boring, all the down-the-hole drill equipment, the rig, and other equipment (as necessary) should be steam cleaned, or cleaned using high-pressure hot water, and rinsed with pressurized potable water to minimize cross contamination, if appropriate. Special attention should be given to the thread section of the casings and to the drill rods. Additional cleaning may be necessary during the drilling of individual holes to minimize the carrying of contaminated materials from shallow to deeper strata by contaminated equipment.

Equipment with porous surfaces, such as rope, cloth hoses, and wooden blocks or tool handles cannot be thoroughly decontaminated. These should be disposed of properly at appropriate intervals. These intervals may be the duration of drilling at the site, between individual wells, or between stages of drilling a single well, depending upon characteristics of the tools, site contamination, and other considerations.

Cleaned equipment should not be handled with soiled gloves. Surgical gloves, new clean cotton work gloves, or other appropriate gloves should be used and disposed of when even slightly soiled. The use of new painted drill bits and tools should be avoided since paint chips will likely be introduced to the monitoring system.

All drilling equipment should be steam cleaned or cleaned using high-pressure hot water, if appropriate, at completion of the project to ensure that no contamination is transported from the sampling site.

The Standard Operating Procedures on Sampling Equipment Decontamination (SOP #8) should be consulted for further details.

The Standard Operating Procedures on Handling Investigation Derived Waste should be consulted for guidance on handling and disposing of decontamination liquids.

5.2 Field Recording and Logging

Lithologic description and all field measurements and comments are to be recorded on the well-log form. The reader is referred to the Standard Operating Procedure for Field Documentation for details on field recording and logging. At a minimum, the following should be recorded on the well-log form:

- Name and complete mailing address of the site;
- Legal description of the well location
- Completion date
- Driller's log of geologic formations (and description thereof) plus any geophysical logs collected
- Well depth
- Depth to static-water level
- Size of the drill hole and method of drilling
- Length, depth, and size of the casing; changes in size of the casing and type of casing
- The amount, type, slurry weight, and location of grout used in the hole; a narrative description of the grouting procedure
- The location and type of packers used in the hole
- The length of the screen or casing perforations

- The location of the top and bottom of the screen, the top and bottom of the aquifer, and the location of multiple screens

- The screen slot or perforation size

- The gravel pack and its volume, type, or size

- Well-test data that include specific capacity, static-water level, flow, shut-in pressure, or pump-test data, if available

- The type and method of disinfection, if used

- The date and signature of the license representative (South Dakota well driller's license)

In addition, the well form should identify the datum from which well measurements are made, the depth of the drilled hole, and the height of riser pipe above the ground. The datum should be a bench mark whenever possible or a permanent structure. Monitoring wells should not be used as datum points for other monitoring wells except at sites were no other points are available.

5.3 Well Construction (See Figure 1)

5.3.1 Well-Construction materials

The most commonly used casing materials include stainless steel, polyvinyl chloride (PVC) and Teflon. Monitor well casing and screen materials should be selected to be structurally competent to withstand any mechanical, hydrodynamic, or chemical stresses anticipated to be present on the site. The casings should preclude the movement of fluids into the well bore except where intended by the well designer.

All well construction materials must be new, steam cleaned or cleaned using high-pressure hot water, if appropriate, and protected from contamination at the well site. Well-site safeguards should include keeping all materials covered with plastic sheeting, off the ground, and ensuring that they are touched only with clean tools and gloves. Equipment or materials to be inserted into the bore hole must not be allowed to touch the ground.

Monitoring-well casing and screen must be of sufficient diameter to achieve the purposes of the well. Normal sampling operations typically require casing which has an inside diameter greater than or equal to 2 inches, though some well-monitoring apparatus may require much larger casing. Additional criteria are drilling method used, well depth (strength requirements), well-development requirements (contaminated-water disposal), pre-sampling well purging volumes (contaminated-water disposal), rate of recovery, and costs.

ARSD 74:02:04:52 requires that casing centralizers "designed to create minimum obstruction in the annulus" and "compatible with casing materials" will be installed "at sufficient intervals to center the casing in the drill hole." These centralizers will be "designed to provide a uniform annulus and to minimize cement channeling and to allow grout to completely surround the casing." One centralizer is required near the bottom of each size of grouted casing. Additional centralizers may be necessary to ensure that the casing remains centered in the bore hole.

Mechanical and hydrodynamic stability of monitoring-well casing and screens are generally measured in terms of "collapse strength," or the ability of the casing to maintain its cylindrical shape during and after installation. American Society for Testing and Materials standard F 480 (American Society for Testing and Materials, 1989) should be consulted for aid in specifying casing materials. Other structural considerations also must be considered. Barcelona and Helfich (1988) has suggested that 2-inch diameter Schedule 40 Teflon pipe not be installed to greater than 320 feet, based upon tensile strength calculations.

ARSD 74:02:04:43 requires PVC casing 5 inches or more in diameter to have 0.25 inch or greater wall thickness.

The possibility of casing collapse can be minimized by attention to some important installation method details:

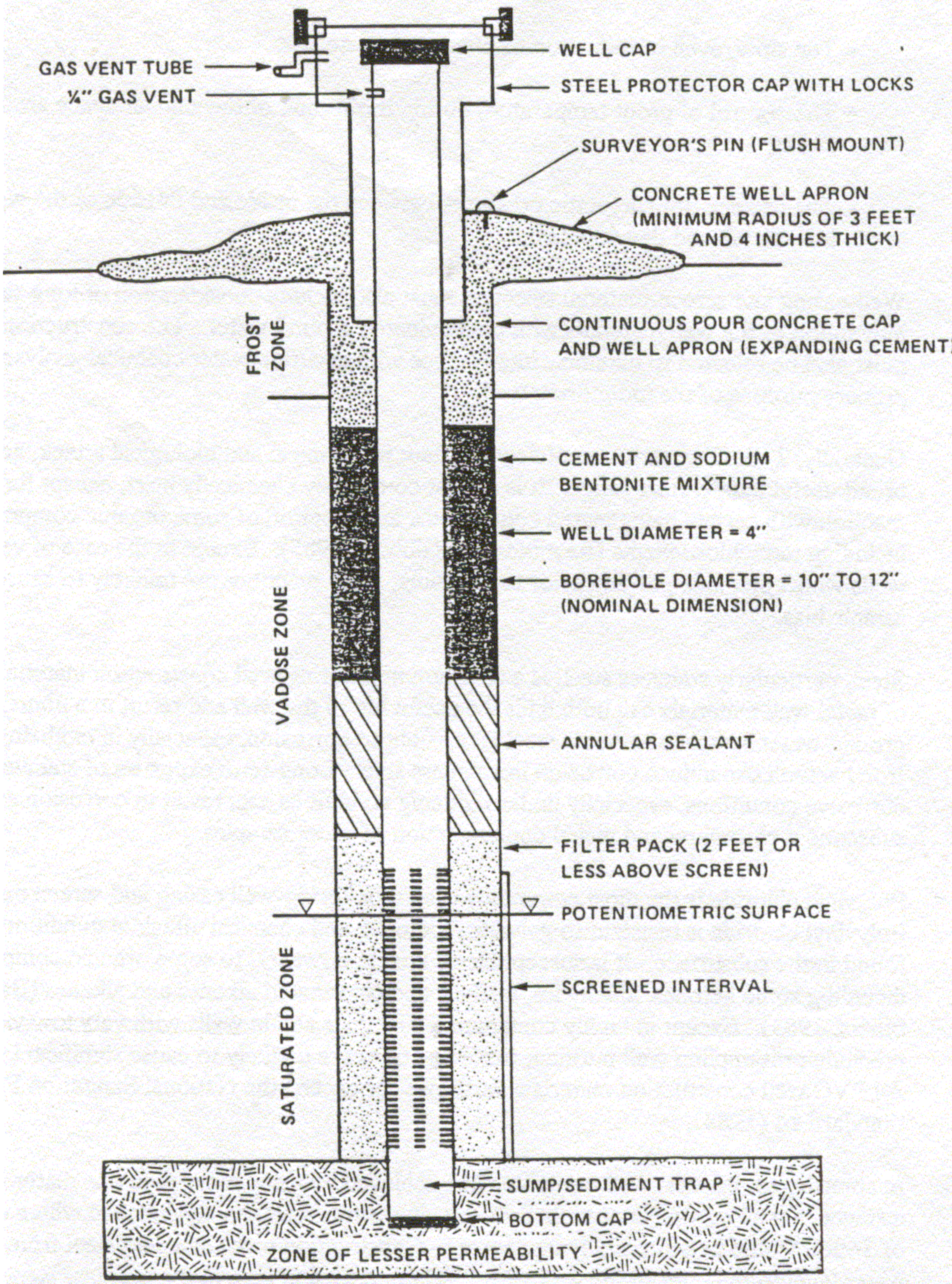
- The drilling of a straight, smooth bore hole
- The slow, even introduction of filter-pack materials
- The control of grout temperature during the sealing of the annular space around PVC casing
- The balance of hydrostatic pressures between the inside and outside of the well during installation and development

Well-casing and screen-material selection must also include consideration of long-term interaction of the well materials with contaminated ground water. The construction materials must also be selected to minimize interference with accurate water chemical analyses, normally a primary purpose of the monitoring well.

Generally, Teflon is nearly completely resistant to chemical and biological attack, and has a broad useful temperature range. It is almost completely chemically inert, except for some reaction with certain halogenated compounds, and sorption of some organic compounds, including tetrachloroethane (Reynolds and Gillham, 1985). Except in the case of very low yield wells which preclude purging prior to sampling, these reactions are unlikely to cause significant sample bias.

Steel, particularly stainless steel, is a common monitoring well construction material. Corrosion of metal well materials can both limit the useful life of the well and result in a nonrepresentative ground water sample. Stainless steel is resistant to corrosion, especially in oxidizing conditions. Iron bacteria can induce corrosion in stainless steel. Long-term exposure of stainless steel to corrosive conditions, especially under reducing conditions, can result in corrosion and subsequent chromium and nickel contamination of water samples.

Figure 1. General Monitoring Well Cross Section



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Polyvinyl chloride is the most commonly used monitoring-well casing and screen material. Polyvinyl chloride is resistant to galvanic, biologic, and chemical attack at conditions normally found in the subsurface. It is susceptible to attack, however, to some organic compounds including some ketones, aldehydes, amines, and chlorinated alkenes and alkanes (Barcelona and others, 1983). Except in highly contaminated settings and in wells with very low yields, which preclude presampling well purging, these reactions are unlikely to cause significant sample bias. All PVC well construction materials must meet or exceed the National Sanitation Foundation Standard 14 (1988).

In some cases, the best well design may be achieved by using more than one material type. For instance, a well may be built with Teflon casing with a stainless steel screen where a well screen of Teflon would be structurally inadequate. Construction using stainless steel from above the water level to the bottom the well with PVC upper casing (above the stainless steel) may save considerable cost over an all-stainless-steel well with little to no compromise of sample integrity.

5.3.2 Casing-Joining methods

A variety of methods are available for joining individual lengths of casing and screen to form a completed monitoring-well string. Heat welding, solvent welding, joining by metal fasteners such as rivets, tacks or screws, threaded and coupled, and flush-joint threaded couplings are available.

Heat welding, solvent welding, and metal fasteners are normally rejected because each process may contribute to interferences with water-chemistry analyses. The cements used in solvent welding of plastic casing materials are organic solvents which can have a major long-term effect upon samples analyzed for organic constituents. The casing materials themselves are mobilized in heat welding of thermoplastics or metals. Casing joined with metal fasteners are prone to leakage and resultant cross contamination between different parts of the well. The metals used in the fabrication of the fasteners are prone to corrosion and subsequent interference with water-chemical analyses.

Threaded and coupled pipe construction is discouraged because the uneven outer diameter creates problems with filter pack and annular seal placement. Monitoring well annular seals may be affected sufficiently by external upset couplings to promote water migration along the outer casing wall (U.S. Environmental Protection Agency, 1991).

All monitoring well joints must be water tight. Some flush joint casing manufacturers provide o-ring joint seals only as an option. The failure to obtain and install these optional o-rings may result in joint leakage. The geologist or hydrologist must ensure that all casing joints are properly constructed and sealed, including o-ring installation.

5.3.3 Monitoring well intake structures

The selection of monitoring well screen materials (PVC, Teflon, stainless steel or others) are governed by the previously discussed considerations. The selection of well screens must place additional emphasis upon structural strength because the openings of the structure inherently weaken it in comparison to casing. Screens are also typically placed at the bottom of a well where collapse stresses are at a maximum.

The primary function of well-intake structures is to allow water and other underground fluids to flow into the well while holding the surrounding sediments in place. The width of the openings must be tightly controlled and designed to reflect filter pack and formation characteristics. At a minimum, the South Dakota Well Construction Standards (ARSD 74:02:04:50) require that well screens or casing to have "openings which are sawed, drilled, punched, rolled, welded, stamped, or made by any means which will control the size of the openings." The code also requires screens which are filter packed to be sized to retain 90 percent of the filter-pack material. Screens within naturally developed filter packs must be sized to retain 50 percent of the aquifer material. Commercially manufactured well intakes are recommended because stricter quality control is normally achieved in the factory setting. Additionally, the process of cutting or drilling openings in casing at the drill site is discouraged because it produces fresh-cut surfaces prone to leaching for a time after fabrication.

Monitoring well screen length is also a variable worthy of some consideration in well design. Most monitoring wells function as both fluid-sampling points and as a piezometer. Monitoring well intakes are normally from 2 to 10 feet long. Shorter intakes provide more specific and precise information about vertically distributed water quality, hydraulic head, and flow. If the objective of the well is to monitor for the gross presence of contaminants in an aquifer, a longer intake may be appropriate. However, long intakes may cause a dilution of depth-specific contaminants during sampling, and thereby provide inaccurate data on the nature of aquifer contamination. One instance in which wells with long intakes may provide discrete data is in geochemical wireline bore hole logging. Geochemical probes are slowly lowered into small diameter wells fully penetrating the aquifer. The resultant log provides a geochemical profile through the aquifer of such parameters as pH, Eh, conductivity, dissolved oxygen, and temperature.

Screen placement may be at the bottom, within, at the top, and even extend above the top of the saturated part of an aquifer to satisfy the design purpose. Monitoring wells installed in unconfined aquifers for the purpose of monitoring light non-aqueous phase liquids (LNAPLs) must extend above the top of the water table. Water table fluctuations should be considered when designing wells to intersect the top of water table aquifers.

5.3.4 Filter pack

The annular space between the well screen and the bore-hole wall is often filled with uniform gravel/sand media to serve as a filter pack. The South Dakota Well Construction Standards (ARSD 74:02:04:50) specify that filter pack will be "clean material, without shale or iron pellets. The driller shall ensure that all well-construction materials, including gravel pack, are clean and sanitary prior to placement."

Monitoring well filter pack materials must be of higher quality than this baseline, however, to ensure accurate water quality samples. Monitoring well filter pack must be chemically inert and composed primarily of clean quartz sand or glass beads. The filter pack should contain less than 5 percent of nonsiliceous material (Driscoll, 1986; U.S. Environmental Protection Agency, 1986) and be free of claystone and carbonaceous debris. The individual grains should be well rounded. The reader is referred to U.S. Environmental Protection Agency (1991), Driscoll (1986), or U.S. Environmental Protection Agency (1975) for guidance on selecting optimum filter pack grain size.

The filter pack should be emplaced by use of a tremie pipe. The annular space of the well along the entire screened interval must be filled to at least 1 to 3 feet above the top of the screen. The depth to the top of the filter pack shall be probed using the tremie pipe, verifying the thickness of the sand pack. Additional filter pack may sometimes be required to compensate for additional settling of the filter pack after emplacement. Under no circumstances should the filter 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 filter pack without threat of cross flow between producing zones through the filter pack.

In materials that will not maintain an open hole, the hollow-stem auger or temporary casing is withdrawn gradually during placement of the filter pack and grout to the extent practical. For example, after filling 2 feet with filter pack, the outer casing should be withdrawn 2 feet. This step of placing more gravel and withdrawing the outer casing should be repeated until the level of the filter pack is at least 1 to 3 feet above the top of the well screen. This ensures that there is no locking of the permanent (inner) casing in the outer casing.

5.3.5 Annular seal

The materials used to seal the annular space must prevent the migration of contaminants to the sampling zone from the surface or intermediate zones and prevent cross contamination between strata. The materials should be chemically compatible with the anticipated waste to unsure seal integrity during the life of the monitoring well and chemically inert so they do not affect the quality of the ground water samples. An annular seal consisting of a minimum of two feet of coarse-granular, chipped or pelletized bentonite installed above the filter pack is appropriate for most monitoring wells. This seal is to prevent grout infiltration into the filter pack and the well screen. If no water is present at that elevation in the bore hole, a small quantity of potable water, with a known chemistry, must be added to expand the coarse-granular, chipped, or pelletized bentonite.

5.3.6 Cement-Bentonite grout

The Administrative Rules of South Dakota contain specific requirements for the grouting of wells. ARSD 74:02:04:53 states:

> "Cement grout requirements. Water used in making cement grout must be clean and may not contain oil or other organic material. The cement grouting of the well casing must be completed in one continuous operation. Bentonite may be added to cement grout in quantities not exceeding 2 pounds of bentonite for each 94-pound sack of cement. Up to 7 gallons of water may be mixed for each sack of cement when 2 pounds of bentonite are added. Calcium chloride may be added to the cement grout except when the mixture will be used to grout thermoplastic casing."

Cement grout is defined elsewhere in the South Dakota Well Construction Standards (ARSD 74:02:04:20) as "a mixture consisting of a high-sulfate-resistant type portland cement and no more than six gallons of water for each 94-pound sack of cement."

ARSD 74:02:04:53.01

> "Bentonite grout requirements. Bentonite material manufactured for use as a drilling fluid does not meet the requirements for bentonite grout. For approval by the chief engineer, bentonite grout must contain a minimum of 20 percent solids by weight and have a minimum slurry density of 9.4 pounds per gallon and must be mixed according to the manufacturer's recommendations."

Bentonite grout is defined elsewhere in the South Dakota Well Construction Standards (ARSD 74:02:04:20) as "a mixture consisting of a high solids, sodium bentonite material, approved by the chief engineer, which has been commercially manufactured and specifically formulated for use as a well casing seal or to plug a borehole or abandoned well." Users may call the Division of Water Rights, DENR (telephone: 605-773-3352) for a current list of approved materials and a copy of the Well Construction Standards.

Care should be exercised to prevent bore hole sealing materials from entering the well bore. A cap placed over the top of the well casing before beginning the sealing process will prevent this.

Grout is pumped through a tremie pipe (normally consisting of a 1.25-inch diameter PVC or steel pipe) to the bottom of the open annulus to below the average frost line (about 60 inches). A side discharge outlet attached to the bottom of the tremie pipe will reduce the chances of "jetting" out the underlying filter pack. If more than a small amount of filter material is removed, sealing materials may encroach upon the well screen and affect the operation of the well or influence the results of analyses of water from the well.

Additional grout may be added to compensate for the removal of any hollow-stem augers or temporary casing and the tremie pipe.

5.3.7 Surface seal

The surface seal extends from below the frost line to above the ground surface. Expanding cement should be used to provide for security and an adequate surface seal. Locating the interface between the cement and bentonite-cement mixture below the frost line serves to protect the well from damage due to frost heaving (U.S. Environmental Protection Agency, 1986). The cement should be placed in the borehole using the tremie method. The top of the surface seal should slope away from the monitoring well to allow water to drain away from the well.

5.3.8 Protective casing

A protective casing is installed around all monitor wells. Exceptions are on a case-by-case basis. The minimum elements in the protection design include:

- A protective steel cap to keep precipitation out of the protective casing, secured to the casing by padlocks.

- A 5-foot minimum length of metal tubing, extending about 1.5 to 3 feet above the ground surface, and set in cement grout. The tubing may be circular, square, or rectangular. The tubing size should be large enough to allow easy placement over the well. A 0.5-inch drain hole in the tubing near ground level is recommended.

- The installation of guard posts in addition to the protective casing in areas where vehicle traffic may pose a hazard. These guard posts may consist of 3-inch diameter steel posts or tee-bar driven steel posts. Groups of three are radially located around each well. Administrative Rule of South Dakota 74:02:04:59 requires that wells constructed in road ditches "shall be protected by installing a minimum of two steel posts around the well."

5.3.9 Well development requirements

In accordance with the well construction standards of South Dakota (ARSD74:02:04:58) wells shall be thoroughly developed by surging, jetting, or any other method which will remove drilling mud or any other material which will pass through the screen openings or casing perforations. The well shall be developed by the driller until the water is clear and reasonably free of silt, mud, and sand. (**Note**: For further information on well development see Groundwater and Wells, Chapter 15, "*Development of Water Wells*".)

5.3.10 Flush-Mount monitoring wells (to be completed)

6.0 CALCULATIONS

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

$$\text{Grout Volume (ft}^3) = \text{Volume of Bore hole (ft}^3) - \text{Volume of Casing (ft}^3)$$
$$= L\,[B(r_B^2 - r_C^2)]$$

where:

p	=	pi (approximately 3.14)
r_B	=	radius of boring (ft)
r_C	=	radius of casing (ft)
L	=	length of bore hole to be grouted (ft)

7.0 QUALITY ASSURANCE/QUALITY CONTROL

There are no specific quality assurance activities which apply to the implementation of these procedures. However, the following general quality assurance procedures apply:

- All data must be documented on standard well completion forms, field-data sheets or within field/site logbooks.

- All instrumentation and equipment must be operated in accordance with operating instructions as supplied by the manufacturer, unless otherwise specified in the work plan. Equipment checkout and calibration activities must occur prior to sampling/operation and they must be documented.

8.0 HEALTH AND SAFETY

The primary hazards associated with drilling operations are physical in nature. At a minimum, the following health and safety equipment should be used at all drilling operations to minimize hazards:

- Hard hat

- Work gloves
- Eye protection (when needed)
- Hearing protection (when needed)

Additional risks are incurred when drilling in a contaminated zone via exposure to the contaminants and/or increased physical hazard resulting from donning protective gear.

For further information on health and safety requirements, the reader is referred to EPA/REAC SOP #3012 REAC Health and Safety Guidelines for Activities at Hazardous Waste Sites wherein Subsection 4.9 outlines specific health and safety practices for drilling operations.

9.0 REFERENCES

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