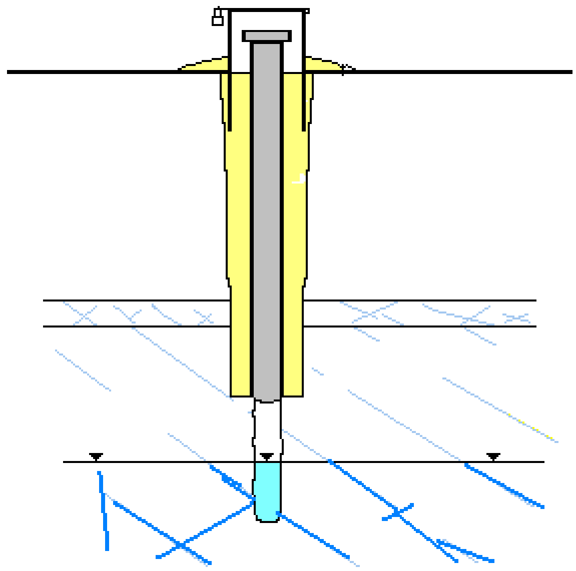

# GROUNDWATER MONITORING GUIDANCE MANUAL

Commonwealth of Pennsylvania

Department of Environmental Protection

December 1, 2001

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**DEPARTMENT OF ENVIRONMENTAL PROTECTION**
**BUREAU OF WATERSHED MANAGEMENT**

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**TITLE:** Groundwater Monitoring Guidance Manual

**AUTHORITY:** Federal Clean Water Act, Pennsylvania Clean Streams Law, Act of 1937 P.L. 1987 No. 394, as amended

**POLICY:** This guidance defines the general principles and practices for monitoring groundwater quality in Pennsylvania.

**PURPOSE:** This manual has been prepared as a guide for DEP hydrogeologists, groundwater consultants, and private industry for implementing a comprehensive monitoring program consistent with the established principles and objectives for protection of the Commonwealth's groundwater resources.

**APPLICABILITY:** This guidance applies to all local, state and federal agencies and programs with groundwater quality monitoring responsibilities.

**DISCLAIMER:** The policies and procedures outlined in this guidance document are intended to supplement existing requirements. Nothing in the policies or procedures shall affect regulatory requirements.

The policies and procedures herein are not an adjudication or a regulation. There is no intent on the part of the Department to give these rules that weight or deference. This document establishes the framework within which DEP will exercise its administrative discretion in the future. DEP reserves the discretion to deviate from this policy statement if circumstances warrant.

**PAGE LENGTH:** 84 pages

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**FIGURES:**



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## INTRODUCTION

Pennsylvania's groundwater is a critical resource that provides environmental benefits and contributes to the well-being of the citizens and the economic growth of the Commonwealth. Groundwater supplies the drinking water needs of nearly 50 percent of the population in the state; in rural areas it represents the only practical source of water for domestic uses. High quality groundwater is important to industry for various commercial and manufacturing processes and to agriculture for irrigation and livestock watering. Additionally, groundwater is critical to the protection of Pennsylvania's surface streams since it provides the sustaining baseflow to the Commonwealth's thousands of miles of surface waters.

Adequate protection of Pennsylvania's groundwater requires periodic monitoring of groundwater quality. This document is intended to provide guidance on implementation of a comprehensive statewide monitoring program consistent with the established principles and objectives for protection and remediation of the Commonwealth's groundwater resources.

Many state regulatory programs, such as the Land Recycling and Environmental Remediation Standards Program, have specific monitoring requirements that have been established by statute, regulation, or policy. This guidance manual does not supersede any of those requirements.

# CHAPTER 1: OVERVIEW

## 1.1 INTRODUCTION

Monitoring of groundwater is an important component in many permit programs and in the application of Act 2 of 1995, the Land Recycling and Environmental Remediation Standards Act (Act 2) to abate unauthorized releases of contamination into groundwater.

The need for and level of monitoring depends upon a number of factors, including:

- the type of permitted facility requiring groundwater monitoring
- complexity of local hydrogeologic conditions
- whether or not the activity is in an aquifer (defined as a geologic formation, group of formations or part of a formation capable of a sustainable yield of significant amount of water to a well or spring).

The five basic types of monitoring are:

1) Ambient monitoring (relating to determination of background conditions under certain permit requirements and to Act 2 Background Standard)
2) Compliance monitoring (relating to determinations of unauthorized releases in various permit programs)
3) Assessment monitoring (relating to documentation of groundwater pollution or compliance monitoring results which indicate potential groundwater pollution from a permitted facility)
4) Remediation monitoring (relating to determination of effectiveness of groundwater clean-up activities and attainment of remediation goals under Act 2)
5) Post-closure monitoring (relating to determination of levels of contaminants at time of cessation of certain permitted activities generally related to solid waste management facilities)

All monitoring activities should incorporate quality control and quality assurance provisions consistent with existing program regulations and policies (see Chapter 8).

## 1.2 AMBIENT MONITORING

Ambient monitoring is a relatively short term activity which is conducted to establish background water quality conditions. The goal is to account for both natural variation and any man-made impacts that may have influenced groundwater quality. These results will form a basis against which future monitoring results will be compared to established background values for specific substances of concern, develop groundwater quality trend analyses, or determine permit compliance or remediation effectiveness under Act 2 when the Background Standard is selected.

## 1.3 COMPLIANCE MONITORING

When a regulated activity is authorized or permitted, certain activities may require compliance monitoring to determine if groundwater has been impacted by an unauthorized release.

Compliance monitoring is usually conducted at regularly established intervals during and following a permitted activity. Compliance monitoring is usually achieved through a combination of effluent, surface water and/or groundwater sampling.

## 1.4 ASSESSMENT MONITORING

If compliance monitoring results indicate an unauthorized release into groundwater, assessment monitoring is usually initiated to determine if the permitted facility actually is the cause of the groundwater impact prior to beginning any remediation operations under Act 2. In some cases the assessment monitoring may lead to a determination that sampling and/or analytical anomalies exist.

## 1.5 REMEDIATION MONITORING

Groundwater remediation may need to be initiated when an unauthorized release has been documented through assessment monitoring. Remediation monitoring is implemented concurrently with groundwater cleanup operations to determine the effectiveness of these clean-up activities and attainment of remediation goals. All groundwater remediation should be conducted in accordance with the provisions of Act 2 and associated regulations and guidances.

## 1.6 POST-CLOSURE MONITORING

In some situations, post-closure monitoring may be required for permitted activities. Post-closure monitoring is conducted to determine any changes in groundwater quality after the cessation of a regulated activity. Analytes to be included are those which were monitored during compliance and/or remediation monitoring. Remediations conducted under Act 2 do not require monitoring after approval of the final report.

Additional discussions on analytes to be monitored and the duration of monitoring periods for these five monitoring categories can be found in Chapter 4.

# CHAPTER 2: MONITORING WELL TYPES AND CONSTRUCTION

## 2.1 OBJECTIVES OF MONITORING WELLS

Monitoring wells should be located and constructed to provide the controlled access necessary to characterize the groundwater system. They must be constructed by a driller who is licensed by the Commonwealth of Pennsylvania. (Drillers do not need to be licensed to install lysimeters, temporary well points or in situ sampling probes, or for borings used to measure the relationship of the water table to the subsurface portion of the proposed structures.)

Monitoring wells should effectively achieve one or more of the following objectives:

1) Provide access to the groundwater system for collection of water samples
2) Measure the hydraulic head at a specific location in the groundwater flow system
3) Provide access for conducting tests or collecting information necessary to characterize the aquifer materials or their hydrologic properties

While achieving these objectives, the monitoring system should also preserve the conditions of the subsurface that is penetrated but not monitored. For example, a well designed to monitor a bedrock aquifer should be designed and installed with minimal impact to the flow system in the unconsolidated material overlying the bedrock.

## 2.2 TYPES OF MONITORING SYSTEMS

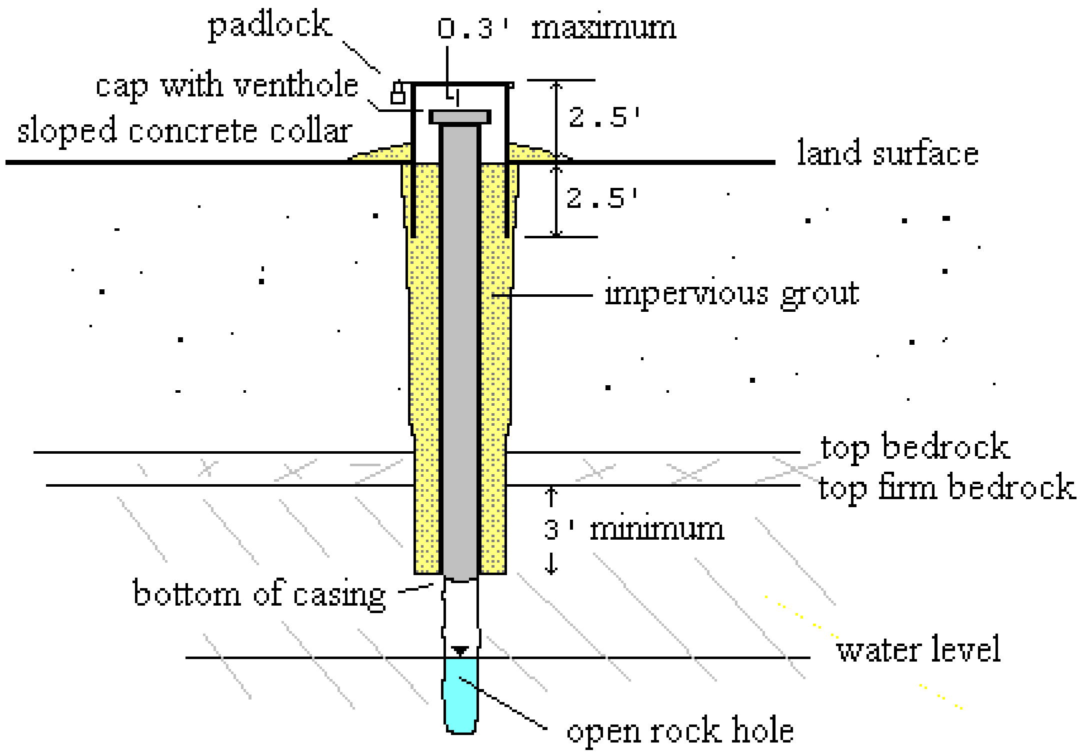
Monitoring systems range from the simple to the complex. Each system has its own place in the monitoring environment. Various types of monitoring systems are described below. For more detailed descriptions of groundwater sampling devices and installations, see U.S. EPA (1993) and Nielsen (1992). General recommendations for the construction of single screened wells and open boreholes are shown in Figures 1 and 2. Site specific circumstances may require modifications to the recommended construction details.

<u>Open boreholes</u> - These are holes that are typically drilled into bedrock and left to monitor groundwater. The overburden (unconsolidated material) is cased off. Recommended installation details are shown in Figure 1.

<u>Single screened wells</u> - These wells consist of a prefabricated screen of polyvinylchloride plastic, stainless steel, etc. that is inserted into an open borehole. Clean sand or gravel is placed around the annular space of the screen for the entire vertical distance of the screen length. Recommended installation details are shown in Figure 2.

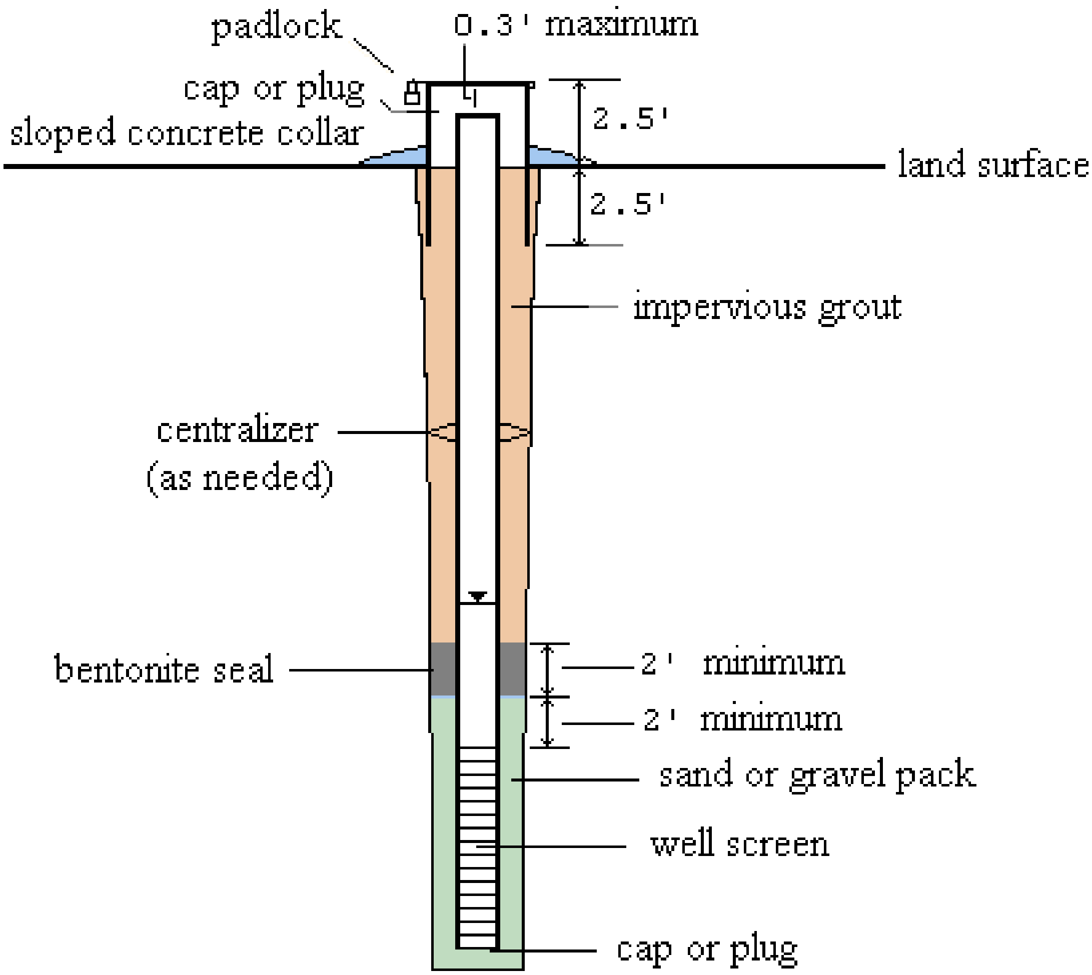
<u>Well clusters</u> - Well clusters or a well nest consist of the construction of open boreholes or screened monitoring wells in one particular location, with each well monitoring a different depth or zone of groundwater. An example of a well cluster is shown in Figure 3.

**Figure 1. Recommended construction of an open borehole well.**




Multiple screened wells - Wells that isolate specific zones of groundwater for sampling within one oversized borehole are called multiple screened wells. Each zone is effectively isolated so that only the desired interval can be accessed for monitoring. An example of a multiple screened well is illustrated in Figure 3. When constructing multiple screened wells, note that the integrity of the grout seal is of extreme importance and should be preserved at all times. Improper and careless construction practices may ultimately create hydraulic communication between each screened interval rendering each monitoring well unsuitable for monitoring purposes. Because of the difficulty in constructing a properly sealed well of this type, multiple screened wells should only be used in uncontaminated areas.

**Figure 2. Recommended construction of a single screened well.**

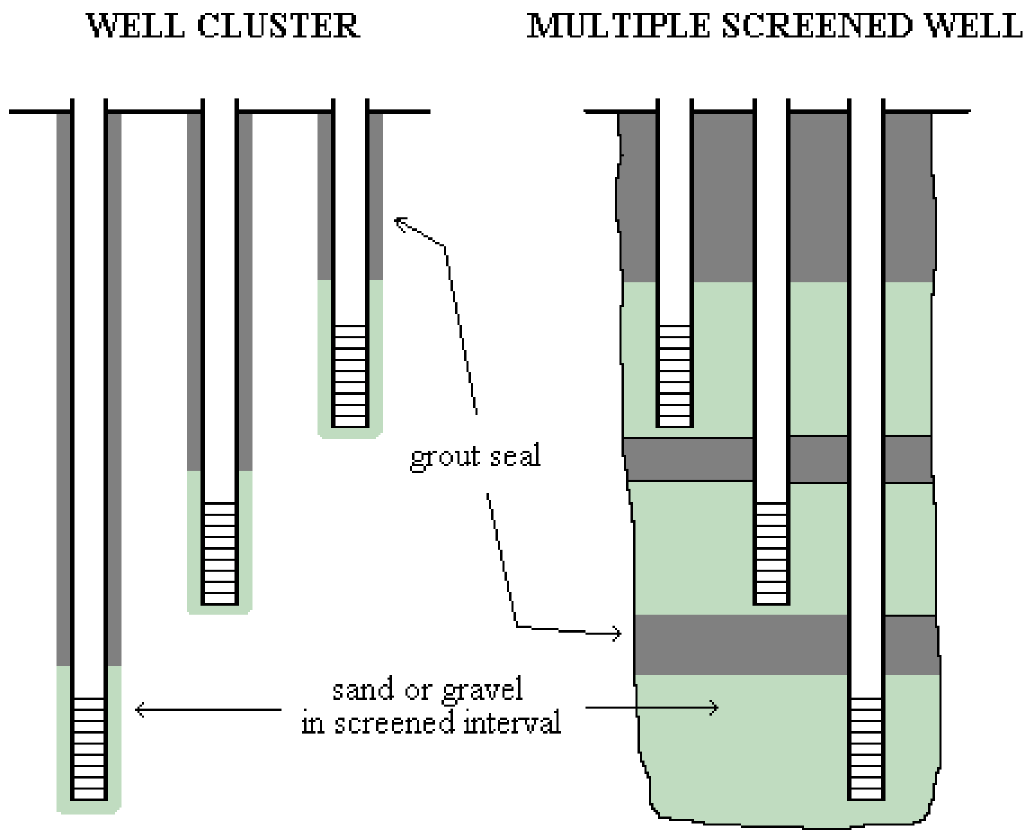



Well points - Well points are usually short lengths (i.e. 1-3 feet) of screen attached to a hardened metal point so that the entire unit can be driven, pushed, or drilled to the desired depth for monitoring. (This method is usually limited to shallow, unconsolidated formations.)

Piezometers - These are small diameter wells, generally non-pumping, with a very short well screen or section of slotted pipe at the end that is used to measure the hydraulic head at a certain point below the water table or other potentiometric surface.

Lysimeters - A lysimeter is an example of a device used to collect soil moisture that passes through the vadose zone. Lysimeters typically consist of a porous ceramic cup or caisson (where water is collected), a sand pack, and collection tubes and vacuum lines. To collect a sample, a vacuum is drawn on the lysimeter, causing moisture to be pulled into the caisson. The vacuum lines convey the water to the surface for collection.

**Figure 3. Example of a well cluster and a multiple screened well.**




### 2.3 CHOICE OF MONITORING SYSTEM

The type of monitoring system chosen depends on the objectives of monitoring at the site. In ambient and compliance monitoring, the monitoring system should offer widespread opportunity for detection of contamination from the site, while minimizing monitoring costs in terms of the number of wells to be drilled and the number of samples to be collected. Once the target zones, or areal locations and depths that are the most likely to be impacted by the facility are defined, ambient and compliance monitoring (prior to the detection of any contamination from a site) is often accomplished adequately by using open rock boreholes or single screened wells that monitor the entire saturated thickness or a large portion of the target zone.

Where contamination has been detected and definition of vertical contaminant stratification is desired, wells that monitor more discrete intervals of the target zone or individual aquifers usually need to be constructed. In this case, well clusters such as shown in Figure 3 will often be the construction of choice, although open holes that monitor a short vertical interval or single water bearing zone also may find application. As the flow beneath the site is better understood, the monitoring system typically will target more specific depths and locations. This is more likely to occur as a site enters assessment, remediation or post-closure monitoring. Then discrete zone monitoring may be most appropriate. Post-closure monitoring can be simple detection or compliance monitoring using the existing compliance system, if the site has caused no problems up to closure.

Well points or in situ sampling probes (such as the trade name Hydropunch) can be valuable reconnaissance tools for preliminary site characterizations or for determining the locations of permanent monitoring wells (see EPA, 1993). However, in situ sampling probes can miss a light non-aqueous phase liquid (LNAPL) on the water table, and may have problems penetrating coarse sands and gravel (where contamination may be located). Other potential problems include very slow fill times in clayey sediments and significant capture of fines in the sample.

Lysimeters may be a useful early warning tool. Because the unsaturated zone beneath an impoundment or a land application (of sludge) site represents a buffer zone between potential contamination and underlying aquifers, monitoring may provide for early detection of migrating contaminants such as a landfill leachate. However, lysimeters are not a substitute for groundwater monitoring wells.

Special well construction will be needed to monitor for certain types of contaminants. For example, if an LNAPL is a concern, the well screen should be open to the top of the water table and within the zone of fluctuation, so that the LNAPL contaminants will not be cased off.

## 2.4 MINIMUM CONSTRUCTION STANDARDS

To properly meet the objectives listed in Section 2.1, monitoring wells should be designed and constructed using minimum standards in each of the following categories.

1) Materials
2) Assembly and installation
3) Well development
4) Record keeping and reporting

Different standards and practices may be necessary depending upon the monitoring objectives of an individual site. Monitoring wells constructed to meet multiple objectives should employ the standards of the most rigorous objective. For instance, a well point may be suitable for monitoring hydraulic head, but may not be optimum for collecting samples. Therefore, a well proposed to monitor head and collect water samples should be designed as a conventional screened well and not as a well point. In addition, construction methods, materials, and well development of each point in the plan must not compromise the objective of other downgradient monitoring wells.

### 2.4.1 Materials

Materials that are used in construction of a monitoring well should not contaminate the groundwater being monitored. A list of materials should include, but not be limited to the drilling tools and equipment, casing, riser pipe, well screen, centralizers, annular sealant, filter pack, and drilling fluids or additives. All materials should be of adequate size and of competent strength to meet the objectives of the monitoring point. All materials introduced into the boring should be free of chemicals or other contaminants that could compromise the monitoring well or other downgradient wells. Practices must be employed to minimize the potential for contamination of the materials during storage, assembly, and installation. Specific cleaning procedures should be employed in situations where the materials might introduce contaminants to the groundwater system. Well screens and risers should be coupled using either water-tight flushjoint threads or thermal welds. Solvent welded couplings are not recommended for monitoring well construction.

### 2.4.2 Assembly and Installation

Equipment and techniques should be used that create a stable, open, vertical borehole of large enough diameter to insure that the monitoring well can be installed as designed while minimizing the impact on the zone(s) being monitored. When material removed during construction will likely be contaminated, procedures commensurate with the type and level of contamination should be followed for the handling, storage, and disposal of the contaminated material. Whenever feasible, drilling procedures that do not introduce water or other liquids into the borehole should be utilized. When the use of drilling fluids is unavoidable, the fluid should have as little impact on the constituents of interest as possible. If air or other gas is used as the drilling fluid, the compressor should be equipped with an oil air filter or an oil trap.

The well screen and riser assembly should be installed using procedures that insure the integrity of the assembly. If water or other ballast is used, it should be of known and compatible chemistry with the water in the boring. Unless designed otherwise, the assembly should be installed plumb and in the center of the boring. Centralizers of proper spacing and diameter can be used. Unless otherwise approved, the riser should extend above grade and be capped to prevent the entry of foreign material.

Installation of the filter pack, sealants, or other materials in the annular space should be done using tremie pipes or other accepted practices. Protective casing and locking well caps must be installed, and any other necessary measures must be taken to insure that the monitoring well is protected from vandalism and accidental damage. To reduce misidentification, all monitoring wells constructed in developed areas, or in any location where they may be mistaken for other structures (such as tank-fill tubes, drains, and breather tubes), should have a locking cap conspicuously labeled "Monitoring Well" (preferably by the well-cap manufacturer). In addition, locks for the monitoring wells should use a key pattern different from locks on other structures at the site. It is also advisable that the well identification number be placed on both the inside and outside of the protective casing.

### 2.4.3 Well Development

Well development removes the fine-grained material to improve the hydraulic efficiency of the well. Well development methods most often include mechanical surging with bailing or pumping, over pumping, air lift pumping, and jetting. Well development should proceed slowly and systematically to prevent the movement of more material than the development method can effectively remove. When it is likely that the water removed during development will be contaminated, procedures commensurate with the type and level of contamination should be employed for the handling, storage, and disposal of the contaminated material. Development methods should minimize the introduction of materials that might compromise the objective of the monitoring. If air is used, the compressor should have an oil air filter or oil trap.

### 2.4.4 Record Keeping and Reporting

Because interpretation of monitoring data from a monitoring well is spatially dependent on both the activity being monitored and other monitoring wells in the system, records and samples of the materials used to construct and drill the monitoring well should be kept. In addition, samples of geologic material such as cuttings, cores, split-spoon samples, formation fluids, etc., should be collected and preserved. Following construction, accurate horizontal and vertical surveys should be performed. A permanent reference point should be made by notching the riser pipe. If possible, all reference points should be established in relation to an established National Geodetic Vertical Datum (NGVD). Monitoring well locations should be surveyed to ± 1 linear foot, and monitoring well elevations should be to the nearest .01 foot. Elevations of the protective casing (with the cap off or hinged back), the well casing, and the ground surface should be surveyed for each monitoring well (see Nielsen, 1991). DEP permitted facilities are generally required to record the latitude and longitude for each monitoring well.

A groundwater monitoring network report should be prepared. This report should include copies of the well boring, test pit and exploratory borehole logs; details on the construction of each monitoring point; maps, air photos or other information necessary to fully describe the location and spatial relationship of the points in the monitoring system; and a recommended decommissioning procedure consistent with the applicable regulatory program and the well abandonment procedures recommended in Chapter 7.

Monitoring well logs should be prepared and should describe, at a minimum, the date of construction; the thickness and composition of the geologic units; the location and type of samples collected; the nature of fractures and other discontinuities encountered; the nature and occurrence of groundwater encountered during construction, including the depth and yield of water bearing zones; and the static water level upon completing construction.

A well completion plan should also be included in the monitoring network report. Each plan should include information on the length, location, slot size, and nature of filter pack for each screen; type, location and quantity of material used as annular seals and filler; description of the type and effectiveness of well development employed; and notes describing how the well, as constructed, differs from its original design.

The reports described above do not relieve the driller from the obligation to submit, for each well drilled, a Water Well Completion Report to the Department of Conservation and Natural Resources, Bureau of Topographic and Geologic Survey, as required by Act 610 (the Water Well Drillers License Act).

## 2.5 REFERENCES

ALLER, L., and others, 1989, Handbook of Suggested Practices for the Design and Installation of Ground-Water Monitoring Wells, National Water Well Association.
This publication covers nearly all aspects of design and construction of monitoring wells. Each of the eight chapters has an extensive reference list.

ANDERSON, K.E., 1993, Ground Water Handbook, National Ground Water Association. A quick reference containing tables, formulas, techniques and short discussions covering, among other things, drilling, well design, pipe and casing, and groundwater flow.

DRISCOLL, F.G., 1986, Groundwater and Wells, Second Edition, Johnson Filtration Systems, Inc., St. Paul, Minnesota 55112, 1089 pp.

GABER, M.S., and FISHER, B.O., 1988, Michigan Water Well Grouting Manual, Michigan Department of Public Health.
Very thorough coverage of grout and sealant formulation, characteristics, handling, and placement.

NIELSEN, D.M., (Editor), 1991, Practical Handbook of Ground-Water Monitoring, NWWA, Lewis Publishers, Inc., Chelsea, Michigan 48118, 717 pp.
Good general reference on the topic.

U.S. ENVIRONMENTAL PROTECTION AGENCY, 1993, Subsurface Characterization and Monitoring Techniques-A Desk Reference Guide, Volume 1: Solids and Ground Water.
Largely 1 to 2 page thumbnail descriptions of methods and equipment. Copious references.

# CHAPTER 3: LOCATIONS AND DEPTHS OF MONITORING WELLS

## 3.1 IMPORTANCE

The locations and depths of monitoring wells are the most important aspects of a monitoring network. A monitoring point that is misplaced is of little use, and may misrepresent the quality of the groundwater migrating to or from a site. On the other hand, a properly positioned monitoring well that detects the earliest contamination could save both time and money spent on cleanup of a site, and prevent extensive contamination of groundwater.

## 3.2 APPROACH TO DETERMINING MONITORING LOCATIONS AND DEPTHS

Different approaches and efforts for determining the location and depth of wells may be necessary based on the type of monitoring to be done. However, before well locations are chosen for any type of monitoring, the existing data should be assessed. This can reduce the costs of implementing the monitoring program, and can help to make appropriate choices for three-dimensional monitoring locations.

Information may be obtained through site visits, site records and previous studies, interviews with present and past workers, aerial photographs, publications on the local and regional hydrogeology, geophysical surveys, borings, wells, aquifer tests, etc. If enough information is available, the designer can determine the groundwater flow paths and design a complete monitoring network. However, actual testing of aquifer parameters provides the best information to evaluate placement of monitoring wells, especially in newly established sites or facilities where little site information is available.

### 3.2.1 Ambient Monitoring

The determination of background water quality is paramount to understanding the effect of an activity or site on groundwater quality. Often insufficient site information is available so that initial well locations may depend on assumptions regarding groundwater flow. If subsequent information shows that monitoring wells are misplaced, new wells should be installed. Act 2 regulations (Chapter 250, Subchapter G) provide requirements for establishing numerical values for regulated substances.

### 3.2.2 Compliance Monitoring

Appropriately placed monitoring points are necessary to detect the spread of contamination due to an unauthorized release from a permitted activity. The more that is known about the (potential) contaminant flow paths and the site, the more likely that compliance wells will be optimally placed to monitor the impact of the permitted activity on groundwater quality. Monitoring well locations should be concentrated in those areas that will first be impacted by the facility, which typically will be located within or comprise the uppermost aquifer.

### 3.2.3 Assessment Monitoring

The greater the complexity of the hydrogeology and the spread of contamination, the more monitoring may be necessary to assess the contamination. Where a contamination plume of unknown dimensions exists, various techniques (such as geophysics, soil vapor studies, etc.) can be used to estimate the extent and magnitude of contamination. Such methods can be used to focus the investigation and then properly position wells that will confirm the studies and complete the assessment to determine if the permitted activity is the cause of the unauthorized release.

#### 3.2.4 Remediation and Post-Closure Monitoring

Further knowledge of groundwater flow directions, aquifer properties, and contaminant distribution may be necessary to select appropriate well locations where cleanup can be monitored and confirmed. Existing wells may be used for remediation monitoring; however, the impact of the remediation method (such as pumping the aquifer) on the groundwater flow paths should also be considered. Appropriately placed wells will allow for an accurate assessment of background water quality, which will be needed for determining the most suitable cleanup standard under Act 2, and determination that the remediation goals have been attained.

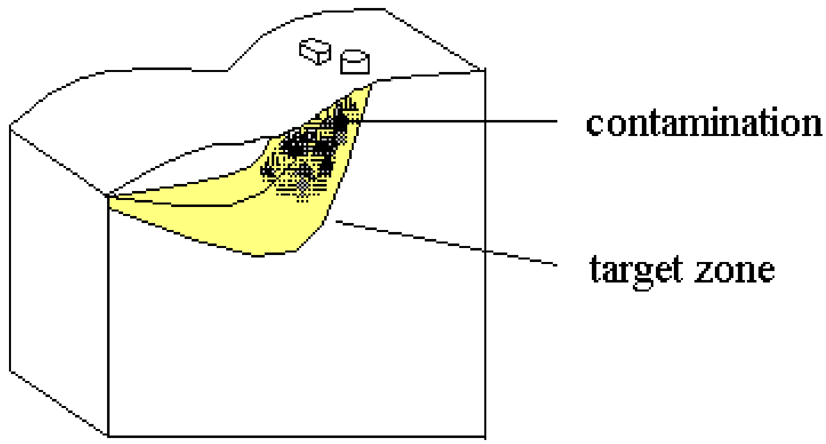
Well locations for post-closure monitoring are generally selected from existing compliance monitoring wells. Where a source of contamination is removed prior to impacting groundwater, post-closure monitoring should continue at locations that will detect any residual contamination in the unsaturated zone that might migrate to the groundwater.

### 3.3 FACTORS IN DETERMINING TARGET ZONES FOR MONITORING

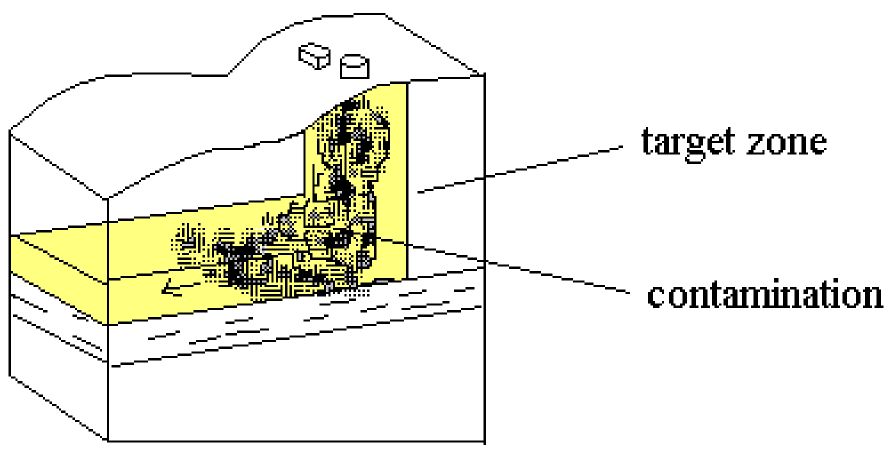
The prime requirement for a successful monitoring system is to determine the "target" zones - the areal locations and depths that are the most likely areas to be impacted by the facility being monitored or site being investigated. The dimensions of target zones depend on the vertical and horizontal components of flow in the aquifers being monitored, the size of the facility being monitored, the potential contaminants, and the distance that contamination may have traveled from the facility. Figure 4 shows how different target zones could be formed based on these factors.

Horizontal and vertical components of groundwater flow are best determined by constructing planar and cross-sectional flow nets based on the measurement of water levels in piezometers. Where the vertical components of flow are negligible, wells, rather than piezometers, drilled into the aquifer to about the same depth, will allow preparation of a contour map of water levels representing horizontal flow. This should be adequate to prepare a planar flow net and determine the target zone.

**Figure 4. Examples of target zones.**




a. Target zone that follows the arcuate flow path of groundwater.




b. Target zone of dense contaminant that sinks beneath a facility until encountering a shale layer; then contamination moves horizontally.

With regard to upgradient wells, target zones (as defined above) do not exist. Upgradient wells should be drilled to depths that are screened or open to intervals similar to that of the downgradient wells, or to depths that yield water that is otherwise most representative of the ambient quality of the water being monitored by the downgradient wells. The latter is especially true for sites where no true upgradient flow exists for the site.

The numerous site details to consider when establishing target zones may be grouped into groundwater movement or the distribution of contamination.

### 3.3.1 Groundwater Movement

In what direction is groundwater flowing? If flow paths are not easily determined, what will influence the direction of groundwater flow? The answers to these questions are critical to selecting target zones and the optimal locations of monitoring wells.

Using the groundwater levels from piezometers or wells at the site, the groundwater gradient can also be determined. At least three monitoring points are needed to determine the horizontal gradient; however, at some sites, knowledge of the vertical component of flow may be important. This is best accomplished by using well pairs of "shallow" and "deep" piezometers or short-screened wells.

It may appear to be a simple task to place monitoring wells in downgradient positions using a map of the groundwater elevation contours, or by anticipating the gradient based on topography or discharge points. However, at many sites, three-dimensional flow zones must be understood to install appropriate monitoring points (see Section 3.5). Figure 5 shows how a well can miss the vertical location of contamination at a site. Water level measurements, piezometer and well construction, and groundwater gradient maps should be reviewed carefully when assessing the dimensions of target zones.

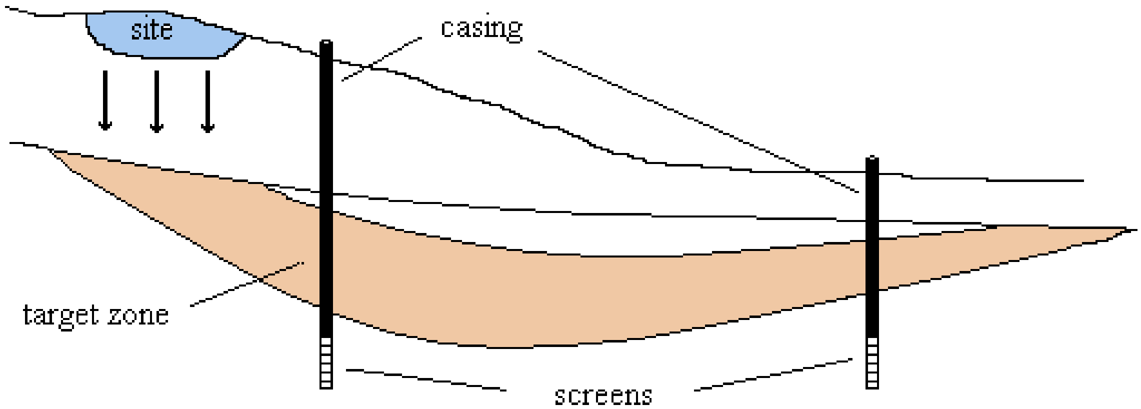
#### 3.3.1.1 Geological Factors

The geology of a site can complicate the selection of the target zones for monitoring. Geological factors can produce aquifers that are anisotropic. In an anisotropic aquifer, groundwater moves faster in one direction than another, and oblique to the hydraulic gradient. Anisotropy can result from various sedimentary or structural features such as buried channels, bedding planes, folds, faults, and fractures.

In Pennsylvania, most of groundwater flow is through fractured rocks. Fracture flow in bedrock (or hardened sediments) requires additional considerations compared to flow in unconsolidated materials. Consolidated materials may exhibit small effective porosities and low hydraulic conductivities that impede groundwater flow. However, the development of secondary porosity may allow substantial flow of groundwater through fractures, joints, cleavage planes and foliations. These features tend to be highly directional, exhibit varying degrees of interconnection, and may produce local groundwater flow regimes that are much different from the regional trends.

Geological factors influence the direction of groundwater flow by controlling the transmissivity. For example, Figure 6 shows the effect of fractures on the spread of contamination. Although the gradient indicates flow to the north, groundwater also follows the major fractures and spreads to the northeast. Monitoring wells "1" and "2" located to the north of the site may detect contamination, but the lack of a monitoring well to the northeast will miss an important direction of migration. Common sedimentary bedding planes also could have a similar effect on groundwater flow.

**Figure 5. Monitoring well screens placed too deeply below the target zone to detect contamination.**



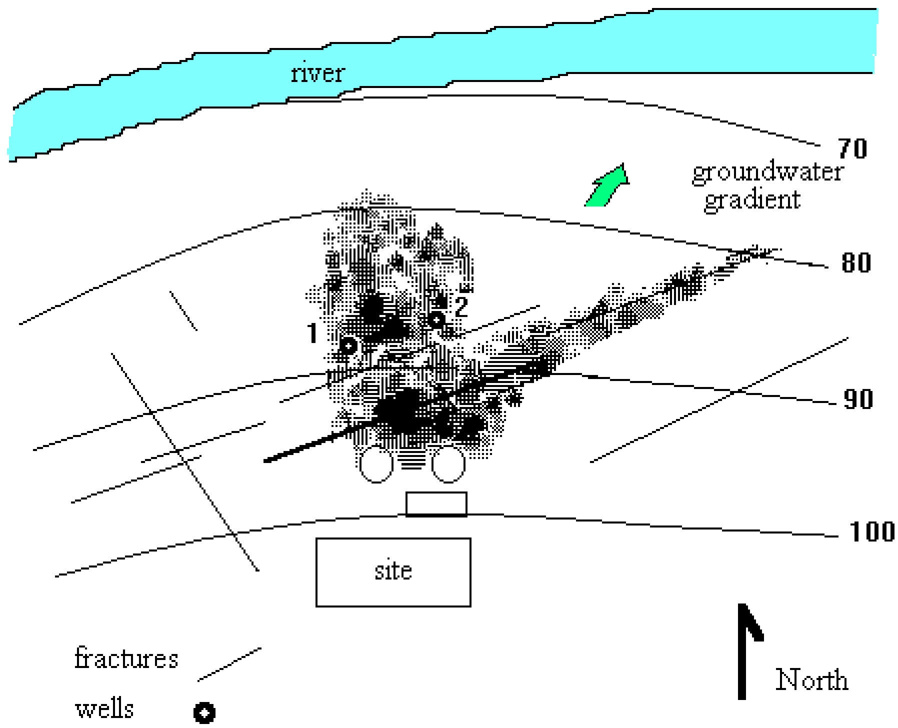

### 3.3.1.2 Groundwater Boundaries

The presence of hydrogeologic boundaries should also be considered when locating wells or approving a groundwater monitoring system. Important types of boundaries include the following:

Geologic faults - Fault planes that contain gouge (soft rock material) or bring rock bodies of widely differing hydraulic conductivity into juxtaposition can influence groundwater flow direction and velocity. Location of downgradient wells across fault zones or planes should not be approved until the nature of the influence of the fault zone on groundwater flow has been evaluated. One method of evaluating fault zones is to conduct pumping tests with wells on either side of the fault plane to evaluate the degree of hydraulic connection.

Dikes - Diabase dikes, common in southeastern Pennsylvania, can function as lithologic barriers to groundwater flow because of their very low permeability. If a dike lies between a site and a proposed downgradient well, the role of the dike should be evaluated prior to approving the well's location.

**Figure 6. Effect of fractures on the spread of contamination.**




Others - Geologically "tight" layers or formations can function in a similar way: they can create subsurface "dams" that cause groundwater to flow in unexpected directions. Additional boundaries to flow can include inclined confining beds, groundwater divides, and artesian aquifers.

### 3.3.1.3 Karst Terrane

Limestone and dolomite are very often susceptible to the formation of sinkholes, solution channels, and caverns. In Pennsylvania, almost all carbonate rocks will exhibit some karst development. Resulting flow patterns can be very complicated; flow depends on the degree of interconnection of the joints, fractures, and solution openings (small and large), the hydraulic gradient, and geologic barriers. Properly monitoring a site in a karst area can be very difficult. Even a relatively small cavernous opening with its connecting drainage paths can control a significant amount of the flow from an area, and may perhaps effectively carry all the groundwater that discharges from underneath a site. In addition, karst geology has the potential to rapidly transmit groundwater over a large distance.

Groundwater flow in a karst terrane can be highly affected by precipitation events, and groundwater divides can be transient. To determine monitoring locations in limestone and dolomite areas, the monitoring designer should investigate the degree to which the rocks are susceptible to dissolution. The more dissolution features that are recognized, the more likely that conduit flow will occur.

Thus, it would seem that monitoring locations should be based on major conduits of flow. However, Figure 7 shows how a monitoring well can easily miss a primary conduit. It may be futile to attempt to establish the locations of such flow zones, because they probably represent only a small fraction of a site. However, several procedures can be used to increase the odds of monitoring the facility of concern (Note that many of the procedures discussed here also can be used in deep-mined areas and other types of fractured rocks).

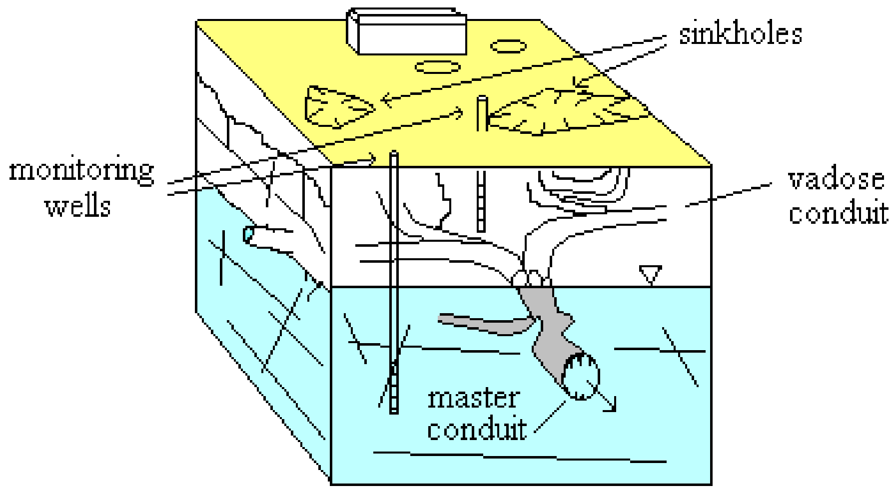
Tracer tests - Tracer tests offer the best possibility of determining where groundwater is flowing and discharging. They are conducted to establish a hydraulic link between a downgradient monitoring point and the facility of concern. Tracer tests should be combined with a thorough inspection for local and regional springs that could serve as discharge points for groundwater at the site. It also could be possible that groundwater beneath a site could discharge to several springs or that the flow directions could be different during flood stages. A determination of the point of regional base flow also should be made and possibly included as a monitoring point.

It is important to understand the potential chemical and physical behavior of the tracer in groundwater. The objective is to use a tracer that travels with the same velocity and direction as the water and does not interact with solid material. For most uses, the tracer should also be nontoxic. It should be easily detected, and be present in concentrations well above natural background quality. The tracer should not modify the hydraulic conductivity or other properties of the medium being studied. Investigations using tracers should have the approval of local authorities or the department and local citizens should be informed of the tracer injections.

Various types of tracers are used including water temperature, solid particles, ions, organic acids, and dyes. Fluorescent dyes are the most common type of tracer used in karst areas. These dyes are used because they are readily available, are generally the most practical and convenient tracers, and they can be adsorbed onto activated coconut charcoal or unbleached cotton. Fluorescent dyes can be detected at concentrations ranging from one to three orders of magnitude less than those required for visual detection of non-fluorescent dyes. This helps to prevent the aesthetically unpleasant result of discoloring a private or public water supply.

Fluorescein (CI Acid Yellow 73 - $C_{20}H_{10}O_5Na_2$) is one of the most widely used water-tracers in karst terrane studies because of its safety, availability, and ready adsorption onto activated coconut charcoal. It is a reddish-brown powder that turns vivid yellow-green in water, is photochemically unstable, and loses fluorescence in water with pH less than 5.5.

**Figure 7. Ineffective monitoring wells in a carbonate aquifer.**




The toxicity of the dyes should also be considered, especially when there is a chance of private or public water supplies being affected. Smart (1984) presents a review of the toxicity of 12 fluorescent dyes. Other excellent references include U.S.EPA and the USGS (1988) and Davis and others (1985).

The mapping of outcrops and associated joints and faults may distinguish directional trends that groundwater might follow. Fracture trace analysis using aerial photographs may detect local and regional trends in fractures, closed depressions, sinkholes, stream alignments, and discharge areas. However, tracer tests are recommended to verify where groundwater is flowing.

Additional site investigation techniques may be helpful in determining flow paths. Geophysical methods such as self-potential (a surface electromagnetic method) and ground penetrating radar can enhance the understanding of karst systems.

Effort should be made to monitor at or near the site of concern, rather than depend on springs that discharge away from the site. Wells sited on fractures traces or other structural trends can be tested with tracers to see if they intercept groundwater flowing from the site. A monitoring network should not be solely dependent on water levels to establish the locations of monitoring wells in such fractured rock settings. These uncertainties and the potential traveling distances may cause monitoring in karst areas to be involved and expensive.

#### 3.3.1.4 Deep Mined Areas

When designing a groundwater monitoring program for a site in which coal or noncoal deep mining has occurred, whether it is a mine site, landfill, or industrial cleanup site, it is necessary to consider the underlying mine.

Because of the extensive mine workings and the associated subsidence fractures, the deep mine often acts as a large drain for the overlying water bearing zones. Groundwater monitoring of this zone should be considered because it is the first saturated zone available for contaminant detection.

Saturated zones within deep mines may be characterized as a mine pool, which is a body of water at a relatively stable elevation, or it may be a pathway for channelized water. Because of these special problems, a drilling plan should be devised that includes provisions for drilling through the coal pillar, mine void or collapsed structures. Several attempts should be made at each well location to intercept the pool, saturated zone and/or mine void.

Well construction requires the placement of a grout basket or plug attached to the riser pipe that is placed above the zone to be monitored. This helps seal the bentonite grout.

### 3.3.2 Contaminant Distribution

In addition to normal groundwater flow (advection), the distribution of contamination is critical to the correct placement of monitoring points. This distribution is based on 1) the chemical characteristics that affect the migration of the contaminant, and 2) its occurrence or source at the site. For example, the density of a contaminant is one of the most important factors in its distribution in the aquifer, and especially for determining the depth of a target zone (see Section 3.5). Isoconcentration maps can be useful in plume interpretation and for placement of groundwater recovery wells. Also, the designer of the monitoring network should keep in mind the relationship of the flow lines with the activity's location or potential sources of contamination.

## 3.4 AREAL PLACEMENT OF WELLS

For establishing the target zones, the monitoring system designer should consider the topics of groundwater movement and contaminant distribution that were discussed above. For the initial placement of wells at a site where little information is available, the downgradient well position is typically assumed to be downslope. In apparent flat-lying sites, drainage patterns can be used to estimate the gradient. The site boundary that is closest to a body of water is a likely choice for downgradient well locations. An upgradient well is typically placed upslope.

As more information is obtained about the site, groundwater gradients will be more accurately defined. Upgradient and downgradient monitoring points may need to be moved. However, even well-defined groundwater gradient maps should be evaluated carefully when choosing the target zones for upgradient and downgradient wells. Because of structural controls in fracture flow described in Section 3.3.1, groundwater can move obliquely to the regional gradient. Some monitoring points may need to be moved as target zones are refined.

In general when comparing sites, intervals between monitoring wells probably should be closer for a site that has:

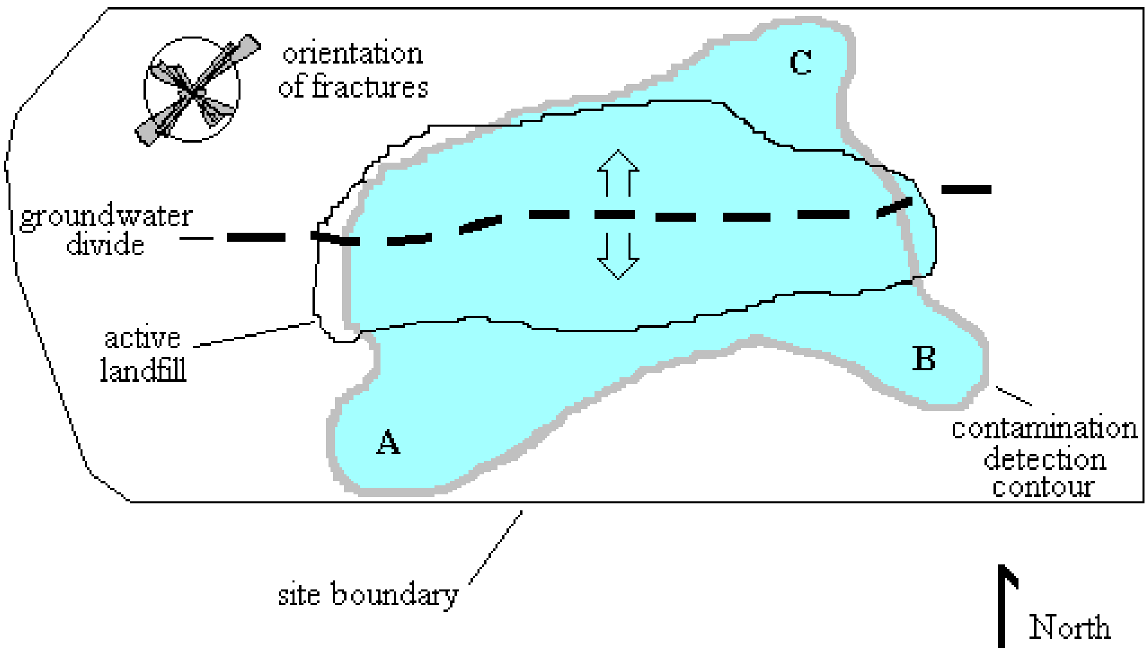
- a small area
- complicated geology such as folding, faulting, closely spaced fractures, or solution channels
- heterogeneous lithologies and hydraulic conductivities
- steep or variable hydraulic gradient
- high seepage velocity
- had liquid contaminants
- buried pipes, trenches, etc.
- low dispersivity potential

Sites without these features may have well interval distances that are greater. See also Section 3.6 on the number of wells.

For assessment monitoring, reconnaissance tools and screening techniques such as surface geophysical techniques and soil gas studies can help to locate plumes before wells are drilled and thus help to determine optimal well locations. Methods for selecting sample locations range from random picks to probability sampling (such as a grid pattern). Random sampling is very inefficient. When selecting many monitoring points in an area where little is known, such monitoring points should be placed in a grid or herringbone pattern.

When selecting the areal locations for wells, the chosen sites should monitor any major branches of flow of the target zones. Figure 8 depicts a landfill site that straddles a groundwater divide. Here an assessment has been required. The groundwater gradient indicates flow to the north and south, but a terrain conductivity study and data results from existing monitoring wells indicate the spread of contamination in at least three major directions. The migration is strongly affected by northeast and northwest trending fractures. These three major areas (A, B, and C) should be included in the assessment and remediation monitoring. In addition, groundwater divides, site boundaries, and objectives should be considered.

**Figure 8. Determination of monitoring locations at a landfill site based on assessment reconnaissance studies.**




## 3.5 WELL DEPTHS, SCREEN LENGTHS, AND OPEN INTERVALS

The first zone of saturation is typically an unconfined or water table aquifer, which is recharged from direct infiltration of precipitation. Impacts to the aquifer under unconfined conditions are more easily evaluated than under confined conditions. The shallowest aquifer should be the target zone for chemicals and substances that are less dense than water.

Sites with confined aquifers that have the potential to be impacted will need to be evaluated in combination with the unconfined aquifer. Such a situation would require more detailed vertical and discrete zone monitoring.

### 3.5.1 Ambient and Compliance Monitoring

Once the subsurface geometry of the monitoring target zone is determined, decisions can be made with respect to the depth and screen lengths of individual wells that will be used for ambient and compliance monitoring. Ambient and compliance monitoring networks should monitor the entire saturated thickness of the target zone or a very large percentage of it. If large vertical intervals of the target zone are unmonitored, chances are increased that groundwater contamination may go undetected, or be underestimated if detected.

Choosing the length of the open interval in a monitoring well is in many respects a balancing act. Shorter open intervals or screen lengths provide better accuracy in determining hydraulic head at a specific point in the flow system. If a sufficient number of shorter well screens or open intervals are stacked or clustered vertically so that the entire saturated thickness of the target zone is adequately monitored, they will, when taken together, provide better resolution of the vertical distribution of any contamination that may be detected. In addition, the possibility of cross-contamination is minimized. Disadvantages of shorter intervals include reduced water volume from each well, and the increased cost of installing, sampling, analyzing, and interpreting the data from the more numerous sampling points, which can be considerable.

Some disadvantages also are likely for longer screen lengths or open intervals. Resolution of hydraulic head distribution in the aquifer decreases, contamination entering the well at a specific point may be diluted by other less contaminated water, and there is less certainty regarding where water is entering the well.

It would be preferable from a strictly technical point of view to monitor the entire saturated thickness of any target zone with a number of individual, shorter screened wells drilled to different depths that together monitor the entire target zone. However, the hydrogeologist designing the project must decide if the increased cost over single, longer screened wells is justified for ambient and compliance monitoring. The goal is to establish screens and open intervals that will detect as quickly as possible any contamination emanating from any portion of the facility.

In many cases, ambient and compliance monitoring can be and is accomplished by using relatively long screen lengths or gravel packed intervals, or open intervals in open rock holes. Exceptions to this include sites where different aquifer systems are being monitored (such as unconsolidated deposits overlying a bedrock formation) or where strong enough vertical gradients exist to lead to concerns about introducing any contamination that might occur into uncontaminated aquifers.

Compliance (detection) monitoring should not be conducted by using a single short screened well that only monitors a small percentage of the target zone. Care should also be taken when monitoring target zones in bedrock formations. In this case, by geologic necessity, the portion of the target zone which is monitored will be determined by the location and number of water producing fractures that are intercepted by the well. Care must be taken not to drill wells too deeply below the target zone in search of a water-producing fracture.

An exception to the goal of monitoring the entire saturated thickness would be in the case of an aquifer that was underlain by an unsaturated zone such as a mine opening. Here a well drilled through the aquifer into a mine opening would drain the aquifer. In such cases, well construction should prevent dewatering of the aquifer.

Where multiple aquifers exist, such as an unconsolidated aquifer overlying a bedrock aquifer, or where two permeable aquifers are separated by an aquitard, the target zones within each aquifer should be monitored separately.

The specific gravity of a contaminant and whether it will most likely be introduced to the environment as a free phase or in a dissolved phase also will influence how a well is constructed. In conducting monitoring for an LNAPL (light non-aqueous phase liquid) contaminant, such as gasoline, wells should be constructed with screens or open intervals that intercept the water table surface at all times of the year. Then, LNAPL can accumulate into a distinct layer and flow into the monitoring well. For materials that exhibit specific gravities greater than water (such as many chlorinated solvents), it is desirable, though not always possible to locate subsurface boundaries on which such contaminants might accumulate if released to the environment in a free phase.

### 3.5.2 Assessment and Remediation Monitoring

The major purpose of assessment monitoring is to determine the vertical and horizontal extent and magnitude of contamination that has been detected during compliance monitoring. In most cases this will require the installation or modification of wells so that they are screened or open to relatively short vertical intervals within each target zone. This work is desirable for resolving any stratification of contamination and to establish the maximum depth of contamination. This information will be useful in targeting remediation options to those portions of the aquifer that are most contaminated and that serve as significant sources of contamination to other portions of the flow system.

If the assessment reveals a significant vertical component of flow, then the possibility exists for long-screened wells to act as conduits for current or future contamination of previously uncontaminated portions of the target zone. These detection wells should be grouted or their construction modified to prevent this outcome.

Remediation monitoring will most likely be conducted in wells that have been drilled for the compliance or assessment phases. In some cases wells will be drilled for the recovery of groundwater. Obviously these will be designed and drilled at locations to maximize their effectiveness in capturing contaminated groundwater. As long as these wells are pumping and recovering groundwater, concerns with their construction are minimal; nevertheless, if their use as recovery wells ceases for any extended period of time prior to restoration of the aquifer to appropriate Act 2 cleanup standards, and adequate justification for not sealing the wells cannot be provided, they should be properly abandoned without delay in accordance with the procedures described in Chapter 7.

## 3.6 NUMBER OF WELLS

The number of wells needed depends on site-specific factors. Compliance monitoring may need only one downgradient well for a small site such as an underground storage tank. In general, the spacing of background or upgradient wells should be adequate to account for any spatial variability in the groundwater quality. Downgradient wells should be positioned to adequately monitor the activity and any other variability of the groundwater quality. The estimate of the separation distance will depend on the extent and type of activity, the geology, and the potential contaminants (see also Section 3.4 on the Areal Placement of Wells, and Section 5.3.4 on Network Design).

For ambient and compliance monitoring, the monitoring well network should cover most of the site. It is recommended that at least 85 percent of the site be monitored. The percentage can be adjusted based on the knowledge of the site, groundwater flow, and the potential or existing contaminants. For example, it might be reasonable to require the well network to cover 95 percent of a site where little information is available. Percentages can be estimated using computer models such as the MEMO model (Wilson and others, 1992). In the absence of models to estimate the coverage of the monitoring well network, best professional judgment should be used to assure the network would detect a plume of reasonable size.

As the monitoring network is refined, active monitoring wells can be established. In some cases, wells can be dropped from active monitoring if it can be shown that the target zones are being monitored completely. For remediation or post-closure monitoring, a lower percentage of coverage may be appropriate after that information on the site has been obtained.

## 3.7 WELL YIELD

Monitoring wells should produce yields that are representative of the formation being drilled. Wells that are located in anomalously low yielding locations are undesirable for several reasons. First, flow lines tend to flow around rather than through low permeability areas. This in effect results in contaminants bypassing low permeability areas and failing to be detected in representative concentrations. In addition, by the time a contaminant shows up in a very low yielding well that is unrepresentative of the formation, other contamination may have traveled extensively downgradient beyond the monitoring well. Therefore, in settings where well yields are variable, the best monitoring wells will be those that are open to the highest permeability flow lines that are potentially able to be contaminated by the site.

The best information regarding representative yield for the target zones selected for a particular site should come from the wells and borings used in the investigation to determine the groundwater flow system for the site. Borehole geophysics can be a valuable tool for determining the location of yielding zones and the presence of contaminants. For more detailed descriptions of borehole geophysical techniques and devices, see EPA (1993) Chapter 3 - Geophysical Logging of Boreholes, and Nielsen (1991). Additional regional hydrogeologic information may be obtained from:

- The Pennsylvania Bureau of Topographic and Geologic Survey (BTGS)
- The United States Geological Survey (USGS)

  Water Resource Reports have been published by the USGS and BTGS for selected counties and areas in Pennsylvania. They are available through the State Bookstore.

In Pennsylvania, there are three general hydrogeologic settings that merit special discussion from a standpoint of well yield.

### 3.7.1 Fractured Rock

In aquifers composed of fractured bedrock, groundwater flow is generally restricted to the fractures. If a well fails to intersect any fractures or a very few small fractures, the well will not detect contamination, or will be inefficient in detecting contamination. For this reason, wells that fail to intersect fractures in the target zone that are representative of the formation should be approved with caution and wells that are essentially dry are not acceptable. Such wells should be relocated nearby and another attempt made to obtain a better yield, when it is determined that it is likely that more representative yields can be obtained. Likewise, wells drilled below the proper target zone, strictly in an effort to obtain yield, should not be used for site characterization.

### 3.7.2 Heterogeneous Unconsolidated Formations

Low permeability clay-rich formations with interbedded or lenticular, higher permeability sand or gravel units can present a significant challenge to designers and installers of monitoring wells. Wells need to be located so that they are open to any high permeability zones within the target zone that are hydraulically connected to the site being monitored. These wells will be higher yielding than their counterparts that are drilled exclusively into the clay-rich portions of the site.

### 3.7.3 Areas of Uniformly Low Yield

Certain geologic formations and hydrogeologic settings are characterized by naturally low permeability over a wide area. Other geologic formations may exhibit low permeability locally in certain settings such as ridge tops, steeply dipping strata, or slopes. In such settings, a permanent or seasonal perched water table or shallow flow system may develop on the relatively impermeable bedrock that may or may not be hydraulically connected to the bedrock system. Depending on the permeability of the soils and unconsolidated material overlying the solid, slowly permeable bedrock, the shallow groundwater flow can express itself as a rather rapid "subsurface storm flow" or a more sluggish, longer lasting saturation in poorly drained soils.

It is important to be sure that the shallow systems are part of the target zone of the site being monitored. In these cases the shallow system may constitute the most sensitive target zone for monitoring a facility. While wells drilled into the bedrock system may be needed to monitor for vertical flow of contaminants, the importance of sampling monitoring wells or springs in the shallow intermittent flow system should not be underestimated, although the usual periodic monitoring schedules may not be appropriate in these settings. If the systems are intermittent, one will have to become aware of when they are active (e.g. in the spring, after significant precipitation) and be prepared to monitor the systems at that time. Monitoring can be conducted in wells, springs that are properly developed, or in some cases, by sampling man-made underdrain systems that are constructed to collect the shallow flow system.

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# CHAPTER 4: ANALYTE SELECTION AND MONITORING FREQUENCY

## 4.1 IMPORTANCE OF ANALYTE SELECTION

There are practical reasons for predetermining a set of analytes for which to monitor. These include the purpose(s) of the monitoring effort, and the amount of resources (time and money) available for sample collection, analysis and data interpretation or program regulatory requirements. Unless a sampling plan is focused, significant data can become lost in a sea of analytical results.

## 4.2 DEVELOPMENT OF AN ANALYTE LIST

In developing an analyte list, it is necessary to establish and define the objectives of the monitoring activity (i.e. ambient, compliance, assessment, remediation monitoring, or post-closure monitoring). The analytes selected should be those of concern based on their generation (including reaction products, etc.) at the facility or from historical uses that may be identified in an assessment of a site.

In addition, it may be beneficial to monitor other analytes beyond the obvious analytes of concern. The general chemistry of an aquifer can be used to monitor changes and differences in the hydrogeologic system. For example, the monitoring of basic analytes can be used to evaluate the mobility of chemical species, correlate recharge and flow zones with the water quality, assess the chemical equilibrium and kinetics of groundwater reactions, and to develop analyte contour maps and graphical plots. Such evaluations can be excellent tools to understand the flow and quality of the groundwater system.

Because of the potential for gathering valuable information at a relatively inexpensive price, monitoring programs should include appropriate and basic chemistry species and analytes. This is especially true of ambient and compliance monitoring at larger sites that have the potential to be complicated in terms of contaminants, neighboring facilities, and groundwater flow paths.

### 4.2.1 Ambient Monitoring

Ambient monitoring is a pre-operational or pre-remediation, relatively short term activity that is conducted to establish groundwater quality conditions at a site prior to any operation of a proposed activity, or to establish groundwater quality that has not been affected by site activities. The goal is to account for both non-site related variation (background), and any impacts from the site that may have influenced groundwater quality. These results will form a basis against which future monitoring results will be compared to determine permit compliance or remediation attainment when the Act 2 Background Standard is selected or is the controlling factor.

The ambient monitoring analytes should include all those that are being generated by an existing activity or will be generated by a proposed activity. Potential degradation products of known contaminants should also be considered. In addition, parameters that may have been generated by past or adjacent activities should also be monitored.

Analytes for existing or proposed activities can be obtained from permits or from permit applications. Analytes of concern from past practices for permitted activities can be obtained from official records including Toxics Release Inventories (TRIs), National Pollutant Discharge Elimination System (NPDES) permits, Bureau of Land Recycling and Waste Management permits, Agriculture Applicators permits, and federal notification and state storage tank registration records. Information on past practices can also be determined by interviewing local residents, past and present employees of a facility, local officials and the owners of the property. In addition, aerial photographs can be a valuable source of information.

Finally, an on-site inspection can provide additional evidence of past activities that may have impacted groundwater quality. This could be in the form of waste disposal sites, discarded or abandoned containers, or abandoned facilities. This on-site inspection can be a critical link between historical practices and a sampling plan.

### 4.2.2 Compliance Monitoring

Analytes for compliance monitoring should include, at a minimum, all those that are generated by the activity. In some cases, it may be necessary to include additional analytes if they are determined to be of concern due to past practices, potential contamination from activities in upgradient areas, or potential degradation products. Reasons for including such additional analytes should be documented along with actions to be taken in the event of permit violations.

### 4.2.3 Assessment Monitoring

Analytes to be included in assessment monitoring include those that have been found to be of concern through the compliance monitoring.

### 4.2.4 Remediation Monitoring

Analytes to be included in remediation monitoring are those that are being remediated, indicator parameters of such, or any parameters that may indicate physical or chemical conditions within the aquifer that could affect the remediation processes being carried out on the site (i.e. pH, Eh, dissolved oxygen, temperature). During active remediation, marker compounds that will monitor the efficiency of the remediation effort and attainment of remediation goals should be selected.

### 4.2.5 Post-Closure Monitoring

Analytes to be included in post-closure monitoring are those that were monitored during compliance monitoring, as discussed above. Indicator compounds may be used in certain cases.

## 4.3 DETECTION LEVELS AND METHODOLOGIES

The term detection limit is most often associated with MDL, Method Detection Limit and PQL, Practical Quantitation Limit. MDL is defined by the EPA as the lowest concentration that can be determined, with 99 percent confidence, to be greater than zero in a given matrix. Approved EPA analytical methods and detection limits for many toxic substances can be found in Table 2 of DEP's Water Quality Toxics Management Strategy - Statement of Policy (Title 25, Chapter 16). A detailed description of the theory and its implementation can be found in 40 CFR Part 136, Appendix B. By definition, MDLs do not address the accuracy of measurements made at or near this concentration. In an effort to provide more meaningful information to the users of analytical data, the terms PQL, Practical Quantitation Limit, and RL, Reporting Limit, have been utilized. PQLs are normally defined as 5 or 10 times the corresponding MDL and should represent the lowest concentration a laboratory has confidence quantitating. An RL is defined by the Bureau of Laboratories as the concentration in the sample that is equivalent to the lowest standard routinely run for that analyte by a given method/instrument combination. It is important to remember that all of these limits may be adversely affected by the sample matrix. Sampling plans should include necessary analytical quality control measures to determine if matrix effects are occurring. Under Act 2, PQLs are the minimum detection level in remedial activities. A list of PQLs is published in Appendix A of the Act 2 Technical Guidance Manual.

Methods chosen for monitoring purposes need to have undergone method validation with regard to the proposed application. Methods published by EPA, ASTM, and Standard Methods generally meet this standard.

The Bureau of Laboratories can provide guidance in selecting appropriate analytical test methods if the following information is available:

a) What analytes are to be monitored?

b) Is there a requirement for the determination of non-target analytes? If so, what types of analytes need to be included?

c) Are there regulatory, or trigger levels that determine the needed detection levels, and what are they?

d) Are there regulatory requirements for high accuracy?

e) What matrices will need to be analyzed?

## 4.4 DURATION AND FREQUENCY OF MONITORING PERIOD

The frequency and duration of monitoring may vary within activities and specific sites. In many cases the duration and frequency of monitoring are established by DEP regulation. For remediation projects, the monitoring requirements are determined on a site-specific basis by permit, DEP order, by agreement with the party responsible for the monitoring, or by a demonstration in a Final Report that an Act 2 standard is met. Most remediation monitoring will be conducted in accordance with the provisions of Act 2 and associated regulations and guidances. Consideration should be given to the statistical aspects of the sampling frequency and duration. See especially Section 5.3.3, Data Sufficiency and Limitations.

### 4.4.1 Ambient Monitoring

The duration of pre-activity or pre-remediation ambient monitoring is determined by the need to establish a credible database. This is especially critical if the Act 2 Background Standard has been selected for remediation. This duration may conflict with the operator's economic needs to start the operation or activity as soon as possible. Ideally, the duration of monitoring should be sufficient to detect any problem or important characteristic at the site before the ambient monitoring is stopped.

The frequency of monitoring also will be influenced by the proposed use of the data. For example, if a valid statistical, ambient database is desired, an adequate number of samples will need to be taken in the pre-activity monitoring period.

In some cases, pre-activity monitoring is required by DEP regulation. In the absence of specific regulations, at least four samples that would reflect any seasonal influences should be collected from each sampling point prior to any activity at the site that could affect groundwater quality.

### 4.4.2 Compliance Monitoring

For most compliance sites and activities, monitoring will continue as long as the activity exists. The frequency of compliance monitoring is often established by DEP regulation or policy. However, if specific policy or regulations do not exist, then the frequency of monitoring may be established on a case-by-case basis.

The interval between sampling events should be short enough to allow the operator to respond and correct a problem before any significant, widespread, or permanent damage is done to the environment. That is, the periodic sampling should be able to detect contamination migrating from the source before (for example) it migrates offsite undetected.

The groundwater velocity and the contaminant characteristics are two main factors that can affect the determination of a sampling frequency. Consider a case where a sampling frequency must be determined for a well that is 500 feet upgradient from the property line. The operator wants to be alerted to any problem before it reaches the property line. If the groundwater velocity has been determined to be 5 feet per day, then it would be necessary to sample the well no less than once every 100 days (500 feet/5 feet/day), minus the number of days required for analysis.

Sampling at this frequency would alert the owner to contamination before it crossed the property line. If the owner wanted to allow enough time for some pre-planned actions, then the interval would have to be an appropriate number of days less than the calculated sampling frequency.

The vulnerability of a site to pulses of contaminant migration during rain events may affect the desired frequency of sampling. This may occur in deep mined areas and karst conditions. In such cases, the chosen sampling frequency may be irregular and keyed to significant rainfall events rather than regular intervals.

Characteristics of the contaminant also can influence the duration and frequency of sampling. For example, the toxicity or health risk of the site's potential contaminants such as carcinogens may be much greater than other substances, and may require more intensive sampling.

Specific and tangible reasons must exist in order to change established sampling frequencies based on groundwater flow and contaminant transport. This may be very difficult to determine and the subsequent sampling frequency should be conservative. However, tangible evidence could include tracer studies and pumping test data which indicate that sampling should occur on a more or less frequent basis.

Also, an indicator analyte might be sampled more often than other analytes (see Section 4.2), or certain wells might be sampled more often. For example, shallow wells may require more attention where the potential contaminants of a permitted facility are less dense than water.

#### 4.4.3 Assessment Monitoring

Assessment monitoring may be required based on sampling data obtained from one or more sampling points during compliance or post-closure monitoring. Assessment monitoring is conducted as a response to either 1) the indication of contamination, or 2) exceeding an action or "trigger" level. Assessment monitoring typically involves resampling of wells to confirm contamination and/or performing an assessment of the extent of contamination.

Resampling should be accomplished as soon as possible after the initial analyses are available. In some programs, the resampling is required within 10 days of completion of the initial analyses that triggered the resampling obligation.

If resampling confirms the initial indication of contamination or exceeding of a permit level, an assessment plan should be implemented. The assessment investigation should be completed as soon as possible so that a thorough remedial action plan can be quickly designed and implemented. New wells that are installed for the assessment purposes are usually sampled two or three times at a frequency of once every two to four weeks.

#### 4.4.4 Remediation Monitoring

The duration and frequency of monitoring during remediation should be designed with two major purposes in mind. Monitoring should be able to demonstrate whether the groundwater contamination is spreading or is adequately contained; and it should be able to objectively document the degree of effectiveness of any remediation effort to achieve one of the three alternatives of Act 2 at the point of compliance.

Remediation monitoring may be more frequent in the early stages of a project than in later stages. This is because understanding and predictability increase as experience with the project accumulates. For example, as a remediation project proceeds, the contaminant concentrations may approach steady levels. Once an asymptotic or steady state condition is verified, the contaminant concentrations remaining should be compared to the three remediation standards found in Act 2. Remediation systems may be stopped at this point.

Monitoring should then continue for some period to assure that contaminants do not return in exceedance of the Background or Statewide Health standard levels specified in Act 2. Seasonal variations in precipitation and the water table levels may affect the migration rates and paths of residual contaminants. A rising water table can collect contamination residue in the unsaturated zone and produce higher concentrations in groundwater during subsequent sampling.

#### 4.4.5 Post-Closure Monitoring

In most cases, post-closure monitoring requirements are established by department regulation.

In general, a potential source of groundwater contamination should be monitored in accordance with post-closure case requirements or until cleanup standards have been met and liability has been released under Act 2.

#### 4.4.6 Cessation of Monitoring

Monitoring should continue as long as there is a clear and practical reason for continuing it. However, monitoring can be conducted at a reduced frequency, or possibly discontinued when any of the following occur:

1. When allowed by regulations, permit, administrative order, or other agreement with DEP.

2. When the goals of a monitoring program have been achieved, such as when cleanup standards have been met.

### 4.5 REFERENCE

BARCELONA, M.J., WEHRMANN, H.A., SCHOCK, M.R., SIEVERS, M.E., and KARNY, J.R., September 1989, Sampling Frequency for Ground-Water Quality Monitoring, EPA Project Summary, EPA/600/S489/032.

# CHAPTER 5: STATISTICAL ANALYSIS OF MONITORING DATA

## 5.1 PURPOSE

The purpose of this chapter is to provide guidance for the use of statistics in assessing groundwater quality. It is not intended to address statistical procedures in detail, but rather to provide a framework and define the key concepts, terms, and references for proper statistical analysis. The references cited and standard texts should be used to perform the procedures as appropriate, or if necessary, professional services should be obtained. The two EPA publications (Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities - Interim Final Guidance, 1989; and Addendum to Interim Final Guidance, 1992) should serve as default guidances where this chapter or existing regulations do not address an issue or procedure. See Section 5.5 for information on obtaining these documents.

In some cases, regulations such as the Hazardous Waste Regulations for treatment, storage, and disposal, require statistical analyses. These are summarized below:

| Chapter | Topic |
|---|---|
| 264.96 | Record keeping and reporting |
| 264.97 | General groundwater monitoring requirements |
| 264.98 | Detection monitoring program |
| 264.99 | Compliance monitoring program |
| 264.278 | Unsaturated zone monitoring |
| 264.280 | Closure and post-closure care |
| 264 | Appendix C |
| 265.91 | Groundwater monitoring system |
| 265.93 | Preparation, evaluation and responses |

On occasion, the recommendations here will contrast with the Bureau of Land Recycling and Waste Management's regulations dealing with statistics. It should be noted that the regulations do allow for alternate approaches when appropriate (Section 264.98 (c)(2)). Also, the resampling approach discussed in this manual (Section 5.4.3.5) may be useful when determining "whether the facility has caused the [statistically significant] change" (Section 264.98 (e)). Where possible, these procedures should be used because they represent updated methods and approaches. It is anticipated that additional guidance on statistical issues will be provided in the future. Specific rulemaking associated with legislation also may provide guidance on statistical methods used in achieving cleanup standards.

Some of the statistical procedures recommended in this chapter will be easier to implement with computer software. The program should be compatible with the database, and should be able to handle data transformations, and both parametric and nonparametric procedures.

Often, however, adequate statistical analysis with small databases can be accomplished through exploratory data analysis using a calculator and time series graphs. The depth of statistical analysis will typically depend on the amount and condition of the data, and the ultimate purpose and goals for monitoring.

## 5.2 STATISTICAL APPROACHES

Both graphical and mathematical methods are used to analyze groundwater monitoring data. Graphical procedures summarize data concisely and aid interpretation of data but are not used to determine confidence levels or probabilities. Confidence levels and probabilities are determined by applying mathematical methods such as parametric and nonparametric statistical procedures.

The first step in the statistical assessment of data should be exploratory data analysis (EDA). This includes the use of graphical techniques and calculation of summary statistics. Graphical methods include probability plots, box charts, and time-series plots to visually review the data for trends or drifts. EPA and most statistical texts recommend that time-series data should be graphed. This visual approach allows for a quick assessment of the statistical features of the data. Calculation of summary statistics are typically done to characterize the data and make judgments on the central tendencies, symmetry, presence of outliers, etc. EDA is critical to selecting additional appropriate mathematical procedures.

For mathematical methods of analysis, both nonparametric and parametric procedures can be used depending on the distribution of the data, the percentage of nondetects, and the database size. However, both procedures have assumptions that must be met to be considered valid analyses. Note also that "from a statistical point of view, all water quality constituents are considered random variables" (Harris and others, 1987).

### 5.2.1 Parametric Procedure Assumptions

Assumptions of parametric procedures include a specific data distribution such as normal (also know as Gaussian or the bell-shaped curve) or lognormal (normality achieved by logtransforming the data), and data variances that are similar. In addition, the data are assumed to be independent (see Section 5.3.3.1).

### 5.2.2 Nonparametric Procedure Assumptions

Assumptions for nonparametric tests also are important. Nonparametric procedures assume equal variances and that the type (shape) of distribution of the population is the same at each well. This is different from assuming a normal distribution when using parametric statistics. In other words, nonparametric methods do not require a specific type of data distribution.

Nonparametric procedures may be preferred because they:

1. are free from normal distribution assumptions thereby eliminating the need for normality tests and data transformations;
2. are resistant to effects of outliers; and
3. are usable when censored (i.e. less-than detection values) data are present.

## 5.3 DATA AND SAMPLING CONSIDERATIONS

Three of the primary purposes of statistics are to 1) estimate the characteristics of the data, 2) compare datasets, and 3) quantify the uncertainty of data. These purposes include such activities as measuring the central tendency of data, comparing data from upgradient and downgradient wells or with established standards, and quantifying the probability of statistical conclusions.

The following topics typically should be considered when using statistics (especially when assessing groundwater data for permitted activities):

- data variability
- significance levels
- data sufficiency and limits
- monitoring network design

### 5.3.1 Data Variability

All groundwater analyte measurements contain a dimension of random variability caused by a variety of factors. Effects of heterogeneous geology, groundwater flow, in situ processes, and errors in sampling and analysis all contribute to this variability.

#### 5.3.1.1 Spatial Variability

Spatial variability is a significant factor when comparing upgradient groundwater quality with data from compliance wells. EPA recommends considering the inclusion of wells that are not necessarily physically upgradient to understand the spatial variability of the groundwater quality. This is because testing a number of downgradient wells against one upgradient well does not consider the upgradient spatial variability. Statistical tests under these conditions often will produce "false positives."

The accompanying effect of using more upgradient wells is that there is a better chance to produce "false negatives." These two concerns must be offset by considering the level of significance of the statistical tests (Section 5.3.2) and the statistical procedures (Section 5.4). See also Network Design (Section 5.3.4).

However, it must be emphasized that if the variability of the upgradient data is not considered through multiple upgradient wells, it may invalidate the statistical procedures that follow or lead to erroneous judgments regarding trends of the data. It is to the advantage of both the regulated and the regulator to adequately characterize the data variability of the upgradient groundwater quality.

#### 5.3.1.2 Temporal Variability

Temporal variability is variability that occurs at a fixed point with the passage of time. For example, a time series plot for a monitoring well that is sampled through time will typically show varying concentrations. Samples that are taken close together may show serial correlation, which is also called autocorrelation (see Section 5.3.3.1).

#### 5.3.1.3 Seasonality

Seasonality, cyclical behavior in water quality due to annual seasons, can contribute to data variability. Davis and McNichols (1994, Part I) state that seasonality is "rarely a concern in analyzing groundwater data... in our experience." However, analytes in "shallow, highly permeable aquifers" and those affected by fluctuating water levels may show seasonal variability (see Montgomery, Loftis, and Harris, 1987).

Major factors that may cause seasonality include land use practices (especially agricultural) and the rise and fall of the water table. Changing elevations of the water table can significantly affect the concentrations of contaminants such as those associated with petroleum hydrocarbons.

The patterns of seasonality can be highly variable because of complicating factors such as variable recharge and permeability (Pettyjohn, 1982). Activities at a site also may override any evidence of seasonality. If seasonality patterns are detected that are on the order of several years, the impact on quarterly sampling will tend to be minimal.

The EPA cautions against using corrections for seasonality, noting that they "represent extrapolation into the future." Recommendations for assessing seasonality in upgradient wells are presented in Gilbert (1987, Chapter 17) and in Montgomery, Loftis, and Harris (1987). Graphical methods should be used for the initial detection of seasonality. See also Dataset Size in Section 5.3.3.3.

### 5.3.2 Significance Levels

A statistical test is typically performed under a confidence level such as 90 percent, 95 percent, or 99 percent. The confidence level is the chosen probability of accepting the hypothesis (of no contamination). The confidence level has a corresponding significance level. The significance level of a test is called alpha ($\alpha$), and corresponding values to the percentages above would be .1, .05, or .01.

The significance level is equal to the false positive rate. This is the rate at which the test indicates contamination when there is none. (This is a Type I error: the hypothesis is incorrectly rejected. Our hypothesis is that there is no contamination.) For example, if $\alpha$ is .05, 1 out of 20 (5 percent) statistical tests would generate a false positive (an incorrect rejection of the hypothesis).

When a confidence level of a test is raised (e.g. from 95 percent to 99 percent), then the $\alpha$ value is lowered (.05 to .01) and the following occurs:

- the test is less likely to generate a false positive (now only 1 out of 100), but
- the test is more likely to miss detecting the contamination, because the hypothesis is harder to reject.

The overall chance of having a false positive over an entire site is cumulative - it increases with the number of statistical tests performed. This effect is called the Facility Wide False Positive Rate (FWFPR).

The formula for determining the FWFPR is:

$$1 - (1- \alpha\cdot)^{\#\ \text{of tests}}$$

where the number of tests is the number of wells times the number of parameters. For example, at $\alpha$ = 0.01, and 20 wells with 15 parameters:

$$\text{FWFPR} = [1 - (1 - 0.01)^{300}] * 100 \text{ percent}$$
$$\text{FWFPR} = 95.1 \text{ percent}$$

This indicates that the chance for generating a false positive at the site is over 95 percent. This high percentage indicates that statistical tests for a facility are likely to indicate an instance of contamination when there really is no contamination. The facility would be subjected to all the actions and expenses that a statistical test might trigger.

Section 5.1 of the EPA Addendum (1992) discusses how to lower the FWFPR, without compromising the test's power. The power of the test is its ability to detect contamination when it exists. Section 5.1 also discusses how to graphically assess the power of a test.

For any individual comparison at a permitted facility, the recommended significance level is at a minimum .01. Large monitoring networks are judged differently because a balance must be sought between the FWFPR and the power of the test. For such sites, the FWFPR should be approximately 5 percent while a certain level of statistical power is held (Section 5.1, EPA Addendum, 1992).

These recommendations should be considered when reviewing or setting significance levels for statistical tests at permitted facilities. Davis and McNichols (1994, Parts I and II) offer suggestions to improve the implementation of the recommendations. EPA expects to issue further guidance in the future.

### 5.3.3 Data Sufficiency and Limitations

#### 5.3.3.1 Independence

All of the statistical methods discussed in this section assume sample independence. A groundwater sample must have a sufficient sampling interval to ensure independence. That is, the well must be allowed to equilibrate with the surrounding aquifer and enough time be permitted to pass for changes to occur in the aquifer before the sampling of a distinct volume of water can occur. For example, a second groundwater sample taken one week later may be highly correlated (serially) to the first. This can be understood by considering the calculation of the average temperature of the day. Two thermometer readings five minutes apart may give little information on the mean and variance of the daily temperature.

Duplicate samples should not be treated as independent groundwater samples. Independence also can be affected by field instruments and analytical laboratories. See the EPA Interim Final Guidance (1989, Section 3 - Choosing a Sampling Interval). This reference shows how to calculate the minimum acceptable sampling interval.

Generally, quarterly sampling programs can continue as normal; however, sample independence should be considered if a greater sampling frequency is required, or groundwater flow at a site is very slow. Moderate to fast groundwater flow typically ensures the independence of a sample. See Davis and McNichols (1994, Part I).

#### 5.3.3.2 Transformations and Distribution

The EPA Addendum (1992, Section 1) recommends methods for addressing the assumptions of statistical tests. The following is a summary of the approach recommended by EPA.

For data transformations, it is recommended that all data be logged, because the lognormal distribution appears to be most appropriate as the default statistical model. The logged data are then checked for normality. If the test for normality is not rejected, further testing is done with the logged data and not the original data.

Note that when the dataset is smaller than 20 - 30 observations, all normality tests do "at best a fair job of rejecting non-normal data." As more data become available, normality assumptions should be revisited.

Two main methods are recommended for checking normality. Referencing is done by using site historical data or data from similar hydrogeologic settings to assume what the distribution of the data is. As more data become available, the assumptions would be verified by standard tests. Probability plotting is the only test recommended by the EPA without any qualifiers. Probability plots are used to look for irregularities in the data. Normally distributed data will plot as a straight line.

Other tests for data normality such as the Coefficient-of-Variation test and the Chi-squared test may give tenuous results and should be backed up by an additional test. See Section 1 of the EPA Addendum (1992) for specific procedures and use of the tests, and for limitations on traditional normality tests such as Coefficient-of-Variation. See also the EPA Interim Final Guidance (1989, Section 4.2 - Checking Distributional Assumptions).

Unequal variances between groups of data (for example, upgradient wells and compliance wells) can invalidate a statistical test; this is particularly true for the parametric analysis of variance (ANOVA). See the EPA Interim Final Guidance (1989, Section 4.3 - Checking Equality of Variance: Bartlett's Test) and the EPA Addendum (1992, Section 1.2 - Testing for Homogeneity of Variance). Davis and McNichols (1994, Part I) argue that nonparametric ANOVA tests also will be invalidated by unequal variances. The EPA Addendum (1992) also reviews the use of box plots for assessing the homogeneity of variance, and the use of Levene's test as an additional check.

#### 5.3.3.3 Dataset Size

In most cases, the necessary dataset size (i.e. the number of samples needed per well) will be a function of the purpose of the test, the power of the test needed to detect the minimum contamination, and the type of test.

Minimum sample sizes of groups for nonparametric ANOVA tests must be a little larger than those for parametric ANOVA tests. For the Wilcoxen Rank Sum test, the EPA recommends having at least four samples for both groups. For the Kruskal-Wallis procedure, EPA gives a rule of thumb that there should be "a minimum of three well groups with at least four observations per group" (EPA Addendum, 1992, Sections 3.1 and 3.2).

Possible scenarios for choosing the number of upgradient samples and the number of downgradient samples for two-phase (retesting) strategies are contained in Section 5.2 of the EPA Addendum (1992).

The power of a statistical test can be increased by increasing the number of samples. The power should be comparable to the EPA reference power curve (see EPA Addendum, 1992 - Section 5.2 and Appendix B). The EPA reference power curve does not depend on the number of wells in the network, but it does depend on the number of upgradient samples that are used to construct the upper prediction limit.

The exception to the benefits of increasing the number of samples is in long-term trend tests (greater than five years) where a greater number of data points (i.e. less time between sampling) may increase problems with serial correlation.

Procedures for seasonality tests (the Seasonal Kendall test) will generally require continuous monthly samples over years (at least 3) for adequate characterization of seasonal variation (see Gilbert, 1987, Chapter 17). Seasonality tests for quarterly sampling programs are not recommended.

#### 5.3.3.4 Outliers

Outlier values often result from identifiable analytical or transcription errors. These need to be corrected through careful review of the data. True outlier values need no special treatment and should not be deleted arbitrarily. This is especially true with the lognormal nature of groundwater data, which by definition may contain a few very large values. Resampling can be used as a tool to judge outliers. In addition, good quality assurance/quality control procedures will include data validation (see Section 8.3, item Q).

The EPA Addendum (1992, Section 6.2) lists a test procedure for normal or lognormal data that can be used, typically for outliers that are orders of magnitude above the rest of the data.

#### 5.3.3.5 Censored Data

Censored data refers to less-than detection or less-than reporting values. The EPA Addendum (1992, Section 2) details methods for handling nondetects. The approach depends on the percentage of nondetects (see Table 1).

### 5.3.4 Network Design

Monitoring network design typically results from prior knowledge or assumptions regarding site location, hydrology, water quality, and economics. Lacking prior information, Gilbert (1987) presents a thorough review of methods available to develop a statistically sound network.

Wilson and others (1992) present an additional method that attempts to quantify monitoring efficiency. A Monitoring Efficiency Model (MEMO) is used to calculate the area of detection compared to the total area of the site. The EPA Interim Final Guidance (1989, Appendix A) recommends that wells are sited so that "at least one of the wells should intercept a plume of contamination of reasonable size."

**Table 1. Procedures for handling nondetects (from the EPA Addendum, 1992).**

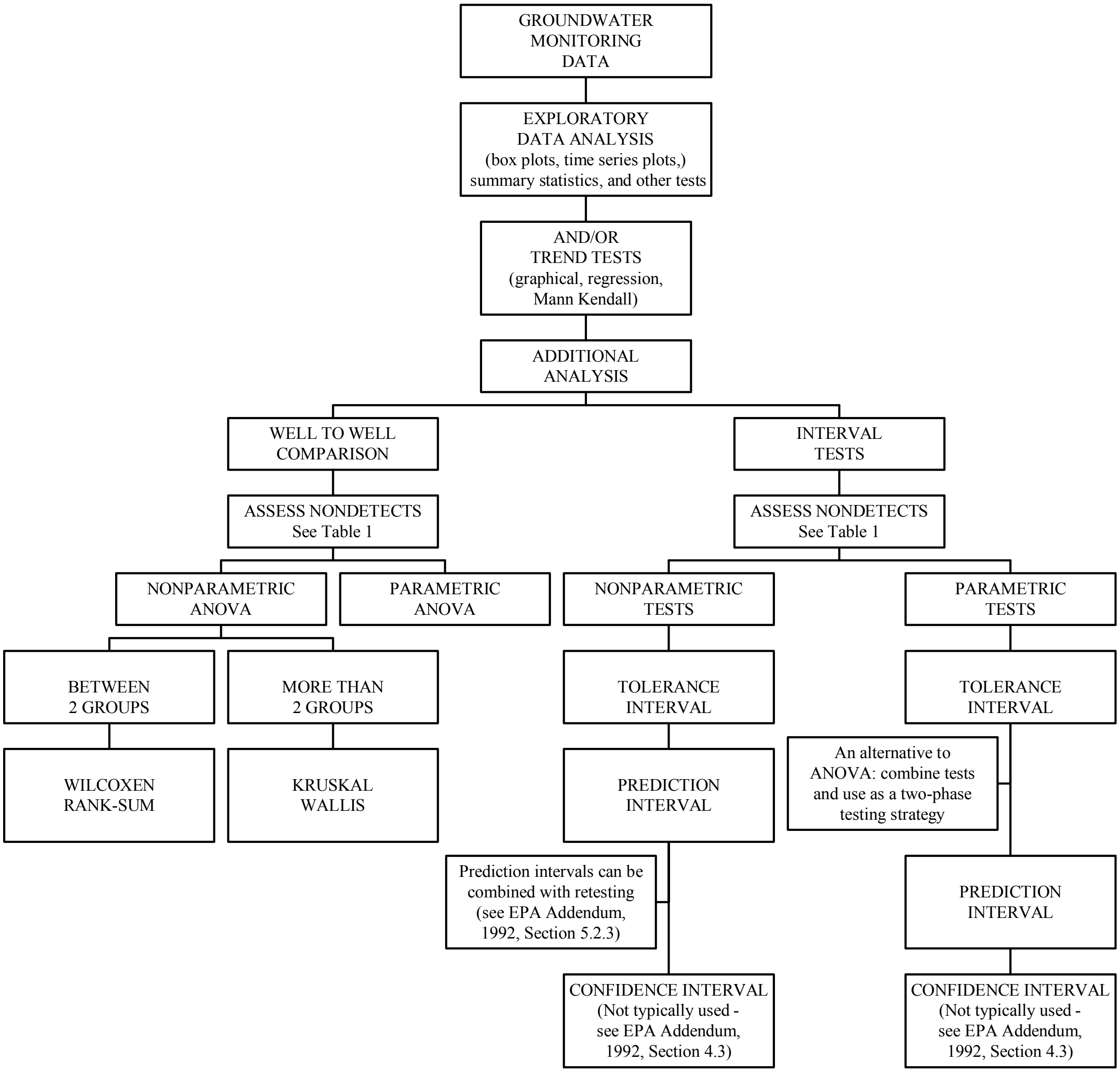
| Percentage of Nondetects | Method |
|---|---|
| Less than 15 percent | Replace nondetects by one-half the detection limit and proceed with parametric ANOVA or interval tests. |
| Over 15 percent | For comparing upgradient with downgradient wells, use a nonparametric test. For all two-group comparisons, use the Wilcoxon Rank-Sum test. For more than two, use Kruskal-Wallis test.<br><br>When using statistical interval tests (Confidence, Tolerance, or Prediction limits), use parametric approach along with Cohen's Procedure or Aitchisons's test to adjust the mean and standard deviation. The decision for Cohen's or Aitchison's test should be made based on the use of probability plots. See the EPA Addendum (1992) for more details. |
| Over 50 percent | With nondetects >50 percent or if tests cannot be justified, use nonparametric interval or nonparametric ANOVA tests (EPA Addendum, 1992, Chapter 4). |
| Over 90 percent | Use Poisson distribution model (EPA Addendum, 1992, Sections 2.2.3 and 2.2.4). |

See also Chapter 3 of the EPA Interim Final Guidance (1989, Location and Depths of Monitoring Wells). As discussed under Data Variability (Section 5.3.1), adequately characterizing the upgradient groundwater quality is very important. Nielsen (1991) recommends that multiple (at least four) upgradient wells be constructed at a site. For small sites or those with roughly homogeneous geologic conditions, two upgradient wells could be sufficient to account for spatial variability.

## 5.4 STATISTICAL PROCEDURES

The specific statistical procedures used depend on the goals and quality of the monitoring data. A general flow chart for statistical analysis is shown in Figure 9. The methods selected should be consistent with the goals of the monitoring. For example, monitoring data analysis at a permitted site may include trend analysis, well-to-standards and well-to-well comparisons, or the use of intervals. Monitoring data collected to characterize an aquifer may consist mainly of graphical displays and summary statistics.

**Figure 9. General guidance on selection of statistical procedures.**



Graphical and parametric statistical procedures discussed here are included in many introductory statistics textbooks (e.g. Iman and Conover, 1983 and Ott, 1988) and are available in many computer statistics packages.

The EPA Interim Final Guidance (1989) and EPA Addendum (1992) describe and provide examples for both the parametric and nonparametric methods. See additional discussions in Helsel and Hirsch (1992), Conover (1980), Gilbert (1987), and Davis and McNichols (1994, Parts I and II).

### 5.4.1 Graphical Procedures

Refer to Cleveland (1993) for a general reference on graphical procedures. The use of boxplots is described in the EPA Addendum (1992).

#### 5.4.1.1 Boxplots

A boxplot summarizes a data set by presenting the percentile distribution of the data. The "box" portion indicates the median and interquartile range (IQR). IQR is the middle 50 percent of data. Difference in the size of box halves represents data skewness.

Normal and symmetrical distributions will have equal size box halves. Extreme outliers are displayed as individual points that are recognized easily. Boxplots can be constructed by hand; however, many computer statistical packages will do them.

The boxplot of a lognormal distribution will have noticeably different-sized box halves. Lack of IQR overlap for different data sets will indicate a probable significant difference. Boxplots of seasonally grouped data can be used to detect data seasonality.

#### 5.4.1.2 Time Series Plots

A time series plot displays individual data points on a time scale. A monthly scale can help to identify seasonal variation. A yearly scale also can identify possible trends. Superimposing data from multiple sampling locations may provide additional information. Improved trend information is often available with data smoothing. One smoothing procedure showing movement of the 'center' of data over time is LOWESS. This procedure is most helpful with data having substantial variability and a long period of record. LOWESS requires computer software.

#### 5.4.1.3 Control Charts

Control charts are used to define limits for an analyte that has been monitored at an uncontaminated well over time. This procedure is a graphical alternative to prediction limits.

A common technique is the Shewhart-CUSUM control chart that plots the data on a time scale. Obvious features such as trends or sudden changes in concentration levels could then be observed. With this method, if any compliance well has a value or a sequence of values that lie outside the control limits for that analyte, it may indicate statistically significant evidence of contamination.

The control chart approach is recommended only for uncontaminated wells, a normal or lognormal data distribution with few nondetects, and for a dataset that has at least eight independent samples over a one-year period. This baseline is then used to judge the future samples. See the EPA Interim Final Guidance (1989, Section 7) and the EPA Addendum (1992, Section 6.1) for procedures.

### 5.4.2 Summary Statistics

Basic summary statistics can be used to characterize groundwater monitoring data. Summary statistics include median, interquartile range (IQR), mean, standard deviation, and range. Median and IQR are determined from percentiles. Median is 50th percentile and IQR is 25th to 75th percentile. Median indicates "center" of data values. The mean is another measure of center but only if data are normally or symmetrically distributed. However, most water quality data are not. Mean and standard deviation are required values with parametric procedures. Range is the minimum to maximum values. Procedures for such summary statistics are found in introductory statistics texts.

### 5.4.3 Interval Tests

#### 5.4.3.1 Statistical Intervals

Statistical interval tests can be used in combination with well to well comparisons, or independently. Statistical intervals include three main types: tolerance intervals, prediction intervals, and confidence intervals. Which ones are used depend on the goals of the data analysis (see Section 4 of the EPA Addendum, 1992 for procedures).

#### 5.4.3.2 Tolerance Intervals

Tolerance intervals will typically be the most useful interval test. They are used to determine the extent of data that is specified to be within a standard or ambient level. For example, the tolerance limit with a population coverage of 95 percent and a 95 percent confidence level calculated from compliance data should not exceed a standard (like an MCL). This tolerance limit will ensure that at least 95 percent of the population values will not exceed a standard with a 95 percent confidence level.

#### 5.4.3.3 Prediction Intervals

Prediction intervals are used to determine if the next one or more samples are within the existing data distribution at a certain confidence level. The prediction interval contains 100 * (1- $\alpha$ value) percent of the distribution. A smaller value will include a larger range of data. Prediction intervals are used for intrawell (single well) comparisons, and for comparison of a compliance well with an upgradient well.

#### 5.4.3.4 Confidence Intervals

Confidence intervals contain a specified parameter of the distribution (such as the mean of the data) at a specified confidence level. Confidence intervals do not address extreme values.

#### 5.4.3.5 Two-Phase Retesting Strategies

Once a tolerance interval is established for upgradient data, data from downgradient compliance wells can be compared to the upper limit of the interval. Such an interval can be combined with a prediction interval to use with the next sample, or it can be combined with resampling. A resampling strategy is used when an analyte exceeds the upper tolerance level. The well is retested for the parameter of concern and the value is compared to the upper limit of a prediction interval. These two-phase testing strategies can be very effective tools for controlling the Facility Wide False Positive Rate while maintaining a high power of detecting contamination.

See Sections 5.2.2 and 5.2.3 of the EPA Addendum (1992) which describe the procedures to use along with recommended coverage and confidence levels.

### 5.4.4 Well-to-Well Comparison Tests

The following tests are outlined in the EPA Interim Final Guidance (1989) and the EPA Addendum (1992). These are the recommended tests for analysis of groundwater data between upgradient and downgradient well groups, downgradient wells and a health-based standard, or of intrawell (single well) comparisons. This does not include all potentially satisfactory statistical tests, but are the preferred tests.

#### 5.4.4.1 Analysis of Variance (ANOVA)

ANOVA includes a group of procedures used for comparing the means of multiple (three or more) independent groups such as upgradient wells and downgradient wells. The ANOVA methods are used to determine if there is statistically significant evidence of contamination at downgradient wells compared to an upgradient well, or groups of wells.

The one-way ANOVA method is described with examples in Section 5.2 of the EPA Interim Final Guidance (1989). This is the EPA recommended procedure for comparing data that do not violate the assumptions of normal distribution and approximately equal variances.

However, as the number of wells (or groups) increases at a site, the power of ANOVA to detect individual instances of contamination decreases. For this reason, tolerance and prediction intervals with retesting provisions are often much better procedures to use.

#### 5.4.4.2 Kruskal-Wallis Test

If assumptions of the one-way ANOVA test are "grossly" violated, the nonparametric Kruskal-Wallis test is used for more than two independent groups of data. It can be used for comparison of upgradient water quality to water quality from many downgradient wells in one procedure. Alternatively, if the wells are grouped by some characteristic (e.g. depth, geology, location, season), comparisons among other groups can be made.

If the null hypothesis (no change) is rejected by Kruskal-Wallis (i.e. the test statistic exceeds the tabulated critical value), then pairwise comparisons should be made to determine what wells are contaminated (see Gilbert, 1987, Section 18.2.2; the EPA Addendum, 1992, Section 3.1; and the EPA Interim Final Guidance, 1989, Section 5.2.2).

#### 5.4.4.3 Wilcoxon Rank Sum

This procedure (also known as Mann-Whitney) is a nonparametric test for differences between two independent groups such as upgradient and downgradient water quality samples, baseline and compliance samples, and assessment and remediation samples. See Section 3.2 of the EPA Addendum (1992).

#### 5.4.4.4 t-test

The t-test is a parametric, ANOVA type of test used to assess differences in means of two independent groups. This test assumes normal distributions and equal variances for both groups. The t-test is best limited to situations where the data sets are too small to use nonparametric procedures. For example, if upgradient groundwater quality is limited to two or three samples, the t-test can be used to test for differences between upgradient and compliance data.

### 5.4.5 Trend Tests

#### 5.4.5.1 Considerations

When monitoring data have been collected over several years or more, trend tests allow the determination of the change in distribution of data over time. In addition to water quality trends, a time series of monitoring data may contain characteristics of seasonality and serial correlation. Other complicating factors include changes in laboratories or procedures involving the sampling and analysis of the analyte.

Seasonality and serial correlation interfere with trend tests either by reducing the power to detect trends or giving erroneous probabilities. Correction for seasonality is available for tests presented here. Serial correlation exists if a data point value is at least partially dependent on nearby data point values. For a given data set, serial correlation decreases with increasing temporal distance between samples. Harris and others (1987) reported difficulty detecting serial correlation in 10 years or less of quarterly groundwater data. Therefore, correction is not recommended for quarterly data. Serial correlation correction is available for Seasonal Kendall trend test (Hirsch and Slack, 1984), but has reduced power with small data sets and not recommended for a monthly time series that is less than five years.

#### 5.4.5.2 Parametric Trend Tests

Parametric trend tests are based on regression methods and allow compensation for exogenous effects (outside influences). Regression analysis between two variables can be used to calculate the correlation coefficient (r). The closer r is to one, the closer the relationship is between the two variables. A t-test of correlation can be done on r to see if it is significant (see Davis, 1987, Chapter 2).

Mixed (i.e. parametric and nonparametric methods) methods also are available when removing the effects of exogenous variables. Helsel and Hirsch (1992) present a thorough review of trend analysis. Methods for detecting trends also are presented in Chapter 16 of Gilbert (1987).

Because regression techniques are based on the assumption of a normal distribution of the data, a nonparametric approach may have to be used.

#### 5.4.5.3 Nonparametric Trend Tests

The Mann-Kendall trend test is a nonparametric test for monotonic (steadily upward or downward) trend. This method is used on a dataset of less than 40 in number, but can be used for as few samples as ten if the dataset does not contain many "ties." For greater than 40 samples, the normal approximation test is used (Gilbert, 1987).

This test requires constant variance in data. Non-constant variance may be changed to constant variance with a power transformation. Logarithm transformation is usually most appropriate. This transformation does not affect the test statistic. Decision rules, exact test tables, normal approximation formulas, and correction for ties can be found in Helsel and Hirsch (1992); Gilbert (1987) and many introductory statistics texts. When a trend is present, the slope of fitted line can be estimated using Sen's estimator (see Gilbert, 1987).

The Seasonal Kendall trend test is a seasonally corrected Mann-Kendall trend test. This should be applied when time series graphs or boxplots of data indicate the presence of seasonal variation. See Chapter 17 of Gilbert (1987).

## 5.5 REFERENCES

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# CHAPTER 6: GROUNDWATER SAMPLING TECHNIQUES

## 6.1 IMPORTANCE OF SAMPLING TECHNIQUE

Proper sampling procedures that will allow a representative measure of groundwater quality are critical to any monitoring program. The potential accuracy of the sample analysis in the laboratory depends on the sampling methodology in the field. A laboratory cannot generate reliable data if the sample was collected improperly. Therefore, taking precautions and selecting the correct sampling methods are imperative to ensure accurate and representative analyses.

Groundwater samples may not be representative of the aquifer for the following reasons:

1. The sample was taken from stagnant water in the well. Water standing in a well and exposed to the atmosphere may undergo a gas exchange (oxygen and carbon dioxide) allowing chemical reactions to occur. Biological organisms capable of driving reactions might also be introduced. Obviously, such waters will no longer be representative of the water within the aquifer and should be purged prior to sampling.

2. The sample was not collected at the appropriate time. The sample should be collected as soon as possible after purging is completed. This reduces the possibility of chemical reactions occurring because of gas exchange and temperature variations. In addition, if the well is pumped too long, the sample may represent water so far from the well site that the groundwater chemistry is not representative of the site being monitored.

3. The sample contained suspended or settleable solids. Because of the natural filtering action and slow velocity of most aquifers, groundwater is generally free of suspended solids. However, even properly constructed monitoring wells will often fail to produce samples that are free of sediment or settleable solids (turbidity). When samples containing suspended solids are analyzed for metals, this sediment is digested (dissolved) in the laboratory prior to performing the analysis. Consequently, any of the metals present in the sediment (primarily iron, manganese, and aluminum) will be included in the results of the analysis made on the water that includes these metals. The analysis of the water samples containing sediment will result in certain analytes such as these metals being reported at higher levels than they actually occur in groundwater.

   In addition to these common metals, numerous other metals that occur in the earth's crust in trace amounts such as lead, chromium, and cadmium also will show up in the analysis. The sediment content of the monitoring wells will often vary across a site, and even samples collected from the same well at different times will vary in sediment content. This problem can make analysis of monitoring well data for metals where samples have not been filtered to remove turbidity an almost futile exercise.

4. The sample was not collected at the proper depth interval. Sampling of domestic water supply wells or wells with similar construction may encounter this problem. Assume that an open well bore penetrates more than one aquifer with one of the aquifers supplying contaminated water near the bottom of the well. If the sampling interval is near the top of the well, the sample may reflect only the uncontaminated

aquifer with the contaminated water remaining near the bottom of the well in the unsampled interval. However, because of mixing, it will not be possible to obtain a true sample from the individual aquifers with this type of well construction.

5. Release of carbon dioxide during pumping increased the pH, allowing many metallic ions to come out of solution (i.e. iron, manganese, magnesium, cadmium, arsenic, selenium, and boron). Pumping can also cause volatilization of VOCs. This emphasizes the importance of conducting field measurements such as pH, specific conductance, temperature, etc. within the well before the sample is brought to the surface.

6. Chemical changes occurred from oxidation of the sample during sampling. Dissolved oxygen is usually very limited within aquifers. Bringing the sample to the surface allows oxygen to dissolve within the water sample. Oxidation also can occur in the pump or can be caused by water cascading into a well installed in tight formations. Depending on the chemical makeup of the sample, the addition of dissolved oxygen may allow chemical reactions to proceed. Some of the changes that can be expected include oxidation of 1) organics, 2) sulfide to sulfate, 3) ferrous iron and precipitation of ferric hydroxide, 4) ammonium ion to nitrate, and 5) manganese and precipitation of manganese dioxide or similar hydrous oxide. In cases where oxidation would be expected to impact on chemical quality, precautions should be employed to reduce oxidation potential (e.g. minimize agitation during purging and sample collection, minimize the length of time the sample is exposed to air, fill the sample container completely to the top, and promptly chill the sample).

7. The sample was not preserved correctly. Increases in temperature will allow certain chemical reactions to occur. Certain metals, especially iron, may coat the insides of the sample container. If the sample is not properly preserved for shipment to the laboratory, the sample which arrives at the lab may be quite chemically different from the sample which was collected in the field.

8. The sample was contaminated by residues in sampling equipment. Residues may cling to the sampling equipment if it is not properly cleaned or decontaminated. Those residues may become mobile in succeeding samples, yielding unreliable results. This becomes critical when the analytes being sampled are in the parts per billion or parts per trillion range.

## 6.2 SAMPLE COLLECTION DEVICES

The most common devices available for the collection of water from monitoring wells include bailers, suction-lift pumps, air-lift samplers, bladder pumps, and submersible centrifugal pumps. Each has its advantages and disadvantages as shown in Table 2. These should be considered before selecting the sample collection device.

**Table 2. Advantages and disadvantages of different sampling devices.**

| | ADVANTAGES | DISADVANTAGES |
|---|---|---|
| Bailer | Portable<br><br>Simple to use | Difficult to ascertain where within the water column the sample is collected<br><br>Allows for oxidation of the sample<br><br>Disturbance of the water column by the sampler<br><br>Impractical for removing large volumes of water |
| Suction-lift Pump | Allows sample to contact only Teflon<br><br>Simple to use for shallow applications | Limited to shallow groundwater conditions<br><br>Causes sample mixing, oxidation, and allows for degassing |
| Air-lift Sampler | Suited for small diameter wells | Causes extreme agitation<br><br>Significant redox, pH, and specie transformations<br><br>Plastic tubing source of potential contamination |
| Bladder Pump | Provide a reliable means for highly representative sample<br><br>Mixing and degassing minimized<br><br>Portable | Somewhat more complex than other samplers |
| Submersible Centrifugal Pump | Higher extraction rates | Considerable agitation and turbulent flow<br><br>Potential to introduce trace metals from the pump materials |

## 6.3 SAMPLE COLLECTION PROCEDURES

The following are general procedures that should serve as a framework for sampling groundwater. These procedures should be modified where necessary for each situation encountered in the field and to conform to monitoring objectives. In addition, appropriate health and safety measures should always be taken before, during, and after sampling.

### 6.3.1 Protective Clothing

Wear protective clothing if the nature of the contaminants dictate that it should be worn. Different types of protective clothing are appropriate for different contaminants.

### 6.3.2 Water Levels

If possible, determine and record the static water level of the well. This level should be determined prior to well purging, which creates drawdown.

### 6.3.3 Field Measurements

In most cases, field measurements should be accomplished before and during the sampling to gauge the purging of the well, and to measure any changes between the time the sample is collected and when it is analyzed in the laboratory. The following measurements and observations are often determined in the field:

- pH
- Eh
- water level
- temperature
- specific conductance
- dissolved oxygen
- acidity/turbidity
- weather conditions
- time of sampling

The specific techniques for obtaining each of these measurements depend upon the instruments used. The operator should carefully read and follow the manufacturer's instructions, including those for equipment maintenance and calibration. A record of the calibration and maintenance checks should be kept.

### 6.3.4 Purging

The purpose of purging a well prior to sampling is to remove stagnant water from the well bore and assure that the sample is representative of the groundwater in the geologic formation being sampled. Stagnant water in the well bore results from the water's contact with the casing and atmosphere between sampling events. What would seem to be a relatively simple and straightforward procedure, purging technique has, in fact, been the subject of considerable scientific investigation and discussion.

There are two basic approaches to purging a well. The first is to use dedicated equipment in which the water is pumped from a fixed position in the well. This technique eliminates the possibility of cross-contamination, but tends to purge only the well section or screen section that is opposite the purge pump. (This is especially a concern when purge rates are much lower than the yield of the water-bearing zone supplying water to the purge pump.)

The second basic approach is to use a transportable pump and purge from the water surface, or preferably by gradually lowering the pump in the well as stagnant water is evacuated. This technique is considered to be more reliable in terms of evacuating the entire well bore. However, the disadvantage is that the equipment must be decontaminated between wells, which in turn increases the potential for cross-contamination.

An excellent summary of purging methods and techniques is given by Herzog et al., (in Nielsen, 1991). The following discussion is based in part on that summary. Four techniques for determining the volume of water to be purged from a well are discussed. These include criteria based on:

1. Numbers of well bore volumes
2. Stabilization of indicator parameters
3. Hydraulic and chemical parameters
4. Time series sampling

By far, the most common choices have been to base the purging volume on either a certain number of well volumes or stabilization of chemical analytes, or some combination of these two.

#### 6.3.4.1 Criteria Based on the Number of Bore Volumes

The purging of three well volumes has become so unquestionably accepted and ingrained in monitoring practice as to be practically elevated to the status of a scientific law. However, Herzog et al. provide references from numerous studies that variously conclude that from less than one to more than 20 bore volumes be purged from wells prior to sampling. They conclude:

"It is obvious that it is not possible to recommend that a specific number of bore volumes be removed from monitoring wells during purging. The range of suggested volumes is too large and the cost of improper purging is too great to permit such a recommendation."

DEP recommends that if the borehole volume technique is going to be used, the number of borehole volumes required for each well should have a technical or scientific basis, such as stabilization of indicator parameters (see following section) conducted at least once for each well during initial sampling events, rather than being based on some arbitrary criterion such as "three well volumes."

When purging is based on some set number of borehole volumes, the borehole volume calculation should take into account the entire original borehole diameter, corrected for the porosity of any sand or filter pack, and not be based just on the innermost casing diameter.

#### 6.3.4.2 Criteria Based on Stabilization of Indicator Parameters

Stagnant water in a well bore differs from formation water with respect to many parameters. Field measurement of indicator parameters such as temperature, pH, specific conductance, dissolved oxygen, and Eh has been used as the criteria for determining the amount of water to purge and when to sample a well. These parameters are measured in the purge water during purging until they stabilize. DEP encourages the use of this method.

DEP recommends that all of the above indicators should be measured during the initial first few sampling events of the monitoring well. The data should then be reviewed to determine which indicator parameters are the most sensitive in indicating when stagnant water has been evacuated from the well. The most sensitive parameters will be those that show the greatest changes and longest times for stabilizing. During the initial sampling, the purging time should probably be extended beyond what initially appears to be stabilization as a check to assure that the parameter stability is maintained. Where this technique is chosen, DEP believes that the wells should be measured for the indicator parameters suggested above and the three most sensitive should be used.

#### 6.3.4.3 Special Problems of Low Yielding Wells

Low yielding wells present a special problem for the sampler in that they may take hours or even days to recover after purging to the extent that there is enough water to take a sample. This waiting period not only increases the cost of sampling but also allows changes in water quality, especially with regard to volatile constituents, to occur between the time the sample water enters the casing and the time it is collected.

In practice, very low yield wells are commonly pumped dry and sampled the following day if necessary. This practice is believed to result in less than truly representative water being sampled from the well due to the loss of volatiles and oxygenation of the water during the waiting period, and as a result of pumping the well dry and exposing the formation to the atmosphere. While there does not appear to be any uniformly agreed upon method for eliminating these concerns, the following considerations are suggested:

- Purge in such a way that the water level does not fall below the well screen.
- Evaluate the use of larger diameter wells that may deliver the required amount of sample water sooner than small diameter wells.

- If full recovery cannot be achieved within two hours, collect the required amount of water as it becomes available, collecting samples for parameters in order of decreasing volatility.

#### 6.3.4.4 Summary on Purging

The following general statements can be made with respect to purging:

- Every groundwater monitoring plan should contain a section dealing with how wells will be purged.

- It is often desirable to use the same device for sampling that was used for purging. In this case the purge pump can be set within the screened section of the well, or across from the yielding zone being monitored.

- If different devices are used for purging and sampling, purging should begin at the static water surface and the device should be lowered down the well at a rate proportional to water stored in the well bore. Because of the better mixing of water in wells with multiple yielding zones, this technique is considered preferable for sampling wells with multiple yielding zones where a composite sample of water in the yielding zones is desired (see Section 3.5 on Well Depths, Screen Lengths, and Open Intervals).

- Where the same device is used to sample and purge a well, it must be established that the sampling device will not change the quality of the groundwater it comes into contact with.

- In sampling for some analytes, such as volatile organics, it is critical that the discharge be reduced to approximately 100 ml/minute to minimize degassing and aeration (Barcelona et al., 1984). Flow control should be by means of an electric current using a rheostat rather than by valving or other flow restrictors.

- Purging should be completed without lowering the water level in the well below the well screen or water bearing zone being sampled.

- Never purge a well at such a rate or in such a way that water cascades into the well bore resulting in increased degassing and volatilization.

### 6.3.5 Management of Purge Water

Groundwater removed during purging should be handled in a way that is environmentally compatible with the type and concentration of the suspected contaminant in the aquifer. Monitoring instruments such as photoionization meters should be used when appropriate to periodically screen the groundwater. A procedure that can be used is outlined in Table 3. The goal of handling potentially contaminated groundwater is to safely discharge the purge water while avoiding pollution of another part of the environment, such as surface water bodies or another aquifer.

### 6.3.6 Private Wells

If the well is a private water supply, sample as close to the well as physically practical and prior to any treatment or filtering devices if possible and practical. If collection has to be made from a holding tank, allow water to flow long enough to flush the tank and the lines. If a sample that passes through a treatment tank must be taken, the type, size, and purpose of the unit should be noted on the sample data sheet and in the field log book.

### 6.3.7 Filtering

When possible, avoid collecting samples which are turbid, colored, cloudy or contain much suspended matter. Exceptions to this include when the sample site has been pumped and flushed, or has been naturally flowing for a sufficient amount of time to confirm that these conditions are representative of the aquifer conditions.

Unless analysis of unfiltered samples for "total metals" is specifically required by program regulation or guidance, all samples for metals analysis should be field-filtered through a 0.45-micron filter prior to analysis.

### 6.3.8 Sample Preservation

Perform sample preservation techniques on-site as soon as possible after the sample is collected. Complete preservation of samples is a practical impossibility. Regardless of the nature of the sample, complete stability for every constituent can never be achieved. For this reason, samples should be analyzed as soon as possible. However, the ongoing chemical and biological changes in the sample may be slowed significantly by proper preservation techniques.

Chemical changes generally happen because of a shift in the physical conditions of the sample. Under a fluctuation in the reducing or oxidizing conditions, the valence number of the cations or anions may change; other analytes may volatilize or dissolve; metal cations may form complexes or precipitate as hydroxides, or they may adsorb onto surfaces.
Biological changes can also alter the valence of a constituent. Organic processes may bind soluble material into the cell structure, or cell material may be released into solution.

**Table 3. Suggested procedure for the management of purge water from groundwater sampling.**

| TYPE OF GROUNDWATER | ACTION |
|---|---|
| Uncontaminated Groundwater | Disposal may proceed with normal precautions (i.e. avoid erosion, stream discharge, and hazards associated with freezing conditions; also, monitor for adverse changes in water quality) |
| Contaminated Groundwater | a) Convey directly into an on-site treatment plant<br>b) Take to off-site treatment<br>c) Place into an area where it will drain to a collection site for on or off site treatment (i.e. leachate collection systems)<br>d) Discharge to ground surface if it is determined that based on the type and concentration of the contaminant , and the volume of the discharge, that the discharge will not impact any surface water body or cause environmental harm<br>e) Other methods approved by DEP |
| Groundwater of Uncertain Quality | Discharge to ground if all of the following conditions are met*:<br>a) The well is not associated with a corrective action or a remediation project<br>b) The groundwater shows no obvious sign of contamination, such as odor, color, or visually-apparent material in the water, or readings from monitoring instruments<br>c) The discharge will not impact any surface water body or cause environmental harm<br><br>*If these conditions cannot be met, then the water is classified as contaminated groundwater and must be handled as indicated above. |

Methods of preservation are relatively limited and are intended to generally 1) retard biological activity, 2) retard hydrolysis of chemical compounds and complexes, 3) reduce the volatility of constituents, and 4) reduce sorption effects. Preservation methods are generally limited to pH control, chemical addition, refrigeration, freezing, and selecting the type of material used to contain the sample.

The best overall preservation technique is refrigeration at or about 4°C. Refrigeration mainly helps to inhibit bacteria. However, this method is not always applicable to all types of samples.

Acids such as $HNO_3$ and $H_2SO_4$ can be used to prevent precipitation and inhibit the growth of bacteria. Preservation methods are specified in the Bureau of Laboratories Users Guide for each of the standard analyses listed.

#### 6.3.9 Decontamination of Sampling Devices

The methods used will vary depending upon the analytes which are being sampled. This is extremely important when sampling for constituents thought to be present in the parts per billion or parts per trillion range. Decontamination procedures are described in Appendix A.

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# CHAPTER 7: WELL ABANDONMENT PROCEDURES

## 7.1 INTRODUCTION

Unsealed or improperly sealed wells may threaten public health and safety, and the quality of the groundwater resources. Therefore, the proper abandonment (decommissioning) of a well is a critical final step in its service life.

Act 610, the Water Well Drillers License Act, includes a provision for abandonment of wells. This legislation makes it the responsibility of a well owner to properly seal an abandoned well according to the rules and regulations of the Department of Conservation and Natural Resources (DCNR). In the absence of more stringent regulatory standards, the procedures outlined in this section represent minimum guidelines for proper abandonment of wells and borings. These procedures may be applicable for, but not limited to, public and domestic water supply wells, monitoring wells, borings or drive points drilled to collect subsurface information, test borings for groundwater exploration, and dry wells (drains or borings to the subsurface).

Proper well abandonment accomplishes the following: 1) eliminates the physical hazard of the well (the hole in the ground), 2) eliminates a pathway for migration of contamination, and 3) prevents hydrologic changes in the aquifer system, such as the changes in hydraulic head and the mixing of water between aquifers. The proper decommissioning method will depend on both the reason for abandonment and the condition and construction details of the boring or well.

## 7.2 WELL CHARACTERIZATION

Effective abandonment depends on knowledge of the well construction, geology, and the hydrogeology. The importance of a full characterization increases as the complexity of the well construction, site geology, and the risk of aquifer contamination increases. Construction information for wells drilled since 1966 may be available from DCNR, Bureau of Topographic and Geologic Survey's (BTGS) Water Well Inventory System database. Additional well construction data and information describing the hydrologic characteristics of geologic formations may be available from reports published by BTGS and the United States Geological Survey (USGS). Site or program records also may exist. The well should be positively identified before initiating the abandonment. Field information should be compared with any existing information.

Water levels and well depths can be measured with a well sounder or weighted tape measure. In critical situations, well construction details and hydrogeology can be determined with borehole geophysics or a downhole camera. For example, a caliper log, which is used to determine the borehole diameter, can be very helpful in locating cavernous areas in open hole wells.

## 7.3 WELL PREPARATION

If possible, the borehole must be cleared of obstructions prior to abandonment. Obstructions such as pumps, pipes, wiring, and air lines must be pulled. Well preparation also may involve fishing obstacles out of the borehole. An attempt should be made to pull the casing when it will not jeopardize the integrity of the borehole. Before the casing is pulled, the well should be grouted to near the bottom of the casing. This will at least provide some seal if the well collapses after the casing is pulled.

The presence of nested or telescoped casing strings complicates well abandonment. Inner strings should be removed when possible, but only when removal will not jeopardize the abandonment of the well. If inner strings cannot be removed and sealing of the annular space is required, then the inner string should be vertically split (plastic cased wells) or cut (metal-cased wells) at intervals necessary to insure complete filling of the annular space.

Damaged, poorly constructed or dilapidated wells may need to be redrilled in order to apply proper abandonment techniques. Also, in situations where intermixing of aquifers is likely, the borehole may need to be redrilled.

## 7.4 MATERIALS AND METHODS

### 7.4.1 Aggregate

Materials that eliminate the physical hazard and open space of the borehole, but do not prevent the flow of water through the well bore, are categorized as aggregate. Aggregates consist of sand, crushed stone or similar material that is used to fill the well. Aggregates should be uncontaminated and of consistent size to minimize bridging during placement.

Aggregate is usually not placed in wells smaller than two inches in diameter. Nominal size of the aggregate should be no more than 1/4 of the minimum well diameter through which it must pass during placement. Because aggregate is usually poured from the top of the well, care must be taken to prevent bridging by slowly pouring the aggregate and monitoring the progress with frequent depth measurements.

Aggregates may be used in the following circumstances: 1) there is no need to penetrate or seal fractures, joints or other openings in the interval to be filled, 2) a watertight seal is not required in the interval to be filled, 3) the hole is caving, 4) the interval does not penetrate a perched or confined aquifer, and 5) the interval does not penetrate more than one aquifer. If aggregate is used, a casing seal should be installed (see Section 7.5.1). The use of aggregate and a casing seal must be consistent with the future land use.

### 7.4.2 Sealants

Sealants are used in well abandonment to provide a watertight barrier to the migration of water in the well bore, in the annular spaces or in fractures and openings adjacent to the well bore. Sealants usually consist of Portland cement based grouts, "bentonite" clay, or combinations of these substances. Additives are frequently used to enhance or delay specific properties such as viscosity, setting time, shrinkage, or strength.

Sealing mixtures should be formulated to minimize shrinkage and ensure compatibility with the chemistry of the groundwater in the well.

A grout pump and tremie pipe are preferred for delivering grout to the bottom of the well. This method insures the positive displacement of the water in the well, and will minimize dilution or separation of the grout.

If aggregate is to be placed above sealant, a sufficient amount of curing time should pass before placing the aggregate above the seal.  Curing time for grout using Type 1 cement is typically 24 - 48 hours, and 12 hours for Type III cement.

General types of sealants are defined as follows:

Neat cement grout:  Neat cement grout is generally formulated using a ratio of one 94-pound bag of Portland cement to no more than 6 gallons of water.  This grout is superior for sealing small openings, for penetrating any annular space outside of the casings, and for filling voids in the surrounding rocks. When applied under pressure, neat cement grout is strongly favored for sealing artesian wells or those penetrating more than one aquifer.  Neat cement grout is generally preferred to concrete grout because it avoids the problem of separation of the aggregate and the cement.  Neat cement grout can be susceptible to shrinkage and the heat of hydration can possibly damage some plastic casing materials.

Concrete grout:  Concrete grout consists of a ratio of not more than six gallons of water, one 94-pound. bag of Portland cement, and an equal volume of sand. This grout is generally used for filling the upper part of the well above the water bearing zone, for plugging short sections of casings, or for filling large-diameter wells.

Concrete grout, which makes a stronger seal than neat cement, may not significantly penetrate seams, crevices or interstices.  Grout pumps can handle sand without being immediately damaged.  Aggregate particles bigger than this may damage the pump.  If not properly emplaced, the aggregate is apt to separate from the cement.  Concrete grout should generally not be placed below the water level in a well, unless a tremie pipe and a grout pump are used.

Grout additives:  Some bentonite (2 to 8 percent) can be added to neat cement or concrete grout to decrease the amount of shrinkage.  Other additives can be used to alter the curing time or the permeability of the grout.  For example, calcium chloride can be used as a curing accelerator.

High-solids sodium bentonite:  This type of grout is composed of 15-20 percent solids content by weight of sodium bentonite when mixed with water.  To determine the percentage content, the weight of bentonite is divided by the weight of the water plus the weight of the bentonite.  For example, if 75 pounds of powdered bentonite and 250 pounds of granular bentonite were mixed in 150 gallons of water (at 8.34 pounds per gallon), the percentage of high-solids bentonite is approximately 20 percent (325/(1251+325)).  High-solids bentonite must be pumped before its viscosity is lowered.  Pumping pressures higher than those used for cement grouts are usually necessary.  Hydration of the bentonite must be delayed until it has been placed down the well.  This can be done by 1) using additives with the dry bentonite or in the water, 2) mixing calcium bentonite (it expands less) with sodium bentonite, or 3) using granular bentonite, which has less surface area.

In addition, positive displacement pumps such as piston, gear, and moyno (progressive cavity) pumps must be used because pumps that shear the grout (such as centrifugal pumps) will accelerate the congealing of the bentonite.  A paddle mixer is typically used to mix the grout.  A high-solids bentonite grout is not made from bentonite that is labeled as drilling fluid or gel.

Chip Bentonite: Chip (coarse grade) or pelletized bentonite can form adequate seals. This type of bentonite is poured directly down the borehole. The size of the bentonite chips also should be no more than 1/4 of the minimum well diameter through which it must pass during placement. Because of the potential for bridging, this material may not be suitable for deep wells or borings where positive displacement is necessary to seal the well.

When coarse bentonite is placed above the water level, water must be added frequently to hydrate the bentonite. Care must be taken with chip or pelletized bentonite to not overload the interval to be sealed. Rapidly swelling bentonite could result in incomplete hydration and a heterogeneous seal containing lumps of dry bentonite. The level of the bentonite should be checked often to make sure that bridging of the chips does not occur.

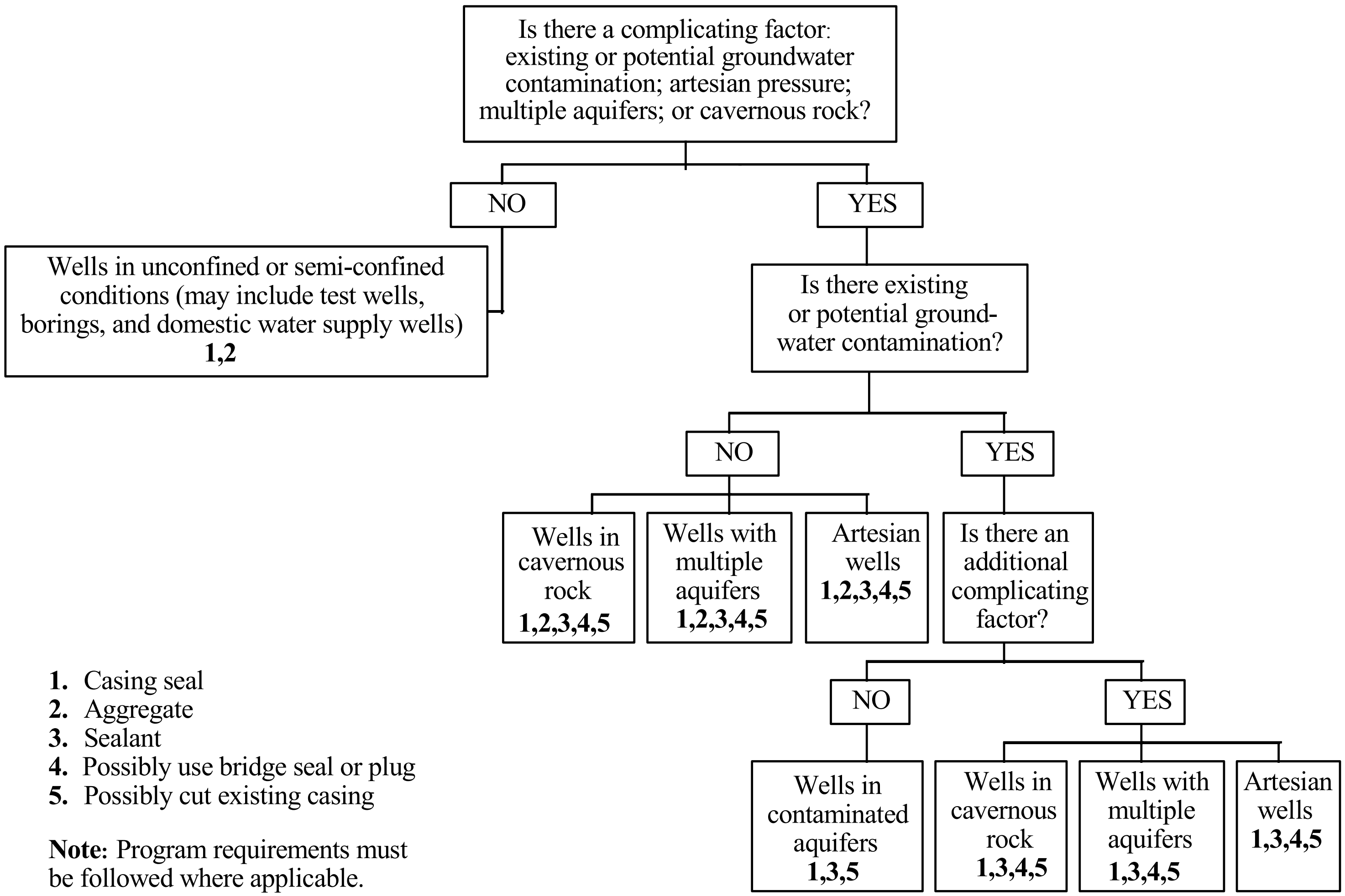
#### 7.4.3 Bridge Seals

A bridge seal can be used to isolate cavernous sections of a well, to isolate two producing zones in the well, or to provide the structural integrity necessary to support overlying materials (and thus protect underlying aggregate or sealants from excessive compressive forces). Bridge seals are usually constructed by installing an expandable plug made of wood, neoprene, or a pneumatic or other mechanical packer. Additional aggregate can be placed above the bridge.

### 7.5 RECOMMENDATIONS

The complexity of the abandonment procedure depends primarily on the hydrogeology, geology, well construction, and the groundwater quality. Four principal complicating factors have been identified; they include 1) artesian conditions, 2) multiple aquifers, 3) cavernous rocks, and 4) the threat or presence of contamination. The recommended procedures for abandoning wells will be more rigorous with the presence of one or more complicating factors. The procedures may vary from a simple casing seal above aggregate to entirely grouting a well using a tremie pipe after existing casing has been ripped or perforated. Figure 10 summarizes the general approach to well abandonment.

**Figure 10. Summary of procedures for well abandonment.**




**1.** Casing seal
**2.** Aggregate
**3.** Sealant
**4.** Possibly use bridge seal or plug
**5.** Possibly cut existing casing

**Note**: Program requirements must be followed where applicable.

### 7.5.1 Casing Seal

The transition from well casing to open borehole is the most suspect zone for migration of water. In order to minimize the movement of water (contaminated or otherwise) from the overlying less consolidated materials to the lower waterbearing units, this zone must be sealed. Generally this can be accomplished by filling at least the upper 10 feet of open borehole and the lower five feet of casing with sealant. The length of open borehole sealed should be increased if extenuating circumstances exist. Such circumstances would include a history of bacterial contamination, saprolitic bedrock, or possibly deep fracture zones. Waterbearing zones reported in the upper 20 feet or so of open borehole are indications of fractures and would warrant additional sealant. Casing that is deteriorated should be sealed along its entire length. If the casing is to be pulled the sealant used should remain fluid for a period of time adequate for removal of the casing.

If the casing is to remain, then whenever feasible, it should be cut off below land surface. After the casing seal discussed above achieves adequate strength, the open casing should at a minimum, be filled with aggregate. It is strongly suggested that a sealant be used in the upper 2 to 5 feet of casing.

### 7.5.2 Wells in Unconfined or Semi-Confined Conditions

These are the most common type of wells in Pennsylvania. The geology may consist of either unconsolidated or consolidated materials. When applicable, unconfined wells in non-contaminated areas may be satisfactorily abandoned using aggregate materials up to 10-15 feet below the ground surface. This would apply mainly to domestic wells, and test borings or wells not covered by existing regulations. Monitoring wells that are not covered by specific regulatory programs and are located at sites with no known contamination, might be abandoned in this manner. Above the aggregate, the casing seal should be installed. A sealant may be used over the entire depth.

### 7.5.3 Wells at Contaminated Sites

An abandoned, contaminated well often mixes contaminated groundwater with uncontaminated groundwater. Complete and uniform sealing of the well from the bottom to the surface is required. Therefore, proper well preparation (Section 7.3) must be done before the well is sealed with a proper sealant (Section 7.4.2).

### 7.5.4 Wells in Cavernous Rocks

Problems can arise when filling wells that penetrate cavernous rock. Although such wells are usually located in carbonate terrain, voids can also occur in areas that have been deep mined. Care must be taken to insure that aggregates and sealants are of a size and consistency to prevent their removal by water flowing in the void. Large voids or high flow velocities warrant placement of a bridge in competent rock over the void. Aggregate and sealants can then be placed above the bridge.

### 7.5.5 Multiple Aquifer Wells

The main goal in sealing wells that extend into more than one aquifer is to prevent the flow of groundwater from one aquifer to another. If no appreciable movement of water is encountered, and there is no threat of groundwater contamination, sealing with concrete, neat cement, grout, or alternating layers of these materials and aggregate will prove satisfactory. When groundwater velocities are high, the procedures for wells with artesian flow (see the next section) are recommended. If alternating plugs (or bridges) and aggregate layers are used, the plugs should be placed in known nonproductive horizons or, if locations of the nonproductive horizons are not known, at frequent intervals.

### 7.5.6 Flowing Wells

The sealing of artesian wells requires special attention. The flow of groundwater may be sufficient to make sealing by gravity placement of concrete, cement grout, neat cement, clay or sand impractical. In such wells, large stone aggregate (not more than 1/4 of the diameter of the hole), well packers (pneumatic or other), or wooden plugs will be needed to restrict the flow and thereby permit the gravity placement of sealing material above the zone where water is produced. If plugs are used, they should be several times longer than the diameter of the well to prevent tilting. Seals should be designed to withstand the maximum anticipated hydraulic head of the artesian aquifer.

Because it is very important in wells of this type to prevent circulation between water yielding zones, or loss of water to the surface or to the annular spacing outside of the casing, it is recommended that pressure grouting with cement be done using the minimum volume of water during mixing that will permit handling.

In wells in which the hydrostatic head producing flow to the surface is low, the movement of water may be stopped by extending the well casing to an elevation above the artesian pressure surface.

### 7.5.7 Wells with Complicating Factors at Contaminated Sites

Wells with one or more of the above complicating factors that are to be abandoned in areas with contaminated groundwater or in areas where the groundwater is at a high risk for future contamination, require the most rigorous abandonment procedures. In general, the entire length of these wells should be sealed.

When the threat of contamination has been established, the elimination of a potential flowpath is critical. For example, a contaminated well in a karst terrain must be carefully sealed to avoid worsening the situation. In general, the entire lengths of these wells should be sealed. In some situations, a bridge seal may have to be installed, and casing may have to be perforated. In each case, a prudent method should be selected that will eliminate all potential vertical flowpaths.

### 7.5.8 Monitoring Wells

Monitoring wells should be abandoned in accordance with the rules and regulations of the program under which they were installed and operated.

Monitoring wells which do not fall under the jurisdiction of a regulatory program, or fall under a program that has no rules or regulations for abandonment, should be abandoned under the following guidelines.

Monitoring wells that were installed and continue to function as designed, can usually be abandoned in place. Exceptions would include wells whose design precludes complete and effective placement of sealant and wells in locations subject to future disturbance that could compromise the abandonment. In such instances all tubing, screens, casings, aggregate, backfilling, and sealant should be cleaned from the boring and the hole should be completely filled with an appropriate sealant.

Monitoring wells that are abandoned in place should be completely filled with sealant. Screened intervals can be backfilled with inert aggregate if sealant will alter the groundwater chemistry and thereby jeopardize ongoing monitoring at the facility. Intervals between screens, and between the last screen and the surface, must be filled with sealant. Generally, sealant must be emplaced from the bottom of the interval being sealed. Protective casings, riser pipes, tubing, and other appurtenances at the surface which could not be removed should be cut off below grade after the sealant has properly set. When the abandonment will be completed below the finished grade, the area of the boring should be covered with a layer of bentonite, grout, concrete, or other sealant before backfilling to grade.

## 7.6 EXISTING REGULATIONS AND STANDARDS

The Water Well Drillers License Act requires that the owner or consultant who is to abandon the well notify the DCNR, Bureau of Topographic and Geologic Survey of the intent to decommission a well at least 10 days before the well is sealed or filled. Individual DEP bureaus may have specific regulations or guidelines.

The Bureau of Oil and Gas Management regulates the plugging of oil and gas wells. Plugging provisions for oil and gas wells in coal and non-coal areas are established in § 210 and § 211 of Act 223, and § 78.91 - 78.97 of Chapter 78. These sections describe methods that would stop any vertical flow of fluids or gas within the well bore. Alternate methods of plugging also are allowed if they would afford the same level of protection. Alternate methods must be approved before the plugging is initiated.

The Bureau of Mining and Reclamation regulates the abandonment of borings and wells associated with the mining of coal. Coal exploration holes must be abandoned according to the § 87.93 for surface mining of bituminous coal, § 88.83 for anthracite coal mining, § 89.54 for deep mining of bituminous coal, and § 90.93, coal refuse disposal.

The Bureau of Water Supply and Wastewater Management uses the AWWA Standard for Water Wells for abandonment of public water supply wells. This standard is referenced in Part II of the Public Water Supply Manual.

## 7.7 REPORTING

All abandoned wells shall be reported to BTGS, along with any bureau that requires a report, on forms required by BTGS (and any other forms). If available, the original driller's log should be included along with the details of the well abandonment procedure. A photograph should be taken of the site, and a reference map should be made to locate the abandoned well. It also may be appropriate to survey the exact location of the well. This is especially important for wells associated with contaminated sites.

## 7.8 REFERENCES


AMERICAN WATER WORKS ASSOCIATION, 1990, Abandonment of Test Holes, partially completed wells and completed wells: AWWA Standard for Water Wells, pp. 25-26.

DRISCOLL, F.G., 1986, Groundwater and Wells, 2nd ed., Johnson Filtration Systems, Inc., St. Paul, Minnesota 55112, 1089 pp.

NYE, J.D., September 1987, Abandoned Wells - How One State Deals with Them, Water Well Journal, pp. 41-46

RENZ, M.E., May 1989, In Situ Decommissioning of Ground Water Monitoring Wells, Water Well Journal, pp. 58-60.

U.S. ENVIRONMENTAL PROTECTION AGENCY, 1975, Manual of Water Well Construction Practices, Office of Water Supply, EPA-570/9-75001.

## WELL ABANDONMENT FORM

CONTRACTOR/AGENT: ______________________________ REGISTRATION NO. ___________________________
DATE: ___________________ TYPE OF SITE OR PROGRAM: ___________________________________________

1. WELL LOCATION: (Show sketch of location on back of this form.)
   Municipality: _________________________________ County _____________________________________
   Quadrangle _________________________________ _____________________________________
   (Road, community, subdivision, lot number)
   Latitude _________________________________ Longitude _____________________________________

2. OWNER AND ADDRESS: ____________________________________________________________________
   ____________________________________________________________________

3. TOPOGRAPHY: (Circle) hilltop, slope, stream terrace, valley, stream channel, draw, local depression, flat

4. USE OF WELL: _________________________________

   WELL DIAGRAM: sketch a diagram showing depths of well, casing (if present), grouting materials, perforations, etc.

5. DEPTH OF WELL: _________________________________
   DIAMETER OF WELL _________________________________

6. AMOUNT OF CASING REMOVED _________________________________
   DIAMETER: _________________________________

7. SEALING MATERIAL

| | | Neat cement | Sand cement |
|---|---|---|---|
| | Bags (94 lbs.): | ___________ | ___________ |
| | gals of water: | ___________ | ___________ |
| | yds of sand: | ___________ | ___________ |

   OTHER MATERIAL ___________________________ amount: ___________________

8. EXPLAIN METHOD OF EMPLACEMENT OF MATERIAL:
   ____________________________________________________________________

9. CERTIFICATION: We hereby certify that this well abandonment record is true and exact, and was accomplished on____________ day of the month of _______________ , __________ with our active with our active participation and that we are qualified to participate in such abandonment actions.

_________________________________ _________________________________
Signature of Participant: Signature of Participant:

Address: _________________________________ Address: _________________________________

_________________________________ _________________________________

Date: ___________________________ Date: ___________________________

# CHAPTER 8: QUALITY ASSURANCE/QUALITY CONTROL REQUIREMENTS

## 8.1 PURPOSE

A Quality Assurance/Quality Control Plan (QA/QC Plan) is a detailed account of methods and procedures that are used in data collection (i.e. monitoring) activities. This plan, when properly developed and implemented, ensures that adequate control and documentation procedures are utilized from initiation to completion of the monitoring so that the data generated are of the highest quality and can be used for the intended purpose with confidence. A QA/QC plan is also an effective tool in assessing and assuring the completeness and adequacy of the basic monitoring plan.

## 8.2 DESIGN

A QA/QC plan should be designed to satisfy the objectives of the monitoring project. Although the elements of each QA/QC plan, as described below, will be basically similar, the intended uses of the collected data will determine the requirements associated with the monitoring activity. For example, data collection to achieve objectives of an ambient monitoring project will require different QA/QC procedures for some QA/QC plan elements than data collection for compliance monitoring for a permitted activity or remediation monitoring activity. In addition, in most cases, there will be sufficient differences within these monitoring categories for each project to require a specific QA/QC plan.

The following paragraphs describe the basic elements of a QA/QC plan. In most cases, the proper development and adherence to this format will be sufficient to ensure that the data collection meets the objectives of a project. However, in some cases it may be necessary to include additional considerations that may be unique to a specific site and/or project. The Bureau of Laboratories should be consulted on any questions or problems which may arise in developing any QA/QC plan.

## 8.3 ELEMENTS

A. <u>Project Name or Title</u>: Provide the project identification and location.

B. <u>Project Required by</u>: Provide the reason(s) or requirement(s) for the project, such as (name) permit compliance monitoring or (name) remediation monitoring.

C. <u>Date of Requirement</u>: Provide date the project was required either by permit or by legal or other order.

D. <u>Date of Project Initiation</u>: Provide date that the project was implemented.

E. <u>Project Officer(s)</u>: Provide name(s) of individual(s) responsible for managing or overseeing the project.

F. <u>Quality Assurance Officer(s)</u>: Provide name(s) of individual(s) responsible for development of and adherence to the QA/QC plan.

G. <u>Project Description</u>: Provide 1) an objective and scope statement which comprehensively describes the specific objectives and goals of the project, such as determining permit compliance, treatment technology effectiveness or remediation effectiveness for specific parameters, 2) a data usage statement that details how the monitoring data will be evaluated including any statistical or other methods, 3) a description of the location of monitoring stations and reasons or such locations, including geological, hydrogeological or other considerations, and 4) a description of the monitoring analytes and frequency of collection including for each analyte the number of samples expected to be collected, the sample matrix (i.e. water) the exact analytical method, reason for selection of analytes, reference, and sample preservation method and holding time.

H. Project Organization and Responsibility: Provide a list of key personnel and their corresponding responsibilities, including the position and/or individual in charge of the following functions: field sampling operations, field sampling QA/QC, laboratory analyses, laboratory analyses QA/QC, data processing activities, data processing QA/QC and overall project coordination.

I. Project Fiscal Information: Provide an estimate in work days of the project time needed for data collection, laboratory support, data input, quality assurance and report preparation.

J. Schedule of Tasks and Products: Provide a projected schedule for completing the various tasks and developing the products associated with the project, such as sample collections (monthly, quarterly, etc.), data analysis/reports (quarterly, annual, biennial, etc.).

K. Data Quality Requirements and Assessments: Provide a description of data accuracy and precision (consult the Bureau of Laboratories for this information), data representativeness, data comparability, and data completeness.

L. Sampling Procedures: Provide a description of the procedures used to collect samples from monitoring wells or other sites, including sampling containers and field preservation and transport procedures.

M. Sampling Plan: A sampling plan should provide necessary guidance on the number and types of sampling quality controls to be used. The following is a list of common sample quality control types and a recommended minimum frequency if used. It is important to remember that all of these quality control samples must be treated with the same dechlorination and/or preserving reagents as the field samples they are associated with.

1) Trip Blanks: These are appropriate sample containers filled with laboratory quality reagent water that are transported to and from the sampling site(s) and are shipped with the samples to the laboratory for analysis. These samples are intended to determine if there was any cross contamination that occurred during the shipping process. They will also validate that the sampling containers used were clean. Each sampling event that uses this type of quality control should have a minimum of one trip blank for each container type used.

2) Field Blanks - These are appropriate sample containers that are filled at the sampling site(s) with laboratory quality reagent water and are shipped with the samples to the laboratory for analysis. These samples are intended to determine if there was any cross contamination that occurred during the sampling process due to ambient conditions. They will also validate that the sampling containers used were clean. Each sampling event that uses this type of quality control should have a minimum of one field blank for each sampling

site of each container type used. This type of sampling quality control is most useful when sampling for volatile compounds.

3) <u>Rinsate Blanks</u> - These are samples of laboratory quality reagent water used to rinse the collection device, including filtration devices and filters, coming into contact with the same surfaces as the sample. The quality control samples(s) are then submitted with the field samples for analysis. This type of quality control sample helps to determine if the sample collection device is contributing any detectable material to the sample. The minimum number of this type of sampling quality control, if utilized, is dependent on operational considerations. If multiple samples are being collected with the same collection device, with field decontamination, you should, at a minimum, submit two of this type of quality control, one before sampling and one at the end of sampling. If you are using disposable sample collection devices or multiple pre-cleaned devices, then a single representative sample should suffice.

4) <u>Split/Duplicate Samples</u> - This is a single large sample that has been homogenized, split into two or more individual samples, and each sample submitted independently for analysis. This quality control determines the amount of variance in the entire sampling/analysis process. This type of quality control is not recommended for samples analyzed for analytes that would be adversely affected by the homogenization process (i.e. volatile organics). The minimum number of this type of sampling quality control, if utilized, is one per sampling event with a rate of 5 percent to 10 percent commonly used.

5) <u>Replicate Samples</u> - These are two or more samples that are collected from the same source, in a very short time frame (i.e. minutes), and each sample submitted independently for analysis. This quality control, like the split/duplicate sample, determines the amount of variance in the entire sampling/analysis process. The amount of variance determined by this type of quality control may be larger than that of a split/duplicate sample. The use of this type of quality control also presumes that the samples material is already homogenous. This type of quality control is recommended for samples analyzed for analytes that would be adversely affected by an external homogenization process (i.e. volatile organics). The minimum number of this type of sampling quality control, if utilized, is one per sampling event with a rate of 5 percent to 10 percent commonly used.

6) <u>Known Samples</u> - These are reference materials that have been characterized as to the acceptable range of values for the analytes of concern. These materials are available from commercial sources. This type of quality control helps determine if the analytical work has adequate accuracy. It must be noted that improper handling or storage of this type of reference material can invalidate the materials characterization. The minimum number of this type of quality control, if used, would be one per subject.

7) <u>Spiked Samples</u> - These are split/duplicate or replicate samples that have been fortified with the analytes of concern. This quality control is intended to determine if there have been changes in concentration due to factors associated with the sample, or shipping and analysis process. This type of quality control is very difficult to use in a field environment and routinely is done

as part of the analysis process. If this type of quality control is determined to be needed, the minimum would be one per project.

N. Sample Custody Procedures: Provide information which describes accountability for sample chain of custody including sample collector identification, sample location identification, sample number, date and time of collection, parameters monitored, preservatives and fixatives, identification of all couriers, identification of laboratory and receiver, time and date of receipt at laboratory, laboratory analyzer, and time and date of analysis. The Bureau of Laboratories should be consulted to ensure that this section is consistent with current policy and procedure.

O. Calibration Procedures and Preventative Maintenance: Equipment maintenance and calibration should be performed in accordance with manufacturers instructions. Calibration and maintenance sheets should be maintained on file for all equipment.

P. Documentation, Data Reduction, and Reporting: Provide discussion on where field data are recorded, reviewed, and filed.

Q. Data Validation: Provide a discussion on or reference to the protocols for validation of chemical data and field instrumentation and calibration. Describe procedure for validating database fields (i.e. through error checking routines, automatic flagging of data outside of specified ranges, and manual review and spot checking of data printouts against laboratory analytical results).

R. Performance and Systems Audits: Provide description of how field staff performance is checked and data files are verified for accuracy and completeness.

S. Corrective Action: Provide discussion on making corrections when errors are found, and actions taken to prevent recurrence of errors.

T. Reports: Provide list of types and frequency of reports to be generated (i.e. performance and systems audits, compliance analyses, remediation effectiveness, etc.).

## 8.4 REFERENCE

U.S. ENVIRONMENTAL PROTECTION AGENCY, May 1984, Guidance for Preparation of Combined Work/Quality Assurance Project Plans for Environmental Monitoring, (OWRS QA-1), USEPA Office of Water Regulations and Standards.

# APPENDIX

## DECONTAMINATION PROCEDURES

Equipment Cleaning

The following guidelines provide methods for cleaning sampling equipment used for sampling wells.

(1) Portable Pump

Disassemble the pump by unscrewing the discharge-hose adaptor and removing the inlet screen; then, remove the four Phillips screws which secure the pumphead to the motor case (Do not remove the single screw at the base of the motor housing).

Clean the Teflon rotors and the stainless stator in warm detergent solution, using a stiff bristled brush to clean the parts. The hose adaptor, pumphead, screen and screws should also be cleaned and, if deemed necessary, they too may be scoured with a brush.

Rinse all parts with tap water.

Rinse all parts with 10 percent nitric acid solution.

Rinse all parts with distilled water (Note: Procedure to be detailed later).

Reassemble pump and rinse internally and externally with ASTM Type IV or better reagent grade water.

(2) Submersible Pump

Since these pumps usually remain dedicated to one well, cross contamination is not a problem. If for any reason the pump is removed or relocated to another well, the decontamination procedures described above should be followed, except that the pump need not be disassembled.

(3) Bailers

Clean bailer and rope or wire line with warm detergent solution.

Rinse with tap water.

Rinse bailer with 10 percent nitric acid solution.

Rinse bailer and rope twice with distilled water, once with ASTM Type IV or better reagent grade water, drain, and air dry in an uncontaminated area.

Place clean bailers and ropes in clean transportation tubes or wrap in clean aluminum foil.

(4) Field Filtration Apparatus

Non-Disposable Filtration Apparatus - Disassemble permanent filtration kit parts, then wash all parts in warm detergent solution, then rinse all parts with tap water, then rinse all parts with 10 percent nitric acid solution, then rinse all parts twice with distilled water, once with ASTM Type IV or better reagent grade water, and then air dry.

Disposable Filtration Apparatus - No cleaning is required for the disposable apparatus since it is only used one time and then disposed. Care should be taken to properly dispose of the apparatus.

However, the plastic hose connecting the vacuum pump to the filtration apparatus should be cleaned, as described above, whenever hose contamination is suspected.

(5) Sample Bottles

All sample bottles should be pre-cleaned at the central laboratory (bacteria bottles, special organic bottles, etc.) and do not require cleaning. The disposable plastic sample bottles should be used directly as obtained from the laboratory, but should receive a field rinse with sample water prior to actual sample collection.

(6) Water Level Indicator

This device should be cleaned in the office with detergent solution followed by tap water rinse and a final distilled water rinse. Between wells, the level indicator should be rinsed with distilled water.

SPECIAL NOTE: Whenever sampling equipment is severely contaminated with organics such as oil, special decontamination procedures should be followed. A detergent solution should be used first, if visible contamination remains on the equipment, it may be necessary to use a solvent rinse. Laboratory grade hexane will usually be sufficient to remove most organics. The equipment should then be subjected to the normal cleaning procedure once the solvent residue has been air-dried. Normally, this cleaning procedure will be done in the lab.

This and related environmental information are available electronically via Internet. For more information, visit us through the PA PowerPort at http://www.state.pa.us or visit DEP directly at http://www.dep.state.pa.us (directLINK "Drinking Water Publications").

www.GreenWorks.tv - A web space dedicated to helping you learn how to protect and improve the environment. The site features the largest collection of environmental videos available on the Internet and is produced by the nonprofit Environmental Fund for Pennsylvania, with financial support from the Pennsylvania Department of Environmental Protection, 877-PA-GREEN.

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