TECHNICAL GUIDANCE MANUAL FOR HYDROGEOLOGIC INVESTIGATIONS AND GROUND WATER MONITORING

CHAPTER 8

MONITORING WELL DEVELOPMENT,

MAINTENANCE, AND REDEVELOPMENT

February 2004

MAJOR CHANGES TO CHAPTER 8
MONITOR WELL DEVELOPMENT

1. Added a predevelopment section. This section suggests steps to take during well installation to make it easier to develop a well. This information will also be added to Chapter 7 (Monitoring Well Design and Installation).

2. Revised stabilization criteria for pH, specific conductance, and temperature. The previously it was indicated all parameters should be stabilized within 10%. This was incorrect. Each parameter should have it's own stability criteria. Also added turbidity (if not less than 10 NTUs) as a stabilization parameter.

3. Added more detail to the methods, such as starting development from the top of the screen and working downward.

4. Added a section on development documentation. Provided a sample well development form/table.

5. Expanded on well maintenance and redevelopment and made it a separate section.

6. Added a precaution about developing wells containing free product.

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CHAPTER 8

MONITORING WELL DEVELOPMENT, MAINTENANCE, AND REDEVELOPMENT

The goal of ground water sampling is to obtain a sample that represents the current ground water conditions. Well development, well maintenance, and re-development (as needed) are critical to any ground water sampling program. The well development procedure and maintenance of the well should be documented.

Due to the effects of installation, the ground water entering a monitoring well may not be representative of natural conditions with respect to yield, chemical characteristics, and amount of suspended particulate matter. To allow for the collection of representative samples, wells must be developed properly. Development involves stressing the formation so that a graded filter pack is created around the screen and particulate matter and fluids (when used) remaining from well drilling and construction are removed. Development restores hydraulic conditions and enhances yield of the saturated zone, stabilizes chemical changes that may have occurred during drilling and construction, and produces a well that is capable of yielding a sample of acceptably low turbidity (Panko and Barth, 1988; Aller et al., 1991, Izraeli et al., 1992).

Proper development creates a graded filter pack around the well screen. When pumping is first initiated, natural materials in a wide range of grain sizes are drawn into the well, producing very turbid water. As pumping continues, natural materials are drawn into the filter, producing an effective filter pack through a sorting process. This sorting process begins when the largest particles are retained by the filter pack, resulting in a layer of coarse particles against the screen. With continued pumping this process produces a progressively finer layer until an effective graded filter pack is produced (Izraeli, et al., 1992).

As indicated above, a key aspect of development is that it can reduce sample turbidity by removing fine particulate matter (clay and silt) from the filter pack and the geologic formation near the well intake, enhancing inflow to the well. Additionally, it can increase the life of wells by reducing or eliminating the potential for filling with fine particles or organic matter. Such "silting up" reduces yield and can result in anaerobic activity (NCASI, 1981). It is essential that filtration not be viewed as a substitute for proper development.

FACTORS AFFECTING DEVELOPMENT

Several factors may affect the performance and selection of a method or combination of methods for monitoring well development. These include, but may not be limited to, site hydrogeologic environment, well design, and the drilling method employed (Aller et al., 1991).

HYDROGEOLOGIC ENVIRONMENT

Ground water moves more easily through permeable, consolidated formations and "clean", coarse-grained sand and gravel; therefore, development may be accomplished quickly and easily. In contrast, flow through relatively impermeable silty or clayey material is slow or limited; consequently, the process can be difficult. Well development should be applied with great care to wells installed in predominantly fine-grained formations (e.g., silts and clays). Rigorous development techniques may actually increase the turbidity of the ground water.

The ease of development is usually less predictable for unconsolidated formations than for rock. In general, more difficulty may be encountered when materials are unconsolidated. If a borehole is not stable, even distribution of the filter pack around the screen may not be achieved, hindering development. (Aller et al., 1991). If materials are silt and clay, drilling may cause smearing along the borehole wall, which also causes problems. On the other hand, drilling causes minimal damage to homogeneous sand and gravel, and development is not affected (Hackett, 1987).

Different types of formations may be developed more effectively by using certain techniques. For example, a highly stratified, coarse-grained deposit is handled best by methods that concentrate energy on small parts of the formation. If the deposit is rather uniform, techniques that apply the same force over the entire length of the well screen can produce satisfactory results. Techniques that withdraw water quickly can reduce the hydraulic conductivity of formations containing a significant amount of silt and clay (Driscoll, 1986). Development of fine-grained materials generally should be accomplished by gentle action (Gass, 1989).

WELL DESIGN

Typical monitoring well design (e.g., small diameter, artificial filter pack, and limited screen open area) makes development difficult. Generally, wells should be designed to keep entrance velocities low enough to avoid degassing and/or alteration of water quality (Gass, 1986). The thickness of the pack has considerable effect on the procedure because it reduces the amount of energy imparted to the borehole wall. The pack should be as thin as possible if development is to be effective at removing fine particulates. Conversely, it should be thick enough to ensure adequate borehole support and good distribution of material around the screen. Generally, a minimum of two inches is sufficient.

Selection of the proper screen slot size and configuration is also essential for successful development. Slots are chosen to permit removal of fine material from the formation (see Chapter 7). Large slots may filter too much material and cause settlement and damage. Alternatively, it may not be possible to develop or sample properly if the slots are too small. According to Driscoll (1986), development works best when screens have both maximum open area and a slot configuration that permits the forces to be directed efficiently into the formation. In general, screens that are continuous slot, wire-wound facilitate easier development because they have the greatest open area (Gass, 1986). However, a study conducted by Paul et al. (1988) indicated that there is no difference in water turbidity obtained from wells finished with factory slot, factory slot with a filter wrap, or continuous, slotted screens.

Large diameter wells (i.e., four inches or larger) are much easier to develop due to equipment availability. However, the high cost of construction materials has resulted in the installation of smaller wells with machine-slotted screens (Gass, 1986).

DRILLING METHODS

The drilling process influences not only choice of development procedures, but also the intensity with which the procedures should be applied (Aller et al., 1991). All drilling methods impair the ability of a formation to transmit water to a borehole or well. Problems that can occur include: 1) the use of air rotary drilling to penetrate consolidated rock can cause fine particles to build up on the borehole walls and may plug fractures and pore spaces, 2) driving casing or using augers can cause smearing of fine-grained particulates between the casing/screen and the natural formation, 3) mud rotary can cause mudcakes to build up on the borehole wall, and 4) all drilling methods potentially can compact sediments. Development should rectify these problems to enhance yield and allow collection of representative samples.

If a drilling fluid of any type is utilized, ground water quality can be affected; consequently, use is discouraged. If a fluid is used, development should remove any that has infiltrated into the formation to allow in-situ ground water quality to return to pre-installation conditions.

PRESENCE OF NON-AQUEOUS PHASE LIQUIDS

Prior to development, the well should be checked for the presence of non-aqueous phase liquids (NAPL). If present, consideration should be given to the degree the well should be developed or even if the well should be developed. Care will need to be taken so that development does not spread the NAPL across the entire screened interval (through the entire sand pack and along the adjacent formation.)

OTHER FACTORS

Site accessibility and ***type and availability of equipment*** should be considered during the selection of an appropriate method or combination of methods. The need for ***proper disposal of contaminated discharge water*** also can drive selection. ***Time and cost*** may dictate selection; however, methods that minimize time and cost often prove to be inadequate. Cost/benefit analysis generally favors proper and complete development. If it is inadequate, time and cost for drilling, well installation, ground water sampling, and sample analysis may be wasted on data that is not representative.

DEVELOPMENT PROCEDURE

The general approach to development involves dislodging and removing fine-grained material and drilling fluids out of the ground water zone and into the well, and then from the well itself. This section describes development procedures, including predevelopment (measures taken during installation and construction), time and duration of development, and development methods.

PREDEVELOPMENT

Whenever possible, steps should be taken during well installation and construction to remove drilling cuttings and fluids prior to placement of the screen, filter pack, and annual seal. This may include removing water from the borehole prior to installation of the well screen and surging and removal of water after the sand pack has been installed, prior to installing the annular seal.

Typically, the water in the borehole is highly turbid and viscous from the drill cuttings. Removing this fluid prior to installing the screen and sand pack may make subsequent development efforts easier. An additional advantage to this technique is that the potential for "bridging" the sand pack during installation may be reduced because the viscosity of the water due to sediments in the boring is greatly reduced.

After the screen and sand pack are in place the well may be surged gently prior to installing the bentonite seal and grout (note that the augers/casing should be at the top of the sand pack during this process to prevent overlying material from falling into the sand pack). Surging at this time is advantageous in that it will be more effective in removing fines from the well and formation and grading and stabilizing the sand pack when the weight of the overlying grout is not present. Additional sand may need to be added to compensate for settling of the sand pack and ensure that sufficient separation exists between the annular seal and well intake. If surging is performed only after the well is completely installed (i.e., the grout is in place), there is a greater chance that the sand pack could settle and create a void between the sand pack and annular seal. If the annular seal sinks into the void space, the well could become contaminated with grout and may need to be replaced.

Mechanically surging the well using the drill rig is likely to be more effective and is much easier than trying to do it manually after the well is installed. Care should be taken not to place to large a force on the well that may cause it to collapse.

DEVELOPMENT CRITERIA

Development should not be implemented until the seal has cured and settled. Ideally, a time of 48 hours is required for neat cement and bentonite grout mixtures (Gaber and Fisher, 1988). However, the time required varies with site conditions and grout type.

The duration of development varies with the type of formation, screen length, height of the water column, thickness of filter pack, and method used. The most frequent mistake is to “give up” before the well has been adequately developed. Adequate development may take less than two hours to more than three days.

Development should proceed until the following criteria are met:

1) Water can enter as readily as hydraulic conditions allow.

2) A representative sample can be collected. In general, representative conditions can be assumed when the water is visually clear of sediments (e.g., turbidity $\leq$ 10 NTU) and pH, and specific conductance have stabilized over at least three successive well

volumes. Other criteria such as temperature, oxidation-reduction potential or dissolved oxygen may also be useful to determine whether a well can produce a representative sample. Stability criteria of water quality parameters listed in Table 8.1 can be used to determine when development objectives have been met. The duration, along with pH, temperature, specific conductivity measurements, and turbidity should be recorded on the well development record (See section on Development Documentation).

In some instances, collection of a sample with a turbidity of ≤ 10 NTU is difficult or unattainable. If a well does not provide a sediment-free sample, development can stop when all of the following conditions are met:

- Several procedures have been tried,
- Proper well construction has been verified,
- Turbidity has stabilized within ±10% over three successive well volumes, and
- Conductivity, and pH have stabilized over at least three successive well volumes. (It should be noted that pH, temperature, and conductivity may not stabilize if water quality has been degraded).

Table 8.1. Stabilization Criteria with References for Water-Quality Indicator Parameters (modified from Yeskis and Zavala, 2002).

Parameter	Stabilization Criteria	Reference
pH	±0.1	Puls and Barcelona, 1996 Wilde et al., 1998
specific electric conductance	± 3%	Puls and Barcelona, 1996
temperature	± 1° C	U.S. Army Corps of Engineers (1998)
turbidity	± 10% (when turbidity is greater than 10 NTUs)	Puls and Barcelona, 1996 Wilde et al., 1998
oxidation -reduction potential (ORP)	± 10 millivolts	Puls and Barcelona, 1996
dissolved oxygen (DO)	± 0.3 milligrams per liter	Wilde et al., 1998

3) The sediment thickness remaining in the well is less than 1 percent of the screen length or less than 0.1 feet for screens equal to or less than 10 feet.

4) A minimum of three times the standing water volume in the well (to include the well screen, casing, plus saturated annulus, assuming 30 percent annular porosity) should be removed. In addition to the “three times standing water volume” criteria, further volumetric removal should be considered if fluids were utilized during well drilling and installation.

METHODS

In general, methods to develop monitoring wells include pumping ,overpumping, surging, bailing, and backwashing. The most effective approach(s) generally is a combination of one or more methods that allow for water movement in both directions through the screen. A technique that allows for reversing the flow helps to minimize bridging in the formation and filter pack.

Other methods exist, such as airlifting, air surging, jetting with water or air, or adding chemicals. Although various chemicals, including acids, surfactants, chelating agents, wetting agents, disinfectants, and dry ice have been employed for water supply wells, their use for monitoring wells is generally not appropriate. The addition of air, water, or chemicals may affect sample analysis in unpredictable ways. Air forced into a formation can reduce its permeability (Kraemer et al., 1991) and can cause volatilization of organics, if present. Water should be added only on rare occasions (i.e., when an insufficient amount exists to provide enough energy to develop the wells adequately). If water is added, it should be chemically analyzed for potential impact on in-situ ground water quality.
Development should be applied cautiously to wells that are known or suspected to contain contaminants, particularly those that pose a hazard through inhalation or direct contact. Appropriate safety precautions should be taken to protect field personnel. Also, it should be noted that contaminated water and sediments removed during development may need to be drummed and disposed of properly.

The following provides a general description of methods commonly used. The advantages and disadvantages of each are summarized and procedures are provided.

Pumping and Overpumping

A widely accepted technique is to pump a well using an intake that is raised and lowered (without excessive surging) throughout the length of the screened interval (Puls and Powell, 1992). Utilizing pumps in which the pumping action creates gentle surging or pumps that can be fitted with a surge block may enhance development. Backwashing may also be combined with pumping to create a surging action.

The recommended approach is to begin pumping at the top of the screen with low pumping rates and incrementally work down the well screen. The process should then be repeated in reverse, from the bottom of the well to the top. When there is no improvement in turbidity, the well should be allowed to equilibrate and then the process should be repeated at higher pumping rates. Alternate pumping and equilibration cycles should continue until the water is free of sediments and no additional sediment accumulates in the bottom of the well. According to Keely and Boateng (1987), however, some settlement and further loosening of fines can occur after the first attempt. Accordingly, a final series of cycles may need to be conducted 24 hours later.

Monitoring well development should begin at low rates (e.g., 100 ml/min) and end at rates at least ten times the sampling rate; however, in most cases, higher rates will be needed. Overpumping at a rate that substantially exceeds water removal during purging and sampling increases influx of fine particles, thereby opening screen slots, pore spaces, and fractures. High rates may not be advisable when wells are in a pristine area and adjacent to a contaminant plume because of the potential to draw in contaminants. Other disadvantages of pumping and overpumping include bridging of particles against the screen and the need for proper disposal of contaminated water.

Development by pumping is most effective in coarse-grained, unconsolidated deposits and rock formations. However, it generally has limited application in highly conductive formations because it is difficult to pump monitoring wells at sufficient rates to create the high entrance velocities necessary for removal of fine particulates (Barcelona et al., 1985). The pumps utilized should be capable of pumping at low to high rates and be controlled by valving. Small diameter pumps that offer a wide range have recently been developed.

Monitoring wells can be developed by using either a centrifugal or submersible pump. A centrifugal pump may be effective for low-yielding wells; however, it can be utilized only if the depth to water is less than approximately 25 feet. The use of a submersible pump is not limited by water level, but is affected by well diameter, construction material of the impeller, and type and concentration of contaminants. According to Kraemer et al. (1991), the presence of fine-grained materials can clog or damage pumps with plastic impellers. The bladder of squeeze-type pumps also may be damaged by fines. It is recommended that a bailer be initially used to remove accumulated sediments. Prior to well development, the pumps should be decontaminated in a manner consistent with the procedures described in Chapter 6 for drilling and subsurface sampling equipment.

Surging

Surging involves pulling and pushing water into and out of a well intake by using a plunger or block. This process destroys bridging and can be effective for small diameter monitoring wells. A surge block is a device with a flexible gasket that is close in size to the well diameter (Figure 8.1). It is attached to a rod that is raised and lowered. Water is forced out of the intake on the downstroke, breaking up the bridged sediments and enabling water and sediments to flow back into the well on the upstroke. The surge block should fit with a minimum clearance of one-fourth inch (Barcelona et al., 1985). It should be of sufficient weight to overcome the inertia and drag of the cable reel and friction of the discs against the casing on the downstroke. Also, it should be of sufficient density to overcome the effects of buoyancy (Schalla and Landick, 1986).

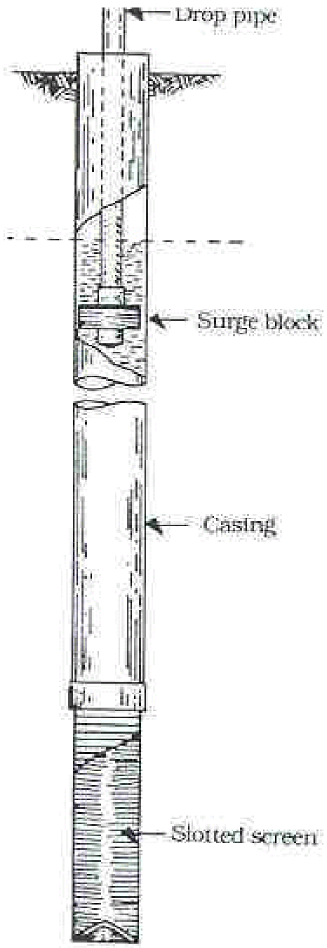

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Figure 8.1 Development with a surge block (Source: "Monitoring Well Development" by T.E. Gass. *Water Well Journal*, Vol. 40, No. 1, p. 53 (Figure 1). 1986. Reprinted from Water Well Journal with permission from National Ground Water Association. Copyright 1986).

Prior to surging, wells should be bailed or pumped to make sure that water will enter the well. If water does not enter the well, then surging should not be conducted. The negative pressure on the upstroke can cause the well to collapse.

For screen lengths of five feet or less, surging above the screen is effective for the entire screen length (Gass, 1986). For lengths greater than five feet, surging should be initiated above the screen and worked gradually downward at 2-3 feet intervals as water begins to easily move in and out of the well screen. To minimize damage, surging should start slowly and increase in force during the process. High differential pressures may cause collapse of the well screen or casing or may damage the filter pack (e.g., channels or voids may form near the screen if the pack sloughs away) (Keely and Boateng, 1987). A significant amount of fines can accumulate in the well during surging. These fines can be forced back into the formation and also make it impossible to remove the surge block. Therefore, it is necessary to withdraw the block at intervals and remove the sediment with a sand pump or bailer.

According to a study by Paul et al. (1988), surging of wells screened in fine-grained sediments should be avoided because it increases turbidity, does not improve hydraulic response significantly, and is unnecessarily costly. However, gentle surging action to agitate the sand pack may assist in improving the turbidity of low-yielding saturated zones.

Bailing

In some instances, a bailer with a check valve at the bottom may be an effective method of development (Lapham, et. al., 1997). The bailer is rapidly lowered down the well until it hits the water column. The impact of the bailer on the water surface will initially force water into the formation. The withdrawal of the bailer causes water to flow back into the well. A stainless steel bailer is recommended to have sufficient weight to create the surging action. A bailer can also be fitted with a flange to serve as a surging tool.

To properly develop the well, rapid motions along the entire length of the intake should be done to create an inward and outward thrust of water that breaks up bridges that may have formed adjacent to the well intake. To enhance the removal of particulates accumulated at the bottom of the well, rapid short strokes near the bottom can be used to agitate and suspend sediments, thus allowing them to be removed. Development by bailing should be limited to gentle action in low-yielding wells (Gass, 1989). If a well is de-watered, it should be allowed to recover and bailing should be resumed.

Development by bailing is very labor-intensive. Depending on the volume of water that must be removed, it may be useful to rig a tripod and pulley to aid in the lifting of the bailer from the well (Kraemer et al., 1991). As with surging, care should be taken not to cause collapse of the well casing or screen.

Air-lift Pumping and Air Surging

Other techniques commonly utilized are air lift pumping and air surging. These methods may induce and trap air in the formation outside the well intake and alter ground water quality. Furthermore, if ground water is highly contaminated, the methods can expose field personnel to hazardous materials. Use is not recommended unless the technique does not introduce air into the well screen and it can be demonstrated that the quality of water to be sampled will not be affected. Air from the compressor should be filtered to insure that oil is not introduced into the well (Barcelona et al., 1985). Generally, air techniques may be effective at removing debris, but cause very little positive effect beyond the well screen (Gass, 1986).

One method that does not introduce air is ***two pipe air-lift pumping*** (Figure 8.2). Air is injected through the inner pipe at high pressure to bubble out into the surrounding outer pipe. The bubbles reduce the unit weight of the water, causing the column of water and sediments to be lifted upward, allowing ground water from the formation to flow into the well (Gass, 1986).

To avoid injecting air into the screened interval, Aller et al. (1991) recommended that the bottom of the pipe be no more than ten feet from the top of the screen. Scalf et al. (1981) indicated that the use of air is restricted by the submergence factor, which equals the height of water in feet above the bottom of the pipe while pumping (blowing water out) divided by the total length of the pipe. The submergence factor should be on the order of at least twenty percent. This may be difficult to achieve with many shallow wells.

Development by ***air surging*** involves applying air intermittently to allow water to fall back down the casing and create a backwashing or surging action to break up any bridging (Keely and Boateng, 1987). This method is not recommended because it causes mixing of aerated water with the water in the well (Aller et al., 1991). Schalla and Landick (1986) have developed an air-vented surge plunger for developing small-diameter wells that does not introduce air into the formation unless the unit is lowered into the screened interval.

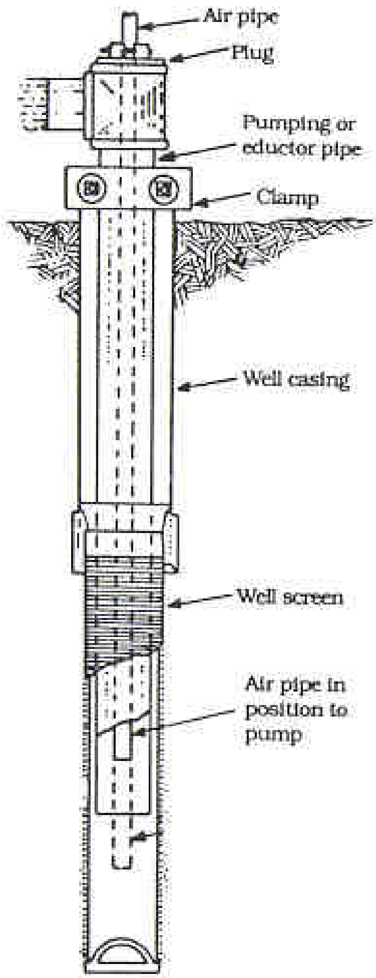

Figure 8.2: Two pipe air-lift system (Source: "Monitoring Well Development" by T.E. Gass. *Water Well Journal*, Vol. 40, No. 1, p. 54 (Figure 4). 1986. Reprinted from Water Well Journal with Permission from National Ground Water Association. Copyright 1986).

Backwashing

Backwashing or rawhiding (Gass, 1986) involves allowing water that is pumped to the top of a well to flow back through the pump and out through the well intake. Backwashing breaks up the bridged particles, allowing them to be pumped and removed; however, it may not be forceful enough to obtain favorable results. The method may only develop materials opposite the upper part of the intake or preferentially develop the most permeable zones in stratified deposits. Also, it may allow potentially contaminated water to enter uncontaminated zones. Thus, the technique may not be appropriate for areas of known or suspected contamination.

Inertial Lift Pump

Inertial lift pumps are constructed of a ball valve at the end of a flexible tube that runs to the surface. The sampler is lowered to the bottom of the well and the ball valve opens, allowing water to enter the tube. As well development begins, the water column in the tubing is equal to that in the well. The tube is then lifted and dropped in a continuous up-and-down motion. As the tube is lifted, the water column is lifted in the tubing a distance equal to the stroke length. Lowering the tube allows the check valve to open, allowing water to enter the tubing. The ball valve seats on the upstroke, capturing the water that has entered the tubing. This cycle continues with each up and down movement until water moves up and out of the tubing.

Inertial lift pumps are inexpensive, fairly portable, and easy to operate. They are particularly useful for development of small diameter wells (<2" ID), since the tubing is available in sizes small enough to fit in small diameter wells. Use of an inertial lift pump that is close in size to the inner diameter of the well can crate a surging action in the well, while the pump simultaneously purges the well, removing the fines that are loosened by the surging action. A potential drawback to inertial lift pumps is that in fine grained formations over surging of the well can cause the well screen to become clogged with fines. Inertial lift pumps may be ineffective in removing large volumes of water and are not effective development tools for wells larger than 2 inches ID (ASTM D 6725).

WELL DEVELOPMENT DOCUMENTATION

Well development documentation is important to show that representative samples can be obtained. Development method(s), time spent on development, volume of water removed, depth of the well, depth to top of the screen, diameter of the well, visual appearance (clarity), turbidity, pH, and specific electrical conductance of discharge water at various intervals should be recorded on a form or log (Lapham, et. al., 1997). Figure 8.3 provides an example of a well development record.

Information on recovery rates and estimated yield should also be documented. This information may be helpful in planning for sampling events and in sampling techniques.

Figure 8.1 EXAMPLE RECORD OF WELL DEVELOPMENT

Site Name:	**Initial Well Depth:**	**Final Well Depth:**
Well ID:	**Well Diameter:**	**Screen Length:**
Developers:	**Static Water Level:**	**Total Purged Volume:**
Start Date: **End Date:**	**Weather Conditions:**	
General Comments (e.g., presence of NAPLS):	**General Development Method(s):**	

Date	Time	Method	Pumping Rate (gal/min)	Volume Purged (gal)	Temp. (°C)	Spec. Cond. (µS/cm)	pH	Turbidity (NTU)	Other ______	Comments (e.g., clarity of water and success of development)

Field Parameter and Stability Guidance: pH (±0.1 standard units); Temperature (±1 °C); specific conductance (±3%, µS/cm); turbidity (10% when turbidity is ≤10 NTU); dissolved oxygen (± 0.3 mg/L); oxidation-reduction potential (± 3%)

NTU- nephelometric unit, µS/cm- microsiemens per centimeter

Ohio EPA

WELL MAINTENANCE CHECKS AND REDEVELOPMENT

During the course of their active lives, monitoring wells should be checked to confirm that the well is still intact and fine particles have not accumulated. Unlike water supply wells, monitoring wells remain predominantly unpumped. There is no continuous removal of fines over an extended period. According to Kraemer et al. (1991), no matter how complete development appears to be, there is a high probability (especially for wells completed in fine-grained formations) that introduction of pumps or bailers will create a surge rendering the water somewhat turbid. In addition to sediments accumulating in the well, the casing and screen can become corroded or plugged by chemical or bio-chemical precipitates, and thus cause a loss of hydraulic connection. Metal well casings are subject to degradation over time from exposure to corrosive ground waters (pH of less than 6.0). Polyvinyl chloride (PVC) casing can dissolve in the presence of PVC solvent or if a pure organic product reaches the well in high concentrations from chemical spills or leaking storage tanks. A deteriorating well structure or a well that is “silting up” can cause a bias to the data that might be difficult to detect or might even be interpreted as trends in ground water quality. To provide a representative sample, these wells should be restored. Restoration typically involves redevelopment.

It is recommended that performance be evaluated during the life of a well. This may include, but not be limited to, noting a significant drop in yield during purging, noting increased turbidity, measuring total well depth to determine if sediments have been deposited, and using a camera to determine if incrustation of the screen or damage to the well casing has occurred. Comparison of water-level fluctuations over time in the well can indicate a possible change in hydraulic connection of the well to the aquifer. For example, a long-term decline in the water level in a well could indicate gradual plugging of the well screen. Slug tests or injection, pressure, or partial-vacuum tests can also be conducted as part of the continual evaluation of the well (Stallman, 1971; Lohman, 1972; U.S. Geological Survey, 1980; Driscoll, 1986; Bedinger and Reed,1988). These tests help evaluate whether there is still good hydraulic connection between the well screen and the ground water zone.

Well maintenance records should be kept including, but not limited to, periodic checks on depths; trends in yield changes and turbidity; the external physical condition of the well, its protective casing, the surface seal; and other criteria utilized to monitor the integrity of the well. At minimum, wells should be redeveloped when 20% of the well screen is occluded by sediments (U.S. EPA, 1988), or records indicate a change in yield and turbidly.

REFERENCES

Aller, L., T. W. Bennett, G. Hackett, R. J. Petty, J. H. Lehr, H. Sedoris, D.M. Nielsen, and J. E. Denne. 1991. Handbook of Suggested Practices for the Design and Installation of Ground Water Monitoring Wells. Environmental Monitoring Systems Laboratory, Office of Research and Development, U.S. Environmental Protection Agency. Las Vegas, Nevada. EPA/600/4-89/034. (In cooperation with the National Water Well Association, Dublin, Ohio).

American Society for Testing Materials (ASTM), Designation D 5092-90. 1994. Standard Practice for Design and Installation of Ground Water Monitoring Wells in Aquifers. American Society for Testing Materials. West Conshohocken, Pennsylvania.

ASTM Designation D 6723-01. Standard Practice for Direct Push Installation of Prepacked Screen Monitoring Wells in Unconsolidated Aquifers. American Society for Testing Materials. West Conshohocken, Pennsylvania .

Barcelona, M. J., J. P. Gibb, J. A. Helfrich, and E. E. Garske. 1985. Practical Guide for Ground-Water Sampling. Illinois State Water Survey, ISWS Contract Report 374. Champaign, Illinois.

Driscoll, F. G. (editor). 1986. Groundwater and Wells. Second Edition. Johnson Division. St. Paul, Minnesota.

Gaber, M. S. and B. O. Fisher. 1988. Michigan Water Well Grouting Manual. Division of Water Supply, Bureau of Environmental and Occupational Health, Michigan Department of Health. Lansing, Michigan.

Gaber, M. S. and B. O. Fisher. 1988. Michigan Water Well Grouting Manual. Division of Water Supply, Bureau of Environmental and Occupational Health, Michigan Department of Health. Lansing, Michigan.

Gass, T. E. 1986. Monitoring Well Development. Water Well Journal. Vol. 40, No. 1, pp. 52-55.

Gass, T. E. 1989. Monitoring Wells in Non-Aquifer Formations. Water Well Journal. Vol. 43, No. 2, pp.27-28.

Hackett, G. 1987. Drilling and Constructing Monitoring Wells with Hollow-Stem Augers. Part 1: Drilling Considerations. Ground Water Monitoring Review. Vol. 7, No. 4, pp. 51-62.

Izraeli, R., D. Yeskis, M. Collins, K. Davies, B. Zavala. 1992. Monitoring Well Development Guidelines for Superfund Project Managers. Ground Water Forum. United States Environmental Protection Agency. Office of Solid Waste and Emergency Response.

Keely, J. F., and K. Boateng. 1987. Monitoring Well Installation, Purging, and Sampling Techniques-Part 1: Conceptualizations. Ground Water. Vol. 25, No. 3, pp. 300-313.

Kraemer, C. A., J. A. Shultz and J. W. Ashley. 1991. Monitoring Well Post-Installation Considerations. In: D. M. Nielsen (editor), Practical Handbook of Ground-Water Monitoring. Lewis Publishers, Inc. Chelsea, Michigan. pp. 334-342.

Lapham, W.W., F.D. Wilde, M.T. Koterba. 1997. Guidelines and Standard Procedures for Studies of Ground-Water Quality. Selection and Installation of Wells and Supporting Documentation. U.S. Geological Survey, Water Resource Investigation Report 96-4233. 110p.

National Council of the Paper Industry for Air and Stream Improvement (NCASI). 1981. Ground Water Quality Monitoring Well Construction and Placement. Technical Bulletin 342. New York, New York. pp. 26-29.

Paul, D.G., C.D. Palmer and D.S. Cherkauer. 1988. The Effect of Construction, Installation, and Development on the Turbidity of Water in Monitoring Wells in Fine-Grained Glacial Till. Ground Water Monitoring Review. Vol. 8, No. 1, pp. 73-82.

Panko, A. W. and P. Barth. 1988. Chemical Stability Prior to Ground-Water Sampling: A Review of Current Well Purging Methods. In: A. J Collins and A. I. Johnson (editors), Ground-Water Contamination Field Methods. ASTM Publications. Baltimore, Maryland. pp. 232-239.

Puls, R. W. and M.J. Barcelona. 1996. Ground Water Issue Paper: Low-Flow (Minimal Drawdown) Ground Water Sampling Procedures; U.S. Environmental Protection Agency, EPA/540/S-95/504. 12pp.

Puls, R. W. and R. M. Powell. 1992. Acquisition of Representative Ground Water Quality Samples for Metals. Ground Water Monitoring Review. Vol. 12, No. 3, pp. 167-176.

Scalf, M. R., J. F. McNabb, W. J. Dunlap, R. Crosby and J. Fryberger. 1981. Manual of Ground Water Sampling Procedures. National Water Well Association. Worthington, Ohio. (Part of a NWWA/US.EPA

Schalla, R. and R. W. Landick. 1986. A New Valved and Air-Vented Surge Plunger for Developing Small- Diameter Monitoring Wells. Ground Water Monitoring Review. Vol. 6, No. 2, pp. 77-80.

U.S. Army Corps of Engineers. 1998. Monitoring Well Design, Installation, and Documentation at Hazardous, Toxic, and Radioactive Waste Sites. Department of the Army. U.S. Army Corps of Engineers. EM 1110-1-4000. Washington, D.C.

U.S. EPA. 1988. Operation and Maintenance Inspection Guide. Office of Waste Program Enforcement.

Wilde, F.D., D.B. Radtke, J. Gibs and R.T. Iwatsubo, eds. 1998. National Field Manual for the Collection of Water-Quality Data. U.S. Geological Survey Techniques of Water -Resources Investigations, Book 9, Handbooks for Water-Resources Investigations, variously paginated

Yeskis, D. and B. Zavala. 2002. Ground-Water Sampling Guidelines for Superfund and RCRA Project Managers. Ground Water Forum Issue Paper. United States Environmental Protection Agency, Office of Solid Waste and Emergency Response. EPA 542-S-02-001.