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Standard Practice for Design and Installation of Ground Water Monitoring Wells in Aquifers¹

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INTRODUCTION

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

1. Scope

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

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

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

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

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

1.6 *This practice offers a set of instructions for performing one or more specific operations. This document cannot replace education or experience and should be used in conjunction with professional judgment. 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.*5092

2. Referenced Documents

2.1 ASTM Standards:

C 150 Specification for Portland Cement²

C 294 Descriptive Nomenclature of Constituents of Natural Mineral Aggregates³

D 653 Terminology Relating to Soil, Rock, and Contained Fluids⁴

D 1452 Practice for Soil Investigation and Sampling by Auger Borings⁴

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

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² Annual Book of ASTM Standards, Vol 04.01.

³ Annual Book of ASTM Standards, Vol 04.02.

⁴ Annual Book of ASTM Standards, Vol 04.08.



- D 1586 Method for Penetration Test and Split-Barrel Sampling of Soils⁴
- D 1587 Practice for Thin-Walled Tube Sampling of Soils⁴
- D 2113 Practice for Diamond Core Drilling for Site Investigation⁴
- D 2487 Classification of Soils for Engineering Purposes (Unified Soil Classification System)⁴
- D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)⁴
- D 3282 Classification of Soils and Soil Aggregate Mixtures for Highway Construction Purposes⁴
- D 3550 Practice for Ring Lined Barrel Sampling of Soils⁴
- D 4220 Practice for Preserving and Transporting Soil Samples⁴
- D 4750 Test Method for Determining Subsurface Liquid Levels in a Borehole or Monitoring Well (Observation Well)⁴
- D 5079 Practices for Preserving and Transporting Rock Core Samples⁴
- D 5088 Practice for Preserving and Transporting Soil Samples⁴
- D 5099 Practice for Development of Ground Water Monitoring Wells in Aquifers⁴
- D 5254 Practice for Minimum Set of Data Elements to Identify a Ground-Water Site⁴
- D 5434 Guide for Field Logging of Subsurface Explorations of Soil and Rock⁴
- D 5730 Guide to Site Characterization for Environmental Purposes with Emphasis on Soil, Rock, the Vadose Zone, and Ground Water⁵
- D 5781 Guide for Use of Dual-Wall Reverse-Circulation Drilling for Geoenvironmental Exploration and Installation of Subsurface Water-Quality Monitoring Devices⁵
- D 5782 Guide for Use of Direct Air-Rotary Drilling for Geoenvironmental Exploration and Installation of Subsurface Water-Quality Monitoring Devices⁵
- D 5783 Guide for Use of Direct Rotary Drilling with Water-Based Drilling Fluid for Geoenvironmental Exploration and Installation of Subsurface Water-Quality Monitoring Devices⁵
- D 5784 Guide for Use of Hollow-stem Augers for Geoenvironmental Exploration and Installation of Subsurface Water-Quality Monitoring Devices⁵
- D 5786 Guide for the Use of Direct Rotary Wireline Casing Advancement Drilling Methods for Geoenvironmental Exploration and the Installation of Subsurface Water-Quality Monitoring Devices⁵

3. Terminology

3.1 Definitions:

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

⁵ Annual Book of ASTM Standards, Vol 04.09.



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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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



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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

3.1.59 *weep hole*—a small diameter hole (usually 1/4 in.) drilled into the protective casing above the ground surface that serves as a drain hole for water that may enter the protective casing annulus.

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

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

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

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

4. Significance and Use

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

4.1.1 Aquifer and aquitard properties, both geologic and hydraulic;

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

4.1.3 Water quality with respect to various indicator parameters;

4.1.4 Migration characteristics of a contaminant release;

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

5. Site Characterization

5.1 *General*—Soil mechanics, geomorphological concepts, geologic structure, stratigraphy, and sedimentary concepts, as well as the nature and behavior of the solutes of interest, must be combined with a knowledge of ground water movement to make a complete application of the results of the monitoring well design and installation guidance. Therefore, development of a conceptual hydrogeologic model that identifies potential



flow paths and the target monitoring zone(s) is recommended prior to monitoring well design and installation. Development of the conceptual model is accomplished in two phases—an initial reconnaissance and a field investigation. When the hydrogeology of a project area is relatively uncomplicated and well documented in the literature, the initial reconnaissance may provide sufficient information to identify flow paths and the target monitoring zone(s). However, where little background data is available or the geology is complicated, a field investigation will generally be necessary to completely develop a conceptual hydrogeologic model.

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

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

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

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

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

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

5.3.1.1 Sampling—Soil and rock properties should not be predicted wholly on field identification or classification, but should be checked by laboratory and field tests made on samples. Representative soil or rock samples, or both, of each

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

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

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

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

5.3.2 Geophysical Exploration—Geophysical surveys may be used to supplement borehole and outcrop data and to aid in interpretation between boreholes. Surface geophysical methods such as seismic surveys, and electrical-resistivity and electromagnetic conductance surveys can be particularly valuable when distinct differences in the properties of materials