

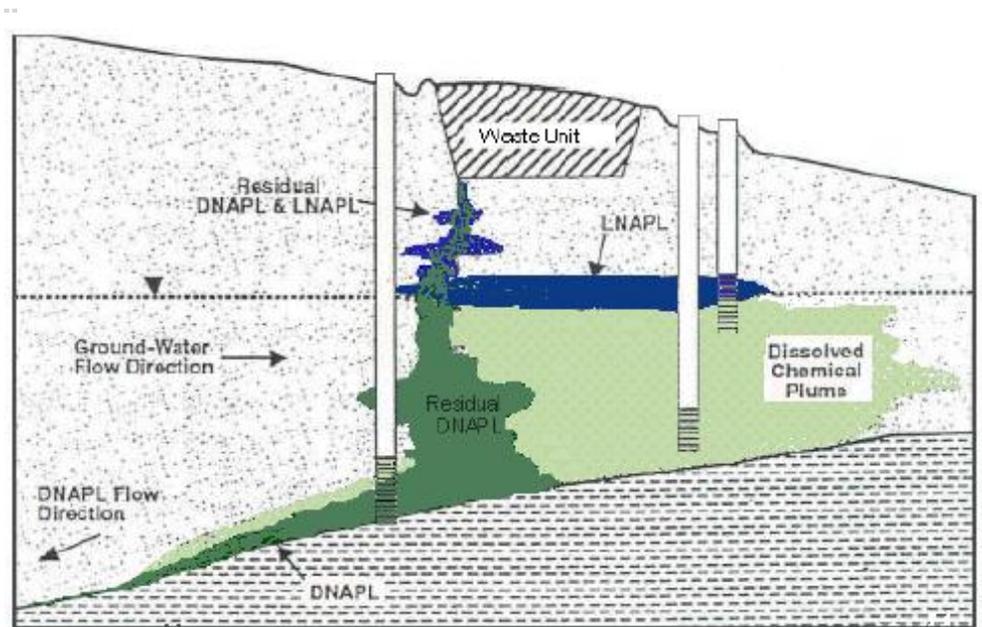
Division of Drinking and Ground Waters

Technical Guidance Manual for Ground Water  
Investigations

Chapter 5

# Monitoring Well Placement

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(Modified from U.S. EPA, 1993a)

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November 2007

Governor : Ted Strickland  
Director : Chris Korleski



**TECHNICAL GUIDANCE  
MANUAL FOR  
GROUND WATER INVESTIGATIONS**

**CHAPTER 5**

**MONITORING WELL PLACEMENT**

**November 2007  
(Revision 1)**

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## PREFACE

This document is part of a series of chapters incorporated in Ohio EPA's *Technical Guidance Manual for Hydrogeologic Investigations and Ground Water Monitoring* (TGM), which was originally published in 1995. DDAGW now maintains this technical guidance as a series of chapters rather than as an individual manual. These chapters can be obtained at <http://www.epa.state.oh.us/ddagw/tgmweb.aspx>.

The TGM identifies technical considerations for performing hydrogeologic investigations and ground water monitoring at potential or known ground water pollution sources. The purpose of the guidance is to enhance consistency within the Agency and inform the regulated community of the Agency's technical recommendations and the basis for them. In Ohio, the authority over pollution sources is shared among various Ohio EPA divisions, including the Emergency and Remedial Response (DERR), Hazardous Waste Management (DHWM), Solid and Infectious Waste (DSIWM), and Surface Water (DSW), as well as other state and local agencies. DDAGW provides technical support to these divisions.

Ohio EPA utilizes *guidance* to aid regulators and the regulated community in meeting laws, rules, regulations, and policy. Guidance outlines recommended practices and explains their rationale. The Agency may not require an entity to follow methods recommended by this or any other guidance document. It may, however, require an entity to demonstrate that an alternate method produces data and information that meet the pertinent requirements. The procedures used usually should be tailored to the specific needs and circumstances of the individual site, project, and applicable regulatory program, and should not comprise a rigid step-by-step approach that is utilized in all situations.

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**Jeff Patzke**, DDAGW-CO, who serves as editor and project coordinator for the Technical Guidance Manual.

The Ohio EPA would also like to thank the numerous people who provided input during its development. The comments and recommendations from the DDAGW-District Offices, and other Ohio EPA Divisions, state and federal agencies, private consultants, and regulated community were greatly appreciated.

## Changes from February 1995 TGM

The Ohio EPA Technical Guidance Manual for Hydrogeologic Investigations and Ground Water Monitoring (TGM) was finalized in 1995. This guidance document represents an update to Chapter 5 (Monitoring Well Placement). No major technical changes were made to the chapter.

## **CHAPTER 5**

# **MONITORING WELL PLACEMENT**

Ground water quality at potential pollution sources can best be evaluated by chemical analysis of ground water samples collected from properly located, installed, and constructed monitoring wells. Several factors will dictate the placement of wells. For purposes of this document, the term, "monitoring well placement", refers to the areal location of a well and the depth and the length of its intake. In general, monitoring wells are placed to collect data representative of ground water at locations that are and are not likely to have been impacted from regulated activities or known or suspected sources of contaminants.

### **FACTORS TO CONSIDER**

Factors that should be considered when placing wells include: purpose of the monitoring, hydrogeologic/geologic characteristics, contaminant characteristics, and anthropogenic influences. In addition, budget and public interest may play a role. The configuration and size of contaminant plumes and/or number of pathways are composites of the hydrogeologic/geologic characteristics, contaminant characteristics, and anthropogenic influences.

### **PURPOSE OF MONITORING**

Proper placement of monitoring wells is necessary to: 1) determine flow direction, 2) detect the release of contaminants from a suspected or known source, 3) determine the extent of contamination, 4) help design a remedy, 5) monitor the effectiveness and efficiency of a remedy, 6) act as a warning system to allow potential receptors to take action in the event of a plume advancement, and 7) determine concentrations of contaminants to assess the risk. Table 5.1 provides a brief discussion on some of the objectives associated with placement of wells.

### **SITE HYDROGEOLOGY**

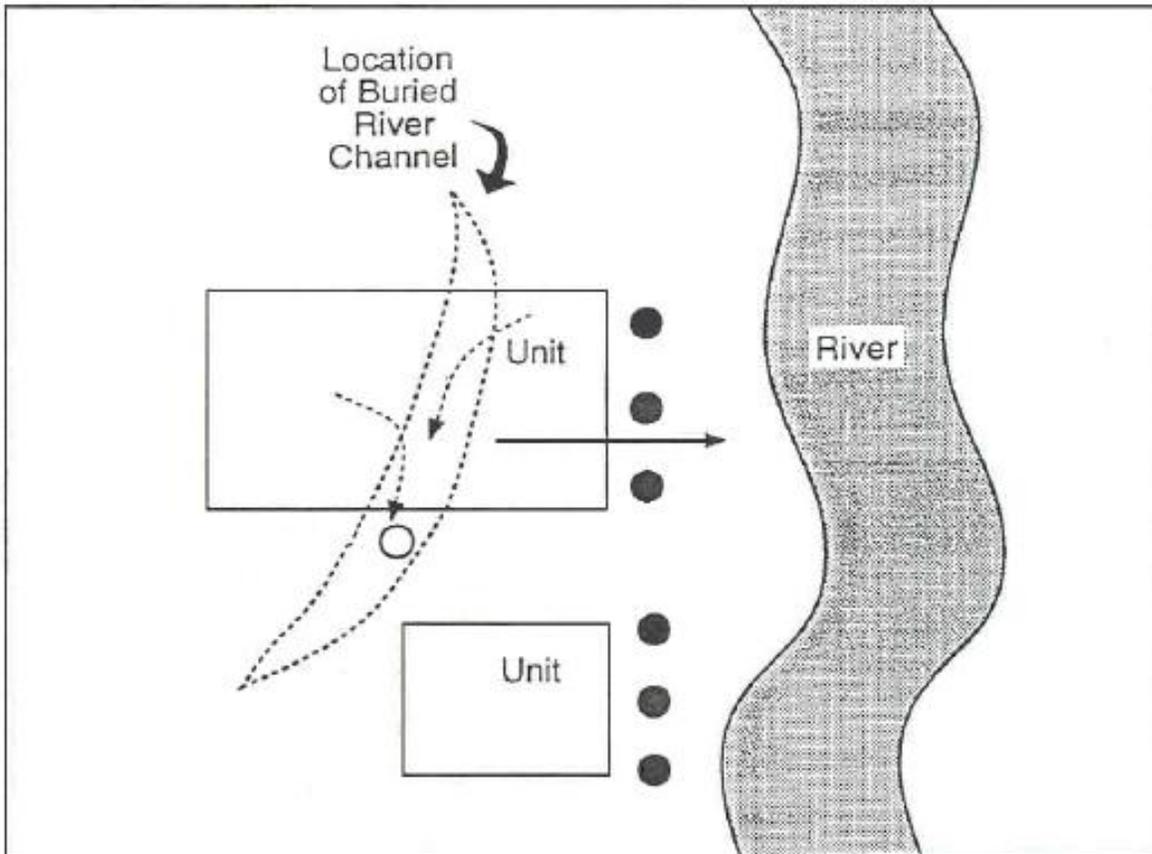
Understanding the principles of ground water movement (flow rate, direction, and gradient) through various types of geologic materials plays a key role in developing strategies for identifying likely contaminant migration routes and selecting ground water monitoring locations. If the distribution and characteristics of materials are not defined, the zones requiring monitoring may be identified incorrectly, and releases may remain undetected. Hydrogeologic conditions affecting the placement of well intakes include: depth of water table, presence of perched water, subsurface materials (e.g., unconsolidated, bedrock), presence of multiple ground water zones, zone type (i.e., confined versus unconfined), presence of continuous zones that may restrict flow, type and amount of recharge and discharge, permeability, fractures, and capillary fringe. The components of a hydrogeologic investigation are outlined in Chapter 3.

**Table 5.1 Objectives of Ground Water Monitoring.**

<b>OBJECTIVE</b>	<b>DISCUSSION</b>
<b>Detection/Compliance</b>	Wells are placed at the downgradient boundary of a potential source to detect a release. These wells are used to determine that compliance requirements are being met according to some minimum or maximum standard.
<b>Assessment</b>	Wells are placed progressively away from the potential source(s) to determine the rate and extent of contaminant migration. Monitoring often occurs at the fringes of the plume.
<b>Risk Assessment</b>	Monitoring to determine the concentrations within a plume to help determine the potential risk to human health and the environment. A toxicologist may require information concerning the reasonable maximum concentration of contaminants to assess risk at specific locations.
<b>Warning System</b>	Wells are placed near a receptor to act as a warning system from any potential sources of contamination. Would allow the owner of potential receptors to take action.
<b>Trend Analysis</b>	Designed to evaluate whether a decreasing or increasing trend is occurring. May be conducted to determine remedy progression or the effects of activities such as application of fertilizer.
<b>Remedy Progression</b>	Wells are used to determine whether the remedy is working properly.
<b>Cause and Effect</b>	Wells are placed to evaluate an action or process (e.g. pumping of ground water.)

Preferential pathways for contaminant migration include zones that are fractured or have relatively high matrix hydraulic conductivity (K). The distribution of these materials can play a significant role in dictating ground water and contaminant movement. The presence of conductive zones within less conductive zones can create multiple paths of migration from a source. For example, Figure 5.1 shows a buried river channel. The regional and local ground water flow is toward the river; however, beneath a portion of the site, ground water is directed along the buried channel. Figure 5.2 demonstrates how water and contaminants may migrate horizontally across a perched water zone and then vertically through the unsaturated zone, transmitting contaminants to an underlying water-bearing zone over a pathway that is circuitous and not easily identified. Figure 5.3 demonstrates how complex flow patterns can occur due to fracturing. Regional and local flow is to the south. However, the orientation, density and connectivity of fractures may initially direct ground water and contaminants to the southeast, then southwest

The processes controlling the movement of dissolved contaminants through porous media include advection, mechanical dispersion, and diffusion. Advection is the transport of solutes by the flowing ground water. Ground water moves at rates both greater and less than the average linear velocity. This is due to: 1) fluids moving faster through the center of the pores than along the edges, 2) fluids travelling shorter pathways and/or splitting or branching to the sides, and 3) fluids travelling faster through larger pores than through smaller pores (Fetter, 2001). Because the invading solute-containing water does not travel at the same velocity, mixing occurs along flow paths. This mixing is called mechanical dispersion and results in distribution of the solute at the advancing edge of flow (Fetter, 1999). The mixing that occurs in the direction of flow is called longitudinal dispersion. Spreading normal to the direction of flow from splitting and branching out to the sides is called transverse dispersion.



- Downgradient detection wells
- Downgradient well in buried channel
- - - - -> Preferential pathway of contaminant migration into the buried river channel
- > Local ground-water flow direction

**Figure 5.1 Geologic setting where ground water flow is affected by a buried river channel. Ground water flow is regionally and locally directed toward the river; however over a portion of the site, the ground water is directed along a buried valley (Source: Modified from U.S. EPA, 1993a).**

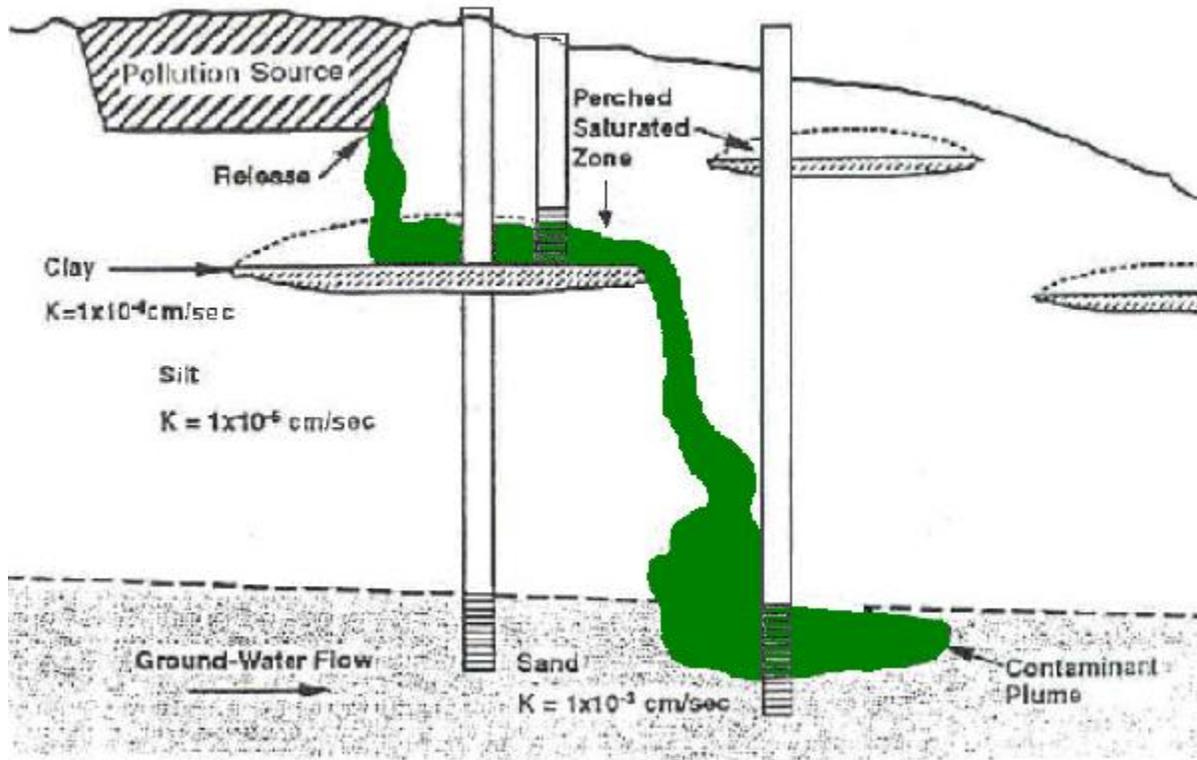


Figure 5.2 Contaminants and fluids migrate horizontally across a perched zone, then vertically to a water-bearing zone (Source: Modified from USEPA, 1993a).

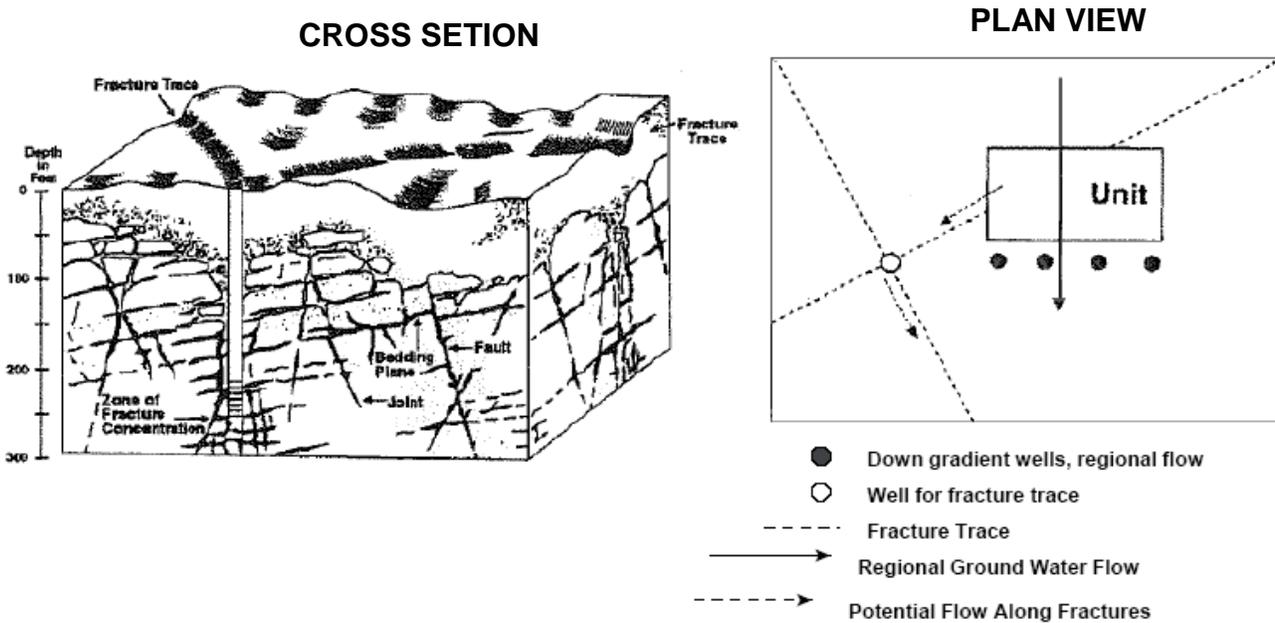


Figure 5.3 Complex fracturing creating multiple pathways for contaminant migration (Modified from U.S. EPA, 1993a).

Diffusion is the process by which ionic and molecular species dissolved in the water move from areas of higher concentration (i.e., chemical activity) to areas of lower concentration. The processes of mechanical dispersion and molecular diffusion cannot be distinguished in a ground water flow system and often are referred to collectively as hydrodynamic dispersion (Fetter, 2001). Depending on the degree of dispersion, a contaminant may form a wide or a narrow plume. Hydrodynamic dispersion phenomena also may cause contaminants to arrive at a given location significantly ahead of the arrival time expected solely from an average flow rate. General textbooks by Freeze and Cherry (1979), Fetter (2001), Luckner and Schestakow (1991), Domenico and Schwartz (1998), and Fetter (1999) should be consulted for additional information on hydrodynamic dispersion.

Colloidal transport may result in higher levels of contaminants being present than would be predicted by the mass solute transport equation. Colloids are particles with diameters less than 10  $\mu\text{m}$  and include dissolved organic macromolecules, microorganisms, microemulsions of nonaqueous phase organic liquids, mineral precipitates, weathered material, precipitates of transuranic elements such as plutonium, and rock and mineral fragments (McCarthy, 1990). Colloids may be small enough to move through the pores of a ground water zone. They can sorb inorganic and organic contaminants and stabilize them, thus creating a second mobile phase.

Colloids may have a velocity greater than the average linear velocity (Enfield and Bengtsson, 1988). This is due to the size-exclusion effect, which occurs when molecules or ions are so large that they cannot travel through the smaller pores. Consequently, colloidal travel is restricted to larger pores in which the ground water velocity is greater than average. This effect is much more prevalent in fine-grained materials that have some pores small enough to exclude some molecules (Fetter, 1999).

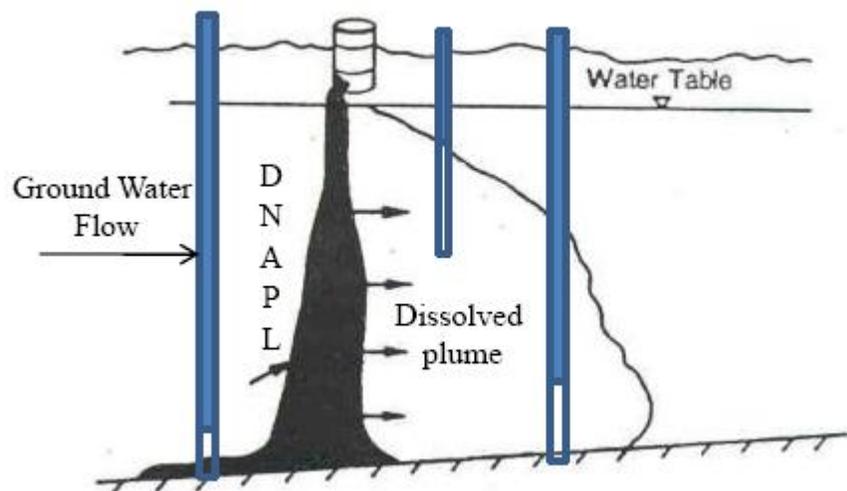
## CONTAMINANT PROPERTIES

Three general types of contaminants that occur in the subsurface include aqueous (those dissolved in the ground water) non-aqueous phase liquids (NAPLS) and particulate matter (colloid size particles that may be inert or biologically active). Fate and transport of these contaminants are functions of their characteristics, including, but not limited to, relative solubility; density; viscosity; and potential for sorption, reaction and degradation. Multiple plumes can form if a combination of contaminants with different properties is present.

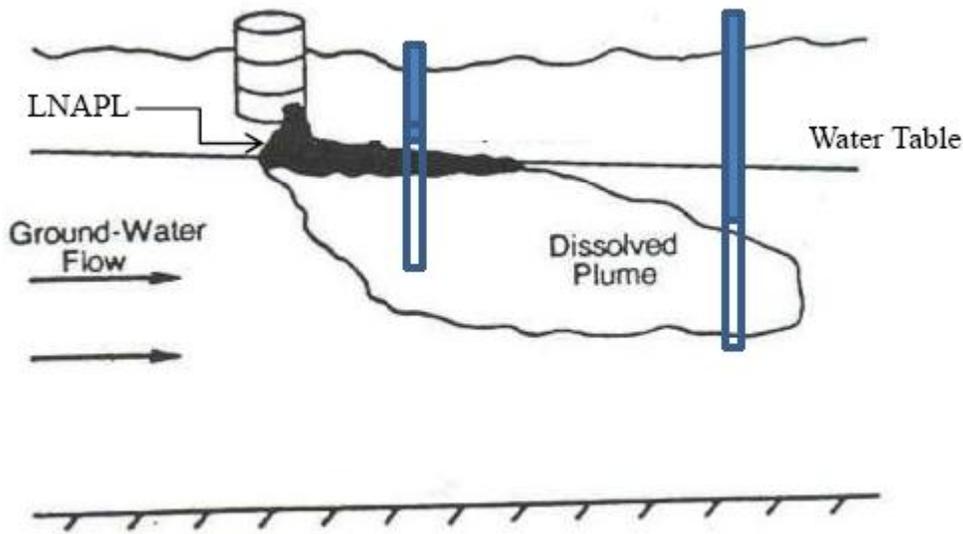
**Relative solubility** controls whether a contaminant exists in ground water primarily as a dissolved (soluble) or free liquid phase (insoluble). Movement of the dissolved phase is generally in the direction of ground water flow and is governed primarily by the processes of advection-dispersion and attenuation (biological/chemical and sorption). The movement of NAPL is influenced by the fluid density. **Fluid density** is defined as the mass of fluid per unit volume ( $\text{g}/\text{cm}^3$ ). If a contaminant is denser than ground water, it tends to sink and may accumulate as a dense non-aqueous phase liquid (DNAPL). Conversely, a contaminant less dense tends to remain in the upper portions of saturated zones as a light non-aqueous phase liquid (LNAPL). Most LNAPLs are hydrocarbon oils and fuels and DNAPLS include chlorinated compounds (e.g., carbon tetrachloride, tetrachloroethene), PCBs, and creosote (U.S. EPA, 1993a; AWWA, 2006).

The density of a contaminant, in conjunction with its relative solubility, affects the shape and disposition of the dissolved and free phase plume(s). Individual contaminants can be classified based on relative solubility and density as: 1) low density and relatively soluble (Figure 5.5), 2) high density and relatively soluble (Figure 5.4), 3) low density and relatively insoluble (Figure 5.7), or 4) high density and relatively insoluble (Figure 5.6). Relatively soluble contaminants are generally mobile in the subsurface and can form large dissolved plumes with relatively small free phase plumes. If a contaminant is a dense, soluble liquid, the plumes that form may cover the entire thickness of the saturated zone (Figure 5.4 and 5.6). Likewise, if a contaminant is soluble but of low density, the major portion of the plume will be limited to the upper portions of the saturated zone (Figure 5.5). The depth of the dissolved phase would be dependent on the vertical flow component.

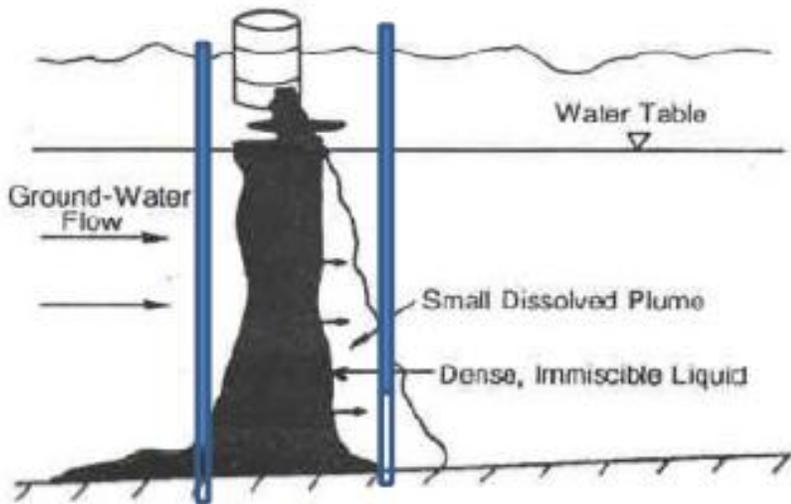
Relatively insoluble liquids can exist as large free liquid plumes with relatively small dissolved plumes (Figure 5.6 and 5.7). DNAPLs tend to migrate vertically and coalesce at the surface of a confining layer, their movement dictated by its dip. In some cases, DNAPLs may migrate in a direction that does not correspond to the direction of ground water flow (Figure 5.4 and 5.6). LNAPLs generally migrate on top of the capillary fringe/water table and have an underlying halo of dissolved substance (Figure 5.5 and 5.7). Identifying whether or not a compound exists as DNAPL or LNAPL can be complicated by the substance in which it is dissolved. For example, free phase PCBs may be denser than water, but PCBs in oil can be transported as an LNAPL. Additional information on NAPL migration is provided in documents by U.S. EPA (1993) and Huling and Weaver (1991).



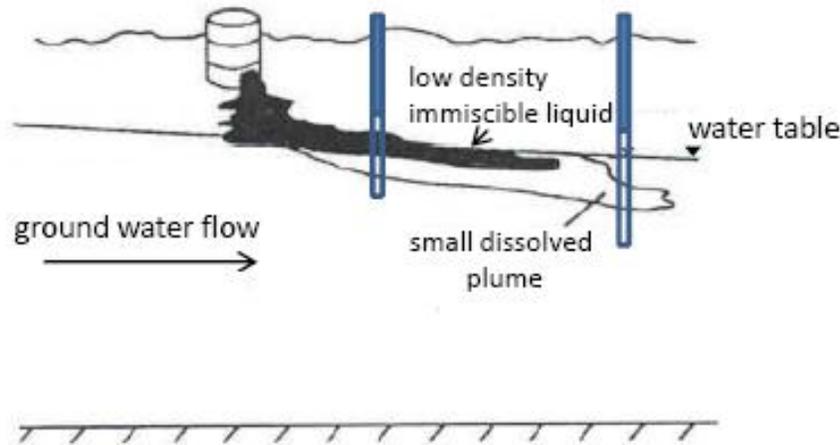
**Figure 5.4. Migration of a dense, soluble contaminant in the subsurface (Aller et al., 1991).**



**Figure 5.5. Migration of a low density, soluble contaminant in the subsurface (Aller et al., 1991).**



**Figure 5.6 Migration of a dense, non-aqueous phase liquid in the subsurface (Aller et al., 1991).**



**Figure 5.7 Migration of a low density, non-aqueous phase liquid in the subsurface (Aller et al., 1991)**

**Kinematic viscosity** of a non-aqueous phase liquid (NAPL) provides an indication of the potential for the compound (in its pure form) to percolate through the subsurface. Kinematic viscosity is the ratio of dynamic viscosity to density. Dynamic viscosity provides an indication of the ease with which a compound (in its pure form) will flow. Lower kinematic viscosity results in greater tendency to penetrate a porous media. In general, mobility can be rated high if the value is less than 0.4 centistokes (cs), moderate if between 0.4 and 0.8 cs, and low if greater than 0.8 cs (U.S. EPA, 1992).

The kinematic viscosity of water is approximately 1 cs. The relative viscosity of a NAPL indicates how fast it penetrates the subsurface relative to water. For example, tetrachloroethene, 1,1,1-trichloroethane, methylene chloride, chloroform, and carbon tetrachloride (low kinematic viscosity) flow 1.5 to 3 times as fast as water, while light heating oil, diesel fuel, jet fuel, and crude oil (high kinematic viscosity) flow 2 to 10 times slower than water (Schwille, 1981, 1988; Huling and Weaver, 1991). The relative permeability of a material can be one or more orders of magnitude higher when low viscosity fluids are moving through it than for water moving through the same material. A low viscosity LNAPL such as gasoline tends to spread on the capillary fringe/water table surface more readily than would a LNAPL of high viscosity. A DNAPL more viscous than water tends to move more slowly than the average linear velocity of ground water.

**Sorption** processes include adsorption, chemisorption, absorption and ion exchange. It is not the intent of this document to define or separate these phenomena. Sorption reactions between solutes and the geologic matrix can retard the movement of a "reactive" solute. From a practical viewpoint, the important aspect is the removal of the solute from solution, irrespective of the process (Fetter, 1999). For example, many heavy metals (e.g., cadmium, lead, and mercury) are adsorbed readily onto particle surfaces or trapped by clays through ion exchange. Adsorption of metals generally increases with increasing pH, although exceptions occur. Synthetic organic compounds in solution can be adsorbed by the organic carbon in soil.

The rate and extent of adsorption depends on the characteristics of the adsorbing agent and the chemicals and the phases in which the chemicals exist. The process by which a contaminant that was originally in solution becomes distributed between the solution and the solid phase is called partitioning. The partitioning coefficient ( $K_d$ ) is used to evaluate the effect of sorption on the retardation of an organic chemical compared with the rate of movement of ground water. The expression:

$$R = 1 + rK_d/n,$$

where  $R$  is the retardation factor that quantitatively expresses the ratio of velocity of water to velocity of the chemical,  $r$  is the bulk density and  $n$  is the porosity of the subsurface material, defines  $K_d$ .

Other parameters that may be useful in predicting extent of adsorption of an organic constituent include the octanol-water partitioning coefficient ( $K_{ow}$ ) and the organic carbon absorption coefficient ( $K_{oc}$ ). The higher the value of  $K_{ow}$  and  $K_{oc}$ , the greater the tendency for adsorption to soils containing appreciable amounts of organic carbon.

***Chemical reactions and biological and chemical degradation*** of a contaminant may form new compounds. For example, trichloroethene degrades to dichloroethene and subsequently to vinyl chloride. The properties of both the original contaminant and its degradation products must be considered. Degradation in the subsurface may not always be predictable merely from the known behavior of compounds. Verification by direct experimentation, such as bench or pilot studies, may be necessary. Also, studies have demonstrated that certain organic and acidic liquid wastes can cause desiccation cracks in clays, which can increase permeability (Brown, 1988).

## **ANTHROPOGENIC INFLUENCES**

Anthropogenic (human-made) influences can alter ground water flow direction and thus dictate contaminant pathways. Pumping wells, artificial recharge, irrigation, and changes in land use patterns (e.g., paving and construction) can also alter flow beneath a pollution source either continuously or intermittently. Other structures that can influence flow include, but are not limited to, infiltration galleries, storm sewers, sanitary sewers, utility lines, underground piping, and drainage tiles. In addition, overhead power lines, road, and other structures may make areas not accessible for the placement of wells.

## **DESIGN OF A MONITORING WELL NETWORK**

The objective of pollution source monitoring is to evaluate ground water occurring in potential contaminant pathways and any specific zone(s) required for regulatory purposes. For each pathway monitored, well placement should allow comparison of downgradient to background quality. The installation of an adequate network of wells generally is an iterative process. The network should be evaluated on a continuing basis as site and waste characteristics become better defined.

Design must also be based on consideration of safety, system maintenance considerations, property boundaries, accessibility, site operations, and vehicle traffic. For example, it may be difficult to locate wells due to traffic patterns, buildings, and neighboring facilities or residences. It may be unsafe to install wells near overhead and buried electrical lines and pipe lines. An additional concern is the number, spacing, and orientation of potential pollution sources. U.S. EPA (1993a)<sup>1</sup> summarized the criteria necessary to determine whether "waste management units" need to be monitored as multiple or individual units.

Components of well placement that must be considered are number, areal location, and depth and length of intakes (vertical placement). The designer must consider both vertical and horizontal placement simultaneously to develop a three-dimensional system. The following guidance cannot be applied without a sufficient understanding of the factors that may dictate well placement (discussed in previous section). The importance of understanding hydrogeologic conditions and waste characteristics cannot be overemphasized (Barcelona et al., 1985).

## **NUMBER OF WELLS**

The number of wells needed depends on the purpose of the monitoring program (which may be dictated by regulatory requirements) and site conditions. A network designed merely to investigate whether contamination has occurred (detection monitoring) may be less extensive than one installed to determine the rate and extent of contaminant migration (assessment monitoring) or to monitor remedial activities. Additionally, rules may specify a minimum number of detection wells. However, the minimum is generally insufficient for large regulated units and when multiple or thick pathways are present.

## **VERTICAL PLACEMENT**

Proper well intake placement is crucial for accurate characterization of the ground water and assessment of the presence of contaminants. Vertical placement of monitoring wells should be based on the depth and thickness of pathways. Components of vertical placement include the depth and length of well intakes.

### **Depth of Intakes**

At a minimum, wells should be screened in the first ground water encountered and any zone that may be required by regulation.

In fine-grained material, such as clays and glacial till, soil is generally moist above the water table. This zone is created by capillary forces (molecular force between the water molecule and the soil particle) and is termed the capillary fringe. In general, the thickness of the capillary fringe varies inversely with grain size, and can range from several inches to feet above the water table. In this zone, the water pressure is below atmospheric; therefore, water does not enter the well. The capillary fringe can easily be mistaken as the water table. Therefore to avoid placing the intake into the capillary fringe only, it is recommended that the water always be observed in the borehole prior to installing the screen.

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<sup>1</sup>This document (U.S. EPA, 1993a) was developed for RCRA-permitted facilities. However, technical issues addressed may be appropriate to all types of pollution source monitoring investigations.

If a pathway is thick (greater than 10 feet), multiple wells installed to various depths at each location may be necessary to sample discrete vertical segments. This can allow determination of the vertical distribution of ground water contamination and flow. Installation of wells that monitor the top, middle, and bottom portions of a saturated zone may be necessary (Figure 5.8). Multiple wells at the same location also may be necessary if multiple, discrete saturated zones that could act as pathways are present (Figure 5.9). Care should be taken during drilling to avoid ground water mixing between saturated zones (see Chapter 6).

When installing wells to detect ground water contamination by LNAPLs, it is essential that intakes are placed across the water table interface and are completed at a depth and length sufficient to compensate for seasonal level fluctuations. Deeper wells may be necessary to determine the vertical extent of contamination if a significant dissolved portion is present. DNAPLs may exhibit overall vertical migration even if horizontal ground water flow predominates; therefore, at a minimum, screens need to be placed at or near the bottom of a saturated zone or just above a confining layer (Figure 5.8, well c). Multiple wells completed at different depths may be required if both LNAPLs and DNAPLs are present.

If detection monitoring has documented the presence of ground water contamination and a potential exists for contaminants to occur at deeper levels, additional wells with intakes at deeper horizons should be installed to allow assessment of the vertical extent of migration.

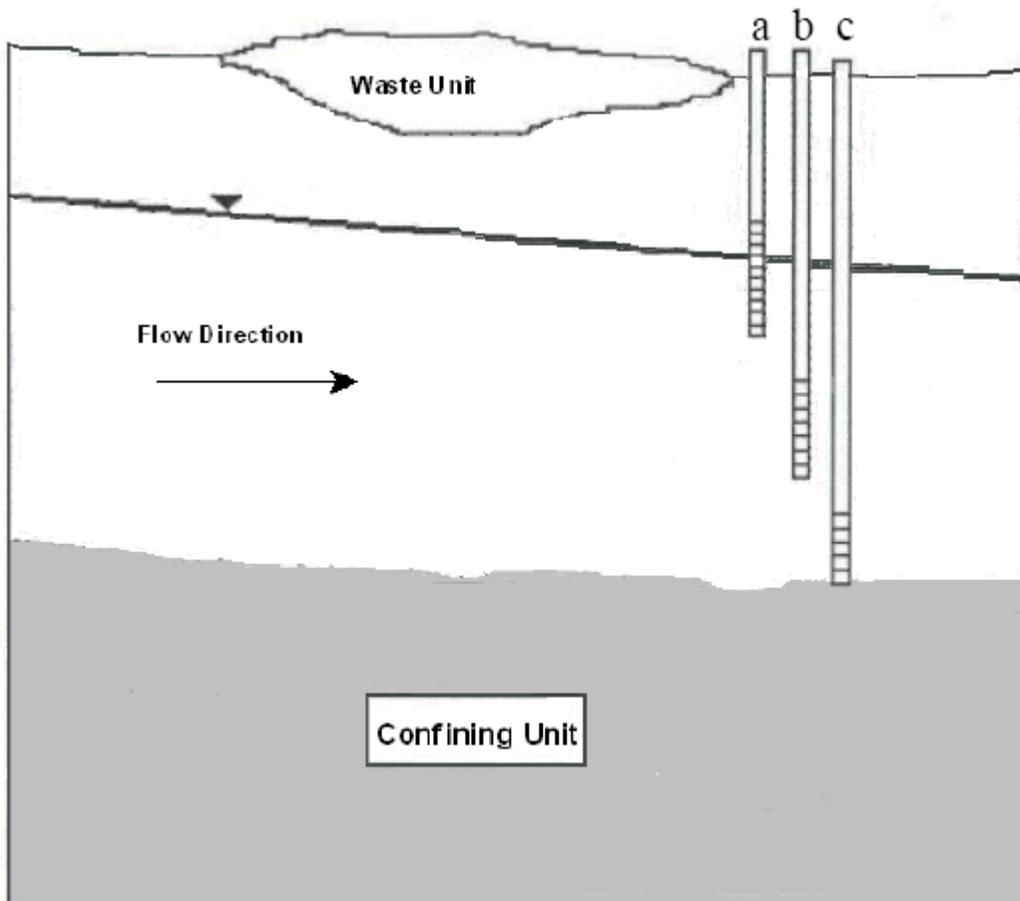


Figure 5.8. Cluster of wells due to thickness of the saturated unit.

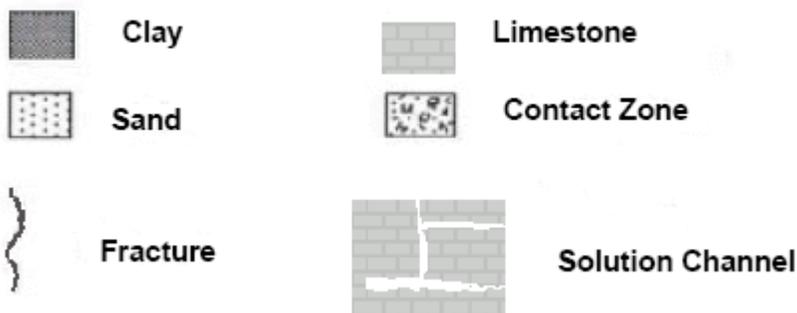
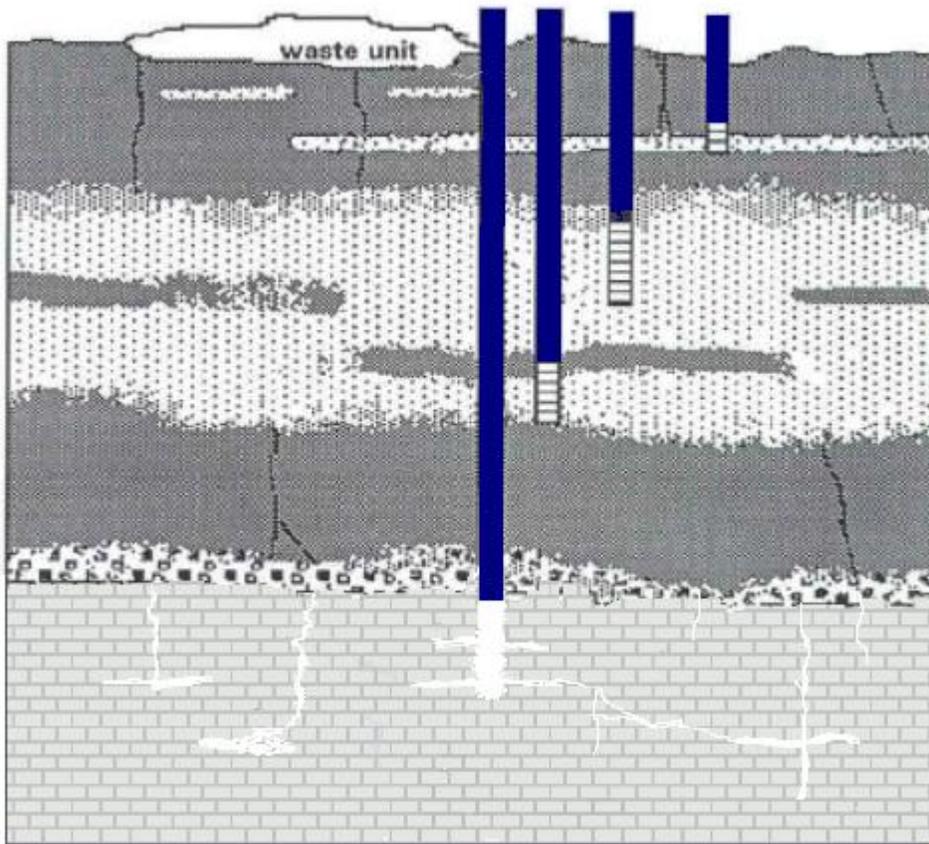


Figure 5.9. Cross-section showing a well cluster.

### Length of Intakes

In general, intakes should not exceed ten feet; however, the complexity of hydrogeologic conditions or the intended use of wells may dictate that longer (or shorter) intakes are necessary. For example, variable formations necessitate shorter intakes that allow discrete portions to be sampled. If an intake crosses through several alternating zones of high and low K, each zone contributes a different volumetric flow to the total yield. If only one zone is

contaminated, a sample obtained from such a well will not be representative of the contaminated zone due to sample dilution. Intakes crossing several zones would also provide inaccurate data for flow direction and rate. Additionally, these wells may act as conduits for contaminant migration.

Though intake length may depend on the thickness of the saturated zone, it is not synonymous. Intakes shorter than the saturated thickness may be necessary when monitoring homogeneous zones because the behavior of the contaminant may cause it to be concentrated at a particular depth, and long intakes may dilute samples. Likewise, longer intakes may be necessary if a fluctuating water table occurs and the contaminant of concern is lighter than water and floats on the water table surface.

## **AREAL PLACEMENT OF DOWNGRADIENT WELLS**

The areal placement of downgradient monitoring wells should be based on the number and spatial distribution of potential contaminant pathways. The components of areal placement include location relative to the pollution source and spacing. The designer should also consider potential receptors such as water supply wells, springs, and surface waters that are downgradient of the pollution source.

### **Placement Relative to Pollution Source**

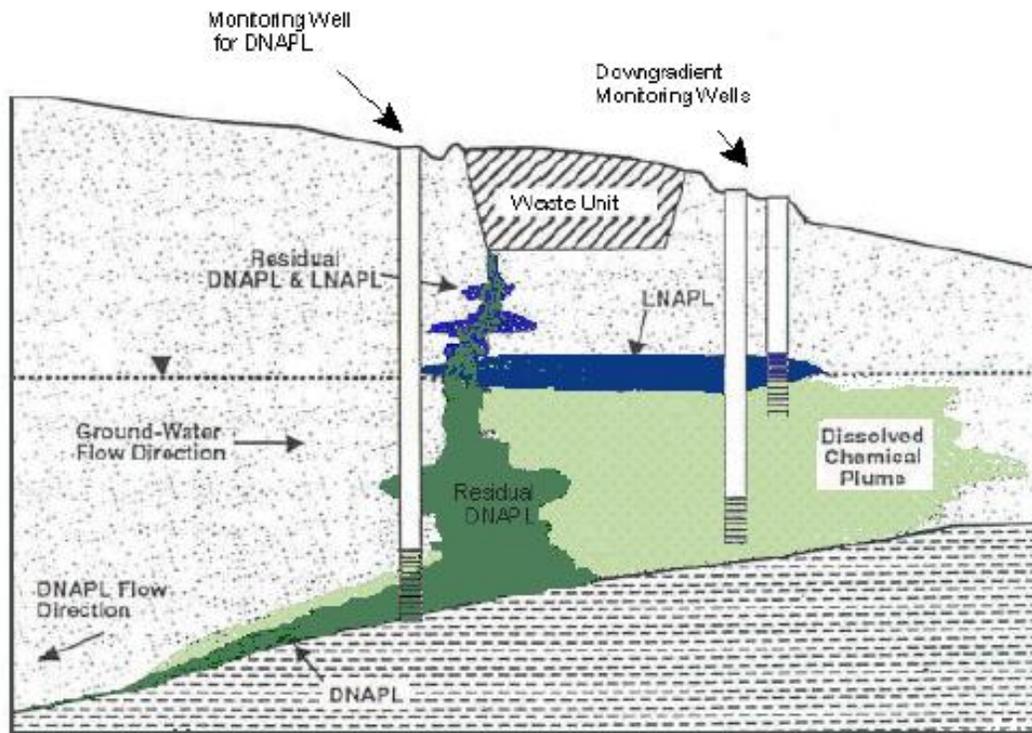
To identify proper locations for ground water sampling, the direction of ground water flow should be determined in all potential contaminant migration pathways. Methods for determining flow direction are discussed in Chapter 3. Knowledge of flow direction is necessary to ensure that wells intended to intercept potentially contaminated ground water are placed hydraulically downgradient of the potential source. To determine if a release has occurred, the downgradient wells should be located laterally along the edge of, or as close as practicable to, the source and have intakes placed to intersect likely pathways. Placing wells through waste management units should be avoided; however, this is sometimes necessary to determine if contaminants are present. In this case, special well construction procedures must be followed to prevent downward movement of waste constituents. In addition, Ohio Revised Code section 3734.02(H) requires authorization from the Director of the Ohio EPA to engage in filling, grading, excavating, building, drilling, or mining on land where a hazardous or solid waste facility has been operated.

Mounding may occur where a potential source is topographically higher than the surrounding landscape or where a surface impoundment is in an area where there is a shallow water table. In these situations, it may be necessary to place downgradient wells entirely around the source.

Where a potential exists for a DNAPL to sink vertically and accumulate at the interface of a lower impermeable boundary, it may be necessary to place wells that are not downgradient of the pollution source to monitor migrating DNAPL. The dense fluid moves in response to gravity and/or the dip of confining layers and, therefore, may migrate in a direction that is different from the ground water flow direction (Figure 5.10). Knowledge of the slope of the confining layer may be needed to locate and monitor the dense phase. Note that if a dense phase is also soluble in water, a dissolved plume will form and move in the direction of

ground water flow (Aller et al., 1991). If a DNAPL is soluble, then a detection monitoring system may only need to enable a comparison of downgradient and background ground water samples.

If detection monitoring has documented contamination, additional wells should be added at increasing distances away from the source area. The wells should be sampled to assess the horizontal extent of contamination.



**Figure 5.10. Migration of a DNAPL along the dip of a confining layer (modified from U.S. EPA, 1993a).**

## Spacing

Spacing refers to the distance between adjacent wells that monitor the same zone. Generally, more complex hydrogeology requires tighter spacing. Monitored zones that exhibit horizontal heterogeneity in material type may necessitate closer or variable spacing. Close spacing may be necessary when a pollution source is underlain by gravelly sand because of the greater potential for rapidly moving, narrow plumes to form. Conversely, zones characterized by low K and high diffusivities (such as a clay-silt) develop wider plumes and larger spacing may be sufficient. Other characteristics that may require wells to be closely spaced include location in or near recharge zones, steep or variable hydraulic gradients, high flow velocity, and variable flow direction.

Placement of wells in fractured bedrock or bedrock containing solution channels may be difficult. Fractured rock contains numerous zones that may act as discrete pathways for contaminant migration. Monitoring wells often must intersect these zones to be able to provide water or detect contaminants (Chapter 3 addresses methods to locate fractures).

Close spacing of wells may be warranted if characterizing leaks of synthetic liners. Such leaks may result in a narrower plume than leaks from an unlined pond. Also, closer spacing may be necessary in areas that are characterized by buried pipes, utility lines, or trenches where point source leaks may occur.

## **BACKGROUND MONITORING WELL(S) PLACEMENT**

Background monitoring wells generally are placed hydraulically upgradient of the pollution source. The wells should provide samples that are unaffected by facility operations and representative of background ground water quality. Sampling should be sufficient to account for hydrogeologic heterogeneity and seasonal, temporal, and spatial changes in background water quality. Upgradient or cross-gradient wells may also serve to indicate unanticipated effects of a remedy (e.g., radial flow due to injection of water). Background wells may also be useful in providing a continuous check on the quality of the regional flow system, thus providing early warning of any new contaminants being transported into the remediation area (Gorelick et al., 1993).

### **Location**

Background wells are completed in the same stratigraphic horizons as downgradient wells to allow for representative comparisons. Intake length should be selected using the same criteria described earlier in this chapter for downgradient wells. It is also important to locate background wells at a distance from the potential pollution source greater than the radii of hydraulic influence so that the wells will not receive contaminants during development or purging.

It may not always be possible or desirable to locate background wells hydraulically upgradient from the source. Situations that may affect the location of background wells include:

- Waste sources that are topographically higher than the surrounding landscape may be characterized by radial flow away from the source due to mounding. Surface impoundments located in an area of shallow ground water also may cause mounding.
- In some instances, the unit being monitored downgradient may pinch out in the upgradient direction.
- If other activities have affected ground water quality upgradient of the pollution source, the contamination may bias the quality comparison.
- Flow direction can vary seasonally or in response to the influence of nearby surface water or ground water pumping. Due to the changes, no location is clearly upgradient under all conditions.

- The pollution source is situated adjacent to the facility property boundary such that the upgradient flow direction would dictate a background well to be located off-property.
- Upgradient locations are inaccessible due to an obstacle (e.g., other pollution sources, buildings, utilities, etc.).

In these situations, background wells do not need to be upgradient as long as it is demonstrated that 1) they are situated beyond the influence of the pollution source, 2) they are completed in the same zone as the downgradient wells, and 3) the samples provided are representative of background ground water quality. In the case of radial flow, the background wells should be located in an area considered upgradient of the predisposal flow trends.

### **Number**

Dependent upon the complexity of hydrogeologic conditions and the number, location, and size of the pollution source, more than one background well may be necessary. Some general situations that may warrant more are as follows:

- The pollution source is very large.
- Multiple potential pollution sources are present.
- The hydrogeologic setting is characterized by distinctly different hydraulic zones.
- Background ground water quality varies spatially or seasonally.

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