APPLICATION OF A GEOGRAPHIC INFORMATION SYSTEM FOR CONTAINMENT SYSTEM LEAK DETECTION

By

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ABSTRACT

The use of physical and hydraulic containment systems for the isolation of contaminated ground water associated with hazardous waste sites has increased during the last decade. Existing methodologies for monitoring and evaluating leakage from hazardous waste containment systems rely primarily on limited hydraulic head data. The number of hydraulic head monitoring points available at most sites employing physical containment systems may be insufficient to identify significant leakage. A general approach for evaluating the performance of containment systems based on estimations of apparent leakage rates is used to introduce a methodology for determining the number of monitoring points necessary to identify the hydraulic signature of leakage from a containment system. The probabilistic method is based on the principles of geometric probability. A raster-based GIS (IDRISI) was

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used to determine the critical diminsions of the hydraulic signature of leakage from a containment system, as simulated under a variety of hydrogeologic conditions using a three-dimensional ground-water flow model. MODRISI, a set of computer programs was used to integrate ground-water flow modeling results into the hydraulic signature assessment method.

INTRODUCTION

Subsurface vertical barriers have been used to control ground-water seepage in the construction industry for many years. Recently, the industrial and regulatory communities have applied vertical barrier containment technologies as supplemental or stand-alone remedial alternatives at hazardous waste sites to prevent or reduce the impact of contaminants on ground-water resources (Rumer and Ryan, 1995). While subsurface barriers appear to be useful for isolating long-term sources of ground-water contamination at many sites, the potential exists for leakage of contaminants through relatively high hydraulic conductivity zones ("windows") within the barriers.

This paper describes the application of a Geographic Information System (GIS) as a tool to help identify leakage through discrete zones within a subsurface vertical barrier. The proposed techniques could be useful for evaluating existing containment systems by providing insight as to how many monitoring points are necessary to determine the approximate locations of discrete leaks, given specified confidence and constraints.

Containment Systems

Subsurface containment systems may be active (e.g., ground-water extraction to manage hydraulic gradient), or passive (e.g., physical barriers only) depending on the remedial objectives and complexity of the hydrogeologic setting (Canter and Knox, 1986). Frequently, containment systems employ a combination of active and passive components, which commonly incorporate vertical barriers keyed into underlying low-permeability units. Many containment systems also include a low permeability cover to reduce the rainfall infiltration, extraction and injection wells, and trenches for ground-water management.

Soil-bentonite slurry cutoff walls (slurry walls) are the most common type of subsurface vertical barriers used at hazardous waste sites and are generally installed around suspected source areas (U.S. EPA, 1984). Construction defects or post-construction property changes are potential failure mechanisms of subsurface vertical barriers (Evans, 1991). Construction defects may result in the formation of relatively high hydraulic conductivity "windows" in a barrier. Some of the mechanisms responsible for the formation of such windows include emplacement of improperly mixed backfill materials, sloughing or spalling of *in situ* soils from trench walls, and failure to excavate all *in situ* material when keying wall to the underlying low permeability unit (U.S.EPA, 1987). Post-construction property changes may result from wet-dry cycles due to water table fluctuations, freeze-thaw degradation, or chemical incompatibility between the slurry wall material and ground-water contaminants.

Monitoring of Containment Systems

The performance of hazardous waste containment systems has generally been evaluated based on construction specifications. Most subsurface vertical barriers are required to maintain a hydraulic conductivity of 1×10^{-7} cm/s, or less. The use of appropriate construction quality assurance (QA) and quality control (QC) testing during installation is essential to ensure that the design performance specifications are achieved. The regulatory community recognized the need to develop procedures to verify post-construction performance and identify unsatisfactory zones in containment systems (U.S.EPA, 1987). While construction dewatering systems are deemed successful if the barriers limit ground-water leakage to reasonably extracted quantities, there are no uniform methods to reliably measure and document the hydrologic performance of existing and proposed hazardous waste containment systems (Grube, 1992).

The minimum number of monitoring points necessary to determine whether a containment system is functioning as designed depends on site-specific conditions. For example, in some cases it may be possible to determine whether leakage has occurred by analyzing the water level trends in monitoring wells (Ross and Beljin, 1998). Subtle variations in the hydraulic head distribution associated with leakage through a subsurface barrier may be identifiable if sufficient hydraulic head data are available for analysis. Such an undertaking would generally be considered prohibitively expensive due to the high cost of installing a piezometer network capable of adequately defining the hydraulic head distribution. However, the recent development of relatively inexpensive installation techniques may make it feasible to install a sufficient number of small diameter piezometers to identify the hydraulic signatures associated with containment system leakage.

A New Monitoring Method

The process of locating a leak in a hazardous waste containment system can be analogous to mineralogical prospecting where a compromise is sought between the cost of exploration and the thoroughness of the search. For mineral exploration applications, the expected benefit of a search is the sum of the value of each target multiplied by the probability of finding it, assuming that the target exists in the search area (Singer, 1972). For containment system leak detection, the expected benefit of a search is the potential reduction in risk to human health and the environment associated with the detection and abatement of significant leaks.

Gilbert (1987) presents a methodology based on the work of Savinskii (1965), Singer and Wickman (1969), and Singer (1972) that can be used to determine the grid spacing required to detect highly contaminated local areas or hot spots at a given level of confidence, or estimate the probability of finding a hot spot of specified dimensions, given a specified grid spacing. Given a specific grid spacing, the probability of detecting a target is determined by the method of geometric probability, which is a function of the ratio of the area of the target to the area of the grid cell. The method assumes that the highly contaminated areas are circular or elliptical in shape, the boundaries of the hot spot are clearly identifiable based on contamination levels, hot spot orientation is random with respect to the sampling grid, and the distance between grid points is much larger than the area sampled. In order to address variations in the distribution of hydraulic head, rather than contaminant concentrations, the assumptions were modified for the methodology presented in the paper.

METHODOLOGY

The hydraulic signature associated with leakage from a containment system is simulated using a numerical model for a variety of hydrogeological settings. The modeling results provide the data on which the hydraulic signature assessment method is demonstrated. A set of computer programs was developed (Ross and Beljin, 1995) to import modeling data into a raster-based GIS, for further processing. The GIS was used to generate the input data for the ground-water model.

Ground-Water Modeling

A model may be defined as a simplified version of a real system that approximates the stimulus-response relationships of that system (Bear and others, 1992). By definition, the use of a model requires the application of simplifying assumptions to describe the pertinent features, conditions, and significant processes that control how the system reacts to stimuli. In this study, one of the primary objectives of the modeling was to predict the hydraulic head distribution associated with leakage through discrete leaks in a vertical barrier under different hydrogeologic conditions.

The conceptual model presented in this paper is based on characteristics of several specific hazardous waste sites that incorporate physical containment as a major component of the remedy. The sites which influenced the development of the model used in this study include the Gilson Road Superfund site (Nashua, New Hampshire), the G.E. Superfund site (Moreau, New York), and the Velsicol/Michigan Chemical Company Superfund site (St. Louis, Michigan). The conceptual model for the containment system consists of a slurry wall fully penetrating an unconsolidated surficial aquifer, keyed in to an underlying low permeability aquitard (Fig. 1).

Hydraulic head values are assumed to be higher in the interior of the containment system, simulating a "worst-case" scenario for potential contaminant losses from the system (Fig. 1). The elevated water levels within the conceptual containment system are assumed to be derived from deficiencies in the the system (i.e., leakage under or through the upgradient wall and infiltration through the cap), and water levels are assumed to be relatively stable over time. Ground-water flow is assumed to be horizontal, except in the immediate vicinity of the vertical barrier. Given the long-term nature of most hazardous waste containment systems, the hydraulic heads are averaged over long time periods. Consequently, steady-state flow conditions are assumed for all simulations used in this study.

The hydraulic head distribution associated with a linear segment of a conceptual vertical barrier was simulated using Visual MODFLOW® (Guiger and Franz, 1995), a commercial version of the three-dimensional, finite difference ground-water flow model MODFLOW, developed by the U.S. Geological Survey (McDonald and Harbuagh, 1988).

Data Processing with a GIS

The hydraulic head data generated by the numerical simulations are extracted, visualized, sampled, analyzed, and appropriately manipulated using several software packages.

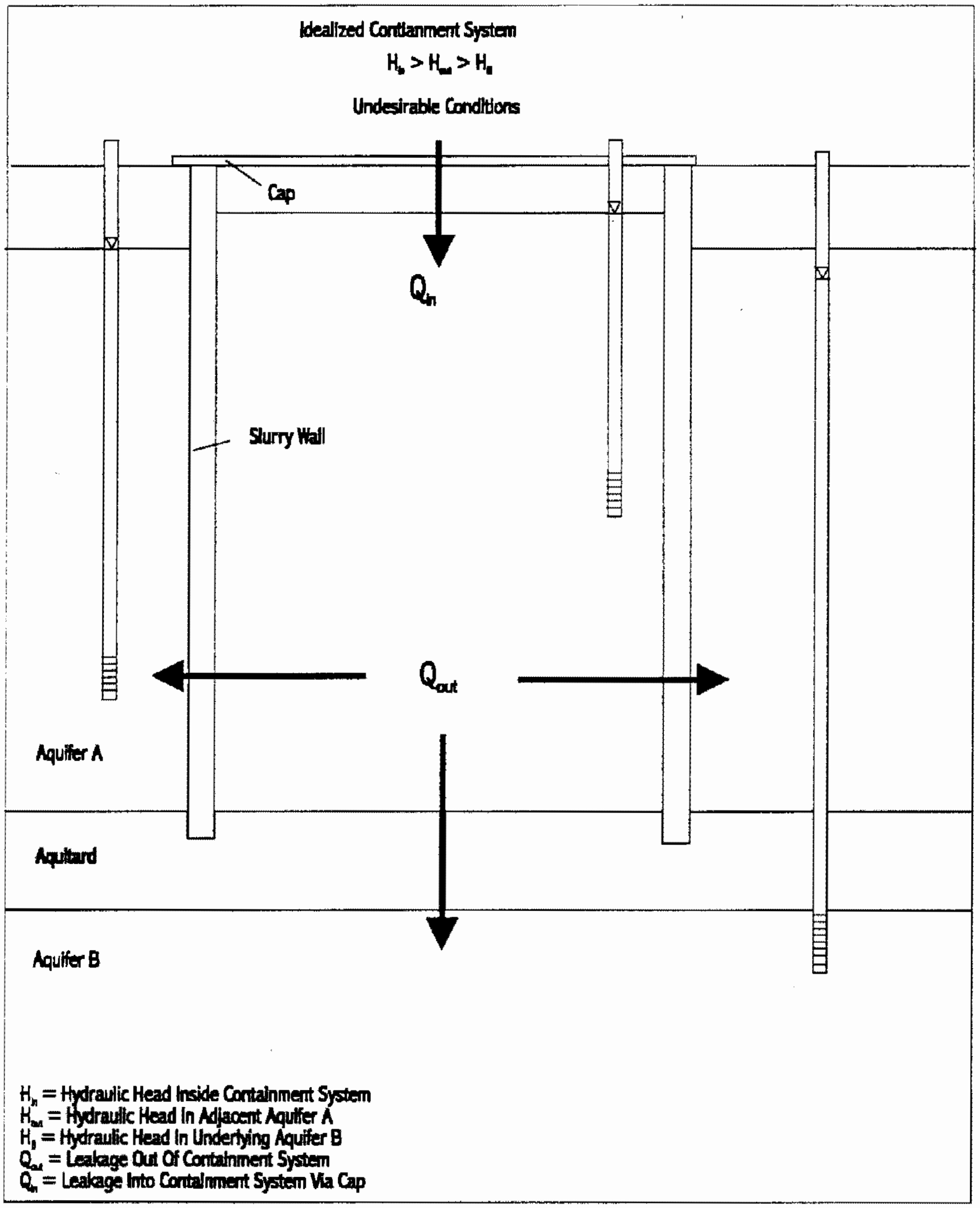


Fig. 1. Major components of an idealized hazardous waste containment system exhibiting unfavorable conditions (e.g., outward hydraulic gradient).

Hydraulic head data from a vertical cross-section parallel to, and immediately down gradient from the simulated vertical barrier are used throughout this study. The data are extracted from MODFLOW output files and reformatted as image files for analysis using MODRISI (Ross and Beljin, 1995). The GIS software used in this study is IDRISI (Eastman, 1995), a raster GIS that provides numerous analytical capabilities that are directly applicable to this, and other hydrogeologic studies. The uniform grid spacing facilitates the transfer of data from one software package to another. The raster format allows import and export of uniform grid model data and also provides a robust platform for the analysis, visualization and data manipulation.

Model Setup

The model domain consists of 51 rows, 51 columns, and 25 layers (Fig. 2) and is discretized into uniform 1 m^3 blocks. This configuration is sufficiently large to reduce boundary effects and provides sufficient resolution to allow identification of subtle variations in hydraulic heads associated with leakage through a vertical barrier. The uniform grid size allows consistent precision over the entire model domain and simplifies data management and transfer between software packages.

The slurry wall is simulated as a one-meter thick barrier with uniform properties, except for the window. The hydraulic conductivity values for the aquifer and window are scenario dependent. Leakage through the wall is simulated as a window with dimensions of 2 x 3 cells (6 m^2), located in the approximate center of the vertical barrier (row 25, columns 24-26, layers 12 and 13).

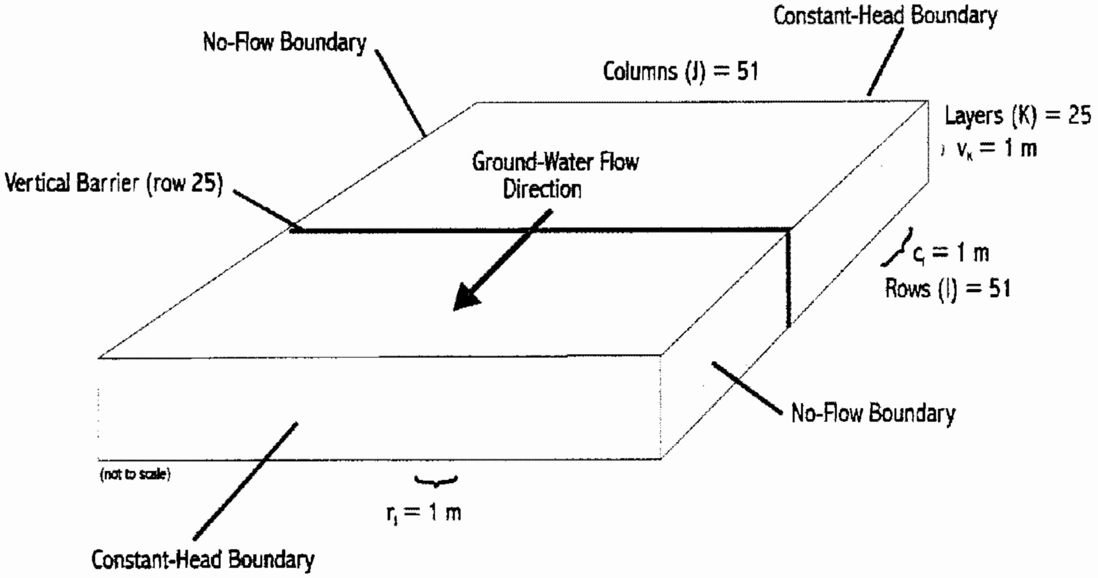


Fig. 2. Conceptual model domain and boundary conditions.

Boundary conditions are depicted in Fig. 2. The upgradient and downgradient sides of the model are constant-head boundaries, resulting in a horizontal hydraulic gradient across the model domain of 0.0196 m/m. This value falls within the range of hydraulic gradients commonly observed in the field. The sides and lower surface of the model oriented parallel to ground-water flow are simulated as no-flow boundaries.

The applicability of the numerical model for simulating the hydraulic head distribution associated with leakage from a containment system was demonstrated by comparing model results to data generated from a laboratory bench scale model of a cutoff wall (Ling, 1995). Simulation results agreed favorably with the physical model results, indicating that the approach described in this study is appropriate for simulating the hydraulic head distribution associated with leaking vertical barriers.

General Simulation Scenarios

Several hypothetical hydrogeologic conditions are evaluated in this study. Different scenarios are used to better understand the potential variability of the hydraulic signatures associated with different subsurface conditions and to account for potential uncertainties associated with predictive modeling.

A range of homogeneous and isotropic conditions were simulated in an effort to provide a reference case for evaluating the effects of varying average aquifer hydraulic conductivity values on the hydraulic signature of a simulated leak. The scenarios spanned a wide range of hydraulic conductivity values with respect to the aquifer material and zone of leakage. The hydraulic conductivity values for the aquifer range from 1×10^{-2} cm/s to $1 \times$

10^{-5} cm/s. The hydraulic conductivity of the vertical barrier is maintained throughout the study at 1 × 10^{-7} cm/s. The hydraulic conductivity values for the window ranged from 1 × 10^{-2} cm/s to 1 × 10^{-5} cm/s. The hydraulic conductivity value for the window is assumed to be less than or equal to that of the adjacent aquifer materials. The scenarios simulate the general effects of layering by varying the horizontal to vertical hydraulic conductivity ratios of aquifer materials.

One of the primary limitations of using ground-water flow models as a predictive tool results from the uncertainty associated with input parameters. This uncertainty is directly related to the spatial variability of hydrogeologic properties of the porous medium (i.e., aquifer material). To account for some of the spatial variability and uncertainties associated with three-dimensional predictive flow modeling, several scenarios utilizing heterogeneous distributions of hydraulic conductivity were assessed. The assumption of lognormally distributed hydraulic conductivity is used for the heterogeneous, isotropic and heterogeneous, anisotropic simulations. Unique lognormal hydraulic conductivity distributions were generated for each of the 25 layers using built-in functions of the GIS software. This approach resulted in the generation of approximately 63,000 hydraulic conductivity values within the model domain.

Hydraulic Signature Assessment Method

The methodology used to address the hydraulic head distribution associated with leakage from a containment system was developed based on the work of Singer and Wickman (1969) and Gilbert (1987). The proposed method is directly applicable to determining the grid spacing necessary to detect the hydraulic signature associated with a discrete leak in a subsurface vertical barrier. The methodology requires the following assumptions:

- the hydraulic signature of the leak is circular or elliptical;
- hydraulic head data are acquired on a square grid;
- the criteria delineating the hydraulic signature are defined; and
- there are no measurement misclassification errors.

The model results indicate that the hydraulic signatures associated with the simulated leaks range in shape from approximately circular to elliptical when viewed in vertical cross-section. An increase in the anisotropy results in the elongation of the signatures in the horizontal directions. As expected, the greater the anisotropy, the more elliptical the hydraulic signature of the leak.

The criteria for delineating the hydraulic signature of a leak from background noise are based on the average hydraulic head value ($\bar{x}_h$) of the model cross-sectional surface. For this study, hydraulic head values of $\bar{x}_h$+0.05 m and $\bar{x}_h$+0.1 m were identified as critical values (C_v), indicating the presence of a hydraulic anomaly associated with containment system leakage. This follows the assumption that any background noise associated with the hydraulic head measurements is significantly less than 0.05 m. The dimensions of the hydraulic anomalies are determined using GIS software by image reclassification to delineate nodes exceeding the average hydraulic head by the specified critical values. The dimensions of the hydraulic signatures delineated by the two values for C_v are expressed as shape factors (S), defined as the ratio of the length short axis to the length of the long axis of the hydraulic signature. The shape factor for a circular feature is 1. An increase in anisotropy results in the elongation of the feature and a decrease in S, where $0 < S \leq 1$.

The probability tables of Singer and Wickman (1969), were used to determine the probability of not detecting a leak when a leak is present (β) to the ratio of the semi-major axis to grid size (L/G). The semi-major axis is defined as one half the length of the long axis of an elliptical feature. The general procedure for determining monitoring point spacing necessary to detect a hydraulic anomaly of given dimensions and specified confidence is outlined in Table 1, and in the following example.

Table 1. General steps for determining monitoring point grid spacing.

1.	Specify the radius or one half the length of the long semi-major axis (L) of the hydraulic signature (mound) associated with the leak;
2.	Assuming a circular hydraulic signature, let the shape factor (S) equal one; for elliptical features, S may be calculated using equation (9);
3.	Specify the maximum acceptable probability (β) of not detecting the hydraulic feature (=0.1);
4.	Knowing L, S and assuming a value for β, determine L/G from Fig. 4, and solve for G (minimum grid spacing required to detect the hydraulic anomaly associated with the leak, given the specified constraints).

In order to determine the minimum grid spacing necessary to identify a hydraulic feature of specified dimensions, an acceptable probability of not detecting the feature must be established. For this example, a value of $\beta = 0.1$ is assumed for a leak signature with dimensions of 5 m by 4 m, as delineated by $C_v = 0.1$ in Fig. 3a. From Fig. 4, a value of approximately 0.64 is indicated for the ratio of the length of the semi-major axis to grid size (L/G), given = 0.1 and S = 0.8. Therefore, solving for G using L = 2.5, it is determined that a minimum grid spacing of approximately 3.9 m is necessary to identify the specified feature with a 90% probability of success. The resulting grid spacing (G) may be used to determine the minimum number of block-centered monitoring points required to detect the feature for a specified area by dividing the total area by the area of one square grid (G^2).

The probability tables were also used to generate nomographs relating the probability of not detecting a leak (β) of specified dimensions (L), for different grid dimensions (G). Figure 5 illustrates this relationship for circular hydraulic signature (S = 1.0). The nomographs may be used to estimate the dimensions of the smallest hydraulic signature capable of being identified by a monitoring network of known dimensions within an acceptable level of confidence (β). For example, given a monitoring point spacing of 20 m, what is the smallest circular hydraulic anomaly that can be detected with 80% probability of success (β= 0.2). From Fig. 5 it is noted that a circular feature with a radius of approximately 10.1 m can be detected with the specified probability and grid spacing. The probability of not detecting the anomaly will increase as the radius of the hydraulic signature decreases.

RESULTS AND DISCUSSION

The dimensions of the hydraulic signatures associated with leakage through a subsurface vertical barrier are a function of the hydrogeologic properties of the aquifer, vertical barrier, and zone of leakage. Assuming all other variables remain constant, the

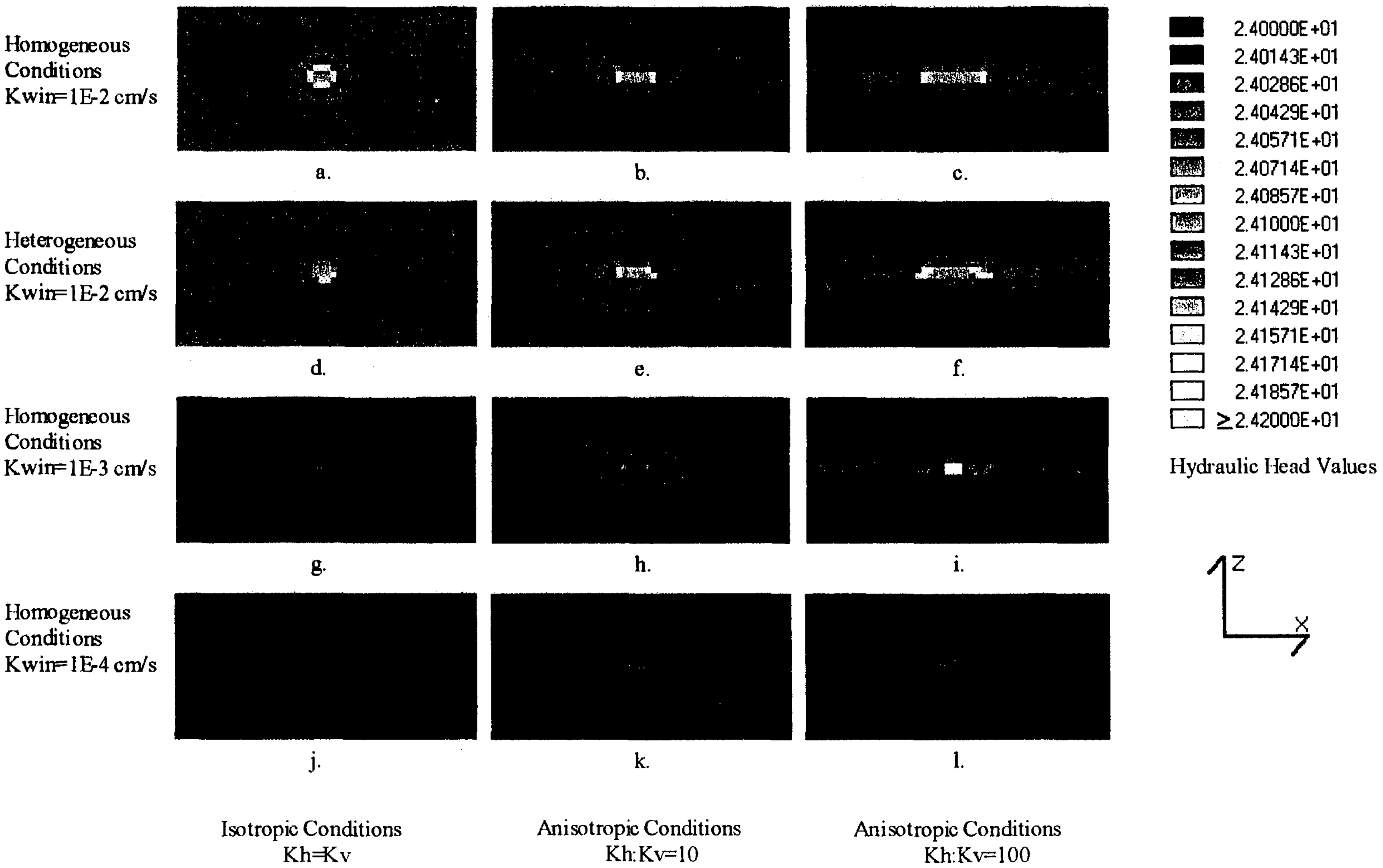


Fig. 3. Vertical cross-section of model results illustrating hydraulic signature (head) variations due to changes in conceptual hydrogeological setting.

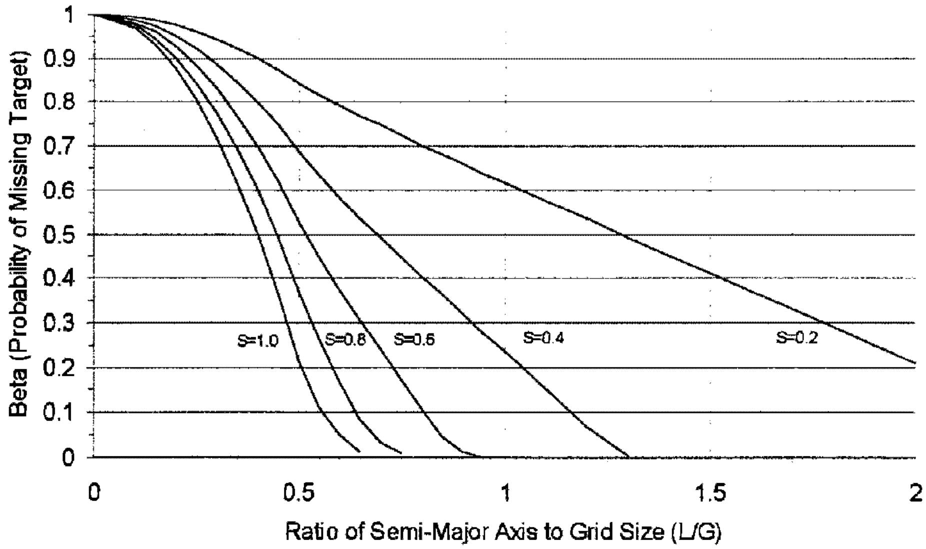


Fig. 4. Nomograph relating ratio of semi-major axis of elliptical target and grid size to the probability of missing the target (Beta) for different shape factors using a square grid pattern.

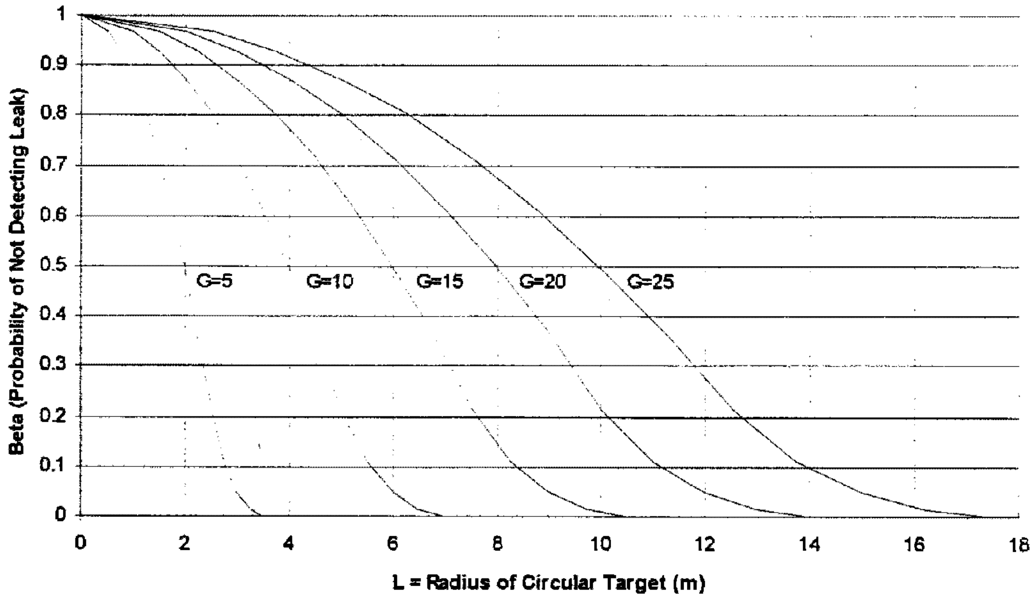


Fig. 5. Nomograph relating radius of circular hydraulic signature to probability of not detecting leak (Beta) for different grid spacings.

magnitude of the hydraulic signature diminishes significantly as the hydraulic conductivity of the window decreases (Fig. 3). The hydraulic signature of leakage through the hydraulic conductivity window becomes less prominent as its value is reduced by one order of magnitute (Fig. 3g). As the value is further reduced, the hydraulic signature becomes discernable only immediately adjacent to the window (Fig. 3j). The decrease in hydraulic signature corresponds to a decrease in flux through the window, as the window hydraulic conductivity is reduced (Table 2).

Table 2. Simulated flux through windows of varying hydraulic conductivity.

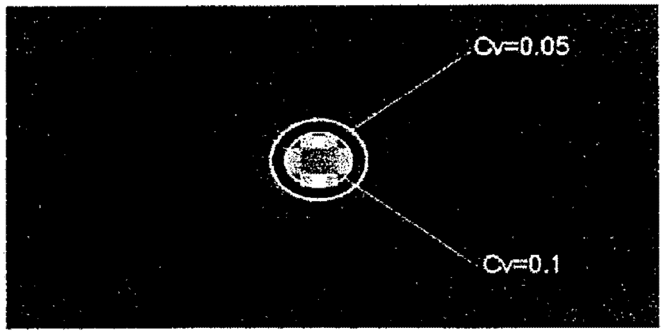
Window Hydraulic Conductivity (cm/s)	Minimum Head Value (m)	Maximum Head Value (m)	Range (m)	Flux Through Window (m^3/d)
1×10^{-2}	24.0293	24.2627	0.2334	1.3110^{1}
1×10^{-3}	24.0117	24.0826	0.0709	3.98
1×10^{-4}	24.0071	24.0165	0.0094	4.9610^{-1}
1×10^{-5}	24.0063	24.008	0.0017	5.0910^{-2}

The effect of varying the horizontal to vertical hydraulic conductivity values is illustrated in Fig. 3. For example, the hydraulic signature from leakage through a window under homogeneous and isotropic conditions forms an approximately circular feature (Fig. 3a). However, as the horizontal to vertical hydraulic conductivity ratio increases, the hydraulic signature of the leak becomes more elliptical (Fig. 3b,c). Similar trends are observed with respect to increasing the horizontal to vertical hydraulic conductivity ratio for the heterogeneous simulations (Fig. 3d,e,f) and other homogeneous simulations with smaller hydraulic conductivity values for the windows (Fig. 3g-l).

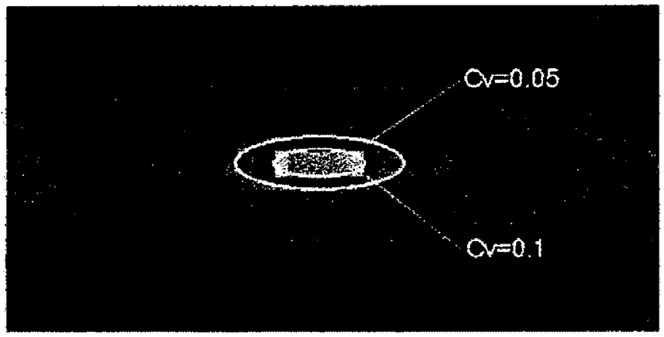
The method was applied to different hydraulic signatures developed from ground-water flow simulations of leakage through a vertical barrier. The criteria used to differentiate the hydraulic signature of leakage from background noise are $C_v = \bar{x}_h+0.05$ m and $\bar{x}_h+0.1$ m. Figure 6a depicts the head distribution associated with hydraulic signature of leakage through a window located in the approximate center of a vertical barrier in a homogeneous, isotropic aquifer. The approximate dimensions of the vertical hydraulic mound as defined by $C_v=\bar{x}_h+0.05$ and $\bar{x}_h+0.1$ are 7 m by 6 m, and 5 m by 4 m, respectively.

An increase in the anisotropy of the simulated aquifer by one order of magnitude produces a vertically compressed and horizontally elongated hydraulic signature (Fig. 6b). Similarly, increasing the anisotropy of the simulated aquifer by two orders of magnitude results in even greater compression and elongation of the hydraulic signature in the vertical and horizontal directions, respectively (Fig. 6c).

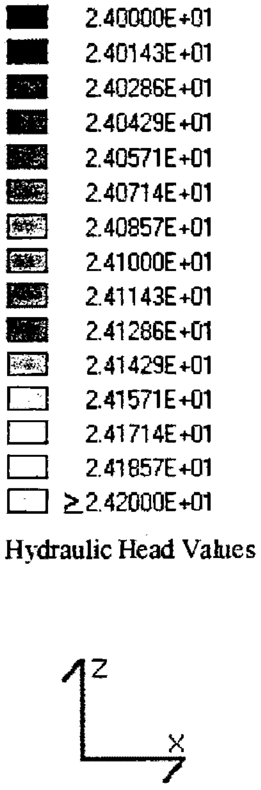
Hydraulic signatures for leakage through a window with a hydraulic conductivity value of 1×10^{-3} cm/s exhibit similar trends in response to increases in anisotropy (Fig. 7a,b,c). However, the overall hydraulic signature of the window is decreased significantly relative to that of the base case. This results in a lack of head values greater than the elevation threshold for $C_v=\bar{x}_h+0.1$ for the homogeneous, isotropic simulations. The hydraulic head values associated with leakage through windows with hydraulic conductivities $< 1\times10^{-3}$ cm/s were all less than $C_v=\bar{x}_h+0.05$, and therefore, could not be evaluated as described above.

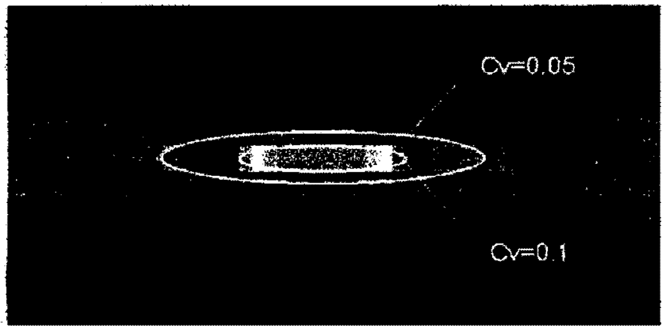


a. Homogeneous and Isotropic Simulation Results



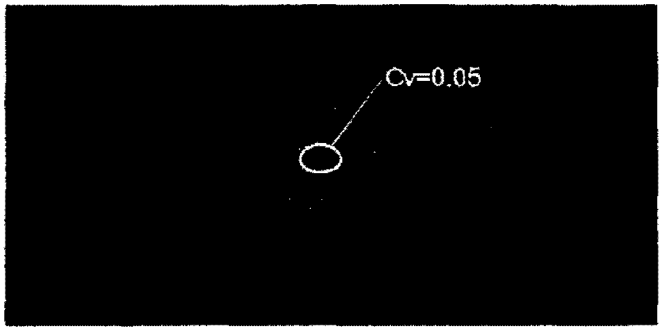
b. Homogeneous and Anisotropic Results (K_h:K_v=10)



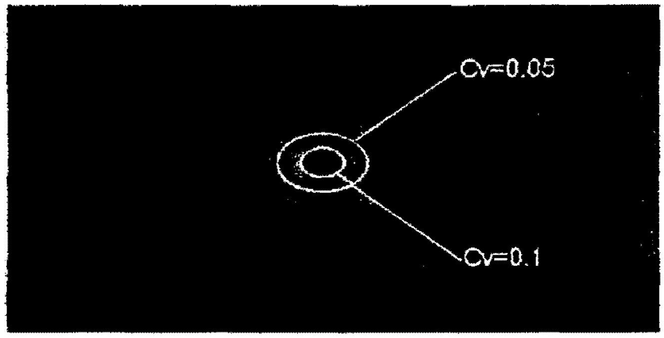


c. Homogeneous and Anisotropic Results (K_h:K_v=100)

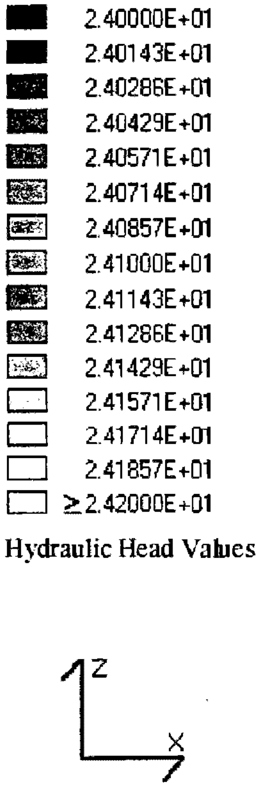
Fig. 6. Vertical cross-section of model results illustrating variations in hydraulic head values due to changes in anisotropy ($K_{aq}=1 \times 10^{-2}$ cm/s, $K_{win}=1 \times 10^{-2}$ cm/s). The ellipses define the approximate boundaries of the hydraulic features defined by specified critical values ($C_v=\bar{x}+0.1$ and $\bar{x}+0.05$).

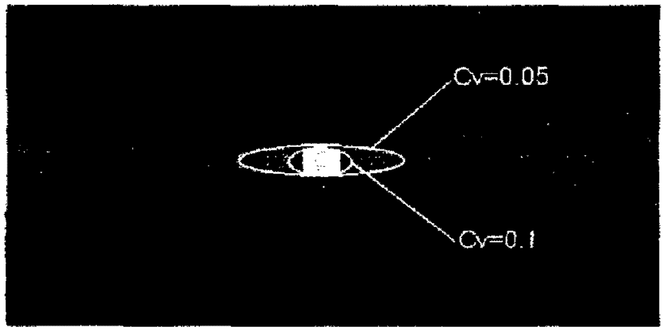


a. Homogeneous and Isotropic Simulation Results



b. Homogeneous and Anisotropic Results (K_h:K_v=10)





c. Homogeneous and Anisotropic Results (K_h:K_v=100)

Fig. 7. Vertical cross-section of model results illustrating variations in hydraulic head values due to changes in anisotropy ($K_{aq}=1 \times 10^{-2}$ cm/s, $K_{win}=1 \times 10^{-3}$ cm/s). The ellipses define the approximate boundaries of the hydraulic features defined by specified critical values ($C_v=\bar{x}+0.1$ and $\bar{x}+0.05$).

The grid sizes necessary to identify the hydraulic features described above with a 90% probability of success (β=0.1) were obtained using the nomograph in Fig. 4. The number of sampling points (N_s) necessary to identify the hydraulic features within the domain of the model cross-section is determined by dividing the cross-sectional area of the model (1,275 m^2) by the area of one square grid spacing (G^2). The results are listed in Table 3.

The number of monitoring points required to identify the hydraulic signatures of the simulated leaks using the prescribed constraints and confidence ranges from approximately 40 to over 300. The wide range of values is a function of the variability in the size and shape of the hydraulic features. This variability results from the use of different critical values to define the hydraulic signatures of the leaks and the wide range of shape factors resulting from the three orders of magnitude range of the anisotropy values.

CONCLUSIONS

Numerical modeling of ground-water flow through high hydraulic conductivity windows in subsurface vertical barriers was conducted to provide data sets for use with a probabilistic method for determining the grid spacing necessary to identify the hydraulic signature associated with the leaks. The proposed method of combined ground-water modeling and GIS represents a potential tool that may be used by the regulatory community and others to evaluate the adequacy of existing and proposed hazardous waste containment systems for identifying containment system leakage. The utility of the proposed method is

Table 3. Parameters and Results Obtained from Hydraulic Assessment Method.

Kwin (cm/s)	Kh:Kv	C_v	S	L	L/G	G	N_s
1×10^{-2}	1	0.1	0.8	2.5	0.64	3.91	84
1×10^{-2}	1	0.05	0.85	3.5	0.62	5.65	40
1×10^{-2}	10	0.1	0.28	3.5	1.64	2.13	280
1×10^{-2}	10	0.05	0.31	6.5	1.51	4.3	69
1×10^{-2}	100	0.1	0.13	7.5	3.5	2.14	278
1×10^{-2}	100	0.05	0.16	12.5	2.9	4.3	69
1×10^{-3}	1	0.1	BCL	-	-	-	-
1×10^{-3}	1	0.05	0.67	1.5	0.74	2.03	311
1×10^{-3}	10	0.1	0.67	1.5	0.74	2.03	311
1×10^{-3}	10	0.05	0.4	2.5	1.17	2.14	280
1×10^{-3}	100	0.1	0.4	2.5	1.17	2.14	280
1×10^{-3}	100	0.05	0.15	6.5	3.05	2.13	281
1×10^{-2}*	1	0.1	0.8	2.5	0.64	3.91	84
1×10^{-2}*	1	0.05	0.85	3.5	0.62	5.65	40
1×10^{-2}*	10	0.1	0.28	3.5	1.64	2.13	280
1×10^{-2}*	10	0.01	0.31	6.5	1.51	4.3	69
1×10^{-2}*	100	0.1	0.13	7.5	3.5	2.14	278
1×10^{-2}*	100	0.05	0.16	12.5	2.9	4.31	69

BCL = All head values below critical value threshold.
*Heterogeneous simulations; all other simulations homogeneous

demonstrated using simulated data. Based on the application of the method presented, the following conclusions were made:

- The number of points necessary to identify the hydraulic signature of a discrete leak within prescribed constraints is a function of the criteria used to delineate the feature;
- The hydraulic signature associated with a minor leak in a vertical barrier may be difficult to detect with a realistic number of monitoring points;
- By using the nomographs described above, the probability of failing to detect the hydraulic signature of a leak can be estimated for a given monitoring well spacing and specified confidence;
- The dimensions of the smallest hydraulic signature detectable with a given monitoring point spacing can be estimated, given the appropriate constraints and specified confidence;
- The monitoring point spacing used at many hazardous waste sites is likely inadequate to detect the hydraulic signatures of all but the largest leaks, and
- The method for delineating the hydraulic signature of a leak using the average hydraulic head plus specified values does not appear to be as sensitive to the heterogeneity of the aquifer as it is to anisotropy.

Disclaimer

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16. ABSTRACT

The use of physical and hydraulic containment systems for the isolation of contaminated ground water associated with hazardous waste sites has increased during the last decade. Existing methodologies for monitoring and evaluating leakage from hazardous waste containment systems rely primarily on limited hydraulic head data. The number of hydraulic head monitoring points available at most sites employing physical containment systems may be insufficient to identify significant leakage. A general approach for evaluating the performance of containment systems based on estimations of apparent leakage rates is used to introduce a methodology for determining the number of monitoring points necessary to identify the hydraulic signature of leakage from a containment system. The probabilistic method is based on the principles of geometric probability. A raster-based GIS (IDRISI) was used to determine the critical diminsions of the hydraulic signature of leakage from a containment system, as simulated under a variety of hydrogeologic conditions using a three-dimensional ground-water flow model. MODRISI, a set of computer programs was used to integrate ground-water flow modeling results into the hydraulic signature assessment method.

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