

**GEORGIA DEPARTMENT OF NATURAL  
RESOURCES**

**MANUAL FOR  
GROUNDWATER MONITORING  
ENVIRONMENTAL PROTECTION DIVISION**

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## CHAPTER I.

### INTRODUCTION

#### Purpose, Scope, and Applicability

Georgia's ground water is a valuable, yet vulnerable, resource. It provides a high quality source of drinking water for 1.5 million Georgians. Ground water also contributes to the base flow of our streams and rivers. Land disposal systems if improperly designed, sited, or operated may contaminate ground water and surface water, making the water unfit for its many beneficial uses. A key part of the operation of any land treatment, storage, or disposal facility should be a monitoring program which is designed to assess the impact of the system on ground-water resources.

Water quality monitoring is required by the Georgia Environmental Protection Division (EPD) to detect and quantify contamination, as well as to measure the effectiveness of engineered disposal systems, and the effectiveness of corrective action for improperly sited or poorly operated sites. Authority to require monitoring is set forth in the Georgia Solid Waste Management Act and the Water Quality Control Act which mandate surveillance of waste handling and disposal practices to determine compliance with State standards and regulations.

This manual sets forth the Division guidelines for monitoring well construction, as well as sampling and analytical techniques. It is intended for use as a guide by all persons involved with the design and permitting of land treatment and disposal facilities. The manual is intended to be a dynamic document, reflecting changes with advancing technology, while maintaining the standards of proven techniques. As a guidance document, the methods and procedures layed out in this document are not mandatory. However, where alternative procedures are employed, their use and rationale for selection should be thoroughly documented and approved by EPD to insure compliance with applicable regulatory requirements and permit condition. Comments and suggestions from interested parties are always welcome and will be considered when revisions to the manual are made. If there are any questions concerning ground-water monitoring requirements, please call the Georgia Environmental Protection Division.

#### Quality Control

The emphasis of this manual is on expert technique in order to obtain an accurate picture of groundwater quality. Poorly constructed wells and careless sample collection and analysis can yield widely varying test results.

Quality control means that boring logs are complete and accurate, well screens are properly sized, gravel packs and seals are carefully placed between the walls of the boring and the casing, and the well is capped and locked for protection. Wells must be thoroughly developed to allow for the collection of sediment-free samples. Sampling equipment must be free of contaminants, and the sample collection and handling method should not alter

the chemical components of interest. Analyses should be conducted promptly, with proper attention given to laboratory quality control. Required laboratory quality assurance data should be submitted as part of the monitoring report.

Error may be introduced at each stage of the monitoring and it is the responsibility of all participants to keep this error to a minimum.

### Objectives of Monitoring

The initial monitoring should focus on the area closest to the boundary of the waste management area to detect pollutants as soon as possible. In some cases, monitoring of the unsaturated zone (area above the water table) may be necessary to provide an early warning of disposal system failure.

Should the initial monitoring show contamination as defined in Chapter II of this manual, further monitoring will be necessary to determine extent and magnitude of the problem. This information will aid in the design of a corrective action system to remedy the problem.

Monitoring should be thought of as a tool used to measure the efficiency of site design and location factors controlling water pollution. Continued monitoring is required after corrective measures have been taken to verify that water quality is improving.

### The Two-Stage Monitoring Concept

Monitoring is a two-stage process. The first stage is the early detection of contamination. The second stage, known as the assessment phase, involves determining the magnitude, extent, and potential impact of contamination. Contamination in this manual is defined as the presence of significantly elevated levels of a chemical parameter and/or a significant physical change in water quality caused by the activities of man. Limits will be set for each parameter at each site based upon background water quality.

In the initial stage the wells and other monitoring points should be located so that they detect contamination as early as possible, while observing standards of good practice and common sense. For example, monitoring wells at sanitary landfills should not pass through refuse or be placed in high-traffic areas, but they should be as close as possible to the outer downgradient edge of the waste. In most cases, the focus of this initial monitoring will be the unsaturated zone and the upper aquifers which are likely to be the first areas impacted.

If the site-specific concentration limits for a given chemical parameter are exceeded, the site operator or permittee should notify EPD of that fact and retest the apparently affected well to verify the results. The Division may also sample the well at that time.

### Monitoring Network Design

Just as each site design must be individually engineered, so must its

monitoring network. The types of monitoring points used will vary by site and may include any combination of shallow wells, deep wells, lysimeters, well nests (or other multi-level sampling devices), and surface water points. The method will depend on results of the site's hydrogeologic investigation, engineered design criteria, and waste characteristics.

Shallow wells and lysimeters placed close to the waste will likely be the firstphase monitoring network at most sites. Deep wells, well nests, or multi-level samplers will be used to monitor water moving into deeper levels. Where surface water may be affected by the discharge of contaminated ground water, it should also be monitored.

The preferred drilling method is hollow stem auger, although it may be necessary to use other methods at greater depth. Split spoon samples should be taken at least every 5 feet and at every change in strata to a depth of 50 feet, and at every change in strata below 50 feet.

All test borings should extend to ground water, and ideally to the first confining bed encountered. Additional deeper borings may be required to adequately define the hydrogeologic setting.

At the completion of the field work, a land surface contour map and potentiometric surface maps should be prepared, including elevations referenced to the National Geodetic Vertical Datum (NGVD). The raw data upon which the potentiometric surface map was based (boring logs, measured water levels, etc.) should be attached. Care should be taken when comparing water elevation data from open boreholes, piezometers, and existing wells. Data from these various sources are not strictly comparable, and may lead to faulty conclusions. A narrative should also be prepared, describing the projected path and rate of contaminant movement and methods used to make those projections. Recharge and discharge areas should be defined, and vertical flow components described. Ground water models may be prepared, and for some sites, water-balance studies can also provide valuable information.

## Chapter II.

### PLACEMENT OF DETECTION MONITORING WELLS

The purpose of this chapter is to examine criteria the owner/operator should use in determining the number and location of detection monitoring wells. The actual placement and construction details of the detection monitoring system are based on the hydrogeologic data gathered prior to the system installation. Monitoring systems should not be designed until preliminary test data is available.

Upgradient monitoring wells provide background ground-water quality data. Upgradient wells should be (1) located beyond the upgradient limit of the waste management unit so that they reflect background water quality, (2) screened at the same stratigraphic horizon(s) as the downgradient wells to ensure comparability of data, and (3) of sufficient number to account for natural variations in background ground water quality.

Downgradient wells must be located, screened, and sufficiently numerous to provide a high level of certainty that releases of constituents from the waste management unit(s) to the uppermost aquifer will be immediately detected. Downgradient wells must be located at the edge of the waste management units. Distance between wells is chiefly a function of site geology and the nature of the waste disposed. Although every detection monitoring system must ultimately be judged against site specific conditions, there are a number of well-placement criteria that apply to ensure that detection monitoring systems are adequate. These criteria are discussed on the following pages.

#### Horizontal Spacing Between Downgradient Monitoring Wells

Downgradient detection monitoring wells must be spaced to assure that contaminant leakage will be immediately detected. Deciding whether monitoring wells are properly spaced requires analysis of site-specific conditions. Table II-1 illustrates several factors that may be used to determine the proper spacing.

Final determination of adequate spacing will often come after discussion with representatives of EPD.

TABLE II-1

FACTORS USED TO ADJUST HORIZONTAL SPACING OF MONITORING WELLS

CLOSER SPACING REQUIRED

- . Manages or has managed liquid waste
- . Is very small (i.e., the downgradient perimeter of the site is less than 150 feet).
- . Has a double liner (and may leak over a relatively small area).
- . Has waste incompatible with liner materials.
- . Is an old facility, with less certainty on design features and past waste disposal practices.
- . Has fill material near the waste management units (where preferential flow might occur).
- . Has buried pipes, utility trenches, etc., where a point-source leak might occur.
- . Has complicated geology
  - closely spaced fractures
  - faults
  - tight folds
  - solution channels
  - discontinuous structures
- . Has heterogenous conditions
  - variable hydraulic conductivity
  - variable lithology
- . Is located in or near a recharge zone
- . Has a high (steep) or variable hydraulic gradient.

WIDER SPACING ALLOWED

- . Has never managed liquid waste.
- . Is new, with more certainty on facility design features and planned/current waste disposal practices.
- . Uses appropriate and proven geophysical techniques to supplement monitoring wells in the detection monitoring program.
- . Has simple geology
  - no fractures
  - no faults
  - no folds
  - no solution channels
  - continuous structures
- . Has homogeneous conditions
  - uniform hydraulic conductivity
  - uniform lithology
- . Has a low (flat) and constant hydraulic gradient

## Depth of Wells/Vertical Sampling Interval(s)

Site specific hydrogeological data generated during the site characterization is also necessary for the identification of the vertical sampling interval(s). Proper selection of the vertical sampling interval provides a third dimension to detection monitoring.

### Depth of Wells

Depth of detection monitoring wells should be determined by test drilling. Detection monitoring wells should be no deeper than necessary to monitor the first water-bearing horizon encountered year-round. Information on depth to the uppermost aquifer is often available from EPD. Please call if in doubt. It is important to screen upgradient and downgradient wells at approximately the same geologic horizon to obtain comparable data.

### Thickness of the Vertical Sampling Interval(s)

Determination of the appropriate thickness of the vertical sampling interval(s) is an extension of the depth selection. The owner/operator should make the decision on the basis of test borings. Other sources of data could include hydrogeologic publications, and EPD or U.S. Geological Survey (USGS) files.

In most cases, monitor-well screens should be no longer than ten feet. Shorter screens promote better resolution of contaminant concentrations than longer screens. At sites where the vertical sampling interval is greater than ten feet, the owner/operator may wish to install a well cluster at each sampling location. A well cluster is a number of wells grouped closely together but screened at different levels.

It is important to remember that the vertical sampling interval is not necessarily synonymous with aquifer thickness. In other words, the owner/operator may select a vertical sampling interval which represents a fraction of the thickness of the uppermost aquifer. The selection should be made on the basis of test borings and the characteristics of the potential pollutants. A sufficiently detailed test boring program may therefore reduce the need for the owner/operator to install more speculative wells by identifying the depth and thickness of the uppermost aquifer. The owner/operator thus tailors the selection of the vertical sampling interval to site-specific conditions.

There are situations where the owner/operator should have multiple wells at a sampling location and others where typically one well is sufficient. These situations are summarized in Table II-2. Generally, the presence of immiscibles in a thick, complex saturated zone of the uppermost aquifer should prompt the owner/operator to use well clusters. Conversely, single phase contaminated ground water and a thin saturated zone within the uppermost aquifer, or isotropic hydrologic properties reduce the need for multiple wells at each sampling location. Where seasonal fluctuation of the water table occurs and the owner/operator intends to sample for light phase immiscibles floating on the water surface, the owner/operator should always use screens long enough to intercept the water table.

TABLE II-2

FACTORS AFFECTING NUMBER OF WELLS PER LOCATION (CLUSTERS)

One Well Per Sampling Location

- . No "sinkers" or "floaters  
(immiscible) liquid phases
  
- . Thin flow zone (relative to  
screen length)
  
- . Homogenous uppermost aquifer;  
simple geology.

More than One Well Per Sampling Location

- . Presence of sinkers or floaters
  
- . Heterogeneous uppermost aquifer;  
complicated geology
  - multiple, interconnected aquifers
  - variable lithology
  - perched water tablediscontinuous structures
  
- . Discrete fracture zones

When the site hydrogeologic data indicate the presence of different but hydraulically interconnected strata, some of the wells should be screened with the bottom of the screens placed at the interface between the strata. Also, the owner/operator should have delineated through site characterization (e.g. flow net analysis) those flow zones in the aquifer(s) in which there is higher potential for contaminant movement. The owner/operator should install enough wells to ensure continuous screening in these zones. As above, these screens should not be longer than ten feet in flow zones in which a higher potential for contaminant movement exists.

#### Placement of Upgradient (Background) Monitoring Wells

The owner/operator must install background wells so that the ground-water samples taken from these wells cannot be affected by contaminant discharge from the facility. Usually, this is accomplished by locating the background wells far enough upgradient from waste management units to avoid contamination by the facility.

The minimum number of upgradient wells the owner/operator may install is one. However, a facility that uses only one well for background sampling may not be able to account for spatial variability in water quality. The owner/operator who makes comparisons of background and downgradient monitoring well results with data from only one background well increases the risk of a false indication of contamination.

The owner/operator should also install enough background monitoring wells to allow for depth-discrete comparisons of water quality. This means simply that for downgradient wells completed in a particular geologic formation and at a particular depth, the owner/operator should install corresponding wells at the upgradient sampling locations so that the data can be compared on a depth-discrete basis.

#### Defining Contamination

Contamination has been defined as the presence of significantly elevated levels of a chemical parameter and/or a significant physical change in water quality caused by the activities of man. To determine if aquifer contamination is taking place, the laboratory results from wells located downgradient of the site must be compared with data from the upgradient wells. Often, contamination is evident simply by inspection of water quality data. For instance, if a downgradient well has a specific conductance that is two or three times the upgradient level, then the site being monitored is probably contributing constituents to the ground water.

In other instances, the answer to the question of contamination may not be as evident. Statistical analysis of trends in chemical data comparing upgradient wells to downgradient is a more definitive approach. For each indicator parameter specified in the design and operation plan, the owner/operator should calculate the arithmetic mean and variance, based on at

least four replicate measurements on each sample, for each well in the detection monitoring system, and compare these results with the initial background arithmetic mean. The comparison must consider individually each of the wells in the monitoring system, and must use the Student's t-test to determine statistically significant increases (or pH decreases) over initial background. An acceptable method is detailed in Appendix I. Further information on Student's t-testing is available in many textbooks on elementary statistics.

A Student's t-test for a downgradient well that shows a significant increase in an indicator parameter (or significant change in pH), signals potential ground-water contamination and is the first indication that a facility may be leaking. If a significant change is detected, the facility moves into ground-water assessment, the second stage of monitoring.

#### Assessment of Contamination

If, during the detection stage, it is established that potentially harmful constituents are being released to the environment, an assessment of contamination will be required. The objectives of an assessment are to define what contaminants are present in the ground water, and to find out how far they have migrated.

An assessment usually involves the installation of several additional monitoring wells. The assessment wells are usually sampled and tested for specific contaminants known to be present in the wastes, although general indicator parameters may be acceptable in specific instances.

Extensive guidance on assessment is available in the RCRA Ground-Water Monitoring Technical Enforcement Guidance Document, available through Government Printing Offices. Throughout the ground-water monitoring process, facility owners, operators, managers, and elected officials are encouraged to contact the Environmental Protection Division if there are any questions. Often, problems solved at other facilities can provide valuable information which saves time and money.

## CHAPTER III.

### MONITORING WELL DESIGN AND CONSTRUCTION

The purpose of this chapter is to examine important aspects of monitoring well design and construction. Included in this chapter are discussions on the following topics:

- . drilling methods for installing wells
- . monitoring well construction materials
- . design of well intakes
- . development of wells
- . documentation of well construction activity
- . plugging of abandoned wells

#### Drilling Methods

A variety of well drilling methods are available for the purpose of installing ground water monitoring wells. Of utmost importance is that the drilling method minimizes the disturbance of subsurface materials and will not cause contamination of the ground water. Table III-1 illustrates the drilling methods the owner/operator might use. It is important to note that regardless of the drilling method selected, drilling equipment should be steam cleaned before use and between borehole locations to prevent cross contamination of wells.

#### Monitoring Well Construction Materials

Well construction materials must be sufficiently durable to resist chemical and physical degradation and yet not interfere with the quality of ground-water samples. Specific well components that are of concern include well casings, well screens, filter packs, and annular seals. Figure 1 is a diagram of a general cross section of a ground-water monitoring well. The following sections describe various materials the owner/operator should use in constructing the well as illustrated in Figure 1.

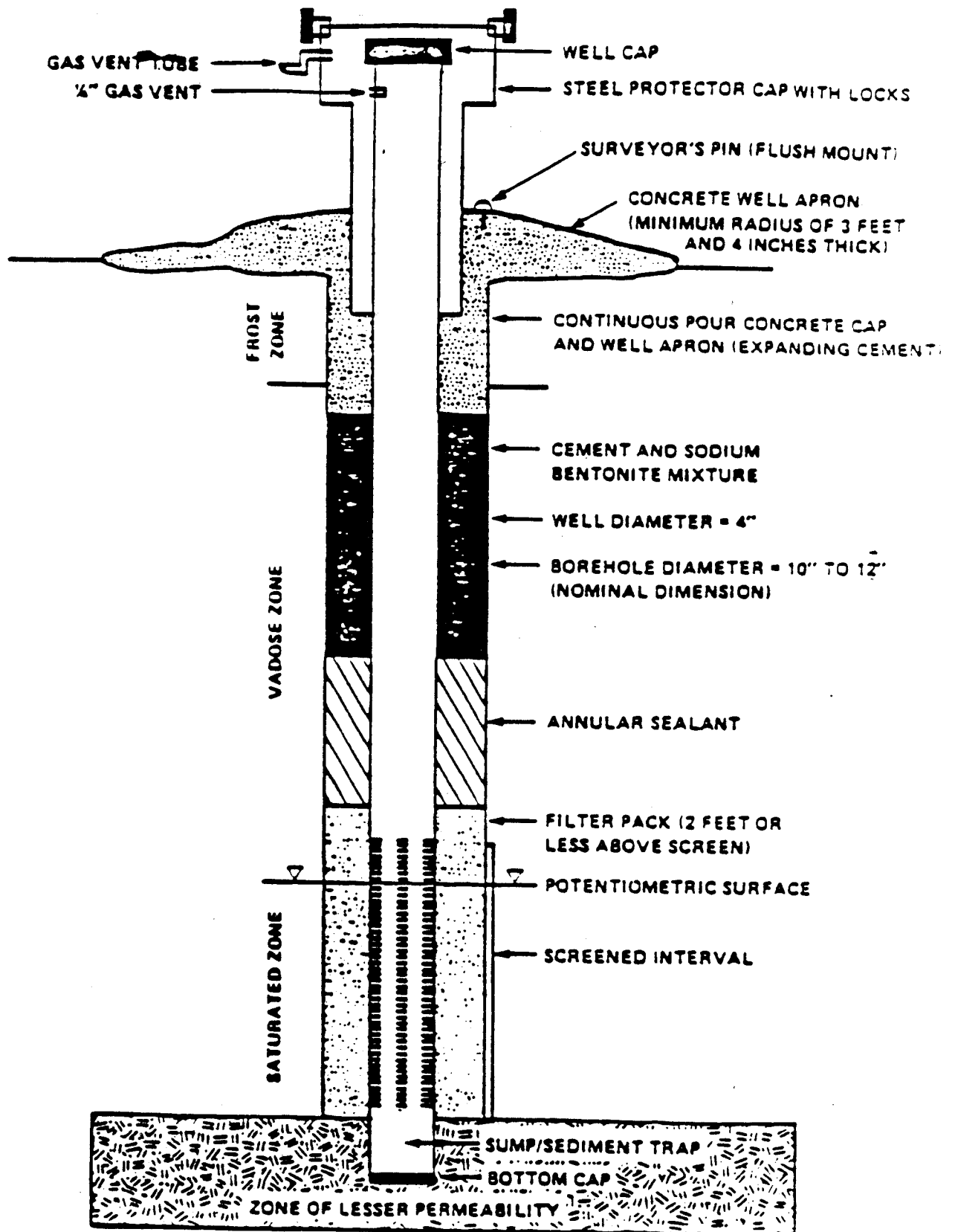


FIGURE -1. GENERAL MONITORING WELL CROSS SECTION

TABLE III-1

DRILLING METHODS FOR  
VARIOUS TYPES OF GEOLOGIC SETTINGS

Geologic Environment	Drilling Methods				
	Air Rotary	Water Rotary	Cable Tool	Hollow-Stem Continuous Auger	Solid-Stem Continuous Auger*
Unconsolidated materials less than 150 feet deep:					
- loose sand and thick clay	4	5	2	1	3
- gravel and resistant zones	2	3	1		
Unconsolidated materials greater than 150 feet deep	2	3	1		
Consolidated rock formation (minimal or no fractured or dissolutioned formations)	2	3	1		
Consolidated rock formations (highly fractured or dissolutioned formations)	2	3	1		

\*Above water table.

NOTES: 1 = First choice  
 2 = Second choice  
 3 = Third choice  
 4 = Fourth choice  
 5 = Fifth choice

## Well Casings and Screens

A variety of construction materials have been used for casing and well screens, including teflon\*, steel (stainless, black, galvanized), PVC, polyethylene, epoxy biphenol, and polypropylene. Many of these materials, however, may affect the quality of ground-water samples and may not have the long-term structural characteristics required for monitoring wells. For example, steel casing deteriorates in corrosive environments; PVC deteriorates when in contact with ketones, esters, and aromatic hydrocarbons; polyethylene deteriorates in contact with aromatic and halogenated hydrocarbons; and polypropylene deteriorates in contact with oxidizing acids, aliphatic hydrocarbons, and aromatic hydrocarbons. In addition, steel, PVC, polyethylene, and polypropylene may absorb and leach constituents which may affect the quality of ground-water samples.

In constructing wells, the owner/operator should use teflon, stainless steel 316, or other proven chemically and physically stable materials for well screens and for those portions of the well casing in the saturated zone. ASTM, NSF rated PVC may be an acceptable material for well screens and casing at some sanitary landfills and land application systems. However, PVC formulations can contain unacceptable concentrations of leachable plasticizers. Noninert materials such as steel, PVC, polyethylene, and polypropylene may be used as well casing above the saturated zone. The owner/operator will be held responsible for the reliability of data collected from the well. If the owner/operator chooses to install PVC pipe as a casing material and, after installation, it is determined that PVC deteriorating compounds are present in the ground water, EPD must assume that the contaminants are from the regulated unit and not from the well casing or screen unless identical compounds are found in the upgradient wells and can not be attributed to wastes placed in the site. An appropriate choice of casing material is the responsibility of the owner/operator.

Plastic pipe sections must be flush threaded or be amenable to connection by another mechanical method such as stainless steel screws. No solvents or glues should be allowed in well construction. These compounds readily leach organic contaminants into the ground water. All well casings and screens should be steam cleaned prior to emplacement to ensure that all oils, greases, and waxes have been removed.

The owner/operator should normally use well casing with either a two-inch or four-inch interior diameter. Water volumes to be purged from the well prior to sampling are minimized by use of smaller casings. Larger casing diameters, however, may be necessary where dedicated sampling equipment is used or where the well is finished in a deep formation.

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\*The term "teflon" in this report is used as a generic expression for polytetrafluoroethylene (PTFE) materials and in no way is meant to serve as an endorsement of PTFE products under the U.S. Trademark name of E.I. DuPont DeNemours and Company

## Filter Pack and Annular Sealant

The materials used to construct the filter pack should be chemically inert (e.g., clean quartz sand, silica, or glass beads), well rounded, and dimensionally stable. Fabric filters should not be used as filter pack materials. Natural gravel packs are acceptable provided an appropriate well screen slot size is used.

The materials used to seal the annular space must prevent cross contamination between strata. The materials should be chemically resistant to ensure seal integrity during the life of the monitoring well and chemically inert so they do not affect the quality of the ground water samples. Figure III-1 illustrates an appropriate distribution of annular sealants. A minimum of two feet of certified coarse grit sodium bentonite should immediately overlie the filter pack. A cement and bentonite mixture, bentonite chips/pellets, or antishrink cement mixtures should be used as the annular sealant in the unsaturated zone above the certified coarse grit sodium bentonite seal and below the frost line. Extending from a little below the frost line to the surface, the cap should be composed of concrete blending into a mounded cement apron (to direct rainwater runoff away from the well) extending outward three feet from the edge of the borehole.

The untreated sodium bentonite seal should be placed around the casing either by dropping it directly down the borehole or, if a hollow-stem auger is used, putting the bentonite between the casing and the inside of the auger stem. Both of these methods present a potential for bridging. In shallow monitoring wells, a tamping device should be used to reduce this potential. In deeper wells, it may be necessary to pour a small amount of formation water down the casing to wash the bentonite down the hole.

The cement-bentonite mixture should be prepared using formation water or potable water and placed in the borehole using a tremie pipe. The tremie method ensures good sealing of the borehole from the bottom.

The remaining annular space should be sealed with expanding cement to provide for security and an adequate surface seal. Locating the interface between the cement and bentonite-cement mixture 1/2 to 1 foot below the frost line serves to protect the well from damage due to frost heaving. The cement should be placed in the borehole using the tremie method.

Figure 1 illustrates an appropriate protective steel cap around the well casing. A one-quarter inch vent hole provides an avenue for the escape of gas. The protective cap guards the casing from damage and the locking cap serves as a security device to prevent well tampering.

As with drilling machinery, it is important to steam-clean well casing and screen before use. Filter sands, well sealant materials, and anything else that may influence sample quality should be free of contamination. Common sense is the best guideline when constructing a monitoring well. After taking all precautions with cleaning drilling equipment, well casing, and screen, it makes no sense to pile filter sand on contaminated ground, or use contaminated water to make up drill mud!

## Well Intake Design

The owner/operator must design and construct the intake of the monitoring wells to: (1) allow sufficient ground water flow to the well for sampling; (2) minimize the passage of formation materials (turbidity) into the well; and (3) ensure sufficient structural integrity to prevent the collapse of the intake structure.

For wells completed in unconsolidated materials, the intake of a monitoring well should consist of a screen or slotted casing with openings sized to ensure that formational material is prohibited from passing through the well during development. Screen size should be selected to retain 90% of the filter pack and 40% of the formational material. Extraneous fine-grained material (clays and silts) that have been dislodged during drilling may be left on the screen, in the filter pack, and in the well water. These fines should be removed from the screen and surrounding area during development. For quality-control purposes, the owner/operator should use commercially manufactured screens or slotted casings. Field slotting of screens is unacceptable.

The annular space between the face of the formation and the screen or slotted casing should be filled to minimize passage of formation materials into the well. The owner/operator should therefore install a filter pack of clean, well rounded, quartz sand or glass beads in each monitoring well that is constructed on site. In order to ensure discrete sample horizons, the filter pack should extend no more than two feet above the well screen as illustrated in Figure 1.

## Well Development

After the owner/operator has completed construction of monitoring wells, natural hydraulic conductivity of the formation should be restored and all foreign sediment removed to ensure turbidity-free ground-water samples.

A variety of techniques are available for developing a well. To be effective, they require reversals or surges in flow to avoid bridging by particles, which is common when flow is continuous in one direction. These reversals or surges can be created by using surge blocks, bailers, or pumps. Formation water should be used for surging the well. In low yielding water-bearing formations, an outside source of water may sometimes be introduced into the well to facilitate development. In these cases, the water should be chemically analyzed to ensure that it cannot contaminate the aquifer. Where possible, compressed air should not be used in the development of wells as trace contaminants may be introduced. If used, sufficient precaution should be taken to prevent introduction of contaminants which may be caused for concern. The owner/operator should steam clean all equipment used to develop a well prior to its introduction into the well.

## Documentation of Well Design and Construction

The owner/operator will be required to compile information on the design and construction of wells. Such information may include:

- . name of drillers, identification of drill rig;
- . date/time of construction;
- . drilling method and drilling fluid\* (primarily drilling muds) used;
- . well location ( $\pm$  0.5 ft.);
- . borehole diameter and well casing diameter;
- . well depth ( $\pm$  0.1 ft.);
- . drilling and lithologic logs
- . casing materials\*;
- . screen materials and design;
- . casing and screen joint type;
- . screen slot size/length;
- . filter pack material\*/size;
- . filter pack volume;
- . filter pack placement method;
- . sealant materials\*;
- . sealant volume;
- . sealant placement method;
- . surface seal design/construction;
- . well development procedure;
- . type of protective well cap;
- . ground surface elevation ( $\pm$  0.01 ft.);
- . well cap elevation ( $\pm$  0.01 ft.);
- . top of casing elevation ( $\pm$  0.01 ft.); and
- . detailed drawing of well (include dimensions).

\*Samples of materials, adequate for leaching/sorption tests should be retained.

## Well Plugging

If it becomes necessary to abandon a monitoring well, the following plugging procedures should be used. Without proper plugging, the abandoned monitoring well will become an avenue of aquifer contamination. Plugging can also serve to inhibit water loss from artesian aquifers and to eliminate the physical hazard of an open hole. Proper plugging materials and techniques vary according to the original well construction and the geohydrology of the site.

The general procedure for plugging shallow monitoring wells completed in water table aquifers includes three steps.

- . removal of obstructions in the well that could interfere with the plugging operation and thorough flushing of the well to purge residual drilling fluids and other fine detritus,

- . removal of the well casing (where practical) to ensure placement of an effective seal - as a minimum when the casing is not properly grouted, the upper 20 feet of casing must be removed,
- . sealing of the well with an impermeable filler such as neat cement.

#### Sealant Materials

Well sealants must be chemically inert and impermeable. Neat portland cement (with or without bentonite clay additives) and bentonite clay are acceptable sealants. General purpose (Type I) neat portland cement is the most commonly used. The cement slurry is mixed with five to six gallons of water for each 94 pound sack of cement. To properly set, the water of the cement slurry should have a low sulfate content and a total dissolved solids content less than 2,000 parts per million. No aggregate materials can be included in the slurry.

#### CAPACITIES OF WELL CASINGS

Diameter of Hole	Gallons per Lineal Foot	Sacks Cement per Lin. Foot	Lin. Feet per Sack Cement Set Volume
2"	0.1632	0.0199	50.2
3"	0.3672	0.0311	32.1
4"	0.6528	0.0791	12.6
5"	1.0200	0.1240	8.0
6"	1.4688	0.1785	5.6
7"	1.9992	0.2430	4.1
8"	2.6112	0.3373	3.2
10"	4.0800	0.4958	2.0
12"	5.8752	0.7140	1.4

Recommended quantities of neat portland cement needed for plugging various diameter wells are shown above. Quantities are based on the set volume, which is somewhat less than the slurry volume.

(taken from "Plugging Abandoned Wells" by Donald K. Keech, Ground Water Age, January, 1973)

The neat cement slurry must be piped to the point of application so that the well is filled upward from the bottom. Free falling of the slurry into the well is unacceptable because the cement will become aerated with a resulting increase in permeability.

Bentonite clay additives reduce shrinking (and cracking) of the cement while the slurry is setting. Three to five pounds of additive and 6-1/2 gallons of water are mixed with each 94 pound sack of cement (the clay and water are mixed together before cement is added to form the slurry).

Bentonite clay can be used separately as a well sealant. The clay is dropped into the well in the form of granules, chunks, pellets, or balls. As the clay hydrates, it also expands to form an impermeable barrier. Where the potentiometric head of an aquifer causes water to rise in the well high above the level of the plug, consideration must be given to the physical form of the bentonite to be used. If a granular bentonite is added by free falling, a possibility is that the clay will hydrate and expand above the intended point of placement. An ineffective plug will result. Adding the bentonite in chunk or pellet form will prolong the effective period of wetting prior to hydration and allow proper placement of the plug. Bentonite clay may not be an appropriate sealant where organic contaminants are present in ground water. Investigations have indicated that although bentonite clay is an impermeable material for water, some organic contaminants can migrate through.

In general, where a monitoring well is completed in a water table aquifer, the emphasis of well plugging is to prevent rainwater runoff through the well opening or the annular space. Where a monitoring well is completed in a confined aquifer, the emphasis is retention of water in the aquifer in which it is encountered.

Shallow monitoring wells installed in unconsolidated sediments or consolidated rocks without fractures or dissolution voids are filled with a sealant. Back filling of the screened or uncased section of the well (up to several feet below the casing) with clean, disinfected sand is permissible. Sand with a diameter of 0.025 inches or less (plaster sand or mortar sand) reduces cement penetration/loss. As a minimum, the upper 50 feet of deep monitoring wells should be plugged with neat cement or bentonite clay.

Consolidated rocks with a high density of fractures or dissolution voids should be filled completely with neat cement. Sand and clay fill materials may not be suitable because the fine grained sediments can be eroded away by ground water flow. The use of bridging materials, such as pea gravel or larger rocks (the diameter of the bridging material should be less than 1/3 of the diameter of the well) below the casing or the placement of a plug at the base of the casing, may be necessary to retain the neat portland cement slurry in the well.

Where several confined aquifers are present in an abandoned monitoring well, impermeable seals between water bearing sections are required. Flow from artesian wells can cause problems with the installation of neat portland cement. Packers or heavy plugs may be necessary to inhibit water flow.

## CHAPTER IV.

### SELECTION OF TEST PARAMETERS

Before a sampling and analysis program is undertaken, EPD and the facility will agree on the parameters of interest. Initially, a set of indicator parameters will be selected as a general indication of ground-water quality. If tests for indicator parameters are positive, more detailed analyses will be required.

#### Sanitary Landfills

When the facility accepts only municipal waste, a test for chloride, specific conductance and pH must be performed quarterly. If a sanitary landfill receives large quantities of industrial waste or small quantities of hazardous waste, then a test for total organic carbon (TOC) and total organic halogen (TOH) may also be required quarterly. Additional parameters related to the wastes handled may be prescribed by EPD in the permit as deemed necessary.

A more extensive monitoring must be conducted annually as follows:

#### 1. Dissolved metals

The water is filtered (see SAMPLING AND ANALYSIS) and tested for the Drinking Water Standard Metals:

Arsenic	Lead
Barium	Mercury
Cadmium	Selenium
Chromium	Silver

#### 2. Volatile Organic Analysis

The unfiltered water is tested for the volatile organic compounds on the Clean Water Act Priority Pollutant list.

### Land Treatment Facilities

When waste is applied to the land for the purpose of waste degradation, the soil beneath the site must be monitored for the major contaminants in the waste. The soil pore liquid (unsaturated zone) may also be monitored on a case-by-case basis. The parameters will be determined by EPD based on the most-difficult-to-degrade constituent. The values obtained are compared to background soil sample results taken nearby to determine significant difference. Samples must be taken quarterly from within the treatment area to make the comparisons. Background samples must be taken quarterly for the first year.

Monitoring wells may also be required for this type facility. The test parameters are those constituents of concern in the waste.

## CHAPTER V

### SAMPLING AND ANALYSIS

An effective ground-water sampling and analysis (S & A) program requires a written plan. This plan must include procedures and techniques for sample collection, sample preservation and shipment, analytical procedures and chain of custody control. The plan allows the compliance officer to thoroughly review how the owner/operator has structured the S & A program. Also, comparison of the written plan to field activities will allow the compliance officer to ensure that the owner/operator is, in fact, properly collecting and analyzing ground-water samples.

#### Elements of the Sampling and Analysis Plan

Specifically, the S & A plan should include information on:

- . Well preparation
- . Sample collection
- . Sample handling and preservation
- . Chain of custody control
- . Analytical procedures
- . Field and laboratory quality assurance/quality control

#### Well Preparation

The plan should include provisions for measurement of static water level elevations in each well. Measurement of water level elevations on a continuing basis is important to determine if horizontal and vertical flow gradients have changed since initial site characterization. A change in hydrologic conditions may necessitate modification to the design of the owner/operator's ground-water monitoring system. The S & A plan should specify the device to be used for water level measurements as well as the procedure for measuring water levels.

The owner/operator's field measurements should include depth to standing water and total depth of the well to the bottom of the intake screen structure. The measurements should be taken to 0.1 foot. Each well should have a referenced point from which its water level measurement is taken. The reference point should be established in relation to a permanent bench mark and the survey should also note the well location coordinates. The device which is used to detect the water level surface must be sufficiently sensitive that a measurement to 0.1 foot can be obtained reliably. A clean steel tape will usually suffice.

The water standing in a well prior to sampling may not be representative of in-situ ground-water quality. Therefore, the owner/operator should remove the standing water so that water which is representative of the formation can enter the well. The owner/operator's S & A plan should include detailed, step-by-step procedures for evacuating wells. The equipment the owner/operator plans to use to evacuate should also be described.

The procedure the owner/operator should use for well evacuation depends on the yield of the well. When evacuating low yield wells, the owner/operator should evacuate wells to dryness once. If a well cannot be bailed dry, then an amount of water equivalent to three well volumes should be evacuated. The volume to be evacuated should be included in the sampling and analysis plan.

In order to minimize the introduction of contamination into the well positive gas displacement teflon bladder pumps are recommended for purging wells. Teflon or stainless steel 316 bailers are also recommended purging equipment. Where these devices cannot be used, peristaltic pumps, gas-lift pumps, centrifugal pumps, and venturi pumps may be used. Some of these pumps produce volatilization and high pressure differentials, causing variability in the analysis of pH, specific conductance, metals, and volatile organic samples. They are acceptable for purging the wells if sufficient time is allowed to let the water stabilize prior to sampling. Twenty four hours is considered a satisfactory interval before sampling.

When purging equipment must be reused, it should be decontaminated with a tap water wash and a distilled water rinse between wells. Purging equipment which becomes heavily contaminated should be cleaned with a nonphosphate detergent wash, a copious rinse with tap water, and followed by rinsing with isopropanol and distilled water. Clean plastic gloves should be worn by the sampling personnel. A clean plastic sheet should be placed adjacent to or around the well in order to prevent purging equipment and lines from contacting the ground, which in turn could introduce contaminants to the well. Plastic sheet and gloves should be discarded between wells.

#### Sample Collection

Extraction of well-water samples requires the use of equipment and sample handling in the field that greatly increases the potential for inadvertent sample contamination. Field sampling error greatly exceeds laboratory error. The traces of chemicals being monitored can be lost to the air by agitation or vaporization. They can pass into and out of the water with temperature and pH changes. They can decompose when allowed to stand in the sun. Contamination from the ground surface can pass to hands, to the bottle and then to the sample. Cleanliness and attention to detail will hold these errors to a minimum.

It is important to note that, for a given facility, once a sampling technique has been established it should be repeated for all subsequent samplings. A change in technique may result in a change in the test values.

1. Use only teflon or stainless steel (316) sampling bailers. These may have a bottom valve which facilitates smooth sample release into the bottle, but the bailer may not fit all bottles. A generally useful design has a side opening near the closed top. Care should be taken to see that bailer rope does not touch the sample water.

2. If possible use dedicated samplers for each well. This eliminates cross-contamination, and allows thorough cleaning in the laboratory before the project. If a dedicated sampler is not available the device must be cleaned between wells. This means thoroughly rinsing in distilled water, followed by a thorough rinse in isopropanol and followed by a final rinse in distilled water. If a bailer shows insoluble contamination field cleaning is not recommended.
3. Positive gas displacement teflon bladder pumps may also be used to extract samples.

The owner/operator's S & A plan should specify in detail the devices to be used for sample withdrawal. The plan should state that devices are either dedicated to a specific well or are capable of being fully disassembled and cleaned between wells. Procedures for cleaning the sampling equipment should be included in the plan.

Sampling equipment should be constructed of inert material. Equipment with neoprene fittings, PVC bailers, tygon tubing, silicone rubber bladders, neoprene impellers, polyethylene, and vitron are not acceptable.

#### Sample Handling and Preservation

##### 1. Dissolved Metals

The well water must not receive preservative before performing a filtration to remove the sediment which may have been stirred up during the purging operation. The sample is either suction filtered in the field, or the bottle is filled to the top without headspace, placed on ice, and filtered in the laboratory immediately after arrival. A 0.45 micron filter disc is used and the filtrate receiving flask must contain the acid preservative. Whichever procedure is adopted should be continued.

The filtrate is tested for the Drinking Water Standard Metals.

2. All sample bottles should be filled to the top, capped with a teflon seal, and be placed on ice immediately after sampling. On arrival at the laboratory they are transferred to a refrigerator. Samples for volatile organic analysis should be filled to the top without headspace. Special vials with septum caps are available for this purpose.

Table V-1 is a list of preservatives and holding times.

3. pH and Specific Conductance should be performed immediately after collection if possible. The calibration and procedure should be recorded and continued at each sampling project. If a sample is returned to the laboratory, it should be tested immediately on arrival and this alternate procedure should be recorded and repeated at each sampling project.
4. Sample delivery to the laboratory should be in the shortest possible time after collection. If delay is incurred this should be entered in the field log book along with the time increment.

TABLE V-1  
Preservation Procedures and Holding Times

<u>Parameter</u>	<u>Recommended Container</u>	<u>Preservative Indicators of Ground-water Contamination</u>	<u>Holding Time</u>	<u>Volume Required For One Analysis</u>
pH	T, P, G	Field determined	None	25 ml
Specific conductance	T, P, G	Field determined	None	100 ml
TOC	G, T-lined cap	Cool 4°C HCl to pH 2	28 days	4 x 15 ml
TOX	G, amber, T-lined septa or caps	Cool 4°C, add 1 ml of 1.1M sodium sulfite	7 days	4 x 15 ml
Chloride	T, P, G	4°C	28 days	50 ml
Arsenic Barium Cadmium Chromium Lead Mercury	T, P	<u>Total Metals</u> Field Acidified to pH 2 with HNO <sub>3</sub>	6 months	1,000 ml
Selenium Silver		<u>Dissolved Metals</u> 1. Field filtration if possible 2. Acidify the filtrate to pH 2 with HNO <sub>3</sub>	6 months	1,000 ml
Fluoride	T, P	Cool 4°C	28 days	300 ml
Nitrate/Nitrite	T, P, G	4°C/H <sub>2</sub> SO <sub>4</sub> to pH 2	14 days	1,000 ml
Volatile Organics	G, T-lined septa or caps	Cool 4°C	7-14 days (extract in 5 days)	60 ml
Pesticides	G	Cool 4°C	(5 days to extract) 30 days	2,000 ml
Extractable Organics	G	Cool 4°C	30 days (extract in 5 days)	
Cyanide	P, G	Cool 4°C NaOH to pH 12 0.6g ascorbic acid (see method)	14 days*	500 ml
Oil & Grease	G only	Cool 4°C, H <sub>2</sub> SO <sub>4</sub> to pH 2	28 days	100 ml
Phenols	G	Cool 4°C, H <sub>2</sub> SO <sub>4</sub> to pH 2	(5 days to extract) 30 days	500

\*Unless sulfide is present, - then 24 hours (see lab method)

P = polyethylene

G - glass

T - fluorocarbon resins (Teflon, PTFE, FEP, etc.)

## 5. Blanks and Background

A distilled water blank should be carried to the field and put through the entire sampling procedure. If positives are found, this will alert the collector to field sampling error. (See Quality Assurance)

In certain situations it may be good procedure to sample neighborhood well water to establish a background concentration for parameters of interest, in addition to installed up-gradient wells.

### Chain of Custody

Custody and protection of samples is an important legal consideration. As few people as possible should handle the samples. The sampler is personally responsible for collected samples, and must be able to attest to the integrity of samples until transfer. If the samples are placed in a vehicle, it must be kept locked. Any ice chest must be locked or located in a place which is locked, and having access only by responsible officials.

A chain-of-custody form documents the handling of samples from the moment of collection until testing. It contains the facility name, date of sampling and name of the collector. Samples must have consecutive ID numbers which are kept in a sampling log book. The ID number is entered on the chain-of-study along with a word description of each sample. Note that several bottles collected for different parameters will have the same ID number if they come from one sampling point. Each transfer of custody is recorded on the chain-of-custody with an appropriate signature, date and time.

If the samples are to be shipped they must be sealed. The driver for the delivery service must sign the custody form and a bill of lading must be secured.

### Analytical Procedures

The S&A plan should identify the method that will be used to test for each specific parameter or constituent. The plan should specify a method in EPA Manual SW-846 Ed. III, EPA Manual 600/4-79-020, or a method approved by the Division. Any planned deviation should be justified and submitted for approval by the Division prior to use

Records of ground-water analyses should include the methods used (by number), the extraction date, and date of actual analysis. Data from samples that are not analyzed within recommended holding times should be considered suspect.

## Field and Laboratory Quality Assurance/Quality Control

It is the responsibility of the owner/operator to ensure the reliability of the analytical data being gathered during the monitoring program. The S & A plan must explicitly describe what will be done in the field. An example procedure is provided in Appendix II as a guide to good technique which can be adapted as required for the situation at hand.

A field blank should be part of each sampling event. Distilled water is taken to the site, and handled like a sample. It is poured into a bailer, and sample bottles filled using identical technique. Analysis of the blank alerts the sampler to technical error. The blank test results are not used to correct the sample results, but are reported as-is. If the contaminant levels in the blank are within an order of magnitude of the groundwater sample results, the wells should be resampled.

Many owner/operators employ commercial laboratories to conduct analyses of groundwater samples. In these cases it is the owner/operator's responsibility to ensure that the laboratory of choice is exercising a proper QA/QC program as described in the S & A plan. The approved EPA test methods contain within them the requirement to run a spiked sample to determine percent recovery. This should be a part of the lab report. Additional quality control such as method blanks and duplicates are also described in the test method and should be included in the laboratory work agreement. The laboratory QA program should be a part of the S & A Plan. Quality assurance procedures are time consuming and increase the cost of testing, but the facility will be regulated based on the results and it is to their advantage to employ the best qualified laboratory.

All field instruments that the owner/operator will use should be calibrated prior to field use and recalibrated in the field before measuring each sample. The owner/operator's S&A plan should describe a program for ensuring proper calibration of field instruments. Other QA/QC practices such as sampling equipment decontamination procedures and chain-of-custody procedures should also be described in the owner/operator's S&A plan.

### Analysis of Results

1. In order to determine whether the groundwater is receiving contamination from the site it is necessary to compare the test results with the background test results. Several inherent variabilities must be considered:
  - a. The sampling technique will vary somewhat from event to event even under ideal conditions.
  - b. The aquifer will contain a certain quantity of elements.
  - c. The laboratory test itself can vary slightly.

A method must be used that shows significant deviation beyond the inherent deviation. A statistical analysis using the Student's t-test is presently approved by EPA for this purpose. While several approaches are possible the details are beyond the scope of this manual and the reader is referred to several texts on statistics listed in the references. The EPA approved Behrens-Fischer method is included as a step by step guide in Appendix I. The facility should submit the statistical method for EPD approval in the S & A plan.

2. A single laboratory result may be very accurate or considerably in error depending on a number of factors:

- a. Interferences in the sample.
- b. Contamination picked up during sample preparation.
- c. The skill of the analyst.
- d. The time delay.
- e. The instrument calibration.
- f. The field sampling error for that day.

If a particular test result shows 100 ppm for example, and the lower detectable limit is 1 ppm, it can be assumed that contamination exists and repeat testing may be at the discretion of the facility. However, most cases are considerably closer to the lower detectable limit of the test, and verification becomes essential.

A properly verified result is accompanied by the following:

- a. A duplicate sample result.
- b. A spiked sample result.
- c. A blank result.
- d. A set of calibration standards run to establish instrument response.

If all are performed with good results, the facility and the Division can be assured that the sample result is representative. At the very least a sample should be spiked with a known quantity of the sought for constituent to determine percent recovery. With good recoveries no interferences are present in the water to suppress or enhance the response of the instrument.

The Division recommends that a second sampling project be undertaken whenever a downgradient result gives cause for alarm.

## RECOMMENDED REFERENCES

- Barcelona, Michael J., J. P. Gibb, and R. A. Miller. 1983. A Guide to the Selection of Materials For Monitoring Well Construction and Ground Water Sampling. Illinois State Water Survey Contract Report 327, 78p.
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## APPENDIX I

### STATISTICAL ANALYSIS

For a valid assessment of aquifer contamination the laboratory results from wells lying downgradient of the site must be compared with the upgradient well data. The normal variation in sampling technique and laboratory handling should standardize over time and a statistical analysis can be performed to determine significant variation. The levels of elements occurring naturally in the aquifer may also vary slowly with time, and assumption is made that over one year these variations will also standardize. The upgradient levels may also be altered by artificial means not related to site failure, and therefore upgradient data should also be analyzed to detect significant changes.

#### 1. Background levels

Establishment of valid background data is essential to correct evaluation of site integrity. A minimum of 4 samplings will be taken from each well during the first year. The samples are split 4 ways to provide a minimum of 16 sets of data for determining background levels. If there are several upgradient wells these results are pooled, and the average ( $\bar{X}$ ) and the variance ( $S^2$ ) are computed for each parameter:

$$\bar{X} = \frac{\sum_{i=1}^n x_i}{n}$$

$$S^2 = \frac{\sum_{i=1}^n (x_i - \bar{X})^2}{n-1}$$

n = number of test results  
x = the lab result for a given parameter  
 $\sum$  = the sum

#### 2. Statistical Analysis

Each set of downgradient well data must be compared to the upgradient data for each indicator parameter.

Calculate the average and the variance as in 1) on each downgradient well for each parameter. There will be a minimum of 4 sets of data collected during the first year. If a permit requires splitting of each sample there will be a greater number of sets to pool.

Behrens - Fisher, Cockran Approach to Student's t Analysis

1. Calculate a t statistic for each parameter:

$$t = \frac{\bar{X}_m - \bar{X}_b}{\sqrt{\frac{S_m^2}{n_m} + \frac{S_b^2}{n_b}}}$$

m = monitoring well  
b = background well

This is the difference between the average well level and the average background level, divided by the square root of the sum of: the well variance divided by the number of tests, and the background variance divided by the number of background tests.

NOTE: If this number is negative there is no significant difference between the well data and the background data.

2. Find a background t ( $t_b$ ) and a monitoring well t ( $t_m$ ) from the table (See Figure 1). Determine the number of tests minus one, and go down the list to this number.

NOTE 1: Use the 0.01 level of significance.

NOTE 2: Use the 0.025 level of significance when testing pH.

3. These t values must be weighted (W).

$$W_m = \frac{S_m^2}{n_m} \qquad W_b = \frac{S_b^2}{n_b}$$

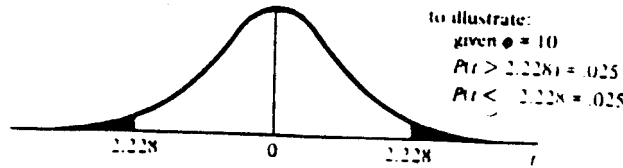
(These W's were calculated in step 1 to determine the t statistic, and represent the variance divided by the number of tests.)

Calculate the comparison t statistic ( $t_c$ ):

$$t_c = \frac{W_b t_b + W_m t_m}{W_b + W_m}$$

Compare the two t statistics:

Table H Percentage points of the *t* distribution



Level of Significance  
→

Number of tests minus one.  
↓

$\alpha$	0.25	0.20	0.15	0.10	0.05	0.025	0.01	0.005	0.0005
1	1.000	1.376	1.963	3.078	6.314	12.706	31.821	63.657	636.619
2	0.816	1.061	1.386	1.886	2.920	4.303	6.965	9.925	31.598
3	0.765	0.978	1.250	1.638	2.353	3.182	4.541	5.841	12.941
4	0.741	0.941	1.190	1.533	2.132	2.776	3.747	4.604	8.610
5	0.727	0.920	1.156	1.476	2.015	2.571	3.365	4.032	6.859
6	0.718	0.906	1.134	1.440	1.943	2.447	3.143	3.707	5.959
7	0.711	0.896	1.119	1.415	1.895	2.365	2.998	3.499	5.405
8	0.706	0.889	1.108	1.397	1.860	2.306	2.896	3.355	5.041
9	0.703	0.883	1.100	1.383	1.833	2.262	2.821	3.250	4.781
10	0.700	0.879	1.093	1.372	1.812	2.228	2.764	3.169	4.587
11	0.697	0.876	1.088	1.363	1.796	2.201	2.718	3.106	4.437
12	0.695	0.873	1.083	1.356	1.782	2.179	2.681	3.055	4.318
13	0.694	0.870	1.079	1.350	1.771	2.160	2.650	3.012	4.221
14	0.692	0.868	1.076	1.345	1.761	2.145	2.624	2.977	4.140
15	0.691	0.866	1.074	1.341	1.753	2.131	2.602	2.947	4.073
16	0.690	0.865	1.071	1.337	1.746	2.120	2.583	2.921	4.015
17	0.689	0.863	1.069	1.333	1.740	2.110	2.567	2.898	3.965
18	0.688	0.862	1.067	1.330	1.734	2.101	2.552	2.878	3.922
19	0.688	0.861	1.066	1.328	1.729	2.093	2.539	2.861	3.883
20	0.687	0.860	1.064	1.325	1.725	2.086	2.528	2.845	3.850
21	0.686	0.859	1.063	1.323	1.721	2.080	2.518	2.831	3.819
22	0.686	0.858	1.061	1.321	1.717	2.074	2.508	2.819	3.792
23	0.685	0.858	1.060	1.319	1.714	2.069	2.500	2.807	3.767
24	0.685	0.857	1.059	1.318	1.711	2.064	2.492	2.797	3.745
25	0.684	0.856	1.058	1.316	1.708	2.060	2.485	2.787	3.725
26	0.684	0.856	1.058	1.315	1.706	2.056	2.479	2.779	3.707
27	0.684	0.855	1.057	1.314	1.703	2.052	2.473	2.771	3.690
28	0.683	0.855	1.056	1.313	1.701	2.048	2.467	2.763	3.674
29	0.683	0.854	1.055	1.311	1.699	2.045	2.462	2.756	3.659
30	0.683	0.854	1.055	1.310	1.697	2.042	2.457	2.750	3.646
40	0.681	0.851	1.050	1.303	1.684	2.021	2.423	2.704	3.551
60	0.679	0.848	1.046	1.296	1.671	2.000	2.390	2.660	3.460
120	0.677	0.845	1.041	1.289	1.658	1.980	2.358	2.617	3.373
$\infty$	0.674	0.842	1.036	1.282	1.645	1.960	2.326	2.576	3.291

Abridged from Table III of R. A. Fisher and F. Yates, *Statistical Tables for Biological, Agricultural and Medical Research*, published by Oliver & Boyd, Edinburgh, and by permission of the authors and publishers.

Figure I

## APPENDIX II

### MONITORING WELL SAMPLING PROCEDURE

The greatest source of inadvertent sample contamination is through incorrect handling by field personnel. The levels of concern are minute, as compared to a waste sample, and extreme care is needed. This will usually slow down the speed of sample collection, but the reliability of test results is increased proportionally.

Water standing in a well may not be a true representation of water quality in the aquifer. Changes in temperature and pressure, contact with air, and prolonged contact with well casing materials can all affect the chemical quality of the water. Therefore, before sampling, the well must be evacuated (purged).

### WELL EVACUATION PROCEDURE

Any item coming in contact with the inside of the well casing or the well water should be kept in a clean container and handled only with gloved hands. Always start with the least contaminated well.

For wells with rapid recovery, which cannot be evacuated, 3 well volumes will be removed. This reflects the present technology in which the goal is to clear standing water without diluting any potential plume by drawing in pure water.

#### A. Assemble Equipment

1. Place a plastic sheet, such as a painter's drop cloth, around the well as a work area. Unlock protective well casing.
2. Bring steel measuring tape and electric sounder to the plastic sheet. The sounder probe and tape have been precleaned in the lab and wrapped in foil. Unwrap without touching them.
3. Put on new gloves. Unlock and remove well cap. Place it top-down on a corner of the plastic sheet.

#### B. Calculate the volume of water to be evacuated:

1. Use the electric sounder ("m-scope") to measure the distance from top of the casing to top of water.
2. Use the steel tape to measure the distance from top of casing to the bottom of the well or use total depth data provided by company.
3. Subtract #1 from #2 to obtain the height (h) of the column of water in the well.

4. Multiply  $h$  times the appropriate conversion factor to obtain the volume of water in the well in gallons.
  - a. For a 2-inch inside diameter well,  
 $h \times 0.1623 = \text{Volume (gal)}$
  - b. For a 4-inch inside diameter well,  
 $h \times 0.6 = \text{Volume (gal)}$
5. Evacuate  $3 \times \text{Volume (gal)}$  to obtain a representative sample.
6. Clean the steel measuring tape and electric sounder probe by rinsing with methanol followed by distilled water. Wrap in foil for use on the next well. If acetone is used, be sure to allow all apparatus to dry thoroughly before proceeding to next well. Do not use methanol if it is a suspected contaminant.

C. Evacuate the Well

1. Bring 2 dishpans and a measuring container to the plastic sheet and line one dishpan with aluminum foil.
2. Bring the bailer, which has been precleaned in the laboratory and wrapped in foil, to the plastic sheet. Unwrap it without touching the bailer.
3. Bring the roll of bailer cord to the sheet. This roll has also been covered with foil to keep it clean. Place it in the unlined dishpan and unwrap it without handling the rope.
4. At this point both bailer-handler and helper should put on a new pair of gloves.
5. The end of the bailer rope is tied to the top of the bailer. Use foil where needed to assure that the rope does not touch any item while in use.
6. The bailer is lifted and lowered carefully into the well until it is submerged.
7. The bailer is raised in a hand over hand manner and the rope is allowed to fall into the polyethylene dishpan lined with foil.
8. Pour groundwater from bailer into the measuring container. Repeat bailing procedure until a  $3 \times \text{volume (gal)}$  (see B4 and 5) has been evacuated. If the bailer touches the container, line the lip with aluminum foil.

9. If the well goes dry before 3 volumes is obtained, then sample when the well has recovered sufficiently to provide a sample volume. Some wells require 24 hours for recovery and settling.
  10. Save the evacuated water in the measuring container for proper\* disposal. Do not pour on the ground next to the well.
  11. The rope is untied from the bailer and the portion used is cut off for discard.
  12. The used gloves, the used rope, the bailer foil, dishpan foil and the plastic sheet are rolled up and discarded in the large trash bag provided.
- D. Proceed with sampling procedure or if well requires a recovery period before sampling, replace well cap and lock protective casing. In general allow 24 hours for well water stabilization. Where recharge is rapid and water is clear of sediment, this waiting period may be shortened.

#### SAMPLING PROCEDURE

##### A. Bailed Samples:

1. Place a plastic sheet such as a painter's drop cloth, around the well as a work area, to prevent sample bottle contact with the ground. Unlock the protective well casing.
2. Bring 2 dishpans to the sheet and line on with aluminum foil.
3. Arrange sample bottles on the sheet. Place waste water container in vicinity of well.
4. Bring the bailer, which has been precleaned in the laboratory and wrapped in foil to the plastic sheet. Unwrap it without touching the bailer.
5. Bring the roll of bailer cord to the sheet. This spool has also been covered generously with foil to keep it clean. Place it in the unlined dishpan and unwrap it without handling the rope.

Selection of inert rope is important. New nylon rope is available from several manufacturers. Where organic contaminants are of interest it may be advisable to use teflon rope for the first 10 feet of cord and discard after each well. However, the value of this may be offset by the additional handling required.

6. Take a pair of gloves and unlock and remove the well-cap. Place it top-down on a corner of the plastic sheet.

7. At this point both bailer-handler and helper should put on a new pair of gloves.
8. The end of the bailer rope is tied to the top of the bailer. The rope must not touch anything but clean aluminum foil. Use foil where needed.
9. The bailer is lifted and lowered carefully into the well until it is submerged.
10. The helper will unscrew the appropriate sample caps and place them top down on the plastic sheet without touching the interiors or dislodging any teflon discs inside the caps.
11. The bailer is raised in a hand over hand manner and the rope is allowed to fall into the polyethylene dishpan lined with foil. The first bailer-full is discarded into the waste container.
12. The samples are poured into the bottles without bubbles, and are filled to the top without headspace. The helper can hold the bottle and be responsible for recapping without touching the interior of the cap, and screwing down tightly. It is not good practice to leave samples in the sun. They should be removed to the ice chest as soon as possible.
13. The organic samples are the most delicate and should be collected first. A sample for volatile analysis must be filled so that the vial has a meniscus. The cap is slid over it and closed so that no bubble can be seen when the sample vial is upended. The volatile samples are always collected in pairs.

The other organics usually require two or three 1-liter bottles without preservative and these should be collected next, also without headspace.

If a sample is to be collected for dissolved metals it will not have preservative and should be collected next. If there is a sediment problem this sample should be collected right after the volatile samples in order to minimize the sediment requiring removal.

Finally, preserved samples should be collected, taking great care that the acids and salts in the bottles do not contact the helper's gloves and thus pass to other caps and bottles.

Do not allow the bailer to touch any sample bottles, or allow any rope end or gloved fingers to contact the sample well water while pouring.

14. All remaining sample bottles should now be carried to the ice chest where they are labeled, placed in zip-loc bags, and iced down.

15. The labels can be pre-filled out leaving less work and time delay at the site.

The label must have:

Name of facility  
Date of sampling and time  
Sample description (monitoring well ID and "up" or "down")  
Sampler's name

Additionally, mark each sample bottle with an identification number using red glass-marking crayon which is resistant to water. Bottle caps are good places to add an I.D. This is a precaution in case labels get wet or come off during transport.

16. The well cap is replaced and locked. Lock the protective well casing.
17. The rope is untied from the bailer and all used rope is discarded.
18. The used gloves, the used rope, the bailer foil, dishpan foil and the plastic sheet are folded up and discarded in the large trash bag provided.
19. Proceed to the next well repeat.

NOTE: It is good practice to take an extra set of sample bottles to the field in case of breakage or accidental contamination.

#### B. BAILER CLEANING

The best procedure is one bailer for one well. However, when this is not possible a single bailer may be cleaned between wells as follows: (Use of any other solvents will interfere with test results).

1. The sampler, without removing gloves, will untie the rope and will open the bailer to allow the helper to pour distilled water into and around the bailer. This will be shaken and poured out.
2. The helper will then pour spectrograde isopropanol into and around the bailer. It is again shaken and poured out.
3. A final rinse is now performed with distilled water in copious amounts into and around the bailer.
4. A fresh piece of aluminum foil is placed on the plastic sheet and the bailer is placed in it. The foil is folded around it for carrying.
5. It is important to sample the upgradient well first and then proceed to the more contaminated wells.

6. The bailer is then returned to the laboratory for a thorough cleaning and foil wrapping.

NOTE 1: For wells that are badly contaminated with insoluble wastes field cleaning is not recommended.

NOTE 2: If isopropanol appears in the test, a resampling will have to be done.

### C. SPLIT SAMPLES

In order to keep sample handling to a minimum the parallel splitting procedure should be used.

#### Parallel Split

1. The 2 sample bottles for a given test are lined up and caps removed.
2. One bailer-full is poured into one bottle, and the next bailer-full is poured into the other bottle, alternating until the 2 sample bottles are full. They are then capped as usual.
3. The 2 sample bottles for another test are then lined up, and filled as in 2).
4. This procedure is continued until all test bottles for a given well are filled for both parties.