CHAPTER III.

MONITORING WELL DESIGN AND CONSTRUCTION

The purpose of this chapter is to examine important aspects of monitoring well design and construction. Included in this chapter are discussions on the following topics:

- drilling methods for installing wells
- monitoring well construction materials
- design of well intakes
- development of wells
- documentation of well construction activity
- plugging of abandoned wells

Drilling Methods

A variety of well drilling methods are available for the purpose of installing ground water monitoring wells. Of utmost importance is that the drilling method minimizes the disturbance of subsurface materials and will not cause contamination of the ground water. Table III-1 illustrates the drilling methods the owner/operator might use. It is important to note that regardless of the drilling method selected, drilling equipment should be steam cleaned before use and between borehole locations to prevent cross contamination of wells.

Monitoring Well Construction Materials

Well construction materials must be sufficiently durable to resist chemical and physical degradation and yet not interfere with the quality of ground-water samples. Specific well components that are of concern include well casings, well screens, filter packs, and annular seals. Figure 1 is a diagram of a general cross section of a ground-water monitoring well. The following sections describe various materials the owner/operator should use in constructing the well as illustrated in Figure 1.

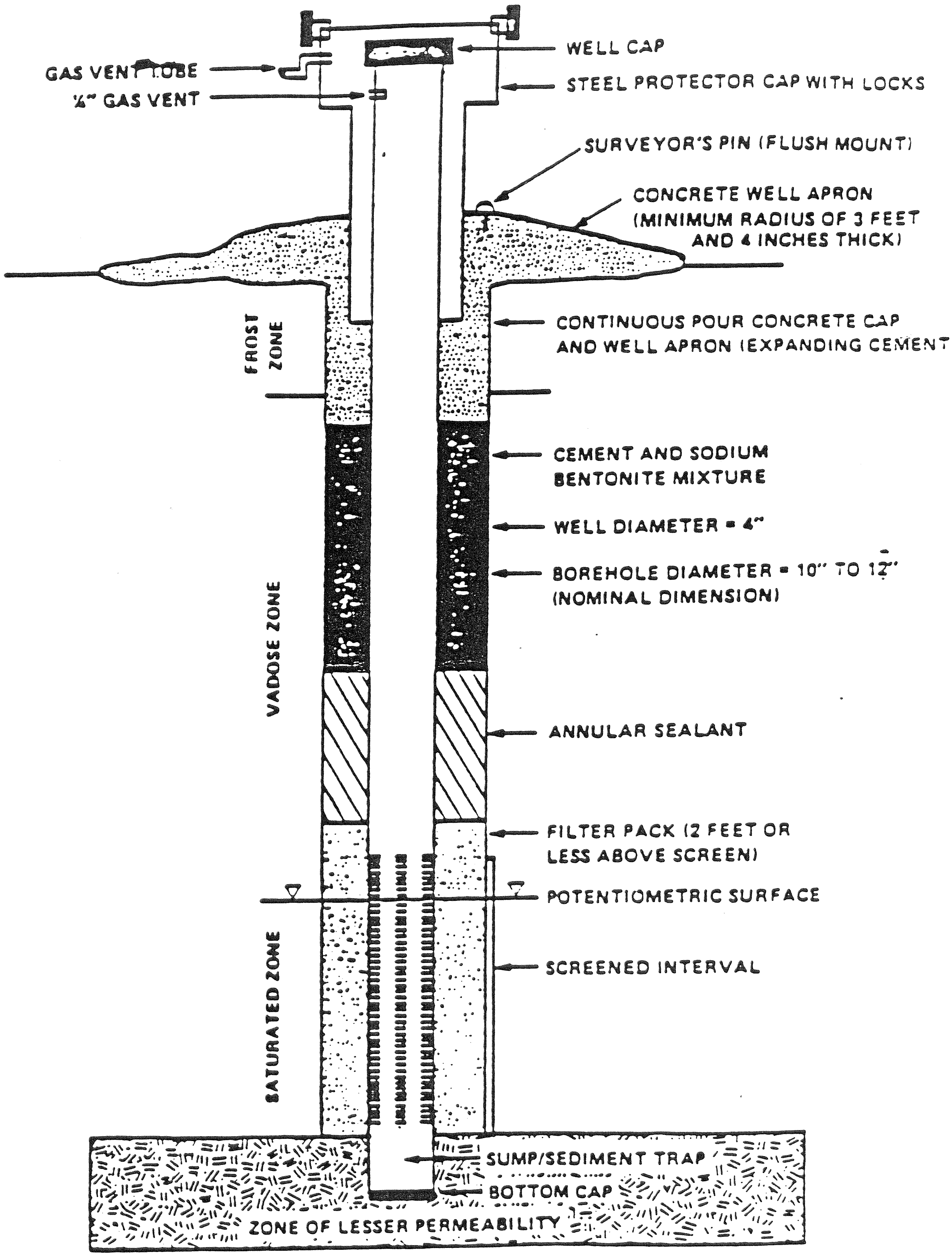

FIGURE -1. GENERAL MONITORING WELL CROSS SECTION

TABLE III-1

DRILLING METHODS FOR
VARIOUS TYPES OF GEOLOGIC SETTINGS

	Drilling Methods				
Geologic Environment	Air Rotary	Water Rotary	Cable Tool	Hollow-Stem Continuous Auger	Solid-Stem Continuous Auger*
Unconsolidated materials less than 150 feet deep:					
- loose sand and thick clay	4	5	2	1	3
- gravel and resistant zones	2	3	1		
Unconsolidated materials greater than 150 feet deep	2	3	1		
Consolidated rock formation (minimal or no fractured or dissolutioned formations)	2	3	1		
Consolidated rock formations (highly fractured or dissolutioned formations)	2	3	1		

*Above water table.

NOTES: 1 = First choice
2 = Second choice
3 = Third choice
4 = Fourth choice
5 = Fifth choice

Well Casings and Screens

A variety of construction materials have been used for casing and well screens, including teflon*, steel (stainless, black, galvanized), PVC, polyethylene, epoxy biphenol, and polypropylene. Many of these materials, however, may affect the quality of ground-water samples and may not have the long-term structural characteristics required for monitoring wells. For example, steel casing deteriorates in corrosive environments; PVC deteriorates when in contact with ketones, esters, and aromatic hydrocarbons; polyethylene deteriorates in contact with aromatic and halogenated hydrocarbons; and polypropylene deteriorates in contact with oxidizing acids, aliphatic hydrocarbons, and aromatic hydrocarbons. In addition, steel, PVC, polyethylene, and polypropylene may absorb and leach constituents which may affect the quality of ground-water samples.

In constructing wells, the owner/operator should use teflon, stainless steel 316, or other proven chemically and physically stable materials for well screens and for those portions of the well casing in the saturated zone. ASTM, NSF rated PVC may be an acceptable material for well screens and casing at some sanitary landfills and land application systems. However, PVC formulations can contain unacceptable concentrations of leachable plasticizers. Noninert materials such as steel, PVC, polyethylene, and polypropylene may be used as well casing above the saturated zone. The owner/operator will be held responsible for the reliability of data collected from the well. If the owner/operator choses to install PVC pipe as a casing material and, after installation, it is determined that PVC deteriorating compounds are present in the ground water, EPD must assume that the contaminants are from the regulated unit and not from the well casing or screen unless identical compounds are found in the upgradient wells and can not be attributed to wastes placed in the site. An appropriate choice of casing material is the responsibility of the owner/operator.

Plastic pipe sections must be flush threaded or be amenable to connection by another mechanical method such as stainless steel screws. No solvents or glues should be allowed in well construction. These compounds readily leach organic contaminants into the ground water. All well casings and screens should be steam cleaned prior to emplacement to ensure that all oils, greases, and waxes have been removed.

The owner/operator should normally use well casing with either a two-inch or four-inch interior diameter. Water volumes to be purged from the well prior to sampling are minimized by use of smaller casings. Larger casing diameters, however, may be necessary where dedicated sampling equipment is used or where the well is finished in a deep formation.

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*The term "teflon" in this report is used as a generic expression for polytetrafluoroethylene (PTFE) materials and in no way is meant to serve as an endorsement of PTFE products under the U.S. Trademark name of E.I. DuPont DeNemours and Company

Filter Pack and Annular Sealant

The materials used to construct the filter pack should be chemically inert (e.g., clean quartz sand, silica, or glass beads), well rounded, and dimensionally stable. Fabric filters should not be used as filter pack materials. Natural gravel packs are acceptable provided an appropriate well screen slot size is used.

The materials used to seal the annular space must prevent cross contamination between strata. The materials should be chemically resistant to ensure seal integrity during the life of the monitoring well and chemically inert so they do not affect the quality of the ground water samples. Figure III-1 illustrates an appropriate distribution of annular sealants. A minimum of two feet of certified coarse grit sodium bentonite should immediately overlie the filter pack. A cement and bentonite mixture, bentonite chips/pellets, or antishrink cement mixtures should be used as the annular sealant in the unsaturated zone above the certified coarse grit sodium bentonite seal and below the frost line. Extending from a little below the frost line to the surface, the cap should be composed of concrete blending into a mounded cement apron (to direct rainwater runoff away from the well) extending outward three feet from the edge of the borehole.

The untreated sodium bentonite seal should be placed around the casing either by dropping it directly down the borehole or, if a hollow-stem auger is used, putting the bentonite between the casing and the inside of the auger stem. Both of these methods present a potential for bridging. In shallow monitoring wells, a tamping device should be used to reduce this potential. In deeper wells, it may be necessary to pour a small amount of formation water down the casing to wash the bentonite down the hole.

The cement-bentonite mixture should be prepared using formation water or potable water and placed in the borehole using a tremie pipe. The tremie method ensures good sealing of the borehole from the bottom.

The remaining annular space should be sealed with expanding cement to provide for security and an adequate surface seal. Locating the interface between the cement and bentonite-cement mixture 1/2 to 1 foot below the frost line serves to protect the well from damage due to frost heaving. The cement should be placed in the borehole using the tremie method.

Figure 1 illustrates an appropriate protective steel cap around the well casing. A one-quarter inch vent hole provides an avenue for the escape of gas. The protective cap guards the casing from damage and the locking cap serves as a security device to prevent well tampering.

As with drilling machinery, it is important to steam-clean well casing and screen before use. Filter sands, well sealant materials, and anything else that may influence sample quality should be free of contamination. Common sense is the best guideline when constructing a monitoring well. After taking all precautions with cleaning drilling equipment, well casing, and screen, it makes no sense to pile filter sand on contaminated ground, or use contaminated water to make up drill mud!

Well Intake Design

The owner/operator must design and construct the intake of the monitoring wells to: (1) allow sufficient ground water flow to the well for sampling; (2) minimize the passage of formation materials (turbidity) into the well; and (3) ensure sufficient structural integrity to prevent the collapse of the intake structure.

For wells completed in unconsolidated materials, the intake of a monitoring well should consist of a screen or slotted casing with openings sized to ensure that formational material is prohibited from passing through the well during development. Screen size should be selected to retain 90% of the filter pack and 40% of the formational material. Extraneous fine-grained material (clays and silts) that have been dislodged during drilling may be left on the screen, in the filter pack, and in the well water. These fines should be removed from the screen and surrounding area during development. For quality-control purposes, the owner/operator should use commercially manufactured screens or slotted casings. Field slotting of screens is unacceptable.

The annular space between the face of the formation and the screen or slotted casing should be filled to minimize passage of formation materials into the well. The owner/operator should therefore install a filter pack of clean, well rounded, quartz sand or glass beads in each monitoring well that is constructed on site. In order to ensure discrete sample horizons, the filter pack should extend no more than two feet above the well screen as illustrated in Figure 1.

Well Development

After the owner/operator has completed construction of monitoring wells, natural hydraulic conductivity of the formation should be restored and all foreign sediment removed to ensure turbidity-free ground-water samples.

A variety of techniques are available for developing a well. To be effective, they require reversals or surges in flow to avoid bridging by particles, which is common when flow is continuous in one direction. These reversals or surges can be created by using surge blocks, bailers, or pumps. Formation water should be used for surging the well. In low yielding water-bearing formations, an outside source of water may sometimes be introduced into the well to facilitate development. In these cases, the water should be chemically analyzed to ensure that it cannot contaminate the aquifer. Where possible, compressed air should not be used in the development of wells as trace contaminate may be introduced. If used, sufficient precaution should be taken to prevent introduction of contaminants which may be caused for concern. The owner/operator should steam clean all equipment used to develop a well prior to its introduction into the well.

Documentation of Well Design and Construction

The owner/operator will be required to compile information on the design and construction of wells. Such information may include:

- name of drillers, identification of drill rig;
- date/time of construction;
- drilling method and drilling fluid* (primarily drilling muds) used;
- well location (± 0.5 ft.);
- borehole diameter and well casing diameter;
- well depth (± 0.1 ft.);
- drilling and lithologic logs
- casing materials*;
- screen materials and design;
- casing and screen joint type;
- screen slot size/length;
- filter pack material*/size;
- filter pack volume;
- filter pack placement method;
- sealant materials*;
- sealant volume;
- sealant placement method;
- surface seal design/construction;
- well development procedure;
- type of protective well cap;
- ground surface elevation (± 0.01 ft.);
- well cap elevation (± 0.01 ft.);
- top of casing elevation (± 0.01 ft.); and
- detailed drawing of well (include dimensions).

*Samples of materials, adequate for leaching/sorption tests should be retained.

Well Plugging

If it becomes necessary to abandon a monitoring well, the following plugging procedures should be used. Without proper plugging, the abandoned monitoring well will become an avenue of aquifer contamination. Plugging can also serve to inhibit water loss from artesian aquifers and to eliminate the physical hazard of an open hole. Proper plugging materials and techniques vary according to the original well construction and the geohydrology of the site.

The general procedure for plugging shallow monitoring wells completed in water table aquifers includes three steps.

- removal of obstructions in the well that could interfere with the plugging operation and thorough flushing of the well to purge residual drilling fluids and other fine detritus,

- removal of the well casing (where practical) to ensure placement of an effective seal - as a minimum when the casing is not properly grouted,the upper 20 feet of casing must be removed,

- sealing of the well with an impermeable filler such as neat cement.

Sealant Materials

Well sealants must be chemically inert and impermeable. Neat portland cement (with or without bentonite clay additives) and bentonite clay are acceptable sealants. General purpose (Type I) neat portland cement is the most commonly used. The cement slurry is mixed with five to six gallons of water for each 94 pound sack of cement. To properly set, the water of the cement slurry should have a low sulfate content and a total dissolved solids content less than 2,000 parts per million. No aggregate materials can be included in the slurry.

CAPACITIES OF WELL CASINGS

Diameter of Hole	Gallons per Lineal Foot	Sacks Cement per Lin. Foot	Lin. Feet per Sack Cement Set Volume
2"	0.1632	0.0199	50.2
3"	0.3672	0.0311	32.1
4"	0.6528	0.0791	12.6
5"	1.0200	0.1240	8.0
6"	1.4688	0.1785	5.6
7"	1.9992	0.2430	4.1
8"	2.6112	0.3373	3.2
10"	4.0800	0.4958	2.0
12"	5.8752	0.7140	1.4

Recommended quantities of neat portland cement needed for plugging various diameter wells are shown above. Quantities are based on the set volume, which is somewhat less than the slurry volume.

(taken from "Plugging Abandoned Wells" by Donald K. Keech, Ground Water Age, January, 1973)

The neat cement slurry must be piped to the point of application so that the well is filled upward from the bottom. Free falling of the slurry into the well is unacceptable because the cement will become aerated with a resulting increase in permeability.

Bentonite clay additives reduce shrinking (and cracking) of the cement while the slurry is setting. Three to five pounds of additive and 6-1/2 gallons of water are mixed with each 94 pound sack of cement (the clay and water are mixed together before cement is added to form the slurry).

Bentonite clay can be used separately as a well sealant. The clay is dropped into the well in the form of granules, chunks, pellets, or balls. As the clay hydrates, it also expands to form an impermeable barrier. Where the potentiometric head of an aquifer causes water to rise in the well high above the level of the plug, consideration must be given to the physical form of the bentonite to be used. If a granular bentonite is added by free falling, a possibility is that the clay will hydrate and expand above the intended point of placement. An ineffective plug will result. Adding the bentonite in chunk or pellet form will prolong the effective period of wetting prior to hydration and allow proper placement of the plug. Bentonite clay may not be an appropriate sealant where organic contaminants are present in ground water. Investigations have indicated that although bentonite clay is an impermeable material for water, some organic contaminants can migrate through.

In general, where a monitoring well is completed in a water table aquifer, the emphasis of well plugging is to prevent rainwater runoff through the well opening or the annular space. Where a monitoring well is completed in a confined aquifer, the emphasis is retention of water in the aquifer in which it is encountered.

Shallow monitoring wells installed in unconsolidated sediments or consolidated rocks without fractures or dissolution voids are filled with a sealant. Back filling of the screened or uncased section of the well (up to several feet below the casing) with clean, disinfected sand is permissible. Sand with a diameter of 0.025 inches or less (plaster sand or mortar sand) reduces cement penetration/loss. As a minimum, the upper 50 feet of deep monitoring wells should be plugged with neat cement or bentonite clay.

Consolidated rocks with a high density of fractures or dissolution voids should be filled completely with neat cement. Sand and clay fill materials may not be suitable because the fine grained sediments can be eroded away by ground water flow. The use of bridging materials, such as pea gravel or larger rocks (the diameter of the bridging material should be less than 1/3 of the diameter of the well) below the casing or the placement of a plug at the base of the casing, may be necessary to retain the neat portland cement slurry in the well.

Where several confined aquifers are present in an abandoned monitoring well, impermeable seals between water bearing sections are required. Flow from artesian wells can cause problems with the installation of neat portland cement. Packers or heavy plugs may be necessary to inhibit water flow.