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Standard Guide for Development of Ground-Water Monitoring Wells in Granular Aquifers¹

This standard is issued under the fixed designation D 5521; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

^{ε1} NOTE—Paragraph 1.5 was added editorially October 1998.

1. Scope

1.1 This guide covers the development of screened wells installed for the purpose of obtaining representative ground-water 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 four inches in inside diameter), some of the techniques described in this guide will be more easily applied to large-diameter wells (that is, four-inches or greater in inside diameter).

1.3 The values stated in inch-pound units are to be regarded as standard. All other units in parentheses are provided for information only.

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 and health 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 be judged, nor should this document be applied without consideration of a project's many unique aspects. The word “Standard” in the title of this document means only that the document has been approved through the ASTM consensus process.

2. Referenced Documents

2.1 ASTM Standards:

- D 653 Terminology Relating to Soil, Rock, and Contained Fluids²
- D 5088 Practice for Decontamination of Field Equipment Used at Nonradioactive Waste Sites²
- D 5092 Practice for Design and Installation of Ground-Water Monitoring Wells in Aquifers²

3. Terminology

3.1 Definitions:

3.1.1 Many of the terms discussed in this guide are contained in Terminology D 653. The reader should refer to this for definitions of selected terms.

3.2 Definitions of Terms Specific to This Standard:

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.

3.2.2 *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

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² *Annual Book of ASTM Standards*, Vol 04.08.

line below the static water level is used in calculating the air pressure required to start air-lift pumping.

3.2.4 annular seal—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 be resistant to chemical or physical deterioration.

3.2.5 backwashing—the reversal of water flow caused by the addition of water to a well that is designed to loosen bridges and facilitate the removal of fine-grained materials from the formation surrounding the borehole.

3.2.6 bailer—a long, narrow tubular device with an open top and a check valve at the bottom that is used to remove water and sediment from a borehole or well.

3.2.7 bailing (development)—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 materials from the well.

3.2.8 borehole wall—the face of an open borehole.

3.2.9 bridge—an obstruction to fluid and sediment movement in the filter pack or formation adjacent to the well due to the arching of fine sand grains across pore spaces. This condition is caused by one-directional movement of water into the well during development, as might occur during overpumping.

3.2.10 bridging (development)—the creation of obstructions to fluid and sediment movement in filter pack or formation materials during well development.

3.2.11 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.

3.2.12 cathead—a rotating power unit on a drilling rig employing either a plain spool or an automatic spool used to hoist drill pipe, casing, small tools, or other drilling equipment.

3.2.13 centrifugal pump (submersible)—a downhole pump consisting of a sealed electric motor that drives impellers through a rotating shaft and seal arrangement at high revolutions per minute.

3.2.14 centrifugal pump (surface)—a pump that moves a liquid by accelerating it radially outward from within a rotating impeller to a surrounding circular-shaped chamber.

3.2.15 development—see *well development*.

3.2.16 drilling fluid—a water- or air-based fluid used in the well drilling operation to remove cuttings from the borehole, to clean and cool the bit, to reduce friction between the drill string and the sides of the borehole and to hold the borehole open during the drilling operation.

3.2.17 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.

3.2.18 filter cake—the solids from a drilling fluid that are deposited on the walls of a borehole in a geologic formation during the process of drilling. Also called mudcake.

3.2.19 filter-packed well—a well in which the natural formation materials adjacent to the well screen has been replaced by a filter pack material.

3.2.20 formation damage—reduction of formation hydraulic conductivity at the borehole wall caused by the drilling process. May consist of compaction, clay smearing, clogging of pores with drilling mud filtrate, or other drilling-related damage.

3.2.21 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.

3.2.22 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.

3.2.23 jetting—see *hydraulic jetting*.

3.2.24 monitoring well—a well that is constructed by one of a variety of techniques that may serve a variety of purposes: (1) extracting ground water for physical, chemical, or biological testing; (2) measuring water levels; (3) measuring formation hydraulic parameters; or (4) measuring formation fluid chemical or physical parameters.

3.2.25 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.

3.2.26 overpumping—a well-development technique that involves pumping the well at a rate that exceeds the design capacity of the well.

3.2.27 rawhiding—starting and stopping a pump intermittently to produce rapid changes in the pressure head in the well.

3.2.28 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.

3.2.29 sloughing—caving of formation materials into an unstabilized open borehole.

3.2.30 spudding—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.

3.2.31 sump—a blank extension of casing beneath the well screen that provides a space for sediment brought into the well during development to accumulate.

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

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

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

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

3.2.36 *well casing*—a durable pipe placed in a borehole to prevent the walls of the borehole from caving, and to seal off surface drainage or undesirable water, gas, or other fluids and prevent their entrance into the well.

3.2.37 *well development*—the act of repairing damage to the borehole caused by the drilling process and removing fine-grained materials or drilling fluids, or both, from formation materials so that natural hydraulic conditions are restored and well yields are enhanced.

3.2.38 *well screen*—a filtering device that allows ground water to flow freely into a well from the adjacent formation, while minimizing or eliminating the entrance of fine-grained material into the well.

4. Significance and Use

4.1 A properly designed, installed, and developed ground-water monitoring well, constructed in accordance with Practice D 5092 should provide the following: representative samples of ground water that can be analyzed to determine physical properties and 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 well may also be utilized for conducting aquifer tests used for the purpose of determining the hydraulic properties of the geologic materials in which the well has been completed.

4.2 Well development is an important component of monitoring well completion. Monitoring wells installed in aquifers should be sufficiently developed to ensure that they serve their intended objectives. Well development methods vary with the physical characteristics of the geologic formation in which the monitoring well is screened, the construction details of the well, the drilling method used during the construction of the borehole in which the well is installed, and the quality of the water. 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 monitoring well completion.

4.3 The importance of well development in monitoring wells cannot be overestimated; all too often development is not performed or is carried out inadequately. 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 will minimize the potential for damaging pumping equipment and in-situ sensors, and increase the probability that ground-water samples are representative of water contained in the monitored formation.

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 the borehole wall and the adjacent formation (that is, clogging, smearing, or compaction of formation materials) that may result in a localized reduction in hydraulic conductivity of the formation near the borehole (see Fig. 1);

5.1.2 To remove fine-grained materials 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. 2³);

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

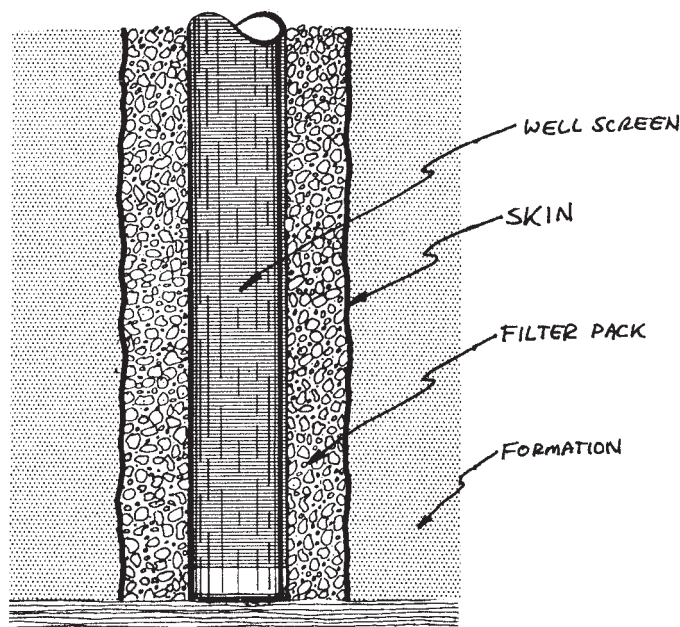
5.1.5 To maximize well efficiency and hydraulic communication between the well and the adjacent formation to provide for the acquisition of representative ground-water samples and formation hydraulic test data.

6. Conducting a Monitoring Well-Development Program

6.1 *Well Development Process*—The well development process consists of three phases: predevelopment, preliminary development, and final development.

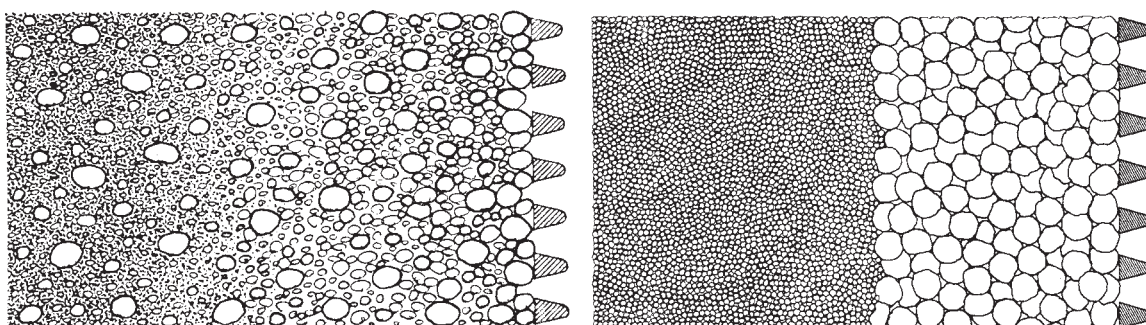
6.1.1 Predevelopment refers to techniques used to mitigate formation damage during well construction. This is particularly important when using direct or reverse rotary drilling systems that depend on drilling fluid to carry cuttings to the surface and support an open borehole. Control of drilling fluid properties,

³ Figure adapted from *Ground Water and Wells*, Second Edition, 1986.



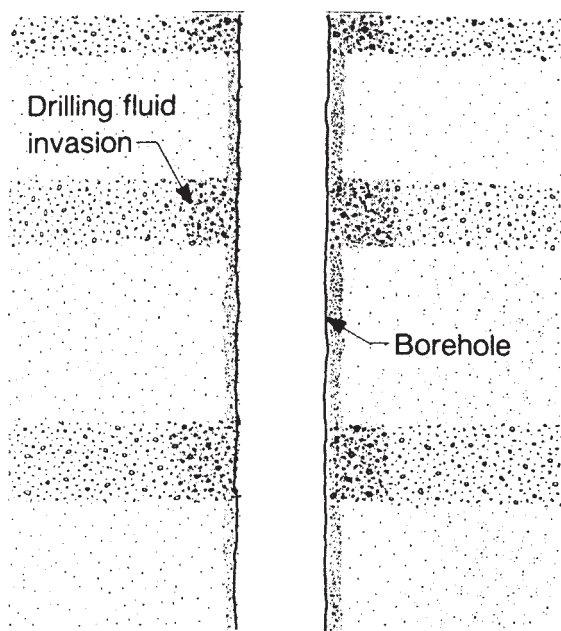
NOTE 1—One of the purposes of development is to rectify the damage done to the borehole wall during drilling, such as the “skin” of fine-grained materials that accumulates on the borehole wall during mud-rotary drilling.

FIG. 1 Example of Rectifying Damage Done During Drilling



NOTE 1—After well development, formation materials in “naturally developed” wells (left) and filter packed wells (right) should be stabilized so that entry of fine-grained materials into the well is minimized and no settlement occurs.³

FIG. 2 Formation Materials in Wells



NOTE 1—When drilling with water-based drilling fluids, some fluid will infiltrate beyond the borehole into the most permeable zones. One of the purposes of development is to remove lost drilling fluid from the formation adjacent to the open interval of the well.³

FIG. 3 Removal of Lost Drilling Fluid

during the drilling operation and immediately prior to the installation of screen, casing, and filter pack, is very important.

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 formation damage due to drilling; removal of fine-grained materials from the screen, filter pack, and formation; stabilization and 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.

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 sedi-

ment. Intensive development of a well that appears to be plugged should not be attempted because damage and destruction of the well may result.

6.1.4 Final development refers to procedures performed with a pump, such as pumping and surging, and backwashing. These techniques are used as the final step in achieving the objectives of well development. If preliminary development methods have been effective, the time required 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 be considered in selecting the method(s) used for developing any given monitoring well; these include: the construction of the 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 well and the thickness of the filter pack); characteristics and hydraulic conductivity of the formation materials adjacent to the well screen; water quality in the aquifer in which the 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, air, water, or chemical solutions) into the well and aquifer; drilling method used during borehole installation; depth to static water level and height of the water column in the well; type and portability of available equipment (that is, whether or not a drilling rig is required); time available for development; and cost effectiveness of the method.

6.3 *Timing of Well Development: When and How Long to Develop*—The point in time at which a monitoring well is developed is a decision that is generally based on design and construction of the well. For example, if the well is installed with the intent of using natural formation material as the filter pack (that is, a “naturally developed” well), development is generally performed after the screen and casing have been installed and the formation material has collapsed against the screen (to at least 5 feet 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 adjacent to the well screen (therefore causing some sloughing in the borehole), developing the 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 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 % 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 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 damage done during drilling to the borehole wall and the adjacent formation, the time for development may be based on the response of the well to pumping. An improvement in recovery rate of the well indicates that the localized reduction in hydraulic conductivity has been effectively rectified by development. If the primary purpose of development is to remove fine-grained materials, 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. These criteria may be difficult or impossible to satisfy in formations with a significant fraction of fine-grained material. Another criterion used for determining when development is complete is the stabilization of certain indicator parameters (that is, temperature, specific conductance, pH, redox potential, dissolved oxygen) that are easily measured in the field. While this criterion may be an indicator of when native formation water is being produced, it does not necessarily indicate that well development is complete.

6.4 *Decontamination of Well Development Equipment*—Any equipment or materials used to develop a monitoring well should be thoroughly cleaned in accordance with Practice D 5088. Cleaning should take place prior to the use of any equipment in any 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 wells installed in predominantly fine-grained formation materials (that is, in formations dominated by fine sand, silt 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 amount of development will measurably improve formation hydraulic conductivity or the hydraulic efficiency of the well.

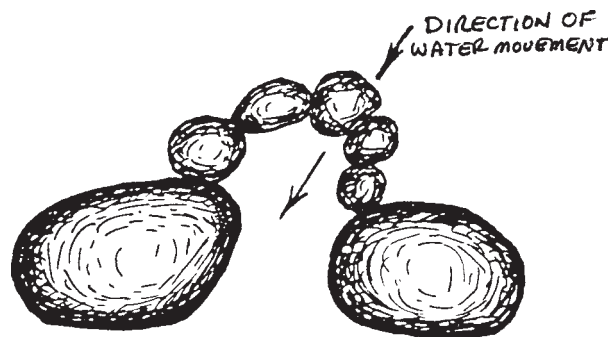
7.2 While development methods which require the addition of a foreign fluid to a well may be applied to ground-water monitoring wells, such methods should be used with an understanding of the negative effects that added fluids may have on the ability of the well to yield representative ground-water quality samples. Only in very extreme or special cases should fluids other than clean water or filtered air be considered

for use in a well during development. Fluids other than water, including deflocculating or dispersing agents (that is, poly-phosphates), 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 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 should be removed by pumping after development is complete. One possible means of reducing potential problems related to the addition of water to the well is to obtain water-quality samples from the well only after natural ground-water flow in the aquifer has had time to flush the remnants of well-development fluids beyond the well. Another means may be to use water that has been taken from the formation itself (that is, water pumped from the formation either prior to or during development) for the development process.

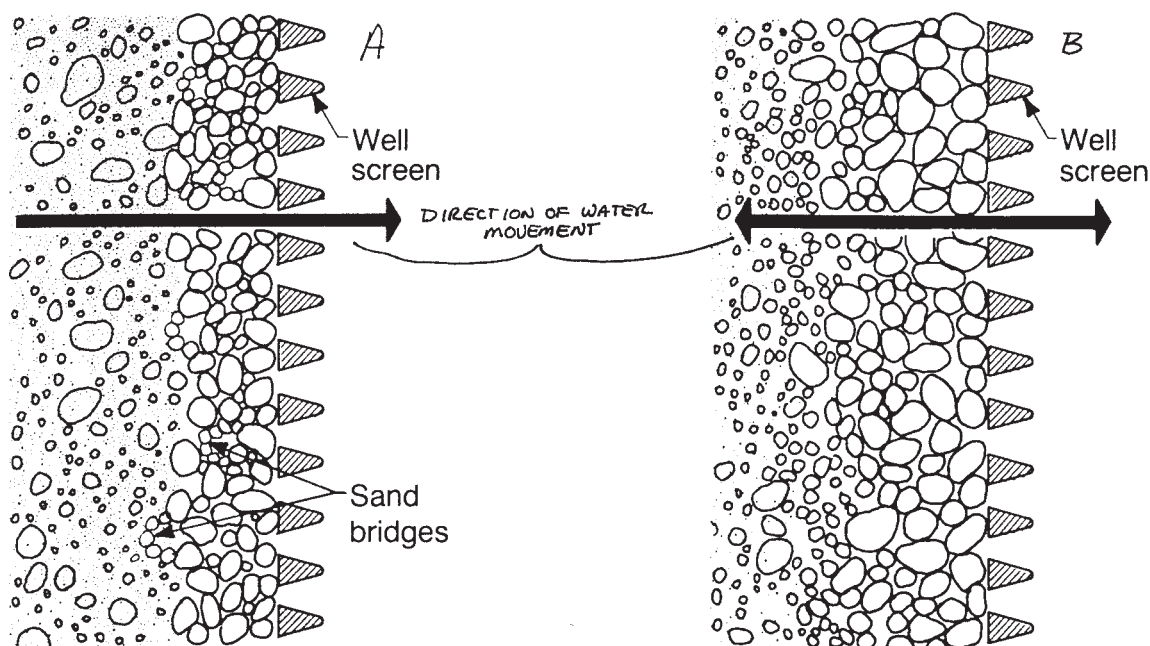
7.3 Development methods using compressed air (that is, air-lift pumping) should be attempted only after great care has been taken to remove any compressor oil or other foreign substances from the air stream prior to introduction into the well. Air should not be forced into the formation or allowed to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

7.4 Development methods that rely only on pumping (“passive” development), especially at low-flow rates, do not sufficiently stabilize formation or filter pack material and do not effectively remove fine-grained material or rectify formation damage done during drilling (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 subsequent activity that agitates the water column in the well (that is, conducting a formation hydraulic



NOTE 1—Bridging in formation and filter pack materials is caused by movement of water in one direction only during well development.³

FIG. 4 Bridging in Formation and Filter Pack Materials



NOTE 1—Effective development action requires movement of water in both directions through the well screen openings. (B) Reversing flow helps to minimize bridging in the formation and filter pack (if used). (A) Movement of water in only one direction, as when overpumping the well, does not produce the proper development effect.³

FIG. 5 Movement of Water in Both Directions

test, purging prior to sampling, or sampling, especially with bailers) can cause considerable turbidity in the well.

7.5 Development should be applied very cautiously to wells that are known or suspected to be contaminated with hazardous chemical constituents, particularly constituents which pose a hazard through inhalation or dermal contact. Appropriate safety precautions should be taken to protect field personnel. It should be noted that contaminated water and sediment removed from monitoring wells during development may also have 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 significantly increase the cost of development.

8. Methods and Processes Available for Monitoring Well Development

8.1 *General*—Of the various methods available for use in developing 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 ground-water monitoring wells. 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, similar to a piston in a cylinder

(see Fig. 6). The downstroke causes a backwash action to loosen bridges in the formation or filter pack and the upstroke then pulls dislodged fine-grained material 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.

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. 7⁴) 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. 8⁵) may also be used to produce the surging action, but these are not as effective as a close-fitting surge block.

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 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,

⁴ Figures a and b adapted from *Ground Water Wells*, Second Edition, 1986, and Figs. c and d adapted from *Handbook of Ground Water Development*, 1990.

⁵ Figure adapted from *Handbook of Ground Water Development*, 1990.