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CONSULTING ENGINEERS

REVIEW OF MONITORING WELL PLACEMENT FOR THE GROUT TREATMENT FACILITY HANFORD SITE, WASHINGTON

Prepared by:

Golder Associates Inc.

Charles R. Wilson
Associate

John S. Velimesis
Project Hydrologist

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GOLDER ASSOCIATES INC. • 4104 - 148TH AVENUE N.E., REDMOND (SEATTLE), WASHINGTON, U.S.A. 98052 • TEL. (206) 883-0777 • FACSIMILE (206) 882-5498 • TELEX 5106002944

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1. INTRODUCTION

This report presents a review of the RCRA groundwater monitoring well locations proposed by Westinghouse Hanford Company (WHC) for the Grout Treatment Facility (GTF) on the Hanford Site. The scope of work includes a review of the degree of conservatism inherent in the currently proposed well locations, and a review of the adequacy of the currently proposed network under expected future groundwater flow conditions at the site. Golder's Monitoring Efficiency Model (MEMO) was used to provide quantitative measures of the efficiency of the currently proposed and alternative monitoring networks. Recommended alternative networks are proposed to more efficiently address the monitoring requirements of the site.

The MEMO model is applied as a simple analytical transport model to evaluate the "efficiency" of various well locations and spacings, based on the abilities of the various well networks to intercept expected plumes of indicator parameters. Monitoring well efficiencies are determined for the current groundwater flow field beneath the GTF, and for expected changes in flow direction resulting from the dissipation of the groundwater mound under B-Pond and a return of the groundwater flow field to pre-Hanford conditions. The location of the GTF with respect to other facilities at the Hanford site is shown in Figure 1.

The results of the model application are used to address two important issues:

1. Is the currently specified monitoring well spacing overly conservative for detecting the potential release of contaminants from vaults under present groundwater flow directions; and

2. Will the current well spacing be adequate as B-Pond is decommissioned and the hydraulic gradients re-equilibrate to the pre-Hanford regional flow regime.

The following sections of this report contain a summary of site geologic and hydrogeologic conditions, a description of MEMO including the assumptions and parameters required, the MEMO analyses and results, and recommendations for changes in detection monitoring well placement to maximize efficiency for both current and expected future conditions at the GTF.

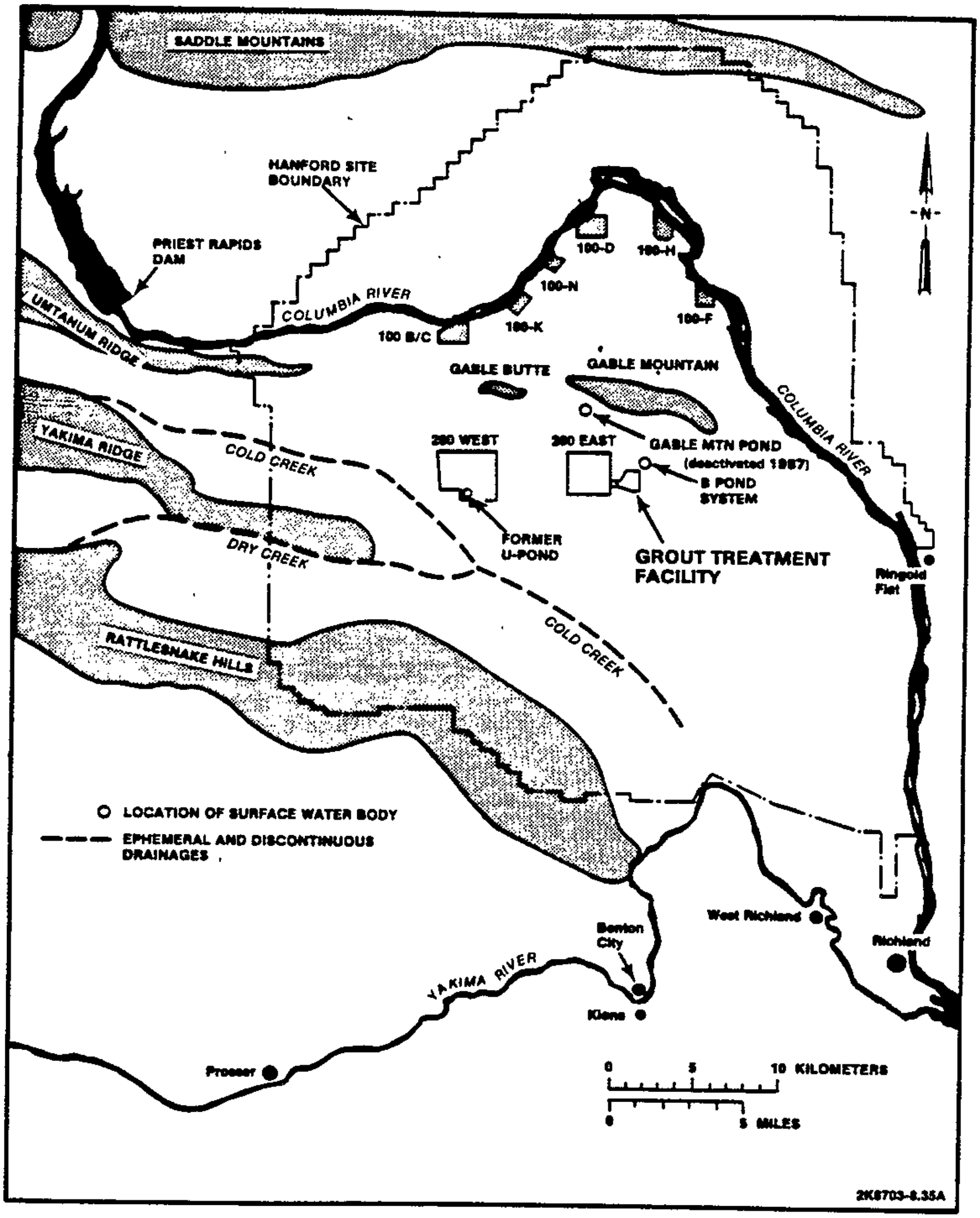

FIGURE 1

LOCATION OF GROUT TREATMENT FACILITY

WHC/GROUT/WA

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2. SITE GEOLOGIC AND HYDROGEOLOGIC CONDITIONS

A detailed presentation of the geology and hydrogeology of the GTF site is contained in the RCRA Part B Permit Application for the facility (Westinghouse Hanford Company, 1988). Brief summaries are presented here to provide background for the application of the MEMO model.

The three major geologic units that underlie the GTF site are, in ascending order: (1) the Elephant Mountain Member of the Columbia River Basalt Group, (2) The middle unit of the Ringold Formation (middle Ringold), and (3) the Pasco Gravels unit of the Hanford formation (Pasco Gravels, informal name). The surface of the Elephant Mountain Member has been eroded significantly to the north of the GTF by Pleistocene catastrophic flooding. Overlying the Elephant Mountain Member are unconsolidated-to-partly-consolidated fluvial and glaciofluvial sediments of the Hanford and Ringold Formations. The Pasco Gravels and the middle Ringold unit consist of unconsolidated to consolidated sands and gravels with minor silt, ranging from 269 to 446 ft thick unconformably overlying basalt. The contact between the Hanford and Ringold Formations underneath the GTF is presently undefined.

Confining units (clay layers) within the unconsolidated sediments are not present in any wells drilled to the top of basalt within or immediately adjacent to the GTF site. The absence of confining beds within the sediments above the basalt surface is typical throughout most of the adjacent 200 East Area. The aquifer in the Hanford and Ringold sediments is therefore considered unconfined beneath the GTF.

Hydraulic conductivity of the Hanford and Ringold sediments in the vicinity of the GTF site ranges from 2,000 to 10,000 ft/day and from 9 to 230 ft/day, respectively (Graham et al. 1981). These are general values which may vary significantly from place to place depending on the local geology. Transmissivity is generally higher in the 200 East Area than in the 200 West Area.

The anisotropic nature of the unconfined aquifer has been quantified at well 699-47-35 (northeast of the GTF), where the ratio of horizontal to vertical hydraulic conductivities ranges between 13 and 16 to one. These data give an indication of the preferred horizontal flow over vertical flow through the unconfined aquifer (Graham et al. 1981).

Sources of natural recharge to the unconfined aquifer are rainfall and runoff from the higher bordering elevations, water infiltrating from small ephemeral streams, and river water along influent reaches of the Yakima and Columbia Rivers. Little natural recharge to groundwater occurs from percolating precipitation due to the high evapotranspiration rates at the site. Potential evapotranspiration rates greatly exceed precipitation rates, with annual potential evaporation in excess of 60 in. Average precipitation is 6.3 in/yr; the 100 yr 24 hr storm is estimated at 2 in of rainfall.

A primary artificial source of recharge to the unconfined aquifer occurs from waste disposal operations at the Hanford Site. This artificial recharge occurs principally within the Separations Area (area around and including the 200 West and 200 East areas), and is

3. MONITORING EFFICIENCY MODEL (MEMO)

The Monitoring Efficiency Model (MEMO) developed by Golder Associates Inc. provides a simple way to quantify the effectiveness of a monitoring well network design. The MEMO model is based upon the simple concept of the generation and growth of a plume as that plume migrates downgradient from a continuous source. The model provides, as output, a map of the waste management area (WMA) showing where releases would and would not be likely to be detected under the known constraints assumed for the analysis. The constraints consist of the input parameters used to compute the shapes and sizes of the plumes, the hydraulic head information used to determine the direction of groundwater movement, the analytical detection limits for water samples from the monitoring wells, and the extent to which the tip of a plume will be allowed to migrate beyond the WMA boundary before it is detected. The principal output of the MEMO model is the "monitoring efficiency," defined as the ratio of the area within the WMA where a release would be likely to be detected, to the total area of the WMA. This definition assumes that development of a release is equally likely at any location within the WMA. At a facility such as the GTF, where waste is not evenly distributed throughout the WMA but limited to specific vault locations, releases can occur only in the areas beneath the vaults and only those areas should be considered in determining monitoring efficiency.

To comply with the groundwater monitoring requirements of WAC 173-303 (Washington Administrative Code, 1988), monitoring wells at dangerous waste sites are located at intervals along "the hydraulically downgradient limit of the waste management area..." (WAC 173-303-645(6)(a)), in which the WMA is defined as "the limit...on which waste will be placed during the active life of the regulated unit" (WAC 173-303-645(6)(b)). These regulations, therefore, require that the monitoring wells be placed as close as reasonably possible to the edge of the burial ground.

The hydraulically downgradient limit of a hypothetical Waste Management Area (WMA) is shown in Figure 2 with monitoring wells located at intervals immediately downgradient of that limit. A plume developing from a continuous release at location A on the figure would be detected because by the time it migrated to the vicinity of the WMA boundary, it would have grown large enough to pass through the location of a monitoring well. However, a plume of the same size, developing from a continuous release between two monitoring wells at location B near the WMA boundary, would not yet have been detected. This illustrates that releases occurring at most locations within the WMA would be expected to be detected, but releases occurring at restricted locations between the monitoring wells and near the downgradient boundary would be less likely to be detected. Given that monitoring wells will always be spaced some finite distance apart, and given the uncertainties inherent in predicting the behavior of a natural geologic system, a level of uncertainty will always be present in the functioning of any groundwater monitoring network design.

An illustration of the application of the MEMO model is shown in Figure 3. The model, in its simplest form, is deterministic and manually applied. Data sets must be developed that will conservatively identify the size and shape of the plumes, the analytical detection limits, and the extent of migration into the "buffer zone" shown in the figure. Having determined

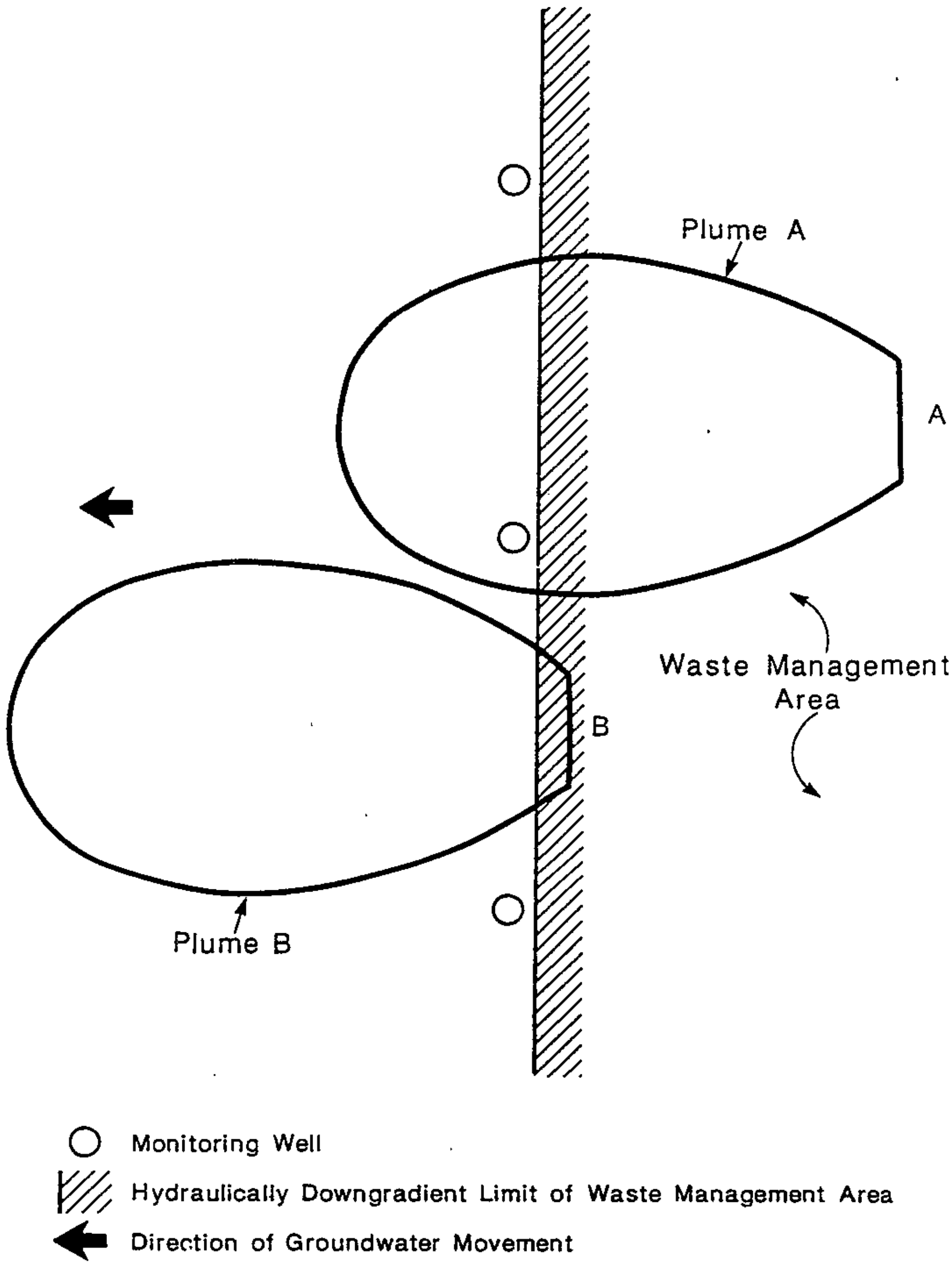

FIGURE 2
ILLUSTRATION OF PLUME DETECTION
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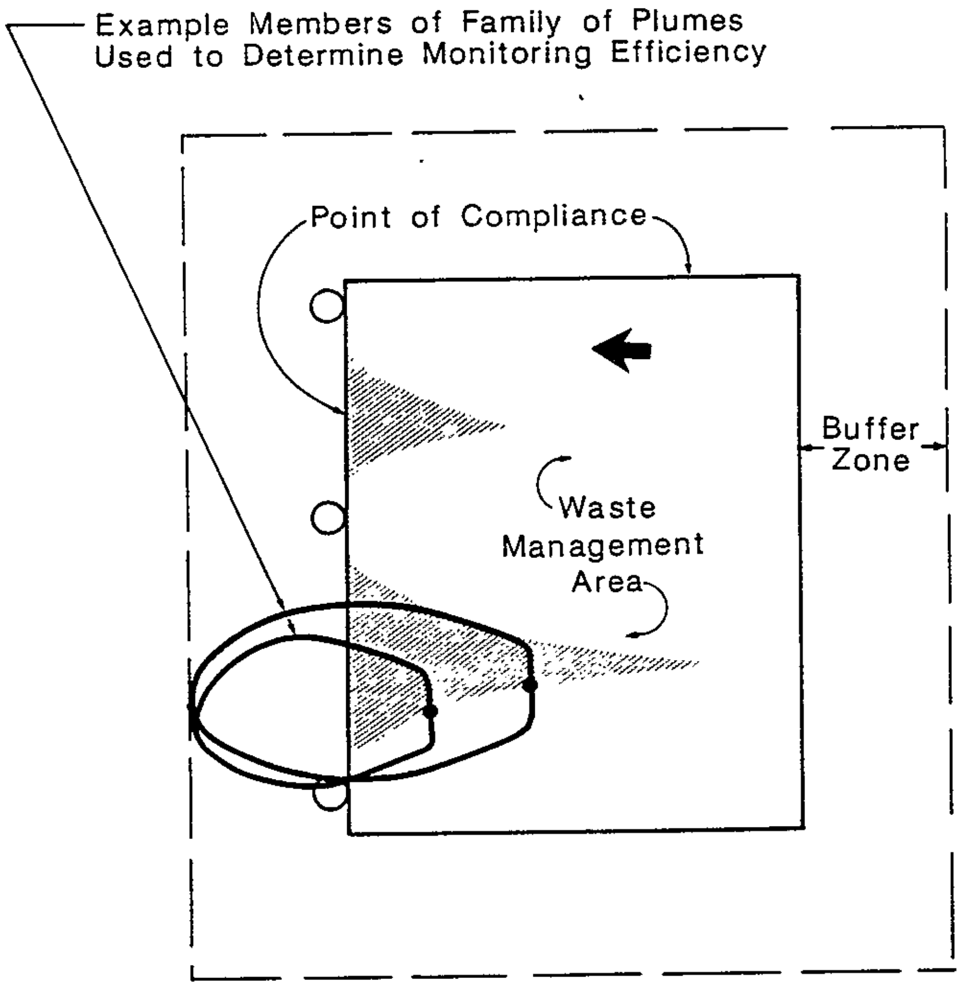

Monitoring Well

Area Where Leak is Less Likely to be Detected

Direction of Groundwater Movement

Monitoring Efficiency: 87%

FIGURE 3

ILLUSTRATION OF MEMO RESULTS

WHC/GROUT /WA

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these constraints, a family of plumes of different sizes is developed, each representing the shape of the plume after traveling a known distance. An example of such a family is shown in Figure 4.

Using successively larger plumes, a series of points is developed on a map of the WMA which, when connected by a smooth curve, represents the boundary between locations of releases that are likely to be detected and locations of releases that are not likely to be detected within the constraints of the method. Each point represents the location of a release where the resulting plume meets the following three criteria: (1) the edge of the plume touches one or more monitoring wells; (2) the axis of the plume is oriented in the direction of groundwater flow; and (3) the tip of the plume touches the edge of the buffer zone. Satisfying these three criteria uniquely locates the plume in space and, therefore, identifies the location of the release.

The monitoring efficiency shown in Figure 3 is 87 percent. This value is lower than what would normally be desirable at an actual site, and is used for illustration. The monitoring efficiency is a function of the constraints of the method, and within practical limits, can be controlled through not only the spacing of the monitoring wells, but also the degree of conservatism in the selection of hydrologic and transport parameters, width of buffer zone, and other model inputs. Detailed discussions of applying the MEMO model, its input parameters, and the inherently conservative assumptions used in analysis of the GTF on the Hanford Site are presented in the following paragraphs.

3.1 Plume Generation Model

The plume generation model is the part of the MEMO model that computes the sizes and shapes of the plumes. The plume generation model used in this analysis of the shallow monitoring well network is the two-dimensional analytical transport model of Domenico and Robbins (1985). This model assumes that solute is released along a continuous line source in a uniform aquifer, and predicts the concentrations that would be observed at points downstream of the source. The governing equation is:

$$C(x,y,t) = (C_o/4)e^{-kt}\ \mathrm{erfc}[(x-vt)/2D_x t^{1/2}]\ [\mathrm{erf}[(y+Y/2)/2(D_y x/v)^{1/2}]-\mathrm{erf}[(y-Y/2)/2(D_y x/v)^{1/2}]]$$

Where:

$C(x,y,t)$ is the	concentration at x,y,t
C_o	is the source concentration
x	is the distance downstream from the source
y	is the transverse distance from the source
k	is the first-order radioactive decay constant
Y	is the width of the source
v	is the seepage velocity

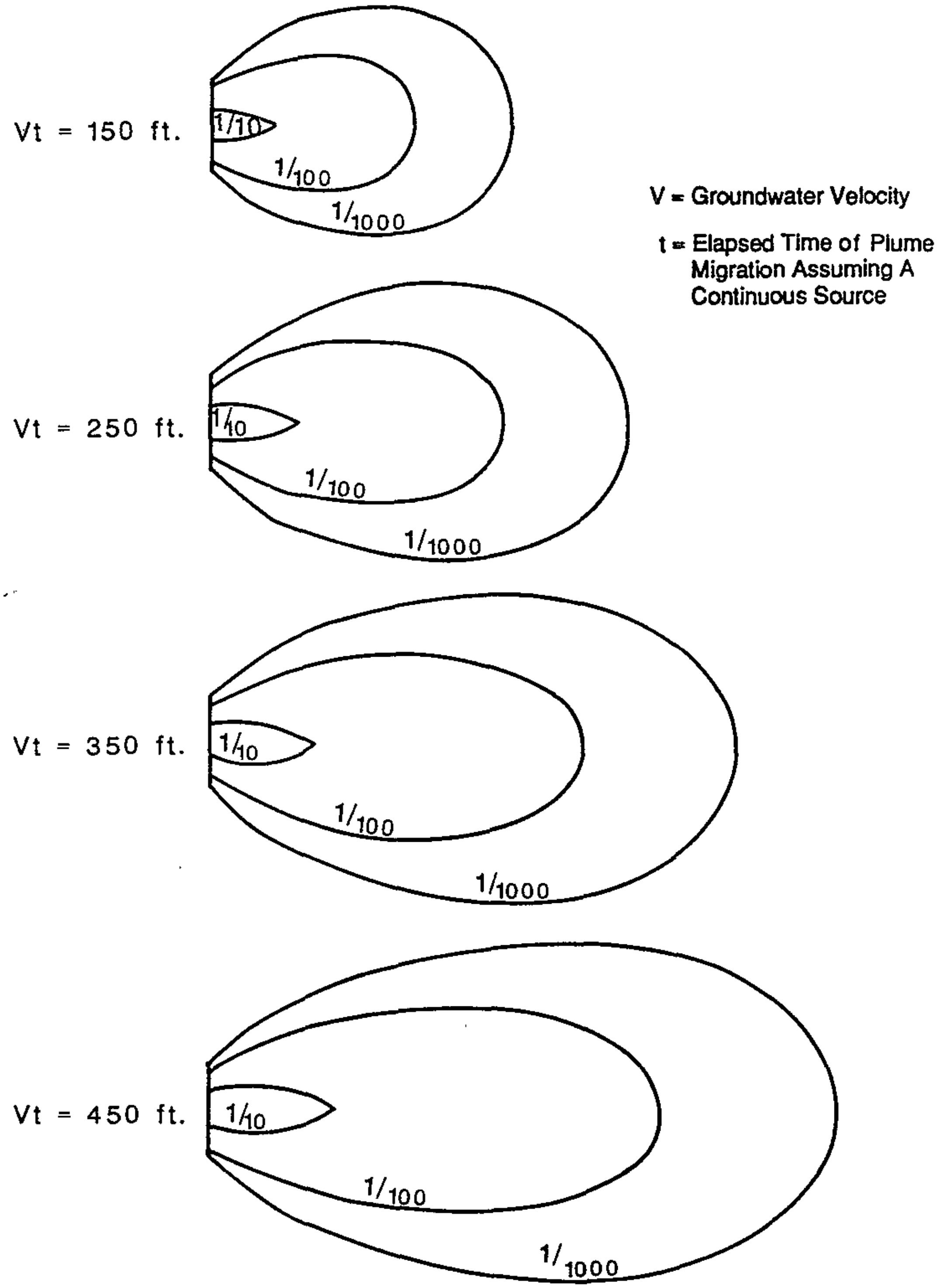

FIGURE 4
DILUTION CONTOURS FOR A FAMILY OF PLUMES
WHC/GROUT/WA

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D_x is the longitudinal dispersion coefficient
D_y is the transverse dispersion coefficient
t is time

The groundwater seepage velocity is computed as:

$$v = Ki/Rn$$

Where:

K is the hydraulic conductivity
i is the groundwater gradient
R is the retardation factor
n is the effective porosity

The dispersion coefficients are functions of the seepage velocity, the dispersivities, and the diffusion coefficient for the chemical of interest in water:

$$D_x = \alpha_x v + D_m$$

$$D_y = \alpha_y v + D_m$$

Where:

α_x and α_y are the longitudinal and transverse dispersivities, respectively; and

D_m is the effective molecular diffusion coefficient for the chemical of interest through the porous medium

For most field situations, the diffusion coefficient is quite small compared to the advective velocity term and can be neglected.

The Domenico and Robbins model is well posed for application to the Hanford Site. The line source assumed in the model can be adjusted to account for dispersion in the vadose zone as the leachate migrates toward the water table. The assumption of two-dimensional flow is appropriate for analysis of the shallow wells which will monitor the lower density constituents that exhibit minor vertical mixing. The assumption of a continuous rather than a finite source of leachate assures that releases from leaks deep within the WMA do not disperse to below detection limits and can also be evaluated by the method.

Other assumptions are also made that were not previously mentioned. The assumption that the volume of leachate is small compared with the flux in the aquifer is appropriate for the arid conditions at the Hanford Site. The assumption of a uniform aquifer generally implies uniform hydrologic and transport properties and a uniform hydraulic gradient over the length of the plume. Although the high variability of these properties over the area of the Hanford Site have been documented, their variability over the several hundred foot lengths of the plumes considered in this analysis will be considerably less. Every model requires an assumption of uniform conditions over some limited domain. The variability of these properties is discussed in further detail below.

In applying the Domenico and Robbins model, it is interesting to note that the shape of a plume of a given length is the same regardless of the time required to attain that length. This means that a plume that traveled 500 ft in five years would be predicted to be the same shape as one that traveled 500 ft in 50 years. The shape of the plume is, therefore, assumed to be independent of the hydraulic parameters governing rate of movement, including the hydraulic conductivity, hydraulic gradient, and effective porosity, so long as those parameters are constant over the area of the plume.

3.2 Plume Generation Data Base

The basic input parameters for generating the plumes are the source characterization, definition of detectable concentrations, the transport parameters, and the groundwater hydraulic parameters. Of these, only the hydraulic conductivities and gradients are known in sufficient detail and permit site-specific evaluation. The remaining parameters must be characterized generically, and are discussed in the following paragraphs.

In applying the MEMO model, it is necessary to identify a dilution contour for the plume generation model that may be related to an appropriate detection limit for the types of constituents likely to be detected in the shallow monitoring wells. Contours of equal dilution of the source concentration define the shape of a plume. Dilution is defined as C/C_o, where C is the concentration at a point in the plume and C_o is the concentration at the source. For purposes of the MEMO model, a plume is defined by the dilution contour C_D/C_o, where C_D is the detection limit for a representative chemical.

To establish dilution contours for the model, both C_D and C_o must be identified for the indicator parameter. The detection limit C_D is governed by the analytical method, and is specified in the WHC contract with the laboratory performing the chemical analysis.

The source concentration C_o may be estimated from site information, or from the regulatory limit of the indicator parameter. Site information would typically consist of either measured concentrations taken from groundwater samples beneath a contaminated site, or estimated concentrations based on the chemical compounds in the waste and the mechanisms available for mobilizing and transporting that waste to the groundwater. Site information would typically not be available for new sites where the waste stream cannot be fully known, and the regulatory limits would then be used to bracket the range of source concentrations of interest in monitoring network design. Lower concentration sources lead to more conservative network designs with the MEMO model, thus the C_o of interest will lie between the detection limit or background concentration on the low end, and the regulatory limit on the high end. In general, C_o should lie closer to the regulatory limit than to the low end of the range to base the design on concentrations whose health effects have potential significance. The final value of C_o chosen as a design basis will depend upon the required degree of conservatism, the sensitivity of the design to the value of C_o, the background concentrations in the groundwater, and other site-specific factors.

The detection level monitoring program indicator parameters for the GTF as presented in the Part B Permit Application are:

- Total organic carbon (TOC)
- Total organic halogen (TOX)
- pH
- Specific conductance
- Arsenic (As)
- Chromium (Cr)
- Selenium (Se)
- Technetium-99 (Tc-99)

Only the last four metals are suitable parameters for establishing dilution contours as C_D/C_o. Specific conductance and pH are not expressed as concentrations, and TOC and TOX are not specific parameters for which convenient C_D/C_o ratios may be readily established.

Although the waste characterization chapter of the GTF Part B Permit Application indicates that the four indicator metals are expected to be present in the grouted waste, no information is currently available concerning the concentrations and chemical forms of these constituents in the grout. In addition, depending upon the mix of waste streams from which the grout is made at any point in time, the concentrations and chemical forms are expected to vary. As a result, it is not possible to determine, with any certainty, the initial concentration, C_o, in the groundwater, of any of the four metals using site information. Instead, it will be necessary to base C_o on the regulatory limit.

Primary Maximum Contaminant Levels (PMCLs) have been established for each of the four metals in WAC 248-54-175 (Washington Administrative Code, 1989). The standards are in the form of metal ion concentrations and are independent of the chemical form in which the metal may have been present in the waste. The current PMCL for each is listed below along with the detection limit as applied in current groundwater sampling procedures at the Hanford Site (Pacific Northwest Laboratory, 1989a).

Chemical	PMCL C_{PMCL} (ppb)	Detection Limit C_D (ppb)	C_D/C_{PMCL}
Se	10	5	1/2
As	50	5	1/10
Cr	50	10	1/5
Tc-99	0.053* (900 pCi/L)	0.0009 (15 pCi/L)	1/60

*Based on standards for beta radiation emission (Pacific Northwest Laboratory, 1989b).

The ratio C_D/C_{PMCL} in the tabulation provides an indication of the variability seen in the ranges of these parameters, which extend for the metals of interest from a factor of two to well over an order of magnitude. Sufficient information on background concentrations of these metals at the GTF was not available, and the detection limit will therefore be used as a lower limit for this range.

In selecting an indicator parameter to serve as the basis for network design, preference should be given to a parameter with a relatively high mobility, that is present in the waste in significant quantity, and that has a relatively high level of toxicity. Such a parameter would serve as a good indicator: its mobility would assure its early appearance in the groundwater should the waste isolation systems be breached, its quantity would help assure its presence in detectable amounts, and its toxicity would make it an important chemical to monitor.

Of the four metals, technetium-99 appears to be best suited as an indicator parameter. It is highly soluble and is not readily sorbed in the range of concentrations of interest. It is therefore expected to be very mobile in groundwater. It is also generally present in the tank wastes in higher concentrations relative to its PMCL than the other metals, as indicated in Section 3 of the GTF Part B permit application (Westinghouse Hanford Company, 1988). Finally, its relatively high toxicity is indicated by the small quantities permitted in drinking water, as shown in the foregoing tabulation. Selenium is rapidly sorbed up to concentrations of 500 ppb, well above the PMCL, and therefore does not have the mobility of technetium. Chromium is also rapidly sorbed and removed from solution under a variety of redox conditions. Although arsenic is present in relatively high concentrations in the tank wastes, its variable mobility, its lower concentrations relative to its PMCL, and relatively lower toxicity all indicate that it would not be as good an indicator chemical as technetium-99.

The PMCL for technetium-99 has been determined to be 900 pCi/L, based on a standard for Beta radiation emission in WAC 248-54-175 (Washington Administrative Code, 1989). A source concentration C_o that is half an order of magnitude below this limit (or 285 pCi/L) is considered to be sufficiently conservative to serve as a design basis for the monitoring wells, and yet not be overly conservative in protecting human health and the environment considering that there are no nearby uses of groundwater at the GTF site. The resulting C_D/C_o ratio for technetium-99 is 15 divided by 285, or 0.0526. This dilution contour is used in all MEMO analyses of the GTF.

A hypothetical release from the GTF is assumed to result from leaching of contaminants from the vaults, with or without the presence of cracks in the concrete shell and the surrounding barrier layers. Cracks would tend to provide a preferential flow path for saturated pulses of water infiltrating through the unsaturated zone. However, since little is known regarding the potential failure modes of the vaults and the barriers, a conservative effective line source width of the contaminant plume is assumed. The depth of the unsaturated zone is typically in excess of 200 ft beneath the GTF. It is assumed that leaching from a given vault will have an equivalent line source length of 40 ft at the top of the unconfined aquifer. This value is less than the minor axis length of a vault (50.5 ft) and is conservative considering the possible spreading of the plume as it migrates downward through the unsaturated zone. Orientation of the line source is always assumed to be perpendicular to the flow field being analyzed.

The transport parameters consist of the retardation factor, the effective porosity, and the longitudinal and transverse dispersivities. Because these parameters are difficult to measure and site-specific data are not available, conservative values were taken from the literature and applied to the GTF.

Retardation was effectively ignored by assuming a factor equal to 1.0. This results in conservatively high constituent mobilities. The effective porosity for the sediments of the unconfined aquifer beneath the 200 Area is expected by Graham et al. (1981) to range from ten to 30 percent. Properties of the unconfined aquifer beneath the GTF are expected to be similar to those beneath the 200 areas. A value of 20 percent is assumed here. As was previously noted, however, the shape of a plume of a given size is independent of both retardation and effective porosity, so long as those parameters are uniform over the area of the plume. Because retardation was not considered, and the effective porosity is an estimated value that varies over a relatively small range, the assumption of uniformity is considered reasonable.

The width of the plume is quite sensitive to the dispersivity, and particularly to the transverse dispersivity. Because the magnitudes of the longitudinal and transverse dispersivities are not known for the GTF, conservative estimates were developed from the literature. Gelhar et al. (1985) have compiled longitudinal dispersivity data for more than 65 sites and have related the values to the scale at which the data were obtained. Although Gelhar et al. warn that the reliability of some of these data are questionable, the value of dispersivity was generally found to increase as the scale of the test increased. With respect to the GTF, the scale of interest is on the order of 300 to 1,000 ft. This is the distance from a hypothetical release location to the edge of the buffer zone.

Reviewing the data presented by Gelhar et al. (1985), the longitudinal dispersivities were found to range from about ten to 100 m (30 to 320 ft) for our scale of interest. One of the data points falling within this range was determined from tests in a multi-layer gravel, sand and silt unit (Wilson, 1971; Robson, 1974), somewhat analogous to the Ringold sediments which underlie the GTF. The value of longitudinal dispersivity was 49 ft, measured over a length of 260 ft. Other data points indicate a longitudinal dispersivity of 30 to 100 ft over a length of 300 ft for alluvial materials derived from a tuff (Daniels, 1981). Smaller dispersivities are more conservative because they produce narrower plumes that are harder to detect. Based on the foregoing information, and considering that specific data from tests in similar lithologies were generally for a smaller scale that is of interest in the GTF, the longitudinal dispersivity was conservatively estimated to be 70 ft.

Data on transverse dispersivity are less common than on longitudinal dispersivity, and are often expressed as a ratio of longitudinal to transverse values. The use of a ratio recognizes that the two parameters are not independent, and simplifies consideration of scale effects by lumping them into the longitudinal dispersivity. Values of the dispersivity ratio were developed from data assembled by Isherwood (1981) and Gelhar et al. (1985), and were generally found to range from one to ten with a mean of about five. Because larger ratios would result in smaller transverse dispersivities, a ratio of seven was conservatively selected for the model. The resulting transverse dispersivity was therefore ten feet.

3.3 Buffer Zone Width

The width of the buffer zone is the distance beyond the limit of the GTF compliance boundary that a plume may extend before it is detected by a monitoring well. For purposes of the MEMO model, plumes that are detected before reaching the boundary of the buffer zone are considered to have been detected. Plumes that are not detected before reaching the boundary of the buffer zone, for purposes of the MEMO model, are considered to not have been detected. It should not be inferred that plumes considered "not detected" for purposes of this model will never be detected. Such plumes will continue to expand over time, and their probability of eventual detection will increase. Identification of a buffer zone width is essential to the model and addresses the fact that some of the leachate that may be generated will cross the GTF compliance boundary before it is detected by a monitoring well, if the monitoring wells are located a reasonable distance apart.

A reasonable, conservative buffer zone width for the GTF is developed by applying the criteria upon which the detection monitoring system is based. The monitoring network is established such that it can "immediately detect" any statistically significant amounts of hazardous waste introduced into the uppermost aquifer (Westinghouse Hanford Company, 1988). As detailed in the Part B Permit Application, "immediately detect" is interpreted to mean that the indicator constituents will be detected within one sampling period of the time waste constituents have entered the groundwater. Because the sampling frequency is semiannual (after background is established), wells must be located such that constituents will be detected within 180 days.

The monitoring network for the GTF, defining the compliance boundary, is 140 ft from the facility perimeter to allow installation of the monitoring wells prior to vault excavation. This allows sampling to establish background concentrations of indicator constituents prior to construction, and permits vault construction without disturbing the zone immediately surrounding the monitoring well.

The estimated groundwater velocities for the current flow field beneath the GTF range from 2 to 3 ft/day (Westinghouse Hanford Company, 1988). Using the conservative value of 2 ft/day, a maximum of 70 days are required for the constituents to travel from the waste facility perimeter to the compliance boundary. Since the maximum period of time to permitted to detect a constituent is 180 days, the buffer zone width may be defined as the distance traveled between 70 and 180 days, or 110 days multiplied by 2 ft/day, or 220 ft.

It should be noted that a smaller buffer zone width is more conservative for the purposes of the model, because it will generate a lower apparent monitoring efficiency. A smaller buffer zone is also advantageous in facilitating cleanup and reducing cleanup costs should a release occur, yet an excessively small zone will increase costs by inflating the required number of monitoring wells.

The current horizontal hydraulic gradient beneath the GTF is expected to be higher than future gradients due to the tall, relatively steep groundwater mound currently beneath the B-Pond complex which dominates the local flow field. As the mound dissipates, the gradient is expected to decrease and change direction. The final gradient is not expected to be as large as the current gradient. As a result, the current horizontal flow velocities are the greatest expected during the period of this analysis. Therefore, a 220 ft buffer zone as defined above is the minimum buffer zone expected and is conservative for all of the conditions examined.

3.4 Considerations in Model Application

It is recognized that the primary benefit of the MEMO model is to provide a standard means of comparing the relative merits of alternative monitoring well network designs. The monitoring efficiencies computed from the model results provide a means of quantifying the improvement gained from alternative well locations and densities, and the graphical output provides a means of visualizing the areas of improvement. As with any analysis of solute transport phenomena, there is expected to be considerable uncertainty in the input parameters that render questionable the precise values developed from the model results. With the model in its present configuration as a deterministic tool, these uncertainties can best be addressed by using conservative estimates of the input parameters, and performing limited sensitivity studies on those parameters. In adopting this approach, the predicted monitoring efficiencies would be expected to be somewhat lower than the actual efficiencies, and the relative magnitudes of the efficiencies should be valid for comparing alternative network designs. This approach has been implemented for the GTF application, and is described in the subsequent paragraphs. Further refinement to develop the model as a probabilistic tool will enable the user to quantify the degree of conservatism in the final network design.

The MEMO model requires the user to address the question of detection and nondetection of a plume under a specific set of input constraints. This distinction is somewhat artificial in that it is considered only as a device for comparing the relative merits of alternative monitoring system designs, and does not address the question of whether a release at a given location would ultimately be detected. In practice, the tendency to generate leachate from the solid waste in the GTF would not be confined to one location, as is conservatively assumed in the model, but would be expected to occur generally throughout the area. This is because the waste is generally of the same type and the same age, and each vault is subject to the same environmental conditions. Multiple "releases," occurring at generally the same time, would have a much better chance of detection than the single releases assumed in the model. Even if a single release did occur under the conservative assumptions used in the model, the probability of detecting it would increase over time as the plume grew larger. As was noted earlier, uncertainty will always be present in attempting to predict the behavior of a geologic system, and application of the MEMO model provides a means of quantifying and therefore controlling some aspects of that uncertainty.

4. MEMO ANALYSIS AND RESULTS

A complete description of the current detection monitoring network is contained in the Part B permit application for the GTF (Westinghouse Hanford Company, 1988), which was submitted to the Washington Department of Ecology (Ecology) in November, 1988. Justification of the well placement is also included in the permit application. Locations for the shallow monitoring wells are identified along the downgradient sides of the GTF. Wells are located approximately 140 ft from the boundary of the waste management area, at the margin of the excavation limits imposed by vault construction. An initial well spacing of approximately 150 ft is used in the permit application. The locations of the currently proposed wells are shown in Figure 5.

4.1 Analysis Under Present Groundwater Flow Conditions

The present groundwater gradient for the GTF is also shown in Figure 5. Application of the MEMO model to the currently proposed monitoring network results in a 100 percent efficiency under present groundwater flow conditions. Using the parameters developed in Section 3 above, the plumes generated by the MEMO model are always intercepted by the monitoring well network. Under current flow conditions, only wells along the eastern and southern compliance boundaries are required. This is consistent with the current network design.

Increasing the spacing of future wells (those not yet constructed) along the southern boundary of the GTF up to 250 ft did not decrease the efficiency of the monitoring well network for present flow conditions. This is due primarily to the acute angle of incidence of the groundwater flow direction with the southern compliance boundary.

4.2 Analysis Under Intermediate Future Groundwater Flow Conditions

Changes in the direction of groundwater flow are expected as the groundwater mound beneath B-Pond decays. The flow is expected to swing from its current southwesterly direction to a southerly orientation, and then eventually to an easterly orientation. Monitoring well spacing is most sensitive to the intermediate condition where groundwater flow is from north to south. The efficiency of any given network is lowest for flow in this direction because the major axes of the vaults and the downstream compliance boundary are perpendicular to the flow field.

The currently proposed well spacing of 150 ft along the southern compliance boundary was found to be 100 percent efficient for the intermediate flow conditions. None of the vaults is positioned such that plumes reach the buffer zone boundary without first encountering a monitoring well.

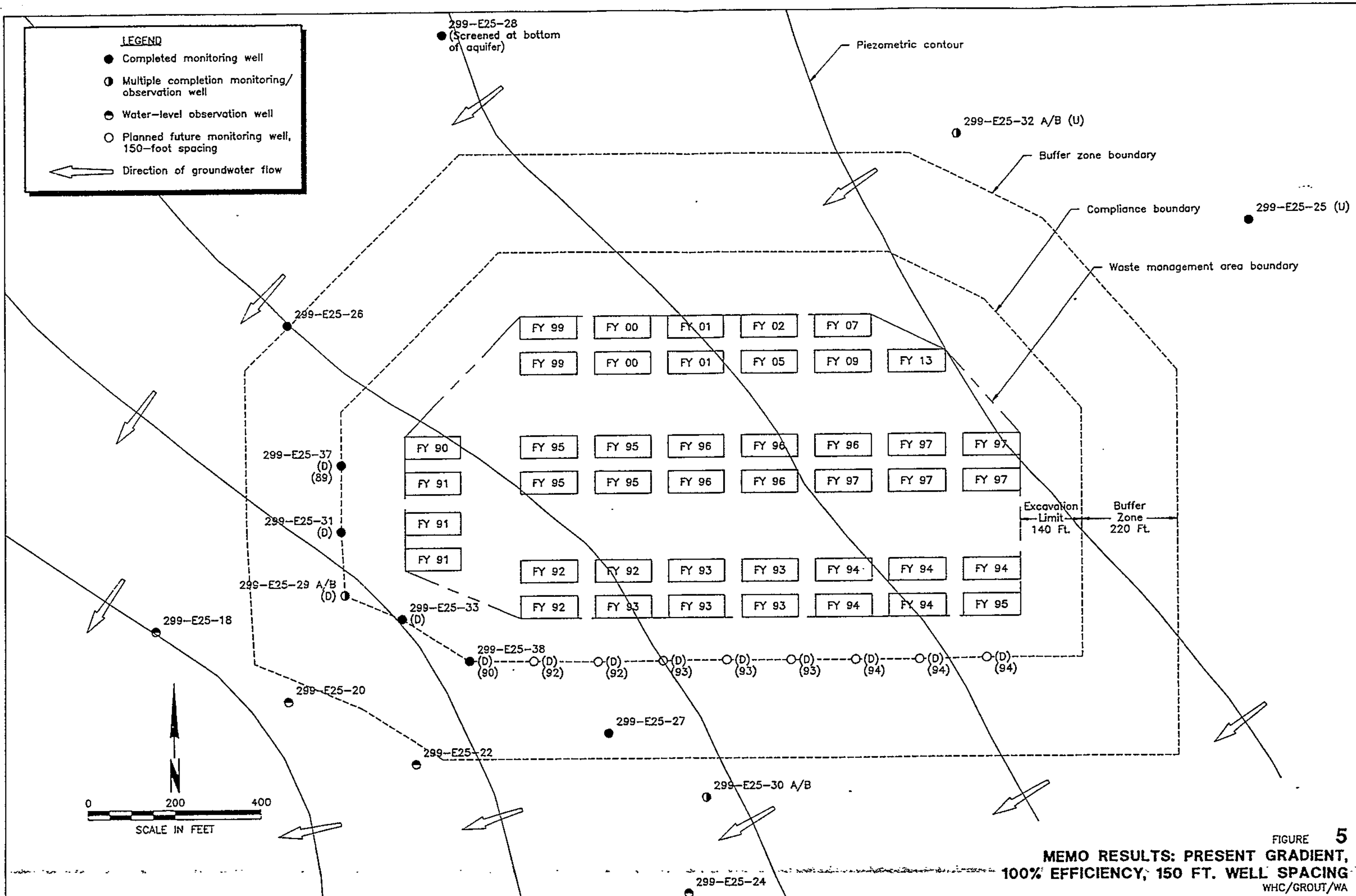

FIGURE 5

MEMO RESULTS: PRESENT GRADIENT, 100% EFFICIENCY, 150 FT. WELL SPACING

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Increasing the spacing of future monitoring wells along the southern compliance boundary to approximately 225 ft, and optimizing their positions to maximize monitoring efficiency, results in a 97 percent monitoring efficiency while reducing the required number of proposed wells on this boundary from eight to six. This well spacing and the corresponding MEMO results are shown in Figure 6.

A further increase in the spacing of the southern boundary wells to about 250 ft, and optimizing their placement, results in a 91 percent monitoring efficiency while reducing the number of proposed wells to five. These results are shown in Figure 7.

In all cases under this intermediate groundwater flow direction, the spacing of monitoring wells along the east and west compliance boundaries does not significantly affect the resulting network efficiency. Again, this is due to the geometry of this most sensitive case.

4.3 Analysis Under Long Term Future Groundwater Flow Conditions

The eventual decay of the groundwater mound under B-Pond is expected to allow the groundwater flow direction to return to pre-Hanford conditions. The resulting flow from west to east is the least sensitive with respect to monitoring network efficiency. As shown in Figure 8, because of the geometry of the GTF vaults, three wells are adequate to provide 100 percent monitoring efficiency under the parameters developed in Section 3 above. One well, placed 140 ft due east from the center of each double column of vaults, provides optimum efficiency. The resulting spacing of these wells, from south to north, is 280 ft and 270 ft, respectively.

4.4 Sensitivity Analysis

Sensitivity studies were performed on source strength (dilution contour selection) and line source width because the model is expected to be particularly sensitive to these parameters. Other parameters to which the model is sensitive are well spacing, buffer zone width, and transverse dispersivity. The effects of well spacing are discussed above for each flow direction, and the buffer zone width is established by the aforementioned requirement for "immediate detection." While the model is moderately sensitive to the value of transverse dispersivity, it is more sensitive to line source width. Therefore, no sensitivity analysis of transverse dispersivity was attempted.

Increasing the source concentration one-half order of magnitude is equivalent to using the PMCL for C_o in the MEMO analysis. This widens the plumes and increases the computed efficiency of the network to 100 percent for all but the intermediate future flow field with a 250 ft spacing, which becomes 99+ percent efficient. Decreasing the source concentration one-half order of magnitude below the initial value (where C_o is one full order of magnitude below the PMCL) results in reducing the efficiency of the present and intermediate future cases. However, this value of C_o is within one-half order of magnitude of the detection limit

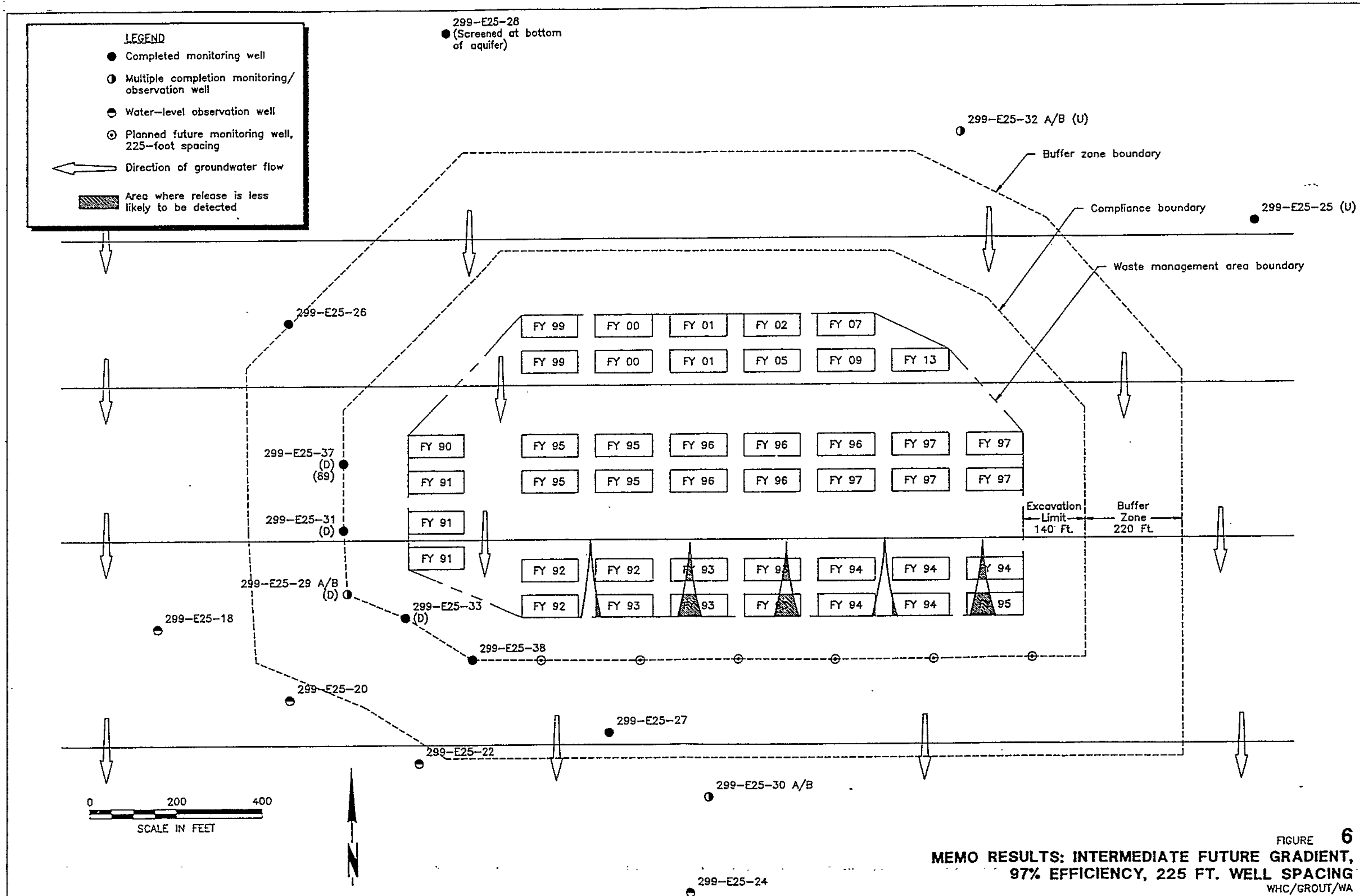

FIGURE 6

MEMO RESULTS: INTERMEDIATE FUTURE GRADIENT, 97% EFFICIENCY, 225 FT. WELL SPACING

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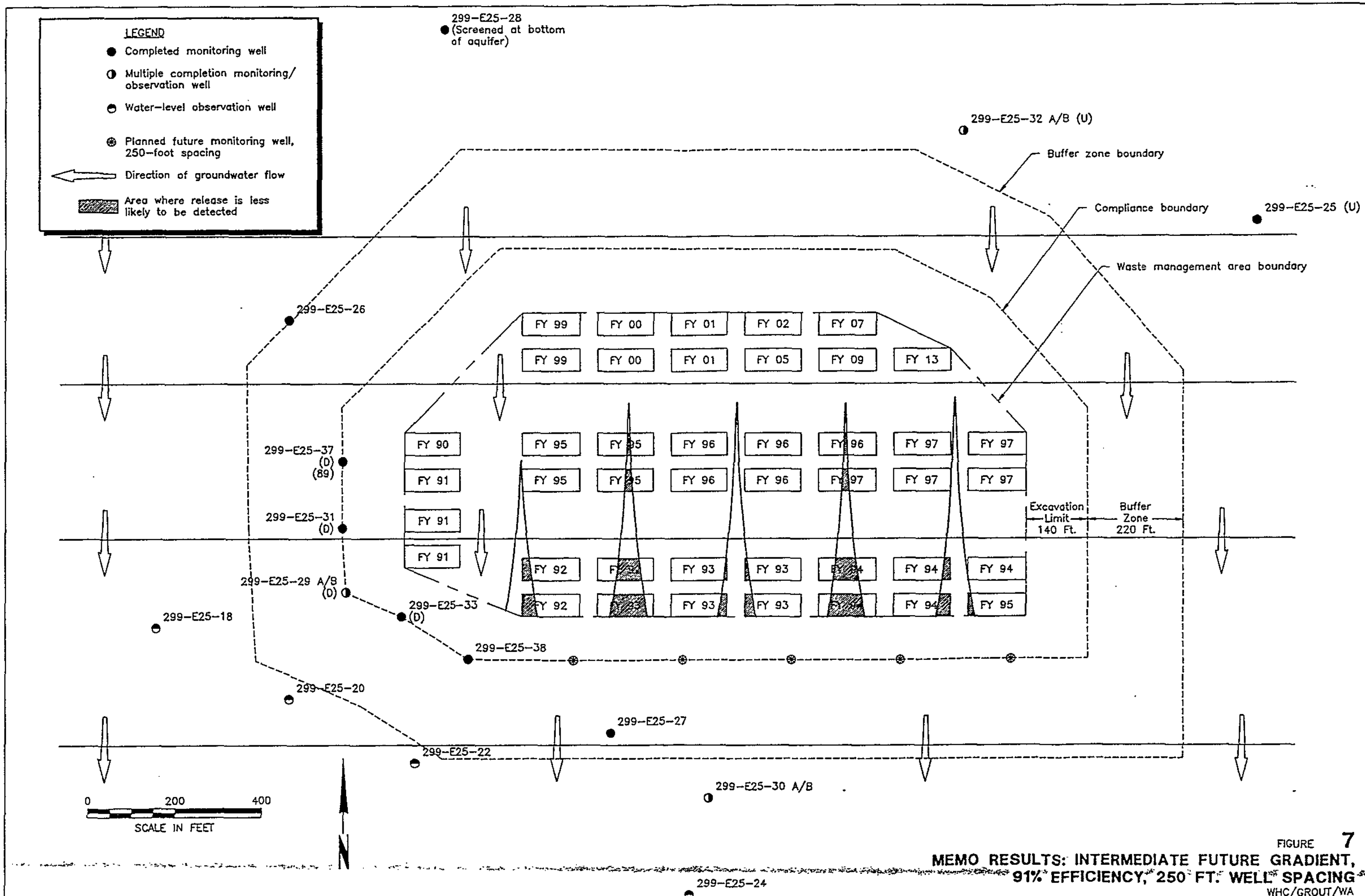

FIGURE 7
MEMO RESULTS: INTERMEDIATE FUTURE GRADIENT, 91% EFFICIENCY, 250 FT. WELL SPACING
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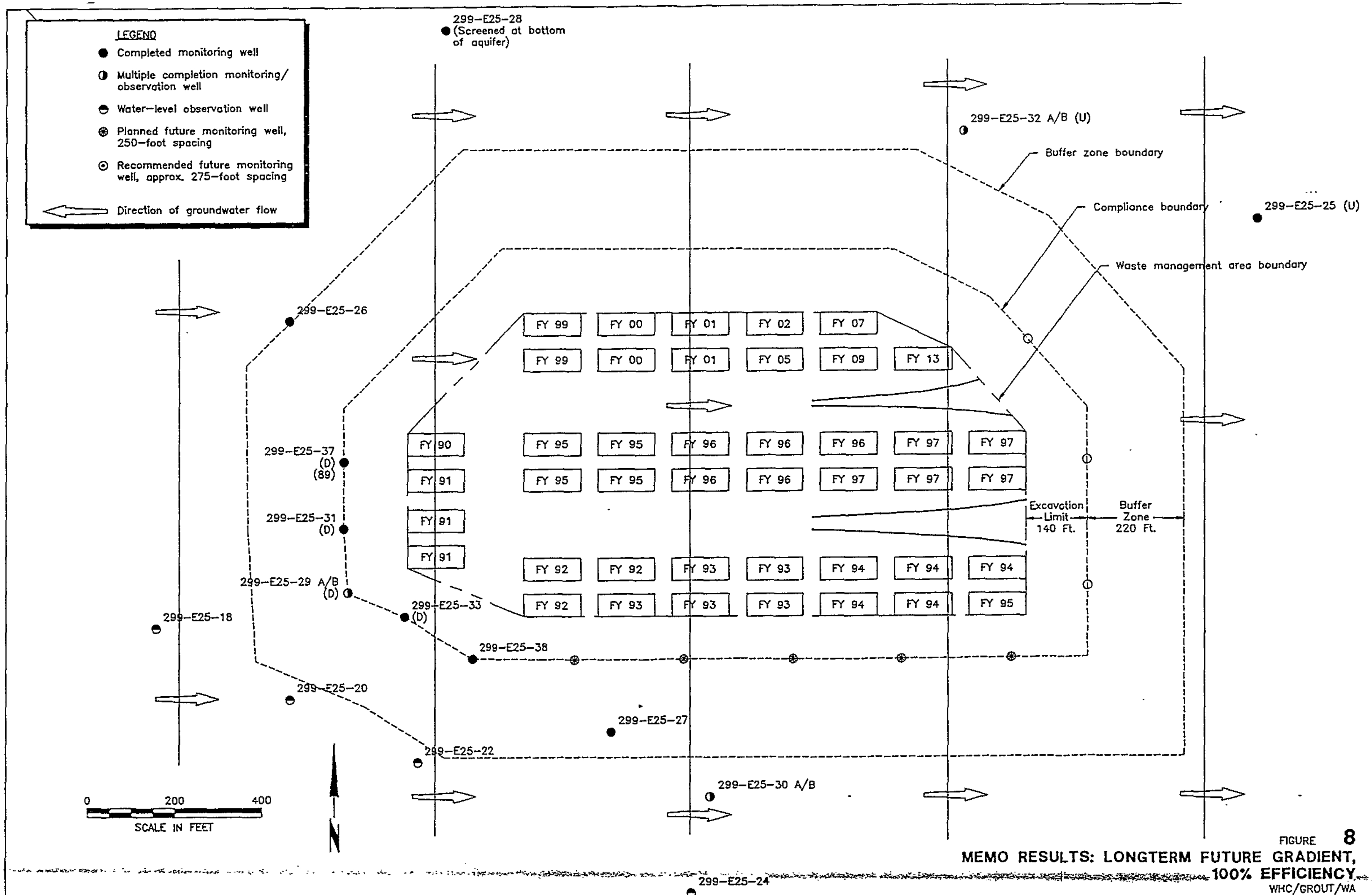

FIGURE 8
MEMO RESULTS: LONGTERM FUTURE GRADIENT, 100% EFFICIENCY
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for technetium-99, and is considered to be overly conservative when added to the conservative nature of all other parameters in the model.

Increasing the line source width from 40 to 70 ft increases the size of the plume. As shown in Figure 9, for a similar length plume, a 70 ft source width results in a wider plume, resulting in higher monitoring efficiencies, or permitting larger well spacings. It could be argued that a 70 ft source width at the groundwater table is not unreasonable, given the dimensions of the vaults and the 200 ft depth to groundwater. However, selecting a line source less than 40 ft long at the groundwater table is not considered to be reasonable, given the dimensions of the vaults and the depth to groundwater. Hence, the 40 ft line source width used in this analysis is considered to be conservative, given the uncertainty of the possible failure modes of the vault/barrier system and the vertical dispersion of contaminants migrating through the vadose zone.

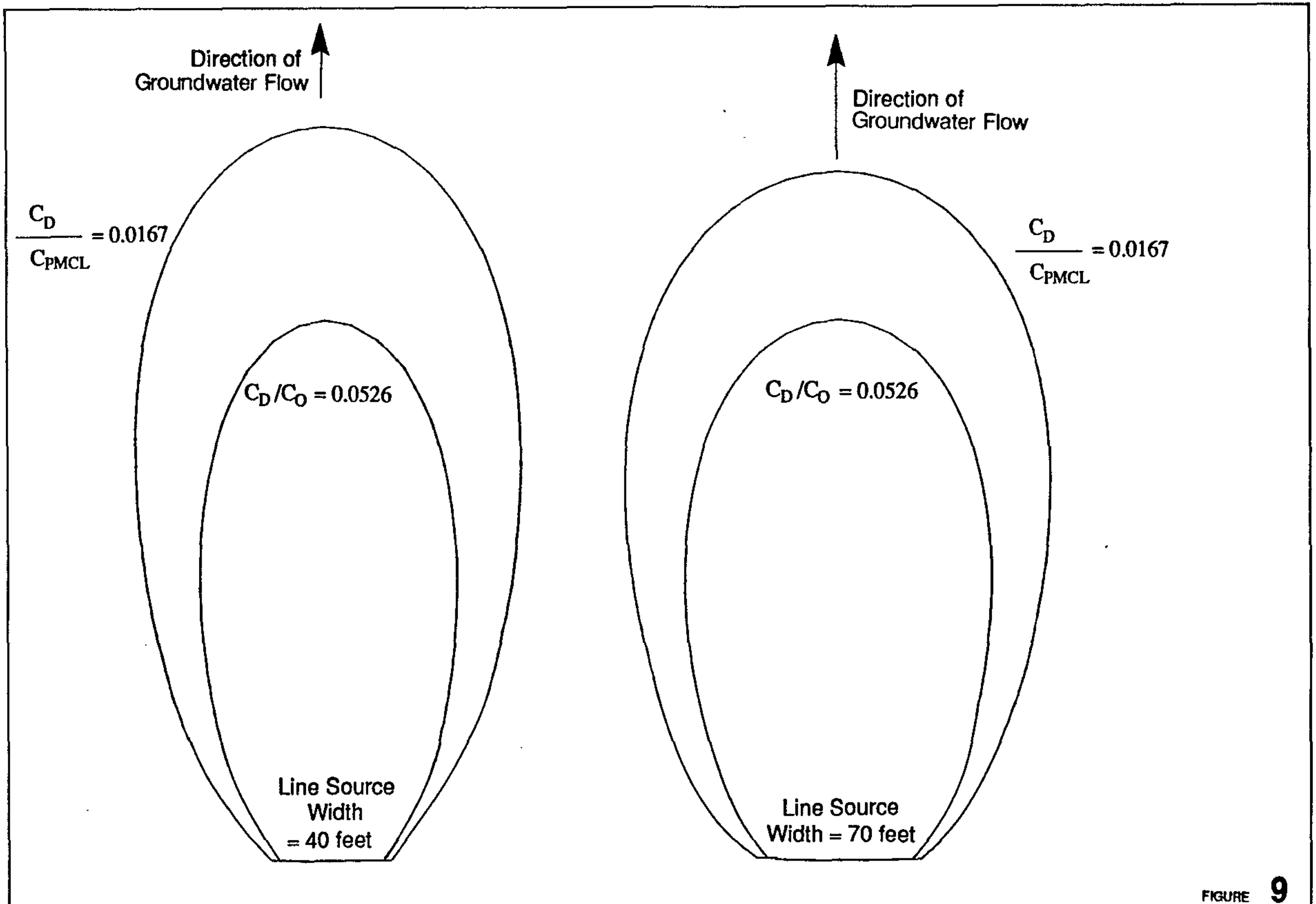

FIGURE 9

COMPARISON OF PLUME SOURCE WIDTH

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5. RECOMMENDATIONS

This report has been prepared to address two primary issues of concern:

1. Is the currently specified monitoring well spacing overly conservative for detecting the potential release of contaminants from vaults under present groundwater flow directions; and

2. Will the current well spacing be adequate as B-Pond is decommissioned and the hydraulic gradients re-equilibrate to the pre-Hanford regional flow regime.

In answering the first question, it is necessary to establish some quantitative guidelines on what is considered to be conservative and what may be overly conservative. In developing the MEMO parameters for the GTF, we have used "conservative" in a qualitative sense to select parameters which yield lower efficiencies and which demonstrate the worst case limits of the scenarios under analysis. This general approach, of basing an analysis on conservative assumptions, should be acceptable to the regulators who will be evaluating the monitoring well network.

Despite the use of conservative assumptions in performing the MEMO model analysis, an additional degree of conservatism would be expected by the regulators to be applied in selecting the target efficiency of the monitoring well network. The MEMO model was informally described to hydrologists on Ecology's staff in conjunction with its application to the 200-Area low level burial grounds. In that meeting, Ecology expressed a positive interest in and approval of the model, and indicated that they would expect to see a monitoring efficiency of better than 90 percent in an approved design. If we therefore consider a 90 percent network efficiency as adequate on a regulatory basis, then since all of the input parameters to the MEMO model are conservative, a monitoring efficiency of better than 90 percent may be considered conservative. On this basis, an efficiency equal to or closely approaching 100 percent may be considered overly conservative, particularly at an isolated facility such as the GTF where a small release that is not immediately detected would pose no immediate danger to human health or the environment. Given these definitions, it may be concluded that the currently proposed well spacing of 150 ft along the southern compliance boundary, which yields 100 percent efficiency, is overly conservative.

Two alternative monitoring well designs have been developed for the southern compliance boundary. The efficiency of these designs has been evaluated for the worst case condition of flow from north to south. As the B-Pond mound dissipates, groundwater flow is expected to swing from its present southwesterly direction to a southerly direction, and finally to an easterly direction. The monitoring efficiency is expected to drop from its present value of 100 percent under the present flow direction to a minimum value when the flow is due south, and then increase back to 100 percent as the direction becomes more easterly. The amount of time that the flow will be in a southerly direction has not, to our knowledge, been estimated.

The alternative designs for the southern compliance boundary incorporate nominal 225 ft and 250 ft well spacings. The 225 ft spacing design is shown in Figure 6 and yields an efficiency of 97 percent. The 250 ft spacing design in shown in Figure 7 and yields an efficiency of 91 percent. The number of wells required for this boundary in the current design is reduced by two for the 225 ft spacing, and by three for the 250 ft spacing. Although the 225 ft spacing has a greater probability of regulatory acceptance because of its higher degree of conservatism, the 250 ft spacing may also be acceptable, given the position informally expressed by Ecology, the temporary nature of the flow field in a southerly direction which presents a worst case analysis for the site, the conservatism already present in the analysis, and the lack of endangerment posed by a small release that is not immediately detected.

Finally, wells will be required on the eastern compliance boundary to provide detection level monitoring for the expected long term groundwater flow direction. The current plans call for no such wells, and so are inadequate to address this concern. Three wells along the eastern compliance boundary, spaced on average 275 ft apart and located along the center lines of the rows of vaults will provide a monitoring efficiency of 100 percent. Although this may be considered overly conservative, it is necessary because no combination of two wells can provide an efficiency of better than 90 percent.

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