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AMERICAN SOCIETY FOR TESTING AND MATERIALS
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# Standard Practice for Design and Installation of Ground Water Monitoring Wells in Aquifers[1]

This standard is issued under the fixed designation D 5092; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

$\epsilon^1$ NOTE—Paragraph 1.6 was added editorially October 1998.

## INTRODUCTION

This practice for the design and installation of ground water monitoring wells in aquifers will promote (*1*) durable and reliable construction, (*2*) extraction of representative ground water quality samples, and (*3*) efficient and site hydrogeological characterizations. The guidelines established herein are affected by governmental regulations and by site specific geological, hydrogeological, climatological, topographical, and subsurface chemistry conditions. To meet these geoenvironmental challenges, this guidance promotes the development of a conceptual hydrogeologic model prior to monitoring well design and installation.

## 1. Scope

1.1 This practice considers the selection and characterization (that is, defining soil, rock types, and hydraulic gradients) of the target monitoring zone as an integral component of monitoring well design and installation. Hence, the development of a conceptual hydrogeologic model for the intended monitoring zone(s) is recommended prior to the design and installation of a monitoring well.

1.2 These guidelines are based on recognized methods by which monitoring wells may be designed and installed for the purpose of detecting the presence or absence of a contaminant, and collecting representative ground water quality data. The design standards and installation procedures herein are applicable to both detection and assessment monitoring programs for facilities.

1.3 The recommended monitoring well design, as presented in this practice, is based on the assumption that the objective of the program is to obtain representative ground water information and water quality samples from aquifers. Monitoring wells constructed following this practice should produce relatively turbidity-free samples for granular aquifer materials ranging from gravels to silty sand and sufficiently permeable consolidated and fractured strata. Strata having grain sizes smaller than the recommended design for the smallest diameter filter pack materials should be monitored by alternative monitoring well designs which are not addressed in this practice.

1.4 The values stated in inch-pound units are to be regarded as standard. The values in parentheses are for information only.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.6 *This practice offers a set of instructions for performing one or more specific operations. This document cannot replace education or experience and should be used in conjunction with professional judgment. Nat all aspects of this practice may be applicable in all circumstances. This ASTM standard is not intended to represent or replace the standard of care by which the adequacy of a given professional service must be judged, nor should this document be applied without consideration of a project's many unique aspects. The word "Standard" in the title of this document means only that the document has been approved through the ASTM consensus process.*

## 2. Referenced Documents

2.1 *ASTM Standards:*

C 150 Specification for Portland Cement[2]
C 294 Descriptive Nomenclature of Constituents of Natural Mineral Aggregates[3]
D 653 Terminology Relating to Soil, Rock, and Contained Fluids[4]
D 1452 Practice for Soil Investigation and Sampling by Auger Borings[4]
D 1586 Method for Penetration Test and Split-Barrel Sampling of Soils[4]
D 1587 Practice for Thin-Walled Tube Sampling of Soils[4]

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[1] This practice is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.21.05 on Design and Installation of Ground-Water Monitoring Wells.

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[2] *Annual Book of ASTM Standards*, Vol 04.01.
[3] *Annual Book of ASTM Standards*, Vol 04.02.
[4] *Annual Book of ASTM Standards*, Vol 04.08.

D 2113 Practice for Diamond Core Drilling for Site Investigation[4]
D 2487 Classification of Soils for Engineering Purposes (Unified Soil Classification System)[4]
D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)[4]
D 3282 Classification of Soils and Soil Aggregate Mixtures for Highway Construction Purposes[4]
D 3550 Practice for Ring Lined Barrel Sampling of Soils[4]
D 4220 Practice for Preserving and Transporting Soil Samples[4]

## 3. Terminology

3.1 *Definitions:*

3.1.1 *annular space; annulus*—the space between two concentric tubes or casings, or between the casing and the borehole wall. This would include the space(s) between multiple strings of tubing/casings in a borehole installed either concentrically or multi-cased adjacent to each other.

3.1.2 *assessment monitoring*—an investigative monitoring program that is initiated after the presence of a contaminant in ground water has been detected. The objective of this program is to determine the concentration of constituents that have contaminated the ground water and to quantify the rate and extent of migration of these constituents.

3.1.3 *ASTM cement types*—Portland cements meeting the requirements of Specifications C 150. Cement types have slightly different formulations that result in various characteristics which address different construction conditions and different physical and chemical environments. They are as follows:

3.1.3.1 *Type I (Portland)*—a general-purpose construction cement with no special properties.

3.1.3.2 *Type II (Portland)*—a construction cement that is moderately resistant to sulfates and generates a lower head of hydration at a slower rate than Type I.

3.1.3.3 *Type III (Portland; high early strength)*—a construction cement that produces a high early strength. This cement reduces the curing time required when used in cold environments, and produces a higher heat of hydration than Type I.

3.1.3.4 *Type IV (Portland)*—a construction cement that produces a low head of hydration (lower than Types I and II) and develops strength at a slower rate.

3.1.3.5 *Type V (Portland)*—a construction cement that is a high sulfate resistant formulation. Used when there is severe sulfate action from soils and ground water.

3.1.4 *bailer*—a hollow tubular receptacle used to facilitate withdrawal of fluid from a well or borehole.

3.1.5 *ballast*—materials used to provide stability to a buoyant object (such as casing within a borehole filled with water).

3.1.6 *blow-in*—the inflow of ground water and unconsolidated material into a borehole or casing caused by differential hydraulic heads; that is, caused by the presence of a greater hydraulic head outside of a borehole/casing than inside.

3.1.7 *borehole* a circular open or uncased subsurface hole created by drilling.

3.1.8 *borehole log*—the record of geologic units penetrated, drilling progress, depth, water level, sample recovery, volumes, and types of materials used, and other significant facts regarding the drilling of an exploratory borehole or well.

3.1.8.1 *Discussion*—The definition of aquifer as currently included in Terminology D 653 varies from the definition as prescribed by US federal regulations. Since this federal definition is associated with the installation of many monitoring wells it is provided herein as a technical note:

*aquifer*—a geologic formation, group of formation, or part of a formation that is saturated, and is capable of providing a significant quantity of water.

3.1.9 *bridge*—an obstruction within the annulus which may prevent circulation or proper emplacement of annular materials.

3.1.10 *casing*—pipe, finished in sections with either threaded connections or bevelled edges to be field welded, which is installed temporarily or permanently to counteract caving, to advance the borehole, or to isolate the zone being monitored, or combination thereof.

3.1.11 *casing, protective*—a section of larger diameter pipe that is emplaced over the upper end of a smaller diameter monitoring well riser or casing to provide structural protection to the well and restrict unauthorized access into the well.

3.1.12 *casing, surface*—pipe used to stabilize a borehole near the surface during the drilling of a borehole that may be left in place or removed once drilling is completed.

3.1.13 *caving; sloughing*—the inflow of unconsolidated material into a borehole which occurs when the borehole walls lose their cohesive strength.

3.1.14 *cement; Portland cement*—commonly known as Portland cement. A mixture that consists of a calcareous, argillaceous, or other silica-, alumina-, and iron-oxide-bearing materials that is manufactured and formulated to produce various types which are defined in Specification C 150. Portland cement is also considered a hydraulic cement because it must be mixed with water to form a cement-water paste that has the ability to harden and develop strength even if cured under water (see *ASTM cement types*).

3.1.15 *centralizer*—a device that assists in the centering of a casing or riser within a borehole or another casing.

3.1.16 *circulation*—applies to the fluid rotary drilling method; drilling fluid movement from the mud pit, through the pump, hose and swivel, drill pipe, annular space in the hole and returning to the mud pit.

3.1.17 *conductance (specific)*—a measure of the ability of the water to conduct an electric current at 77°F (25°C). It is related to the total concentration of ionizable solids in the water. It is inversely proportional to electrical resistance.

3.1.18 *confining unit*—a term that is synonymous with "aquiclude,"" aquitard," and "aquifuge;" defined as a body of relatively low permeable material stratigraphically adjacent to one or more aquifers.

3.1.19 *contaminant*—an undesirable substance not normally present in water or soil.

3.1.20 *detection monitoring*—a program of monitoring for the express purpose of determining whether or not there has been a contaminant release to ground water.

3.1.21 *drill cuttings*—fragments or particles of soil or rock, with or without free water, created by the drilling process.

3.1.22 *drilling fluid*—a fluid (liquid or gas) that may be used in drilling operations to remove cuttings from the borehole, to clean and cool the drill bit, and to maintain the integrity of the borehole during drilling.

3.1.23 *d-10*—the diameter of a soil particle (preferably in millimetres) at which 10 % by weight (dry) of the particles of a particular sample are finer. Synonymous with the effective size or effective grain size.

3.1.24 *d-60*—the diameter of a soil particle (preferably in millimetres) at which 60 % by weight (dry) of the particles of a particular sample are finer.

3.1.25 *flow path*—represents the area between two flow lines along which ground water can flow.

3.1.26 *flush joint or flush coupled*—casing or riser with ends threaded such that a consistent inside and outside diameter is maintained across the threaded joints or couplings.

3.1.27 *gravel pack*—common nomenclature for the terminology, primary filter of a well (see *primary filter pack*).

3.1.28 *grout (monitoring wells)*—a low permeability material placed in the annulus between the well casing or riser pipe and the borehole wall (that is, in a single-cased monitoring well), or between the riser and casing (that is, in a multi-cased monitoring well), to maintain the alignment of the casing and riser and to prevent movement of ground water or surface water within the annular space.

3.1.29 *grout shoe*—a *plug* fabricated of relatively inert materials that is positioned within the lowermost section of a permanent casing and fitted with a passageway, often with a flow check device, through which grout is injected under pressure to fill the annular space. After the grout has set, the grout shoe is usually drilled out.

3.1.30 *head (static)*—the height above a standard datum of the surface of a column of water (or other liquid) that can be supported by the static pressure at a given point. The static head is the sum of the elevation head and the pressure head.

3.1.31 *head (total)*—the sum of three components at a point: (*1*) elevation head, $h_e$, which is equal to the elevation of the point above a datum; (*2*) pressure head, hp, which is the height of a column of static water than can be supported by the static pressure at the point; and (*3*) velocity head, hv, which is the height the kinetic energy of the liquid is capable of lifting the liquid.

3.1.32 *hydrologic unit*—geologic strata that can be distinguished on the basis of capacity to yield and transmit fluids. Aquifers and confining units are types of hydrologic units. Boundaries of a hydrologic unit may not necessarily correspond either laterally or vertically to lithostratigraphic formations.

3.1.33 *jetting*—when applied as a drilling method, water is forced down through the drill rods or casings and out through the end aperture. The jetting water then transports the generated cuttings to the ground surface in the annulus of the drill rods or casing and the borehole. The term jetting may also refer to a development technique (see well screen jetting).

3.1.34 *loss of circulation*—the loss of drilling fluid into strata to the extent that circulation does not return to the surface.

3.1.35 *mud pit*—usually a shallow, rectangular, open, portable container with baffles into which drilling fluid and cuttings are discharged from a borehole and that serves as a reservoir and settling tank during recirculation of the drilling fluids. Under some circumstances, an excavated pit with a lining material may be used.

3.1.36 *multi-cased well*—a well constructed by using successively smaller diameter casings with depth.

3.1.37 *neat cement*—a mixture of Portland cement (Specification 150) and water.

3.1.38 *observation well*—typically, a small diameter well used to measure changes in hydraulic heads, usually in response to a nearby pumping well.

3.1.39 *oil air filter*—a filter or series of filters placed in the air flow line from an air compressor to reduce the oil content of the air.

3.1.40 *oil trap*—a device used to remove oil from the compressed air discharged from an air compressor.

3.1.41 *packer (monitoring wells)*—a transient or dedicated device placed in a well that isolates or seals a portion of the well, well annulus, or borehole at a specific level.

3.1.42 *potentiometric surface*—an imaginary surface representing the static head of ground water. The water table is a particular potentiometric surface.

3.1.42.1 *Discussion*—Where the head varies with depth in the aquifer, a potentiometric surface is meaningful only if it describes the static head along a particular specified surface or stratum in that aquifer. More than one potentiometric surface is required to describe the distribution of head in this case.

3.1.43 *primary filter pack*—a clean silica sand or sand and gravel mixture of selected grain size and gradation that is installed in the annular space between the borehole wall and the well screen, extending an appropriate distance above the screen, for the purpose of retaining and stabilizing the particles from the adjacent strata. The term is used in place of *gravel pack.*

3.1.44 *PTFE tape*—joint sealing tape composed of polytetrafluoroethylene.

3.1.45 *riser*—the pipe extending from the well screen to or above the ground surface.

3.1.46 *secondary filter pack*—a clean, uniformly graded sand that is placed in the annulus between the primary filter pack and the over-lying seal, or between the seal and overlying grout backfill, or both, to prevent movement of seal or grout, or both, into the primary filter pack.

3.1.47 *sediment sump*—a blank extension beneath the well screen used to collect fine-grained material from the filter pack and adjacent strata. The term is synonymous with rat trap or tail pipe.

3.1.48 *shear strength (monitoring wells)*—a measure of the shear or gel properties of a drilling fluid or grout.

3.1.49 *single-cased well*—a monitoring well constructed with a riser but without an exterior casing.

3.1.50 *static water level*—the elevation of the top of a column of water in a monitoring well or piezometer that is not influenced by pumping or conditions related to well installation, hydrologic testing, or nearby pumpage.

3.1.51 *tamper*—a heavy cylindrical metal section of tubing that is operated on a wire rope or cable. It slips over the riser and fits inside the casing or borehole annulus. It is generally used to tamp annular sealants or filter pack materials into place and prevent bridging.

3.1.52 *target monitoring zone*—the ground water flow path from a particular area or facility in which monitoring wells will be screened. The target monitoring zone should be a stratum (strata) in which there is a reasonable expectation that a vertically placed well will intercept migrating contaminants.

3.1.53 *test pit*—a shallow excavation made to characterize the subsurface.

3.1.54 *transmissivity*—the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient.

3.1.54.1 *Discussion*—It is equal to an integration of the hydraulic conductivities across the saturated part of the aquifer perpendicular to the flow paths.

3.1.55 *tremie pipe*—a pipe or tube that is used to transport filter pack materials and annular sealant materials from the ground surface into the borehole annulus or between casings and casings or riser pipe of a monitoring well.

3.1.56 *uniformly graded*—a quantitative definition of the particle size distribution of a soil which consists of a majority of particles being of the same approximate diameter. A granular material is considered uniformly graded when the uniformity coefficient is less than about five (Test Method D 2487). Comparable to the geologic term *well sorted*.

3.1.57 *vented cap*—a cap with a small hole that is installed on top of the riser.

3.1.58 *washout nozzle*—a tubular extension with a check valve utilized at the end of a string of casing through which water can be injected to displace drilling fluids and cuttings from the annular space of a borehole.

3.1.59 *weep hole*—a small diameter hole (usually ¼in.) drilled into the protective casing above the ground surface that serves as a drain hole for water that may enter the protective casing annulus.

3.1.60 *well completion diagram*—a record that illustrates the details of a well installation.

3.1.61 *well screen*—a filtering device used to retain the primary or natural filter pack; usually a cylindrical pipe with openings of a uniform width, orientation, and spacing.

3.1.62 *well screen jetting (hydraulic jetting)*—when jetting is used for development, a jetting tool with nozzles and a high-pressure pump is used to force water outwardly through the screen, the filter pack, and sometimes into the adjacent geologic unit.

3.1.63 *zone of saturation*—a hydrologic zone in which all the interstices between particles of geologic material or all of the joints, fractures, or solution channels in a consolidated rock unit are filled with water under pressure greater than that of the atmosphere.

## 4. Significance and Use

4.1 An adequately designed and installed ground water monitoring well system for aqueousphase liquids provides essential information for decisions pertaining to one or more of the following subjects:

4.1.1 Aquifer and aquitard properties, both geologic and hydraulic;

4.1.2 Potentiometric surface of a particular hydrologic unit(s);

4.1.3 Water quality with respect to various indicator parameters;

4.1.4 Migration characteristics of a contaminant release;

4.1.5 Additional installations or decommissioning of installations, or both, no longer needed.

## 5. Site Characterization

5.1 *General*—Soil mechanics, geomorphological concepts, geologic structure, stratigraphy, and sedimentary concepts, as well as the nature and behavior of the solutes of interest, must be combined with a knowledge of ground water movement to make a complete application of the results of the monitoring well design and installation guidance. Therefore, development of a conceptual hydrogeologic model that identifies potential flow paths and the target monitoring zone(s) is recommended prior to monitoring well design and installation. Development of the conceptual model is accomplished in two phases—an initial reconnaissance and a field investigation. When the hydrogeology of a project area is relatively uncomplicated and well documented in the literature, the initial reconnaissance may provide sufficient information to identify flow paths and the target monitoring zone(s). However, where little background data is available or the geology is complicated, a field investigation will generally be necessary to completely develop a conceptual hydrogeologic model.

5.2 *Initial Reconnaissance of Project Area*—The goal of the initial reconnaissance of the project area is to identify and locate those zones with the greatest potential to transmit a fluid from the project area. Identifying these flow paths is the first step in selecting the target ground water monitoring zone(s).

5.2.1 *Literature Search*—Every effort should be made to collect and review all applicable field and laboratory data from previous investigations of the project area. Data such as, but not limited to, topographic maps, aerial imagery, site ownership and utilization records, geologic and hydrogeologic maps and reports, mineral resource surveys, water well logs, personal information from local well drillers, agricultural soil reports, geotechnical engineering reports, and other engineering maps and report related to the project area should be reviewed.

5.2.2 *Field Reconnaissance*—Early in the investigation, the soil and rocks in open cut areas in the vicinity of the project should be studied, and various soil and rock profiles noted. Special consideration should be given to soil color and textural changes, landslides, seeps, and springs within or near the project area.

5.2.3 *Preliminary Conceptual Model*—The distribution of the predominant soil and rock units likely to be found during subsurface exploration may be hypothesized at this time in a preliminary hydrogeologic conceptual model using data obtained in the literature search and field reconnaissance. In areas where the geology is relatively uniform, well documented in the literature, and substantiated by the field reconnaissance, further refinement of the conceptual model may not be necessary unless anomalies are discovered in the well drilling stage.

5.3 *Field Investigation*—The goal of the field investigation is to refine the preliminary conceptual hydrogeologic model so that the target monitoring zone(s) is selected prior to monitoring well installation.

5.3.1 *Exploratory Borings and Test Pits*—Characterization of the flow paths conceptualized in the initial reconnaissance involves defining the porosity, hydraulic conductivity, gradation, stratigraphy, lithology, and structure of each hydrologic unit. The characteristics are defined by conducting an exploratory boring program which may include test pits. Exploratory borings and test pits should be deep enough to develop the required engineering and hydrogeologic data for determining the flow path(s), target monitoring zone, or both.

5.3.1.1 *Sampling*—Soil and rock properties should not be predicted wholly on field identification or classification, but should be checked by laboratory and field tests made on samples. Representative soil or rock samples, or both, of each material that is significant to the analysis and design of the monitoring system should be obtained and evaluated by a geologist, hydrogeologist, or engineer trained and experienced in soil and rock analysis. Soil sample extraction should be conducted according to Practice D 1452, Method D 1586, Practice D 3550, or Practice D 1587, whichever is appropriate given the anticipated characteristics of the soil samples. Rock samples should be extracted according to Practice D 2113. Soil samples obtained for evaluation of hydraulic properties should be containerized and identified for shipment to a laboratory. Special measures to preserve either the continuity of the sample or the natural moisture are not usually required. However, soil and rock samples obtained for evaluation of chemical properties often require special field preparation and preservation to prevent significant alteration of the chemical constituents during transportation to a laboratory (see Practice D 4220). Rock samples for evaluation of hydraulic properties are usually obtained using a split-inner-tube core barrel. Evaluation and logging of the core samples is usually made in the field before the core is removed from half of the split inner tube core barrel.

5.3.1.2 *Boring Logs*—Care should be taken to prepare and retain a complete boring log and sampling record for each exploratory borehole and test pit.

NOTE 1—Site investigations for the installation of ground-water monitoring wells can vary greatly due to the availability of reliable site data or the lack thereof. The general procedure would however be as follows: (*1*) gather factual data regarding the surficial and subsurface conditions, (*2*) analyze the data, (*3*) develop a conceptual model of the site conditions, (*4*) locate the monitoring wells based on the first three steps. Monitoring wells should only be installed with sufficient understanding of the geologic and hydrogeologic conditions present on site. Monitoring wells often serve as part of an overall site investigation for a specific purpose, such as determining the extent of contamination present, or for prediction of the effectiveness of aquifer remediations. In these cases extensive additional geotechnical and hydrogeologic information may be required that would go beyond the Section 5 Site Characterization description.

Boring logs should include the location, geotechnical (that is, penetration rates or blow counts), and sampling information for each material identified in the borehole either by symbol or word description, or both. Identification of all soils should be in accordance with Practice D 2488 or Practice D 3282. Identification of rock material should be based on Nomenclature C 294 or by an appropriate geologic classification system. Observations of seepage, free water, and water levels should also be noted. The boring logs should be accompanied by a report that includes a description of the area investigated; a map illustrating the vertical and horizontal location (with reference to nearest National Geodetic Vertical Datum [NGVD] and to a standardized survey grid, respectively) of each exploratory borehole or test pit, or both; and color photographs of rock cores, soil samples, and exposed strata labeled with a date and identification.

5.3.2 *Geophysical Exploration*—Geophysical surveys may be used to supplement borehole and outcrop data and to aid in interpretation between boreholes. Surface geophysical methods such as seismic surveys, and electrical-resistivity and electromagnetic conductance surveys can be particularly valuable when distinct differences in the properties of contiguous subsurface materials are indicated. Borehole methods such as resistivity, gamma, gamma-gamma, neutron, and caliper logs can be useful to confirm specific subsurface geologic conditions. Gamma logs are particularly useful in existing cased wells.

5.3.3 *Ground Water Flow Direction*—Ground water flow direction is generally determined by measuring the vertical and horizontal hydraulic gradient within each conceptualized flow path. However, because water will flow along the path of least resistance, flow direction may be oblique to the hydraulic gradient (buried stream channels or glacial valleys, for example). Flow direction is determined by first installing piezometers in the exploratory boreholes. The depth and location of the piezometers will depend upon anticipated hydraulic connections between conceptualized flow paths and their respective lateral direction of flow. Following careful evaluation, it may be possible to utilize existing private or public wells to obtain water level data. The construction integrity of such wells should be verified to ensure that the water levels obtained from the wells are representative only of the zones of interest. Following water level data acquisition, a potentiometric surface map should be prepared. Flow paths are ordinarily determined to be at right angles, or nearly so, to the equipotential lines.

5.4 *Completing the Conceptual Model*—A series of hydrogeologic cross sections should be developed to refine the conceptual model. This is accomplished by first plotting logs of soil and rock observed in the exploratory borings or test pits, and interpreting between these logs using the geologic and engineering interrelationships between other soil and rock data observed in the initial reconnaissance or with geophysical techniques. Extrapolation of data into adjacent areas should be done only where geologically uniform subsurface conditions are known to exist. The next step is to integrate the profile data with the piezometer data for both vertical and horizontal hydraulic gradients. Plan view and cross-sectional flow nets may need to be constructed. Following the analysis of these data, conclusions can be made as to which flow path(s) is the appropriate target monitoring zone(s).

NOTE 2—Ground water monitoring is difficult and may not be a reliable technology in fine-grain, low hydraulic conductivity, primary porosity strata because of (*1*) the disproportionate influence that microstratigraphy has on ground water flow in fine-grain strata; (*2*) flow lines proportionally higher for the vertical flow component in low hydraulic conductivity strata; and (*3*) the presence of indigenous metallic and inorganic constituents that make water quality data evaluation difficult.

## 6. Monitoring Well Construction Materials

6.1 *General*—The materials that are used in the construction of a monitoring well and that come in contact with the water sample should not measurably alter the chemical quality of the sample for the constituents being examined using the appropriate sampling protocols. Furthermore, the riser, well screen, and annular sealant injection equipment should be steam cleaned or high-pressure water cleaned (if appropriate for the selected riser material) immediately prior to well installation or certified clean from the manufacturer and delivered to site in a protective wrapping. Samples of the cleaning water, filter pack, annular seal, and mixed grout should be retained to serve as quality control until the completion of at least one round of ground water quality sampling and analysis.

6.2 *Water*—Water used in the drilling process, to prepare grout mixtures and to decontaminate the well screen, riser, and annular sealant injection equipment, should be obtained from a source of known chemistry that does not contain constituents that could compromise the integrity of the well installation.

6.3 *Primary Filter Pack*:

6.3.1 *Materials*—The primary filter pack (gravel pack) consists of a granular material of known chemistry and selected grain size and gradation that is installed in the annulus between the screen and the borehole wall. The filter pack is usually selected to have a 30 % finer (d-30) grain size that is about 4 to 10 times greater than the 30 % finer (d-30) grain size of the hydrologic unit being filtered (see Fig. 1). Usually, the filter is selected to have a low (that is, less than 2.5) uniformity coefficient. The grain size and gradation of the filter are selected to stabilize the hydrologic unit adjacent to the screen and permit only the finest soil grains to enter the screen during development. Thus, after development, a correctly filtered monitoring well is relatively turbid-free.

NOTE 3—When installing a monitoring well in Karst or highly fractured bedrock, the borehole configuration of void spaces within the formation surrounding the borehole is often unknown. Therefore, the installation of a filter pack becomes difficult and may not be possible.

6.3.2 *Gradation*—The filter pack should be uniformly graded and comprised of hard durable siliceous particles washed and screened with a particle size distribution derived by multiplying the d-30 size of the finest-grained screened stratum by a factor between 4 and 10. Use a number between four and six as the multiplier if the stratum is fine and uniform; use a factor between six and ten where the material has highly nonuniform gradation and includes silt-sized particles. The grain-size distribution of the filter pack is then plotted using the d-30 size as the control point on the graph. The selected filter pack should have a uniformity coefficient of approximately 2.5 or less.

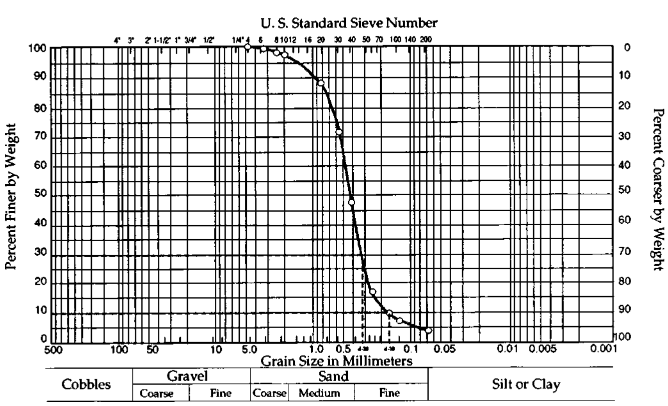


FIG. 1 Example Grading Curve for Design of Monitoring Well Screens

NOTE 4—This practice presents a design for monitoring wells that will be effective in the majority of aquifers. Applicable state guidance may differ from the designs contained in this practice.

NOTE 5—Because the well screen slots have uniform openings, the filter pack should be composed of particles that are as uniform in size as is practical. Ideally, the uniformity coefficient (the quotient of the 60 % passing, D-60 size divided by the 10 % passing D-10 size [effective size]) of the filter pack should be 1.0 (that is, the D-60 % and the D-10 % sizes should be identical). However, a more practical and consistently achievable uniformity coefficient for all ranges of filter pack sizes is 2.5. This value of 2.5 should represent a maximum value, not an ideal.

NOTE 6—Although not recommended as standard practice, often a project requires drilling and installing the well in one phase of work. Therefore, the filter pack materials must be ordered and delivered to the drill site before soil samples can be collected. In these cases, the suggested well screen slot size and filter pack materials are presented in Table 1.

6.4 *Well Screen*:

6.4.1 *Materials*—The well screen should be new, machine-slotted or continuous wrapped wire-wound and composed of materials most suited for the monitoring environment and site characterization findings. The screen should be plugged at the bottom. The plug should be of the same material as the well screen. This assembly must have the capability to withstand installation and development stresses without becoming dislodged or damaged. The length of the slotted area should reflect the interval to be monitored. Immediately prior to installation, the well screen should be steam cleaned or high-pressure water cleaned (if appropriate for the selected well screen materials) with water from a source of known chemistry if not certified by the manufacturer, delivered, and maintained clean at the site.

NOTE 7—Well screens are most commonly composed of PVC, stainless steel, fiberglass, or fluoropolymer materials.

6.4.2 *Diameter*—The minimum nominal internal diameter of the well screen should be chosen based on the particular application. However, in most instances, a minimum of 2 in. (50 mm) is needed to allow for the introduction and withdrawal of sampling devices.

6.4.3 *Slot Size*—The slot size of the well screen should be determined relative to the grain size analysis of the stratum interval to be monitored and the gradation of the filter pack material. In granular non-cohesive strata that will fall in easily around the screen, filter packs are not necessary. In these cases of natural development, the slot size of the well screen is to be determined using the grain size of the materials in the surrounding strata. The slot size and arrangement should retain at least 90 % and preferably 99 % of the filter pack. The method for determining the correct gradation of filter pack material is described in 6.3.2.

6.5 *Riser*:

TABLE 1 Recommended (Achievable) Filter Pack Characteristics for Common Screen Slot Sizes

| Size of Screen Opening, mm (in.) | Slot No. | Sand Pack Mesh Size Name(s) | 1 % Passing Size (D-1), mm | Effective Size, (D-10), mm | 30 % Passing Size (D-30), mm | Range of Uniformity Coefficient | Roundness (Powers Scale) |
|---|---|---|---|---|---|---|---|
| 0.125 (0.005) | 5[A] | 100 | 0.09 to 0.12 | 0.14 to 0.17 | 0.17 to 0.21 | 1.3 to 2.0 | 2 to 5 |
| 0.25 (0.010) | 10 | 20 to 40 | 0.25 to 0.35 | 0.4 to 0.5 | 0.5 to 0.6 | 1.1 to 1.6 | 3 to 5 |
| 0.50 (0.020) | 20 | 10 to 20 | 0.7 to 0.9 | 1.0 to 1.2 | 1.2 to 1.5 | 1.1 to 1.6 | 3 to 6 |
| 0.75 (0.030) | 30 | 10 to 20 | 0.7 to 0.9 | 1.0 to 1.2 | 1.2 to 1.5 | 1.1 to 1.6 | 3 to 6 |
| 1.0 (0.040) | 40 | 8 to 12 | 1.2 to 1.4 | 1.6 to 1.8 | 1.7 to 2.0 | 1.1 to 1.6 | 4 to 6 |
| 1.5 (0.060) | 60 | 6 to 9 | 1.5 to 1.8 | 2.3 to 2.8 | 2.5 to 3.0 | 1.1 to 1.7 | 4 to 6 |
| 2.0 (0.080) | 80 | 4 to 8 | 2.0 to 2.4 | 2.4 to 3.0 | 2.6 to 3.1 | 1.1 to 1.7 | 4 to 6 |

[A] A 5-slot (0.152-mm) opening is not currently available in slotted PVC but is available in Vee wire PVC and Stainless; 6-slot opening may be substituted in these cases.

6.5.1 *Materials*—The riser should be new and composed of materials that will not alter the quality of water samples for the constituents of concern and that are appropriate for the monitoring environment. The riser should have adequate wall thickness and coupling strength to withstand installation and development stresses. Each section of riser should be steam cleaned or high-pressure water cleaned (if appropriate for the selected material) using water from a source of known chemistry immediately prior to installation.

NOTE 8—Risers are generally constructed of PVC, stainless steel, fiberglass, or fluoropolymer materials.

6.5.2 *Diameter*—The minimum nominal internal diameter of the riser should be chosen based on the particular application. However, in most instances, a minimum of 2 in. (50 mm) is needed to accommodate sampling devices.

6.5.3 *Joints (Couplings)*—Threaded joints are recommended. Glued or solvent welded joints of any type are *not* recommended since glues and solvents may alter the chemistry of the water samples. In most cases, square profile flush joint threads do not require PTFE taping, however, tapered thread joints should be PTFE taped to prevent leakage of water into the riser. Alternatively, O-rings composed of materials that would not impact the water sample for the constituents of concern may be selected for use on flush joint threads.

6.6 *Casing*—Where conditions warrant, the use of permanent casing installed to prevent communication between water-bearing zones is encouraged. The following subsections address both temporary and permanent casings.

6.6.1 *Materials*—The material type and minimum wall thickness of the casing should be adequate to withstand the forces of installation. All casing that is to remain as a permanent part of the installation (that is, multi-cased wells) should be new and cleaned to be free of interior and exterior protective coatings.

NOTE 9—The exterior casing (temporary or permanent multi-cased) is generally composed of steel, although other appropriate materials may be used.

6.6.2 *Diameter*—Several different casing sizes may be required depending on the subsurface geologic conditions penetrated. The diameter of the casing for filter packed wells should be selected so that a minimum annular space of 2 in. (50 mm) is maintained between the inside diameter of the casing and outside diameter of the riser. In addition, the diameter of the casings in multi-cased wells should be selected so that a minimum annular space of 2 in. is maintained between the casing and the borehole (that is, a 2-in. diameter screen will require first setting a 6-in. (152-mm) diameter casing in a 10-in. (254-mm) diameter boring).

NOTE 10—Under difficult drilling conditions (collapsing soils, rock, or cobbles), it may be necessary to advance temporary casing, under these conditions a smaller annular space may be maintained.

6.6.3 *Joints (Couplings)*—The ends of each casing section should be either flush-threaded or bevelled for welding.

6.7 *Protective Casing*:

6.7.1 *Materials*—Protective casings may be made of aluminum, steel, stainless steel, cast iron, or a structural plastic. The protective casing should have a lid capable of being locked shut by a locking device.

6.7.2 *Diameter*—The inside dimensions of the protective casing should be a minimum of 2 in. (50 mm) and preferably 4 in. (101 mm) larger than the nominal diameter of the riser to facilitate the installation and operation of sampling equipment.

6.8 *Annular Sealants*—The materials used to seal the annulus may be prepared as a slurry or used un-mixed in a dry pellet, granular, or chip form. Sealants should be selected to be compatible with ambient geologic, hydrogeologic, and climatic conditions and any man-induced conditions anticipated to occur during the life of the well.

6.8.1 *Bentonite*—Bentonite should be powdered, granular, pelletized, or chipped sodium montmorillonite furnished in sacks or buckets from a commercial source and free of impurities which adversely impact the water quality in the well. Pellets consist of roughly spherical or disk shaped units of compressed bentonite powder. Chips are large, irregularly shaped, and coarse granular units of bentonite free of additives. The diameter of pellets or chips selected for monitoring well construction should be less than one fifth the width of the annular space into which they are placed to reduce the potential for bridging. Granules consist of coarse particles of unaltered bentonite, typically smaller than 0.2 in. (50 mm).

6.8.2 *Cement*—Each type of cement has slightly different characteristics that may be appropriate under various physical and chemical conditions. Cement should be one of the five Portland cement types that are specified in Specification C 150. The use of quick-setting cements containing additives is not recommended for use in monitoring well installation. Additives may leach from the cement and influence the chemistry of the water samples.

6.8.3 *Grout*—The grout backfill that is placed above the bentonite annular seal and secondary filters (see Fig. 2) is ordinarily a liquid slurry consisting of either a bentonite (powder or granules, or both) base and water, or a Portland cement base and water. Often, bentonite-based grouts are used when it is desired that the grout remain flexible (that is, to accommodate freeze-thaw) during the life of the installation. Cement or bentonite-based grouts are often used when the filling in of cracks in the surrounding geologic material,

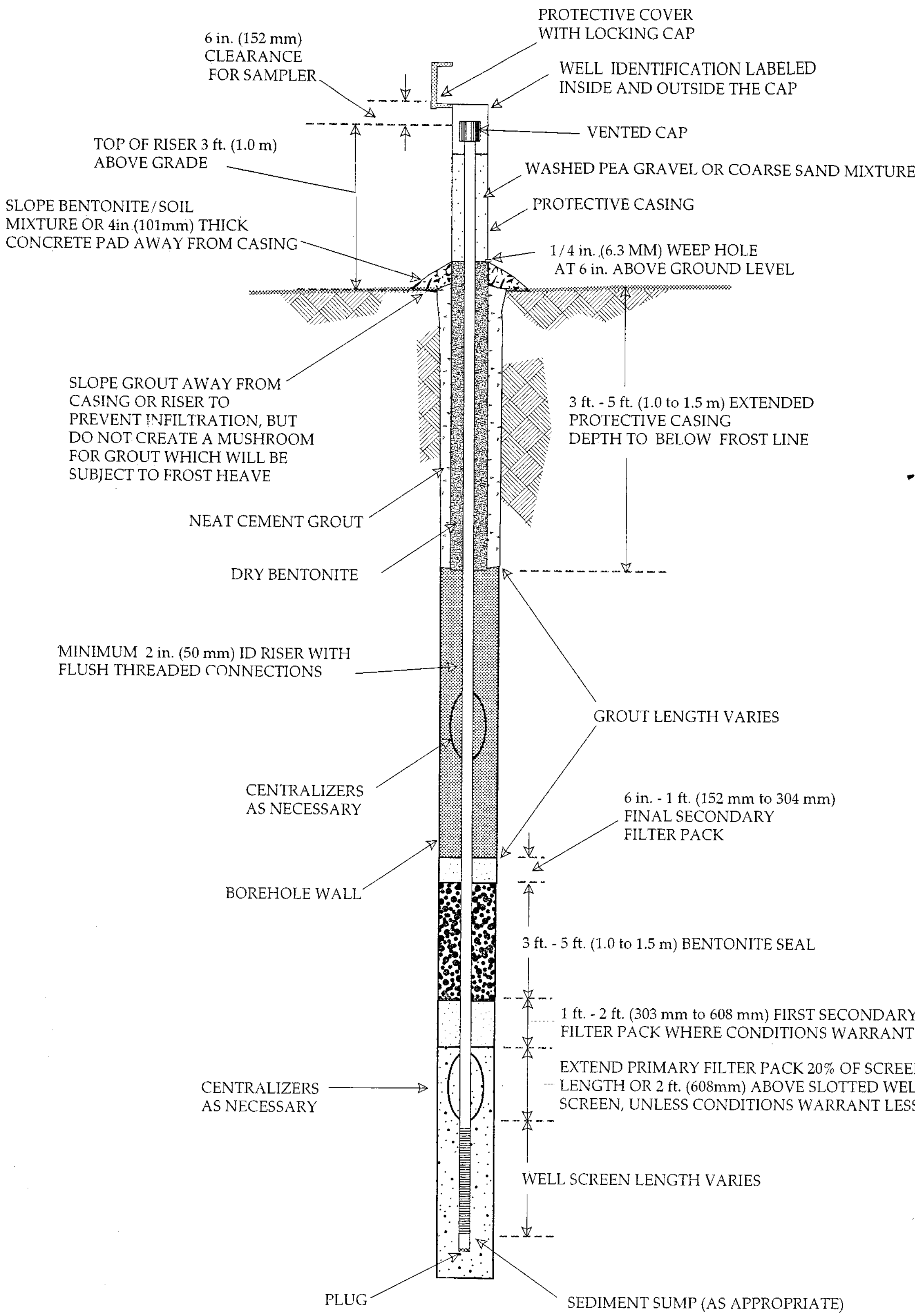


**FIG. 2 Monitoring Well Design—Single–Cased Well**

adherence to rock units, or a rigid setting is desired.

6.8.3.1 *Mixing*—The mixing (and placing) of a grout backfill should be performed with precisely recorded weights and volumes of materials, and according to procedures stipulated by the manufacturer that often include the order of component mixing. The grout should be thoroughly mixed with a paddle type mechanical mixer or by recirculating the mix through a pump until all lumps are disintegrated. Lumpy grout should not be used in the construction of a monitoring well to prevent bridging within the tremie.

NOTE 11—Lumps do not include lost circulation materials that may be added to the grout if excessive grout losses occur.

6.8.3.2 *Typical Bentonite Base Grout*—When a bentonite base grout is used, bentonite, usually unaltered, *must* be the first additive placed in the water through a venturi device. A typical unbeneficiated bentonite base grout consists of about 1 to 1.25 lb (0.57 kg) of unaltered bentonite to each 1 gal (3.8 L) of water. After the bentonite is mixed and allowed to "yield or hydrate," up to 2 lb (0.9 kg) of Type I Portland cement (per gallon of water) is often added to stiffen the mix. 100 % Bentonite grouts should not be used solely for monitoring well annular sealants in the vadose zone of arid regions because of their propensity to desiccate. This could result in non-representative waters affecting the target monitoring zone.

NOTE 12—High solids bentonite grouts (minimum 20 % by weight with water) and other bentonite-based grouts may contain granular bentonite to increase the solids content and other components added under manufacturer's directions to either stiffen or retard stiffening of the mix.

*All additives* to grouts should be evaluated for their effects on subsequent water samples.

6.8.3.3 *Typical Cement Base Grout*—When a cement-based grout is used, cement is usually the first additive placed in the water. A typical cement-based grout consists of about 6 to 7 gal (23 to 26 L) of water per 94-lb (43-kg) bag of Type I Portland cement. From 0 to 10 % (by dry weight of cement) of unaltered bentonite powder is often added after the initial mixing of cement and water to retard shrinkage and provide plasticity. The bentonite is added *dry* to the cement-water slurry without first mixing it with water.

6.9 *Secondary Filter Packs*:

6.9.1 *Materials*—A secondary filter pack is a layer of material placed in the annulus between the primary filter pack and the bentonite seal, and between the bentonite seal and the grout backfill (see Fig. 2 and Fig. 3).

6.9.2 *Gradation*—The secondary filter pack should be uniformly graded fine sand with a 100 % by weight passing the No. 30 U.S. Standard sieve, and less than 2 % by weight passing the 200 U.S. Standard sieve.

6.10 *Annular Seal Equipment*—The equipment used to inject the annular seals and filter pack should be steam cleaned or high-pressure water cleaned (if appropriate for the selected material) using water from a source or known quality prior to use. This procedure is performed to prevent the introduction of materials that may ultimately alter the water sample quality.

## 7. Drilling Methods

7.1 The type of equipment required to create a stable, open, vertical borehole for installation of a monitoring well depends upon the site geology, hydrology, and the intended use of the data. Engineering and geological judgment is required for the selection of the drilling methods utilized for drilling the exploratory boreholes and monitoring wells. Whenever feasible, drilling procedures should be utilized that do not require the introduction of water or liquid fluids into the borehole, and that optimize cuttings control at ground surface. Where the use of drilling fluid is unavoidable, the selected fluid should have as little impact as possible on the water samples for the constituents of interest. In addition, care should be taken to remove as much drilling fluid as possible from the well and the aquifer during the well development process. It is recommended that if an air compressor is used, it is equipped with an oil air filter or oil trap.

## 8. Monitoring Well Installation

8.1 *Stable Borehole*—A stable borehole must be constructed prior to attempting to install the monitoring well screen and riser. Steps must be taken to stabilize the borehole before attempting installation if the borehole tends to cave or blow-in, or both. Boreholes that are not straight or are partially obstructed should be corrected prior to attempting the installations described herein.

8.2 *Assembly of Well Screen and Riser*:

8.2.1 *Handling*—The well screen, bottom plug, riser, should be either certified clean from the manufacturer or steam cleaned or high-pressure water cleaned (if appropriate for the selected material) using water from a source of known chemistry immediately prior to assembly. Personnel should take precautions to assure that grease, oil, or other contaminants that may ultimately alter the water sample do not contact any portion of the well screen and riser assembly. As one precaution, for example, personnel should wear a clean pair of cotton or surgical (or equivalent) gloves while handling the assembly.

8.2.2 *Riser Joints (Couplings)*—Flush joint risers with square profile threads normally do not require additional PTFE taping to obtain a water tight seal. In addition, O-rings of known chemistry, selected on the basis of prevailing environmental or physical conditions, may be used to assure a tight seal of flush-joint couplings. Couplings are often tightened by hand; however, if necessary, steam cleaned or high-pressure water cleaned wrenches may be utilized. Precautions should be taken to prevent damage to the threaded joints during installation.

8.3 *Setting the Well Screen and Riser Assembly*—When the well screen and riser assembly is lowered to the predetermined level and held into position, the assembly may require ballast to counteract the tendency to float in the borehole. Ballasting may be accomplished by continuously filling the riser with water from a source of known chemistry or, preferably, water which was previously removed from the borehole. Alternatively, the riser may be slowly pushed into the fluid in the borehole with the aid of hydraulic rams on the drill rig and held in place as additional sections of riser are added to the column. Care must be taken to secure the riser assembly so that personnel safety is assured during the installation. The assembly must be installed straight with the appropriate centralizers to allow for the introduction and withdrawal of sampling devices. Difficulty in maintaining a straight installation may be encountered where the weight of the well screen and riser assembly is significantly less than the buoyant force of the fluid in the borehole. The riser should extend above grade and be capped temporarily to deter entrance of foreign materials during completion operations.

8.4 *Installation of the Primary Filter Pack*:

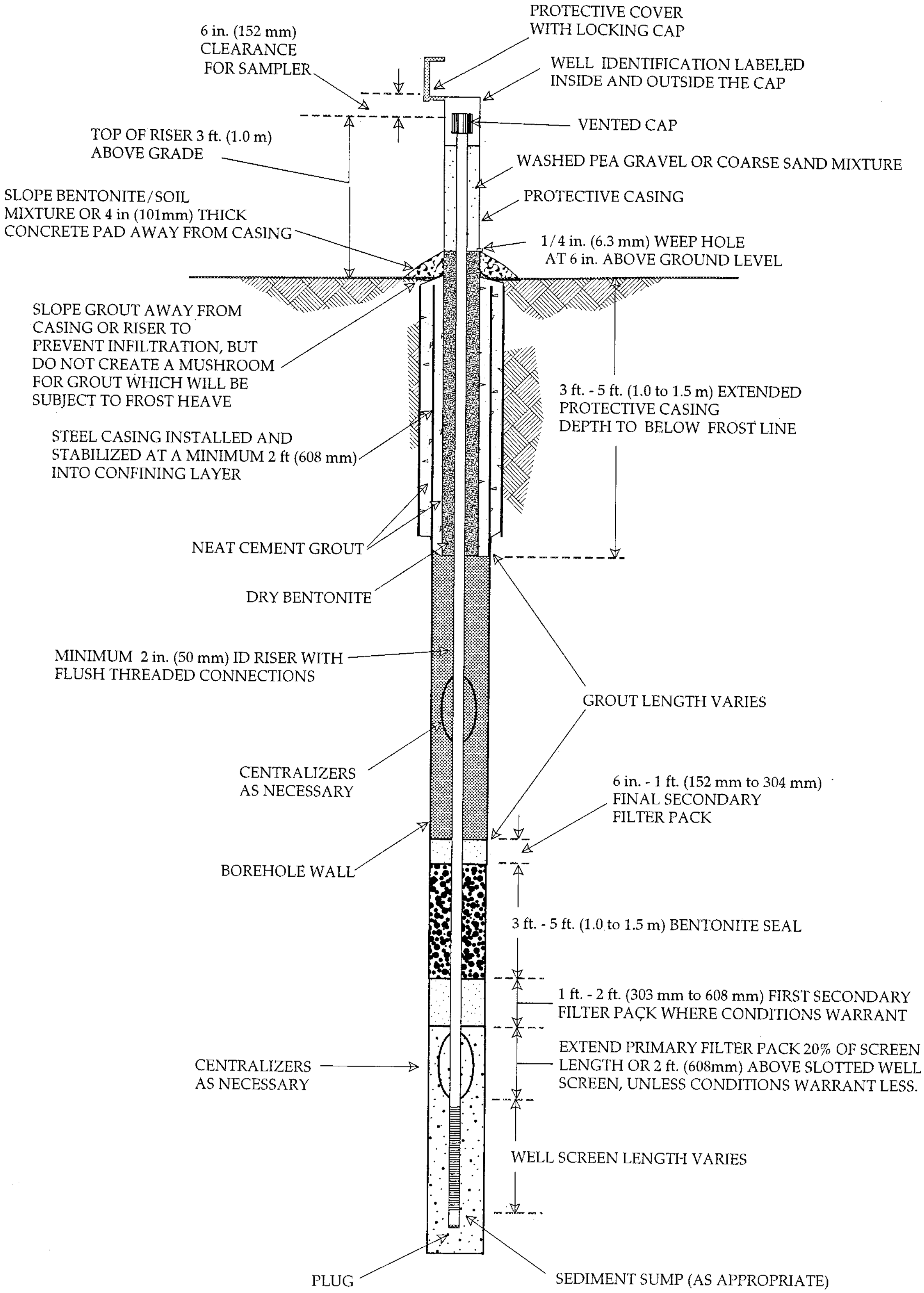


**FIG. 3 Monitoring Well Design—Multi–Cased Well**

8.4.1 *Volume of Filter Pack*—The volume of filter pack required to fill the annular space between the well screen and borehole should be computed, measured, and recorded on the well completion diagram during installation. To be effective, the filter pack should extend above the screen for a distance of about 20 % of the length of the well screen but not less than 2 ft (600 mm) (see Fig. 2 and Fig. 3). Where there is hydraulic connection between the zone to be monitored and the overlying strata, this upward extension should be gauged to prevent seepage from overlying hydrologic units into the filter pack. Seepage from other units may alter the water sample.

8.4.2 *Placement of Primary Filter Pack*—Placement of the well screen is preceded by placing no less than 2 % and no more than 10 % of the primary filter pack into the bottom of the borehole using a decontaminated, flush threaded, 1-in. (25-mm) minimum internal diameter tremie pipe. Alternatively, the filter pack may be added directly between the riser pipe and the auger or borehole or casing and the top of the filter pack located using a tamper or a weighted line. The well screen and riser assembly is then centered in the borehole using one or more centralizer(s) or alternative centering device located not more than 10 ft (3 m) above the bottom of the well screen (see Fig. 2 and Fig. 3). The centralizer should not be located in the bentonite seal. The remaining primary filter pack is then placed in increments as the tremie is gradually raised. As primary filter pack material is poured into the tremie pipe, water from a source of known chemistry may be added to help move the filter pack. The tremie pipe or a weighed line inserted through the tremie pipe can be used to measure the top of the primary filter pack as work progresses. If bridging of the primary filter pack occurs, the bridged material should be broken mechanically prior to proceeding with the addition of more filter pack material. The elevation, volume, and gradation of primary filter pack is recorded on the well completion diagram.

8.4.3 *Withdrawal of the Temporary Casing/Augers*—If used, the temporary casing or hollow stem auger is withdrawn, usually in stipulated increments. Care should be taken to minimize lifting the riser with the withdrawal of the temporary casing/augers. To limit borehole collapse, the temporary casing or hollow stem auger is usually withdrawn until the lower most point on the temporary casing or hollow stem auger is at least 2 ft (608 mm), but no more than 5 ft (1.5 m), above the filter pack for unconsolidated materials; or at least 5 ft, but no more than 10 ft (3.0 m), for consolidated materials. In highly unstable formations, withdrawal intervals may be much less. After each increment, it should be ascertained that the primary filter pack has not been displaced during the withdrawal operation (that is, a weighed measuring device).

8.5 *Placement of First Secondary Filter*—A secondary filter pack may be installed above the primary filter pack to prevent the intrusion of the bentonite grout seal into the primary filter pack (see Fig. 2 and Fig. 3). To be effective, measured and recorded volume of secondary filter material should be added to extend 1 to 2 ft (304 to 608 mm) above the primary filter pack. As with the primary filter, a secondary filter must not extend into an overlying hydrologic unit (see 8.4.1). The well designer should evaluate the need for this filter pack by considering the gradation of the primary filter pack, the hydraulic heads between adjacent units, and the potential for grout intrusion into the primary filter pack. The secondary filter material is poured into the annular space through a decontaminated, flush threaded, 1-in. (25-mm) minimum internal diameter tremie pipe lowered to within 3 ft (1.0 m) of the placement interval. Water from a source of known chemistry may be added to help move the filter pack into its proper location. The tremie pipe or weighed line inserted through the tremie pipe can be used to measure the top of the secondary filter pack as work progresses. The elevation, volume, and gradation of the secondary filter pack is recorded on the well completion diagram.

8.6 *Installation of the Bentonite Seal*—A bentonite pellet or a slurry seal is placed in the annulus between the borehole and the riser pipe on top of the secondary or primary filter pack (see Fig. 2 and Fig. 3). This seal retards the movement of cement-based grout backfill into the primary or secondary filter packs. To be effective, the bentonite seal should extend above the filter packs approximately 3 to 5 ft (1.0 to 1.5 m)—depending on local conditions. The bentonite seal should be installed using a tremie pipe lowered to the top of the filter packs and slowly raised as the bentonite pellets or the slurry fill the annular space. Bentonite pellets may bridge and block the tremie pipe in deep wells. In these cases, pellets may be allowed to free-fall into the borehole. As a bentonite pellet seal is poured into the tremie pipe or allowed to free-fall into the borehole, a tamper or weighed line may be necessary to tamp pellets into place. If the seal is installed above the water level, water from a source of known chemistry would be added to allow proper hydration of the annular seal. The tremie pipe or a weighed line inserted through the tremie pipe can be used to measure the top of the bentonite seal as the work progresses. If a bentonite pellet seal is being constructed above the water level, approximately 5 gal (20 L) of water from a source of known chemistry can be poured into the annulus to ensure that the pellets hydrate. Sufficient time should be allowed for the bentonite pellet seal to hydrate or the slurry annular seal to expand prior to grouting the remaining annulus. The volume and elevation of the bentonite seal material should be measured and recorded on the well completion diagram.

8.7 *Final Secondary Filter Pack*—A 6-in. to 1-ft (152 to 304-mm) secondary filter may be placed above the bentonite seal in the same manner described in 8.5 (see Fig. 2 and Fig. 3). This secondary filter pack will provide a confining layer over the bentonite seal to limit the downward movement of cement-based grout backfill into the bentonite seal. The volume, elevation, and gradation of this final secondary filter pack should be documented on the well completion diagram.

8.8 *Grouting the Annular Space*:

8.8.1 *General*—Grouting procedures vary with the type of well design. The following procedures will apply to both single- and multi-cased monitoring wells. Paragraphs 8.8.2 and 8.8.3 detail those procedures unique to single- and multi-cased installations, respectively.

8.8.1.1 *Volume of Grout*—The volume and location of grout used to backfill the remaining annular space is recorded on the well completion diagram. An ample volume of grout should be premixed on site to compensate for unexpected losses. The use of alternate grout materials, including grouts containing gravel, may be necessary to control zones of high grout loss.

8.8.1.2 *Injection Procedures*—The grout backfill should be injected under pressure to reduce the chance of leaving voids in the grout, and to displace any liquids and drill cuttings that may remain in the annulus. Depending upon the well design, grouting may be accomplished using a pressure grouting technique or by gravity feed through a tremie pipe. With either method, grout is introduced in one continuous operation until full strength grout flows out at the ground surface without evidence of drill cuttings or fluid. The grout should slope away from the riser or casing at the surface, but care should be taken not to create a grout mushroom that would be subjected to frost heave.

8.8.1.3 *Grout Setting and Curing*—The riser or casing or both should not be disturbed until the grout sets and cures for the amount of time necessary to prevent a break in the seal between the grout and riser or grout and casing or both. The amount of time required will vary with grout content and climatic conditions and should be documented on the well completion diagram.

8.8.2 *Specific Procedures for Single-Cased Wells*—Grouting should begin at a level directly above the final secondary filter pack (see Fig. 2). Grout should be injected using a tremie pipe equipped with a side discharge; this dissipates the fluid-pumping energy against the borehole wall and riser, reducing the potential for infiltration of grout into the primary filter pack. The tremie pipe should be kept full of grout from start to finish with the discharge end of the pipe completely submerged as it is slowly and continuously lifted. Approximately 5 to 10 ft (1.5 to 3.0 m) of tremie pipe should remained submerged until grouting is complete. For deep installations or where the joints or couplings of the selected riser cannot withstand the shear or collapse stress exerted by a full column of grout as it sets, a staged grouting procedure may be considered. If used, the temporary casing or hollow stem auger should be removed in increments immediately following each increment of grout installation and in advance of the time when the grout begins to set. If casing removal does not commence until grout injection is completed, then, after the casing is removed, additional grout may be periodically injected into the annular space to maintain a continuous column of grout up to the ground surface.

8.8.3 *Specific Procedures for Multi-Cased Wells*—If the outer casing of a multi-cased well cannot be driven to form a tight seal between the surrounding stratum (strata) and the casing, it should be installed in a predrilled borehole. After the borehole has penetrated not less than 2 ft (608 mm) of the first targeted confining stratum, the outer casing is lowered to the bottom of the boring and the annular space is filled with grout. Grouting may be accomplished using a pressure grouting method or gravity feed through a tremie pipe. Pressure grouting will require the use of a grout shoe or packer installed at the end of the outer casing to prevent grout from moving up into the casing. If a tremie pipe is used to inject grout into the annular space, it should be equipped with a side discharge. With each alternative, the grout must be allowed to cure and form a seal between the casing and the grout prior to advancing the hole to the next hydrologic unit. This procedure is repeated as necessary to advance the borehole to the desired depth. Upon reaching the final target depth, the riser and screen is set through the inner casing. Subsequent to the placement of the filter packs and bentonite seal, the remaining annular space is grouted as described in 8.8.2 (see Fig. 3).

NOTE 13—When using a packer, pressure may build up during grout injection and force grout up the sides of the packer and into the casing.

8.9 *Well Protection*—Well protection refers specifically to installations made at the ground surface to deter unauthorized entry to the monitoring well and to prevent surface water from entering the annulus.

8.9.1 *Protective Casing*—The protective casing should extend from below the frost line (3 to 5 ft [1.0 to 1.5 m]) below the grade depending on local conditions to slightly above the well casing tip. The protective casing should be initially placed before final set of the grout backfill. The protective casing should be sealed and immobilized in concrete placed around the outside of the protective casing above the set grout backfill. The casing should be positioned and stabilized in a position concentric with the riser (see Fig. 1 and Fig. 2). Sufficient clearance, usually 6 in. (152 mm) should be maintained between the lid of the protective casing and the top of the riser to accommodate sampling equipment. A ¼-in. (6.3-mm) diameter weep hole should be drilled in the casing 6 in. above the ground surface to permit water to drain out of the annular space. In cold climates, this hole will also prevent water freezing between the well protector and the well casing. Dry bentonite pellets, granules, or chips should then be placed in the annular space below ground level within the protective casing. Coarse sand or pea gravel or both is placed in the annular space above the dry bentonite pellets and above the weep hole to prevent entry of insects. All materials chosen should be documented on the well completion diagram. The monitoring well identification number should be clearly visible on the inside and outside of the lid of the protective casing.

8.9.2 *Completion of Surface Installation*—The well protection installation may be completed in one of three ways:

8.9.2.1 In areas subject to frost heave, place a soil or bentonite/sand layer adjacent to the protective casing sloped to direct water drainage away from the well.

8.9.2.2 In regions *not* subject to frost heave, a 4-in. (101-mm) thick concrete pad sloped to provide water drainage away from the well may be placed around the installation. Care must be taken not to lock the concrete pad onto the protective casing if subsidence of the surface may occur in the future.

8.9.2.3 Where monitoring well protection must be flushed with the ground, an internal cap should be fitted on top of the riser within the manhole or vault. This cap should be leak-proof so that if the vault or manhole should fill with water, the water will not enter the well casing. Ideally, the manhole cover cap should also be leak-proof.

8.9.3 *Additional Protection*—In areas where there is a high probability of damaging the well (high traffic, heavy equipment, poor visibility), it may be necessary to enhance the normal protection of the monitoring well through the use of posts, markers, signs, etc. The level of protection should meet the damage threat posed by the location of the well.

## 9. Well Development

9.1 *General*—The development serves to remove the finer grained material from the well screen and filter pack that may otherwise interfere with water quality analyses, restore the ground-water properties disturbed during the drilling process and to improve the hydraulic characteristics of the filter pack and hydraulic communication between the well and the hydrologic unit adjacent to the well screen. Methods of well development vary with the physical characteristics of hydrologic units in which the monitoring well is screened and with the drilling method used.

9.2 *Development Methods*—Methods of development most often used include mechanical surging and bailing or pumping, over-pumping, air-lift pumping, and jetting. An important factor in any method is that the development work be stated slowly and gently and be increased in vigor as the well is developed. Most methods of well development require the application of sufficient energy to disturb the filter pack, thereby freeing the fines and allowing them to be drawn into the well. The coarser fractions then settle around and stabilize the screen. The well development method chosen should be documented on the well completion diagram.

NOTE 14—Any time an air compressor is used, it should be equipped with an oil air filter or oil trap to minimize the introduction of oil into the screen area. The presence of oil would impact the organic constituent concentrations of the water samples.

NOTE 15—Development procedures for wells completed in fine sand and silt strata should involve methods that are relatively gentle so that the strain material will not be incorporated into the filter pack. Vigorous surging for development can produce mixing of the fine strata and filter pack and produce turbid samples from the installation. Also, development methods should be carefully selected based upon the potential contaminant(s) present, quality of waste water generated, and requirements for containerization or treatment of waste water.

9.2.1 *Mechanical Surging*—In this method, water is forced to flow into and out of the well screen by operating a plunger (or surge block) or bailer up and down in the riser. A pump or bailer should then be used to remove the dislodged sediments following surging.

9.2.2 *Over Pumping*—With this method, the monitoring well is pumped at a rate considerably higher than it would be during normal operation. The fine-grain materials would be dislodged from the filter pack and surrounding strata influenced by the higher pumping rate. This method is usually conducted in conjunction with mechanical surging.

9.2.3 *Air Lift Pumping*—In this method, an air lift pump is operated by cycling the air pressure on and off for short periods of time. This operation will provide a surging action that will dislodge fine-grained particles. Applying a steady, low pressure will remove the fines that have been drawn into the well by the surging action. Efforts should be made (that is, through the use of a foot valve) to avoid pumping air into the filter pack and adjacent hydrologic unit because the air may lodge there and inhibit future sampling efforts and may alter ambient water chemistry. Furthermore, application of high air pressures should be avoided to prevent damage to small diameter PVC risers, screens, and filter packs.

9.2.4 *Well Jetting*—Another method of development involves jetting the well screen area with water while simultaneously air-lift pumping the well. However, the water added during this development procedure will alter the natural, ambient water quality and may be difficult to remove. Therefore, the water added should be obtained from a source of known chemistry. Water from the monitoring well being developed may also be used if the suspended sediments are first removed.

9.3 *Duration of Well Development*—Well development should begin after the monitoring well is completely installed and prior to water sampling. Development should be continued until representative water, free of the drilling fluids, cuttings, or other materials introduced during well construction is obtained. Representative water is assumed to have been obtained when pH, temperature, and specific conductivity readings stabilize and the water is visually clear of suspended solids. The minimum duration of well development should vary in accordance with the method used to develop the well. For example, surging and pumping the well may provide a stable, sediment-free sample in a matter of minutes; whereas, bailing the well may require several hours of continuous effort to obtain a clear sample. The duration of well development and the pH, temperature, and specific conductivity readings should be recorded on the well completion diagram.

9.4 *Well Recovery Test*—A well recovery test should be performed immediately after and in conjunction with well development. The well recovery test not only provides an indication of well performance but also provides data for determining the transmissivity of the screened hydrologic unit. Estimates of the hydraulic conductivity of the unit can then be determined. Readings should be taken at intervals suggested in the table below until the well has recovered to 90 % of its static water level. Table 2

NOTE 16—If a monitoring well does not recover sufficiently for sampling within a 24-h period and the well has been properly developed, the installation should not generally be used as a monitoring well for detecting or assessing low level organic constituents. The installation may, however, be used for long-term water level monitoring if measurements of shorter frequency water level changes are not required.

## 10. Installation Survey

10.1 *General*—The vertical and horizontal position of each monitoring well in the monitoring system should be surveyed and subsequently mapped by a licensed surveyor. The well location map should include the location of all monitoring wells in the system and their respective identification numbers, elevations of the top of riser position to be used as the reference point for water level measurements, and the elevations of the ground surface protective installations. The locations and elevations of all permanent benchmark(s) and pertinent boundary marker(s) located on-site or used in the survey should also be noted on the map.

10.2 *Water Level Measurement Reference*—The water level measurement reference point should be permanently marked, for instance, by cutting a V-notch into the top edge of the riser pipe. This reference point should be surveyed in reference to the nearest NGVD reference point.

**TABLE 2 Suggested Recording Intervals for Well Recovery Tests**

| Time Since Starting Test | Time Interval |
|---|---|
| 0 to 15 min | 1 min |
| 15 to 50 min | 5 min |
| 50 to 100 min | 10 min |
| 100 to 300 min (5 h) | 30 min |
| 300 to 1440 min (24 h) | 60 min |

10.3 *Location Coordinates*—The horizontal location of all monitoring wells (active or decommissioned) should be surveyed by reference to a standardized survey grid or by metes and bounds.

## 11. Monitoring Well Network Report

11.1 To demonstrate that the goals as set forth in Section 1, the Scope, have been met, a monitoring well network report should be prepared. This report should:

11.1.1 Locate the area investigated in terms pertinent to the project. This should include sketch maps or aerial photos on which the exploratory borings, piezometers, sample areas, and monitoring wells are located, as well as topographic items relevant to the determination of the various soil and rock types, such as contours, streambeds, etc. Where feasible, include a geologic map and geologic cross sections of the area being investigated.

11.1.2 Include copies of all well boring test pits and exploratory borehole logs, initial and post-completion water levels, all laboratory test results, and all well completion diagrams.

11.1.3 Include the well installation survey.

11.1.4 Describe and relate the findings obtained in the initial reconnaissance and field investigation (Section 5) to the design and installation procedures selected (Sections 7-9) and the surveyed locations (Section 10).

11.1.5 This report should include a recommended decommission procedure that is consistent with the well construction and local regulatory requirements.

## 12. Keywords

12.1 aquifer; borehole drilling; geophysical exploration; ground water; monitoring well; site investigation