Groundwater Sampling Reduction at the Savannah River Site

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1. Introduction

Optimization of a well network for the monitoring of groundwater contamination around a hazardous waste management site can ensure a reliable and cost-effective operation. Wells that provide irrelevant, redundant, or unreliable information can be removed from the sampling schedule. The assessment of contaminant migration and clean-up effectiveness would then be based on a more accurate set of data and be accomplished at a substantial reduction in cost.

This paper provides an overview on a technique used at the U.S. Department of Energy Savannah River Site to optimize the selection of monitoring wells placed on a sampling schedule. The technique involves assessments of a geochemical database to identify irrelevant wells, redundant wells that are predictive of each other, and unreliable wells. These wells can be removed from the sampling schedule to enhance the reliability of the data and reduce the cost of sampling and creating the database.

2. Methods

The efficiency of the SRS monitoring well network is assessed using a multidisciplinary approach combining geochemistry, geohydrology, statistics, and regulatory knowledge. This approach is based on a process for monitoring well assessment using the “4Rs,” relevancy, redundancy, reliability, and regulatory. The process is presented as sequential but, in practice, it is iterative, using the information generated in one phase to reassess earlier results. This process is outlined below.

2.1 Well Relevancy

Geohydrologic judgment and site-specific knowledge are used to identify wells that do not provide pertinent information about a contaminant plume. Groundwater models and contaminant isoconcentration maps can be examined to determine whether wells are in the optimum location to define plume conditions. In order to effectively monitor a groundwater contaminant plume, a well must be located with its screen zone situated along a flow line the plume is following, either within the plume or “in front” of the plume. If a well screen is not located along such a flow line, it will not detect contaminants that are being transported within that groundwater plume.

Monitoring wells must be situated accurately in both the horizontal and vertical planes. Well screens may be located at the proper elevation within the appropriate aquifer, but be located side-gradient from the contaminant plume flow line. Similarly, a monitoring well screen may be located correctly in the horizontal plane, but with the screen zone located in a vertical position such that the plume is not intercepted. The latter case may exist for
wells that penetrate only a few feet into the top of the water table aquifer with only uncontaminated recharge water intercepted.

Knowledge of groundwater flow systems is often inadequate to locate all monitoring wells along a flow path of a contaminant plume emanating from a disposal facility; however, the understanding of local groundwater flow systems usually increases as additional wells are installed. Some of the wells installed early in the implementation process may later be discovered to be incorrectly located to intercept the groundwater flow path carrying the contaminant plume. These wells are considered irrelevant and subject to elimination from the sampling schedule.

Reactions may occur that alter the chemistry of groundwater exposed to the atmosphere in a well bore. The presence of oxygen may cause oxidation of contaminants with multiple valence states, such as chromium and mercury. This can lead to erroneous conclusions about the mobility and toxicity of the contaminants. In addition, dissolved iron and manganese may oxidize and precipitate from solution. Water in or near a well bore can also equilibrate with atmospheric carbon dioxide causing changes in pH and, in turn, changes in the behavior of contaminants. Thus, samples drawn from wells that cannot be properly purged may not be representative of groundwater in the aquifer of interest. A typical sampling procedure requires purging two well bore volumes prior to sampling. Wells that repeatedly produce less than this volume (three of the most recent five quarters or all quarters if less than three quarters of data are available) are identified as having inadequate water production. If the wells are not required for monitoring the edge of the plume, they are recommended for removal from the sampling schedule.

To evaluate whether monitoring wells might be located side-gradient from the contaminant plume, a visual examination of well locations relative to the contaminant source area and contaminant plume position is conducted for the monitoring well network. Additionally, data base screenings are conducted to identify monitoring wells that penetrate only a few feet into the saturated zone, and wells that do not produce a sufficient quantity of water to obtain a protocol groundwater sample. The latter condition occurs in wells that are screened in low-permeability material. Typically, a well is not completed with its screen in low-permeability material unless the water table occurs within that material. Pumping dry during attempts to collect groundwater samples is indicative of this well condition.

A Structured Query Language (SQL) query of the SRS Geochemical Information Management System (GIMS) data base is used to obtain information indicating how often wells have pumped dry during the collection of samples over the period of record for each well. The criterion selected to flag those wells that pump dry prior to collection of a sample was established to be 20 percent of the time. When a well pumps dry prior to purging a sufficient volume of groundwater to collect a protocol sample, the samplers return the following day after a water level in the well has re-equilibrated, and collect a sample from that water in the wellbore.
2.2 Well Redundancy

The intent of well redundancy analysis is to determine whether or not all wells in close proximity to one another are all providing unique information regarding the spatial distribution of the contaminant. Based on geostatistical methods, a list of candidate wells for exclusion from the sampling plan is created. Previous studies at SRS have shown that as many as 15 to 20 percent of the wells within a network provide completely redundant information. This outcome has historically occurred as wells have been successively drilled, many in close proximity to one another. The geostatistical method described below summarizes the well data by representing a concentration as a weighted average of nearby wells. A well can be considered redundant if the concentration of a contaminant can be predicted nearly as well without including the candidate well in the prediction process.

The chief characteristic of a geostatistical application is that each measurement is associated with a location (e.g., well coordinates). Groundwater monitoring well locations are not chosen at random, but are located purposely near the source of contamination. Wells that are positioned near each other tend to have more similar measurements than wells located further apart. Closely clustered wells can be highly predictive of each other. Sampling all of the wells in such a cluster may produce considerable redundant information. Conversely, the network of wells may poorly describe other areas. In these situations, an additional well may be necessary to fully characterize a waste site.

In geostatistics, the closeness of any two measurements is assumed to be related to the distance, and possibly direction, between them. The similarity of measurements is portrayed by the variogram, which offers a simple, intuitive way of capturing and displaying the relationships between the measurements. The variogram is also the basis for predicting and mapping groundwater constituent concentrations.

The horizontal axis in the graph represents the distance between a pair of wells. The vertical axis, labeled “variogram,” represents an average disparity between two measurements taken from the wells. The variogram value is zero if the two measurements have exactly the same value. The variogram value becomes larger as the two measurements become increasingly different. Each plotted value represents the average disparity between the constituent measurements in pairs of wells that are separated by approximately the same distance.

The smooth line drawn on the variogram represents a fitted model. At separation distances close to zero feet, the variogram value is zero. This is interpreted to mean that random analytical and sampling uncertainties are negligible, and that the constituent measurement is highly predictable in the neighborhood (several hundred feet) of a well. For greater distances, the smooth curve rises steadily until it levels off at just under 2,000 feet separation. This separation distance is called the range. Any two wells separated by a distance greater than the range are not predictive of each other.
The key concept in geostatistics is that well measurements are spatially related (correlated). This leads to the idea that the best prediction of groundwater contamination at a location is a weighted average of the concentrations in nearby wells. The variogram provides a means to quantify the relative influence (weight) of each well measurement in the prediction process. This prediction method is called kriging.

Kriging is used in the study of the SRS monitoring well network to create concentration contour maps. First, a variogram is created for the entire monitoring well network of each aquifer. The contour map is created by overlaying a grid and making a prediction of each grid intersection using the variogram and weighted averages. A set of wells thought to provide redundant data are then removed from the database, and the process is repeated for the reduced database to create a second contour map. When the two contour maps look alike, or the difference between them is sufficiently small, the wells in the removed set are considered redundant.

Besides providing predicted groundwater concentrations, these geostatistical methods produce a confidence interval (Hahn and Meeker, 1991) that bounds the predicted groundwater concentrations. A relatively large change in the upper confidence limit for a predicted concentration, when the data from a particular monitoring well is eliminated, reflects the importance of that well to the monitoring network. However, little or no change in the upper confidence limit for a predicted concentration, when data from a monitoring well is eliminated, confirms that the particular well has provided mostly redundant information.

After qualifying the well concentration data retrieved from the GIMS database, the five most recent quarterly concentration measurements are selected for each well and constituent. The median of these five values is calculated as a representative concentration for a given well. Selecting the median avoids any inordinate influence that a single very large or very small value may have on the representative concentration. These median concentration values comprise the data set used for well redundancy analysis.

2.3 Well Reliability

Monitoring wells are designed to produce samples that are representative of groundwater within the aquifer. Well construction or development problems can defeat this purpose. Such problems may be indicated by high pH and turbidity values. Wells with a history of producing samples with elevated pH or turbidity are regarded as less reliable.

Grout contamination occurs when the bentonite seal separating grout from the well screen is breached and grout enters the screen zone. Equilibration with groundwater causes pH to be elevated to as high as 11.3 units. The magnitude of elevation depends on the grout surface area in contact with the groundwater and on the duration of the contact. The elevated pH alters the chemistry of the groundwater around the well bore by affecting the solubility of many constituents, changing surface-solute interactions, and mobilizing colloidal clays. Many contaminants may appear more concentrated and others may
appear less concentrated than they actually are in the groundwater. It is for this reason that grout-contaminated wells are recommended for removal from the sampling schedule. Groundwater pH can be used to determine the presence of grout contamination. However, the presence of calcareous sands in the aquifer may mask wells that have minor contamination. Water in equilibrium with calcareous sands may have a pH as high as 8.5 units and, thus, is indistinguishable from water that is sampled from a well with minor contamination. Only wells with pH consistently above 8.5 units are recommended for removal from the sampling schedule.

A SQL query of the GIMS database is used to obtain sample analytical data for pH and turbidity for each monitoring well. The criteria for determination of anomalous values are pH<4.0 units or pH>8.5 units and turbidity >20 nominal turbidity units (NTU). Consideration is only given to elevated values (>8.5) of pH since the grout material used in well construction is very alkaline. Low values of pH, on the other hand, may be indicative of contaminants to be monitored. The presence of calcareous sands in an aquifer may cause natural elevation of groundwater pH to as high as 8.5 units. Therefore, wells with chronic pH values >8.5 units could indicate problems that relate to the grout emplacement at the time of well installation. Excessively high pH can bias the concentration of most potential contaminants in groundwater samples collected from that well.

2.4 Regulatory Analysis

Regulatory requirements must be considered when determining which wells should be eliminated from the sampling schedule. The regulatory purpose of the well (point of compliance, plume definition, etc.) may have a bearing on whether or not elimination is appropriate. The type of monitoring program being pursued (detection, compliance, or corrective action) may also be relevant to the decision to keep or eliminate a well.

3. Other Analyses

3.1 Analyte Reduction Analysis

The list of groundwater monitoring constituents contained in Resource Conservation and Recovery Act (RCRA) Part B Permits for SRS is quite lengthy. In order to determine how useful the various constituents are and where they are useful, a study has been conducted of their spatial distributions. The concentrations of nonhazardous, hazardous, and radioactive constituents are plotted on maps. Plots are made for each aquifer using concentration data from the most recent sampling quarter for which qualified data are available.

The isoconcentration maps are examined to determine whether or not areas of high contaminant concentration are present near any of the known source sites. In most cases, no such areas are identified indicating that the constituents in question have not been released to groundwater and do not require monitoring. In cases where this examination...
does reveal the presence of a contaminant plume, the size and location of the plume are used to determine which wells are appropriate to monitor the contaminant in question.

3.2 Sampling Frequency Reduction Analysis

The Lawrence Livermore National Laboratory, with assistance from the Savannah River Technology Center, has developed a method for selecting a sampling frequency for wells within a groundwater monitoring network (Johnson et al., 1996). This method is based on a statistical trend analysis of the most recent six to eight quarters of contaminant concentration data for each well. Wells that show steady and steep increases or decreases in concentration are recommended for quarterly sampling, while those with little or no change in concentration are recommended for annual sampling. This technology also examines the temporal variation in contaminant concentration as additional evidence to support a recommended sampling frequency.

4. References
