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Standard Practice for Design and Installation of Groundwater Monitoring Wells¹

This standard is issued under the fixed designation D5092; 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.

^{ε1} NOTE—The units statement in 1.5 was revised editorially in August 2010.

1. Scope

1.1 This practice describes a methodology for designing and installing conventional (screened and filter-packed) groundwater monitoring wells suitable for formations ranging from unconsolidated aquifers (i.e., sands and gravels) to granular materials having grain-size distributions with up to 50 % passing a #200 sieve and as much as 20 % clay-sized material (i.e., silty fine sands with some clay). Formations finer than this (i.e., silts, clays, silty clays, clayey silts) should not be monitored using conventional monitoring wells, as representative groundwater samples, free of artificial turbidity, cannot be assured using currently available technology. Alternative monitoring technologies (not described in this practice) should be used in these formations

1.2 The recommended monitoring well design and installation procedures presented in this practice are based on the assumption that the objectives of the program are to obtain representative groundwater samples and other representative groundwater data from a targeted zone of interest in the subsurface defined by site characterization.

1.3 This practice, in combination with proper well development (D5521), proper groundwater sampling procedures (D4448), and proper well maintenance and rehabilitation (D5978), will permit acquisition of groundwater samples free of artificial turbidity, eliminate siltation of wells between sampling events, and permit acquisition of accurate groundwater levels and hydraulic conductivity test data from the zone screened by the well. For wells installed in fine-grained formation materials (up to 50 % passing a #200 sieve), it is generally necessary to use low-flow purging and sampling techniques (D6771) in combination with proper well design to collect turbidity-free samples.

1.4 This practice applies primarily to well design and installation methods used in drilled boreholes. Other Standards,

including Guide D6724 and Practice D6725, cover installation of monitoring wells using direct-push methods.

1.5 The values stated in inch-pound units are to be regarded as standard, except as noted below. The values given in parentheses are mathematical conversions to SI units, which are provided for information only and are not considered standard.

1.5.1 The gravitational system of inch-pound units is used when dealing with inch-pound units. In this system, the pound (lbf) represents a unit of force (weight), while the unit for mass is slugs.

1.6 *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.*

1.7 *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. Not 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:*²

C150 Specification for Portland Cement

C294 Descriptive Nomenclature for Constituents of Concrete Aggregates

D421 Practice for Dry Preparation of Soil Samples for Particle-Size Analysis and Determination of Soil Constants

D422 Test Method for Particle-Size Analysis of Soils

¹ This practice is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.21 on Groundwater and Vadose Zone Investigations.

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² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

- D653 Terminology Relating to Soil, Rock, and Contained Fluids
- D1452 Practice for Soil Exploration and Sampling by Auger Borings
- D1586 Test Method for Penetration Test (SPT) and Split-Barrel Sampling of Soils
- D1587 Practice for Thin-Walled Tube Sampling of Soils for Geotechnical Purposes
- D2113 Practice for Rock Core Drilling and Sampling of Rock for Site Exploration
- D2217 Practice for Wet Preparation of Soil Samples for Particle-Size Analysis and Determination of Soil Constants
- D2487 Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)
- D2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)
- D3282 Practice for Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes
- D3441 Test Method for Mechanical Cone Penetration Tests of Soil (Withdrawn 2014)³
- D3550 Practice for Thick Wall, Ring-Lined, Split Barrel, Drive Sampling of Soils
- D4220 Practices for Preserving and Transporting Soil Samples
- D4700 Guide for Soil Sampling from the Vadose Zone
- D4750 Test Method for Determining Subsurface Liquid Levels in a Borehole or Monitoring Well (Observation Well) (Withdrawn 2010)³
- D5079 Practices for Preserving and Transporting Rock Core Samples
- D5088 Practice for Decontamination of Field Equipment Used at Waste Sites
- D5254 Practice for Minimum Set of Data Elements to Identify a Ground-Water Site
- D5299 Guide for Decommissioning of Groundwater Wells, Vadose Zone Monitoring Devices, Boreholes, and Other Devices for Environmental Activities
- D5434 Guide for Field Logging of Subsurface Explorations of Soil and Rock
- D5518 Guide for Acquisition of File Aerial Photography and Imagery for Establishing Historic Site-Use and Surficial Conditions
- D5521 Guide for Development of Groundwater Monitoring Wells in Granular Aquifers
- D5608 Practices for Decontamination of Field Equipment Used at Low Level Radioactive Waste Sites
- D5730 Guide for Site Characterization for Environmental Purposes With Emphasis on Soil, Rock, the Vadose Zone and Groundwater (Withdrawn 2013)³
- D5753 Guide for Planning and Conducting Borehole Geophysical Logging
- D5777 Guide for Using the Seismic Refraction Method for Subsurface Investigation
- D5781 Guide for Use of Dual-Wall Reverse-Circulation Drilling for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices
- D5782 Guide for Use of Direct Air-Rotary Drilling for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices
- D5783 Guide for Use of Direct Rotary Drilling with Water-Based Drilling Fluid for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices
- D5784 Guide for Use of Hollow-Stem Augers for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices
- D5787 Practice for Monitoring Well Protection
- D5872 Guide for Use of Casing Advancement Drilling Methods for Geoenvironmental Exploration and Installation of Subsurface Water-Quality Monitoring Devices
- D5875 Guide for Use of Cable-Tool Drilling and Sampling Methods for Geoenvironmental Exploration and Installation of Subsurface Water-Quality Monitoring Devices
- D5876 Guide for Use of Direct Rotary Wireline Casing Advancement Drilling Methods for Geoenvironmental Exploration and Installation of Subsurface Water-Quality Monitoring Devices
- D5978 Guide for Maintenance and Rehabilitation of Groundwater Monitoring Wells
- D5979 Guide for Conceptualization and Characterization of Groundwater Systems
- D6001 Guide for Direct-Push Groundwater Sampling for Environmental Site Characterization
- D6067 Practice for Using the Electronic Piezocone Penetrometer Tests for Environmental Site Characterization
- D6167 Guide for Conducting Borehole Geophysical Logging: Mechanical Caliper
- D6169 Guide for Selection of Soil and Rock Sampling Devices Used With Drill Rigs for Environmental Investigations
- D6235 Practice for Expedited Site Characterization of Vadose Zone and Groundwater Contamination at Hazardous Waste Contaminated Sites
- D6274 Guide for Conducting Borehole Geophysical Logging - Gamma
- D6282 Guide for Direct Push Soil Sampling for Environmental Site Characterizations
- D6286 Guide for Selection of Drilling Methods for Environmental Site Characterization
- D6429 Guide for Selecting Surface Geophysical Methods
- D6430 Guide for Using the Gravity Method for Subsurface Investigation
- D6431 Guide for Using the Direct Current Resistivity Method for Subsurface Investigation
- D6432 Guide for Using the Surface Ground Penetrating Radar Method for Subsurface Investigation
- D6519 Practice for Sampling of Soil Using the Hydraulically Operated Stationary Piston Sampler
- D6639 Guide for Using the Frequency Domain Electromagnetic Method for Subsurface Investigations

³ The last approved version of this historical standard is referenced on www.astm.org.

- D6640** Practice for Collection and Handling of Soils Obtained in Core Barrel Samplers for Environmental Investigations
- D6724** Guide for Installation of Direct Push Groundwater Monitoring Wells
- D6725** Practice for Direct Push Installation of Prepacked Screen Monitoring Wells in Unconsolidated Aquifers
- D6771** Practice for Low-Flow Purging and Sampling for Wells and Devices Used for Ground-Water Quality Investigations (Withdrawn 2011)³
- F480** Specification for Thermoplastic Well Casing Pipe and Couplings Made in Standard Dimension Ratios (SDR), SCH 40 and SCH 80

3. Terminology

3.1 Definitions:

3.1.1 *annular space; annulus*—the space between two concentric strings of casing, or between the casing and the borehole wall. This includes the space(s) between multiple strings of casing in a borehole installed either concentrically or adjacent to one another.

3.1.2 *artificial turbidity*—particulate matter that is not naturally mobile in the groundwater system and that is produced in some way by the groundwater sampling process. May consist of particles introduced to the subsurface during drilling or well construction, sheared from the target monitoring zone during pumping or bailing the well, or produced by exposure of groundwater to atmospheric conditions.

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

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

3.1.5 *borehole*—an open or uncased subsurface hole, generally circular in plan view, created by drilling.

3.1.6 *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 and/or installation of an exploratory borehole or well.

3.1.7 *bridge*—an obstruction within the annulus that may prevent circulation or proper placement of annular fill materials.

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

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

3.1.10 *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.

3.1.11 *caving; sloughing*—the inflow of unconsolidated material into a borehole that occurs when the borehole walls lose their cohesiveness.

3.1.12 *cement*—commonly known as Portland cement. A mixture that consists of 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 **C150**. Portland cement is 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.

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

3.1.14 *confining unit*—a body of relatively low hydraulic conductivity formation material stratigraphically adjacent to one or more aquifers. Synonymous with “aquiclude,” “aquitard,” and “aquifuge.”

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

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

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

3.1.18 *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.

3.1.19 *gravel pack*—common term used to refer to the primary filter pack of a well (see *primary filter pack*).

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

3.1.21 *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.

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

3.1.23 *neat cement*—a mixture of Portland cement (Specification **C150**) and water.

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

3.1.25 *piezometer*—a small-diameter well with a very short screen that is used to measure changes in hydraulic head, usually in response to pumping a nearby well. Synonymous with observation well.

3.1.26 *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 formation(s). The term is used in place of *gravel pack*.

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

3.1.28 *riser*—the pipe or well casing extending from the well screen to just above or below the ground surface.

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

3.1.30 *sediment sump*—a blank extension of pipe or well casing, closed at the bottom, beneath the well screen used to collect fine-grained material from the filter pack and adjacent formation materials during the process of well development. Synonymous with rat trap or tail pipe.

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

3.1.32 *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, or hydraulic testing.

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

3.1.34 *target monitoring zone*—the groundwater flow path from a particular area or facility in which monitoring wells will be screened. The target monitoring zone should be an interval in subsurface materials in which there is a reasonable expectation that a monitoring well will intercept groundwater moving beneath an area or facility and any migrating contaminants that may be present.

3.1.35 *tremie pipe*—a small-diameter pipe or tube that is used to transport filter pack materials and annular seal materials from the ground surface into an annular space.

3.1.36 *uniformity coefficient*—the ratio of d_{60}/d_{10} , where d_{60} and d_{10} are particle diameters corresponding to 60 % and 10 % finer on the cumulative particle size curve, respectively.

3.1.37 *uniformly graded*—a quantitative definition of the particle size distribution of a soil that consists of a majority of particles being of approximately the same diameter. A granular

material is considered uniformly graded when the uniformity coefficient is less than about five (Test Method **D2487**). Comparable to the geologic term *well sorted*.

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

3.1.39 *weep hole*—a small-diameter hole (usually ¼ in.) drilled into the protective casing above the ground surface that serves to drain out water that may enter the annulus between the riser and the protective casing.

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

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

4. Significance and Use

4.1 This practice for the design and installation of groundwater monitoring wells will promote (1) efficient and effective site hydrogeological characterization; (2) durable and reliable well construction; and (3) acquisition of representative groundwater quality samples, groundwater levels, and hydraulic conductivity testing data from monitoring wells. The practices established herein are affected by governmental regulations and by site-specific geological, hydrogeological, climatological, topographical, and subsurface geochemical conditions. To meet these geoenvironmental challenges, this practice promotes the development of a conceptual hydrogeologic model prior to monitoring well design and installation.

4.2 A properly designed and installed groundwater monitoring well provides essential information on one or more of the following subjects:

- 4.2.1 Formation geologic and hydraulic properties;
- 4.2.2 Potentiometric surface of a particular hydrologic unit(s);
- 4.2.3 Water quality with respect to various indicator parameters; and
- 4.2.4 Water chemistry with respect to a contaminant release.

5. Site Characterization

5.1 *General*—A thorough knowledge of site-specific geologic, hydrologic and geochemical conditions is necessary to properly apply the monitoring well design and installation procedures contained within this practice. Development of a conceptual site model, that identifies potential flow paths and the target monitoring zone(s), and generates a 3-D picture of contaminant distribution and contaminant movement pathways, is recommended prior to monitoring well design and installation. Development of the conceptual site model is accomplished in two phases -- an initial reconnaissance, after which a preliminary conceptual model is created, and a field investigation, after which a revised conceptual model is formulated. 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 limited or no background data are available or where the

geology is complex, a field investigation will be required to develop the necessary conceptual site 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 or preferential flow pathways with the greatest potential to transmit fluids from the project area. Identifying these flow pathways is the first step in selecting the target groundwater 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. Information such as, but not limited to, topographic maps, aerial imagery (see Guide [D5518](#)), site ownership and utilization records, geologic and hydrogeologic maps and reports, mineral resource surveys, water well logs, information from local well drillers, agricultural soil reports, geotechnical engineering reports, and other engineering maps and reports related to the project area should be reviewed to locate relevant site information.

5.2.2 Field Reconnaissance—Early in the investigation, the soil and rocks in open cut areas (e.g., roadcuts, streamcuts) 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 conceptual site model using information 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 site model so that the target monitoring zone(s) is (are) identified prior to monitoring well installation.

5.3.1 Exploratory Borings and Direct-Push Methods—Characterization of the flow paths conceptualized in the initial reconnaissance involves defining the porosity (type and amount), hydraulic conductivity, stratigraphy, lithology, gradation and structure of each hydrologic unit encountered beneath the site. These characteristics are defined by conducting an exploratory program which may include drilled soil borings (see Guide [D6286](#) for selection of drilling methods) and direct-push methods (e.g., cone penetrometers [see Test Method [D3441](#) or Guide [D6067](#)] or direct-push machines using soil sampling, groundwater sampling and/or electrical conductivity measurement tools [see Guides [D6282](#) and [D6001](#)]). Exploratory soil borings and direct-push holes should be deep enough to develop the required engineering and hydrogeologic data for determining the preferential flow pathway(s), target monitoring zone(s), or both.

5.3.1.1 Sampling—Soil and rock properties should not be predicted wholly on field description or classification, but should be confirmed by laboratory and/or field tests made on samples or in boreholes or wells. Representative soil or rock samples of each material that is significant to the design of the

monitoring well system should be obtained and evaluated by a geologist, hydrogeologist, soil scientist or engineer trained and experienced in soil and rock analysis. Soil sample collection should be conducted according to Practice [D1452](#), Test Method [D1586](#), Practice [D3550](#), Practice [D6519](#) or Practice [D1587](#), whichever is appropriate given the anticipated characteristics of the soil samples (see Guide [D6169](#) for selection of soil sampling methods). Rock samples should be collected according to Practice [D2113](#). 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 [D6640](#)). 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 done in the field before the core is removed from the 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 soil boring or direct-push hole (see Guide [D5434](#)).

NOTE 1—Site investigations conducted for the purpose of generating data for the installation of groundwater monitoring wells can vary greatly due to the availability of reliable site data or the lack thereof. The general procedure would 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 hydrologic and geochemical conditions present at the 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 predicting the effectiveness of aquifer remediation. 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 data (that is, penetration rates or blow counts), and sample description information for each material identified in the borehole either by symbol or word description, or both. Description and identification of soils should be in accordance with Practice [D2488](#); classification of soils should be in accordance with either Practice [D2487](#) or Practice [D3282](#). Identification of rock material should be based on Nomenclature [C294](#) 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 either North American Vertical Datum of 1988 [NAVD 88] or to a standardized survey grid) of each exploratory soil boring 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 soil boring and outcrop observation data and to aid in interpretation between soil borings. Appropriate surface and borehole geophysical methods for meeting site-specific project objectives can be selected by consulting Guides

D6429 and **D5753** respectively. Surface geophysical methods such as seismic (Guide **D5777**), electrical-resistivity (Guide **D6431**), ground-penetrating radar (Guide **D6432**), gravity (Guide **D6430**) and electromagnetic conductance surveys (Guide **D6639**) 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 (see Guide **D6167**) can be useful to confirm specific subsurface geologic conditions. Gamma logs (Guide **D6274**) are particularly useful in existing cased wells.

5.3.3 Groundwater Flow Direction—Groundwater flow direction is generally determined by measuring the vertical and horizontal hydraulic gradient within each conceptualized flow pathway. However, because water will flow along the pathways of least resistance (within the highest hydraulic conductivity formation materials at the site), actual flow direction may be oblique to the hydraulic gradient (within buried stream channels or glacial valleys, for example). Flow direction is determined by first installing piezometers in the exploratory soil borings that penetrate the zone(s) of interest at the site. The depth and location of the piezometers will depend upon anticipated hydraulic connections between conceptualized flow pathways 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 zone(s) of interest. Following water-level data acquisition, a potentiometric surface map should be prepared. Flow pathways are ordinarily determined to be at right angles, or nearly so, to the equipotential lines, though consideration of complex geology can result in more complex interpretations of flow

5.4 Completing the Conceptual Model—A series of geologic and 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 soil 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 geologic profile data with the potentiometric data for both vertical and horizontal hydraulic gradients. Plan view and cross-sectional flow nets should be constructed. Following the analysis of these data, conclusions can be made as to which flow pathway(s) is (are) the appropriate target monitoring zone(s).

NOTE 2—Use of groundwater monitoring wells is difficult and may not be a reliable technology in fine-grained, low hydraulic conductivity formation materials with primary porosity because of (1) the disproportionate influence that microstratigraphy has on groundwater flow in fine-grained strata; (2) the proportionally higher vertical flow component in low hydraulic conductivity strata; and (3) the presence of indigenous metallic and inorganic constituents in the matrix 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 that come in contact with water samples should not alter the chemical quality of the sample for the constituents being examined. The riser, well screen, and annular seal installation equipment should be cleaned immediately prior to well installation (see either Practice **D5088** or **D5608**) or certified clean from the manufacturer and delivered to the site in a protective wrapping. Samples of the riser and screen material, cleaning water, filter pack, annular seal, bentonite, and mixed grout should be retained to serve as quality control until the completion of at least one round of groundwater quality sampling and analysis has been completed.

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 General—The purposes of the primary filter pack are to act as a filter that retains formation material while allowing groundwater to enter the well, and to stabilize the formation to keep it from collapsing on the well. The design of the primary filter pack is based on the grain-size distribution of the formation material (as determined by sieve analysis—see Test Method **D422**) to be retained. The grain size distribution of the primary filter pack must be fine enough to retain the formation, but coarse enough to allow for unrestricted movement of groundwater into and through the monitoring well. The design of the well screen (see **6.4.3**) must be done in concert with the design of the filter pack. After development, a monitoring well with a correctly designed and installed filter pack and screen combination should produce samples free of artifactual turbidity.

6.3.2 Materials—The primary filter pack should consist of an inert granular material (generally ranging from gravel to very fine sand, depending on formation grain size distribution) of selected grain size and gradation that is installed in the annulus between the well screen and the borehole wall. Washed and screened silica sands and gravels, with less than 5 % non-siliceous materials, should be specified.

6.3.3 Design—The design theory of filter pack gradation is based on mechanical retention of formation materials.

6.3.3.1 1 For formation materials that are relatively coarse-grained (i.e., fine, medium and coarse sands and gravels), the grain size distribution of the primary filter pack is determined by calculating the d-30 (30 % finer) size, the d-60 (60 % finer) size, and the d-10 (10 % finer) size of the filter pack. The first point on the filter pack grain-size distribution curve is the d-30 size. The primary filter pack is usually selected to have a d-30 grain size that is about 4 to 6 times greater than the d-30 grain size of the formation material being retained (see **Fig. 1**). A multiplication factor of 4 is used if the formation material is relatively fine-grained and well sorted or uniform (small range in grain sizes); a multiplication factor of 6 is used if the formation is relatively coarse grained and poorly sorted or