Designation: ~~D5521/D5521M – 13~~ D5521/D5521M – 18

Standard Guide for Development of Groundwater Monitoring Wells in Granular Aquifers[1]

This standard is issued under the fixed designation D5521/D5521M; 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 guide covers the development of screened wells installed for the purpose of obtaining representative groundwater information and water quality samples from granular aquifers, though the methods described herein could also be applied to wells used for other purposes. Other well-development methods that are used exclusively in open-borehole bedrock wells are not described in this guide.

1.2 The applications and limitations of the methods described in this guide are based on the assumption that the primary objective of the monitoring wells to which the methods are applied is to obtain representative water quality samples from aquifers. Screened monitoring wells developed using the methods described in this guide should yield relatively sediment-free samples from granular aquifer materials, ranging from gravels to silty sands. While many monitoring wells are considered "small-diameter" wells (that is, less than 10 cm [4 in.] inside diameter), some of the techniques described in this guide will be more easily applied to large-diameter wells (that is, 10 cm [4 in.] or greater inside diameter).

1.3 The values stated in either SI units or inch-pound units 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.

1.4 *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~~ safety, health, and ~~health~~environmental practices and determine the applicability of regulatory limitations prior to use.*

1.5 *This guide offers an organized collection of information or a series of options and does not recommend a specific course of action. This document cannot replace education or experience and should be used in conjunction with professional judgment. Not all aspects of this guide 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~~ needs to 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.*

1.6 *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.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

D5088 Practice for Decontamination of Field Equipment Used at Waste Sites

D5092 Practice for Design and Installation of Groundwater Monitoring Wells

[1] This guide 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.

Current edition approved ~~Aug. 1, 2013~~June 1, 2018. Published ~~September 2013~~July 2018. Originally approved in 1994. Last previous edition approved in ~~2005~~2013 as D5521 – ~~05.~~13. DOI: ~~10.1520/D5521_D5521M-13.~~10.1520/D5521_D5521M-18.

[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.

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

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of common terminology terms used within this guide, refer to Terminology D653.

3.1 *Definitions of Terms Specific to This Standard:* *Definitions:*

3.2.1 *air entrapment*—trapping of air or other gas in pore spaces of the formation or filter pack during development with compressed air.

3.1.1 For definitions of common terminology terms used within this standard, refer to Terminology D653.

3.2.2 *air lift pump*—a device consisting of two pipes, with one (the air line) inside the other (the eductor pipe), used to withdraw water from a well. The lower ends of the pipes are submerged, and compressed air is delivered through the inner pipe to form a mixture of air and water. This mixture rises in the outer pipe to the surface because the specific gravity of this mixture is less than that of the water column.

3.2.3 *air line*—a small vertical air pipe used in air-lift pumping. It usually extends from the ground surface to near the submerged lower end of the eductor pipe. The length of the air line below the static water level is used in calculating the air pressure required to start air-lift pumping.

3.1.2 *annular seal*—*seal, n—in groundwater,* material used to provide a seal between the borehole and the casing of a well. The annular seal should have a hydraulic conductivity less than that of the surrounding geologic materials and materials, be resistant to chemical or physical deterioration.

3.1.3 *backwashing*—*backwashing, n—in groundwater,* the reversal of water flow caused by the addition of water to a well that is designed to loosen bridges and or break sediment bridges within the filter pack and well screen and facilitate the removal of fine-grained materialssediment from the formation surrounding the borehole.

3.1.4 *bailing (development)*—*(development), n—in groundwater,* a development technique using a bailer which is raised and lowered in the well to create a strong inward and outward movement of water from the formation to break sand bridges and to remove fine materialswell to the formation and vice versa to loosen or break sediment bridges within the filter pack and well screen and to remove fine-grained sediment from the well.

3.1.4.1 *Discussion—*

In unconsolidated formations, casing is usually driven as drilling proceeds to prevent collapse of non-cohesive materials (that is, sand) into the borehole.

3.2.7 *cable tool drilling*—a drilling technique in which a drill bit attached to the bottom of a weighted drill stem is raised and dropped to crush and grind formation materials. In unconsolidated formations, casing is usually driven as drilling proceeds to prevent collapse of noncohesive materials into the borehole.

3.2.8 *eductor pipe*—the vertical discharge pipe used in air-lift pumping, submerged at least one third but usually two thirds of its length below the pumping water level in the well.

3.1.5 *filter-packed well*—*well, n—in groundwater,* a well in which the natural formation where the in situ geologic materials adjacent to the well screen has been replaced by a an engineered or processed filter pack material.

3.1.6 *formation damage*—*damage, n—in groundwater,* disturbance or reduction of formation hydraulic conductivity in situ aquifer hydrogeologic parameters at the borehole wall caused by the drilling process. process, the well installation process, or destructive, subsurface geoengineering/geotechnical testing. May consist of sediment compaction, clay smearing, clogging of pores with drilling mud filtrate, or other drilling-relateddrilling/testing-related damage.

3.2.11 *hydraulic jetting*—a well-development method that employs a jetting tool with nozzles and a high-pressure pump to force water outwardly through the well screen, the filter pack, and sometimes into the adjacent geologic unit, for the purpose of dislodging fine sediment and correcting formation damage done during drilling.

3.2.12 *indicator parameters*—chemical parameters, including pH, specific conductance, temperature and dissolved oxygen content, which are used to determine when formation water is entering a monitoring well.

3.2.13 *jetting*—see *hydraulic jetting.*

3.2.14 *naturally developed well*—a well in which the formation materials collapse around the well screen, and fine formation materials are removed using standard development techniques.

3.1.7 *overpumping*—*overpumping, n—in groundwater,* a well-development well development technique that involves pumping the well at a rate that exceeds the design capacity of the well.

3.1.8 *rawhiding—in groundwater,* starting and stopping a pump intermittently to produce rapid changes in the pressure head in the well.

3.1.9 *sandlocking*—refers to the accumulation of sand and other sediment on development tools while they are working in the well screen, resulting in the tools becoming lodged in the screen. ~~Also refers to the accumulation of sand and other sediment in the impeller section of a submersible pump, resulting in the impellers binding.~~

3.1.9.1 *Discussion—*

This refers to the accumulation of sand and other sediment in the impeller section of a submersible pump, resulting in the impellers binding.

~~3.2.18 *sloughing*—caving of formation materials into an unstabilized open borehole.~~

3.1.10 ~~*spudding*—~~*spudding, n—in drilling,* the operation, in cable-tool drilling, of drilling a collar hole and advancing a casing through overburden. Also a general term in rotary or diamond core drilling applied to drilling through overburden.

3.1.11 ~~*sump*—~~*well sump, n—in groundwater,* a blank extension of easing beneath the well screen that provides a space for fine-grain sediment ~~brought~~introduced into the well during development or groundwater sampling to accumulate.

3.1.12 *surge* ~~*block*—~~*block, n—in groundwater,* a plunger-like tool consisting of disks of flexible material ~~(for example,~~(that is, neoprene) sandwiched between rigid ~~(for example,~~(that is, metal) disks that may be solid or valved, and ~~that is~~ used in well development. See *surging*.

3.1.13 ~~*surging*—~~*surging, n—in groundwater,* a ~~well-development technique in which~~ well development technique where a surge block is alternately raised and lowered within the well casing or screen, or both, to ~~create~~induce a strong inward and outward movement of water through the well screen.

~~3.2.23 *tool string*—the drill pipe or drill rod and all attached drilling or development tools used in the borehole or well.~~

~~3.2.24 *turbidity*—cloudiness in water due to suspended and colloidal material.~~

3.1.14 *well* ~~*development*—~~*development, n—in groundwater,* the act of ~~repairing damage to the borehole~~ addressing potential formation damage caused by the drilling ~~process and~~and well installation process by removing fine-grained ~~materials~~sediment or drilling fluids, or both, from ~~formation materials so that natural hydraulic conditions are restored and~~ in situ geologic formation and filter pack such that the evaluated in situ aquifer hydrogeologic parameters are more likely to be representative of the assumed pre-drilling/monitor well installation conditions and overall well yields are enhanced.

4. Significance and Use

4.1 A ~~properly~~correctly designed, installed, and developed groundwater monitoring well, constructed in accordance with Practice D5092 should provide the following: representative samples of groundwater that can be analyzed to determine physical properties and ~~water-quality~~ water quality parameters of the sample or potentiometric levels that are representative of the total hydraulic head of that portion of the aquifer screened by the well, or both. ~~Such a~~ The well may also be utilized for conducting aquifer performance tests used for the purpose of determining the ~~hydraulic~~hydrogeologic properties of the ~~geologic materials~~ targeted hydrostratigraphic unit in which the well has been completed.

NOTE 1—An extensive research program on annular sealants was conducted from 2001 through 2009 and in subsequent years by the Nebraska Grout Task Force (Lackey et al., 2009 and State of California, 2015). This research included cement and bentonite grouts and the use of pellets and chips. The general finding of the study indicates 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 percent solids. Especially problematic is the use of low solids content bentonite slurries in the unsaturated zone leading to a prohibition on their use in California (State of California, 2015). It is also highly recommended that State and Federal codes/regulations regarding seals within the unsaturated zone be evaluated prior to design to ensure codes are met.

4.2 Well development is an important component of monitoring well ~~completion.~~completions. Monitoring wells installed in aquifers should be sufficiently developed to ~~ensure~~such that they serve their intended objectives. Well development methods vary with the physical characteristics of the ~~geologic formation~~ targeted hydrostratigraphic unit in which the monitoring well is screened, the construction details of the well, the drilling method ~~used~~utilized during the construction of the borehole ~~in which the well is installed,~~ prior to well installation, and the quality of the ~~water.~~groundwater. The development method for each individual monitoring well should be selected from among the several methods described in this guide and should be employed by the well construction contractor or the ~~person responsible for~~ qualified personnel in responsible charge of the monitoring well completion.

4.3 The importance of well development in monitoring wells cannot be ~~overestimated; all too often development is~~overestimated. If a monitoring well is inherited with a project, it is best for the well construction contractor or the qualified personnel to consider the possibility that well development was not performed or ~~is carried out inadequately.~~ was carried out inadequately, which may influence both previous and future sampling results if the wells were not redeveloped and/or appropriate documentation of well development cannot be obtained. Proper and careful well development will improve the ability of most monitoring wells to provide representative, unbiased chemical and hydraulic data. The additional time and money spent performing this important step in monitoring well completion or maintenance will ~~minimize~~reduce the potential for damaging pumping equipment and ~~in-situ~~ in situ sensors, and increase the probability that groundwater samples are representative of ~~water contained in the monitored formation.~~ the targeted formation water monitored. Practice D3740 provides evaluation factors for the activities in this guide.

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.~~ <u>testing/sampling/evaluation/and the like.</u> Users of this standard are cautioned that compliance with Practice D3740 does not in itself assure reliable results. Reliable results depend on many ~~factors;~~<u>factors.</u> Practice D3740 provides a means of evaluating some of those factors.

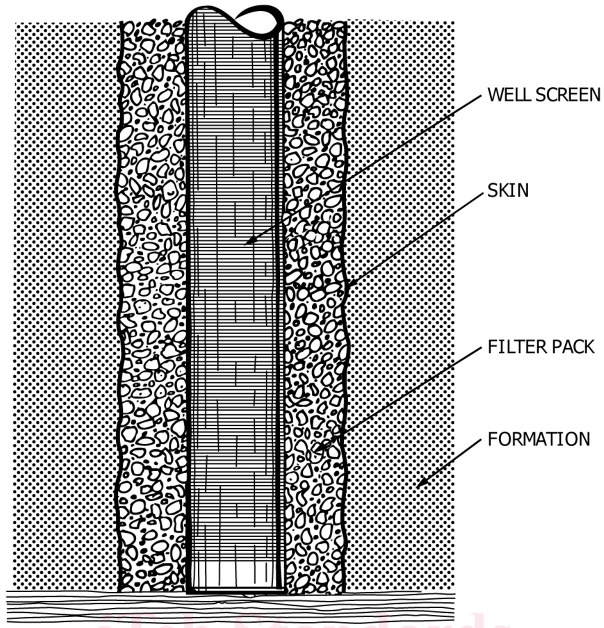

FIG. 1 Example of Rectifying Damage Done During Drilling

5. Purposes of Monitoring Well Development

5.1 Monitoring wells are developed primarily for the following reasons:

5.1.1 To ~~rectify damage done during drilling to~~ <u>address potential damage, which may occur during the drilling and monitoring well installation processes at</u> the borehole wall and the adjacent <u>geologic</u> formation (that is, clogging, smearing, or compaction of ~~formation materials) that may result in a localized reduction in hydraulic conductivity of the~~ <u>geologic materials comprising the formation or targeted hydrostratigraphic unit). This may potentially result in localized alterations of the hydrogeologic characteristics of the</u> formation near the borehole (see Fig. 1);

<u>NOTE 3—One of the purposes of development is to address the potential damage done to the borehole wall during drilling and monitoring well installation processes. The "skin" of fine-grained sediment that accumulates along the borehole wall during mud-rotary drilling is an example of the potential distress.</u>

5.1.2 To remove fine-grained ~~materials~~<u>sediment</u> from the formation and filter pack (where applicable) that may result in the acquisition of turbid, sediment-laden samples;

5.1.3 To stabilize formation and artificial filter pack materials (where applicable) adjacent to the well screen (see Fig. 2[3]);

<u>NOTE 4—After well development, formation materials in "naturally developed" wells (left) and filter packed wells (right) should be stabilized such that</u>

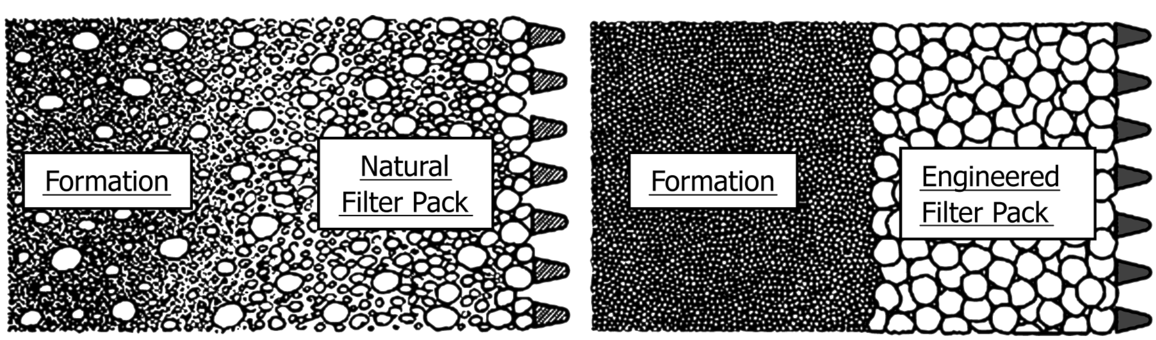

FIG. 2 Formation Materials in Wells

[3] Figure adapted from *Ground Water and Wells*, Second edition, 1986.

potential entry of fine-grained materials into the well is reduced, little settlement occurs, and groundwater flow to and from the well is not significantly hindered or impaired.

5.1.4 To retrieve potentially lost drilling fluid (if drilling fluid was used in the borehole installation process) that may alter the quality of ~~water~~groundwater in the vicinity of the well and interfere with ~~water~~groundwater quality analysis (see Fig. 3[3]); and

NOTE 5—When drilling with water-based drilling fluids, some drilling fluid will infiltrate beyond the borehole into the most permeable zones. This creates the mud cake effect desired by well drillers as one of the means of keeping a borehole open during the drilling process. One of the purposes of development is to remove this drilling fluid from the formation adjacent to the open interval of the well.

5.1.5 To ~~maximize~~ increase the potential well efficiency and hydraulic communication between the well and the adjacent formation to provide for the acquisition of representative groundwater samples and ~~formation hydraulic test data.~~conduct aquifer performance tests.

6. Conducting a Monitoring ~~Well-Development~~ Well Development Program

6.1 *Well Development Process*—The well development process consists of three phases: predevelopment, preliminary development, and ~~final development.~~development. If a monitoring well is inherited with a project, the three well development phases should be evaluated by the well construction contractor and/or qualified personnel prior to groundwater sampling or completing aquifer performance tests.

6.1.1 Predevelopment refers to techniques used to mitigate potential formation damage during ~~well construction.~~ the drilling and well construction processes. This is particularly important when using direct or reverse rotary drilling systems that depend on drilling fluid to carry cuttings to the surface and support an open borehole. Control and monitoring of drilling fluid properties, during the drilling operation and immediately prior to the installation of screen, casing, and filter pack, is very ~~important.~~crucial and should be documented during the drilling process.

6.1.2 Preliminary development takes place after the screen, casing, and filter pack have been installed. Methods used to accomplish this task include surging, bailing, hydraulic jetting, and air lifting. The primary purpose of this operation is to apply sufficient energy in the well to ~~facilitate rectification of~~ address potential formation damage ~~due to drilling;~~ from the drilling process; removal of fine-grained ~~materials~~sediment from the screen, filter pack, and ~~formation; stabilization and~~ geologic formation adjacent to the filter pack; stabilization and overall consolidation of the filter pack; retrieval of drilling fluid (if used); and creation of an effective hydraulic interface between the ~~filter pack and the formation.~~well and the geologic formation through the filter pack.

6.1.2.1 During this phase of well development, the preferred technique is to gradually apply the selected well development method, increasing intensity as long as the well responds to treatment. Response generally is indicated by increased yields of water and sediment, typically fine-grained. Intensive development of a well that appears to be plugged should not be attempted because damage and destruction of the well casing and screen may result.

~~6.1.3 During this phase of well development, the preferred technique is to gradually apply the selected method, increasing intensity as long as the well responds to treatment. Response generally is indicated by increased yields of water and sediment. Intensive development of a well that appears to be plugged should not be attempted because damage and destruction of the well may result.~~

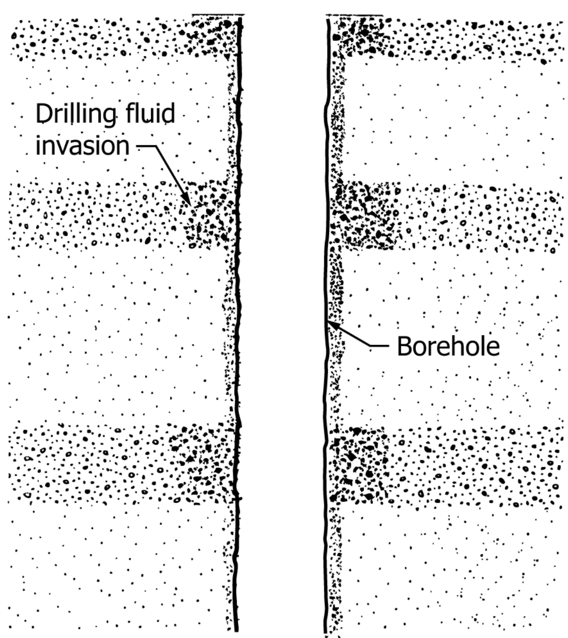

FIG. 3 Removal of Lost Drilling Fluid

6.1.3 ~~Final development~~ Development refers to procedures performed with a pump, such as ~~pumping~~overpumping and surging, and backwashing. These techniques are used as the ~~final~~last step in achieving the objectives of well development. If preliminary development methods have been effective, the time ~~required~~needed for ~~final~~ development should be relatively short. However, if the preliminary methods have not been successful, or if conditions preclude the use of the preliminary techniques listed, the ~~final~~ development phase should be continued until the development completion criteria (described below) are satisfied.

6.2 *Factors Affecting the Selection of a Well-Development Method*—A variety of factors ~~must~~ need to be considered in selecting the method(s) used for developing ~~any given monitoring well; these include:~~ a given monitoring well. These include, but are not limited to: the construction of the monitoring well (that is, material used for well casing and screen, type and open area of well screen, type of joint between casing sections, screen length and slot size, casing and screen diameter, whether or not a filter pack was used in the construction of the monitoring well and the thickness of the filter pack); ~~characteristics and hydraulic conductivity~~ hydrogeologic characteristics of the ~~formation materials~~ geologic formation or targeted hydrostratigraphic unit adjacent to the well screen; ~~water~~groundwater quality ~~in the aquifer~~ of the geologic formation or targeted hydrostratigraphic unit in which the monitoring well is installed (that is, whether or not it may be contaminated, requiring special safety or handling considerations, or both, such as containment or treatment upon removal from the well); consequences of introducing foreign fluids ~~(that is,~~such as, air, water, or chemical ~~solutions)~~solutions into the ~~well and aquifer; drilling method used during borehole installation; depth to~~ monitoring well and/or geologic formation or targeted hydrostratigraphic unit; the drilling method employed during monitoring well construction/installation; the depth to the static water level and height of the water column ~~in~~within the monitoring well; type and portability of available sampling/testing/well development equipment (that is, ~~whether or not~~ Is a drilling rig ~~is required);~~ needed?); time available for well development; and ~~cost effectiveness~~ cost-effectiveness of the well development method.

6.3 *Timing of Well Development: When and How Long to Develop*—The point in time ~~at which~~ when a monitoring well is ~~developed~~ determined to be "developed" is a decision that is generally based on design and construction of the ~~well.~~ monitoring well by the well construction contractor and/or qualified personnel overseeing the well development. For example, if the well is installed with the intent of using natural formation material as the filter pack ~~(that is, a~~ (a "naturally developed" well), development is generally performed after the well screen and casing have been installed and the formation material has collapsed against the screen (to ~~at least~~ 1.5 m [5 ft] above the screen), but before the annular seal is installed. Because this type of well design is based on the assumption that well development will remove a significant fraction of the ~~formation materials~~ fine-grained sediment from the formation adjacent to the well ~~screen (therefore~~screen, therefore causing some sloughing ~~in~~within the ~~borehole),~~borehole, developing the monitoring well after installing the annular seal may result in portions of the annular seal collapsing into the vicinity of the well screen. On the other hand, ~~properly~~correctly designed and constructed filter-packed wells may be developed after the annular seal materials have been installed and given sufficient time to set or cure, because the well screen is designed to retain at ~~least 90 % and preferably 99 %~~ a minimum 90 percent (preferably 99 percent) of filter pack materials and little ~~or no~~ sloughing should occur.

6.3.1 The duration of well development is based on the primary purpose(s) of the development process. For example, if the primary purpose for development is to remove drilling fluid lost to the ~~formation during borehole installation, the time required~~geologic formation or targeted hydrostratigraphic unit during the drilling process, the time needed for completion of development may be based on the time it takes to remove from the well some multiple of the estimated volume lost. If the primary purpose of development is to ~~rectify~~ address potential damage done during the drilling process to the borehole wall and the adjacent ~~formation,~~ geologic formation or targeted hydrostratigraphic unit, the time for development may be based on the response of the well to pumping. An improvement in recovery rate of the monitoring well ~~indicates~~ may indicate that the potentially altered localized ~~reduction in hydraulic conductivity has been effectively rectified~~ in situ hydrogeologic characteristics may have been improved by development. If the primary purpose of development is to remove fine-grained ~~materials,~~sediment, development may continue until visibly clear water is discharged from the well, or until the turbidity of water removed from the well is at some specified ~~level.~~ level, and/or the sediment within the well screen sump have been removed such that the well total depth per the construction design is significantly reestablished. These criteria may be difficult or ~~impossible~~impractical to satisfy in formations with a significant fraction of fine-grained ~~material.~~sediment. Another criterion used for determining when development is complete is the stabilization of certain ~~indicator parameters (that is,~~ field water quality indicator parameters including, but not limited to: temperature, specific conductance, pH, redox potential, ~~dissolved oxygen) that are easily measured in the field.~~ and dissolved oxygen. While this criterion may be ~~an indicator~~ evidence of when native formation water is being ~~produced,~~ produced at the monitoring well, it does not necessarily indicate that well development is complete.

6.4 *Decontamination of Well Development Equipment*—~~Any equipment~~ Equipment or materials used to develop a monitoring well should be thoroughly cleaned in accordance with Practice D5088. Cleaning should take place prior to the use of ~~any~~ equipment in ~~any~~a monitoring well, and between uses in either the same well or in other wells.

7. Limitations of Well Development

7.1 Well development should be applied with great care to monitoring wells installed in predominantly fine-grained formation materials ~~(that is, in formations dominated by fine sand, silt or clay).~~such as fine sand, silt, and/or clay. If vigorous development is attempted in such wells, the turbidity of water removed from the well may ~~actually~~ increase many times over. In some fine-grained ~~formation materials, no~~ geologic formations or targeted hydrostratigraphic units, the amount of development will not measurably improve ~~formation hydraulic conductivity or the~~ the in situ hydrogeologic characteristics or hydraulic efficiency of the monitor well.

7.2 While development methods which require the addition of a foreign fluid to a well may be applied to groundwater monitoring wells, such methods should be used with an understanding of the potential negative effects that added fluids may have on the ability of the well to yield representative groundwater quality samples. Only in very extreme or special cases should fluids other than clean water or filtered air be considered for use in a monitoring well during development. Fluids other than water, including deflocculating or dispersing agents (that is, polyphosphates), acids (that is, hydrochloric or hydrofluoric acid), surfactants, and disinfectants (that is, sodium hypochlorite), may produce severe and persistent chemical alterations of water quality in the immediate vicinity of the well. The use of chemicals for well development is not discussed further for these reasons.

7.2.1 ~~Any water~~ Water added to a monitoring well for the purpose of development should be of known and acceptable chemistry. The impact of added water on in situ water quality should be evaluated and, to the extent ~~possible, this water~~ practicable, should be removed by pumping after development is complete. One ~~possible~~ means of reducing potential problems related to the addition of water to the monitoring well is to obtain water-quality samples from the well only after natural groundwater flow in the aquifer has had time to flush the remnants of ~~well-development~~development fluids beyond the ~~well.~~ confines of the well and filter pack, if installed. Another means may be to use water that has been taken from the formation ~~itself (that is,~~itself, such as water pumped from the ~~formation~~well either prior to or during ~~development)~~development, for the development process.

7.3 Development methods using compressed air (that is, air-lift pumping) should be attempted only after great care has been taken to remove ~~any~~ compressor oil or other foreign substances from the air stream prior to introduction into the well. Air should not be forced into the geologic formation or targeted hydrostratigraphic unit or allowed to be released directly into the well without the use of a containment ~~device (that is,~~device, such as an eductor ~~pipe).~~pipe. The injection of air into the ~~formation~~ geologic formation or targeted hydrostratigraphic unit may cause air entrapment and result in ~~a dramatic reduction in formation hydraulic conductivity.~~negative impact to the in situ hydrogeologic characteristics. An uncontrolled release of air into the well may cause significant chemical changes in the water ~~in~~ quality within the well and the adjacent ~~formation.~~geologic formation or targeted hydrostratigraphic unit.

7.4 Development methods that rely only on pumping ~~("passive"development),~~ ("passive" development), especially at low-flow rates, do not sufficiently stabilize formation or filter pack materials and do not effectively remove fine-grained ~~material~~sediment or ~~rectify formation damage done during drilling~~ address potential damage to the geologic formation, which may have occurred during the drilling process (see Fig. 4). Effective development action requires movement of water in both directions through the well screen openings (see Fig. 5). Although visibly clear water may eventually be discharged ~~as a result of such pumping, any~~ from overpumping, subsequent activity that agitates the water column in the ~~well (that is, conducting a formation hydraulic test, purging prior to sampling, or sampling, especially with bailers)~~ well, such as conducting aquifer or well performance tests or purging the well prior to water quality sampling via pumping or bailing, can cause considerable turbidity ~~in~~within the monitoring well.

NOTE 6—A bridge is an obstruction within the annulus that may prevent circulation or proper placement of annular fill materials. Bridging in sediment and filter pack materials is caused by movement of groundwater in one direction only during well development.

NOTE 7—Effective development action requires movement of water in both directions through the well screen openings and filter pack. (*A*) Movement of water in only one direction, as when overpumping the well, does not produce the proper development effect. (*B*) Reversing flow helps to reduce the potential for bridging of sediment within the targeted aquifer and filter pack (if used).

7.5 Development should be applied very cautiously to monitoring wells that are known or suspected to be contaminated with hazardous chemical constituents, particularly constituents ~~which~~ that may pose a health or safety hazard through inhalation or dermal contact. Appropriate safety precautions should always be taken to protect field personnel. It should be noted that contaminated water and sediment removed from monitoring wells during development ~~may also have~~ will need to be contained in drums, tanks, or other storage vessels until the water and sediment have been tested and evaluated to determine an appropriate disposal or treatment method. This ~~could~~will significantly increase the cost of the well development.

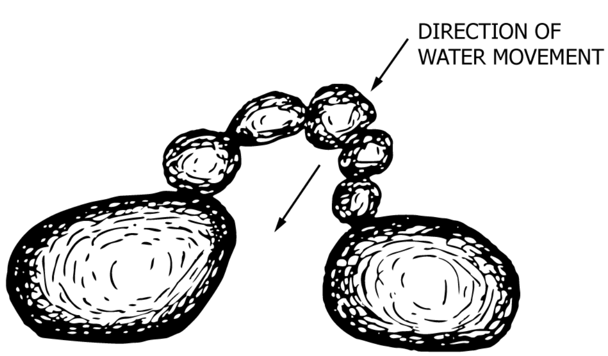

FIG. 4 Bridging in ~~Formation~~Sediment and Filter Pack Materials

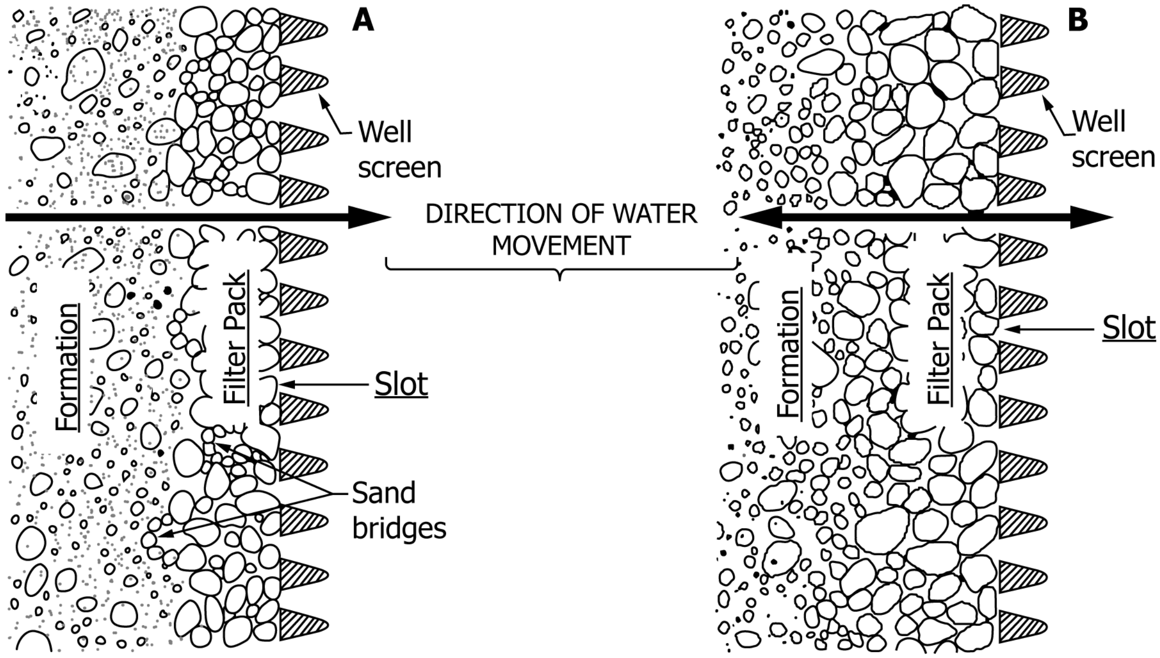

FIG. 5 Movement of Water in Both Directions

8. Methods and Processes Available for Monitoring Well Development

8.1 *General*—Of the various methods available for use in developing monitoring wells in general, mechanical surging, overpumping and backwashing, and high-velocity hydraulic jetting with pumping (or combinations of two or more of these methods) are ~~best~~ suited for use in developing groundwater monitoring ~~wells.~~ wells in granular aquifers. The method most appropriate for use in a given situation depends on a variety of factors discussed in 6.2. The user should evaluate the methods described herein and select the method that is most appropriate for the situation at hand.

8.2 *Mechanical Surging*—Mechanical surging is accomplished by using a close-fitting surge block (sometimes referred to as a surge plunger or swab) affixed to the end of a length of drill pipe, a solid rod, or a cable, operating like a piston in the well casing or screen. The up-and-down plunging action alternately forces water to flow into (on the upstroke) and out of (on the downstroke) the ~~well,~~ well screen, similar to a piston in a cylinder (see Fig. 6). The down stroke causes a backwash action to loosen sediment bridges in the formation ~~or~~ and/or the filter pack and the upstroke then pulls dislodged fine-grained ~~material~~sediment into the well. This method is equally applicable to small-diameter and large-diameter wells and is the most effective method for small-diameter wells.

NOTE 8—For certain types of geologic formations, a surge block is an effective tool for well development. On the downstroke, water is forced outward into the formation, while water, silt, and fine sand are then pulled into the well screen during the upstroke.

8.2.1 Several designs for surge blocks, including a solid surge block, a valved or vented surge block, a spring-loaded surge block, and a multiple-flange surge block (see Fig. 7~~:~~) can be utilized. A heavy bailer or a pump (such as a gas-drive pump or an inertial lift pump) fitted with flexible disks similar to those on a surge block (see Fig. 8) may also be used to produce the surging action, but these are not as effective as a close-fitting surge block.

NOTE 9—Various configurations of surge blocks: (*a*) solid surge block; (*b*) valved surge block; (*c*) double-flanged surge block; and (*d*) valved double-flanged surge block.

NOTE 10—A heavy (steel) bailer fitted with a flange to serve as a surging tool. Arrows indicate the direction of water movement during retraction of the bailer.

8.2.2 The proper procedure for mechanical surging is to bail or pump the well first to make sure that the well will yield water. If the screen is completely plugged and water does not enter the well upon bailing or pumping, surging should not be attempted, as the strong negative pressure created on the upstroke of the surge block may cause the well screen to collapse. When it is determined that the well will yield water, the surge block is lowered until it is below the static water level, but above the screen, and a relatively slow, gentle surging action is started. This surging action should allow ~~any~~ material blocking the screen to break up, go into suspension, and move into the well. The surge block should be operated with particular care if the formation above the screen consists mainly of fine sand, silt, or clay, which may slump into the screened interval. The water column should effectively transmit the action of the surge block to the screened section of the monitoring well. As water begins to move easily in and out of the ~~well, the~~ well through the well screen, the surge block is lowered (in steps) farther into the well and the speed (and, therefore, the force) of the surging movement is increased. If initial development is too vigorous, particularly in fine-grained

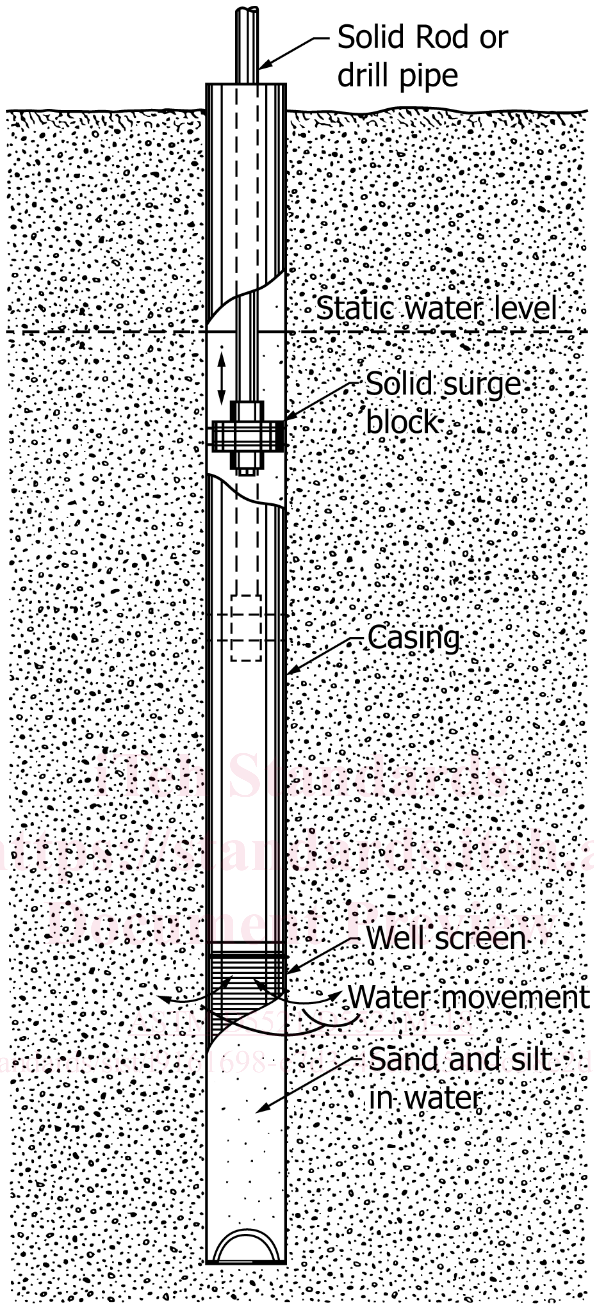

FIG. 6 Mechanical Surging

formations, surging can harm a monitoring well rather than improve it. Because significant pressure differentials can occur during mechanical surging, great care ~~must~~ needs to be taken to avoid damaging (that is, collapsing) the casing or well screen by overzealous development.

8.2.3 In wells with short ~~(that is, less~~ (less than 1.5 m [5 ft]) screens, it may not be necessary to operate the surge block within the screen to develop the entire screened ~~interval; in~~interval. In wells with longer ~~(that is, 3~~ (3 m [10 ft] or more) screens, it may prove more effective to operate the surge block within the screened area to concentrate its action at various levels. Surging should always begin above the screen and move progressively downward to prevent the surge block from becoming sand locked and to prevent damage to the screen. The surge block should be lowered in intervals equal to the length of the stroke until the entire screen has been surged. If surging of long screened wells is done exclusively in the casing, especially in situations in which the formation adjacent to the screen is highly variable, surging may preferentially develop only the material adjacent to the top of the screen or the most permeable zones of ~~material~~ the monitored zone adjacent to the screen.

8.2.4 The force exerted on the formation depends in part on the length of the stroke and the vertical velocity of the surge block. The length of the stroke depends on the mechanism used to operate the surge block. For cable-tool rigs, that are ideally suited to

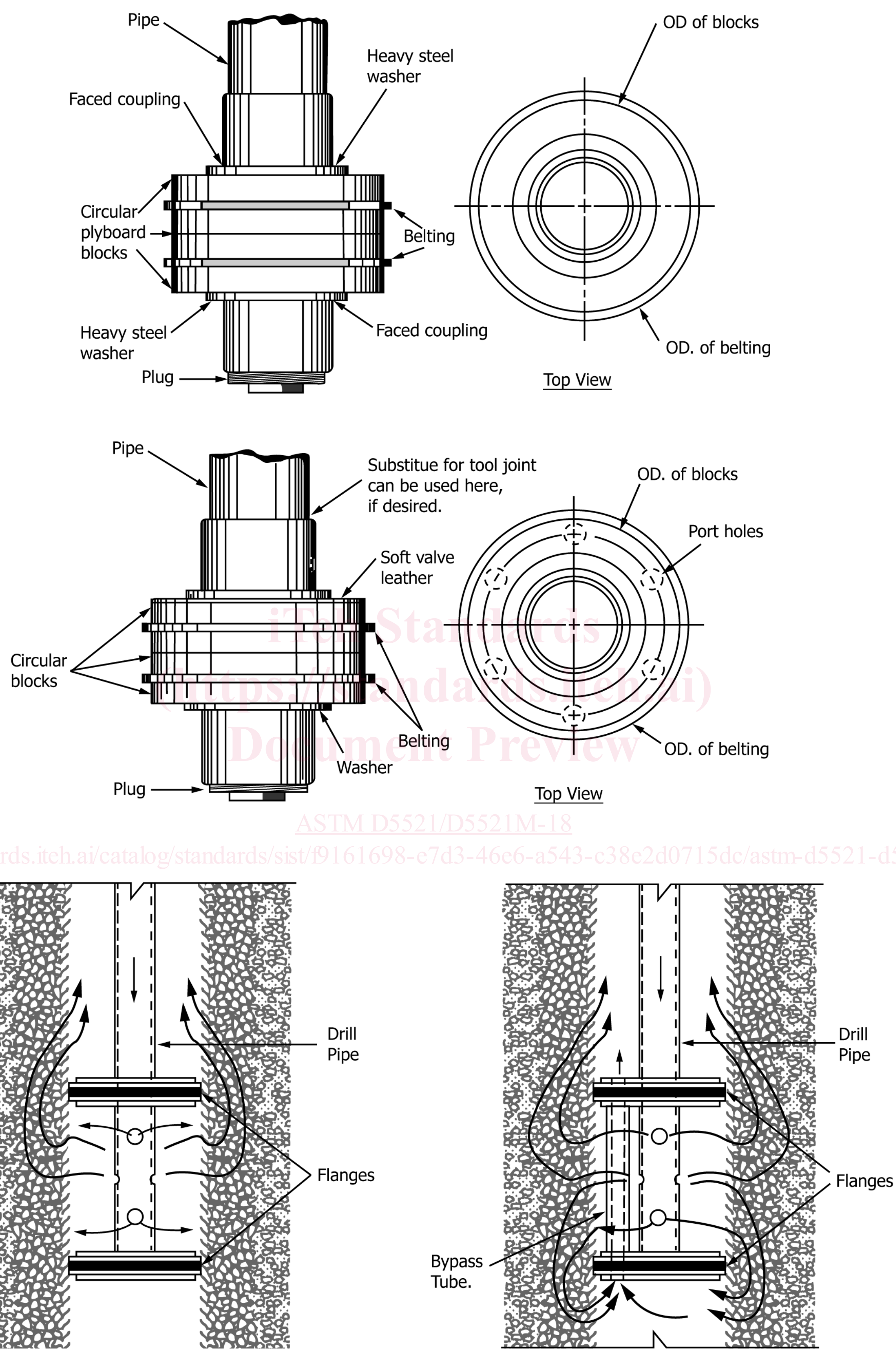

FIG. 7 Various Configurations of Surge Blocks

the surging operation, the length of the stroke is determined by the spudding motion. For rigs using a cathead to surge, the length