# Source Water Protection Monitoring Guidance

Division of Drinking and Ground Waters
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# FOREWORD

The Federal Safe Drinking Water Act amendments of 1986 established the Source Water Protection Program, which required states to administer a program designed to protect the ground water that supplies their public water systems that provide drinking water from wells. In 1996, the Safe Drinking Water Act was amended again to provide states with funding to complete source water assessments for all their public water systems. At that time, the program was extended to include surface water systems and was renamed Source Water Assessment and Protection (SWAP). Ohio EPA's Division of Drinking and Ground Waters administers the program in Ohio following program approval by U.S. EPA in 1999.

Under Ohio's SWAP Program, Ohio EPA staff provides public water suppliers with information (in the form of a "Drinking Water Source Assessment Report") about the area that contributes water to their wells or intakes, and the susceptibility of that area to contamination. This information should assist the public water supplier in determining what activities can be undertaken to better protect the drinking water from contamination.

The responsibility for developing and implementing protective strategies lies with the local public water supplier, with the assistance of other stakeholders. Once a public water system has been assessed, Ohio EPA expects the public water supplier to develop a local "Source Water Protection Plan" that explains what protective activities will be undertaken, by whom, and how.

Ground water monitoring is one of the many protective activities that can be undertaken. This document has been prepared by the Division of Drinking and Ground Waters (DDAGW) at the Ohio Environmental Protection Agency (Ohio EPA) to assist community officials, water suppliers, and their consultants in: (1) assessing whether ground water quality within a community's SWAP area should be monitored; and (2) how to design a ground water monitoring system that will effectively realize the goals of Source Water Protection.

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# GROUND WATER MONITORING IN A SOURCE WATER PROTECTION AREA

## INTRODUCTION

Ohio's dependence on ground water makes it a critical resource. It is estimated that Ohio uses approximately one billion gallons of ground water every day. About 77 percent of the State's 1,224 community water systems rely on ground water for all or part of their water supply. Source Water Protection planning can help Ohioans manage the risks associated with activities in or near their wellfields and prevent the degradation of ground water resources supplying those wellfields.

Ohio's Source Water Protection Program calls for each public water system to submit a Source Water Protection plan to Ohio EPA for its review. Developing a Source Water Protection (SWAP) Plan involves three main steps:

1) **Delineating the Source Water Protection Area** to identify the area contributing ground water to the public water supply, in which SWAP efforts will be focused;

2) Completing a **Potential Contaminant Source Inventory** to identify those activities in and around the SWAP area that have the potential to contaminate ground water; and

3) Developing a **Management Plan** that provides strategies for reducing the likelihood of ground water contamination impacting the public water supply. The plan must include a public involvement and education program and a contingency/emergency response plan.

**Ground water monitoring is just one of many strategies that a community may use to protect its public water supply.** If SWAP planners have developed other protective strategies that provide sufficient protection to the aquifer, they may conclude--and Ohio EPA may agree--that ground water monitoring is not necessary. On the other hand, some communities have made ground water monitoring a primary part of their Source Water Protection Plan. And in some cases, Ohio EPA has strongly recommended that a community install some monitoring wells, to supplement other selected protective strategies. The main criterion for Ohio EPA endorsement of a Source Water Protection Plan is whether or not the known and potential Contaminant sources are adequately addressed to prevent the public water system from being impacted.

The first purpose of this document is to assist Source Water Protection planners in deciding whether or not they need to include ground water monitoring in their Protection Plan. Factors in making this decision are discussed in the remainder of this chapter.

If a community determines that it needs ground water monitoring, then this document may assist Source Water Protection planners in designing a ground water monitoring system that will provide sufficient information about ground water quality in their community's SWAP area. This guidance is presented in Chapters 2 through 4, and covers such topics as: where to site ground water monitoring wells; how to decide which constituents to sample for, and how often; and how to evaluate the ground water quality results. Ohio EPA reviews ground water monitoring plans for their adequacy, and may withhold endorsement of a community's Protection Plan if it is centered around an inadequate ground water monitoring plan.

## BENEFITS AND COSTS OF GROUND WATER MONITORING IN A SWAP AREA

### Benefits

Ground water monitoring complements other Source Water Protection strategies in a number of ways. Most importantly, properly constructed and located monitoring wells provide an **early warning of ground water contamination** prior to its impacting the wellfield. Unlike most Source Water Protection strategies, this is not a pollution *prevention* strategy, but it does provide an additional measure of protection to the public water supply. Early warning allows the public water supplier to take steps to remediate or contain a contaminant plume before it enters the public water supply. In the case of nonpoint source contamination, which does not form a discrete plume, a gradual increase in levels of contamination at monitoring wells warns the water supplier that these levels may soon appear in the water supply unless some protective and/or corrective measures are taken.

**Table 1. Benefits and Costs of Ground Water Monitoring**

| Benefits | Costs |
|---|---|
| 1. Early warning of impending contamination | 1. Well installation |
| 2. Ability to evaluate effectiveness of protective strategies | 2. Laboratory analysis |
| 3. Enhanced public confidence in public water supply | 3. Salary of people who design plan, collect samples, prepare paperwork, and record and evaluate results |
| 4. Additional hydrogeologic information. | 4. Sealing wells, if monitoring is discontinued. |

Ground water monitoring wells also enable a community to **evaluate the effectiveness of other selected management practices**. For instance, if non-point sources of nitrate are the main threats to a SWAP area, an education program encouraging voluntary action for upgrading septic systems and implementing best management practices (BMPs) for agricultural use of fertilizer may be instituted. The effectiveness of this management approach can be evaluated by instituting a ground water monitoring plan to track increases or decreases in nitrate values.

Ground water monitoring may be conducted in response to an emergency spill or release, such as a fire or accident. Under these circumstances, it complements **contingency planning** for the SWAP area. For example, the City of Dayton has a detailed plan for rapid mobilization and installation of wells, in the event of a serious chemical spill or release. Such a plan was a priority for this city, because its wellfields are located over a highly vulnerable sole-source aquifer, and there are numerous contaminant sources and known contaminant plumes within the SWAP area.

Another benefit is the **additional confidence** that the public may feel regarding the safety of their public water supply. This is especially true in situations where the public water supply is threatened by numerous and/or serious potential (or verified) contaminant sources.

Finally, wells installed as part of a ground water monitoring network can provide **additional information about the area's hydrogeology**, which may enable a community to fine-tune the delineation of its SWAP area. Ground water elevations are among the most important data used to delineate a SWAP area, and these can only be measured through appropriately constructed wells. If a community's SWAP area delineation was based on barely adequate amounts of hydrogeologic data, installation of wells in appropriate sites can greatly improve the accuracy of the delineation.

### Costs

Initiating a ground water monitoring program may involve significant costs. Most communities hire an environmental consultant to develop the monitoring system and the sampling and analysis plan. If monitoring wells must be installed, there is a significant one-time cost involved. Analysis of samples by commercial laboratories can be costly, depending on the types of constituents that are sampled and the frequency of sampling.

Investment of **time** by the water supplier or his/her designees also may be significant. Depending on the number of wells in a monitoring system and ease of access, sampling events can consume several days. Preparation for a sampling event (filling out forms, arranging the sampling containers for each well, etc.) also may involve many hours. Entering the ground water quality data onto a database and analyzing it will require time. Some communities may elect to retain a consultant to analyze the ground water quality data, especially where the amount and complexity of the data is significant.

Finally, the monitoring wells themselves are a **potential source of contamination** if they are vandalized or poorly maintained. If the community decides to stop monitoring, it will need to abandon its monitoring wells in accordance with industry standards. Depending on the depth of the well(s), this can involve considerable expense. For all these reasons, a ground water monitoring system must be regarded as a serious investment by the community.

## WHEN TO MONITOR GROUND WATER IN A SWAP AREA

The decision of whether or not to monitor ground water in a SWAP area should be based on the potential for ground water supplying the public water system to become contaminated. A public water system should consider three primary criteria in making this determination.

1. the sensitivity of the aquifer providing the public water supply,
2. the degree of threat posed by the contaminant sources identified in and around the SWAP area, and
3. whether other protective strategies make monitoring wells unnecessary.

### Sensitivity of the Aquifer

The sensitivity of the aquifer refers to the likelihood that the aquifer can become contaminated *based solely on the hydrogeologic properties* of the area. For example, some typical hydrogeologic indicators of aquifer sensitivity include:

- shallow depth to ground water
- high surface soil permeability (typical of very sandy soils)
- flat terrain (resulting in more infiltration, less run-off)
- coarse-grained or highly fractured geologic material overlying the aquifer

This kind of information should be provided in a community's SWAP area delineation report. Any community considering a ground water monitoring system for its SWAP area should review the delineation component carefully. A ground water monitoring system should not be initiated before this kind of information has been obtained and reviewed by the SWAP planners.

### Threat Posed by Contaminant Sources

The threat posed by contaminant sources refers to the likelihood that the aquifer can become contaminated *based solely on the characteristics of the contaminant sources*. Characteristics that increase the threat posed by a potential contaminant source include:

- Existence of a verified **contaminant plume**
- A history of chemical **spills/releases**
- **Proximity** of site to the public water supply wells
- Highly **toxic** chemicals handled at the site
- **Large amounts** of chemicals handled at the site
- **Underground storage** of the chemicals used at the site
- **Mobility in the subsurface** of the chemicals handled at the site (for example, high solubility in water, low adsorption to soil particles)
- Disposal or storage in or on the ground (**noncontainerized**)
- **Poor management** of site (carelessness, inadequate design of storage areas, poorly trained operators, etc.)

The first step in determining the threat posed by the contaminant sources is to review the Potential Contaminant Source Inventory for the SWAP area. Sites of *known contaminant plumes* are automatically good candidates for ground water monitoring, as are sites of *known releases*. Most of the sites identified in the Potential Contaminant Source Inventory, however, will require a more detailed evaluation, based on the characteristics of the sources. It is important to remember that most sites identified in a Potential Contaminant Source Inventory are *potential* sources of contamination. In most cases, the investigators did not acquire very detailed information about how the site is designed or managed. In many cases, detailed information has not been obtained about the amounts and types of chemicals. Therefore, it may be necessary to obtain additional detailed information about certain potential contaminant sources. Only then can the SWAP planners begin to evaluate the *actual threat* posed by the various sources.

Ohio EPA does not advocate any particular methodology for determining *actual threat*. Some communities have developed their own methodologies to make this determination, including elaborate methods based on weighted ranking, etc. However, even with the most elaborate method, the final determination is likely to be somewhat subjective. Common sense and familiarity with making these kinds of decisions are more important than adherence to any particular methodology.

For example, volatile organic chemicals (such as those used as solvents, degreasers, and fuels) comprise most of the contaminants that have been detected in public water supply wells in Ohio. A relatively small release of these kinds of chemicals can contaminate an enormous amount of ground water at concentrations that oblige the public water supplier to take some kind of corrective measures--or cease providing water. Knowing this, a SWAP planner should be especially concerned about those sites that handle volatile organic chemicals as part of the daily industrial or commercial process. These would include not only many large industrial firms--which should already be subject to strict environmental regulation and regular inspections--but many small commercial establishments, such as dry cleaners, printers, painters, and auto body shops . Gas stations are another type of potential contaminant source that is often implicated in ground water contamination. These establishments are regulated by Ohio's Bureau of Underground Storage Tank Regulation (BUSTR), but across the state there are gas stations that have never registered their underground storage tanks with BUSTR.

The design of storage containers/facilities and the chemical handling practices at these kinds of facilities should be reviewed. If they appear to be inadequate, then the facility can be considered to pose a relatively high threat.

### Usefulness of Other Protective Strategies

The third criterion to be weighed is whether other protective strategies can reduce the need for a monitoring system. Some contaminant sources may be serious enough to warrant monitoring, but would be difficult to monitor effectively. For example, leaking sanitary sewer lines can be a significant contaminant source but it would be difficult to locate monitoring wells appropriately unless the locations of leaks had been identified. (And if those locations are known, it usually makes more sense to repair the leaks than to install wells to monitor them!) Similarly, spills from railways or highways may be a major concern but there would be no point in installing wells--at least for early warning purposes--until after a spill had actually occurred. A high-risk point source located close to a public water supply well might not be worth monitoring because by the time the sampling results were received, any contaminant plume originating at that site already would have advanced to the well.

Facilities that are obvious contaminant sources--such as landfills and industrial waste pits--should already be monitoring their ground water under State and/or Federal waste disposal regulations. In these cases, a community's SWAP planners may need to verify that ground water monitoring is occurring and then request that the regulated facility routinely provide them with copies of the sampling results. Copies of a facility's sampling results also can be requested from the appropriate regulatory agency. If ground water monitoring is not occurring at a site that *should* be monitoring ground water by regulation, then the SWAP planners should notify the appropriate agency (usually Ohio EPA).

It must be remembered that *prevention* of ground water contamination is the goal of Source Water Protection, and ground water monitoring is not preventive. Although ground water monitoring may be strongly recommended for a given site, protective strategies that *prevent* ground water contamination generally should be given a higher priority than ground water monitoring.

### Making the Decision

Because so many site-specific variables are involved, it is impractical to advance any "standard methodology" for deciding whether or not to initiate ground water monitoring. The decision must be made by the SWAP planners. Realistically, the decision will be based not only on the potential for ground water supplying the public water system to become contaminated, but also on available resources. Often, the decision will be obvious. For example, ground water monitoring may be rejected by a community because its aquifer is overlain by fifty or more feet of solid clay, there are almost no upgradient wells or quarries providing direct access to the aquifer, and there never have been any source-related water quality problems in the public water system (see **Case History 1**). Another community may reject ground water monitoring because it has almost no potential contaminant sources or only a handful that pose very little actual risk. Many communities located over highly sensitive aquifers with potential contaminant sources may need to spend time considering whether the sources that pose significant risk can be addressed adequately with other protective strategies (see **Case History 2**). However, in some cases a community may choose to make ground water monitoring a large portion of the overall Management Plan (see **Case History 3**).

### Obtaining Ohio EPA Endorsement

The decision to implement a ground water monitoring program must be documented in the Management Plan. If the community rejects ground water monitoring as a management option, it should explain why. If the community elects to initiate ground water monitoring, then it will need to document the reasons for this decision. In either case, the reasoning should be based on evaluation of the aquifer sensitivity, the actual threat posed by contaminant sources within the SWAP area, and the usefulness of other SWAP protective strategies.

A community that decides to conduct ground water monitoring will also need to document *how* it proposes to monitor ground water quality within its SWAP area. *How to monitor* is the subject of the next two chapters of this guidance.

## SUMMARY OF CHAPTER ONE

Addressing whether or not a SWAP area warrants ground water monitoring is a required element of the Management Plan for a local SWAP plan. If SWAP planners conclude that the SWAP area warrants ground water monitoring, they must provide a plan for conducting that effort.

The main benefit of ground water monitoring is that it may provide early warning of impending contamination, which may enable the public water supplier to remove or remediate the contaminant before it reaches the public water supply. Other benefits include the ability to evaluate the effectiveness of protective strategies and the ability to collect additional hydrogeologic information (such as ground water levels and detailed local geology). The costs of ground water monitoring include those for planning, installing wells, laboratory analysis of samples, and staff time.

The decision of whether or not to monitor should be based primarily on an evaluation of the potential for ground water contamination. This is determined by considering three criteria: the sensitivity of the aquifer, the actual threat posed by contaminant sources, and the availability of other protective strategies. If the aquifer is well protected by thick layers of relatively impermeable material or if there are few potential contaminant sources upgradient of the wells, the need for protective strategies--including ground water monitoring--is diminished. If the aquifer is sensitive and there are a number of sites in the SWAP area that handle toxic substances--especially solvents or fuels--ground water monitoring may be warranted. This is particularly true if the sites are poorly managed.

# CHAPTER TWO —
# DESIGNING AND INSTALLING A MONITORING WELL NETWORK

## INTRODUCTION

The steps in designing a ground water monitoring network can be grouped into three tasks: designing the monitoring network; developing the sampling and analysis plan; and developing procedures for data management and analysis (**Figure 1**).

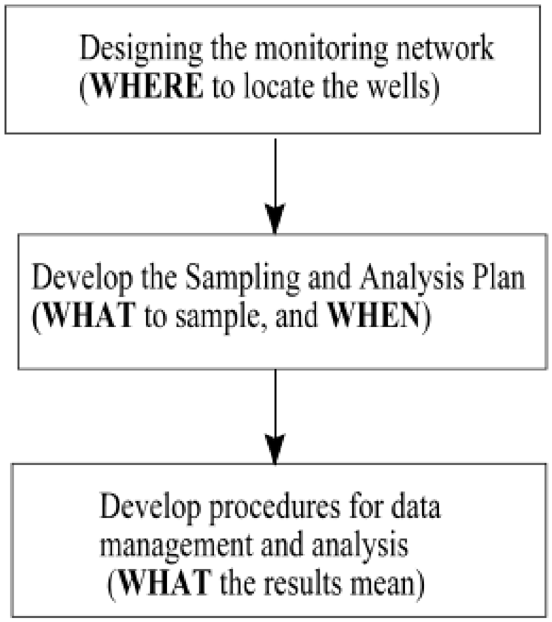


**Figure 1. Main tasks in developing a ground water monitoring program**

The purpose of this chapter is to provide guidance on the first of these tasks: designing the monitoring well network. Essentially, this involves deciding where to locate ground water monitoring wells so that they can achieve their intended purpose. “Location” refers to where the well is sited within the SWAP area, and also to the vertical interval in the subsurface that will be monitored. Because there is abundant literature on the technical aspects of locating monitoring wells, this chapter focuses on aspects specific to Source Water Protection goals. This chapter also covers practical aspects in some detail, such as selecting sites with all-weather accessibility, obtaining permission to drill and sample at the desired sites, and contracting a drilling firm.

It is essential that planners thoroughly review the Delineation and Potential Contaminant Source Inventory before siting the monitoring well network. Since monitoring wells are located downgradient of the sites they are monitoring, it is necessary to have information on the direction(s) of flow in the SWAP area. This information may be provided in the Delineation component. It is also necessary to know where the high-priority contaminant sources are located, since these are the sites that will be monitored. Information on potential contaminant sources should be provided in the Potential Contaminant Source Inventory; however, planners may need to prioritize the sources before starting to design the monitoring program (see pages 6-7 of this Guidance).

## DESIGNING THE MONITORING WELL NETWORK

Designing the monitoring well network involves deciding on the **numbers and locations of wells**. The *number* of wells ideally should be related to the number of significant contaminant sources, but may be constrained by the amount of money available for well installation. (If there are numerous existing wells such as private wells that can be used, however, a community may have an adequate number of wells at low cost.) The *locations* of the wells will depend primarily on the objectives of the monitoring. As discussed in Chapter One, most ground water monitoring systems are designed to monitor specific sources (point or nonpoint) or general background water quality. Five categories of monitoring well locations can be distinguished, each of which satisfies one or both of these objectives:

1. Monitoring at the water supply well(s)
2. Monitoring at the boundaries of the SWAP area
3. Monitoring of a particular point source
4. Monitoring of a nonpoint source
5. Monitoring without regard to any boundaries or specific sources.

The advantages and disadvantages of each location are described below.

**1. Monitoring at the (public) water supply well.** Using the public water supply wells themselves as sampling points is attractive because--first of all--this method usually is the least expensive. No installation of wells is necessary, and the wells are under the control of the public water supplier. Moreover, if the ground water becomes contaminated, monitoring at this point is most likely to detect it since the public water supply well is the ultimate destination of all water within the well's capture area.

A major disadvantage of sampling only at the public water supply wells is that this monitoring provides no early warning function of a serious plume from a point source-- the kind of contamination that has caused the biggest problems for public water systems in Ohio. If contamination is detected at this point, it will not be remediated before impacting the public water supply. Additional treatment of the water supply may be required, and the primary economic benefits of Source Water Protection will be lost.

**2. Monitoring at the boundary of a SWAP area.** In the context of Source Water Protection, this usually refers to locating wells along the one-year or the five-year time-of-travel area boundaries (or both). Other possible boundaries are the boundaries of the municipality or the wellfield. In some SWAP documents these wells are called "sentinel wells"; they are meant to monitor generally for contaminants coming into the one-year or five-year time-of-travel area from outside the area. They obviously will not detect contaminants originating from *inside* the boundary. This type of monitoring is most applicable when the goal of SWAP is the maintenance of a remedial action zone or an attenuation zone. The success of a remedial action zone, in fact, depends on any contamination being detected at the boundary--this provides sufficient time for remediation.

It was in the interest of providing a sufficient remedial action zone that Ohio designated the five-year time-of-travel area as the basis for SWAP area delineation; it was felt that five years is enough time to effectively remediate a contaminant spill or plume *at the boundary.* (And contaminant sources within the boundary theoretically will be managed to minimize their potential impact to the public water supply.) However, Ohio EPA does not recommend indiscriminately placing wells along the five-year time-of-travel boundary, without consideration for the *locations of contaminant sources* outside the five-year time-of-travel area. Wells located along the expected flow paths from acknowledged contaminant sources are much more likely to detect any contaminant plumes that may be emanating from those sources. If there are no known or suspected contaminant sources outside the SWAP area boundary, then the community should reassess the need for sentinel wells.

Some communities tend to cluster their monitoring wells along the *one-year* time-of-travel boundary, which is closer to the public water supply wells, and is often within the boundaries of the wellfield or the municipal boundaries. Such a location is practical, because the municipality usually owns the wellfield, and has some authority over the land within the municipal boundaries. However, such wells may not provide early enough warning of an approaching plume to enable effective remediation before the plume reaches the public water supply wells. Wells at these locations may be effective at providing information on background ground water quality, and may also provide warning of nonpoint source contamination. They are less likely to be effective as early-warning wells for a discrete plume from a point source--the kind of plume that is most likely to cause serious problems for a public water supplier.

**3. Monitoring of a particular point source.** Generally speaking, wells that are located directly downgradient of a targeted point source are the most likely to detect any contaminant releases--and thus must be considered the most cost-effective. Under the Resource Conservation and Recovery Act (RCRA), ground water monitoring may be required for facilities that handle hazardous wastes. Most operating facilities that have ever land-treated or disposed of hazardous waste on-site are required to monitor the treatment/disposal units. In these cases, Ohio's RCRA regulations provide specific minimum requirements for ground water monitoring. The facility's compliance with these requirements will be monitored by Ohio EPA staff, and noncompliance may result in heavy penalties. Similarly, the Bureau of Underground Storage Tank Regulations (BUSTR) regulates registered underground storage tanks containing petroleum products, and will require ground water monitoring where there has been sufficient evidence of a release. For such monitored facilities, SWAP planners generally will not need to provide additional wells, and should simply establish procedures for receiving and reviewing copies of the facilities' ground water sampling results.

As noted in Chapter One, numerous smaller facilities exist that may be disposing of their wastes improperly, but are not subject to ground water monitoring regulations under RCRA or BUSTR. In addition, there are many abandoned facilities throughout the state with hazardous waste units still in place, still containing hazardous residues. While some of them are being addressed under CERCLA regulations, many are not. These kinds of facilities should be targeted as high-priority contaminant sources, and any planned early-warning wells should be located directly downgradient of the hazardous area.

**4. Monitoring of a non-point source.** "Non-point sources" are sources of contamination that are diffuse and spread over large areas, such as pesticides leaching into ground water from an agricultural area, contaminants introduced into the aquifer via a large network of storm water drainage wells, or road salt washing off a highway and infiltrating into the subsurface. (By contrast, a truck spill of chemicals on that same highway would be considered a point source, because the contamination is concentrated in a small area.) Nonpoint sources do not produce a distinct contaminant "plume". Instead, ground water contamination from nonpoint sources tends to increase in concentration gradually over a large area.

Locating monitoring wells to detect this kind of contamination is less problematic; almost anywhere downgradient of the nonpoint source area may detect the contamination. Some locations are undoubtedly better than others. For example, along geologic zones of higher transmissivity, ground water (and ground water contamination) are likely to be transmitted more rapidly to the public water supply wells. However, identifying such zones often requires a level of initial hydrogeologic investigation that many communities are unwilling or unable to finance.

The most common nonpoint source contaminant of concern in Ohio is nitrate. Applica- tion of fertilizer to agricultural fields is the most common source of nitrate; however, poorly sited or maintained septic leachfields may also be responsible. **Case History 4** discusses how the Village of Waynesville designed its ground water monitoring system to provide more information concerning troublesome nitrate levels in the public water system.

**5. Monitoring that is not boundary or source-specific.** Non-source-specific wells are essentially sentinel wells, but they are scattered throughout an area (such as the five-year time-of-travel or one-year time-of-travel area) rather than being located along a specific boundary or downgradient of a specific source. These wells are sometimes installed as a second line of defense for boundary wells, in case a contaminant slips through the monitoring network established at the zone boundary.

Nonsource-specific wells are probably the least cost-effective type of wells to maintain. Since they are not located to monitor any specific source, it is pure luck if they happen to be located in the right place to detect an unknown contaminant plume. Also, since a specific source is not targeted, the samples from such wells need to be analyzed for a wide range of contaminants, which becomes very expensive. This type of well can be effective for analyzing general background ground water quality but should not be considered a reliable "early-warning" well.

Despite their disadvantages, in certain circumstances a community may consider non-source- specific wells worth the expense and effort. For example, the City of Dayton has installed nonsource-specific monitoring wells throughout its Source Water Protection area that are meant to: (a) act as deterrents to careless or illegal waste handling, and (b) provide early-warning for contaminants from releases that are unknown and could not be predicted based on the locations of existing potential contaminant sources (see **Case History 3**). For Dayton, with its highly developed wellfield protection areas, critical dependence on the aquifer, and ability to defray the expense across a very large ratepayer base, nonsource-specific wells were deemed a good value--especially compared to the enormous hardship that contaminated source water would cause.

### Summary

The most effective SWAP monitoring program will include *a combination of the five monitoring strategies* just discussed. A single well can often be used for more than one purpose. A well installed to monitor a point source can also be used to monitor a non-point source in the same area, as well as for general monitoring that is not source-specific. However, the Ohio SWAP Program considers point source monitoring and nonpoint source monitoring to be the most effective tool in achieving the objectives of Source Water Protection. **Case History 4** illustrates how the Village of Waynesville combined some limited point source monitoring with nonpoint source monitoring when it designed its SWAP ground water monitoring network.

## PRACTICAL CONSIDERATIONS IN LOCATING MONITORING WELLS

The preceding section described *ideal* monitoring locations, as if it were always possible to install a well precisely where it is needed. In reality, there are many potential obstacles to siting wells in their ideal locations. These include:

- securing permission to install a new well
- securing permission to sample a well
- accessibility in all seasons
- unobtrusiveness

These obstacles are discussed in more detail below.

### Securing Permission to Install a New Well

Obtaining permission to install a monitoring well can be a delicate process. If SWAP planners wish to install a new well on property that is not owned by the municipality, they will need to obtain permission from the property owner. Property owners sometimes are hesitant to give permission. They may want to know what the well will look like (for this purpose, it is useful to have a photograph of a typical monitoring well to show them--with a person standing nearby for scale). They may be concerned about damage to their property by the drilling equipment. This concern is justified, as a drilling rig is very heavy and may leave deep ruts in the land surface, especially when the ground is wet and soft. (Such damage may be minimized by drilling in dry weather or during winter; however, winter drilling presents its own problems!) Most importantly, property owners are often concerned that they will be held liable if the well on their property produces contaminated samples. For all these reasons, it may be difficult to persuade a property owner to grant permission to drill on his or her land.

Where property owners are willing to grant access, there are several means of legally executing the agreement. The municipality may *purchase* a strip of land from the property owner, including the monitoring well installation site and an access corridor from the nearest road. However, this rarely occurs. More commonly, the property owner and the municipality will negotiate an *easement*. This involves the property owner signing an *easement document*, granting the municipality certain rights (which the landowner may tailor), such as unrestricted access. The easement document becomes part of the land title and often the deed itself, and if the land is sold, the easement transfers with it. The negotiation may or may not include a payment to the property owner.

An owner may grant either a temporary easement, or an easement-in-perpetuity. After granting an easement-in-perpetuity, the property owner may not change his/her mind. However, he or she may request tax relief from the County Auditor's Office. Land taken by an easement-in-perpetuity generally has a lower value and thus the land taxes may be lowered. An appraisal by a commercial real-estate assessor may cost around $1,000 to $1,500; however, the County will reassess the value of the land at no cost to the landowner.

Sometimes landowners are resistant to granting easements--especially easements-in-perpetuity -- but are willing to grant access for a limited period of time. In this case they sign a *right-of-way license*, which is not recorded with the land title or deed. If the land is sold, the new owner may deny access and the municipality will have no legal recourse to regain access. The Ohio Department of Natural Resources has executed right-of-way licenses with private landowners for many years to enable ODNR staff to install and maintain ODNR's statewide network of observation wells.

### Securing Permission to Monitor a Well

In some cases landowners already have a well, and the municipality wishes to include that well in the SWAP ground water sampling network. Property owners may be unwilling to grant access to their wells for a range of reasons. For example, they may not want strangers periodically coming onto their property to sample, or they may worry that the samplers will contaminate the well or damage the pump. They may not like the idea of discharging several well volumes of water across their yards or into a drainage ditch before sampling. Also, as mentioned before, they may be concerned about liability if contamination should be detected.

If such resistance can be overcome, then the types of agreements listed in the previous paragraphs will cover access needs for sampling, except when a right-of-way license or easement is executed that grants only a few years of access. In this case, a second agreement will need to be executed when the first agreement expires, if sampling is to be continued.

### Accessibility in All Seasons

Ideal sampling points do not always conveniently occur next to an all-weather road. Sampling points distant from roads present several problems. If the terrain between the nearest road and the sampling point is very **steep** or very **muddy**, or being **cultivated for crops**, then access by vehicles may be impossible or limited to dry weather or the nongrowing season. A drilling rig and its supply trucks may not even be able to reach the site. (And if they reach the site, they may not be able to get out afterwards!) Approaching the site by foot to sample may be difficult, especially if the sampling equipment is heavy. If the sampling method requires truck-mounted equipment, such a well location may prove unusable.

Sampling points in a floodplain may be inaccessible because of **floods**, especially in the Spring. Sites that are easily accessed in the winter, when **foliage** has died, may be lost in almost impenetrable jungles in the summer. Samplers may need to arm themselves with machetes and insect repellant before approaching such sites, and sometimes they may be difficult to find. An otherwise desirable monitoring well site may be located adjacent to--or under--a **utility line**. **Overhanging tree limbs** may be a problem. In developed areas, drilling rigs may not be able to access the desired location because of **buildings** enclosing the space or because of **low roofs**.

One of the most popular places to locate a well is the right-of-way along roads. This area is next to the road and is under the jurisdiction of the local government, so problems with permission and accessibility are minimized. Wells located in such areas also can be used to monitor the impacts on ground water quality of road salting.

**Unobtrusiveness**
A monitoring well should not be too obvious or in the way. For example, a well proposed for the middle of a ball field might be ideally located in terms of detecting a contaminant, but would pose a danger to ball players. Wells located too close to driveways, especially near curves, are likely to be hit by vehicles. Wells located in agricultural fields can easily be run over by farm equipment, seriously damaging not only the well but the equipment. Wells that are in public parks or that are otherwise highly visible may attract vandals. Flush-to-ground wells can be installed in high-traffic areas, and these are much less visible and vulnerable to accidental or deliberate damage. However, they may be more vulnerable to contamination by surface water, especially in areas prone to flooding.

**Summary.** Obstacles such as those discussed above may make it difficult for SWAP planners to install new wells in ideal locations. The effectiveness of a proposed monitoring well network may be severely compromised as a result. It is advisable to thoroughly assess the practical problems that may be encountered at chosen “ideal” locations before finalizing the monitoring well network.

## VERTICAL PLACEMENT OF MONITORING WELLS

To ensure that any contaminant plume in a given area is detected, a monitoring well must not only be located appropriately in terms of *direction and distance* from a source, but also in the terms of *depth* of the screened interval. As illustrated in **Figure 2**, a well that is screened in the wrong interval may fail to detect a plume that is passing through. Deciding which vertical portion of an aquifer to screen can be a more perplexing problem than deciding where to locate the well within the SWAP area. At least three considerations are relevant to the decision:

- Whether the aquifer is unconfined and vulnerable to surface/near surface releases, or deeply confined and relatively invulnerable;
- Whether the site being monitored handles (or handled) any “floaters” or “sinkers”; and
- Where the most transmissive zones are within the aquifer.

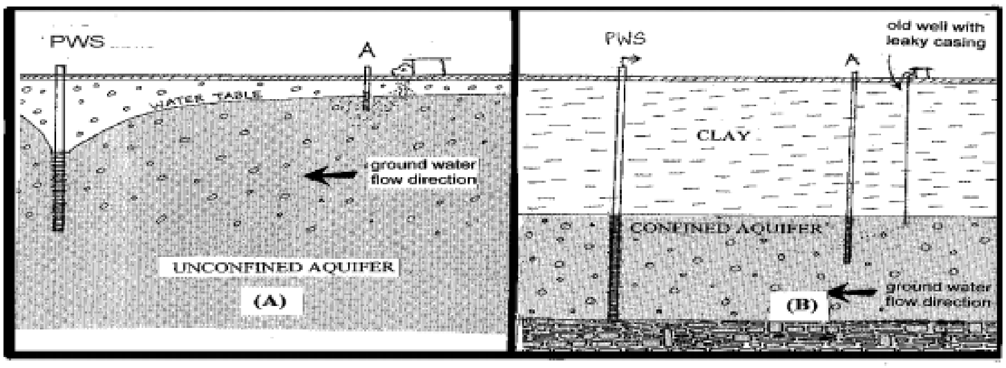


**Figure 2.** Vertical placement of the well screen in an unconfined aquifer (A) vs. a confined aquifer (B)

### Aquifer Type: Unconfined or Confined

For unconfined aquifers that are especially vulnerable to surface contamination, **shallow** monitoring wells are most effective as early-warning wells. By installing the well screen at the top of an unconfined aquifer, the monitoring well has a better chance of detecting a surface or near-surface contaminant release before it is greatly diluted and dispersed. If the public water supply wells are also screened at shallow depths, this choice is noncontroversial.

It is sometimes argued that if the public water supply wells are screened at much deeper intervals of the unconfined aquifer--say, 100-120 feet below surface--the concentration of contaminants near the surface is not relevant for SWAP purposes. What is relevant, according to this view, is the concentration of contaminants in *the water that is entering the public water supply wells*.

The Ohio SWAP Program recognizes the value of both deep monitoring wells that monitor the interval screened by the public water supply wells *and* shallow monitoring wells that monitor the top of the aquifer. However, **in unconfined aquifers the Program encourages the use of shallow monitoring wells**, especially if they are meant to monitor specific point sources or nonpoint sources. The reasoning is, shallow monitoring wells are more likely to detect a release occurring at or just below the ground surface, and *knowledge that a release is occurring is valuable*, regardless of whether that release actually results in detectable contamination of the public water supply. At the very least, such a detection indicates that the owner/operator of the contaminant source needs to initiate better ground water protection activities, or reevaluate activities that are already in place. Also, detection near the ground surface allows more time to remediate the release before it percolates down to the zone screened by public water supply wells.

On the other hand, **in confined aquifers, monitoring wells screened in the zone screened by the public water supply wells may be more useful.** For example, if the aquifer supplying the public water supply is deeply buried under 100 feet of continuous, unfractured clay--as is the case in some parts of northwestern Ohio--shallow contamination is not likely to penetrate to the aquifer. Contaminants are more likely to enter the aquifer through leaky casings around various types of wells, or from the recharge area (which may be quite distant). For less deeply buried aquifers, contaminants may enter the aquifer from excavations that penetrate through the entire layer of clay into the aquifer, such as those completed for quarries and building foundations. In this case, useful information is more likely to be provided by monitoring wells that screen the zone screened by the public water supply wells.

### Contaminant Type: "Floaters vs. Sinkers"

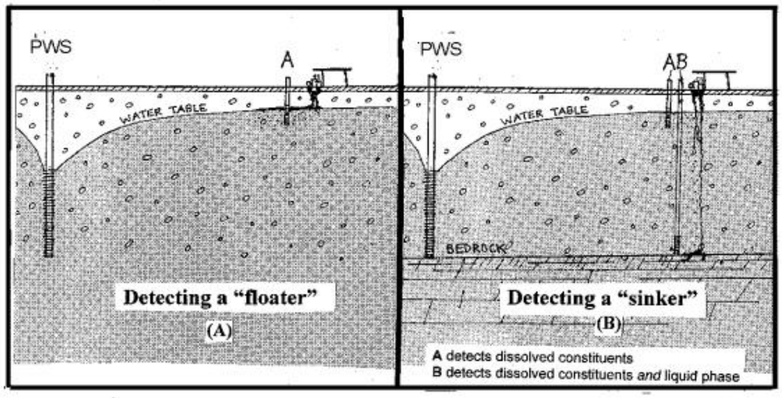


**Figure 3.** Vertical placement of the wellscreen to detect floating constituents (A) and sinking constituents (B)

Many chemicals break down into several phases in the subsurface. Where high concentrations of a chemical are present, a portion will dissolve into the ground water (where it can be detected by a monitoring well) and the remainder will form “free product”. If the free product has a specific gravity less than water, it will float on the water table, whereupon it is called a “floater”--or more formally, a Light Non-Aqueous Phase Liquid (LNAPL). For example, several constituents in gasoline--including highly toxic benzene--tend to float on the water table. Therefore, if a monitoring well is installed to monitor a specific site for floaters, **the well should be screened across the water table**, where the highest concentrations of the floater will occur (**Figure 3**).

However, sinkers are often very difficult to detect. Thoughout the United States, numerous multi-million dollar investigations have been conducted to search for suspected DNAPL pools--often without success. At sites with *known releases* of sinkers, an effort should be made to have the site investigated under existing hazardous waste regulations. In this case, the responsible party or Ohio EPA would be expected to finance the investigation, not the public water supplier.

For the purposes of Source Water Protection, at sites that warrant monitoring but have *<u>no</u> known releases* of sinkers, it would probably be more cost-effective to install shallow wells. If monitoring or other sources of information suggest that a release has occurred of a sinker, then the site may become subject to investigation under existing hazardous waste regulations.

### Location of Transmissive Zones

In some cases, SWAP planners may wish to install their wells to screen the most transmissive zone(s) in an aquifer. Obviously, to do this effectively, a great deal of detailed knowledge is needed about the aquifer.

**Unconsolidated (sand-and-gravel) Aquifers.** In sand-and-gravel aquifers that are extremely *homogeneous*, identifying the “most transmissive zones” might be difficult, and committing to screening monitoring wells in such zones probably would not be cost-effective or logical. For *heterogeneous* sand-and-gravel aquifers, it may be useful to install monitoring wells in the first highly transmissive zone encountered. This is especially worth considering for non-source-specific wells, where contaminant is suspected but specific contaminant sources cannot be identified. For example, the City of Dayton used this focus when installing its nonsource-specific wells. The wells were screened across the first highly transmissive zone encountered below the water table, as identified during investigative hydropunch/ground water sampling activities.

**Consolidated (bedrock) Aquifers.** In bedrock aquifers, where water is transmitted primarily through fractures and along bedding planes, locating the most transmissive zones is perhaps the most important factor in a monitoring well’s effectiveness. The “most transmissive zones” in this context typically will consist of the largest and most connected fractures in the network, or particularly fractured zones within the bedrock. However, locating vertical fractures and determining the main flowpaths through the network of horizontal and vertical openings can be very difficult. A detailed knowledge of the flow network is rarely obtained, even after the most thorough hydrogeologic investigations. Guidance for installing monitoring wells in bedrock aquifers is available in numerous other sources, and is generally relevant to monitoring wells installed for SWAP purposes (see Sources of Information, Appendix A).

**Multiple Wells.** Of course, multiple wells screened at various depths can be installed at a given site, and often this is required by regulatory programs. In some cases, multiple-level wells for SWAP purposes may be advisable. There is a great deal of technical guidance available on how to monitor numerous screened intervals, either through a single well or by installing clusters of wells, and it will not be reviewed here (see Sources of Information, Appendix A). Generally speaking, if contamination is so strongly suspected that multiple wells are warranted, then ground water at the suspect facility should probably be investigated under an existing hazardous waste regulatory program.

## WELL INSTALLATION PLAN

If new monitoring wells will be installed as part of a community's SWAP monitoring network, the SWAP planners should write up a well installation plan. This plan not only documents decisions made about the monitoring network, but also describes the specifications for the well installers. The plan should address such items as: the drilling method (and geologic sampling method, such as split-spoon sampling); approximate depth of wells; use of lubricants; backfilling policy; casings (type of material, internal diameter, whether above-ground or flush-mounted); screens (length, type of material, slot size, and internal diameter), filter pack (type of material) and vertical interval; annular sealant; surface sealant; well caps; protective steel casing; well pad; and well development. The Well Installation Plan should include a map showing the approximate locations of the wells to be drilled, with their designations marked (i.e., MW-1, MW-2, etc.).

SWAP monitoring wells should be installed in accordance with the industry standards provided in "Standard Practice for Design and Installation of Ground Water Monitoring Wells in Aquifers" (Standard Designation #D 5092-90) by the American Society for Testing and Materials (ASTM). Numerous other sources address correct installation of ground water monitoring wells, and these sources should be consulted for more detailed technical guidance (see Sources of Additional Information, Appendix A).

**Length and Placement of Well Screens.** One item that deserves additional discussion is how to decide the proper length of well screens. Well screens typically come in lengths of five feet, ten feet, or 20 feet. A longer well screen has a better chance of straddling the interval in which a plume is traveling (**Figure 5**). However, longer well screens also allow for greater dilution of a sample. Because of this concern about dilution, most regulatory programs recommend that five-foot screens be used, and that multiple wells be installed if a large vertical interval needs to be monitored.

Many, if not most, of the wells installed for SWAP monitoring purposes will be shallow wells, designed to straddle the water table. In this case, the *range of water table fluctuation* will be the most critical concern in selecting the length of well screen. For example, if the water table typically fluctuates more than five feet over the four seasons, a five-foot screen will not be sufficient. At some time the water table will either be above the well screen (and any "floaters" will more likely be missed) or the water table will be below the well screen, and the well will be dry. **For SWAP purposes, in most parts of the State, ten-foot screens usually are sufficient.** Twenty-foot screens should be avoided when possible, due to the potential for dilution.

It is very important to have a good idea of how the water table fluctuates seasonally at a site when installing wells designed to straddle the water table in an unconfined aquifer. In Ohio water tables tend to be highest in the late spring and lowest in the late summer/early fall. If wells are being installed during the spring, the screen should be positioned so that the top is about one or two feet above the current water table (the water table probably will not rise much higher). If wells are being installed during the fall, the full range of water table fluctuation must be accounted for. For example, if the water table fluctuates about two feet over the seasons, and the water table is encountered in September at a depth of seven feet, then the on-site geologist should instruct drillers to set a ten-foot screen at a depth interval of about 4-14 feet.

**Casing/Screen Material.** Concerns are often raised about the type of casing/screen material that regulatory programs will accept for monitoring well construction. In the past, some regulatory programs have required stainless steel casing, which is very expensive. In recent years, however, polyvinyl chloride (PVC) casing has been found acceptable for most types of wells. This material is strong and much less expensive than casing constructed from stainless steel or Teflon.

There is evidence that PVC leaches constituents into the casing water, and also adsorbs some constituents from ground water. However, if a well is adequately purged just before sampling, the sample should not be significantly altered by leaching or adsorption.

Another concern voiced about PVC is that it degrades in the presence of strong concentrations of solvents. In most SWAP areas, strong concentrations of solvents are not expected in the ground water, and if they are encountered, a detailed investigation under RCRA or CERCLA standards should be conducted. For these reasons, Ohio's SWAP Program regards PVC casing as suitable for monitoring wells designed for SWAP purposes.

**Casing Diameter.** Casing used for monitoring wells usually has a two-inch internal diameter. However, if a community plans to use certain types of sampling devices, it should first make certain that those devices will fit into the wells. If the community plans to use *dedicated* sampling devices (i.e., a sampling device for each well that remains inside the well), then they will need to be sure that there is enough room around the device to take water level measurements. If not, they will need to specify a larger diameter casing. The disadvantages associated with larger diameter casings are: (a) they are more expensive; (b) they require a larger-diameter borehole (which makes drilling more expensive); and (c) purging them is more time-consuming, because they hold more water.

## PREPARING TO INSTALL MONITORING WELLS

**Contracting a Driller.** SWAP planners should contact several drillers to obtain itemized quotations for services. Drilling companies often itemize their expenses differently, making it difficult to compare them. The best way to obtain prices that can be compared is to send the company a bid sheet for them to fill out.

When selecting a company to perform services, it is always valuable to contact other entities that have hired the company previously, and ask about the quality of service provided. Some drilling firms may be particularly experienced in certain drilling techniques or well installations, and less experienced in others. The technical requirements of a monitoring well differ from those for a public water supply well, an observation well, or a geotechnical boring. It is important that the driller have the appropriate expertise and equipment.

**Staking out the Well Locations.** At least a week before drilling is to commence, SWAP planners should go out to the well locations and stake each one out with a brightly-colored flag. Using indelible marker, the designation for the well should be written on the stake (for example, MW-1, MW-2, etc.). (This helps ensure that everyone involved knows the exact location and identification number of each well. Also, the geologist logging the well boring can properly identify the well on all of the paperwork, especially the well log and drilling report.) For any location that is on private property, the property owner should be asked to review the site, to ensure that he/she agrees to the precise location.

Once the property owners have agreed to the site locations, Ohio Utilities Protection Service (OUPS) should be contacted, to review the sites for proximity to any utility lines. Ohio law requires that OUPS be given 48 hours notice--excluding weekends and holidays--before digging. OUPS can be contacted at 8-1-1 or 1-800-362-2764.

**Overseeing Well Installation.** The person selected to oversee the well installation (Site Manager) is responsible for seeing that the wells are installed in accordance with the Well Installation Plan. Some drillers tend to install wells according to their own preferences unless the Site Manager holds them to the specifications of the Plan. The Site Manager must ensure that the drillers have completed all the work, including installation of concrete pads and well development, before they demobilize the rig (i.e., return the rig to the company's headquarters). Most drilling companies charge a flat fee each time the rig must be mobilized, so mistakes and oversights can become costly.

Anyone who has ever worked at a drill site will agree that Murphy's Law prevails when drilling wells. Weather can be a major problem. Thunderstorms are extremely dangerous to drillers, because the rig is a natural lightning rod. When the ground is wet or soft after a rain, rigs and supply trucks may get stuck. In the winter, severe cold can lock up a rig, freeze the bentonite grout, or cause metal parts to break more easily. Rig breakdowns are common in any weather, however, because the equipment undergoes such heavy wear.

The formation itself may cause problems: sometimes augers get "stuck" when they reach a certain depth and are very difficult to extract. Heaving sands may be encountered in confined aquifers under pressure, and the drillers may need to pour distilled water down the borehole to counter the upward pressure. Augers sometimes encounter a boulder that they cannot dislodge or auger through; in those cases, the augers must be withdrawn completely, and another borehole must be initiated about ten feet away. Finally, operator error can cause problems. It is not uncommon for tools to fall down the borehole, requiring time to "fish" them out. These kinds of problems may cause considerable delays. A planned two-day job can stretch out to two weeks. Usually the driller does not charge for delays due to weather, rig breakdowns, or operator error; however, the conditions that constitute billable downtime should be thoroughly understood before drilling commences.

## SUMMARY OF CHAPTER TWO

The main steps in designing a monitoring well network for SWAP purposes are:

1. Review the Delineation for hydrogeologic information and the Potential Contaminant Source Inventory for information on contaminant sources;
2. Select the number of monitoring wells and their "ideal" locations, based on whether they are intended to monitor general ground water quality, act as an early-warning "sentinel" against nonspecific (and perhaps unknown) sources, or provide early warning of releases from point or nonpoint sources;
3. Modify the "ideal" locations, based on practical considerations;
4. Decide on the depth of the wells, and the interval to be screened, based primarily on whether the aquifer is confined or unconfined, and whether the wells are meant to monitor specific or nonspecific contaminant sources.
5. Write up a Well Installation Plan that documents all the decisions made in steps 2-4 , and specifies well materials;
6. Contract with a drilling company;
7. Prepare for well installation by marking the sites and calling Ohio Utilities Protection Services

For early-warning purposes, wells located directly downgradient of a specific source (point or nonpoint) are most cost-effective. Also, shallow monitoring wells are encouraged for monitoring specific contaminant sources in an unconfined aquifer. Where releases of "floaters" are to be monitored for in unconfined aquifers, wells should be screened across the water table.

Where the aquifer is confined under a thick and continuous confining layer, it may be more effective to install wells screened in the interval screened by the public water supply well(s). In bedrock aquifers, an attempt should be made to install monitoring wells so that they monitor the most transmissive zones, which will consist of the largest and most connected fractures in the network, or particularly fractured zones within the bedrock.

# CHAPTER THREE —
# DESIGNING A SAMPLING AND ANALYSIS PLAN

## INTRODUCTION

The intent of this chapter is to summarize the information needed to design a sampling and analysis plan that will achieve the main goals of source water protection monitoring: early-warning and identification of general water quality trends. A monitoring network with ideally located and installed wells may fail to achieve its purpose if samples are collected improperly, or analyzed for the wrong set of constituents. Source water protection planners should write a Sampling and Analysis Plan (SAP) that documents:

- which parameters will be sampled for (and why);
- how frequently samples will be collected (and why);
- what methods will be used to analyze the parameters;
- what equipment will be used to collect samples; and
- the procedure to be followed at each well when collecting samples.

This chapter presents guidance for making the decisions that will be formalized in the Sampling and Analysis Plan.

Much of the guidance in this chapter is consistent with guidance available for regulatory ground water monitoring programs. The section on selecting appropriate sampling equipment reflects the main concern of all ground water monitoring programs: to obtain a "representative" ground water sample, one that reflects ground water quality as it occurs in the subsurface. However, some practices that are required or strongly recommended for various regulated programs may not be necessary for source water protection monitoring (e.g., field filtering, containerization of purge water, the exclusive use of top-of-the-line sampling equipment). Also, this guidance considers practical considerations as well as technical considerations when discussing the selection of sampling equipment.

## SELECTING THE PARAMETERS

Common sense should guide the selection of parameters that will be sampled and analyzed for. Generally speaking, the list of parameters for any given well should be based on the types of contaminants that well is supposed to monitor for. For example, if a particular well is supposed to monitor potential releases from a service station, samples from that well should be analyzed for the signature components of gasoline: benzene, toluene, ethylbenzene, and xylene (collectively referred to as "BTEX"). If other kinds of petroleum products are suspected, the list may also include total petroleum hydrocarbons, collectively referred to as "TPH". If another well is supposed to monitor potential releases from an area where solvents were disposed of, samples from that well should be analyzed for a general list of volatile organic compounds. If a well is supposed to monitor for agricultural chemicals, the samples should be analyzed for nitrates and a general list of pesticides.

One disadvantage of nonsource-specific wells is that it is not possible to "narrow down" the list of parameters to sample and analyze for, at least not initially. Many communities choose to do a few initial rounds of "baseline" monitoring–analyzing all wells for a comprehensive list of parameters that includes inorganics, volatile organic compounds, semi-volatile compounds, pesticides, nitrates, and possibly TPH. Later, the list may be reduced to only those compounds that showed up during baseline monitoring, and/or only those compounds that are of greatest concern, although they may not have been detected. For example, the Village of Waynesville conducted baseline monitoring during 1996. In March, June, September, and December of 1996, samples were collected from the six monitoring wells and were analyzed for a comprehensive list of parameters. From this sampling, it became clear that the parameter of greatest concern for this public water system was nitrate. Subsequent monitoring was greatly reduced and focused on nitrate levels. Although no volatile organics or pesticides were detected during the baseline monitoring, sampling and analysis for these parameters was retained, but at less frequent intervals. (Wayneville's Source Water Protection Ground Water Monitoring Plan is included as Appendix B).

## FREQUENCY OF SAMPLING

How frequently to sample depends on a number of factors, including the purpose of the monitoring (baseline vs. specific), the distance of the monitoring well from the public water supply well, and the nature of the constituents being monitored.

### Baseline Monitoring

Baseline monitoring is an excellent idea as it provides the community with comprehensive and detailed information on the ground water quality of the monitored area. Because precipitation varies with the change of seasons, the quality, flow directions, and depth below surface of ground water also tend to vary with the seasons. Quarterly sampling allows for documentation of these variations. Such comprehensive monitoring is expensive, however, and the number of baseline sampling events conducted may be limited by financial concerns. Where funding permits, Ohio EPA recommends conducting four baseline sampling events, to take place on a quarterly basis. For systems with a large number of monitoring wells, baseline sampling of all wells may not be financially feasible, but it may be possible to conduct baseline sampling of the wells that are deemed most critical.

### Subsequent Monitoring

Once baseline monitoring is complete, the number of constituents and frequency of monitoring may be revised. At this point, frequency of monitoring should be based on:

- How close the monitoring well is to the public water supply wells
- How much "risk" is associated with the pollution source(s) being monitored by the well

**Distance from public water supply well(s).** If a monitoring well located close to the public water supply wells is monitored infrequently, a contaminant plume could pass through the well and enter the public water system in the time period between the two sampling events. Even if the plume is detected before it reaches the public water system, there will be little time to halt its advance or remediate it before it reaches the public water supply wells. For this reason, **Ohio EPA recommends sampling wells within the one-year time-of-travel area on a quarterly basis.** Wells between the one- and five-year time-of-travel boundaries, or outside the SWAP area, may be sampled less frequently.

**Nature of constituents monitored for.** Wells that are sited to monitor for volatile organics–at sites that pose a definite risk to the aquifer–need to be monitored more frequently than wells designed to monitor for other parameters. Plumes of volatile organics such as trichloroethylene (TCE) and perchloroethylene (PCE) have caused more havoc for Ohio's public water systems than any other types of constituents. For this reason, high-risk pollution sources involving volatile organics should be monitored **at least semi-annually** if they are located between the one- and five-year time-of-travel areas.

Where the two conditions bullet-pointed above do not prevail, **annual** sampling and analysis may be sufficient. However, semi-annual monitoring (in a wet season and a dry season) is preferable. For semi-annual sampling, spring and autumn are preferred times to sample.

## SELECTING METHODS OF ANALYSIS

There may be a number of standardized methods for analyzing a ground water sample for certain constituents. For example, VOCs can be analyzed by U.S. EPA Method 524.2 (which is required for public drinking water sampling); by U.S. EPA Method 8260B (which is often used for CERCLA sites), and by U.S. EPA Method 624 (which is used for wastewater sampling). When contracting a laboratory for sample analysis, the laboratory will need to know the purpose of the sampling. **For source water protection purposes, analytical methods approved *for public drinking water analysis* should be requested.**

The actual methods used will depend on the laboratory, but they should meet the requirements established by U.S. EPA for public drinking water analysis. (Methods approved in Ohio for drinking water analysis are codified in Ohio Administrative Code Chapter 3745-81-27.) The laboratory should be able to provide the method detection limits for all methods used, and SWAP planners should request this information before signing a contract with the laboratory. (It should be recognized, too, that the "method detection limit" reflects the ability of an instrument under specific, ideal conditions. The actual limit may differ from the listed method detection limit due to matrix interferences, extremely high concentrations that require dilution, the analyst, and numerous other factors.) Most methods are used to analyze multiple constituents, some of which may have Maximum Contaminant Limits (MCLs) for public drinking water. **It is important that the method detection limits be lower than the MCLs for any constituents analyzed by that method.**

Laboratory standards are documented in a quality assurance/quality control (QA/QC) program. This program should be available in writing and should be reviewed before contracting the laboratory's services. The QA/QC plan will address such items as

- qualifiers (how irregularities or uncertainties in the data will be indicated)
- performance criteria (percentage error)
- methods for obtaining performance measures (standards, blanks, duplicates, spikes, etc.)
- documentation and reporting procedures

**Blanks.** A "blank" is a sample of distilled, deionized water that is used to rule out accidental contamination of samples by sources other than contamination in the ground water.

A "trip blank" is a sample that is prepared in the laboratory and sealed, then transported out to the sampling site and back with all the other samples. If the trip blank indicates contamination, there is a possibility that the other samples transported with it may also have been contaminated. The source of contamination may be contaminated water from a broken sample bottle in the cooler, or constituents leaching from the containers themselves. If ground water samples show contamination by the constituents found in the trip blank, the samples may not represent actual ground water quality. In this case, resampling may be advisable.

An "equipment blank" is obtained by passing distilled, deionized water through a cleaned sampling apparatus (pump, bailer, filtration gear, etc.) and collecting it in a clean container. This blank is used to assess the effectiveness of the decontamination procedures implemented between sampling locations. If a historically clean well produces a contaminated sample, but the equipment blank taken previously shows similar contamination, there is a possibility that the sample was contaminated by the sampling device, not by some contamination in the ground water.

For source water protection purposes, it is advisable to include **at least one trip blank for each sampling event.** (However, some laboratories automatically include one trip blank in each cooler, as required by their own QA/QC standards.) **At least one equipment blank should be taken prior to**

**sampling,** for any nondedicated sampling device that is used–especially if it is rented or borrowed, or has been used by others. Wherever monitoring wells are expected to be relatively free of contamination, it should not be necessary to take an equipment blank after sampling each well. However, if significantly contaminated wells have been included in the monitoring network, it may be advisable to take equipment blanks of any nondedicated sampling equipment after sampling those wells.

**Duplicates.** Most laboratories' QA/QC procedures require them to provide containers for duplicate samples–usually one duplicate for every ten samples to be analyzed. The cost of analyzing duplicates is incorporated into the laboratory's quoted price for services, and usually is not itemized.

### Traditional Methods of Analysis

Traditional methods of analyzing water quality parameters include gas chromatography, flame ionization, mass spectrometry, and others. These methods are approved by U.S. EPA and Ohio EPA, are well-tested, and can provide very precise numbers for the concentrations of a large number of environmental contaminants. However, some of these methods involve extensive sample preparation, which must be performed by trained specialists. Instruments used for these methods, such as mass spectrometers, can be extremely expensive. These factors account for the high cost of some types of analysis. For example, analysis of 60 VOCs using EPA Method 524.2 typically costs between $100 and $200 per sample (2015 prices).

### Immunoassay Methods of Analysis

Recently, immunoassays have come into use for some types of environmental testing, including water quality analysis. An immunoassay consists of injecting specific antibodies (complex proteins) into a sample to detect a single compound, or small groups of related compounds. Immunoassays have long been the method of choice in clinical analytical laboratories, for analyzing drugs, proteins, and hormones. More recently, this method has been successfully applied to a wide variety of compounds, including environmental contaminants.

An immunoassay is designed to:

- Detect qualitatively the *presence* of the contaminant; or
- Measure quantitatively the *concentration* of the contaminants.

For analyzing ground water chemistry, enzyme immunoassays commonly are used. Generally, the process involves adding an antibody to the water sample that will bind specifically with the analyte of interest—if that analyte is present in the sample. This interaction either enhances or inhibits the production of enzymes, and the level of enzyme activity is measured. Often, substances are added that will produce color ("chromogenic substrates") if the appropriate enzymatic activity is occurring. The color intensity may be measured by spectrophotometers to calculate the amount of analyte present in the sample. In other cases, substances may be added that produce fluorescence or radioactive signals, which then can be measured by the appropriate instrument.

***Advantages.*** Immunoassay methods are an attractive option because they are usually much less expensive than traditional methods of analysis. The lower cost is related primarily to replacing human labor with automated systems. They are relatively easy to use, but some training is required. Immunoassays have been developed to enable processing of very large numbers of samples, often by robotic equipment. Qualitative immunoassays may require only a few minutes to process. Quantitative immunoassays may require as much time to process as traditional methods, but many more samples can be processed in that time. Also, immunoassays can analyze many thermally unstable or nonvolatile materials that are not amenable to conventional methods. Because they are so portable and can be used to analyze both soil and water samples, immunoassay methods are especially useful as a field screening tool to determine better placement of monitoring wells for monitoring existing contaminant plumes.

***Disadvantages.*** Immunoassay techniques have not been approved for drinking water quality analysis by U.S. EPA or Ohio EPA. Currently they are being studied by U.S. EPA for possible approval. The main technical limitation of immunoassay methods is that they tend to be highly specific; the "screening" methods typically can detect only a limited number of substances, and each quantitative method may be able to measure only a single substance. Sometimes a test works only for compounds within a certain concentration range. (By contrast, U.S. EPA Method 524.2 is capable of accurately measuring over 60 different VOCs within a single sample, and concentration ranges are not a great problem because laboratory technicians can dilute highly concentrated samples to make them readable by the instrument.)

Immunoassay methods may be less effective than other methods in detecting compounds that have a very low molecular weight, are unstable in water, or are highly lipophilic (binding easily with oily substances). Other limitations are more critical when using test kits in the field to site monitoring wells, and include: many compounds are affected by temperature and humidity; small errors in measurement of the volume of compound can result in large errors in the concentration readings; test kits tend to have a short holding time. Finally, there is a danger that immunoassay screening tests are *too* easy to use; people without training in their use may apply them inappropriately, or make erroneous conclusions from the results.

***Summary.*** Immunochemical methods are most applicable to analyses of large sample sets containing one or a few specific chemicals. They are a very cost-effective method for screening ground water samples for the presence of various contaminants. For example, the Village of Waynesville has used immunoassay test kits to screen for various pesticides within its Source Water Protection Area (**Figure 4**). For Source Water Protection monitoring, Ohio EPA encourages the use of immunoassay methods as a screening tool, and would accept any immunoassay tests that are eventually included in the OAC 3745-81-27. Where immunoassay methods are used as a screening tool, provision should be made in the Sampling and Analysis Plan for confirmatory quantitative sampling when contaminants of concern are detected by the screening method.

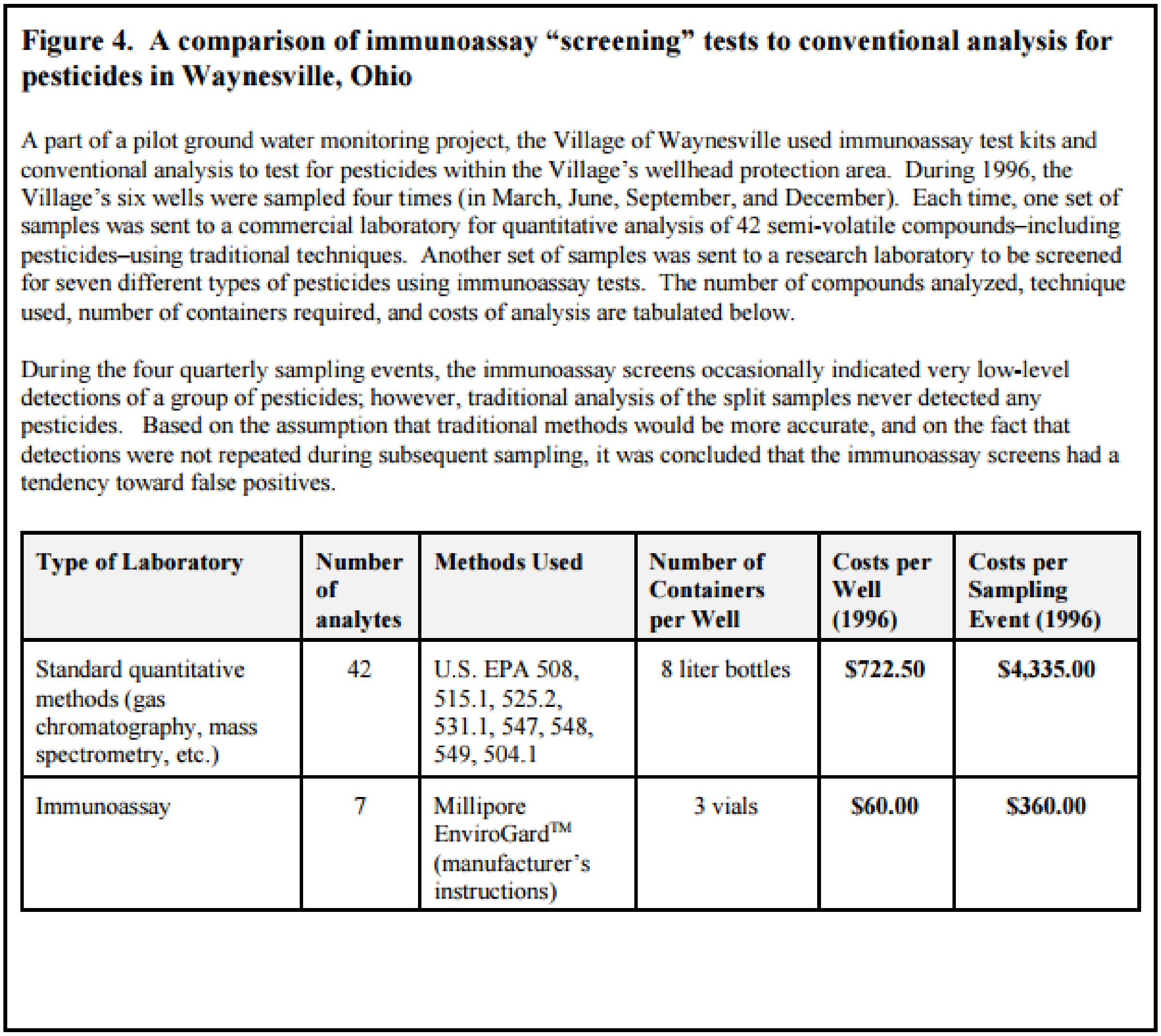


**Figure 4. A comparison of immunoassay "screening" tests to conventional analysis for pesticides in Waynesville, Ohio**

A part of a pilot ground water monitoring project, the Village of Waynesville used immunoassay test kits and conventional analysis to test for pesticides within the Village's wellhead protection area. During 1996, the Village's six wells were sampled four times (in March, June, September, and December). Each time, one set of samples was sent to a commercial laboratory for quantitative analysis of 42 semi-volatile compounds–including pesticides–using traditional techniques. Another set of samples was sent to a research laboratory to be screened for seven different types of pesticides using immunoassay tests. The number of compounds analyzed, technique used, number of containers required, and costs of analysis are tabulated below.

During the four quarterly sampling events, the immunoassay screens occasionally indicated very low-level detections of a group of pesticides; however, traditional analysis of the split samples never detected any pesticides. Based on the assumption that traditional methods would be more accurate, and on the fact that detections were not repeated during subsequent sampling, it was concluded that the immunoassay screens had a tendency toward false positives.

| Type of Laboratory | Number of analytes | Methods Used | Number of Containers per Well | Costs per Well (1996) | Costs per Sampling Event (1996) |
|---|---|---|---|---|---|
| Standard quantitative methods (gas chromatography, mass spectrometry, etc.) | 42 | U.S. EPA 508, 515.1, 525.2, 531.1, 547, 548, 549, 504.1 | 8 liter bottles | **$722.50** | **$4,335.00** |
| Immunoassay | 7 | Millipore EnviroGard™ (manufacturer's instructions) | 3 vials | **$60.00** | **$360.00** |

## SELECTING SAMPLING METHODS/EQUIPMENT

Proper sample collection is increasingly important as technological improvements in laboratory instruments continue to lower detection limits (currently in the parts per trillion range for some constituents). The sampling equipment selected may largely determine the effectiveness of a monitoring system, especially one intended for early warning. Therefore, selecting sampling methods/equipment is a critical task in the development of a ground water monitoring program.

The factors that need to be considered and compared when selecting sampling equipment include: maximum sample depth, minimum well diameter, ability to vary flow rate, portability, power source, durability, ease of decontamination, average cost to rent or purchase, and potential for chemical aeration. Many of these factors are practical considerations. However, the potential for chemical aeration is a major technical consideration and warrants some additional discussion.

**Potential for Chemical Aeration.** Ground water is generally under pressure that is greater than atmospheric pressure. Upon entering the well casing and encountering atmospheric pressure, gases and volatile constituents that were dissolved in the ground water "outgas". (Where ground water contains high amounts of methane, it is often possible to put one's ear to the well and hear the methane gas bubbling out of solution!) This loss of volatile constituents to the atmosphere results in samples that are not representative of the level of constituents occurring in the ground water. The inability to collect a representative sample is a serious deficiency in a ground water monitoring system, especially when there are volatile constituents(s) of concern—such as chlorinated solvents. The levels of VOCs in a sample that has been aerated may be significantly lower than the levels actually occurring in the ground water.

Aeration also can result in artificially low levels of inorganic constituents in the ground water sample. This is caused by two basic processes: oxidation-reduction changes, and pH changes. Exposure to oxygen in the atmosphere increases the redox state of a ground water sample. Constituents such as iron, manganese, arsenic and cadmium may be oxidized from a reduced state, which causes them to precipitate from solution. When dissolved iron precipitates as ferric hydroxide, the pH of the sample increases—and this causes other dissolved metals to precipitate out of solution. Outgassing of dissolved carbon dioxide and other gases also results in pH increases, with resulting precipitation of metals. As a result, the level of metals in a ground water sample that has been aerated will be lower than the level actually occurring the ground water.

To prevent aeration of a sample, many sampling techniques have been developed that focus on minimizing the exposure of the ground water sample to air. Generally speaking, it is believed that one of the best ways to minimize exposure is to avoid turbulence. Using low-flow pumping rates is considered an effective way to avoid turbulence.

U.S. EPA has supported the use of low-flow pumps for many years, and has sponsored much research—both laboratory experiments and field experiments—comparing the ability of various sampling devices to recover VOCs. The variation in VOCs recovery among various devices appears to be related to:

- **Depth of wells.** In deep aquifers, water tends to be under greater pressure and thus to hold more dissolved gas. Upon entering a well, the dissolved gases are likely to bubble out more rapidly. By contrast, VOCs recovery in samples from shallow wells tends to vary much less among the various methods.

- **Volatility of the compound.** More variation in VOCs recovery is noted when the constituents being collected are highly volatile. ("Volatility" is measured by the Henry's Law Constant of a chemical. Henry's Law Constants are listed in various chemical reference books.)

It is widely believed that suction-lift pumps are least effective in recovering VOCs, and that bladder pumps generally are the most effective. This is illustrated in a graph from a study by Unwin and Maltby, 1988 (**Figure 5**), which compared a suction lift device, an electric submersible pump, a bailer, and a bladder pump . However, a similar comparative study conducted by Ohio EPA in 1997 indicated that a suction-lift pump recovered VOCs more effectively than a bailer for most of the 12 constituents (**Figure 6**). More surprisingly, for four of the 12 constituents, the suction-lift device recovered VOCs as well as the Grundfos low-flow submersible pump, which is widely considered one of the most effective sampling devices. From this study, Ohio EPA concluded that *for source water protection monitoring purposes*, suction-lift devices may be acceptable sampling tools where ground water is shallow enough to enable their use. However, they clearly will be most acceptable in areas where VOCs are not a major concern (for example, in undeveloped or agricultural areas where nitrates are likely the major ground water quality concern).

**Dedicated vs. Non-dedicated Sampling Equipment.** Most sampling devices can be either dedicated or non-dedicated; that is, planners may decide that for each monitoring well they will provide a sampling device that is dedicated *to that well*. The device may be marked and stored in a safe place, or—more commonly—it may be installed inside the well. Bailers are very frequently tied up beneath the casing cover and left to hang inside the well.

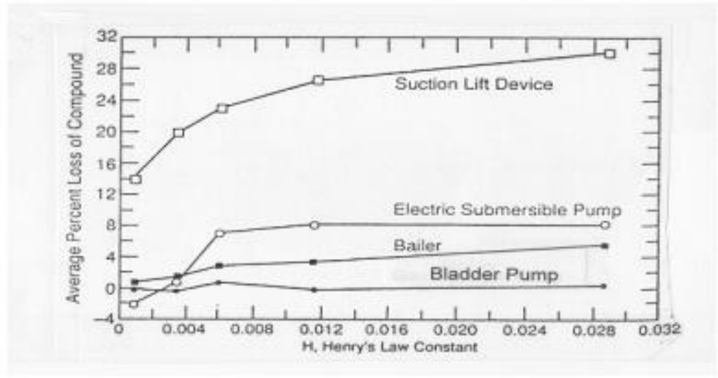


**Figure 5. Comparison of the effect of sampler type on loss of volatile organics (Unwin and Maltby, 1988)**
(Sampling depth was 23 feet)

The main advantage of having dedicated equipment is that there is no need to decontaminate the sampling device between wells. Decontamination is time-consuming and requires carrying rinse water and collection containers out to the site, or else returning to some central location to decontaminate the equipment after visiting each well. Where bailers are the sampling device chosen, it may truly be more cost-effective to purchase a bailer for each well.

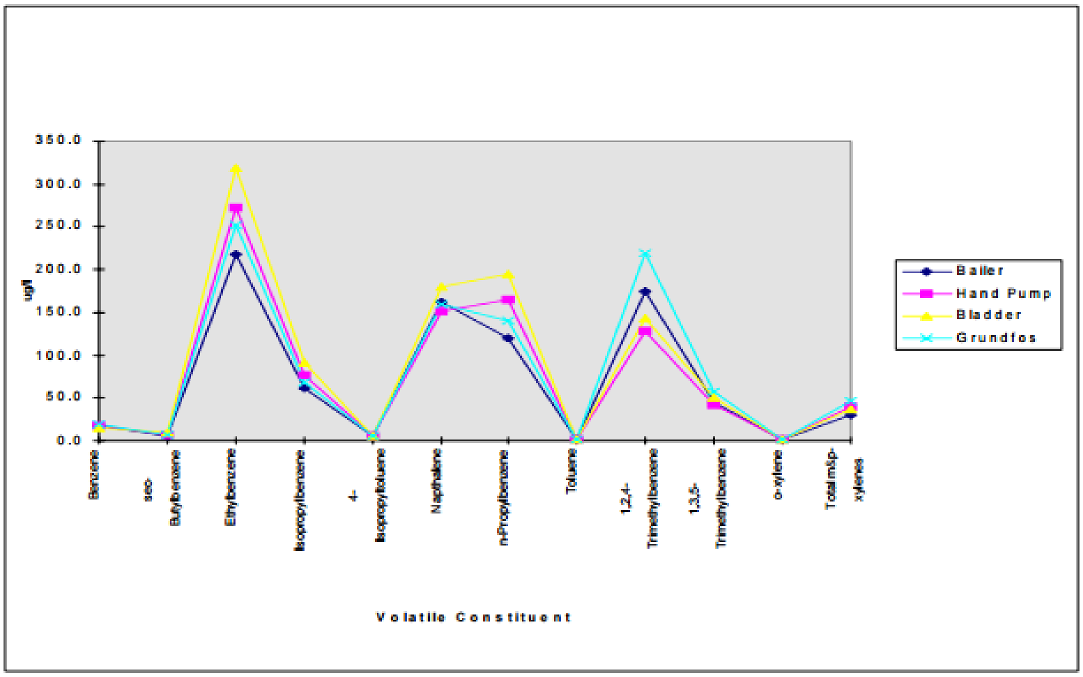


**Figure 6. Comparison of the effect of sampler type on detected concentrations of volatile organic constituents at a contaminated site in Dayton, Ohio (Ohio EPA, 1997)**
(Sampling depth was 25 feet)

With dedicated equipment there is no fear of cross-contamination and no need to take equipment blanks. Also, where dedicated pumps are permanently installed below the water table, there is less disturbance of the sampling point and samples are likely to be more representative. The obvious disadvantage of dedicated equipment is that the up-front costs for the monitoring network are greatly increased. Also, any device left in the water must be capable of withstanding that environment. It should not leach constituents into the casing water, nor should it adsorb constituents present in the ground water. To avoid these problems, dedicated in-situ devices need to be constructed from inert materials such as Teflon and stainless steel—which are relatively expensive.

**Filtration.** Ground water samples may contain noticeable amounts of sediment or particulate matter, often referred to as "turbidity". Colloidal particles of metals and metalloids tend to be adsorbed onto these particles. Most of the larger particles are not actually mobile in the natural ground water environment; they represent particles pulled into the well casing by vigorous purging or sampling. Thus, their presence in a ground water sample is unrepresentative of actual ground water quality. Once the samples are acidified (for preservation purposes), the adsorbed colloidal metals will dissolve and become detectable by laboratory instruments. As a result, the concentration of dissolved metals in the natural ground water environment will be overestimated.

This leads to the following problems:

- Sample turbidity varies over time, with the type of sampling device, and with the person conducting the sampling. Consequently, comparisons of ground water quality data over time may not reflect actual trends.

- The amount of sediment entering a well may vary across a site due to natural hydrogeologic conditions. Consequently, apparent variations of ground water quality throughout the SWAP area may not reflect actual spatial variations.

Because of these problems, particulate matter has often been removed by filtration prior to containerization and acidification. However, filtration presents its own host of problems, including filter clogging and breaking, contamination of the sample by the filter materials, increased aeration of the sample, and the proper choice of filter size. (Some authorities have recommended 10 micron filters; others have recommended 0.4 micron filters.) More recently, some investigators have recommended against field-filtering. To minimize turbidity, they advocate careful well installation, construction, and development, and low-flow sampling and purging.

**For source water protection monitoring, field filtering is *not* recommended.** Source water protection areas generally are aquifers, which tend to consist of relatively coarse-grained and well-sorted sediments, or fractures in consolidated materials. Monitoring wells completed in such materials are not as likely to produce turbid samples as wells completed in glacial tills and other fine-grained materials. If the monitoring well is installed and developed carefully, and if low-flow sampling is practiced, turbidity should not be a problem. If a community's newly-installed monitoring wells yield turbid samples, the wells should be developed again. Some wells take longer than others to "get clean". Also, bailers have a tendency to stir up any loose sediment at the sampling point. Sampling instead with a submersible pump or a bladder pump, set at the lowest achievable flow rate, should lower the turbidity of the samples.

## TYPES OF SAMPLING EQUIPMENT

The information in this section summarizes a sizable body of literature discussing the pros and cons of various ground water sampling methods. In addition, a number of Ohio consultants and ground water equipment sales/rental companies were surveyed by Ohio EPA, to obtain their impressions of what equipment was favored for various applications. The goal of this section is to offer some basic guidance on selecting sampling methods that will be appropriate for a source water protection monitoring program. Recommended reference materials are provided in Appendix A.

For the purpose of discussion, ground water sampling devices are often grouped into four major categories: grab samplers (such as bailers), suction-lift devices (such as peristaltic pumps), gas-lift devices, and positive displacement mechanisms (such as bladder pumps and submersible pumps). In practice, the devices currently being used most are:

- Bailers
- Peristaltic pumps
- Low-flow submersible pumps
- Bladder pumps

These types of sampling equipment are discussed below.

### Bailers

A bailer is a hollow cylinder attached to a rope and lowered into a well to collect the sample. It is fitted with a ball check-valve at the bottom. As the bailer enters the water, the water fills the bailer through the bottom opening. When the bailer stops descending through the water, the ball falls back down and seals the bottom opening, so that the water is contained. The water then may be lifted up and poured into sample containers from the open top of the bailer. Alternatively, a smaller cylinder (called a "bottom-emptying device", or BED) may be inserted into the bottom end to push the ball up, and the bailer may be emptied from the bottom (**Figure 7**).

Collecting a water sample from the bottom of a polyethylene bailer (photo by Ohio EPA, 1997)

Bailing a monitoring well using the "windmill technique" (photo by Ohio EPA, 1996)

**Figure 7. Using a bailer to sample a well.**

Bailers are typically 3 or 4 feet in length and constructed from polyethylene, polyvinyl chloride (PVC), Teflon, or aluminum. However, they can easily be constructed to any specified dimensions. Disposable polyethylene bailers can be purchased for less than $10.00 per bailer. The only "accessory equipment" needed is twine or rope.

***Advantages.*** Bailers are the least expensive of the common sampling methods. They are extremely portable, rugged, and easy to use. They are very easy to decontaminate. Because of their low cost, dedicated bailers are often purchased for each well and left inside the well, eliminating the need to decontaminate. Sometimes disposable bailers are used, also eliminating the need to decontaminate. There are no technical limitations on the depth at which bailers can be used. However, they are not recommended for very deep wells because of the time and effort that would be involved.

***Disadvantages.*** Bailers hold small amounts of water, so using a bailer to purge a well can be time-consuming and exhausting. The act of lowering a bailer into the water tends to create turbidity in the water samples. This may result in elevated levels of metals in the sample that do not reflect the actual level of dissolved metals in the ground water itself. Inaccuracies due to operator inconsistencies or errors are more likely to occur with bailers. Conventional wisdom has long held that bailers do not recover VOCs well due to considerable exposure of the sample to air, and because of turbulence when the bailer hits the water surface. (However, comparative studies do not bear out this assumption consistently; in fact, bailers appear to compare favorably with other methods, especially in shallow wells).

***Summary.*** Bailers are not recommended for deep wells and would not be the method of choice in shallow wells where metals or VOCs are a significant concern. They are especially suited to remote sites in shallow aquifers where metals or VOCs are not a concern. Because purging wells with a bailer is so time-consuming, planners may choose to obtain an additional device just for purging the wells, such as a nondedicated suction-lift pump.

### Suction-lift pumps

Suction-lift pumps (also called “vacuum pumps”) deliver samples by applying a vacuum at the surface. The negative pressure is applied by a portable pump attached to a tube that is lowered to the desired sampling depth.

The peristaltic pump is the most widely used of the suction-lift pumps for ground water monitoring. It is self-priming and uses a squeeze action on the tubing to create a vacuum. The pump may be operated manually using a foot pedal or hand lever. However, the most popular peristaltic pumps are powered by electricity, and may be designed to plug into a standard outlet, a generator, or the cigarette lighter on a car dashboard, or use batteries. Accessory equipment consists only of tubing and possibly foot valves.

***Advantages.*** Suction-lift pumps tend to be relatively inexpensive and straightforward to operate. They usually are durable, relatively lightweight, and highly portable, as they are operated manually or use batteries. They are easy to decontaminate. On peristaltic pumps, the flow rate can be controlled. They can be used in wells of any diameter and plumbness.

***Disadvantages.*** Suction-lift pumps can only operate in wells with water levels less than 25 feet below ground. Where the water table is deeper, the pump cannot maintain suction and will not draw up the water. Also, suction-lift pumps are considered most likely to aerate the sample; in some studies they have fared worst in recovery of VOCs. Finally, some suction-lift pumps need to be “primed” before use (that is, water must be poured into the pump to initiate suction). Therefore, it is necessary to carry clean distilled water out to the well site. This kind of pump may “lose prime” when pumping is discontinued momentarily, unless a foot valve is attached to the tubing at the bottom of the well.

***Summary.*** Suction-lift pumps are most appropriate for collecting samples from shallow wells in remote locations where VOCs are not a concern. Usually a single pump is used, which must be decontaminated between wells. The pump often is attached to dedicated tubes in each well. Even where bailers are being used, and/or VOCs are a concern, suction-lift pumps may be an appropriate device for purging the wells. Professional samplers tend to prefer battery-operated peristaltic pumps for purging and sampling in remote locations.

(Above right) This peristaltic pump is battery-operated and flow rate is adjustable (Photo by Ohio EPA, 1997)

(Above left) Using a manual 'pitcher pump' to develop a newly-installed well (Photo by Ohio EPA, 1996)

**Figure 8. Using suction-lift pumps for developing a well and for sampling**

**Figure 9. Using a low-flow submersible pump to sample a well** (photo by Ohio EPA, 1997)

**Submersible Pumps**
Submersible pumps are also known as "impeller-driven pumps". These pumps have a rotating impeller that accelerates water within the pump body, building up pressure and forcing the sample up the discharge line (**Figure 9**). The pump itself is lowered into the well. Required accessory equipment includes a gasoline-powered generator and a control box.

***Advantages.*** The most attractive feature of the currently popular submersible pumps is their range of pumping rates– from 9 gallons/minute (for purging) to 100 ml/minute (for sampling). As a result, only one device needs to be lowered down the well to do all the work. Also, unlike the peristaltic pumps, the flow rate is very steady, not "pulsed". Due to the low and steady flow rates achievable, turbidity should be minimized and VOCs recovery should be maximized. Unlike suction-lift pumps, submersible pumps can lift samples from depths of up to 250 feet. The most popular models are relatively straightforward to use.

***Disadvantages.*** Submersible pumps are considerably less portable and less rugged than the previously mentioned devices, due to their need for a generator and a control box. They are considerably more expensive as well. One survey respondent noted that controllers may malfunction if splashed with water, and repair costs are high. Submersible pumps may need to be "primed", which involves carrying distilled water out to the site. Decontamination is not as simple as for the devices previously mentioned; grit from turbid water can build up and lead to pump malfunctions. Due to their high cost and their design as a portable sampling device, these pumps are rarely dedicated.

***Summary.*** Low-flow submersible pumps are currently very popular with professional ground water samplers due to their versatility. They are suitable for sampling in most kinds of wells, both shallow and deep, but may not be practical for sampling remote wells that are not accessible by vehicle. When a flow rate of 100 ml/minute can be achieved, they are a good choice for VOCs sampling.

### Bladder Pumps

Bladder pumps are hollow cylinders containing a flexible "bladder" inside with check valves at each end. Gas (usually compressed air or nitrogen) is pumped from a cylinder on the ground surface into the space between the bladder and the cylinder wall, "squeezing" the bladder and forcing the water sample up the discharge line (**Figure 10**). An air compressor and regulator turn the pressure on and off, which allows new water to enter the bladder and the cycle is repeated. The separate bladder chamber does not allow the sample to come in contact with the compressed air. Accessory equipment includes control box, bottles of gas, compressors, and the tubing with safety cable.

**Figure 10. Using a bladder pump to sample a well** (photo by Ohio EPA, 1997)

***Advantages.*** Bladder pumps are considered to have the best VOCs recovery of available sampling devices. They can yield water samples from depths of up to 400 feet (however, such deep sampling may require many cylinders of gas). They provide a range of easily controlled flow rates (up to 3 gallons/minute) and despite the "pulsing" nature of the bladder, the flow is relatively steady. Bladder pumps provide a superior ground water quality sample and generally cost less than the low-flow submersible pump.

***Disadvantages.*** Bladder pumps are probably the least portable and the most complicated to operate of the common sampling devices, because of the many accessory devices required. They are expensive to rent and are difficult to decontaminate thoroughly. Some rental services rent bladder pumps only on a weekly (rather than daily) basis because of the time required to adequately clean the pump after each client's use. Gas cylinders must be transported carefully. Bladder pumps are not as rugged as some of the simpler sampling devices and are prone to wearing out in a few years. Sediment in the water can cause failure of the check valves in some models. They are not an optimum choice for purging a well, because their flow rates are relatively slow.

***Summary.*** Bladder pumps are suitable for sampling all kinds of wells, and all kinds of contaminants. However, because of the amount of supporting equipment and supplies needed, it may not be practical to use a bladder pump at remote sampling locations. Because of the difficulty of decontamination, bladder pumps are sometimes dedicated. Some landfills and other regulated entities have installed dedicated bladder pumps that can be operated by teams of samplers who go from well to well with the control box and gas cylinders.

**Conclusions**

For any well that cannot be reached by vehicle, bailers (and in some cases, suction-lift pumps) may be the only sampling method usable. However, where vehicle access is not a problem, the presence of VOCs contamination may be the most limiting factor, because it will rule out the use of suction-lift pumps, and the use of bailers will be discouraged. Where access and VOCs are not a problem, the depth to water level will be the next consideration. Where water levels are 50 feet or more below surface, the use of bailers will be impractical, and suction-lift pumps will not lift the sample. Where several methods can be used, factors such as ruggedness, ease of use, and cost of the various sampling methods will weigh in the final decision. All of these factors are summarized in **Table 2**. A decision-making flow chart is shown in **Figure 11** for deciding among the four methods discussed.

**Table 2. Summary of information on ground water sampling devices[1]**

| Sampling Device | Bladder Pump | Submersible Pump | Suction Lift Pump | Bailer |
|---|---|---|---|---|
| **Max. sample depth (ft.)** | 400 | 250 | 25 | No limit |
| **Min. well diameter** | 1.5 | 1.75 | 0.5 | 0.5 |
| **Avg. pump rate** | 0-3 gpm | 0.026-9 gpm | 0.01-0.3 gpm | Variable |
| **Portability[2]** | Low | Low | High | High |
| **Power Source** | Compressed gas | Generator | Batteries/gen. | None |
| **Durability[3]** | Moderate | Moderate | High | High |
| **Ease of Decontamination[4]** | Difficult | Moderate | Easy | Easy |
| **Avg. cost (rental)[5]** | $110/week | $200-325/week | $75-100/wk | N/A |
| **Avg. cost (purchase)[5]** | $3000-3500 | $4000-4500 | $200-1500 | $7-40 |
| **Flow controllability[6]** | Moderate | High | High | N/A |
| **Potential for Aeration[7]** | min.-slight | slight-moderate | high-moderate | high-moderate |
| **Major advantage(s)** | Good for analysis of most compounds, including VOCs | Flow rate can be adjusted over a wide range, enabling both rapid purging *and* very low-flow sampling | Portable and easy to operate | Very portable and easy to operate, low cost |
| **Major disadvantage(s)** | Complicated and difficult to transport; hard to decontaminate | High cost | Only usable for shallow wells | Time consuming and laborious |

[1] Data extracted from Nielson (1991), Eastern Research Group (1993) and Pohlmann and Hess (1988)

[2] *Portability* describes the ease of transporting the equipment on foot. High=easy to carry, low=difficult or impossible to carry

[3] *Durability* describes how well the equipment holds up in field conditions. High=very durable/rugged; low=very sensitive

[4] *Ease of decontamination* describes how easily and completely the equipment can be decontaminated between sampling events

[5] *Average costs* are based on 1997 quotes and do not include costs of power sources, tubing and other accessories

[6] *Flow controllability* relates to how precisely the flow can be regulated; high=easily regulated; low=difficult to regulate

[7] *Potential for aeration* describes the potential for compounds to volatilize and/or change chemical composition

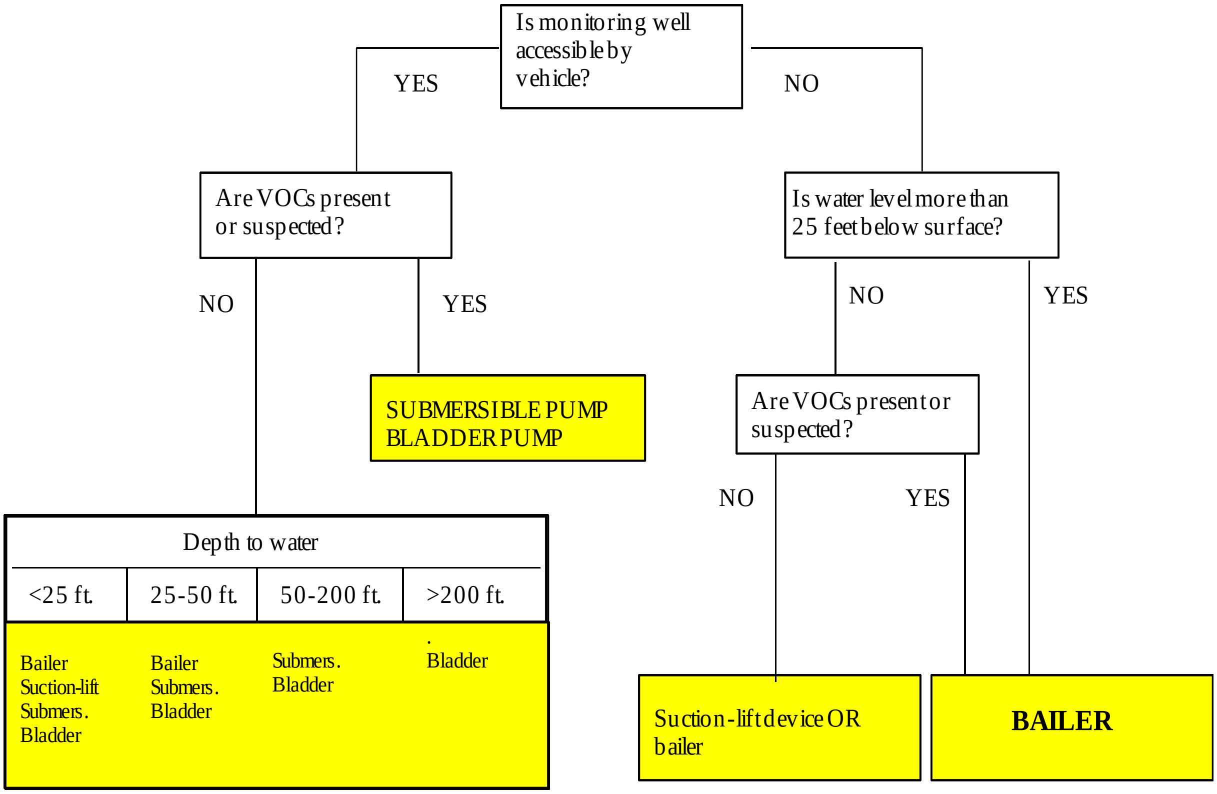


**Figure 11. Flowchart for Selecting An Appropriate Sampling Method**

### Other Types of Sampling Equipment

In addition to the four types of sampling equipment listed above, there are numerous others that are less commonly used. They include syringe samplers, gear-drive pumps, helical rotor pumps, gas-lift pumps, and in-situ devices. Some innovative methods have been tested in research efforts and may provide excellent results, but are not familiar to users outside academia, or are not widely available. If a community wishes to conduct source water protection monitoring using a sampling device that is not discussed in this guidance, it should research that device and propose it the ground water monitoring plan portion of its Source Water Protection Plan. Statements concerning the adequacy of the device should be based on professional testing, and the results of the tests ideally should have been published in a peer-reviewed document (as opposed to being based exclusively on statements in the company catalog). Ohio EPA generally would not recommend using a device that has never been independently tested.

## CONDUCTING A SAMPLING EVENT

Careful planning, organization, and good weather are the keys to a successful sampling event. Samplers should have gathered all the necessary equipment in advance. Equipment should be in working order and where necessary, should be calibrated in advance. Batteries should be checked, and extra batteries should be taken out to the field. If rented or unfamiliar equipment is being used, samplers should make sure that the various components connect properly. (Professional samplers tell horror stories of arriving at a remote site only to find that the plug on a rented pump does not match the outlet on the generator!)

Details on ground water sampling procedures are available in numerous other textbooks and guidance documents, and will not be discussed in depth here. (See Sources of Information, Appendix A.) Procedures for source water protection monitoring generally should follow those specified for other ground water monitoring programs. They include: measuring water levels and well depth; collecting field measurements of pH, specific conductance and temperature; purging; and obtaining the samples. One note: some regulatory programs strongly advise or require that all purge water be containerized and tested for hazardous characteristics. For source water protection purposes, such precautions may be excessive. If a well is suspected or known to yield highly contaminated water, containerization of its purge water is advisable. However, for wells that historically have yielded uncontaminated water and continue to do so, containerization of purge water should not be necessary.

During the sampling event, a field notebook should be maintained. Information to be recorded at each well site should include: date, climatic conditions, names of sampling staff, time, identification of well, condition of well casing and pad, static water level depth, total depth of well, values of pH, specific conductance, temperature, rate of water removal, appearance of water, and any problems encountered. To avoid oversights, it would be advantageous for samplers to have a “field Sampling and Analysis Plan”–a checklist of the procedures to be followed at each well. This is especially useful for a new sampling crew, or inexperienced samplers.

## SUMMARY OF CHAPTER THREE

If monitoring wells are to achieve their purpose, SWAP planners must develop and follow a Sampling and Analysis Plan that addresses:

**Parameter list.** The list of parameters for any given well should be based on the types of contaminants that well is supposed to monitor for. However, it is advisable to conduct a few initial rounds of “baseline sampling” for a range of ground water quality parameters at all of the wells.

**Sampling frequency.** Quarterly baseline sampling is recommended for the first year of sampling. For subsequent sampling events, it is advisable to conduct quarterly sampling of wells located within the one-year time-of-travel area. High-risk pollution sources located between the one- and five-year time-of-travel areas should be monitored at least semi-annually. Less frequent monitoring may be proposed for wells that do not fit into these categories.

**Analytical methods.** Methods designated by OAC 3745-81-27 for drinking water quality analysis should be used. However, other methods–such as immunoassay methods–may be proposed as screening tools.

**Sampling equipment.** For shallow wells with no VOCs contamination, most of the standard sampling devices can be used. For wells with VOCs contamination of persistent turbidity, devices with a low-flow capability (primarily the low-flow submersible pumps and bladder pumps) are recommended. For wells with water levels deeper than 25 feet, suction-lift pumps cannot be used.

**Sampling procedures.** A field SAP should be written to ensure that samplers follow the planned procedures. For SWAP purposes, some leniency can be offered regarding disposal of purge water and collection of field blanks. Field filtering is not recommended for source water protection purposes.

# CHAPTER FOUR —
# COMPILING AND ANALYZING THE RESULTS

## INTRODUCTION

The purpose of a ground water monitoring program is to enable the public water supplier to know when raw water quality is impacted and he/she needs to take action to ensure that the public water itself remains safe. Therefore, it is important that SWAP planners design a system for compiling the ground water quality data and making it available in a format that is easy to understand and analyze. They also need to decide what would "trigger" action, and what kinds of actions might be taken. Some general guidelines are provided in this final chapter for recognizing a water quality problem and for deciding what the appropriate response should be.

## RECOGNIZING A WATER QUALITY PROBLEM

When ground water monitoring is conducted for a regulatory program, trigger values typically are spelled out in regulations or in guidance. For public drinking water, the quality of ground water as an acceptable drinking water source is measured against the Primary and Secondary standards established by the U.S. EPA under the Safe Drinking Water Act of 1974. Ohio EPA has adopted similar standards, or Maximum Contaminant Levels (MCLs) to serve as the basis for water supply regulations and compliance within the State. However, there are no specific standards for *raw* ground water quality (before treatment). Ground water monitoring regulations for various hazardous waste management programs set standards for untreated ground water that are similarly based on MCLs or on site-specific risk assessment (where the likelihood of the contaminant being ingested or inhaled by humans is factored into the clean-up goals). However, application of these standards can be complicated. As an example, for inorganic parameters, the Resource Conservation and Recovery Act (RCRA) regulations require a statistical comparison of samples from upgradient (presumably unimpacted) and downgradient wells (**Figure 12**). In recent years the U.S. EPA technical guidance on this subject has become very detailed; the selection and application of a statistical method may require the assistance of a ground water professional with statistical expertise.

As noted throughout this document, for Source Water Protection purposes, it is not critical that ground water quality measurements be quantitatively precise. What *is* critical is that the public water supplier be able to recognize quickly what values may indicate a problem so that repeat sampling can be conducted as soon as possible. Therefore, the following simple rules of thumb are proposed:

(1) If the detected constituent is a **manmade (i.e., not naturally occurring) organic compound**, it will be considered an indication of potential contamination.

(2) If the detected constituent is an **inorganic compound with an MCL/action level**, it will be considered an indication of potential contamination only if it exceeds the action level for the constituent.

(3) If the detected constituent is an **inorganic compound with no MCL**, it will be considered an indication of potential contamination only if it significantly exceeds historical levels of that constituent.

Rules (1) and (2) are based on numerical standards, and require no judgement call. However, rule (3) requires the public water supplier to decide when a value “significantly” exceeds historical levels. One of the best ways to recognize a significant departure from historical levels is to graph the data for each well, with time on the x-axis and concentration of constituent on the y-axis (see **Figure 13**). If the water quality data from each sampling event is entered into a standard spreadsheet computer program, it can be graphed very easily and accurately by the program. Therefore, Ohio EPA strongly advises any public water system implementing a ground water monitoring program to maintain the data on a computerized spreadsheet with graphing capabilities.

Ohio EPA does not propose any more rigorous method of identifying a significant exceedance of historical levels for three reasons: (1) any method that would be straightforward to apply would almost certainly be too simplistic to be scientifically valid; (2) common sense can be sufficient for recognizing a departure; and (3) the kinds of constituents that would be subject to this analysis pose a relatively low risk to human health and do not warrant such effort.

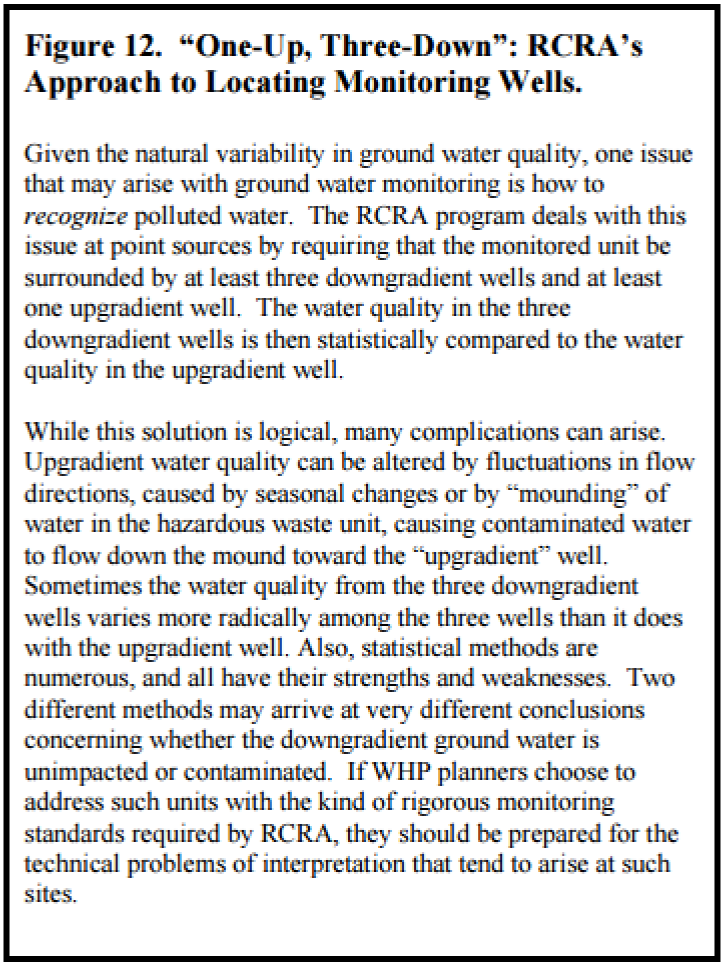


**Figure 12. “One-Up, Three-Down”: RCRA’s Approach to Locating Monitoring Wells.**

Given the natural variability in ground water quality, one issue that may arise with ground water monitoring is how to *recognize* polluted water. The RCRA program deals with this issue at point sources by requiring that the monitored unit be surrounded by at least three downgradient wells and at least one upgradient well. The water quality in the three downgradient wells is then statistically compared to the water quality in the upgradient well.

While this solution is logical, many complications can arise. Upgradient water quality can be altered by fluctuations in flow directions, caused by seasonal changes or by “mounding” of water in the hazardous waste unit, causing contaminated water to flow down the mound toward the “upgradient” well. Sometimes the water quality from the three downgradient wells varies more radically among the three wells than it does with the upgradient well. Also, statistical methods are numerous, and all have their strengths and weaknesses. Two different methods may arrive at very different conclusions concerning whether the downgradient ground water is unimpacted or contaminated. If WHP planners choose to address such units with the kind of rigorous monitoring standards required by RCRA, they should be prepared for the technical problems of interpretation that tend to arise at such sites.

Source Water Protection planners may always propose methods and standards more rigorous than these guidelines to identify a potential water quality problem, but they must be prepared for the costs and effort of the proposed methods. Conversely, if they wish to propose methods and standards less rigorous than the guidelines provided here, they must be prepared to explain why they consider their proposed methods or standards adequate for the SWAP area in question.

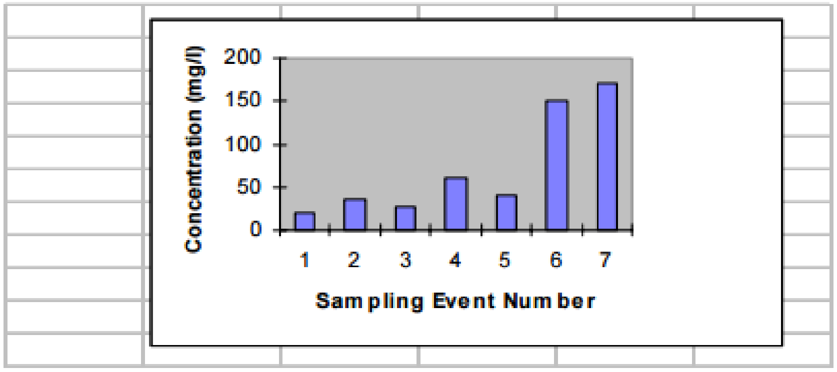


**Figure 13. Hypothetical chloride data.** The concentrations for Sampling Events 6 and 7 are noticeably higher than the trend of the preceding years. These 'spikes' may or may not be significant. They may simply reflect a natural variance in ground water quality. However, the public water supplier should consider rechecking the WHP area for potential sources of high chlorides (such as road salt or leaking oil wells or overflowing brine pits)

## RESPONDING TO A POTENTIAL WATER QUALITY PROBLEM

The flow chart in **Figure 14** summarizes the decision points for responding to a potential water quality problem. As shown, any well with a reported water quality value above the action level should be resampled as soon as possible after receipt of the laboratory report. Ideally, duplicate samples should be collected and sent to different laboratories (however, both should be analyzed using the same analytical procedure). If the exceedance is not repeated for either sample, no further action need be taken. If the exceedance is confirmed, the system will need to initiate a response that may range from continued monitoring to a full site investigation, depending on the level of concern. The actual threat to the public water system is related to the distance of the monitoring well from the production well(s), the level of contamination, the type of contaminant, and the existence or absence of any apparent potential pollution sources. For example, a slight exceedance of the action level for nitrate in a monitoring well located near the five-year time-of-travel line will be much less cause for alarm than a significant exceedance of the MCL for vinyl chloride in a well located near the one-year time-of-travel line.

If a preliminary assessment is undertaken to locate the source of the apparent ground water quality problem, an initial evaluation of potential sources will be made. Any subsequent actions will depend on whether potential sources can be identified and their locations. If the identified source(s) is located on property owned by the municipality or by the public water system owner, the system should report it to the Ohio EPA's Division of Drinking and Ground Waters at the District Office. Any further actions taken by the system would need to be coordinated with the District Office.

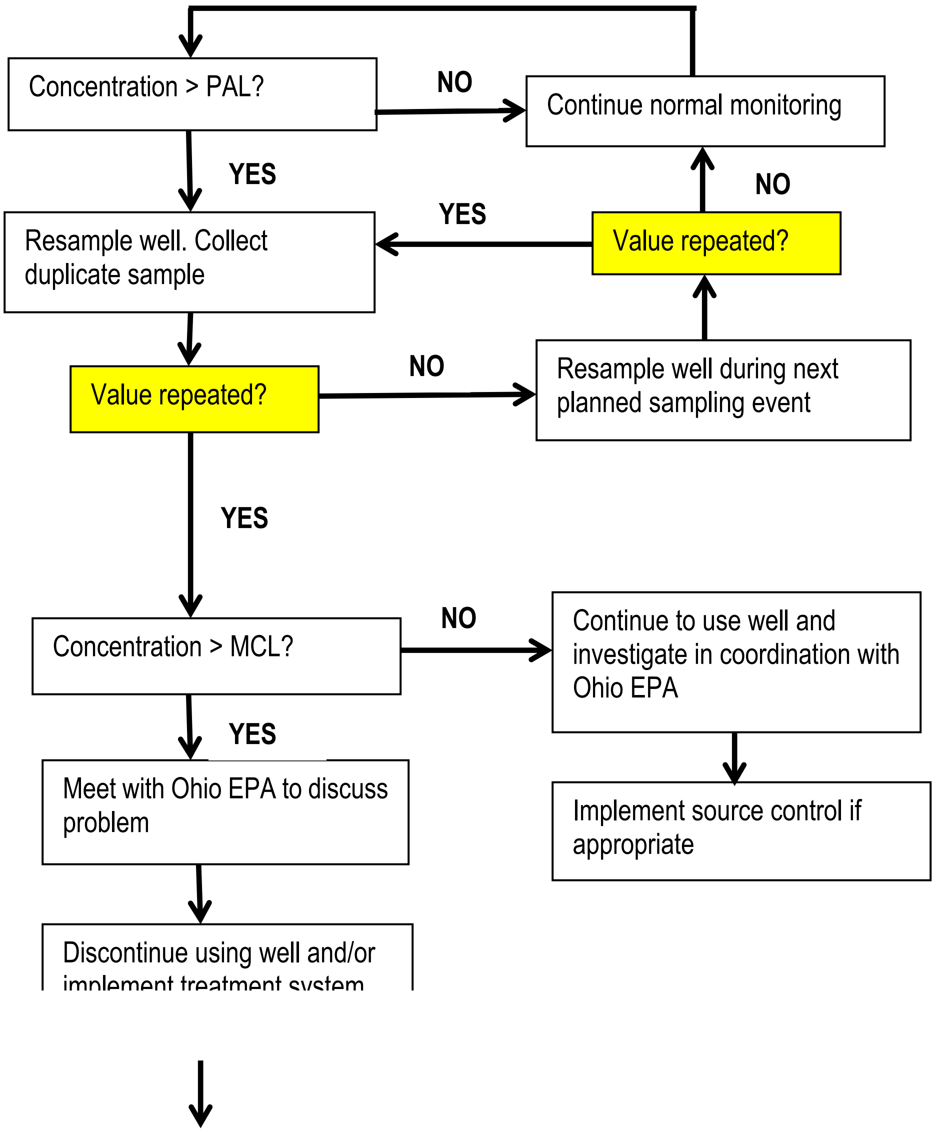


**Figure 14. Flowchart for responding to significant detections in monitoring wells**

Unidentified or suspected offsite sources of contamination should be reported to the Ohio EPA District Office. Further actions can be determined after receiving Ohio EPA's response, which will depend upon the priority assigned to the case relative to other requests for assistance, and upon the Agency's clean-up budget. If the Agency is unable to respond in a timely manner, the public water supplier may consider implementing an interim remedial measure to protect its production wells or it may consider conducting its own investigation and seek reimbursement from the responsible party. In this case, even if the Agency is unable to initiate its own investigation, it may be able to assist the public water supplier in obtaining offsite access agreements.

At this point, the ground water monitoring plan overlaps with the SWAP contingency plan. The various actions that might be taken to address verified ground water contamination are most appropriately detailed in the contingency portion of the Source Water Protection Plan.

## REPORTING THE RESULTS

Ohio EPA does not expect or wish public water systems to automatically forward copies of their SWAP monitoring results to the Agency. The information obtained from the monitoring program is intended to help the public water system make decisions about how to keep the public water at its highest possible quality. The information can be used to inform the water consumers about their drinking water. It is not essential that the Agency receive this information, as long as it does not indicate a contamination problem. However, if the data indicate a potential contaminant plume, this information must be reported to the appropriate District Office, as discussed above.

# CASE HISTORIES

## Case History 1 — *Village of Minster: A Well-Protected Aquifer*

The Village of Minster (in Auglaize County) obtains its public water supply primarily from wells completed in the regional carbonate bedrock. This bedrock is overlain by 90-100 feet of clay that appears to contain few layers of sand or other coarse-grained material. Clay is a natural sealant, often used for lining landfills. This thick layer of clay protects the carbonate aquifer from chemical spills at the surface or near subsurface. Although there are a number of commercial and industrial facilities within Minster's SWAP area, they pose relatively little risk to the aquifer. Chemical contaminants never have been detected in Minster's public water system.

The main concern at Minster is the potential for chemicals to enter the aquifer via unsealed abandoned wells or along poorly installed casings. Therefore, Minster's SWAP Management Plan emphasizes locating and properly sealing such wells. The village does not propose to conduct ground water monitoring at this time. Ohio EPA endorsed the Ground Water Monitoring element of Minster's Management Plan in 1997.

## Case History 2 — *Warren County: Ground Water Monitoring vs. Other Protective Strategies*

A public water system in northern Warren County is located over the Great Miami Valley sole-source aquifer. The aquifer providing water to the public water system consists of an unconfined unit of sand and gravel 35-90 feet thick. This aquifer is considered highly sensitive to ground water contamination.

Land use within the SWAP area is primarily residential and undeveloped. Over half of the undeveloped land is zoned industrial. Within the SWAP area are some home fuel oil tanks and one known underground storage tank (UST). In addition, some significant potential pollution sources lie just outside the 5-year time-of-travel area (a landfill, a paper mill, and a former liquid treatment plant that handled large amounts of hazardous materials).

Initially, the SWAP planners proposed some wells that were intended to monitor the heating oil tanks and the UST. After further discussion, the planners agreed that more information needed to be obtained. If the heating oil tanks were above-ground and were currently sound in construction, then *periodic visual inspection might be sufficient*. If the UST was installed recently, constructed of fiberglas, and was subject to some kind of leak detection monitoring (through wells, an alarm system, inventory reconciliation, etc.), then a monitoring well would not be needed there.

Also, some of the potential pollution sources outside the SWAP area were already being monitored. The SWAP planners agreed that they should make arrangements to *obtain copies of sampling results.*

## Case History 3 — *City of Dayton: Ground Water Monitoring as a Key SWAP Strategy*

The City of Dayton (population 141,000) derives all its public water from three wellfields, all of which draw water from the thick sand-and-gravel units that comprise the Great Miami River sole-source aquifer. It pumps on average 85 million gallons per day from over 100 public water supply wells.

Within the SWAP areas of the three wellfields lie some 350 businesses. One of the wellfields is adjacent to a major air force base, where a number of serious releases have occurred in the past. A serious warehouse fire on the wellfield in 1987 (see below) heightened local awareness of the vulnerability of the public water supply. In 1988 the City established a Source Water Protection ordinance that restricts the amount of chemicals that may be handled at newly established businesses, and encourages existing businesses to reduce their chemical use via incentives.

The City also has a sophisticated "early warning" system made up of 180 monitoring wells. Of these, 130 belong to the City and 50 are installed on the property of private businesses and homes. The wells are sampled on a quarterly basis. In addition to providing for early warning of plumes and general water quality changes, these wells act as a deterrent to any company tempted to dispose of its chemical wastes irresponsibly. They also help to maintain public confidence in the quality of the public water supply.

**An environmental nightmare:** The Sherwin-Williams warehouse fire in 1987. The reportedly "fireproof" facility was located in one of the City of Dayton's wellfields, over an aquifer that is the sole source of drinking water for 1.5 million people. Emergency responders let the site burn to the ground rather than douse it with water that would immediately seep into the ground, carrying toxic solvents into the drinking water supply. Clean-up and subsequent monitoring cost an estimated $12 million.

### Case History 4 — *Village of Waynesville: SWAP Monitoring to Track Nitrate Levels*

**Background.** The Village of Waynesville (population about 3,100) is located in northeastern Warren County, along the Little Miami River valley. The village is concentrated along the western bedrock slopes of the valley, but its public water supply is pumped from the Little Miami River valley aquifer. This aquifer consists of fairly homogeneous sand and gravel deposits that infill the valley and are about 50 feet deep. Approximately 200,000 gallons per day are pumped from these deposits. Land uses within this valley are primarily agricultural and recreational. The agricultural land is privately owned, and the parkland is managed by Warren County or the Ohio Department of Natural Resources.

In 1995 Waynesville embarked on Source Water Protection planning, in part because Village staff were concerned about levels of nitrate in the public water supply, which had been steadily rising over the previous few years, and were approaching the federal action level of 5.0 mg/l. Waynesville contracted with a consulting firm to delineate the SWAP area and inventory the potential pollution sources. The consulting firm located about 60 potential pollution sources within the SWAP area, which included two state highways, existing and former service stations, and areas over which agricultural chemicals were being applied.

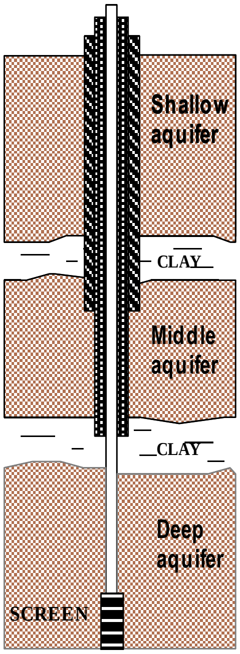
**Ground Water Monitoring Project.** In the summer of 1995, Ohio EPA solicited public water suppliers statewide to participate in a ground water monitoring project that involved installing and sampling monitoring wells for the purposes of SWAP monitoring. This project was partially funded by a Clean Water Act Section 319 grant from U.S. EPA, Region V. The Village of Waynesville was ultimately selected. Staff from Ohio EPA and Ohio Department of Natural Resources met with Waynesville's village staff in autumn 1995 to design the monitoring well program. The team agreed on a six-well network. Two wells would be installed to monitor some areas in which potential pollution sources (service stations, etc.) were concentrated. One of the four public water supply wells was taken off-line and converted to a monitoring well. Two more wells were installed north of the wellfield. Also included in the network was an existing well that was installed by ODNR at Spring Valley, which lay several miles up the valley, in Green County. Although distant from the SWAP area, this well was included to provide more information on nitrate levels along the valley. A seventh well that originally was to be located on a property a half mile north of the wellfield (MW-5) could not be installed at the time because negotiations were underway to purchase this property and convert it to an aggregate quarry. All wells had ten-foot screens, and were designed to monitor the water table.

After one year of quarterly baseline sampling, it was determined that the main source of the high nitrate levels was application of fertilizers on agricultural fields just north (upgradient) of the wellfield. The Village purchased a parcel of this land in 1995, and has kept it uncultivated. It also asked County extension agents to help local farmers select agricultural chemicals that would optimize the crop while protecting the ground water quality. Since 1995, nitrate levels have declined, indicating that these strategies have been effective.

### Case History 5 — *The City of Heath: The Challenge of Installing Multiple Wells Through a Contaminated Zone*

**Background.** The City of Heath (population 10,000) is located in central Licking County, just southwest of the City of Newark. The city's wellfield pumps about one million gallons a day from an extensive buried valley aquifer system through which the South Fork of the Licking River cuts a shallow channel. The aquifer system is over 200 feet deep in places and consists of three separate aquifer units that are referred to as the shallow, middle, and deep aquifers. The middle aquifer is separated from the shallow and deep aquifers by layers of clay-rich, semi-confining materials. Pumping tests indicate that the three aquifers are somewhat connected hydraulically. Heath's municipal wells are all screened in the deep aquifer, while other major production wells in the area are screened in the shallow or middle aquifers.

At least as early as 1970, hydrocarbon contamination was discovered in the shallow aquifer and nearby Ramp Creek. This plume apparently resulted from former activities at a petroleum refinery that had been in existence since 1919. The facility is located approximately 1.5 miles west of the Heath wellfield.



In 1990, the City requested a permit from Ohio EPA to install a sixth public water supply well. As a condition for permit approval, Ohio EPA required the City to submit a schedule for SWAP planning. The City retained an environmental consultant to delineate the SWAP area and inventory the potential pollution sources. A ground water monitoring plan also was developed. These components of a SWAP Plan were endorsed by Ohio EPA in 1992.

**Ground Water Monitoring Plan.** By 1991, the hydrocarbon contamination had extended into the municipal wellfield's five-year time-of-travel area. Ground water monitoring was highly advisable to determine if the plume of contamination was working its way down toward the deep aquifer. A total of seven wells was proposed, including three shallow wells (two of them already existing); two wells monitoring the middle aquifer (both already existing), and a "cluster" well that would separately monitor the shallow, middle, and deep aquifers.

Because of the danger of contaminating the middle and deep aquifers in the process of drilling through the contaminated shallow aquifer, a "telescope method" was proposed. This involves drilling a borehole with successively smaller augers. For example, to install a well to monitor the deep aquifer:

1. The shallow aquifer is augered down into the first clay layer. A 14-inch diameter steel casing is grouted and allowed to harden. A cement plug is installed at the bottom of the borehole.

2. Then the drillers insert a small auger at the bottom of the cased boring and drill through the cement plug and the middle aquifer, into the next clay layer. A 10-inch diameter steel casing is grouted in and allowed to harden. A cement plug is installed.

3. Finally, a 4-1/4 diameter auger is used to drill through the cement plug and into the deep aquifer, where the screen is set.

# APPENDIX A

## SOURCES OF INFORMATION ON GROUND WATER MONITORING

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# APPENDIX B

# GROUND WATER MONITORING PLAN FOR THE VILLAGE OF WAYNESVILLE

# GROUND WATER MONITORING COMPONENT
# of the
# Village of Waynesville's Source Water Protection Plan

## INTRODUCTION

Ohio's Source Water Protection Program includes ground water monitoring as one of the strategies that a public water supplier can implement to protect the drinking water source from contamination. A properly designed monitoring program may provide early warning that a plume is advancing toward the wellfield, or that the overall level of some contaminant (such as nitrates) is steadily increasing over time. It also can provide information on the effectiveness of protective strategies. Ground water monitoring within and around a source water protection (SWAP) area is strongly recommended for SWAP areas that:

- contain numerous potential contaminant sources that are--or have been--poorly managed;
- have a known contaminant plume; or
- have a known water quality problem, such as elevated nitrate levels.

In June 1995, the Village of Waynesville applied for a Clean Water Act Section 319 grant to create a ground water monitoring program for its SWAP area. The grant was funded in part by U.S. EPA, Region V, and was directly administered by Ohio EPA's Division of Drinking and Ground Waters with assistance from the Ohio Department of Natural Resources' Division of Water. At the time, the Village was concerned because the level of nitrates in the public water system had been steadily increasing over time toward the 5.0 mg/l action level for nitrates (Figure 1). It was hoped that by initiating a monitoring program, the source of the nitrates could be better determined, and strategies could be developed to reduce the level of nitrates entering the ground water.

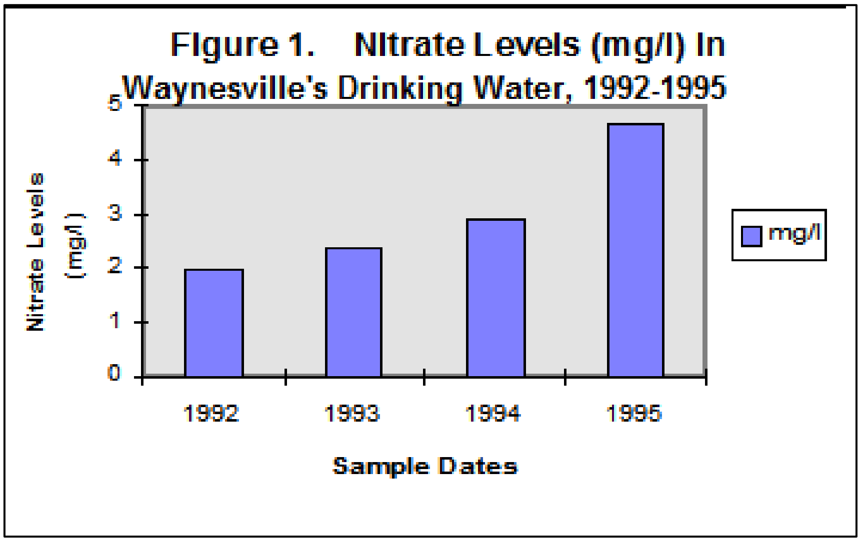
Figure 1. Nitrate Levels (mg/l) in Waynesville's Drinking Water, 1992-1995

In August 1995, the Village was selected for participation in the grant program. Staff from the State agencies met with members of Waynesville's Source Water Protection Committee during the months of August through October to plan the effort. Monitoring wells were installed and developed during December 1995 and January 1996. Beginning in March, ground water samples were withdrawn and analyzed on a quarterly basis, with sampling events occurring on March 14, June 24, September 17, and December 9, 1996. The remainder of this Ground Water Monitoring Plan documents this effort in some detail, and provides the plan for future monitoring.

## DESIGN OF MONITORING NETWORK

### Siting the Monitoring Wells

State agency staff and Waynesville's Source Water Protection Committee studied the potential contaminant source inventory map to determine which portions of the SWAP area most warranted monitoring (Figure 2). ***Monitoring Well-1*** was sited on undeveloped private land approximately 50 feet east of Route 42, and was intended to monitor a cluster of current and historic potential contaminant sources that included old oil wells, an underground storage tank leak at the Wayne Township trustees building, and an underground storage tank leak at the Township garage. ***Monitoring Well-2*** was sited north of Corwin on private land between Bowman Park and the Little Miami River, to monitor the cluster of potential contaminant sources identified in Corwin, as well as the agricultural chemicals applied in the adjacent agricultural fields. This site is often flooded during the Spring, and usually is planted in soybeans or corn during the summer.

The remaining proposed wells (MW-3 through MW-7) were primarily intended to monitor water quality along the Little Miami River valley north of the wellfield. Ground water in this area flows south toward the Village wells, and is known for elevated nitrate levels. The SWAP planners hoped to gain some more detailed information about nitrate levels along the valley. ***Monitoring Well-3*** is a former production well in the Village's existing wellfield, which currently is maintained on emergency stand-by status. Although it is located too close to the production wells to provide effective early warning, it provides an additional sampling point for comparison of ground water quality parameters along the valley. ***Monitoring Well-4*** was installed in the middle of the property purchased by the Village in 1995 for a new wellfield (located directly north of the existing wellfield). This property was formerly used as agricultural land–usually planted in corn or soybeans–but is now an open field that is periodically mowed. This site is sometimes flooded in the Spring. ***Monitoring Well-5*** was to be located on a private property about a half mile further north. At the time, sale of the property to a sand-and-gravel quarrying operation was being negotiated, and the prospective buyer had agreed to install and maintain at least one monitoring well, if the negotiation was successful. However, the effort was abandoned in late 1995, and Monitoring Well-5 has never been installed. ***Monitoring Well-6*** was sited further north, just south of a former sand-and-gravel quarry that is littered with abandoned machinery. ***Monitoring Well-7*** is an existing well far up the valley in a wooded area known as "Spring Valley" (Greene County). It was installed in 1988 by a gravel mining operation on land owned by the State of Ohio and managed by the Ohio Department of Natural Resources.

Once these sites were sketched out on the map, the Waynesville Utilities Manager contacted the land owners to request permission to install wells and periodically enter the property to sample them. Each site was visited to ensure accessibility and note any obvious problems, such as foliage, utility lines, steeply sloping or consistently swampy ground, etc. On October 20, the precise location of each well was staked out, and the property owners were contacted again to verify their permission to drill at the staked location. The Ohio Utilities Protection Service also was contacted to verify that drilling in these locations would not damage any buried utilities lines.

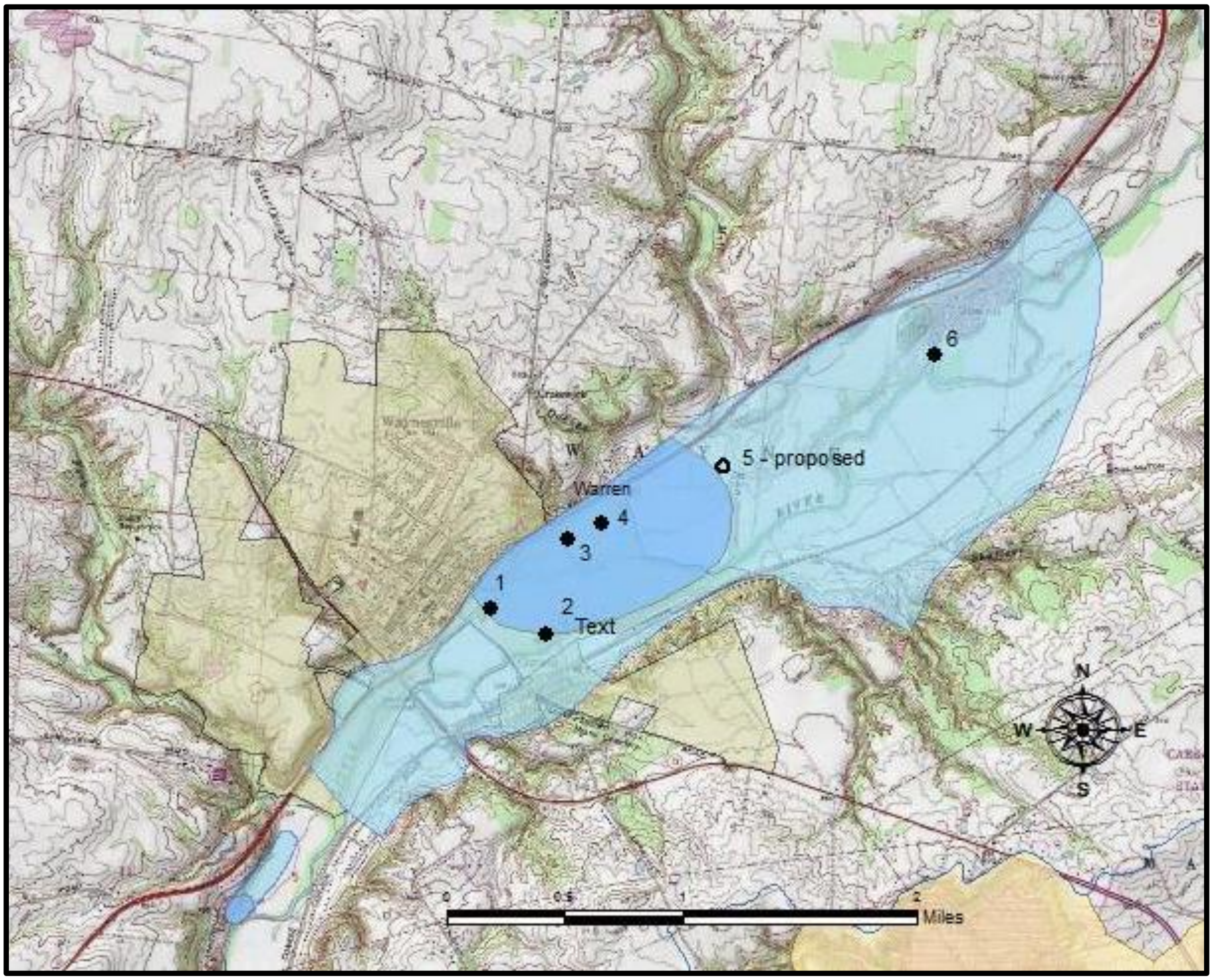

Figure 2. Map of the Village of Waynesville's Source Water Protection Monitoring Network (monitoring well locations approximate)

### Vertical Placement of Monitoring Wells

The depth of the monitoring wells and the placement and length of the well screens were designed to monitor the water table rather than the bottom of the aquifer, where the production wells are screened. This was because the potential contaminant sources of concern involved mostly surface activities, and any chemicals leaching from those sites would tend to be at their highest concentrations near the water table. Also, the types of contaminants deemed most likely to impact the Waynesville wellfield (i.e., petroleum products, agricultural chemicals, and nitrates) are not constituents that tend to sink through an aquifer and become concentrated at the bottom. Moreover, if sinking constituents were detected in the existing wells, then deeper wells could be installed as part of an investigation.

Water level measurements taken from wells located in Spring Valley indicated an annual seasonal fluctuation of about 5-6 feet. From this, it was determined that the well screens would need to be at least ten feet long, to ensure that they intersected the water table at all times of the year. The wells were drilled eight feet below the point where saturated materials were encountered (the water table) and then the well screen was inserted.

### Well Installation

The well installation plan for the monitoring wells was based on guidance in Ohio EPA's *Technical Guidance Manual for Hydrogeologic Investigations and Ground Water Monitoring , Ohio EPA , February 1995* guidance document. During the well installation in December 1995, borings were advanced using hollow stem augers and soil samples were collected every five feet using a split-barrel sampler. Each sample was classified and logged in the field by staff from ODNR's Division of Water. The sampler was decontaminated between sampling events and the augers and sampling equipment were steam cleaned between the drilling of each boring.

Each boring was completed as a monitoring well by installing two-inch diameter polyvinyl chloride (PVC) threaded risers and a ten-foot 20-slot screen inside the augers. A filter pack of medium-sized sand was placed between the borehole walls and the screen to a point two feet over the top of the screened section. This was followed by two feet of bentonite pellet seal and the remaining annular space was sealed with bentonite grout. The monitoring wells were protected with a steel casing extending from the top of the cement grout to a height above the ground surface. The well installation plan called for cement pads that were raised above surface and graded away from the steel casing to prevent surface water from seeping down the sides of the steel casing and into the aquifer. However, the driller did not complete the cement pads to specifications; instead the cement was leveled off with the ground surface. Also, the mixture of cement and bentonite used is quite friable and prone to cracking. As a result, the well seals are less than optimal and should be checked periodically, and patched or replaced when necessary.

During the summer of 1996, surveyors were contracted to survey the locations of the monitoring wells, and the elevations at ground surface and top-of-casing (Table 1). Prior to sampling each well, the water level is measured as depth from top-of-casing and then converted to the actual elevation.

**Table 1. Monitoring Well Information**

| Well Number | Latitude | Longitude | Elevation at TOC, amsl | Depth to water (ft from TOC) on 3/14/96 | Elevation of static water level, amsl on 3/14/96 | Screen length (ft.) | Depth to bottom of well (ft. from ground surface) |
|---|---|---|---|---|---|---|---|
| MW-1 | 561456.2813 | 1522134.6187 | 718.91 | 6.93 | 711.98 | 10 | 16 |
| MW-2 | 560421.2072 | 1523540.5500 | 717.07 | 7.60 | 709.47 | 10 | 18 |
| MW-3 | 562643.9192 | 1524057.2906 | 726.64 | x | x | 30 | 68 |
| MW-4 | 562740.8810 | 1533611.4856 | 720.54 | 6.95 | 713.59 | 10 | ?? |
| MW-6 | 568211.3057 | 1533611.4856 | 737.51 | 15.76 | 721.75 | 10 | 26 |
| MW-7 | 578222.0376 | 1537785.9814 | 747.78 | ** | ** | 10 | 30 |

TOC - top of well casing
amsl - feet above mean sea level
x - not measured. MW-3 is a production well that is on emergency stand-by basis.
** - not measured during this initial sampling event. Subsequent measurements have averaged a depth of 13.37 ft. below TOC, giving an average water level at elevation of 734.41 amsl.

**Surface Water Sampling Points**

The Source Water Protection planners also agreed to sample surface water from five points in the Source Water Protection area, including the Little Miami River, the Mill Race, and several small intermittent tributaries to these streams. The intent was to gain information on the water quality of these streams in general, and throughout the various seasons. It was hoped that these data might shed some light on the nature of the interrelationships between ground water and surface water in this area.

As shown in Figure 2, surface water sampling points were designated at:

the junction of Satterthwaites Run and Route 42, just east of Route 42
the junction of Mill Race and Route 42, just east of Route 42
Mill Race, next to the future wellfield
the junction of Shaffers Run and Corwin Road, east of Corwin Road
the junction of Furnas Ditch and the bicycle trail, west side of the trail

## DESIGN OF SAMPLING AND ANALYSIS PLAN

### First-Year Baseline Sampling Plan

During the first year of sampling, Waynesville conducted quarterly sampling for a comprehensive set of constituents, to provide baseline ground water quality data against which future data could be compared. This comprehensive monitoring was made possible by the Ohio EPA grant, which provided a generous budget for monitoring.

Ground water samples from each well were analyzed for:

**volatile organic compounds** (VOCs), a group that includes many solvents, which are the organic chemical constituents most commonly detected in ground water;

**synthetic organic compounds** (SOCs), which include the most common pesticides, various industrial chemicals such as the phthalates, and a number of constituents found in heavy petroleum products, such as naphthalene;

**inorganic compounds**, including all regulated inorganics, such as nitrates and the heavy metals, as well as other nonregulated constituents such as calcium and sodium;

**total petroleum hydrocarbons** (TPH), a group of petroleum-based constituents whose presence is an indication of petroleum leaks.

***Surface Water Sampling.*** Surface water samples were collected for analysis of nitrates, total petroleum hydrocarbons, and methylene blue activated substances (MBAS). Methylene blue activated substances are foaming agents found in detergents and–like nitrates--are typically associated with wastewater discharge. The purpose of sampling for MBAS was to help determine the source of nitrates in surface water. If surface water showed high nitrates but no MBAS, then the surface water likely was predominantly impacted by fertilizers applied to agricultural fields. If surface water showed high nitrates *and* high levels of MBAS, this would be an indication that the stream is being impacted by wastewater discharges. The list of parameters that were sampled for in 1996 is included in Table 2.

**Table 2. List of Baseline Constituents for Waynesville's SWAP Ground Water Monitoring Program**

| Inorganics | Volatile Organics | | Semi-Volatile Organics | Others |
|---|---|---|---|---|
| aluminum | trichloroethene | fluorotrichloromethane | 1,2-dibromoethane (EDB)* | TPH |
| ammonia | benzene* | sec-butylbenzene | 1,2-dibromo-3-chloropropane (DBCP)* | MBAS** |
| antimony | carbon tetrachloride* | 1,1-dichloroethane | aldrin | |
| arsenic* | 1,2-dichloroethane* | bromobenzene | total chlordane* | |
| barium* | vinyl chloride* | isopropylbenzene | dieldrin | |
| beryllium* | 1,1-dichloroethene* | m,p-xylene, o-xylene | endrin* | |
| cadmium* | 1,1,1-trichloroethane | n-propylbenzene | heptachlor* | |
| calcium | p-dichlorobenzene* | o-chlorotoluene, | heptachlor epoxide* | |
| chloride | cis-1,2-dichloroethene | p-chlorotoluene | hexachlorobenzene* | |
| chromium* | tetrachloroethene | m-dichlorobenzene | hexachlorocyclopentadiene* | |
| cobalt | o-dichlorobenzene* | 1,2,3-trichlorobenzene | lindane* | |
| copper | trans-1,2-dichloroethe | 1,2,4-trimethylbenzene | methoxychlor* | |
| cyanide* | chlorobenzene* | n-butylbenzene | toxaphene* | |
| fluoride* | styrene* | 1,3,5-trimethylbenzene | total PCBs* | |
| iron | toluene | | 2,4-D* | |
| lead* | 1,2-dichloropropane* | | dalapon* | |
| magnesium | 1,1,2-trichloroethane* | | dicamba (Banvel) | |
| manganese | methylene chloride* | | dinoseb* | |
| mercury* | ethyl benzene* | | picloram* | |
| nickel* | 1,2,4-trichlorobenzene | | silvex* | |
| nitrate* | chloroform | | pentachlorophenol* | |
| nitrate & nitrite* | bromoform | | alachlor* | |
| nitrite* | bromodichlorometha | | atrazine* | |
| phosphorus | dibromochlorometha | | benzo (a) pyrene* | |
| potassium | 2,2-dichloropropane | | bis (2-ethylhexyl) adipate* | |
| selenium* | dichlorodifluorometha | | bis (2-ethylhexyl) phthalate* | |
| silica | dibromomethane | | metolachlor | |
| silver | 1,3-dichloropropane | | simazine* | |
| sodium | chloromethane | | propachlor | |
| strontium | bromomethane | | butachlor | |
| sulfate | bromochloromethane | | metribuzin | |
| thallium* | 1,2,3-trichloropropane | | aldicarb* | |
| vanadium | 1,1,1,2-tetrachloroethane | | aldicarb sulfone* | |
| zinc | 1,1,2,2-tetrachloroethane* | | aldicarb sulfoxide* | |
| | 1,1-dichloropropene | | carbaryl | |
| | chloroethane | | carbofuran* | |
| | cis-1,3-dichlorooropropene | | 3-hydroxycarbofuran | |
| | trans-1,3-dichloropropene | | methomyl | |
| | hexachlorobutadiene | | oxamyl (Vydate)* | |
| | naphthalene | | glyphosate* | |
| | tert-butylbenzene | | endothall* | |
| | p-isopropyltoluene | | diquat* | |

*Has a Maximum Contaminant Level (MCL) for primary drinking water standards, established by U.S. EPA

**Analyzed in surface water samples only

### Subsequent Years Monitoring Plan

The "subsequent years" sampling plan calls for a much reduced sampling schedule. Sampling is to be conducted twice a year, preferably in the spring and fall (wet and dry seasons). Also, analysis will be undertaken only for constituents that are associated with the types of potential pollution sources each well was designed to monitor. Therefore, all wells are monitored for nitrate, but only wells #1 and #2 are analyzed for VOCs, because these are the only two wells designed specifically to monitor industrial sites. The surface water sites are sampled only for nitrates. The sampling schedule for Waynesville's continuing monitoring program is included as Table 3.

**Table 3. Annual Sampling Schedule for Waynesville's SWAP Ground Water Monitoring Program**

| Monitoring Well | Analytes | Frequency |
|---|---|---|
| MW-1 | VOCs, Nitrate, Iron and Manganese | Semi-annually |
| MW-2 | VOCs, Nitrate, Iron and Manganese | Semi-annually |
| MW-3 | Nitrate, Iron and Manganese | Semi-annually |
| MW-4 | Nitrate, Iron and Manganese | Semi-annually |
| MW-5 | (Nitrate–if installed), Iron and Manganese | Semi-annually |
| MW-6 | Nitrate, Iron and Manganese | Semi-annually |
| MW-7 | Nitrate, Iron and Manganese | Semi-annually |
| Surface Water Sampling Points | Nitrate | Semi-annually |
| All wells | Water level measurements | Semi-annually |

## SAMPLING PROCEDURES

### Ground Water Sampling Procedures

***Purging.*** The sampling and analysis protocol developed for Waynesville's ground water monitoring program is based on standard procedures developed by U.S. EPA for various regulatory programs. During each sampling event, water levels are measured with an electronic tape. Then the well is purged with a portable hand pump that is attached to dedicated polyvinyl standpipes that have been placed inside each well. The purpose of "purging"–removing water continuously from the well–is to ensure that the water sampled is fresh ground water and not stagnant casing water, which may differ significantly in quality. Samplers periodically measure the temperature, pH, and specific conductance of the pumped water during the process, until the measurements stabilize. Stabilization is defined as less than 0.1 units for pH and temperature, and less than ten percent for specific conductance. At Waynesville stabilization tends to occur after removing about 20 gallons of water, or the equivalent of four to six well volumes. (U.S. EPA guidance typically requires the removal of at least three well volumes before sampling.)

***Collecting Samples.*** Ground water samples are collected by pumping directly into the sampling containers, using the hand pump. This method of sample removal was chosen because it was by far the most efficient. However, during the first sampling event bottom-loading PVC bailers were used to collect the samples, because most U.S. EPA guidances advise against using use hand pumps for this purpose. (The conventional wisdom was that the suction of a hand pump would immediately volatilize any volatile constituents in the ground water.) The issue was resolved in favor of using the hand pump after Ohio EPA conducted a separate comparative study at a site contaminated with varying levels of twelve volatile constituents. In this study, samples were collected using a hand pump, a bailer, a low-flow submersible pump, and a bladder pump. Analytical results indicated that the hand pump generally captured VOCs at least as well as the bailer; more strikingly, it captured certain VOCs nearly as well as the low-flow submersible pump, which is widely acknowledged to be one of the most accurate sampling devices currently available. Another reason the hand pump was considered acceptable for this effort is that knowing the *precise level* of a constituent is not critical for Source Water Protection monitoring purposes. Instead, the technique must simply be capable of detecting a contaminant present in high enough concentrations to impact the water supply at the production wells.

After collecting the samples, the containers were packed in a cooler and ice was added to keep the samples cool. Coolers were sealed and shipped to the laboratory the next day via UPS. One field blank was included with each cooler.

### Surface Water Sampling Procedures

Surface water samples were collected from the five surface water sampling points within 24 hours of sampling the ground water monitoring wells. The sampler was careful to collect the water from a point in the stream that was flowing, and to avoid entrapping air in the container. (Note: these streams tend to run dry during summer months, making sample collection impossible.)

## PROCEDURES FOR EVALUATING WATER QUALITY

Generally speaking, the quality of ground water as an acceptable drinking water source is measured against the Primary and Secondary standards established by the U.S. EPA under the Safe Drinking Water Act of 1974. Ohio EPA has adopted similar standards, or Maximum Contaminant Levels (MCLs) to serve as the basis for water supply regulations and compliance within the State. There are no specific standards for raw ground water quality (before treatment), but drinking water standards are acceptable measures of relative ground water quality for Source Water Protection monitoring programs.

In accordance with Ohio EPA’s draft guidance for monitoring ground water in a SWAP area (Ohio EPA, 1999, revised 2015), the Village of Waynesville took the following approach to detections of various constituents in its monitoring well samples:

If the detected constituent is a **manmade organic compound**, it will be considered an indication of potential contamination and will be resampled immediately.

If the detected constituent is an **inorganic compound and has an MCL**, it will be considered an indication of potential contamination only if it exceeds the MCL or action level for that constituent.

If the detected constituent is an **inorganic compound but has no MCL**, it will be considered an indication of potential contamination only if it significantly exceeds historical levels of that constituent. ("Significant" is to be defined by the public water supplier.)

This ground water monitoring plan does not establish any specific actions to be taken once it is determined that contamination may be occurring, but notes the following general guidelines. Exceedance of some MCL by raw ground water collected *from a monitoring well* is not automatically subject to enforcement by Ohio EPA. If the contaminant is clearly linked to some particular facility that is subject to regulations under the federal Resource Conservation and Recovery Act (RCRA), reporting and some kind of response may be required. (This also applies to sites with underground storage tanks containing hazardous materials and petroleum products.) If the source of contamination proves to be located on the wellfield or other property owned by the Village of Waynesville, the Village will be at least partially responsible for remediation and may be subject to enforcement action. Otherwise, the Village has some discretion in how it responds to discovery of "contamination" in a monitoring well.

Once suspicion of contamination is verified by resampling, "action" may consist of notifying appropriate authorities, taking remedial action, talking to the land owner about removing the source or containing it more securely, or extending the monitoring program. In general, continuing evidence of ground water contamination will be dealt with in accordance with any regulations that may apply, and/or with the level of health risk posed to the water consumers.