This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

Designation: D5092/D5092M – 16

Standard Practice for
Design and Installation of Groundwater Monitoring Wells[1]

This standard is issued under the fixed designation D5092/D5092M; 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.

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 (that is, 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 (that is, silty fine sands with some clay). Formations finer than this (that is, silts, clays, silty clays, clayey silts) can be monitored but the well may not yield sufficient water required for sampling, and fine filter pack and screen requirements are difficult and costly to install. Use of coarser filter/screens in fine formations will result in wells with unstable filter packs and associated elevated sample turbidity that may adversely affect sample accuracy and data quality objectives. This practice is not applicable in fractured or karst rock conditions, but may be applicable for other porous rock 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 when used on coarse grained sand and gravel aquifers, 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 artifactual 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, it is generally necessary to use much finer pre-packed well screens (6.3.3.2) and/or employ sampling methods that minimize screen intake flow velocity, and disturbance of the well column including suspension of settled solids in the well. Using low-flow purging and sampling techniques (D6771) or passive sampling devices (D7929) are two means to minimize the potential sample bias associated with turbidity.

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 *Units*—The values stated in either inch-pound units or SI units [presented in brackets] are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard. Equivalent values given in parentheses are shown for mix designs and sieves sizes.

1.5.1 Sieve Designations (Specification E11) are identified using the "alternate" system, for example, #40, #200 sieve etc. with nominal opening size in inches and particle sizes in mm. See Specification E11 for standard metric sieve sizes.

1.5.2 Well screen slots are expressed in inches and the metric equivalent is given in the terminology section and when necessary in the standard (see 3.3.6).

1.6 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D6026, unless superseded by this standard.

1.7 *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.*

1.8 *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.*

1.9 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the*

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[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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***A Summary of Changes section appears at the end of this standard**

Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C150 Specification for Portland Cement
C294 Descriptive Nomenclature for Constituents of Concrete Aggregates
D422 Test Method for Particle-Size Analysis of Soils (Withdrawn 2016)[3]
D653 Terminology Relating to Soil, Rock, and Contained Fluids
D1129 Terminology Relating to Water
D1452 Practice for Soil Exploration and Sampling by Auger Borings
D1586 Test Method for Standard Penetration Test (SPT) and Split-Barrel Sampling of Soils
D1587 Practice for Thin-Walled Tube Sampling of Fine-Grained Soils for Geotechnical Purposes
D2113 Practice for Rock Core Drilling and Sampling of Rock for Site Exploration
D2487 Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)
D2488 Practice for Description and Identification of Soils (Visual-Manual Procedures)
D3282 Practice for Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes
D3550 Practice for Thick Wall, Ring-Lined, Split Barrel, Drive Sampling of Soils
D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction
D4448 Guide for Sampling Ground-Water Monitoring Wells
D5088 Practice for Decontamination of Field Equipment Used at Waste Sites
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 Sampling and Non Sample Contacting Equipment Used at Low Level Radioactive Waste Sites
D5753 Guide for Planning and Conducting Borehole Geophysical Logging
D5777 Guide for Using the Seismic Refraction Method for Subsurface Investigation
D5778 Test Method for Electronic Friction Cone and Piezocone Penetration Testing of Soils
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
D6001 Guide for Direct-Push Groundwater Sampling for Environmental Site Characterization
D6026 Practice for Using Significant Digits in Geotechnical Data
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
D6274 Guide for Conducting Borehole Geophysical Logging - Gamma
D6282 Guide for Direct Push Soil Sampling for Environmental Site Characterizations
D6285 Guide for Locating Abandoned Wells
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

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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.

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

D6639 Guide for Using the Frequency Domain Electromagnetic Method for Subsurface Investigations (Withdrawn 2017)[3]

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]

D6914 Practice for Sonic Drilling for Site Characterization and the Installation of Subsurface Monitoring Devices

D7242 Practice for Field Pneumatic Slug (Instantaneous Change in Head) Tests to Determine Hydraulic Properties of Aquifers with Direct Push Groundwater Samplers

D7929 Guide for Selection of Passive Techniques for Sampling Groundwater Monitoring Wells

D8037 Practice for Direct Push Hydraulic Logging Profiling Variations of Permeability Soils

E11 Specification for Woven Wire Test Sieve Cloth and Test Sieves

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 For definitions of common technical terms in this standard, refer Terminology D653.

3.1.2 *artifactual turbidity, n—in wells, filters*, particulate matter that is not naturally mobile in the groundwater system and that is produced in some way by the groundwater sampling process.

3.1.2.1 *Discussion*—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 *ballast, n—in drilling*, materials used to provide stability to a buoyant object (such as casing within a water-filled borehole).

3.1.4 *borehole, n—in drilling*, an open or uncased subsurface hole, generally circular in plain view, created by drilling.

3.1.5 *borehole log, n—in drilling*, 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.

3.1.6 *bridge, n—in drilling*, an obstruction within the annulus that may prevent circulation or proper placement of annular fill materials.

3.1.7 *casing, n—in drilling*, 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.

3.1.8 *casing, protective, n—in drilling*, 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.

3.1.9 *casing, surface, n—in drilling*, 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.

3.1.10 *caving; sloughing, v—in drilling*, the inflow of unconsolidated material into a borehole that occurs when the borehole walls lose their cohesiveness.

3.1.11 *cement, n—in drilling*, 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.

3.1.12 *centralizer, n—in drilling*, a device that assists in the centering of a casing or riser within a borehole or another casing.

3.1.13 *confining unit, n—in hydrogeology*, a body of relatively low hydraulic conductivity formation material stratigraphically adjacent to one or more aquifers.

3.1.13.1 *Discussion*—Synonymous with or may include formations that are considered to be "aquiclude," "aquitard," and "aquifuge."

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

3.1.15 *gravel pack, n—in wells, filters*, common term used to refer to the primary filter pack of a well (see *primary filter pack*).

3.1.16 *hydrologic unit, n—in geology, hydrogeology*, 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.

3.1.17 *neat cement, n—in grouting*, a mixture of Portland cement (Specification C150) and water.

3.1.18 *piezometer, n—in wells, hydrogeology*, 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.

3.1.19 *piping, n*—the progressive removal of soil particles from a mass by percolating water, leading to the development of channels.

3.1.20 *primary filter pack, n—in wells*, 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*.

3.1.21 *PTFE tape, n—in drilling*, joint sealing tape composed of polytetrafluoroethylene.

3.1.22 *riser, n—in wells*, the pipe or well casing extending from the well screen to just above or below the ground surface.

3.1.23 *secondary filter pack, n—in wells*, 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.

3.1.24 *sediment sump, n—in wells*, 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.

3.1.25 *static water level, n—in hydrogeology*, 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.

3.1.26 *tamper, n—in piezometers and wells*, 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.

3.1.27 *target monitoring zone, n—in geoenvironmental programs*, 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.

3.1.28 *tremie pipe, n—in wells*, 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.

3.1.29 *uniformity coefficient, n—in soils*, 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.

3.1.30 *uniformly graded, n—in soils*, 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*.

3.1.31 *vented cap, n—in wells/piezometers*, a cap with a small hole that is installed on top of the riser.

3.1.32 *weep hole, n—in drilling*, 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.

3.1.33 *well completion diagram, n—in wells*, a record that illustrates the details of a well installation.

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

3.2 *Terms Referenced in D1129, Committee D19 on Water:*

3.2.1 *turbidity, n*—expression of the optical properties of a sample that causes light rays to be scattered and absorbed rather than transmitted in straight lines through the sample. (Turbidity of water is caused by the presence of suspended and dissolved matter such as clay, silt, finely divided organic matter, plankton, other microscopic organisms, organic acids, and dyes.)

3.2.1.1 *Discussion*—The D19 definition is related to measurement of turbidity. For the purpose of this standard, turbidity is cloudiness or haziness in a fluid caused by the presence of small suspended solids that are otherwise imperceptible to the naked eye.

3.3 *Definitions of Terms Specific to This Standard:*

3.3.1 *annular space; annulus, n*—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

3.3.2 *grout (monitoring wells), n*—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.

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

3.3.4 *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.

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

3.3.6 *slot, n—wells screen opening*, slot openings have been designated by numbers which correspond to the width of the openings in thousandths of an inch. A No. 10 slot screen, for example, is an opening of 0.010 inch [0.25 mm].

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.

NOTE 1—This practice presents a design for monitoring wells that will be effective in the majority of formations. This practice is in general accordance with other national and state guidance documents on well construction (ANSI/NGWA-01-14 (**1**)[4] and California EPA (**2**)) however; national, state, or local design regulations may control 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.

NOTE 2—The quality of the result produced by this standard is dependent on the competence of the personnel performing it, and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D3740 are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of this standard are cautioned that compliance with Practice D3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D3740 provides a means of evaluating some of those factors.

Practice D3740 was developed for agencies engaged in the laboratory testing and/or inspection of soils and rock. As such, it is not totally applicable to agencies performing this practice. However, user of this practice should recognize that the framework of Practice D3740 is appropriate for evaluating the quality of an agency performing this practice. Currently there is no known qualifying national authority that inspects agencies that perform this practice. Use of certified water well drillers are recommended. There are national and state agencies that certify water well drillers.

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 the target monitoring zone(s), and generates a three dimensional (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 exploration, 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 exploration 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 explorations 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 exploration, the soil and rocks in open cut areas (for example, 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 Exploration*—The goal of the field exploration 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 Boreholes 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, but not limited to: drilled boreholes (see Guide D6286 for selection of drilling methods) and direct-push methods (for example, cone penetrometers (see Test Method D5778 or Guide D6067) or direct-push machines using soil sampling, groundwater sampling and/or electrical conductivity measurement tools (see Guides D6001 and D6282; Practices D7242 and D8037). Exploratory boreholes 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, Guide D6282, Practice D6519 or Practice D1587, whichever is appropriate given the anticipated characteristics of the soil samples (see Guide D6169 for

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[4] The boldface numbers in parentheses refer to a list of references at the end of this standard.

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 boring or direct-push hole (see Guide D5434).

NOTE 3—Site explorations 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 exploration 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 intervals), 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 national vertical datum such as North American Vertical Datum of 1988 [NAVD 88] or to a standardized survey grid) 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 observation data and to aid in interpretation between 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 in the highest hydraulic conductivity, most transmissive, formation materials at the site, actual flow direction may be oblique to the average hydraulic gradient (within buried stream channels or glacial valleys, for example). Flow direction is determined by first installing piezometers in the exploratory boreholes 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 (Guide D6285). 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 boreholes 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).

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.

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. Water used in the process should be analyzed for the same analytes if required in the sampling plan.

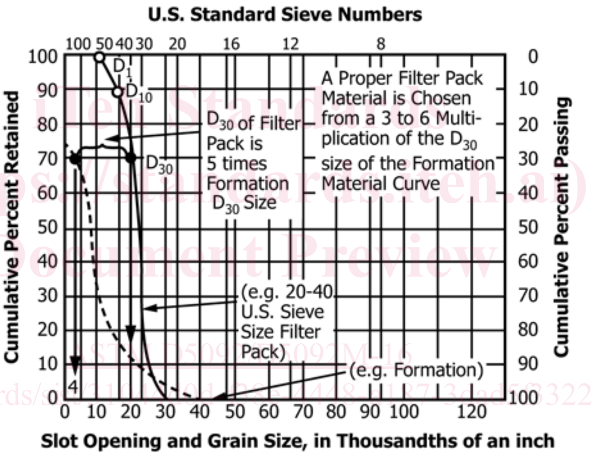
6.3 *Primary Filter Pack:*

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 (**3, 4, 5, and 6**). 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 and Fig. 1) 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.

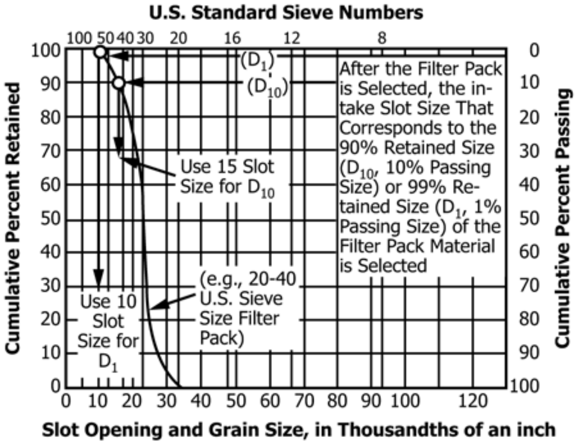
6.3.2 *Materials*—The primary filter pack should consist of an inert granular material (generally ranging from gravel to very fine sand, depending on formation grain size distribution) of selected grain size and gradation that is installed in the annulus between the well screen and the borehole wall. 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 *Coarse Grained Formations*—For formation materials that are relatively coarse-grained (that is, 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



The filter-pack material selected to surround the well screen should have a 70% retained size that is three to six times greater than the 70% retained size of the formation materials. In this example, a multiplier of 5 was selected, based on formation material characteristics.



The well screen slot size is selected to retain between 90 and 99% of the selected filter-pack material.

FIG. 1 Example Grading Curves for Design of Filter Pack and Slot Size (5)

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 non-uniform (large range in grain sizes). Thus, 70 % of the filter pack will have a grain size that is 4 to 6 times larger than the D_{30} size of the formation materials. This ensures that the filter pack is coarser (with a higher hydraulic conductivity) than the formation material, and allows for unrestricted groundwater flow from the formation into the monitoring well.

(1) The next 2 points on the filter pack grain-size distribution curve are the D_{60} and D_{10} grain sizes. These are chosen so that the ratio between the two grain sizes (the uniformity coefficient) is less than 2.5. This ensures that the filter pack has a small range in grain sizes and is uniform (see technical Note 4). The D_{60} and D_{10} grain sizes of the filter pack are calculated by a trial and error method using grain sizes that are close to the D_{30} size of the filter pack. After the D_{30}, D_{60} and D_{10} sizes of the filter pack are determined, a smooth curve is drawn through these points. The final step in filter pack design is to specify the limits of the grain size envelope, which defines the permissible range in grain sizes for the filter pack. The permissible range on either side of the grain size curve is 8 %. The boundaries of the grain size envelope are drawn on either side of the filter pack grain-size distribution curve, and filter pack design is complete. For examples, see references (**3**, **4**, **5**). A filter medium having a grain-size distribution as close as possible to this curve is then obtained from a local sand supplier.

NOTE 4—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.

6.3.3.2 *Fine-Grained Formations*—In formation materials that are predominantly fine-grained (finer than fine to very fine sands), soil piping can occur when a hydraulic gradient exists between the formation and the well (as would be the case during well development and sampling). To prevent soil piping in these materials, the following criteria are used for designing granular filter packs (**7**):

$$\frac{D_{15}\text{of filter}}{D_{85}\text{of formation}} \leq 4 \text{ to } 5 \text{ and} \frac{D_{15}\text{of filter}}{D_{15}\text{of formation}} \geq 4 \text{ to } 5$$

The left half of this equation is the fundamental criterion for the prevention of soil piping through a granular filter, while the right half of the equation is the hydraulic conductivity criterion. This latter criterion serves the same purpose as multiplying the D_{30} grain size of the formation by a factor of between 4 and 6 for coarser formation materials. Filter pack materials suitable for retaining formation materials in formations that are predominantly fine-grained are themselves, by necessity, relatively fine-grained (for example, fine to very fine sands), presenting several problems for well designers and installers. First, well screen slot sizes suitable for retaining such fine-grained filter pack materials are not widely available (the smallest commercially available slotted well casing is 6 slot, 0.006 in. [0.15 mm]; the smallest commercially available continuous-slot wire-wound screen is 4 slot, 0.004 in. [0.10 mm]). Second, the finest filter pack material practical for conventional (tremie tube) installation is a #40 by #70 sieve size, [425 to 212 µm] sand, which can be used with a well screen slot as small as 8 slot, 0.008-in., [0.20 mm]. Finer grained filter pack materials cannot be placed practically by either tremie tubes or pouring down the annular space or down augers.

(1) Pre-Packed Well Screen—The best method for ensuring proper installation of filter packs in predominantly fine-grained formation materials is to use pre-packed or sleeved screens, which are described in detail in Practice D6725. A #50 by #100 [300 to 150 µm] sieve size filter-pack sand can be used with a 6 slot size pre-packed or sleeved screen, and a #60 by #120 [250 to 125 µm] filter-pack sand can be used with a 4-slot slot size pre-packed or sleeved screen. Filter packs that are finer than these (for example, sands as fine as #100 by #120 [150 to 125 µm], or silica flour as fine as #200 mesh [75 µm]) can only be installed within stainless steel mesh sleeves that can be placed over pipe-based screens. While these sleeves, or the space between internal and external screens in a pre-packed well screen may be as thin as ½-in. [15 mm], the basis for mechanical retention dictates that a filter-pack thickness of only two or three grain diameters is needed to contain and control formation materials. Laboratory tests have demonstrated that a properly sized filter pack material with a thickness of less than ½-in. [15 mm] successfully retains formation particles regardless of the velocity of water passing through the filter pack. (**3**, **4**)

(2) The theoretical limit of mechanical filtration for monitoring wells is defined by the finest filter pack material that can be practically installed via a pre-packed or sleeved screen encased within a very fine mesh screen of stainless steel or other suitable material. Dam filter design practice has found that a medium sand filter with sufficient fine fraction (10 to 30 %) of #50 to #100 sand with a D_{15} less than 0.2 mm is effective in retaining most all clay formation materials (**8**, **9**).

NOTE 5—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 material combinations are presented in Table 1.

6.4 *Well Screen:*

6.4.1 *General*—Purposes of the well screen are to provide designed openings for groundwater flow through the well, and to prevent migration of filter pack and formation material into the well. Well screen design is based on either the grain-size distribution of the formation (in the case of a well with a naturally developed filter pack), or the grain-size distribution of the primary filter pack material (in the case of a filter-packed well). Screen openings must be small enough to retain most if not all of the formation or filter-pack materials, yet large enough to maintain groundwater flow velocities, from the well screen/filter pack interface back to the natural formation materials. Users are cautioned to limit entrance velocity as required to prevent turbulent flow conditions that result in

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

Size of Screen Opening, in. [mm]	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)
0.005 [0.125]	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
0.010 [0.25]	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
0.020 [0.50]	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
0.030 [0.75]	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
0.040 [1.0]	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
0.060 [1.5]	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
0.080 [2.0]	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.

mobilization of formation sediment and reduction in well efficiency especially when fine grained materials are present. These entrance flows are a result of the pumping rates during sampling and thus methods like low flow sampling (Practice D6771) are often employed for water quality sampling to minimize flow velocity and sample turbidity.

NOTE 6—This standard previously recommended limiting entrance velocities to less than 0.1 ft/s based on reference (**3**) to limit consequences of turbulent flow. Entrance velocities exceeding 0.10 ft/s [(0.03 m/s] do not always produce turbulent flow and mobilize formation sediment specially in coarse grained gravel packed aquifers where velocities as high as 1.5 ft/s can be stable with little reduction in well efficiency (**10**).

6.4.2 *Materials*—The well screen should be new, machine-slotted casing or continuous wrapped wire-wound screen composed of materials compatible with the monitoring environment, as determined by the site characterization program. The screen should be plugged at the bottom (unless a sediment sump is used), and the plug should generally be of the same material as the well screen. This assembly must have the capability to withstand well installation and development stresses without becoming dislodged or damaged. The length of the well screen open area should reflect the thickness of the target monitoring zone. Immediately prior to installation, the well screen should be cleaned (see either Practice D5088 or Practice D5608) with water from a source of known chemistry, if it is not certified clean by the manufacturer, and delivered, and maintained in a clean environment at the site.

NOTE 7—Well screens are most commonly composed of PVC or stainless steel. Stainless steel may be specified based on knowledge of the occurrence of microbially influenced corrosion in formations (specifically reducing or acid-producing conditions).

6.4.3 *Diameter*—The minimum nominal internal diameter of the well screen should be chosen based on factors specific to the particular application (such as the outside diameter of the purging and sampling device(s) to be used in the well). The typical rotary drilled well riser is a minimum of 2 in. [50 mm] diameter or larger. Well screens as small as ½-in. [15 mm] nominal diameter are available for use in monitoring well applications and can be used for special applications and are often used for smaller diameter direct push wells (Guide D6724 and Practice D6725).

6.4.4 *Design*—The design of the well screen should be determined based on the grain size analysis (in accordance with Test Method D422) of the interval to be monitored and the gradation of the primary filter pack material. In granular, non-cohesive formation materials that will fall in easily around the screen, filter packs can be developed from the native formation materials—filter pack materials foreign to the formation are not necessary. In these cases of naturally developed filter packs, the slot size of the well screen is determined using the grain size of the materials in the surrounding formation. The well screen slot size selected for this type of well completion should retain at least 70 % of formation materials—the finest 30 % of formation materials will be brought into the well during development, and the objectives of filter packing (to increase hydraulic conductivity immediately surrounding the well screen, and to promote easy flow of groundwater into and through the screen) will be met. In wells in which a filter pack material of a selected grain size distribution is introduced from the surface, the screen slot size selected should retain at least 90 %, and preferably 99 %, of the primary filter pack materials. The method for determining the primary filter pack design is described in 6.3.3.

6.4.5 *Prepacked or Sleeved Well Screens*—An alternative to designing and installing filter pack and well screens separately is to use a pre-packed or sleeved screen assembly. A pre-packed well screen consists of an internal well screen, an external screen or filter medium support structure, and the filter medium contained between the screens, which together comprise an integrated structure. The internal and external screens are constructed of materials compatible with the monitored environment, and are usually of a common slot size specified by the well designer to retain the filter pack material. The filter pack is normally an inert (for example, siliceous) granular material that has a grain-size distribution chosen to retain formation materials. A sleeved screen consists of a slotted pipe base over which a sleeve of stainless steel mesh filled with selected filter media is installed. Pre-packed or sleeved screens may be used for any formation conditions, but they are most often used where heaving, running or blowing sands make accurate placement of conventional well screens and filter packs difficult in rotary drilling, or where predominantly fine-grained formation materials are encountered. In the latter case, using pre-packed or sleeved screens is the only practical means of ensuring that filter pack materials of the selected grain-size distribution (generally fine to very fine sands) are installed to completely surround the screen (see 6.3.3.2).

NOTE 8—The practice of using a single well screen/filter pack combination (for example, 0.010 in. [0.25 mm]) well screen slot size with a 20/40 sand) for all wells, regardless of formation grain-size distribution, will result in siltation of the well and significant turbidity in samples when applied to formations finer than the recommended design. It will also result in the loss of filter pack, possible collapse of the screen, and invasion of overlying well construction materials (for example, secondary filter pack, annular seal materials, grout) when applied to formations coarser than the recommended design. For these reasons, the universal application of a single well screen/filter pack combination to all formations is not recommended, and should be avoided.

6.5 *Riser:*

6.5.1 *Materials*—The riser should be new pipe composed of materials that will not alter the quality of water samples for the constituents of concern and that will stand up to long-term exposure to the monitoring environment, including potential contaminants. The riser should have adequate wall thickness and coupling strength to withstand the stresses imposed on it during well installation and development (**3, 4**). Each section of riser should be certified as cleaned when new from the manufacturer or cleaned onsite (see either Practice D5088 or Practice D5608) using water from a source of known chemistry immediately prior to installation.

NOTE 9—Risers are generally constructed of polyvinyl chloride (PVC), galvanized steel, or stainless steel.

6.5.2 *Diameter*—The minimum nominal internal diameter of the riser should be chosen based on the particular application. Risers as small as ½-in. [15-20 mm] in diameter are available for applications in monitoring wells.

6.5.3 *Joints (Couplings)*—Threaded joints are recommended. Glued or solvent-welded joints of any type are not recommended because glues and solvents may alter the chemistry of water samples. Because square profile flush joint threads (Specification F480) are designed to be accompanied by O-ring seals at the joints, they do not require PTFE taping. However, tapered threaded joints should be PTFE taped to prevent leakage of water into the riser.

6.6 *Casing*—Where conditions warrant, the use of permanent casing installed to prevent or reduce 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, in multi-cased wells) should be new and cleaned to be free of interior and exterior protective coatings.

NOTE 10—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 geologic formations penetrated. The diameter of the borehole and the well casing for conventionally 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 to provide working space for a tremie pipe. For naturally developed wells and pre-packed or sleeved screen completions, this annular space requirement need not be met. In addition, the diameter of the casings in multi-cased wells should be selected so that a minimum annular space of 2 in. [50 mm] is maintained between the casing and the borehole (that is, a 2-in. [50 mm] diameter screen will require first setting a 6-in. [150 mm] diameter casing in a 10-in. [250 mm] diameter boring).

NOTE 11—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 beveled for welding.

6.7 *Sediment Sump*—A sediment sump, a length of blank pipe, generally of the same diameter and made of the same material as the riser and well screen—may be affixed to the bottom of the screen, and capped with a bottom plug, to collect fine-grained material brought into the well by the process of well development. A drainage hole may be drilled in the bottom of the sump to prevent the sump from retaining water in the event that the water level outside the well falls below the bottom of the well screen. Because the sediment that collects in the sump may harbor geochemistry-altering microflora and reactive metal oxides, this sediment must be removed periodically to minimize the potential for sample chemical alteration.

6.8 *Protective Casing:*

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

6.8.2 *Diameter*—The inside dimensions of the protective casing should be a minimum of 2 in. [50 mm] and preferably 4 in. [100 mm] larger than the nominal diameter of the riser to facilitate the installation and operation of sampling equipment.

6.9 *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, geochemical and climatic conditions and any man-induced conditions (for example, subsurface contamination) anticipated during the life of the well. This standard was written assuming that thick liquid grout slurries are used for sealant from the filter zone to the surface as shown on Figs. 2 and 3. However, under certain conditions where bentonite pellets or chips can be placed and are allowed in the regulations and sampling plan, the grout zone shown on the figures may be backfilled with bentonite pellets or chips placed in lifts, hydrated and tamped, and placed in stages allowing zones to hydrate prior to placement of the next stage.

NOTE 12—An extensive research program on annular sealants has been conducted from 2001 through 2009 and subsequent years by the Nebraska Grout Task Force (**11**). This research included cement and bentonite grouts and also use of pellets and chips. The general findings of the study indicate all sealing methods suffer from some shrinkage in the portion of the well in the unsaturated zone. The best grouts were cement-sand, bentonite chips, neat cements, and bentonite slurries with more than 20 % solids. Especially problematic is the use of low solids content bentonite slurries leading to a ban on their use in California (**12**). The bentonite slurries used in this standard are high solids slurries with more than 20 % solids and bentonite slurry is not recommended in the unsaturated zone regardless of solids content.

6.9.1 *Bentonite*—Bentonite should be powdered, granular, pelletized, or chipped sodium montmorillonite from a commercial source, free of impurities that may adversely impact the water quality in the well. Pellets consist of roughly spherical units of moistened, compressed bentonite powder. Chips are