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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 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:*[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

3. Terminology

3.1 *Definitions:*

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

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.

[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.

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

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

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.

3.2.4 *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 *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.

3.2.7 *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.

3.2.9 *filter-packed well*—a well in which the natural formation materials adjacent to the well screen has been replaced by a filter pack material.

3.2.10 *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.

3.2.11 *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.

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

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

3.2.17 *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.

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

3.2.19 *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.

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

3.2.21 *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.*

3.2.22 *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.

3.2.23 *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.

3.2.25 *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.

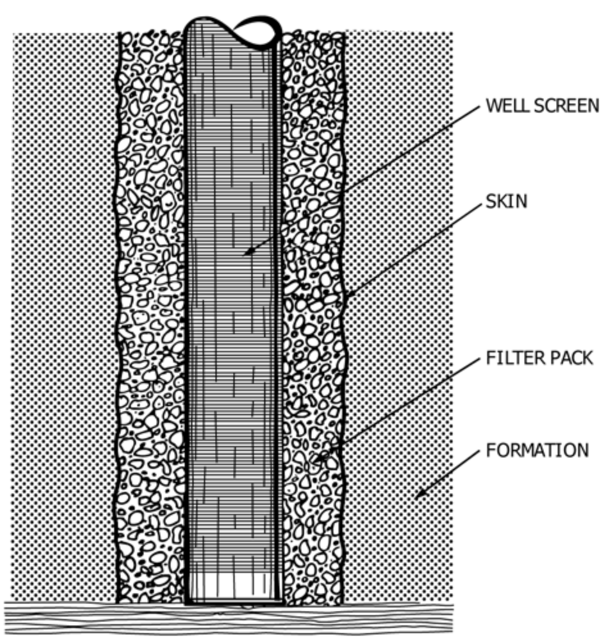
4. Significance and Use

4.1 A properly 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 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 groundwater samples are representative of water contained in the monitored formation. Practice D3740 provides evaluation factors for the activities in this guide.

NOTE 1—The quality of the result produced by this standard is dependent on the competence of the personnel performing it, and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D3740 are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of this standard are cautioned that compliance with Practice D3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D3740 provides a means of evaluating some of those factors.



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

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. 2[3]);

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[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 groundwater 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.

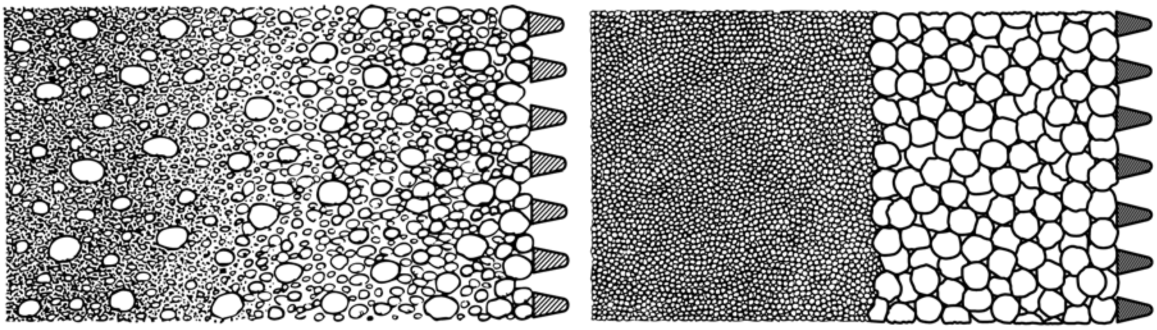
6.1.1 Predevelopment refers to techniques used to mitigate formation damage during well construction. This is particularly important when using direct or reverse rotary drilling systems that depend on drilling fluid to carry cuttings to the surface and support an open borehole. Control of drilling fluid properties, 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 sediment. Intensive development of a well that appears to be plugged should not be attempted because damage and destruction of the well may result.

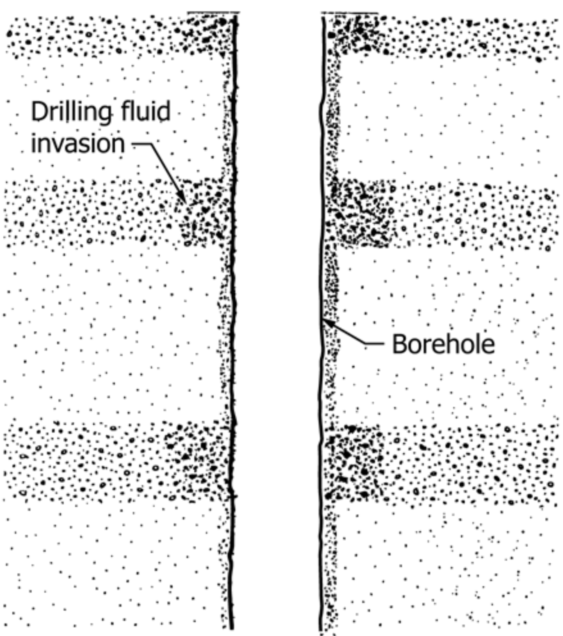
6.1.4 Final development refers to procedures performed with a pump, such as pumping and surging, and backwashing. These techniques are used as the final step in achieving the objectives of well development. If preliminary development methods have been effective, the time required for final development 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.

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



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.

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.

FIG. 3 Removal of Lost Drilling Fluid

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 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 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 D5088. 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 groundwater 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 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 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 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 groundwater 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.

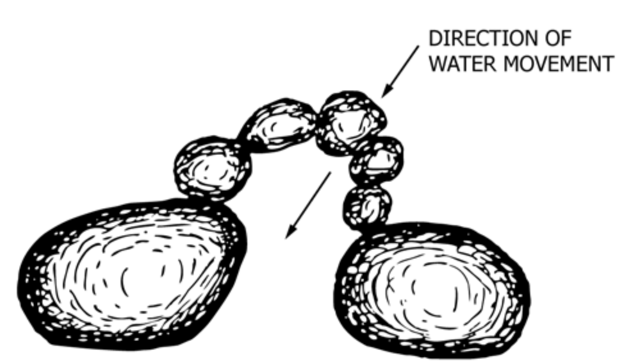
7.4 Development methods that rely only on pumping (“passive”development), especially at low-flow rates, do not sufficiently stabilize formation or filter pack materials and do not effectively remove fine-grained material or rectify formation damage done during drilling (see Fig. 4[3]). Effective development action requires movement of water in both directions through the well screen openings (see Fig. 5[3]). 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 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

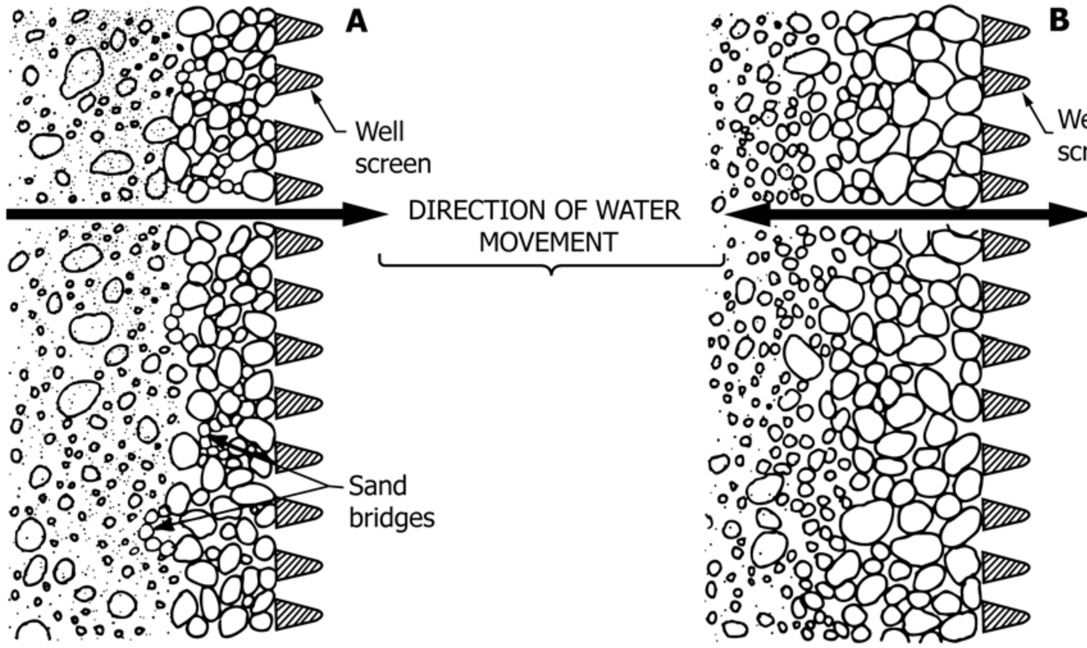
8.1 *General*—Of the various methods available for use in developing wells in general, mechanical surging, overpumping and backwashing, and high-velocity hydraulic jetting with pumping (or combinations of two or more of these methods) are best suited for use in developing groundwater monitoring wells. 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



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

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. (*A*) Movement of water in only one direction, as when overpumping the well, does not produce the proper development effect.[3] (*B*) Reversing flow helps to minimize bridging in the aquifer and filter pack (if used).

FIG. 5 Movement of Water in Both Directions

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[3]). The down stroke 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.

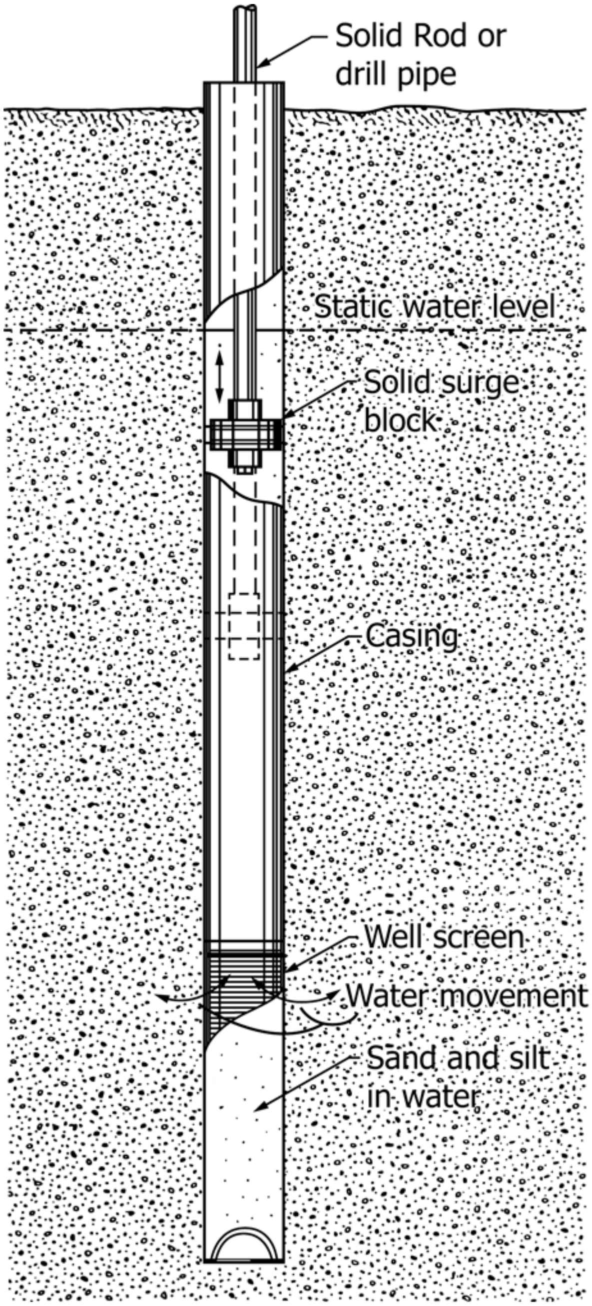
8.2.1 Several designs for surge blocks, including a solid surge block, a valved or vented surge block, a spring-loaded surge block, and a multiple-flange surge block (see Fig. 7[3,4]) can be utilized. A heavy bailer or a pump (such as a gas-drive pump or an inertial lift pump) fitted with flexible disks similar to those on a surge block (see Fig. 8[5]) 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, 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 well. As water begins to move easily in and out of the well, 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 formations, surging can harm a well rather than improve it. Because significant pressure differentials can occur during mechanical surging, great care must be taken to avoid damaging (that is, collapsing) the casing or screen by overzealous development.

8.2.3 In wells with short (that is, 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 wells with longer (that is, 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 adjacent to the screen.

[4] Figs. *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.



NOTE 1—For certain types of formations, a surge block is an effective tool for well development. On the downstroke, water is forced outward into the formation; water, silt, and fine sand are then pulled into the well screen during the upstroke.

FIG. 6 Mechanical Surging

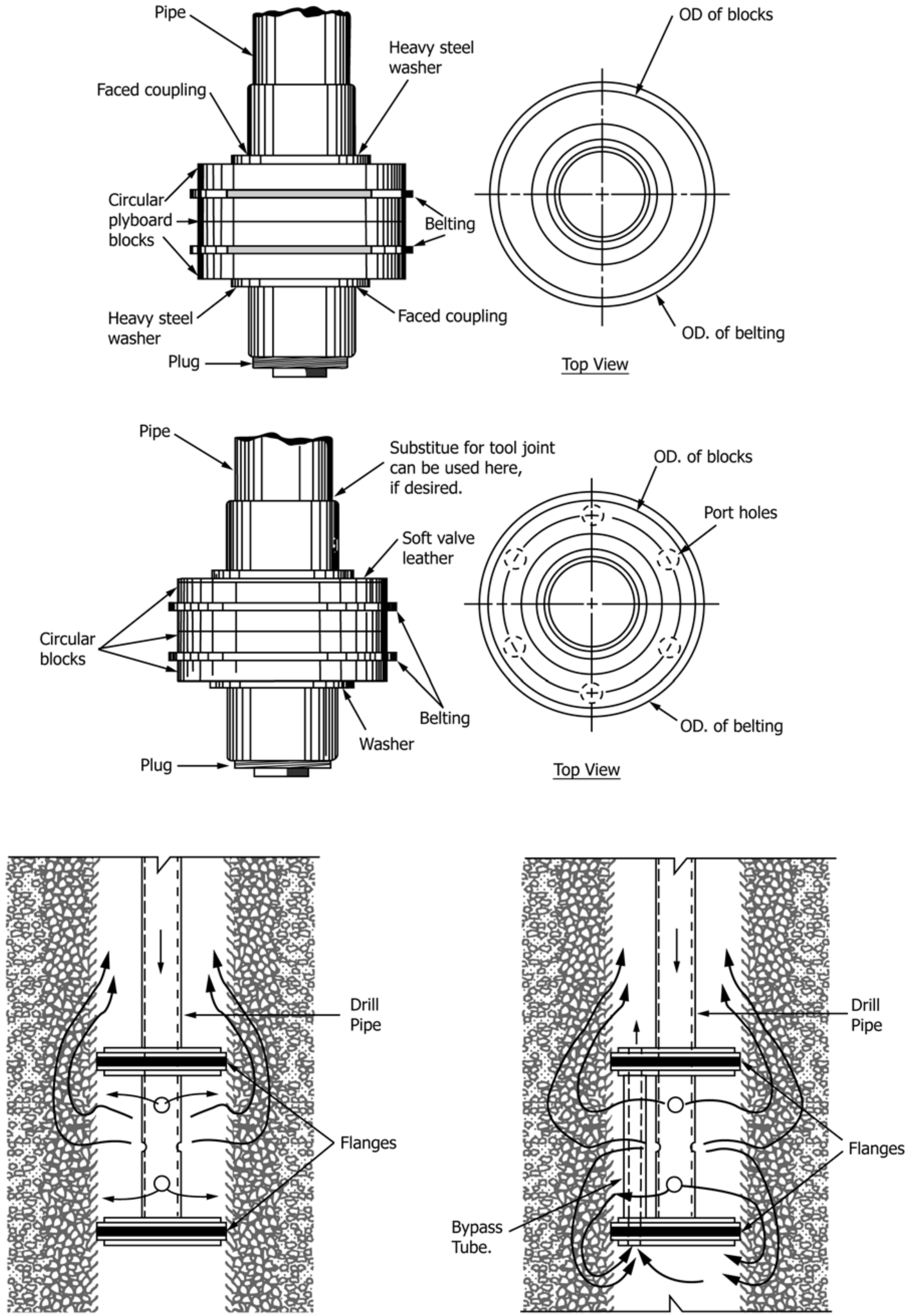
8.2.4 The force exerted on the formation depends in part on the length of the stroke and the vertical velocity of the surge block. The length of the stroke depends on the mechanism used to operate the surge block. For cable-tool rigs, that are ideally suited to the surging operation, the length of the stroke is determined by the spudding motion. For rigs using a cathead to surge, the length of the stroke can be varied by varying the length of time that the rope is tightened on the spool. For manual surging, the length of the stroke is generally limited to the range of motion of the operator's arms. Generally, a 0.6 to 0.9 m [2 to 3 ft] stroke is sufficient to achieve proper well development with mechanical surging.

8.2.5 The vertical velocity of the surge block depends on the weight exerted on the block and the retraction speed. Generally, a vertical velocity of between 0.9 to 1.5 m/s [3 and 5 ft/s] is most effective. On the downward stroke, the surge block assembly must be of sufficient weight to free-fall through the water column in the well and create a vigorous outward surge. The surge block assembly should not be permitted to fall out of plumb because of the hazard of the assembly falling against and possibly damaging the screen. When used with a cable-tool rig, a surge block may be weighted using the drilling tool string so it will fall at the desired rate, with the spudding motion controlled to vary the retraction speed. If a rotary rig is used, the weight on the surge block can be provided by drill pipe, with the retraction speed controlled by the rate of response of the hydraulic system. For rigs using a cathead to assist in surging, weight must be supplied to the surge block through either drill rod or the addition of weights above or below the surge block; the speed of retraction can be varied by the tension of the rope on the spool. For manual surging, only a limited amount of weight can be added to the surge block assembly because of the difficulty of working by hand with a heavy tool string in a well. Down force may be applied more easily manually by pushing the surge block into the well. The speed of manual retraction is controlled by the rate at which the individual is capable of pulling the surge block assembly back out of the well.

NOTE 2—Manual surging is a very tiring and laborious procedure that commonly exhausts field personnel long before development is complete.

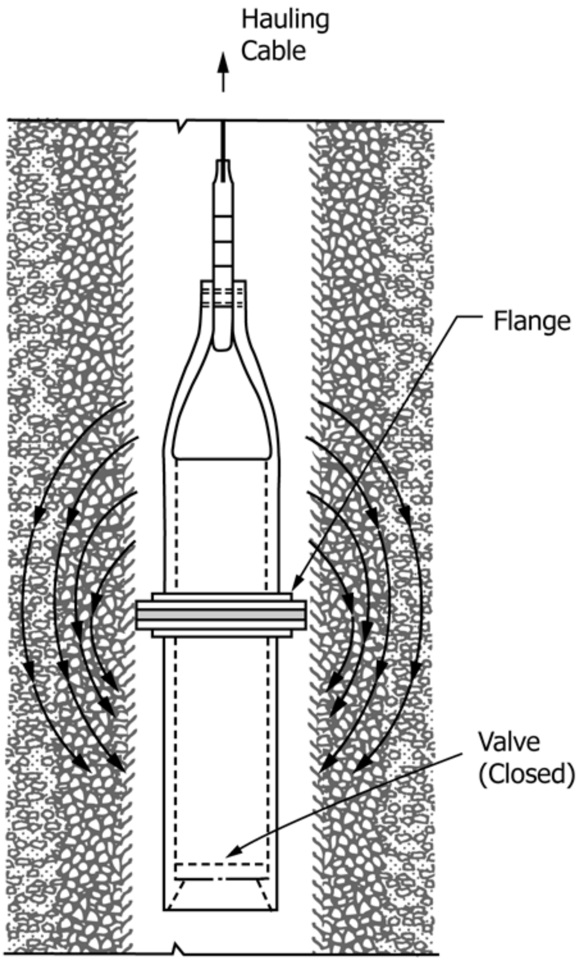
8.2.6 The effectiveness of mechanical surging is also governed in part by how tightly the surge block fits into the well casing or screen. If surging is to be performed only in the casing, the outside diameter of the surge block should be sized to be within 0.3 to 0.6 mm [⅛ to ¼ in.] of the inside diameter of the casing. (Care should be taken during casing assembly to ensure a smooth inner surface, especially at joints; shoddy assembly or irregular surfaces at casing joints could result in damage to the surge block or the casing, or both.) If surging is to be performed within the screen, care should be taken to avoid "sandlocking" the surge block. If sandlocking is a concern, the surge block can be sized to be slightly smaller. This reduction in size reduces the pressure exerted on the screen by allowing some water to flow past the surge block on both the upstroke and the downstroke, and it allows fine sediment to flow around the block rather than lodging between the block and the screen. A valved or vented surge block creates the same effect. Prior to the surging operation, the surge block or a dummy pipe of equivalent diameter and length should be tested to be certain that it will fit into the casing or screen, or both, without becoming lodged.

8.2.7 The first surging run should be very short so that the operator can judge the amount of sediment entering the screen. Surging should continue for several minutes, and the surge block should be removed from the well and the accumulation of sediment measured. Subsequent surging runs should be done over short to increasingly longer periods, keeping records of how quickly sediment enters the screen. When the sediment



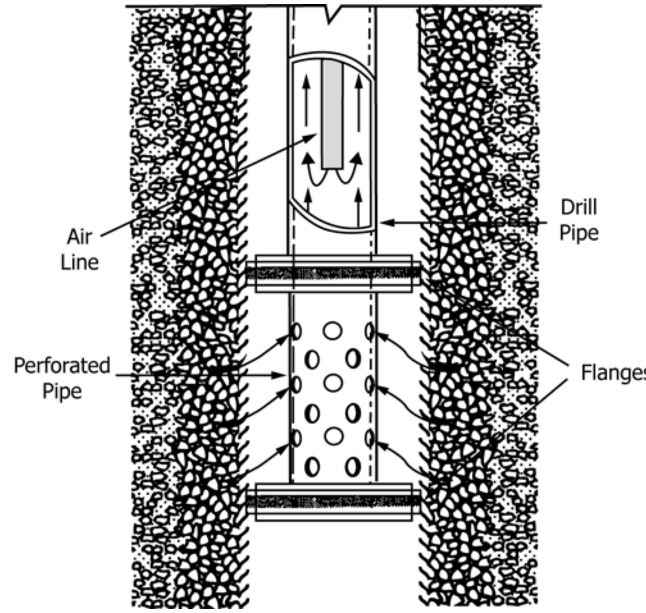
NOTE 1—Various configurations of surge blocks: (*a*) solid surge block; (*b*) valved surge block; (*c*) double-flanged surge block; and (*d*) valved double-flanged surge block.

FIG. 7 Various Configurations of Surge Blocks



NOTE 1—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.

FIG. 8 Bailer



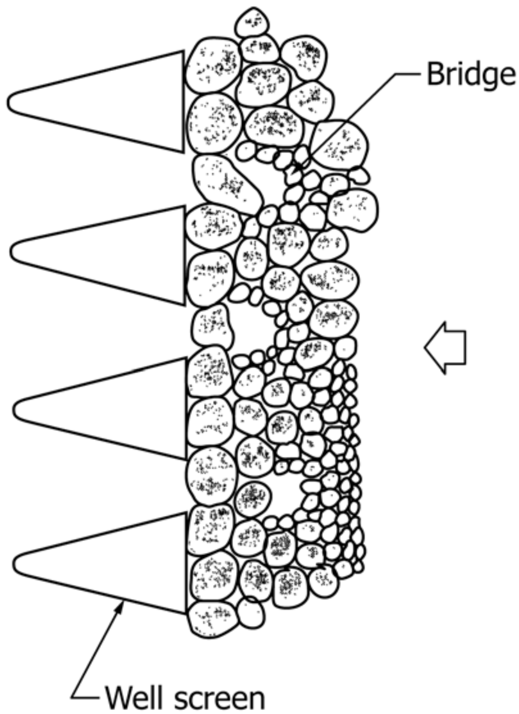
NOTE 1—A specially designed surging tool combining a double-flanged surge block with an air-lift pumping system to allow simultaneous surging and pumping. Arrows indicate the direction of water and sediment movement during pumping.

FIG. 9 Specially Designed Surging Tool

accumulated at the bottom of the screen begins to block off a portion of the screen, the sediment should be removed by pumping or bailing. Alternately, it may be possible to surge and pump simultaneously, using a specially designed surging tool (see Fig. 9[5]) or a surge block affixed to an open pipe with a swivel for attachment to a pump and alternating surging without pumping with surging and pumping. Because development is more effective if the amount of sediment in the screen is kept to a minimum, accumulated sediment should be removed as often as possible. A "sump" or length of blank casing installed beneath the screen may help to keep the screen free of sediment. Surging should not be attempted when the screen is full of sediment because the force of surging may cause the casing above the screen to collapse. The rate and volume of sediment accumulation should be recorded to provide data on the progress of development. Surging and cleaning should be continued until little or no sediment is measured after surging. The time required to properly surge a well depends on the character of the aquifer material and its apparent response to development, and may vary widely from well to well.

8.2.8 Manual mechanical surging can be accomplished effectively only in relatively shallow small-diameter wells (that is, wells less than 10 cm [4 in.] in diameter that are less than 15 m [50 ft] deep). Development of larger diameter or deeper wells will require either mechanical assistance (that is, by means of a block and tackle or pulley system used with a tripod assembled atop the well) or the use of a drilling rig or pump-pulling rig.

8.3 *Overpumping and Backwashing*—The simplest of method removing formation fines is by overpumping, or pumping at a higher rate then the well will be pumped when it is purged and sampled. Theoretically, increasing the drawdown to the lowest possible level results in increased flow velocities toward the well, resulting in the movement of fine-grained materials into the well (that is, any monitoring well that can be pumped sediment-free at a high pumping rate can then be pumped sediment-free at a lower rate). However, five important limitations to overpumping include: overpumping by itself will not adequately develop a well because water flow is in only one direction; it may cause bridges to form in the formation or filter pack, or both, resulting in only partial stabilization of these materials (see Fig. 10[3]); it often requires the use of larger pumping equipment than will fit into the small-diameter casings that are used in many monitoring wells; it subjects the pump used in the operation to abrasion, excessive wear, and loss of efficiency, as well as the possibility of sandlocking; and it results in the production of potentially large volumes of water that may require containment or treatment. Furthermore, because the pump is normally set above the top of the well screen, most of the development that takes place during overpumping occurs in the zones of highest hydraulic conductivity closest to the top of the screen. For a



NOTE 1—During development by overpumping, sand grains can bridge openings because flow occurs in only one direction. Once the well is placed into service, agitation by normal pump cycling can break down the bridges, causing sand pumping.

FIG. 10 Overpumping

given pumping rate, the longer the screen, the less development will take place in the lower part of the screen. After fine-grained material has been removed from the high hydraulic conductivity zones near the top of the screen, water entering the screen moves preferentially through these zones, leaving the rest of the well poorly developed. Overpumping may be effective in filter-packed wells or in non-stratified sands in which flow toward the well is more or less uniform. Overpumping is also useful for removing drilling fluid lost to the formation, but it is not an adequate development method if used alone. Overpumping is best used in combination with backwashing. Backwashing is the term applied to the method of well development in which water is added to the well to create a flow reversal.

8.3.1 A commonly used backwashing procedure is to pump water into the well in a sufficient volume to maintain a head greater than that in the formation. This requires a high-capacity water source. Water can be obtained by diverting part of the water pumped from the well during overpumping into a large tank. After the well is pumped, the stored water is pumped back down the well, either through the pump column or through a separate pipe. This method of backwashing should not be used in cases in which the water pumped from the well is potentially contaminated.

NOTE 3—There may be regulatory or legal constraints on returning potentially contaminated fluids to a monitoring well.

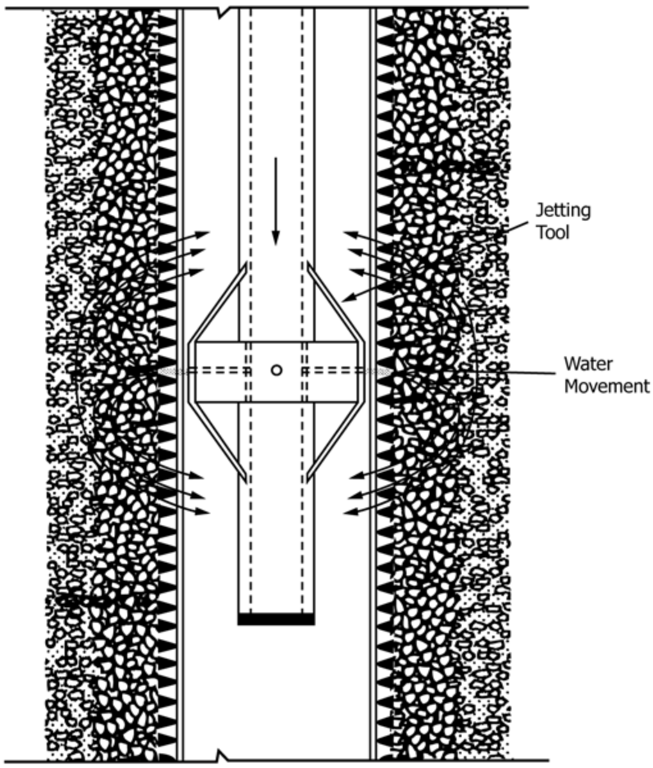
8.3.2 "Rawhiding" consists of starting and stopping a pump intermittently to produce rapid changes in the pressure head within the well. The alternate lifting and dropping of a column of water in the pump discharge pipe creates a surging action in the well. During a surge, the amount of water contained in the discharge pipe, combined with the well's natural recovery, may not be sufficient to cause the water level in the well to rise above the static water level. In this situation, supplemental water is generally added to the well when pumping is stopped for a surge. Judgment should be exercised concerning the duration of the backwash and the quantity of water added, because to some extent the success of this method depends on the frequency of flow reversals rather than the magnitude of water level change in the well.

8.3.3 Before beginning the rawhiding procedure, the pump should be started at reduced capacity and gradually increased to full capacity to minimize the danger of sandlocking the pump. When the pump discharge is clear of sediment, the pump is shut off and the water in the pump discharge or column pipe falls back into the well; the pump is then repeatedly started and stopped as rapidly as the power unit and starting equipment will permit. The pump used must not be equipped with a check valve or other backflow prevention device. To avoid damaging submersible pumps, the control box should be equipped with a starter lockout so the pump cannot be started when it is back spinning. During the rawhiding procedure, the well should be pumped occasionally to remove the sediment that has been brought in by the surging action.

8.3.4 Some wells respond satisfactorily to rawhiding, but in some cases the surging effect is not vigorous enough to obtain optimum results. Also, rawhiding is very hard on pumping equipment.

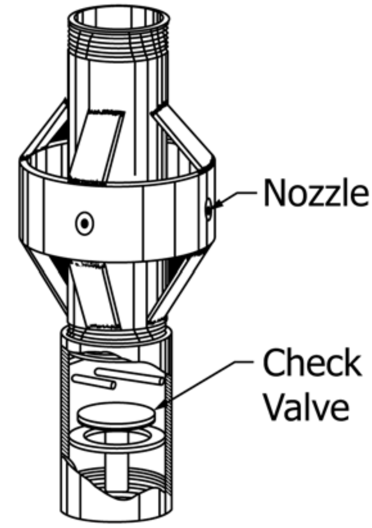
8.3.5 Various types of pumps can be used to rawhide a monitoring well. To be effective for development by rawhiding, a pump must be capable of pumping at a rate of at least 20 to 40 L/min [5 to 10 gal/min] . Surface centrifugal or diaphragm pumps are capable of these rates, but can only be used if the depth to static water level in the well is less than about 6 m [20 ft] below ground surface. Submersible centrifugal pumps with these pumping capacities are available for small-diameter monitoring wells, but the impellers in these pumps are relatively easily damaged by sand because of the very high speed at which they operate. Air-lift pumps can be constructed to easily fit into a small-diameter monitoring well and these pumps are capable of pumping in excess of 40 L/min [10 gpm]. However, air-lift pumping and backwashing results in mixing of aerated water with water in the well and adjacent formation, temporarily altering groundwater quality.

8.4 *High-Velocity Hydraulic Jetting*—Where conditions permit, another effective method available for use in developing monitoring wells, is high-velocity hydraulic jetting. Because of the size of the equipment required, this method is more easily applied to wells of 10 cm [4 in.] or greater diameter. Development by high-velocity hydraulic jetting employs several horizontal jets of water operated from inside the well screen so that high-velocity streams of water exit through the screen and loosen fine-grained material and drilling mud residue from the formation (Fig. 11[5]). The loosened material moves inside the well screen and can be removed from the well by concurrent pumping or by bailing. Jetting is particularly successful in developing highly stratified unconsolidated



NOTE 1—Development by high-velocity hydraulic jetting employs a tool using several horizontal jets of water operated from inside the well screen. High-velocity streams of water are directed through the screen into the formation or filter pack to loosed fine-grained material and drilling mud residue and bring it into the well, where it can be pumped out.

FIG. 11 High-Velocity Hydraulic Jetting



NOTE 1—A jetting tool with four nozzles spaced 90° apart around the circumference of the tool. The check valve at the bottom of the tool closes when water pressure is introduced from the surface, and opens to allow pumping through the drop pipe after jetting is completed.

FIG. 12 Jetting Tool With Four Nozzles

formations, consolidated bedrock wells, large-diameter wells, and naturally developed wells. Jetting can also be useful in filter-packed wells provided that filter pack material is carefully chosen to provide some, but not excessive, loss through the well screen, and that the filter pack is not too thick (that is, not greater than 50 to 70 mm [2 to 3 in.]).

8.4.1 The equipment required for jetting includes a jetting tool with two or more equally spaced nozzles; a high-pressure pump, hose, and connectors; a string of pipe; and a water tank or other high-volume water supply. The high-velocity jets direct water through the screen openings, and agitate and rearrange the particles of the formation materials surrounding the screen. The filter cake that is formed on the borehole wall during mud rotary drilling is broken down and dispersed, allowing easy removal by pumping. Jetting is also useful in correcting other damage done during drilling.

8.4.2 Fig. 12[3] shows a jetting tool with four nozzles. Nozzles should be equally spaced around the circumference of the jetting tool, and generally range from 4 to 9.5 mm [0.15625 to 0.375 in.]. The jetting tool should be constructed so that the nozzle outlets or holes are as close to the inside diameter of the screen as practical (generally within 12.7 mm [0.5 in.]), with the bottom end of the tool capped and the top end threaded so it can be screwed on to the lower end of the pipe string. If the outside diameter of the jetting tool is too small in relation to the inside diameter of the screen, much of the energy of the jet is dissipated by the turbulence created within the well.

8.4.3 Every effort should be made to limit sediment concentrations in the water used for jetting. Sediment-laden water that is recirculated through the jetting tool, causes erosion of the nozzle bores and may produce a pronounced pressure reduction at the nozzle face. Sediment in water used for jetting can also damage screens if the jets are directed at one area for a prolonged period of time.

8.4.4 A nozzle velocity of as low as 30 m/s [100 ft/s] can produce effective jetting results, though much better results can be expected when the nozzle velocities are between 45 and 90 m/s [150 and 300 ft/s]. Velocities greater than 90 m/s [300 ft/s] may not result in sufficient additional benefit to justify the additional cost. In general, (1400 and 2800 kPa) [200 to 400 psi] at the nozzle are the preferred operating pressures for jetting in wells constructed with metallic screens. However, great care must be exercised in jetting screens constructed of PVC or other less-abrasion-resistant materials. All jetting of PVC screens should be done only with clean, sediment-free water to minimize abrasion, and the pressure used should not exceed 700 kPa [100 psi]. In general, pressures higher than 700 kPa [100 psi] are required when working in predominantly fine-grained formations or filter-packed wells.

8.4.5 The energy that agitates formation particles outside the well screen is a function of both the velocity and the diameter of the water stream. The energy of the jetting stream will depend on the capacity of the pump (maximum pressure output and flow rate at that pressure) and the orifice size of the discharge nozzle. The nozzle size should be the largest possible diameter that will maintain a minimum line pressure of 700 kPa [100 psi] at the minimum anticipated flow rate of the pump. For a given nozzle size (water stream diameter), greater pressures will result in greater energy to penetrate formation materials. The pipe that is attached to the jetting tool should be large enough to minimize friction losses so that the velocity at the nozzle is as high as possible.

8.4.6 Although jetting can be accomplished without a drilling rig, it is usually done with a rig such as a rotary rig or another type of rig with rotating capability that is equipped with a mud pump that can supply the required down-hole pressure. When using a drilling rig, the jetting tool is attached to the lower end of the drill string and tool rotation is controlled by the rig. The jetting tool is placed near the bottom of the well screen and rotated slowly while being pulled upward at a rate of 2 to 5 m/min [5 to 15 ft/min] of screen. Material loosened from the formation is brought into the well by the turbulence created above and below the jets, and accumulates at the bottom of the screen (or in a sump if one is used) as the jetting tool is raised. This material must be removed concurrently or periodically. Slowly rotating and gradually raising the tool exposes the entire surface of the screen to the vigorous action of the jets. Several passes up and down the screen are made until the amount of additional material removed from the formation becomes negligible. To avoid erosion of the screen and to expedite development, the jetting tool should never be operated in a stationary position; it should always be slowly rotated and slowly raised or lowered.

8.4.7 In general, the effectiveness of the jetting process is controlled by the ratio of the filter-pack thickness to the jet radius, the velocity of the jet, the distance from the jet to its impact point on the screen, and the ratio of the hydraulic conductivity of formation materials to that of the filter pack materials.

8.4.8 Optimal removal of sediment by jetting will depend on the time allotted to the process. Because the jetting energy can focus on only a small part of the formation at a given moment, more time may be necessary for jetting than for other methods that affect a larger portion of the formation. Less satisfactory results from jetting almost inevitably occur when not enough time is allowed for a thorough job.

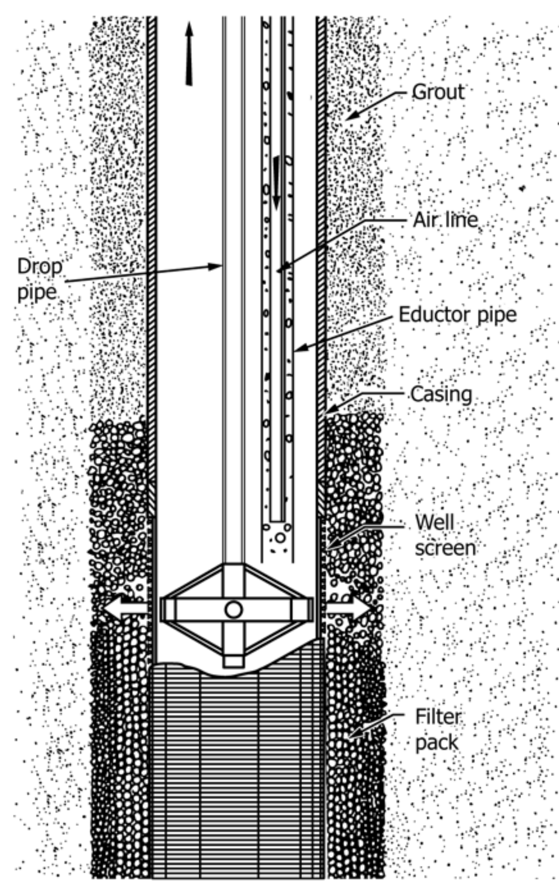
8.5 *High-Velocity Hydraulic Jetting Combined with Simultaneous Pumping*—Although jetting is effective in dislodging material from the formation, maximum development efficiency is achieved when jetting is combined with simultaneous pumping. This combination of development techniques is particularly successful for wells in unconsolidated sands and gravels. It is not always practicable, but should be considered where permitted by the size of the well, the available equipment, and the position of the static water level with respect to the screen.

8.5.1 In jetting, water is added to the well at a rate governed by the nozzle size and the pump pressure. The volume of water simultaneously pumped from the well should always exceed the volume pumped in during jetting, by as much as 1.5 to 2 times, so that a gradient is created toward the well. The movement of water into the well helps to remove some of the formation material loosened by jetting. The pump then delivers the sediment from the well before it can settle in the screen. This procedure also serves to immediately remove most of the water added to the well during jetting, which may be a concern in some monitoring wells.

8.5.2 An added advantage of pumping is that water removed from the well provides a continuous supply that can be recirculated through the pump and jetting equipment after the sediment has settled out in a tank (to avoid damaging the high-pressure pump, jetting nozzles, or screen). This partially alleviates concerns regarding the quality of water added to the well during jetting, because the water used in this situation is water from the well being pumped. This water may be altered chemically during pumping, particularly if the equipment is not cleaned prior to use. Pumping while developing also permits an appraisal of the effectiveness of the jetting, based on the size and volume of the sediment collected at the bottom of the holding tank.

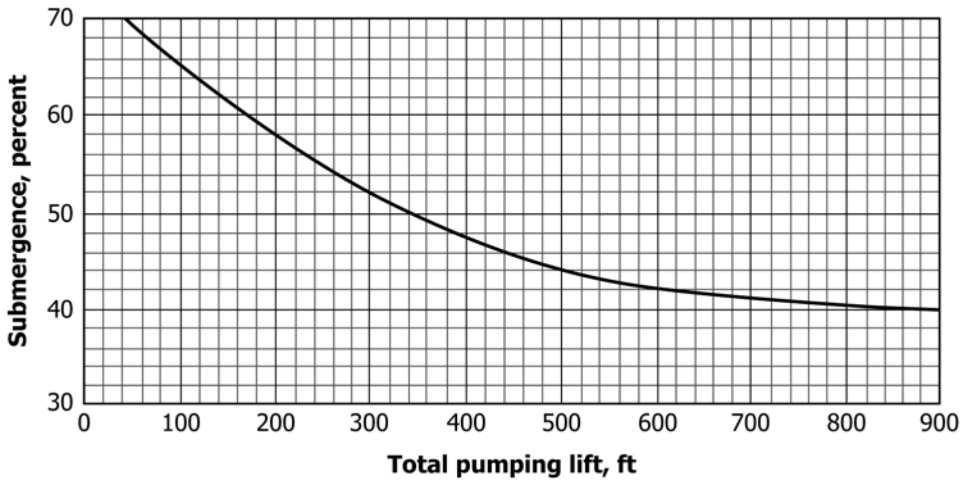
8.5.3 An air-lift pump (see Fig. 13[3]) is the most common type of pump employed in this development operation, because of its small diameter and efficiency in removing sediment without damage to the pumping mechanism. Occasionally, the size of the air line and eductor pipe may have to be decreased somewhat so that the air line and eductor pipe will both fit into the annulus between the jetting pipe and the well casing. The air-lift system operates best when the air line is at least 40 % submerged (see Fig. 14[3]) and when the bottom of the eductor pipe is placed just above the jetting tool allowing more suspended sediment to be pumped out of the well.

8.5.4 Compressed air used for development must be filtered to ensure that oil from the air compressor is not introduced into the well. In theory, this could be accomplished relatively easily with high-volume carbon filters. In practice, however, the



NOTE 1—In this configuration, the jetting tool and drop pipe are separate from an air-lift pumping system so that jetting and air-lift pumping can be done simultaneously.

FIG. 13 Air-Lift Pump



Metres	0	30	61	91	122	152	183	213	244	275
Feet	0	100	200	300	400	500	600	700	800	900

NOTE 1—Approximate percent pumping submergence for optimum air-lift efficiency. In general, development proceeds most efficiently when the discharge is maximized. Therefore, the submergence should always be as great as possible within practical limits.

FIG. 14 Submerged Air Line

effectiveness of air/oil filters in removing entrained oil is questionable. It is difficult to ensure that the air used has a non-detectable oil content. Thus, development with compressed air may actually introduce oil into the well, albeit at very low levels. This oil may have the effect of confusing water quality analytical results. Alternately, oil-less or oil-free compressors may be used to obviate the problems inherent with common oil-lubricated air compressors.

8.5.5 When air-lift pumping is impractical or undesirable, a submersible pump can be used, but this is only possible in large-diameter wells. Usually, the pump must be placed above the jetting tool so that the amount of sediment passing through the pump is minimized to avoid damaging the pump. Thus, the pump causes material temporarily placed in suspension by the jetting action to move into the well, but much of the sediment falls to the bottom. This sediment must be removed periodically during the jetting and pumping operation so that the entire screen can be effectively developed.

8.6 *Developing with Air*—Developing with air is not recommended for monitoring wells. Air development may force air into contact with the formation, which may alter the oxidation-reduction potential of the formation water and change the chemistry of the water in the vicinity of the well. The effects of this type of chemical disturbance may persist for several weeks or more after well development.

8.6.1 Blowing air into the well during the process of air development may cause air to become entrapped in the narrow slots of some monitoring well screens, the pores of the filter pack or formation materials immediately adjacent to the borehole. Entrapped air is difficult to remove and it may significantly reduce formation hydraulic conductivity and effectively reduce the amount of open area of the well screen.

8.6.2 In situations in which the well is installed in an area of contaminated groundwater, development with air may potentially result in the exposure of field personnel to hazardous materials. Though precautions can be taken to minimize personnel exposure, other development methods, which may also be more effective, can be used without such exposure problems and are, therefore, generally preferable.

8.6.3 For these reasons, compressed air alone should not be used to develop monitoring wells. Air-lift pumping, in which the air stream is not released directly into the well but instead is confined within an eductor pipe (see Fig. 15), should not produce the deleterious effects of air surging, and can thus be used in conjunction with other development processes.

9. Report: Test Data Sheets/Forms

9.1 Keep records of the various operations performed during development and the progress and results of the development procedure. Report the following information: recorded:

9.1.1 Date of activities, companies and personnel involved;

9.1.2 Well identification, location coordinates;

9.1.3 Baseline turbidity (to be compared with turbidity levels obtained later in the life of the well);

9.1.4 Chemical quality, physical characteristics (that is, color, odor, etc.) volume, and sediment content of water added to the well or removed from the well;

9.1.5 Amount and particle size of sediment that accumulates in the well between phases of development;

9.1.6 Type(s) of equipment used during development;

9.1.7 Well construction details;

9.1.8 Static water level prior to, during, and after development;

9.1.9 Time spent during development; and

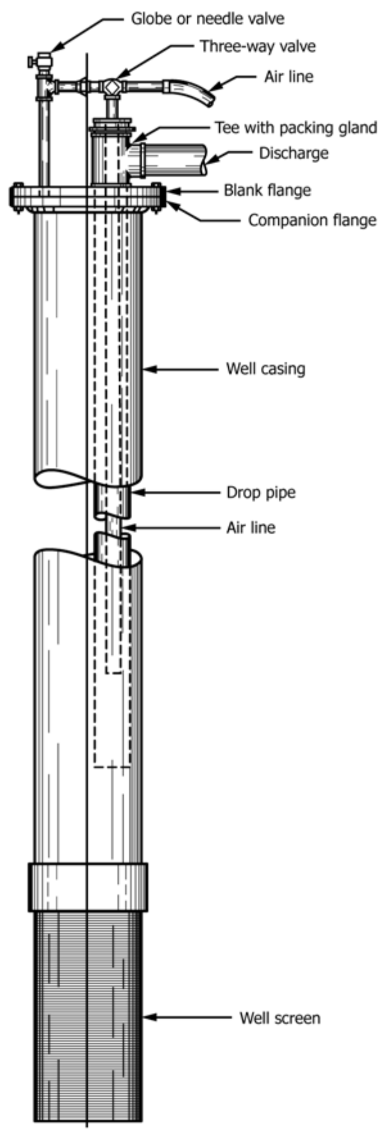


FIG. 15 A Typical Air-Lift Pumping Configuration

9.1.10 Other details pertinent to the development process and the objectives of development. A well development data form, such as that illustrated in Fig. 16, can be used for this purpose.

10. Keywords

10.1 aquifer; groundwater; high-velocity; hydraulic jetting; jetting; mechanical surging; monitoring well; over-pumping and backwashing; representative sample; well development

WELL DEVELOPMENT DATA

SITE TYPE	SITE ID
WELL	

DEPTH TO BOTTOM (INITIAL) ____________________

(FINAL) ____________________

STATIC WATER LEVEL (INITIAL) ____________________

(FINAL) ____________________

MEASURING POINT ____________________

CASING I.D. ____________________

RESPONSIBLE PROFESSIONAL ____________________

DRILLER ____________________

PROJECT NO. ____________________

DATE(S) INSTALLED ____________________

DATE(S) DEVELOPED ____________________

PUMP (TYPE) ____________________

(CAPACITY) ____________________

BAILER (TYPE) ____________________

(CAPACITY) ____________________

TIME	VOLUME OF WATER REMOVED	pH	SPECIFIC CONDUCTANCE AT 25°C	TEMP	SAND CONTENT	OTHER PHYSICAL CHARACTERISTICS (CLARITY, ODOR, PARTICULATES, COLOR)

FOPM 14 / SEPT 87

FIG. 16 Example of a Well Development Data Form

SUMMARY OF CHANGES

Committee D18 has identified the location of selected changes to this standard since the last issue (D5521 – 05) that may impact the use of this standard. (Approved Aug. 1, 2013.)

(1) Revised the standard into a dual measurement system with the units of measurement now stated in either SI units or inch-pound units.
(2) Revised Section 3 to conform to D18 policy.
(3) Added Note 1 and renumbered notes accordingly.
(4) Revised title of Section 9 to conform to D18 policy and added content.