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DESIGN, PLACEMENT, AND SAMPLING OF GROUNDWATER MONITORING WELLS FOR THE MANAGEMENT OF HAZARDOUS WASTE DISPOSAL FACILITIES

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ABSTRACT

Groundwater monitoring is an important technical requirement in managing hazardous waste disposal facilities. The purpose of monitoring is to assess whether and how a disposal facility is affecting the underlying groundwater system. This paper focuses on the regulatory and technical aspects of the design, placement, and sampling of groundwater monitoring wells for hazardous waste disposal facilities. Such facilities include surface impoundments, landfills, waste piles, and land treatment facilities.

INTRODUCTION

The migration of hazardous materials in groundwater supply systems is a primary concern in the Resource Conservation and Recovery Act of 1976 (RCRA). The Act requires that owners and operators of facilities that store, treat, or dispose of hazardous waste have a groundwater monitoring plan or justify why such a plan is unnecessary. The primary purposes of the plan are to detect any release of contaminants into groundwater and to take corrective action when such contamination threatens human health or the environment. To develop the plan, the Act states that a "sufficient" number of wells be drilled to define the nature of the groundwater flowing beneath a site.

The groundwater protection section of RCRA applies to "new and existing surface impoundments, landfills, waste piles, and land treatment units that manage hazardous waste" (U.S. Environmental Protection Agency [EPA] 1982). Each disposal facility is considered as a waste management unit. If there is more than one regulated unit at a facility, the waste management area is considered to be the entire area enclosed by a line drawn around all the units (Figure 1).

TYPES OF MONITORING PROGRAMS

The RCRA regulations establish a three-stage monitoring program designed to detect, evaluate, and correct groundwater contamination arising from leaks or discharges from hazardous waste management facilities. The program is graduated so that the monitoring and clean-up responsibilities of the owner/operator expand as the effect of the facility on groundwater becomes better understood. The three monitoring programs are detection monitoring, compliance monitoring, and corrective action. In the United States, the permit to operate a regulated unit is issued by EPA, which specifies the use of at least one of these programs. The permit may require all three.

The first stage of the monitoring program -- detection monitoring -- is to be implemented before any leakage of hazardous constituents into the groundwater occurs. Early implementation ensures that any subsequent leakage is detected. When groundwater contamination has already occurred, the second stage -- compliance monitoring -- is implemented to determine whether groundwater quality criteria have been exceeded. The standard from which the criteria are drawn is based on data obtained from background water quality analyses. The standard comprises four principal elements (EPA 1982, 1985).

1. The hazardous constituents potentially derived from the facility.

2. The concentration limits for each constituent listed in the facility permit.

3. The point of compliance for measuring concentration limits.

4. The compliance period.

The compliance point is the location at which the groundwater protection standard applies and, hence, is the point where monitoring must occur. The RCRA regulations specify that the point of compliance is the vertical surface, located at the hydraulically downgradient limit of a waste management unit, that extends down into the uppermost aquifer underlying the management unit (Figure 2). The compliance period is the period during which the groundwater protection standard applies. This period is equal to the active life of the facility plus the closure period.

If the criteria set forth in the protection standard are exceeded at the compliance point, then the owner/operator must implement the third stage -- corrective action (EPA 1982, 1985). The goal of corrective action is to bring the facility back into compliance with its protection standard. To achieve this goal, a remedial action plan must be developed for the facility for removing the hazardous constituents or treating the constituents in place. The remedial action plan must remain in effect until groundwater quality meets compliance standards.

A detection monitoring system may have to be expanded or refined before (1) it can fully delineate a contaminant plume and thereby qualify as a compliance monitoring system, or (2) it can verify that a corrective action program is functioning as designed. Although the purpose of the groundwater monitoring system may vary according to which program it is designed to evaluate, the basic elements of the system and the technical approach to its installation remain constant.

NUMBER AND LOCATION OF MONITORING WELLS

The monitoring wells must be installed at appropriate locations and depths to yield groundwater samples from the uppermost aquifer. The results of the sample analyses will define the background water quality as well as the quality of the water flowing beneath the regulated unit. The RCRA regulations state that the monitoring systems must include a minimum of one upgradient well and three downgradient wells. However, it is incumbent upon the owner/operator to prove that the number of wells installed is sufficient to properly characterize local groundwater quality and the contaminant plume.

Several variables must be considered when deciding how many wells will be needed. The size and shape of the waste management area are perhaps the most obvious ones. The larger the area, the more monitoring points are necessary to ensure that any contaminant plume will be intercepted. In the past, EPA has recommended at least one well for every 76 m of waste management unit frontage (EPA 1977).

Most information available on aquifer characteristics is developed from macro or regional data. These data generally project that the average nature of the aquifer material will affect the shape of the contaminant plume. Unconsolidated aquifers having large hydraulic conductivities will produce narrow, cigar-shaped plumes. Aquifers of lower conductivity allow more dispersion, producing plumes having a wider front. Fractured bedrock media further complicate groundwater monitoring programs because flow directions in fractured media tend to be unpredictable.

The characteristics of the aquifer within and contiguous to the site depend much more on the physical characteristics of that particular terrestrial environment than on the general hydrogeological characteristics of the region. In the latter instance, the size and travel characteristics of the leachate plume are based on averaging the hydrogeological features of a formation. However, the specific and necessary microhydrogeologic features of the site cannot be ascertained without monitoring wells and intensive analysis that considers the microanisotropic geology within the site. Such details will likely affect the distribution of the contaminant plume and the pathways.

RCRA states that EPA ". . . will consider the presence of the constituent in the groundwater at the compliance point as a sufficient initial indication that the constituent is derived from waste in the regulated unit." Every facility has site-specific variables that affect both the number and location of the wells required to properly characterize the site.

MONITORING WELL DESIGN AND CONSTRUCTION

Monitoring well design and construction specifications must be carefully developed, with proper consideration given to the full range of factors that can affect measurements of water quality during the implementation of RCRA monitoring programs. Figure 3 shows the basic elements of some typical monitoring well designs. The central element of the well is a casing, which is generally grouted into the borehole. The intake portion of the well is located at the bottom of the casing and usually consists of a screen or slotted casing around which a gravel or sand pack is placed. Those elements of well design and construction that have the greatest effect on the suitability of a well for RCRA monitoring programs include drilling methods used during construction, well construction materials, well diameter, well intake and development, and sealing and annular space (Everett 1980, EPA 1983).

RCRA requires that all monitoring wells be cased in a way that maintains the integrity of the monitoring well borehole and that they be screened and packed with sand or gravel to enable sample collection at various depths. Also, a suitable grout must be used above the sampling depth to prohibit vertical movement of contaminants within the annular space.

The necessary well depth is a function of the microhydrogeologic properties of the aquifer within the site and plume, as well as the nature of the wastes that the well is designed to detect. RCRA states only that the monitoring system must be capable of sampling groundwater in the "uppermost aquifer," which is defined as the first aquifer "capable of yielding a significant amount of water to wells and springs" (EPA 1984). What constitutes "a significant amount" of water, and therefore an aquifer, varies from region to region. The EPA regional administrator may make the final determination. In most cases, the depth to the local water table will probably constitute this depth.

Other considerations in well depth are the ability of the aquifer to attenuate wastes, the specific gravity of the waste, and the solubility of the waste in water. Wastes that exhibit a specific gravity greater than 1.0 may be found close to the piezometric surface and may require only shallow monitoring wells. Highly miscible wastes may spread through the aquifer thickness and require more extensive monitoring. Slightly soluble, heavier-than-water constituents may be found only near the bottom of the aquifer; deep wells will be required to detect them (Figure 4).

If a variety of wastes are disposed of at the same site, it may be necessary to screen the entire aquifer thickness. Although this type of well design may produce diluted samples, current analytical equipment capable of detecting contaminants in the part-per-billion range should make the design sufficient.

Since the passage of RCRA in 1976, the well drilling industry has developed a plethora of well casing and screen designs. Galvanized and stainless steel, polyvinyl chloride, polypropylene, polyethylene, and Teflon are some of the materials used in casing and well screens. These materials have substantially different properties with respect to strength, corrosion resistance, interference with specific constituent measurements, expense, and availability. Consequently, the one selected must be demonstrated to be the most appropriate for the particular monitoring program. The most common material currently specified for hazardous waste site investigations is polyvinyl chloride because of its ease of handling and relatively low cost. Chemical deterioration of polyvinyl chloride pipe can occur in the presence of certain organic compounds; if high levels of those constituents are anticipated, that material should not be used.

The proper diameter for the well casing will depend on the projected use of the well, the depth to the water table, and the availability of proper drilling equipment. If the well will only be used to monitor a shallow aquifer, a 3.8-cm-diameter casing is sufficient to measure the depth to the piezometric surface and to draw the water samples required by RCRA.

However, if the depth to the water table is greater than 6.7 m or if the well is to be used in the future as a pumping well in an aquifer restoration system, a larger casing may be appropriate. When the water table is at depths of greater than 6.7 m, the smallest sized submersible pump available requires at least a 5-cm-diameter casing. The pumping rates necessary for any restoration project generally require at least a 10-cm-diameter casing.

A suitable washed sand is to be installed in the annular space around the screen to improve well efficiency and reduce the introduction of fines into the discharge water. The annular space above the sand pack is to be backfilled with either a bentonite or concrete grout. A locked, hardened steel protective casing around the polyvinyl chloride casing, in 6-9 m of concrete, will protect against vandalism.

WELL EVACUATION AND SAMPLING

The chemical characteristics of water found standing in a monitoring well prior to sampling may not be representative of in situ groundwater quality. To ensure that representative samples are collected, standing water in a well has to be evacuated prior to sampling. Two general approaches are available for water evacuation. For monitoring wells that can be pumped dry, all the water standing in the well can be evacuated. Otherwise, the general approach is to remove a sufficient amount of water from the well borehole to ensure the exchange of any stagnant water standing in the well with water recently derived from the formation (Fenn 1977).

The validity of environmental sampling depends on, among other things, the consistency and efficiency of well evacuation and sampling techniques. The type of sample collection used relates to the width and depth of the monitoring point. Small-diameter wells (less than or equal to 7.5 cm) are usually sampled with a bailer or a pneumatic displacement pump. Larger-diameter wells (7.5-15 cm) are usually sampled with portable submersible pumps. The largest-diameter wells (greater than 15 cm) are usually production wells that use dedicated impeller pumps. Each apparatus has its own limiting factors that must be understood when it is used for monitoring purposes.

Evacuation Volumes. In the United States, the state and federal regulatory agencies use 4-10 bore volumes as the standard for a presampling well evacuation (Scalf et al. 1981). However, the number of volumes of groundwater that must be evacuated before a representative sample is collected should be decided on a site-specific basis.

In evaluating a sampling program, evacuation procedures must be consistent so that the sample is collected at about the same point over time. If static water levels do not fluctuate widely, the same evacuation volumes should be maintained for individual well points. Because of variable formations, transmissivities, and well recoveries, different evacuation volumes might have to be adopted for alluvial and bedrock zones and for individual wells.

The volume of groundwater to be evacuated must also be determined by the efficiency of the sampling apparatus (typically a bailer or pump). In small-diameter piezometers, pneumatic displacement pumps generally do not exceed a rate of 1 gallon per minute (gpm) and usually produce closer to 0.5 gpm. In wells exceeding 60 m in depth, pumping four casing volumes might take six to eight hours. For practical reasons, reduced evacuation volumes in these wells should be used. The key is to prove that representative water samples can be collected at the lower evacuation volume.

Sampling Techniques. The main variable to evaluate in sample collection is the efficiency of the sampler in collecting and preserving a representative groundwater sample. This requirement is most important for samples collected for analysis of volatile constituents such as the halogenated ethenes and ethanes.

It is very difficult to compare the available collection techniques. Error is usually associated with each of them. Choosing a sampling device should therefore be based on the following considerations: communication within the scientific community, past experience, best available equipment, casing diameter and depth, and constituents selected for analysis.

The techniques of sample collection, like evacuation, must be consistent. The sample vials should always be capped immediately after the samples are collected. Samples with an air space in the vial should be discarded. Samples for analysis of volatiles should never be "split" in the field (i.e., pouring subsamples from a larger sample). Joint samples by regulatory agencies and managing consultants should be duplicates collected in sequence, not splits. Samples should be appropriately preserved or iced. Consistent chain-of-custody and field documentation procedures should be adopted and carefully followed.

CONCLUSION

When establishing a groundwater monitoring plan for hazardous waste disposal facilities, the following steps are essential:

1. Review all available background data to become familiar with the site.

2. Using these background data, geophysical survey results, borings, and sampling results, establish the local aquifer characteristics and the groundwater flow directions.

3. Identify potential off-site sources of background groundwater contamination.

4. Determine the chemical composition of the waste material to evaluate the potential for its movement within the aquifer.

5. Site a sufficient number of wells upgradient of the site to characterize the background groundwater quality.

6. Site a sufficient number of wells downgradient of the site to detect any contaminant plume moving off site.

7. Select the proper size and composition of well casings and screens.

8. Use an approved well design.

9. Maintain well evacuation and sampling techniques both consistently and efficiently.

Finally, plans should be flexible, so that the unexpected can be responded to (e.g., a need for multiple use of wells or future expansion of the system).

ACKNOWLEDGMENT

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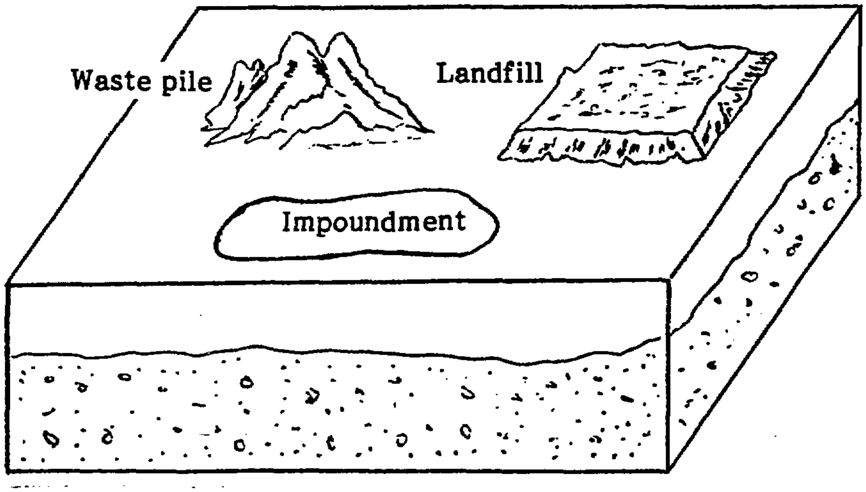


FIGURE 1 Waste Management Area Containing Several Regulated Units

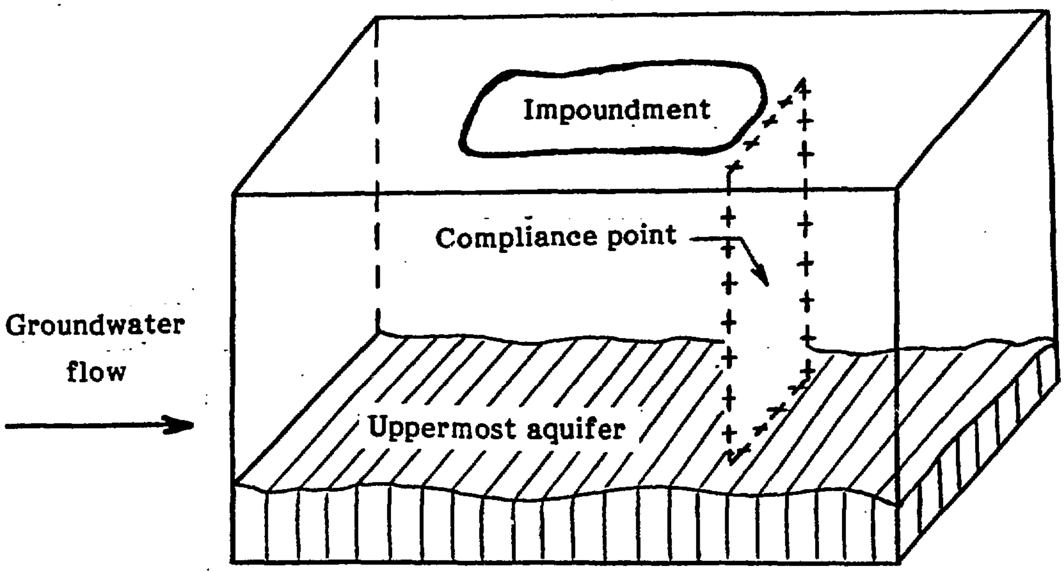


FIGURE 2 Relationship of the Waste Management Area to the Point of Compliance

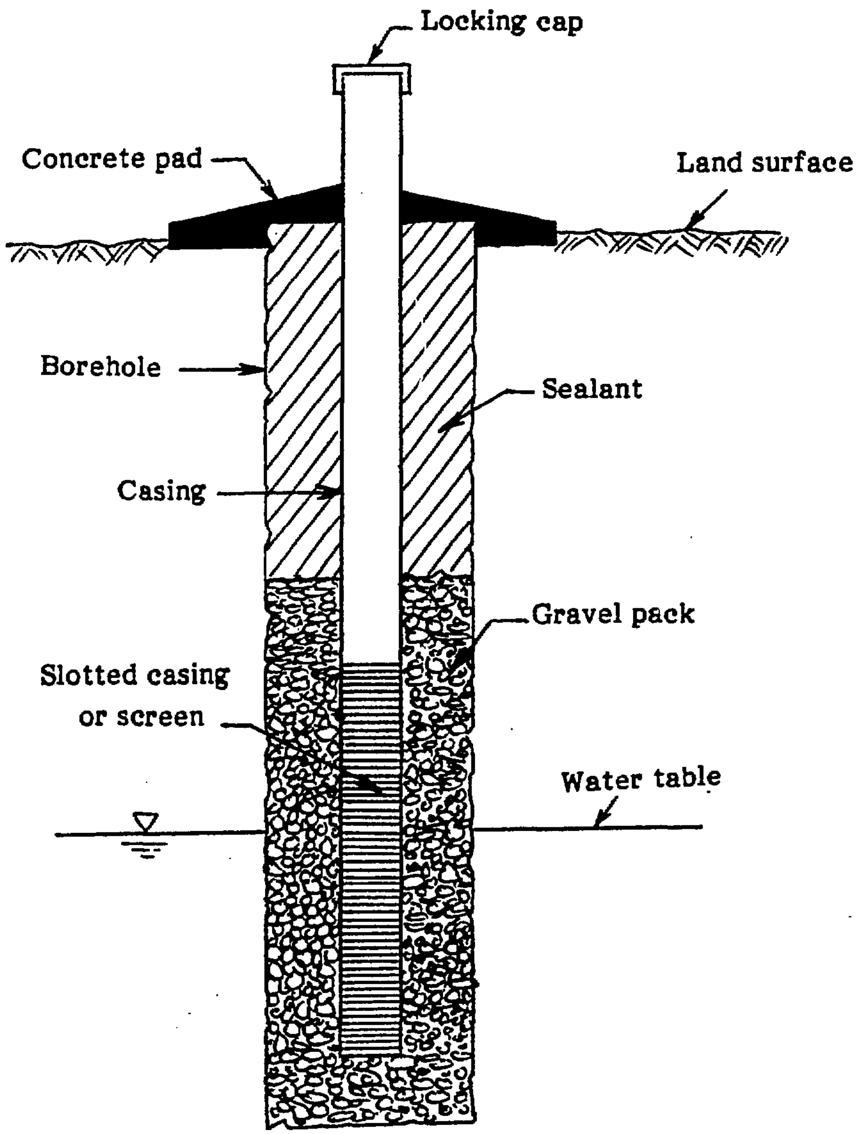
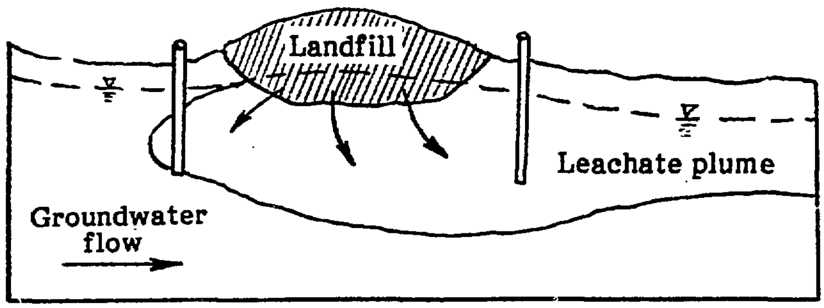
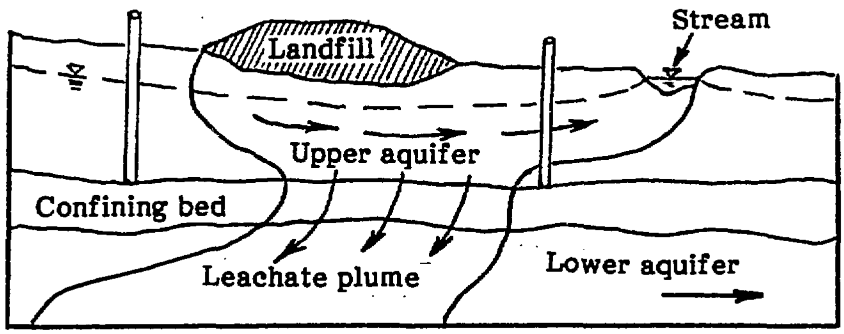


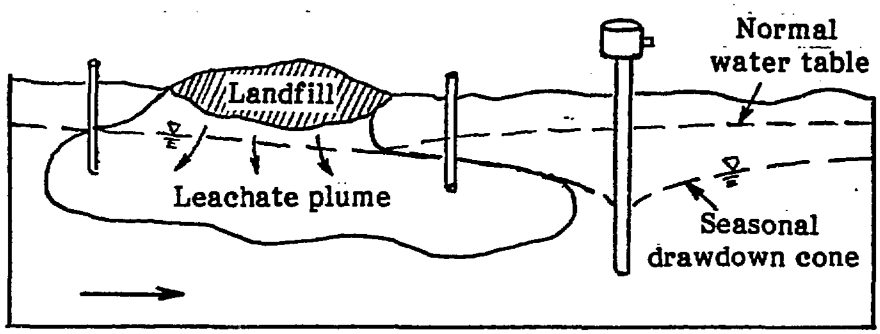
FIGURE 3 Components of Typical Monitoring Well Designs



(a) ɹntamination of Background Well by Groundwater Monitoring Effect



(b) Improperly Designed Monitoring System in Dual Aquifer System



(c) Localized Reversal of Groundwater Flow Direction Caused by Seasonal Pumping of Production Well

FIGURE 4 Modifications of Normal Groundwater Flow Directions