Chapter 6
Well Development

6-1. General

Well development is the procedure that locally improves or restores the aquifer's hydraulic conductivity and removes well drilling fluids, muds, cuttings, mobile particulates, and entrapped gases from within and adjacent to a newly installed well. The resulting inflow should be physically and chemically representative of that portion of the aquifer adjacent to the screened interval. The appropriate development method/procedure to use will vary according to the hydrologic characteristics of the aquifer, the geologic composition of the screened interval, the drilling method, and the type of well completion. Of the various methods available for use in developing wells in general, mechanical surging, pumping, backwashing, and bailing are best suited. Additional guidance on the development of ground-water monitoring wells may be found in ASTM Standard Guide D 5521.

6-2. Timing and Record Submittal

The final development of monitoring wells should be initiated no sooner than 48 hours after or more than 7 days beyond the final grouting of the well. Predevelopment, or preliminary development may be initiated before this minimum 48 hour period. Preliminary development takes place after the screen, casing and filter pack have been installed, but before the annular seal is installed. Preliminary development is done in order to remove any mud cake that may be on the side of the borehole in a timely manner. Predevelopment is also recommended if the well is installed with the intent of using the natural formation material as the filter pack. 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. It is not good practice to wait and develop all the monitoring wells on a project after the last one is complete. The record of well development should be submitted to the FA.

6-3. Development Methods

A thorough discussion of monitoring well development methods can be found in ASTM Standard Guide D 5521.

a. Mechanical Surging. Operation of a piston-like device termed a surge block affixed to the end of a length of drill rod, or drill stem, is a very effective development method that can be effective in all diameter of wells, even in stratified formations having variable permeability. The up-and-down plunging action alternately forces water to flow into and out of the well, similar to a piston in a cylinder. The use of a surge block can agitate and mobilize particulates around the well screen. Periods of surging should be alternated with periods of water extraction from the well so that sediment, brought into the well, is removed. Surging should initially be gentle to assure that water can come into the well and that the surge block is not so tight as to damage the well pipe or screen. For short well screens (1.6 m (5 ft) or less) set in a homogeneous formation, the surge block does not have to be operated within the screen interval. However, if the screened interval includes materials of high and low permeabilities, the block may have to be operated gently within the screen.

b. Pumping. A commonly used development method consists of pumping a well at a higher rate than water will be extracted during purging or sampling events. This overpumping, however, is usually only successful in relatively non-stratified, clean-sand formations. By pumping the well at a higher rate than expected during sampling, the mobilized particulates may be removed, thereby providing a cleaner well for sampling. Overpumping should be supplemented with the use of a bottom discharge/filling bailer, (for sediment removal). During development, water should be removed throughout the entire water column in the well by periodically lowering and raising the pump intake. A disadvantage of only pumping the well is that the smaller soil grains of the filter pack may be bridged in the screen or in the filter pack, as the direction of flow is only towards the screen. To overcome this, overpumping is often used in conjunction with backwashing or surging.

c. Backwashing. Backwashing is the reversal of water flow in a well, causing soil particles to dislodge that may have become wedged in or bridged around the screen due to overpumping of the well. Backwashing when supplemented with overpumping, facilitates the removal of fine-grained materials from the formation surrounding the borehole. A commonly used backwashing procedure called “rawhiding” consists of starting and stopping the pump intermittently to allow the rising water in the well pipe to fall back into the well. This backwashing procedure produces rapid changes in the pressure head within the well. If rawhiding is to be used, there cannot be a backflow prevention valve in the pump or eductor line. Another method of backwashing is to pump water into the well in sufficient volume to maintain a head greater than that in the formation. This method of backwashing should only be done when the water pumped into the well is of known and acceptable chemistry. The impact of added water on in situ water quality should be evaluated and, this water should be removed by pumping after development is complete. This method of backwashing, not withstanding the quality of water pumped into the well, may not be allowed by local, state, or federal agencies. Do not use this method in cases where the water pumped into the well is potentially contaminated.

d. Bailing. The use of bailers is an effective way of manually developing small diameter wells that have a high static water table or are relatively shallow in depth (<4.5 m (15 ft)). As the diameter of the bailer is commonly close to the same diameter as the well screen, the bailer agitates the water in the well in much the same manner as a surge block, but to a lesser extent. It is good practice to surge the well using the bailer for 10 to 20 minutes prior to beginning bailing. To have its most effective surging action, the bailer should be operated throughout the screened interval. Bottom loading bailers can extract sediment that has settled to the bottom of the well by rapid short upward/down motions of the bailer at the bottom of the well which stir up the sediment and take it into the bailer. Pumps may be replaced by bottom filling bailers where well size or slow recharge rates restrict pump usage. Bailers should not be left inside the wells after development is completed. Such storage promotes accidental bailer release or loss down the well and inhibits convenient and accurate water-level measurements.

e. High-velocity hydraulic jetting. Another effective method available for use in developing some monitoring wells, is high-velocity hydraulic jetting. This method 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. The loosened material moves inside the well screen and can be removed from the well by concurrent pumping or by bailing. Because of the size of the equipment required, this method is more easily applied to wells of 100 mm (4 in.) or greater diameter. Jetting is particularly successful in developing highly stratified unconsolidated formations, consolidated bedrock wells, large-diameter wells, and natural formation wells. Jetting is generally simple to use, effectively rearranges and breaks down bridging in the filter pack, and effectively removes mud cakes around screen. The disadvantage of using jetting even in ideal conditions is the introduction of foreign water and possible contaminants into the aquifer. Jetting is not effective in cases where slotted pipe is used for the screen. Jetting is much more effective where continuous-wrap v-wire screens, having a greater open area, are used.

f. Special Concerns.

(1) Where monitoring well installations are made in formations that have low hydraulic conductivity, none of the preceeding well development methods may be found to be completely satisfactory. In this situation clean water can be circulated down the well casing, out through the well intake and gravel pack, and up the open borehole prior to placement of the grout or seal in the annulus. Relatively high water velocities can be maintained, and the mud cake from the borehole wall will be broken down effectively and removed. Flow rates should be controlled to prevent floating the gravel pack out of the borehole. Because of the relatively low hydraulic conductivity of geologic materials outside the well, a negligible amount of water will penetrate the formation being monitored. However, immediately following the procedure, the well sealant should be installed and the well pumped to remove as much of the water used in the development process as possible (Barcelona et al. 1985). Adding water to the well for flushing should only be done, however, when no better options are available. In some fine grained deposits vigorous development can be detrimental to the well. 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. Alternative sampling methods, such as lysimeters (ASTM D 4696), should be considered in low conductivity formations.

(2) Drilling methods. The drilling process influences not only development procedures but also the intensity with which these procedures must be applied. Typical problems associated with special drilling technologies that must be anticipated and overcome are: 1) When drilling an air rotary borehole in rock formations, fine particulate matter typically builds up on the borehole walls and plugs fissures, pore spaces, bedding planes and other permeable zones. The matter must be removed and the openings restored by the development process; 2) If casing has been driven or if augers have been used, the interface between the natural formation and the casing or the auger flights are “smeared” with fine particulate matter that must subsequently be removed in the development process; 3) If a mud rotary technique is used, a mud cake builds up on the borehole wall that must be removed during the development process; and 4) If there have been any additives, as may be necessary in mud rotary, cable tool or augering procedures, the

development process must attempt to remove all of the fluids that have infiltrated into the natural formation (EPA/600/4-89/034). A comparison of the advantages and disadvantages of various drilling methods is in Table 3-1.

6-4. Development Criteria

a. Development should proceed until the following criteria are met:

(1) Satisfaction of applicable federal, state, and local regulatory requirements. Some of these requirements may specify that development continue until the readings for some indicator parameters like pH, conductivity, temperature, oxidation-reduction potential (ORP), dissolved oxygen (DO), or turbidity have stabilized; e.g., vary within a specified range. Stabilization is commonly considered to have been achieved after all parameters have stabilized for three successive readings. Generally three successive readings should be within ±0.2 for pH, ±3% for conductivity, ±10 mV for oxidation-reduction potential (ORP), ±1 degree Celsius for temperature, and ±10% for turbidity and DO. In general the order of stabilization is pH, temperature, and conductivity, followed by ORP, DO and turbidity (Puls and Barcelona 1996).

(2) The well water is clear to the unaided eye and the turbidity of the water removed is at some specified level. Some regulators may require that the turbidity, as measured in nephlometric turbidity units (NTUs), be less than 5 NTUs. It should be noted that natural turbidity levels in ground water may exceed 10 NTUs. Turbidity is always the last indicator parameter to stabilize. There are instances where minimizing turbidity will result in a sample that is not representative of the water that is moving through the formation. If the ground water moving through the formation is, in fact, turbid, or if there is free product moving through the formation, then some criteria may cause a well to be constructed such that the actual contaminant that the well was installed to monitor will be filtered out of the water. Therefore, it is imperative that the design, construction and development of the monitoring well be consistent with the objective of obtaining a sample that is representative of conditions in the ground.

(3) The sediment thickness remaining within the well is less than 1 percent of the screen length or less than 30 mm (0.1 ft) for screens equal to or less than 3 m (10 ft) long.

(4) A minimum removal of three times the standing water volume in the well (to include the well screen and casing plus saturated annulus, assuming 30 percent annular porosity). **IN ADDITION** to the "three times the standing water volume" criteria, further volumetric removal should be considered as follows:

(a) For those wells where the boring was made without the use of drilling fluid (mud and/or water), but water was added to the well during well installation, then three times the amount of any water unrecovered from the well during installation should be removed (in addition to three times the standing volume).

(b) For those wells where the boring was made or enlarged (totally or partially) with the use of drilling fluid (mud and/or water), remove three times the measured (or estimated) amount of total fluids lost while drilling, plus three times that used for well installation (in addition to three times the standing volume).

(5) 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 (ASTM D 4050). An improvement in recovery rate of the well indicates that the localized reduction in hydraulic conductivity has been effectively rectified by development. A commonly used method for determining hydraulic conductivity is the instantaneous change in head, or slug test. The slug test method involves causing a sudden change in head in the well and measuring the water level response within the well. Head change can be induced by suddenly injecting or removing a known quantity or "slug" of water into the well. However, instead of injecting a "slug" of water, a solid or mechanical slug of known volume should be used. The mechanical slug may be constructed of a section of weighted pipe, of known volume, capped on both ends. Water level and elapsed-time data can be recorded with a data logger and pressure transducer. Both "rising heads" and "falling heads" are recorded. Guidance on conducting slug tests may be found in ASTM Standard D 4044.

b. Prior to placement of the seal, if the borehole contains an excessively thick, particulate-laden fluid which would hinder proper well installation, this fluid should be diluted and/or flushed with clean water and purged from the well. Water should not be added to a well as part of development once the initial bentonite seal atop the filter pack is placed. It is essential that any water added to the well is of known and acceptable chemistry. The impact of added water on in situ water quality should be evaluated and removed after development is complete.

c. The use of air to develop a well **SHOULD NOT** be allowed. The introduction of air into a well enhances the occurrence of chemical, physical, and biological changes to the local aquifer system monitored by the well. Furthermore, procedures involving compressed air at HTW sites increase potential exposure/health risks to site personnel from the volatilization and misting of the aerated water. If air development is deemed the most appropriate method for a site, the above factors should be evaluated and mitigation procedures documented in the drilling plan.

d. If any of the following circumstances occur, the FA should be contacted for guidance:

(1) Well recharge so slow that the required volume of water cannot be removed during 48 consecutive hours of development;

(2) Persistent water discoloration after the required volumetric development; and

(3) Excessive sediment remaining after the required volumteric removal.

6-5. Development-Sampling Break

Time should be allowed for equilibration of the well with the formation after development before sampling of the well is undertaken. Well development should be completed at least 14 days before well sampling. The intent of this hiatus is to provide time for the newly installed well and backfill materials to surficially equilibrate to their new environment and for that environment to re-stabilize after the disturbance of drilling. Though a significant volume of water may be pulled through the well during development, the well and granular backfill surfaces over which this water passes are not likely to be at chemical equilibrium with the aquifer. Intuitively, the hiatus allows time for that equilibrium to be created, thereby enhancing the probability of the resulting sample to be more representative of the local aquifer. The 14-day hiatus is a "rule-of-thumb," unsubstantiated by rigorous scientific analysis. If a different value is proposed based upon technical data or overall project considerations, such a change should be evaluated and, if deemed appropriate, implemented. Generally, high permeability formations require less time (e.g., several days) to equilibrate than low permeability formations (e.g., several weeks). The FSP should state the amount of time that will be required to permit the equilibration of the monitoring well following development and prior to sampling and the justification for selection of that time interval.

6-6. Development Water Sample

For each well, a 0.5 L (1-pint) sample of the last water to be removed during development should be placed in a clear glass jar and labeled with well number and date. No preservation of these samples is required. Each sample should be individually agitated and immediately photographed close-up by the FDO with a 35-mm camera and color print film, using a back-lit setup to show water clarity. These photos, minimally 125 mm x 175 mm (5 in. x 7 in.), individually identified with project name, well number, and photo date, should be provided to the FA after all wells are developed. The film negatives should be provided to the FA after the FA has received the prints. The FDO should dispose of these water samples in the same manner as the rest of the water removed during development.

6-7. Well Washing

Part of well development should include the washing of the entire well cap and the interior of the well casing above the water table using only water from that well. The result of this operation will be a well casing free of extraneous materials (grout, bentonite, sand, etc.) inside the well cap and blank casing, between the top of the well and the water table. This washing should be conducted before and/or during development, not after development.

6-8. Well Development Record

The following data should be recorded as part of development and submitted to the FA:

a. Project name, location.

b. Well designation, location.

c. Date(s) and time(s) of well installation.

d. Date(s) and time(s) of well development.

e. Static water level from top of well casing before and 24 hours after development.

f. Quantity of mud/water:

(1) Lost during drilling.

(2) Removed prior to well insertion.

(3) Lost during thick fluid displacement.

(4) Added during granular filter placement.

g. Quantity of fluid in well prior to development:

(1) Standing in well.

(2) Contained in saturated annulus (assume 30 percent porosity).

h. Field measurement of pH (ASTMs D1293 and D5464), conductivity (ASTM D1125), oxidation-reduction (redox) potential (ASTM D1498), dissolved oxygen (ASTMs D888 and D5462), turbidity (ASTM D1889), and temperature (EPA Method 170.1) before, twice during, and after development using an appropriate device and method. Field methods for these parameters can also be found in EPA 600/4-79/020, and Standard Methods.

i. Depth from top of well casing to bottom of well.

j. Screen length.

k. Depth from top of well casing to top of sediment inside well, before and after development (from actual measurements at time of development).

l. Physical character of removed water, to include changes during development in clarity, color, particulates, and any noted odor.

m. Type and size/capacity of pump and/or bailer used.

n. Description of surge technique, if used.

o. Height of well casing above ground surface (from actual measurement at time of development).

p. Typical pumping rate.

q. Estimated recharge rate.

r. Quantity of fluid/water removed and time for removal (present both incremental and total values).

6-9. Potential Difficulties

Many difficulties may arise during development and presample purging. Some are readily apparent but troublesome to resolve; e.g., a well that is easily pumped dry but slow to recharge or one that will not produce clear, particulate-free water. Other difficulties are not easily observed but may bias the analytical results, e.g., pulling-in distant parts of the aquifer in an effort to achieve a repetitively consistent field reading or aerating the aquifer adjacent to the well in a hurried attempt at well development. In addition, the unanticipated presence of dense (or light) nonaqueous phase liquids (NAPL) in the screened interval would affect the chemical homogeneity of that interval and hydrologic parameters derived from that well. The anticipation, evaluation, and tentative solution for these problems should begin early in the formulation of each drilling plan.