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DRAFT FINAL
ONE-DIMENSIONAL VADOSE ZONE MODELING

for the

Laboratory for Energy-Related Health Research (LEHR)
University of California at Davis, California

Submitted to:

United States Department of Energy
Oakland Operations Office
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SUMMARY

One-dimensional vadose zone modeling was performed to estimate contaminant transport in unsaturated sediments beneath the Laboratory for Energy-Related Health Research (LEHR) facility, Davis, California. The modeling was limited to the U.S. Department of Energy areas of concern at the LEHR site and may be used as a decision-support tool for evaluating site characterization data and removal actions, and as input to the human health risk assessment.

Soil boring logs of the LEHR site were used to develop three generalized stratigraphic columns representing the primary areas of concern at the site. Contaminant transport simulations were conducted using these geologic models to evaluate the effects of varying sediment types beneath the site. Five Indicator Constituents (ICs) were selected to represent site Contaminants of Concern (COCs). These ICs are nitrate, radium 226 (Ra-226), strontium 90 (Sr-90), chlordane, and hexavalent chromium.

Preliminary site characterization data indicate that elevated levels of COCs are generally limited to the upper few ft of soil beneath the site. To conservatively represent potential contaminant sources, we assigned initial IC concentrations to the upper six ft of the models. Sensitivity analyses indicate that the travel time to the simulated water table of the non-sorbing IC, e.g. nitrate, is not highly sensitive to the initial contaminant distribution depth. However, the maximum calculated ground water concentration is sensitive the quantity of contaminant mass assigned to the model.

The calculated results are also very sensitive to the surficial infiltration rate applied to the model. Based on soil moisture content data and analytic results of soil samples we estimate that the average infiltration rate may be about 3 cm/y at the LEHR site, which is less than 10% of the average annual precipitation. Higher infiltration rates, up to 50% of the average annual precipitation, were also applied to the models to evaluate the effects of this parameter on contaminant transport rates.

The model results indicate that observed levels of Sr-90, Ra-226, and chlordane in soil should not impact ground water above either 95% Upper Threshold Limit (UTL) approximations of background or Maximum Contaminant Levels (MCLs). Model results also indicate that concentrations of hexavalent chromium in shallow soil near maximum observed levels may exceed the 95% UTL, but should not impact ground water above the total chromium MCL. Nitrate transport simulation results suggest that nitrate concentrations above preliminary soil background levels may impact ground water above both the nitrate as N MCL and the 95% UTL.

As described above, the initial IC concentrations were assigned to the uppermost sediments in these models. Although contaminants may exists at greater depths, it is not likely that the total contaminant mass in soil beneath the LEHR site is greater than the mass assigned to the models.

Based on this and other conservative assumptions, the ground water concentrations calculated by these models should represent an upper limit of potential ground water impact.

1. INTRODUCTION

One-dimensional (1D) contaminant transport modeling was performed to assess potential ground water impact resulting from downward migration of contaminants through unsaturated sediments beneath the Laboratory for Energy-Related Health Research (LEHR) facility in Davis, California (Figure 1). This report presents the modeling methods, assumptions, input parameter values, and the model setup and initialization. The results of the simulations and sensitivity analyses, and ensuing conclusions, are also discussed.

The scope of this modeling project was limited to the U.S. Department of Energy (DOE) areas of concern at the LEHR site. The model results will provide guidance for estimating site soil clean-up levels and evaluating planned removal actions, and as input to an upcoming human health risk assessment. The model may also be used in the future as a decision-support tool.

The numerical computer-code NUFT (Non-isothermal, Unsaturated Flow and Transport) (Nitao, 1996) was used to develop 1D models representing the unsaturated sediments beneath the LEHR facility. The NUFT model is described in more detail in Section 2.4.1 of this report. The portions of the LEHR site investigated include the Southwest Trenches, Ra/Sr Leach Systems, Western Dog Pens, and Domestic Septic Tanks Areas (Table 1).

Due to limited data, the Eastern Dog Pens Area was not considered during this analysis. However, analytic results indicate that concentrations/activities in shallow soil samples collected at depths up to 1.5 ft beneath the Eastern Dog Pens are similar to those reported for the Western Dog Pens Area (Figures A-12 through A-15).

2. METHODOLOGY

This section presents the methodologies, assumptions, and rationale used during development of the LEHR site vadose zone models. The lithology, contaminants, input parameter values, model setup, and subsequent sensitivity analyses are described below.

2.1 Conceptual Model

LEHR site soil boring logs were used to characterize the geology and develop conceptual models for the areas of interest (Table 1 and Figure 1). The logs were obtained from the 1996 Characterization Investigation of the LEHR site (Weiss Associates, 1997) and from previous reports describing the LEHR site geology (Dames & Moore, 1993, 1994; Stewart *et al.*, 1996). Geophysical logs (Natural Gamma and Induction) were run in two boreholes, SB-5 & SB-6, at the LEHR site (Weiss Associates, 1997). The geophysical data were used to evaluate the field geologist's descriptions of subsurface sediments. In addition, surficial sediments have been described by Bates (1977), and Helley and Harwood (1985).

Four previously constructed cross sections (Dames and Moore, 1994; Stewart *et al.*, 1996) present interpretations of subsurface deposits within hydrostratigraphic units 1 and 2 (HSU-1 and HSU-2, respectively) beneath the LEHR facility and show the lateral and vertical distribution of both relatively coarse-grained (sand and gravel) and fine-grained (generally silty and clayey) deposits. To refine these interpretations, detailed cross sections were constructed from 1996 Characterization Investigation soil borings and previously published well logs (Dames & Moore, 1993) for Areas 1-3 (Table 1). These new cross sections contain additional correlations associated with the refinement of the units previously identified as interbedded clay, silty clay, and silt (Figures 2, 3, and 4). The boring logs used to construct the new cross sections and develop the composite stratigraphic logs for each area are summarized in Table 2.

Based on the soil borings used to construct the detailed cross sections, a composite stratigraphic column was created for each of the three areas (Figures 5, 6, and 7). Where discrepancies existed between soil borings and correlation was not plausible, a conservative sediment type for a particular depth range was assumed for the composite soil column. For transport modeling purposes, a conservative sediment type is generally more permeable, because constituents will usually travel faster through coarser sediments and reach the water table sooner. For example, at a depth of 13 to 15 ft below ground surface (bgs) in the composite column for the Ra/Sr Leach System Area (Figure 6), clayey sandy silt was chosen over both silty clay and clay.

Because the Septic Tanks are located at various sites across the LEHR facility, it is difficult to construct a single composite stratigraphic column for all the tanks. However, because well logs near the various septic tanks were used to develop the generalized soil columns for each area, we

assume these soil columns adequately represent the vadose zone deposits near the various septic tanks.

2.2 Indicator Constituents

To facilitate modeling, a subset of the site Contaminants of Concern (COCs) (Weiss Associates, 1997) was developed. COCs in this subset are referred to as Indicator Constituents (ICs) and are defined as those compounds that are present in relatively high concentrations/activities, widespread, and representative from a transport-and-fate perspective of all COCs identified.

2.2.1 Selection of Indicator Constituents

Based on the criteria described above, we identified strontium 90 (Sr-90), radium 226 (Ra-226), nitrate, and chlordane as site ICs. We also conducted hexavalent chromium transport simulations to support the upcoming risk assessment.

Compounds that were detected during the 1996 Characterization Investigation but not chosen as ICs are listed in Table 3. This table contains an explanation of why these compounds were not selected as ICs. Some compounds were omitted because of their limited vertical and horizontal distribution at the LEHR facility as compared to the large number of samples in which Sr-90 and chlordane were detected. Some constituents with limited distribution were only detected slightly above preliminary soil background levels (Weiss Associates, 1997) or were generally detected at low concentrations (when background values were not available). If two constituents have similar partitioning coefficients (K_d), the constituent found at greater depth will reach the water table sooner than the constituent only found near the surface. Therefore, compounds found to exist only at or within a few feet of the surface were not considered as ICs. K_d values for constituents were obtained from Thibault *et al.* (1990). In addition, if concentrations for a particular constituent found at the LEHR facility were only slightly above preliminary soil background levels, the constituent was not considered to be an IC.

2.2.2 Baseline Distribution of ICs

The lateral and vertical distribution of these ICs in the vadose zone was evaluated by reviewing figures presented in the Draft Final Characterization Report (Weiss Associates, 1997). The vertical distribution was further examined by creating plots of concentration or activity versus depth for each IC in various locations within each area of interest (Appendix A). Table 4 summarizes the general distribution of each compound in Areas 1-3. For the Southwest Trenches Area, the distribution based on analytical values from soil samples was evaluated separately from the distribution based on analytical values from solid waste samples. Preliminary soil background values for each IC are summarized in Table 5.

The following are some general observations regarding the distribution of the high concentrations/activities of the ICs. Chlordane was not detected in the Ra/Sr Leach System Area, and Sr-90 and Ra-226 generally attenuate with depth. Nitrate detections above background were limited to the upper 14 ft in the Ra/Sr Leach System Area. Detections of chlordane and concentrations/activities significantly above background for each of the other constituents were generally limited to the surface or upper six ft of the soil column in the Dog Pens Area. The highest concentrations of chlordane were found at the surface in the Dog Pens Area, and at about three ft bgs in the Southwest Trenches Area. Nitrate, Sr-90, and Ra-226 appear to be limited to the upper 15 ft bgs in the Southwest Trenches Area, while chlordane is generally limited to the upper 4 ft bgs. Nitrate is the only IC detected above background during the investigation of the LEHR septic tanks. Nitrate was reported at 120 mg/kg at a depth of 9.5 ft near Septic Tank No. 7. In general, IC concentrations above background were not observed below 19 ft, 18 ft, and 6 ft in the Southwest Trenches, Ra/Sr Leach Systems, and Dog Pens areas, respectively. However, elevated activities of Sr-90 have been reported for soil samples collected at depths to 29 ft bgs beneath the Ra/Sr Leach System Area. WA is currently examining the validity of these analytic results.

Ra-226 and nitrate have limited lateral distribution at the surface in the Dog Pens Area, whereas Sr-90 and chlordane were detected above background levels in surface samples throughout this area. In the Ra/Sr Leach System Area, chlordane was not detected and Ra-226 is generally restricted to the Ra dry wells, associated piping, and leach line. Detection of nitrate above background was limited to one sample location at the former Imhoff Treatment System Building, and nitrate is not observed to have spread laterally near the Ra Leach System.

In the Southwest Trenches Area, Ra-226 is generally confined to disposal pits and trenches, but Sr-90 appears to have spread up to 7 ft laterally in soil. Except for a few isolated surface detections above background, nitrate is generally restricted to Trench 6, where the highest nitrate concentration was reported during the 1996 Characterization Investigation. Chlordane is present throughout the Southwest Trenches Area from the surface to four ft bgs, but below this level it is generally restricted to the Trench 6 area.

Based on this analysis and because chromium has a K_d value similar to Sr-90 (Thibault *et al.*, 1990), hexavalent chromium was not originally chosen as an IC (Table 3). However, preliminary risk assessment results suggest that hexavalent chromium may be a site COC. Therefore, we conducted additional transport simulations for hexavalent chromium. The results of the simulations are discussed in Sections 3 and 4 of this report.

2.3 Parameter Value Estimation

The primary assumptions employed during development of the LEHR site vadose zone models are summarized below. Physical properties for each sediment type and the required input parameter values are presented below, and in Tables 5 and 6.

2.3.1 Vadose Zone Thickness

A conservative (i.e. thinnest) vadose zone thickness was assumed for each model based on historical ground water levels. Because ground water levels can seasonally vary more than 20 ft beneath the site, contaminants in soil at the highest seasonal ground water level may impact ground water. The average seasonal-high ground water level observed in onsite HSU-1 wells during 1995 was at about 30 ft bgs (Stewart *et al.*, 1996). Due to recently rising water levels beneath the site, the average seasonal-highs for the previous five years (1990 through 1994) were all lower than 30 ft bgs. Therefore, as a conservative estimate, we assumed a vadose zone thickness of 30 ft for each area of interest.

2.3.2 Partitioning C

Kds → Superfund Soil Chemical Data Matrix

The liquid/soli nodels are summarized in Table 5. K_d values for the : based on ranges presented in Thibault *et al.* (1990). (more mobile) the constituent. Therefore, we assume Ra-226, Sr-90, and hexavalent chromium (100, 10, an hlordane was determined using the method outlined i dered to be non-sorptive, non-degrading and non-volatile, therefore zero values were used for K_d, the decay half-life, and the Henry's Law constant (Table 5).

2.3.3 Hydraulic Properties

Hydraulic parameter input values (e.g. porosity, hydraulic conductivity, etc.) were generally determined from soil physical property data obtained during the 1996 Characterization Investigation (Daniel B. Stephens and Associates, Inc., 1996). Because samples of all sediment types were not submitted for physical property analysis, input values for these sediments were estimated from values for similar sediment types, if available, in the Unsaturated Soil Hydraulic Database (UNSODA) (Leij *et al.*, 1996). The van Genuchten parameter values for these sediments were estimated by entering the UNSODA data values into the Retention Curve (RETC) computer program (van Genuchten *et al.*, 1991). In general, the UNSODA database did not contain records for coarse-grained (i.e. gravelly) sediments. Values for these coarse-grained sediments were estimated based on comparison with properties determined from the 1996 Characterization Investigation and UNSODA data, as well as values published in Fetter (1994) and Freeze and Cherry (1979). The physical and hydraulic properties for each soil type used in the LEHR modeling are summarized in Table 6.

Gelhar *et al.* (1985) concluded that dispersivity values appear to increase with the scale of observation. As described above, the minimum thickness of the vadose zone beneath the LEHR facility is on the order of about 30 ft (10 m). Based on Gelhar's review of several laboratory and field experiments, a uniform longitudinal dispersivity value of 0.3 ft (0.1 m) appears reasonable for the LEHR site. However, as described above in Section 2.3.2, the K_d values are fairly large for the sorbing ICs, and therefore their transport velocities should be quite low. As a result, effects of

dispersion are not expected to significantly impact the 1D model results. Hence, to reduce nodal spacing requirements and simulation run-times, we assumed that dispersion is negligible for these transport simulations. To support this assumption, we conducted a sensitivity analysis for dispersion. Results of this analysis are discussed in Section 2.5.4 of this report.

2.3.4 Infiltration Rate

Transport of a contaminant in the vadose zone is directly related to the infiltration rate of surficial recharge. The mean annual precipitation rate in the LEHR site vicinity is about 43 cm/y (17 in/y) (Dames and Moore, 1994). Initially, an infiltration rate equivalent to 50% of the annual precipitation rate (21.5 cm/y) was assigned to the model. However, as discussed below, an infiltration rate of 3 cm/y may be more reasonable, based on the distribution of nitrate in the unsaturated zone in the Southwest Trenches Area.

As shown in Figure 8, the maximum concentrations of nitrate detected in soil samples collected from Exploratory Trenches T-2 and T-6 in the Southwest Trenches Area occur at depths between 5 and 15 ft bgs. As discussed in the Draft Final Characterization Report (Weiss Associates, 1997), disposal trenches in this area were used from 1963 through 1965. Hence, these data suggest that the average vertical transport rate of nitrate may be approximately 10 cm/y (0.33 ft/y) beneath this area. Because nitrate is a conservative (non-sorbing) tracer, this transport rate is equivalent to the average linear velocity of water through the sediments. Based on a porosity value of 0.3, this average linear velocity corresponds to a specific discharge of about 3 cm/y, which is less than 10% of the average annual precipitation. Therefore, an infiltration rate of 3 cm/y was selected as the baseline value. To support this assumption, we conducted a sensitivity analysis on this parameter to further examine the effects of the infiltration rate on contaminant transport. The results of this analysis are discussed in Section 2.5.1.

2.4 Model Setup and Initialization

This section describes the boundary conditions and initialization of the LEHR site NUFT models. After initialization, the models were used to simulate unsaturated flow and transport of contaminants beneath the LEHR site. Results of the transport simulations are presented in Section 3.

2.4.1 NUFT Model

NUFT was developed and verified (Lee *et al.*, 1993) at the Lawrence Livermore National Laboratory (LLNL) by Dr. John Nitao, in collaboration with Dr. Jacob Bear, to simulate multiphase flow and contaminant transport in one-, two-, or three-dimensions. With oversight and concurrence from the U.S. Environmental Protection Agency, the California Department of Toxic Substances Control, and the California Regional Water Quality Control Board, LLNL has used NUFT extensively as part of its Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Remedial Investigation to simulate the flow and transport of volatile organic compounds

(VOCs) and tritium in the vadose zone beneath the Livermore Site. NUFT was also applied at LLNL's Site 300 to simultaneously simulate the flow and transport of VOCs in both the unsaturated and saturated zone at Site 300.

2.4.2 Conceptual Model and Boundary Conditions

The conceptual model for these simulations is a 1D, two-phase (liquid and gas) system where flow is vertically downward due to gravity. As described in Section 2.1, three separate models were constructed to represent the variable lithology beneath the LEHR site. Each model is comprised of a continuous column of finite-difference cells. Soil and hydraulic property values were assigned to these cells to represent the generalized soil columns shown in Figures 5 through 7. The physical parameter values for these sediment types are presented in Table 6.

To properly represent the physical conditions, the top of the model (i.e. the ground surface) is fixed at atmospheric conditions. Although highly conservative, a continuous flux of water is applied at the top surface of the model to represent infiltration. As described in Section 2.3.4, the assumed basecase infiltration rate is 3 cm/y, which is less than 10% of the mean annual precipitation rate.

As described in Section 2.3.1, the assumed water table is located 30 ft bgs at the bottom of the vadose zone. A four-ft thick saturated zone extends beneath the simulated water table to represent the uppermost portion of the ground water system (Figures 5 through 7). The uppermost saturated finite-difference cell is used to calculate the predicted IC concentration at the water table, therefore the results presented in this report are not dependent upon the total thickness of the simulated saturated zone. As described in Section 2.5.4, this cell is less than 1 ft thick (0.25 m).

As discussed in Section 2.2, ICs beneath the LEHR site are commonly restricted to the upper few feet of soil (Appendix A). Therefore, as shown in Figures 5 through 7, the initial soil concentration of each contaminant was assigned from the surface to a depth of approximately six ft. Infiltration of the applied recharge drives contaminants through the assumed 30 ft vadose zone toward a static water table. The initial soil concentrations are presented in Table 7 and are discussed in more detail in Section 3.

2.4.3 Initial Conditions

Prior to conducting unsaturated flow and contaminant transport simulations, the models were calibrated to initial moisture content and porosity data collected during the 1996 Characterization Investigation (Weiss Associates, 1997). The initial percent saturation of these samples was determined by dividing the initial moisture content by the porosity for each sample. These initial saturation values were then compared to the saturation values calculated by the model. The recharge applied to the initialization was then adjusted until the model saturation values closely matched that of the site conditions. This initialization recharge value was 2 cm/y, which may be interpreted as the minimum infiltration rate necessary to maintain the degree of saturation observed beneath the site. The moisture content samples were collected during August 1996, therefore the degree of saturation, and corresponding recharge rate, may increase during the winter months. However, as described in

Section 2.3.4, this initialization recharge rate of 2 cm/y is similar to the 3 cm/y value estimated from the distribution of nitrate concentrations in soil.

Using these initialized models as steady-state conditions, the initial soil concentrations were assigned to the model for each IC. Contaminant transport simulations were then conducted assuming a constant infiltration rate. Results of these simulations are presented in Section 3. To evaluate the effects of varying parameter values and to better evaluate the results of the models, sensitivity analyses were conducted. Results of the sensitivity analyses are presented in Section 2.5.

2.5 Parameter Sensitivity Analyses

This section presents the results of simulations conducted to evaluate the sensitivity of model results to various input parameters, such as infiltration rate, lithology, dispersion, grid-cell spacing, and initial contaminant mass inventory and distribution. Sensitivity analysis results are also useful for evaluating the validity of assumed input parameter values and to aid in the interpretation of subsequent model results.

2.5.1 Infiltration Rate Sensitivity

For non-sorbing compounds (K_d = 0 L/kg), such as nitrate, the contaminant migration rate will be most sensitive to varying infiltration rates. To evaluate this effect, we assumed infiltration rates of 50% (21.5 cm/y), 23% (10 cm/y), and 7% (3 cm/y) of the LEHR area mean annual precipitation rate of 43 cm/y (17 in/y) (Dames and Moore, 1994). As shown in Table 7, the peak nitrate concentration at the water table occurs after 17 y when an infiltration rate of 21.5 cm/y is applied to the Southwest Trenches model. An arrival time of 26 y is obtained when a steady infiltration rate of 10 cm/y is applied, and an arrival time of about 107 y is achieved when the infiltration rate is 3 cm/y.

The results of these simulations are also shown graphically in Figure 9. These curves represent the aqueous nitrate concentration at the water table over time. As seen in this figure and in Table 7, the peak concentration is not highly sensitive to the infiltration rate; ranging from 18 to 25 mg/L. However, for compounds that degrade over time, the peak concentration will decrease more rapidly as the travel time to the water table increases.

2.5.2 Sensitivity to Lithology

As described in Section 2.1, the model for each simulated area has a different lithology to account for the variable distribution of sediments beneath the LEHR site. Although the sediment types are similar, the distribution and geometry can impact travel time estimates. Because we have assumed the vadose zone thickness to be the same for each area (30 ft) and we are applying a constant infiltration rate, we can evaluate the model results to determine the sensitivity of travel time

to lithology. Similarly, we can use these results to indicate where contaminants may travel most rapidly beneath the LEHR site.

As shown in Figure 10, we conducted two similar transport simulations for the conservative tracer nitrate. In the first case, we applied a constant infiltration rate of 21.5 cm/y. In the second case, we applied a rate of 10 cm/y. These higher recharge rates were used to accentuate the differences in lithology for each model. As seen in this figure, nitrate will travel through the vadose zone in the Western Dog Pens Area most rapidly, followed by the Southwest Trenches and the Ra/Sr Leach Field Areas, respectively. Although these results are more evident for the case where the infiltration rate is 21.5 cm/y, the results are consistent when the infiltration rate is 10 cm/y (Figure 10).

Results of these simulations also indicate that the peak ground water concentrations decrease with shorter arrival times (Figure 10). This may be due to the contaminants dispersing more rapidly through the soil column when the sediments are more permeable, as is the case in the Western Dog Pens Area. Therefore, we have chosen the Southwest Trenches as the lithology for our conservative basecase scenarios.

2.5.3 Sensitivity to Contaminant Mass Inventory and Distribution

As discussed in Section 2.2, ICs beneath the LEHR site are generally restricted to the upper few feet of soil (Appendix A). As a result, the initial contaminant soil concentration was assigned to the upper six ft of the model for all cases. To evaluate the effects of more pervasive contaminant distribution beneath the site, an additional transport simulation was conducted where the initial nitrate concentration was assigned from 0 to 15 ft bgs (Figure 5). As shown in Figure 11, the peak ground water concentration arrival time at the water table is not highly sensitive to the location of the center of mass of the initial inventory, which were 3 and 7.5 ft bgs for these cases. However, the magnitude of the peak concentration is sensitive to the quantity of contaminant mass in the subsurface (Figure 11). As shown in Table 7, the initial nitrate concentration for these simulations was 10 mg/kg.

2.5.4 Sensitivity to Dispersion

As described in Section 2.3.3, we assumed the effects of dispersion were negligible in these 1D vadose zone transport simulations. To test this assumption, we ran two additional simulations of nitrate transport in the Southwest Trenches area using an infiltration rate of 10 cm/y. To accurately calculate the effects of dispersion, the finite-difference grid spacing was reduced from 0.25 m to 0.01 m.

To test the sensitivity of the model results to the grid spacing, we did not include dispersion in the first simulation. The peak nitrate concentration at the water table was about nine percent higher compared to the results of the basecase scenario (25 and 23 mg/L, respectively). This may be a result of increased accuracy due to the refined grid or possibly the decreased size of the first saturated finite-difference cell where the peak ground water concentration is calculated.

In the second simulation, we assumed a dispersivity value of 10 cm. The peak nitrate concentration at the water table for this dispersion scenario was about 65% less than the basecase scenario (15 and 23 mg/L, respectively). The arrival time also decreased by 1 y. As shown in Figure 12, the difference is associated with the additional spreading of the contamination due to dispersion. Therefore, although the dispersion-case peak concentration was much less than the basecase solution, the basecase solution (i.e. no dispersion) provides a conservative estimate of the peak concentration.

3. MODEL RESULTS

All five ICs (nitrate, Sr-90, Ra-226, chlordane, and hexavalent chromium) were modeled for the Southwest Trenches Area. For the sorptive ICs (Sr-90, Ra-226, chlordane, and hexavalent chromium), the times estimated for the peak activity/concentration to reach the water table are in the hundreds to thousands of years. Therefore, we assumed that the sensitivity of the IC to the lithology of the Ra/Sr Leach Systems, Western Dog Pens, or Southwest Trenches Areas is negligible for the sorptive ICs (Table 7). To support this assumption, the transport of hexavalent chromium and nitrate were also simulated beneath both the Ra/Sr Leach Systems and Western Dog Pens Areas.

3.1 Results for the Southwest Trenches Area

For the non-sorptive IC, nitrate (K_d = 0 L/kg), the peak concentration (18 mg/L) occurs at the water table (30 ft bgs) after 107 y if a continuous infiltration rate of 3 cm/y is applied. This result is based on an initial nitrate soil concentration of 10 mg/kg evenly distributed from zero to six ft bgs (Table 7). As discussed in Section 2.5.1, sensitivity analyses of the infiltration rate indicate that the peak nitrate concentration will slightly increase and arrive at the water table more rapidly if the infiltration rate is more than 3 cm/y.

As shown in Figure 13, the peak nitrate concentration exceeds the 10 mg/L nitrate (as N) Maximum Contaminant Level (MCL). As shown in Table 5, the 95% Upper Tolerance Limit (UTL) approximation of background for nitrate in ground water (25.2 mg/L) also exceeds this 10 mg/L drinking water standard (Stewart *et al.*, 1996). The preliminary background concentration in soil for this area is about 29 mg/kg (Weiss Associates, 1997). Therefore, the model results indicate that nitrate concentrations in soil above background levels may impact ground water beneath the LEHR site.

As described in Section 2.3.4 and shown in Figure 8, elevated nitrate concentrations have been observed in soil about 10 ft beneath the bottom of a disposal trench (15 ft bgs) in the Southwest Trenches Area. Based on a simulated infiltration rate of 3 cm/y, the peak concentration is calculated to migrate to a depth of about 20 ft after 30 y. Therefore, these results suggest that the use of a constant 3 cm/y infiltration rate approximates the average recharge conditions at the LEHR site.

As shown in Figure 14, Sr-90 with an assumed K_d value of 10 L/kg migrates very slowly to the water table. The peak activity of 1.3 pCi/L is estimated to arrive at the water table at 470 y when a constant infiltration rate of 10 cm/y is applied (Table 7). This higher infiltration rate was used because Sr-90 is highly sorptive yet has a fairly short half-life of 29 y. The initial soil activity assigned to the uppermost six ft of soil for this simulation was 10 million pCi/g (10 μCi/g). The maximum activity of Sr-90 detected in soil beneath the LEHR site is 23 pCi/g. Therefore, although the simulated initial activity of Sr-90 is over five orders of magnitude higher than observed levels,

the estimated peak activity of Sr-90 arriving at the water table is below both the 1.63 pCi/L 95% UTL and the 8 pCi/L MCL when a large infiltration rate is applied (Figure 13).

Figure 15 presents the results of the Ra-226 transport simulation with an assumed K_d value of 100 L/kg. As expected, the Ra-226 travel time to the water table is much greater than that of Sr-90. Although a high infiltration rate of 10 cm/y is applied to the model, the calculated peak activity is not estimated to arrive at the water table until more than 10,000 y. As seen in Figure 15, results of this simulation indicate that the estimated peak Ra-226 activity will be lower than the 0.272 pCi/L 95% UTL if an activity of 10 pCi/g is assigned to the upper six ft of soil (Table 7). This initial soil activity is slightly less than the maximum Ra-226 soil activity of 15 pCi/g detected at LEHR during the Characterization Investigation (Weiss Associates, 1997). When 100 pCi/g was used as the initial soil Ra-226 activity, the peak estimated ground water activity was 1.9 pCi/L, which is less than the 5 pCi/L MCL.

If we apply a constant infiltration rate of 3 cm/y to the Southwest Trenches Area model, the Ra-226 peak ground water concentration decreases significantly due to the much longer travel time. To achieve results similar to the 10 cm/y case, the initial soil activity must be increased by nearly five orders of magnitude. As shown in Figure 16 and in Table 7, the peak ground water Ra-226 activity is at background levels if an initial soil activity of 1 million pCi/g (1 ~~m~~ μC/g) is assigned from zero to six ft bgs.

Based on calculations outlined by Strenge *et al.* (1989) and assuming a 10% soil organic content, chlordane is apparently very sorptive (Table 5). Assuming a K_d value of 650 L/kg and a very high infiltration rate of 21.5 cm/y, the model results indicate an extremely long travel time of about 24,000 y for the peak concentration of 1E-4 mg/L (0.1 μg/L) to reach the water table (Figure 17). Therefore, based on an initial soil concentration of 100 mg/kg, model results indicate that ground water will not be impacted at concentrations greater than the 1.0E-4 mg/L (0.10 μg/L) MCL (Table 7). The maximum concentration of chlordane detected in soil from beneath the LEHR site is 15 mg/kg (Weiss Associates, 1997).

Figure 18 presents the results of the Southwest Trenches Area hexavalent chromium transport simulation. As shown in this figure and in Table 7, the calculated peak concentration is estimated to arrive at the water table after 9,000 y when a constant infiltration rate of 3 cm/y is applied and a K_d value of 10 L/kg is used. When an initial concentration of 1.0 mg/kg is assigned to the upper six ft of soil, the model results indicate that the peak hexavalent chromium concentration will be lower than the 0.05 mg/L (50 μg/L) total chromium MCL and the 0.0229 mg/L (22.9 μg/L) 95% UTL for hexavalent chromium. When the initial soil concentration is increased to 10 mg/kg, the calculated peak ground water concentration increases to 0.21 mg/L (210 μg/L), which is greater than the 95% UTL but less than the total chromium MCL. As shown in Table 5, concentrations of hexavalent chromium detected in soil samples collected during the Characterization Investigation ranged from 0.15 to 7 mg/kg (Weiss Associates, 1997).

As shown in Table 7 and described in Section 2.5.1, the magnitude peak of the concentration is not highly sensitive to the infiltration rate. If a constant infiltration rate of 10 cm/y is applied to the hexavalent chromium simulation, the peak concentrations only increase by about 50%. However, the arrival times decrease significantly (Table 7).

3.2 Results for the Radium/Strontium Leach Systems Area

Based on the generalized lithology in the Ra/Sr Leach Systems Area model (Figure 6), nitrate has a slightly longer travel time to the water table of about 116 y compared to 107 y in the Southwest Trenches Area model (Table 7). These results are based on an initial soil concentration of 10 mg/kg and a constant infiltration rate of 3 cm/y. As shown in Figure 19, the peak ground water concentration and arrival time do not change significantly when the infiltration is increased. As discussed in Section 3.5.2, this insensitivity of the arrival time and peak concentration to recharge is probably due to the finer-grained sediments in the Ra/Sr Leach systems model (Figure 6). Therefore, for the other ICs, the peak concentration and travel time to the water table should be similar to the estimated values for the Southwest Trenches Area.

As shown in Table 7, the results of the hexavalent chromium transport simulations for the Ra/Sr Leach Systems Area are very similar to the results of the Southwest Trenches Area model. The peak ground water concentrations are about 10% larger and the water table arrival times are about 2% less for the Ra/Sr Leach Systems model compared to the Southwest Trenches model. Due to this similarity, transport simulations assuming higher infiltration rates were not conducted.

3.3 Results for the Western Dog Pens Area

For the lithology in the Western Dog Pens Area (Figure 7), nitrate has a slightly faster arrival time at the water table; 100 y compared to 107 y in the Southwest Trenches Area (Table 7). These results are based on a constant infiltration rate of 3 cm/y. The Western Dog Pens model lithology is the least variable and does not contain an abundance of finer-grained sediments compared to the other two areas (Figures 5 through 7), so it is not surprising that the peak nitrate concentration arrives at the water table more rapidly. As shown in Figure 20, the peak concentration does not change significantly when the infiltration is increased.

As expected, the results of the hexavalent chromium transport simulations indicate that the peak concentration may also arrive at the water table slightly sooner beneath the Western Dog Pens Area as compared to the Southwest Trenches Area model. Similar to the nitrate model results, the peak ground water concentration in the Western Dog Pens Area model is also lower than the Southwest Trenches model (Table 7). As discussed in Section 2.5.2, this may be due to an increased spreading of the contaminant mass through the more permeable sediments in the Western Dog Pens Area model. As shown in Table 7, the peak ground water concentration for this 10 cm/y infiltration rate model is less than the 0.0229 mg/L 95% UTL for hexavalent chromium when 1.0 mg/kg is assigned as the initial soil concentration. Therefore, a simulation assuming a 3 cm/y infiltration rate was not conducted. When an initial soil concentration of 10 mg/kg is assigned to this model, the peak ground water concentration is less than the 0.05 mg/L total chromium MCL. These results are consistent with the results of the Southwest Trenches and Ra/Sr Leach System models.

4. CONCLUSIONS

Results of the LEHR vadose zone modeling indicate that observed levels of Ra-226, Sr-90, and chlordane in soil beneath the LEHR site should not result in ground water activities/concentrations that exceed either MCLs or 95% UTL background concentrations. Hexavalent chromium transport simulation results suggest that concentrations above the maximum soil concentrations detected beneath the LEHR site should not exceed the MCL for total chromium, but may exceed the 95% UTL for hexavalent chromium. Simulations of nitrate transport suggest that soil concentrations above preliminary background levels may impact ground water above both the nitrate (as N) MCL and the 95% UTL. A summary of these peak concentrations, arrival times, and initial soil concentrations are presented in Table 7.

Considering the magnitude of the Sr-90 initial activity (mCi/L) and the relatively short 29 y half-life of this radionuclide, it appears that levels of Sr-90 observed at the LEHR site in the upper portion of the vadose zone should not impact ground water at levels near either the 1.63 pCi/L 95% UTL or the 8 pCi/L MCL (Figure 14). Similarly for Ra-226, the model results suggest that even extremely high (mCi/L) shallow soil concentrations should not impact ground water above either the 95% UTL or the MCL, when the baseline 3 cm/y infiltration rate is assumed (Figure 16).

Model results for chlordane indicate that, due to its assumed high K_d value of 650 L/kg, the transport velocity is extremely slow. As shown in Table 7 and Figure 17, the time estimated for the peak concentration of chlordane to reach the water table beneath the Southwest Trenches is more than 20,000 y even though an infiltration rate equal to 50% of the average annual precipitation is applied. This calculated peak concentration of 1E-4 mg/L (0.1 µg/L) is equivalent to the chlordane MCL. Chlordane is not a naturally occurring chemical, hence there is not a corresponding background concentration. The initial chlordane concentration of 100 mg/kg assigned to this model is higher than the maximum concentration of 15 mg/kg observed in soil beneath the LEHR site (Weiss Associates, 1997). We conservatively assumed a very high infiltration rate and that no degradation would occur during the 20,000 y travel time; therefore, we believe it is reasonable to assume that chlordane does not pose a significant risk to the quality of ground water beneath the LEHR site.

Model results from hexavalent chromium simulations indicate that concentrations in shallow soil of 1 mg/kg should not impact ground water above the 0.0229 mg/L (22.9 µg/L) 95% UTL for hexavalent chromium. Similarly, the calculated peak ground water concentrations should not exceed the 0.05 mg/L (50 µg/L) MCL for total chromium if shallow soil concentrations are less than 10 mg/kg. These results were based on a simulation of hexavalent chromium transport beneath the Southwest Trenches using a K_d value of 10 L/kg and a constant infiltration rate of 3 cm/y. The maximum concentration detected in soil from beneath the Ra/Sr Leach Systems Area is 7 mg/kg (Weiss Associates, 1997).

For nitrate, the model results indicate that concentrations above the 29 mg/kg preliminary soil background level (Weiss Associates, 1997) may impact ground water beneath the LEHR site (Figure 12). Based on an initial nitrate soil concentration of 10 mg/kg evenly distributed from zero to six ft bgs and a continuous infiltration rate of 3 cm/y, the model calculated a peak nitrate concentration of 18 mg/L. As shown in Table 5, this value is greater than the 10 mg/L nitrate (as N) MCL, but below the 25.2 mg/L 95% UTL approximation of background for nitrate in ground water (Stewart *et al.*, 1996).

The initial IC soil concentrations were distributed along the generalized soil columns from the ground surface to a depth of six ft (Figures 5 through 7). Although the contaminants may exist at greater depths, the model results indicate that transport is highly retarded for the sorptive constituents (e.g. chlordane, hexavalent chromium, Sr-90, and Ra-226) and therefore the travel times necessary to reach ground water should be extremely large (hundreds to thousands of years). Although it is unlikely based on existing data, if the total contaminant mass in soil beneath the LEHR site is greater than that which was modeled, the peak concentration in ground water may increase. However, the peak concentrations predicted by these models are conservative estimates and, therefore, should represent an upper limit of concentrations that may impact ground water.

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6. ACKNOWLEDGMENTS

The following LEHR Project personnel worked on the preparation of the Vadose Zone Modeling Report:

Name and Position	Responsibility
Michael Dresen Program Manager, WA	Guidance and senior review
Robert Devany Senior Project Manager, WA	Project management, guidance and review
Salem Attiga Principal, EMS	Senior review
Peter McKereghan Project Manager, WA	Project management, technical guidance and review, and report writing
Truc DeLorenzo Senior Staff Scientist, WA	Computer modeling and data analysis
John Pekala Senior Staff Geologist, WA	Data compilation, analysis, and report writing
Keith Commiskey Graphics, WA	Figures
Elizabeth Carrier Administrative Assistant, WA	Word processing and report compilation
Deborah Long Administrative Assistant, WA	Word processing
Craig Adams Production Personnel, WA	Graphics and report production

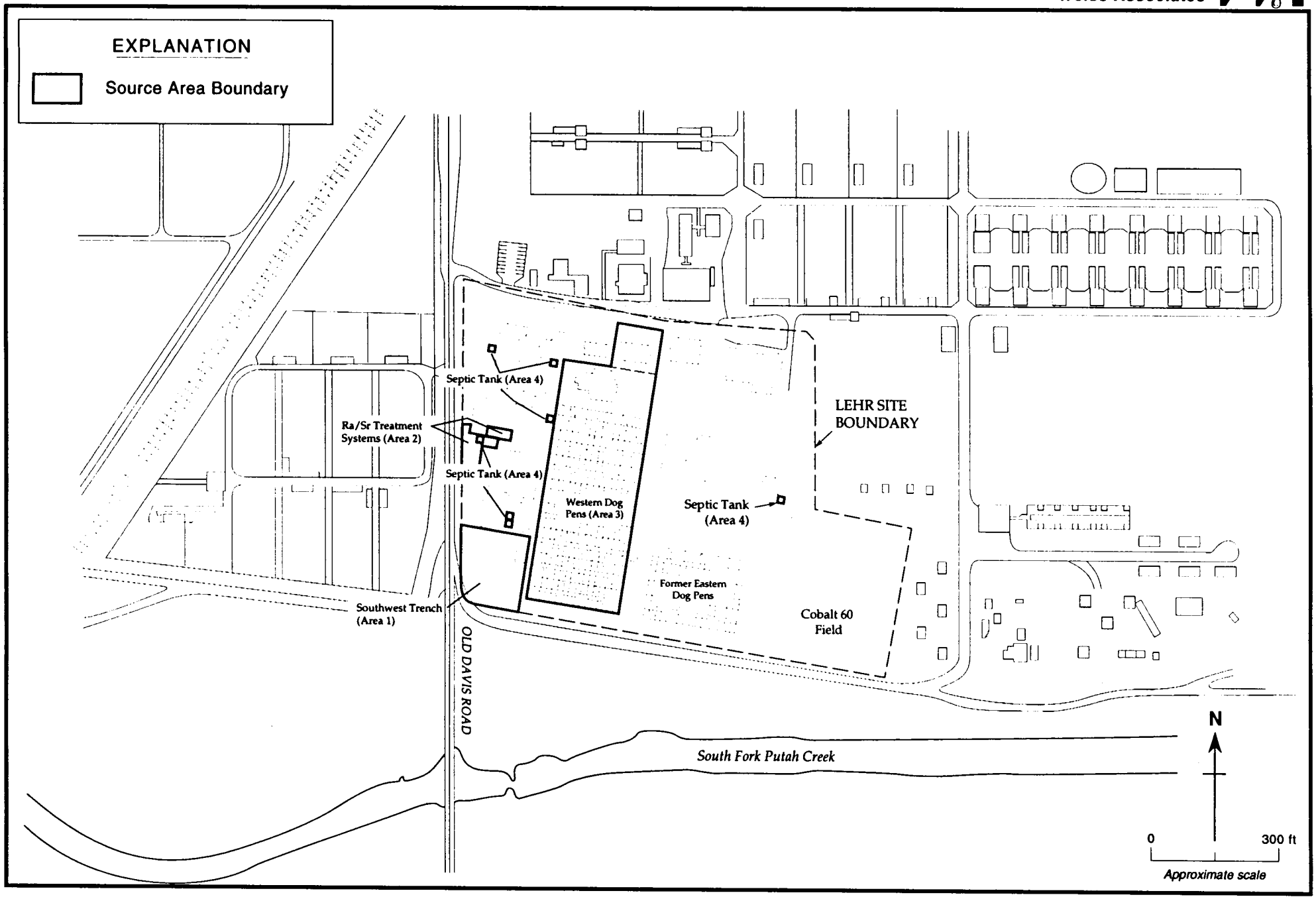


Figure 1. LEHR Site Map Showing Areas Investigated during the Vadose Zone Modeling Project.

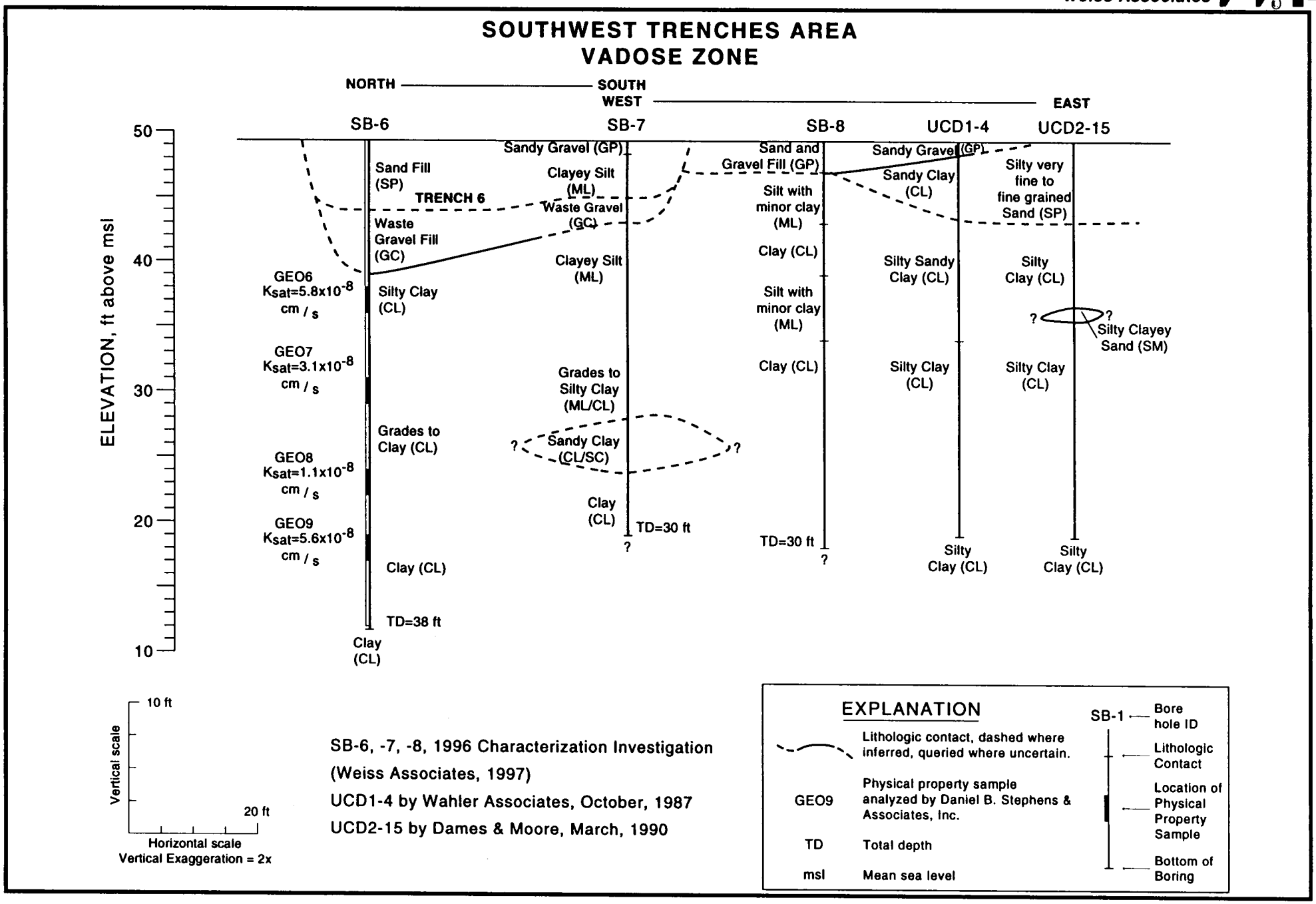


Figure 2. Cross Section for the Southwest Trenches Area at the LEHR Site.

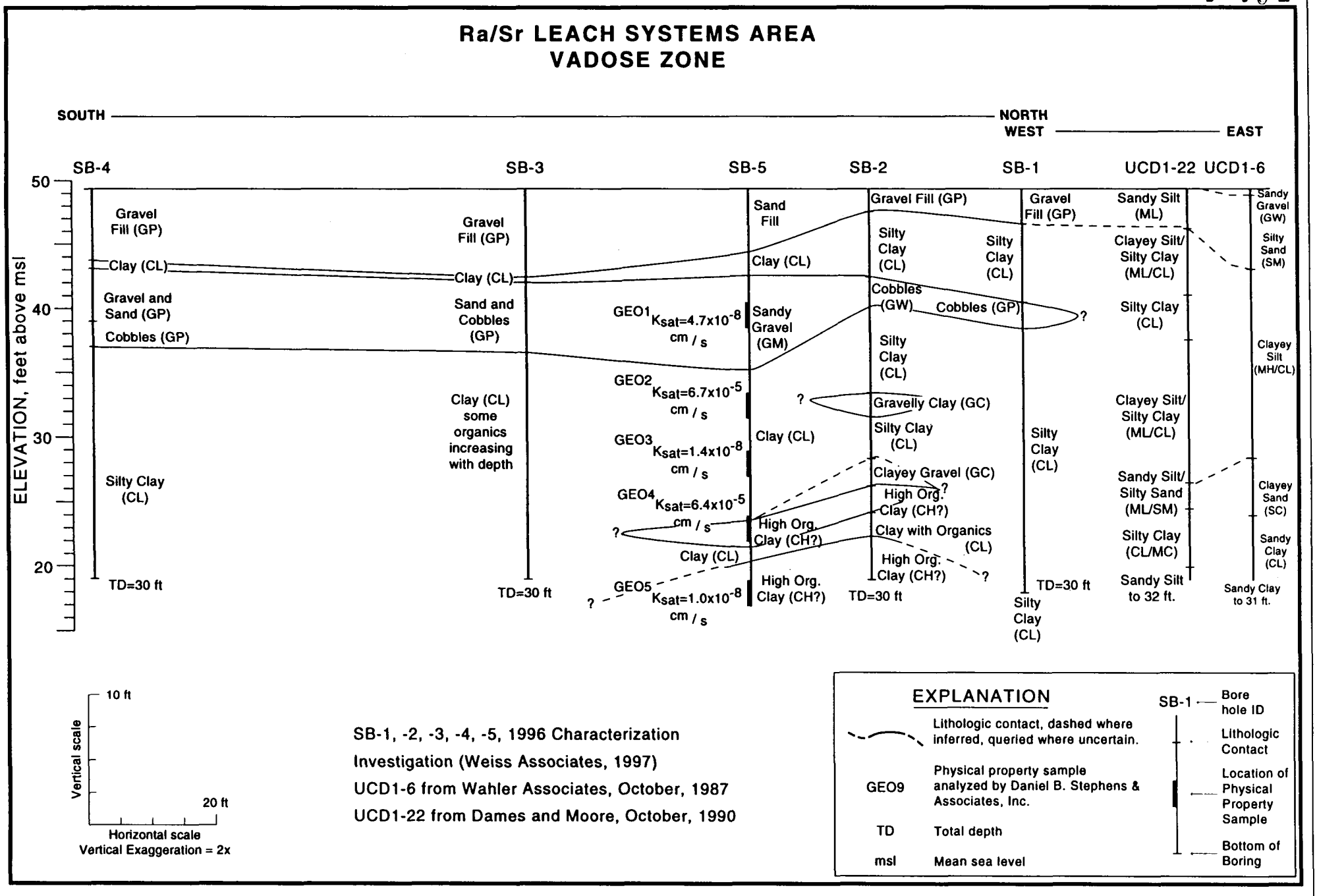


Figure 3. Cross Section for the Ra/Sr Leach Systems Area at the LEHR Site.

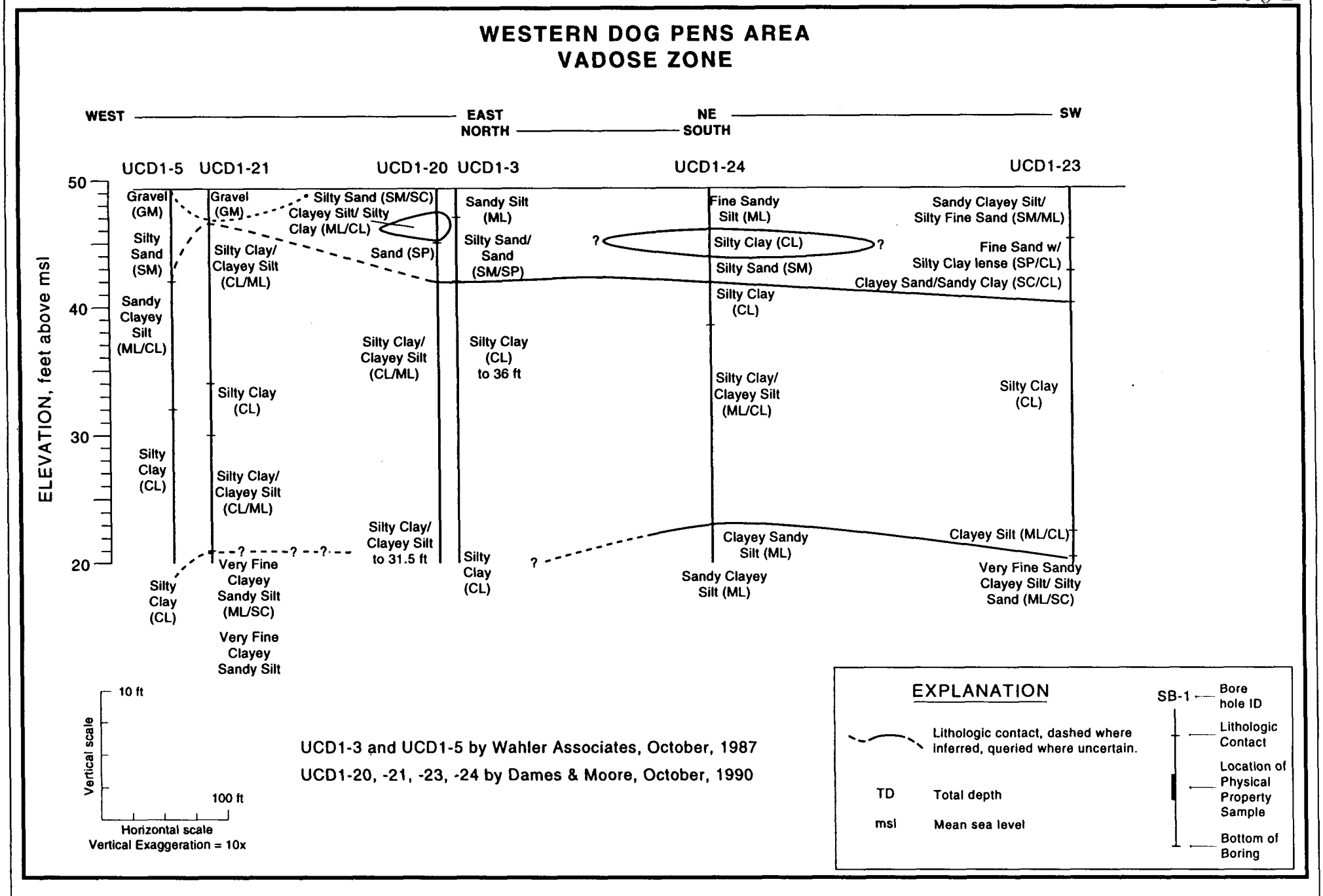


Figure 4. Cross Section for the Western Dog Pens Area at the LEHR Site.

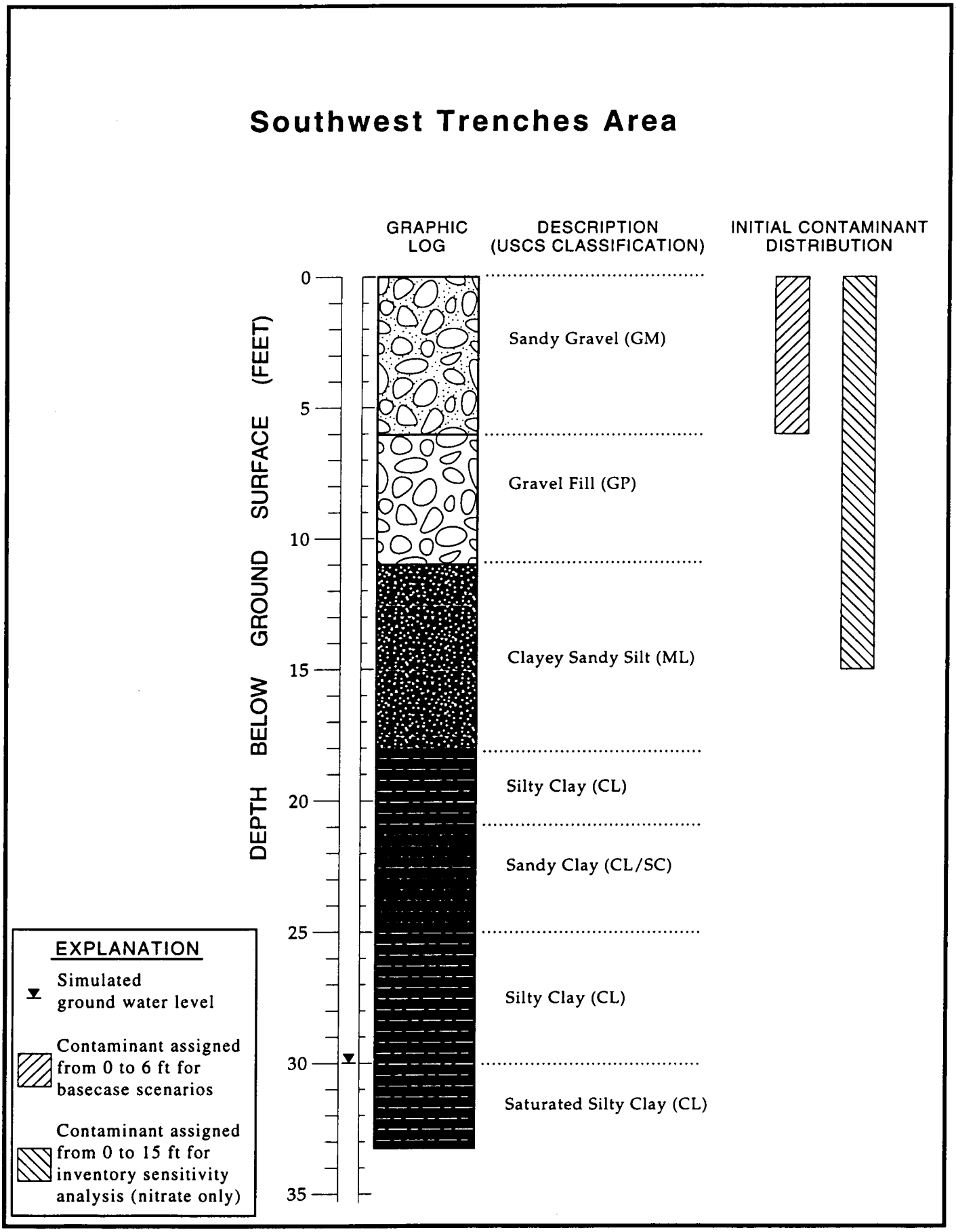


Figure 5. Generalized Lithology Representing Sediments Beneath the Southwest Trenches Area.

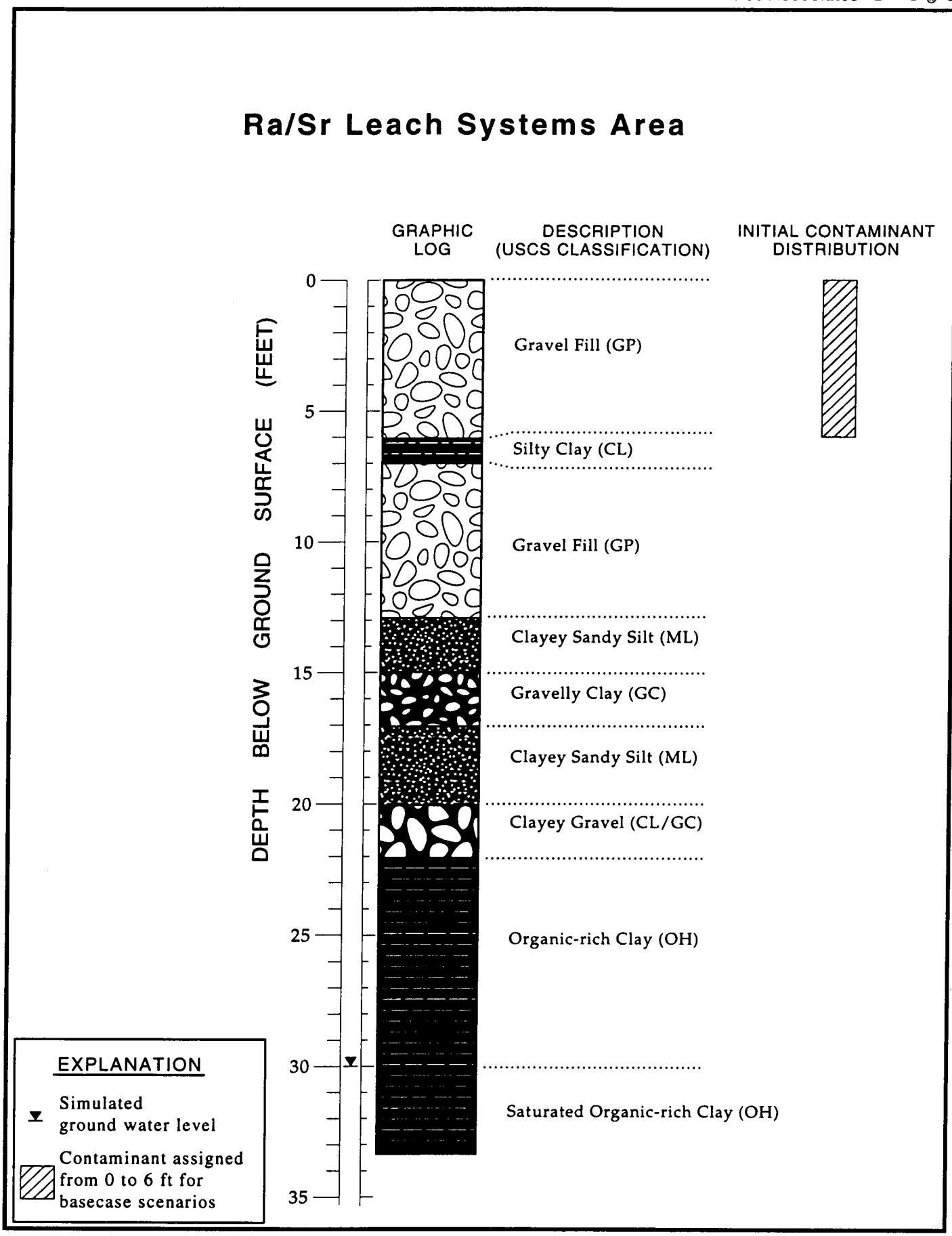


Figure 6. Generalized Lithology Representing Sediments Beneath the Ra/Sr Leach Systems Area.

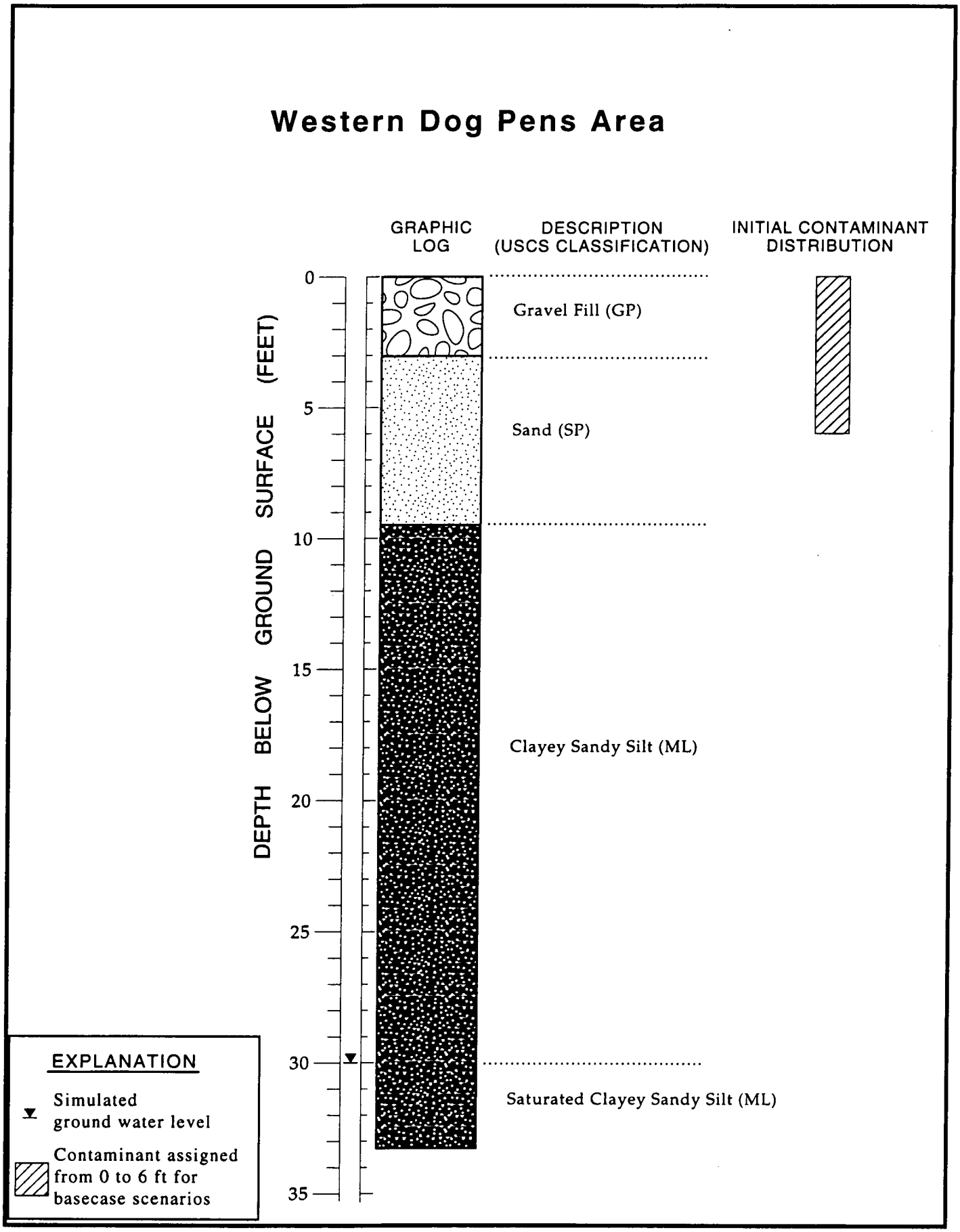


Figure 7. Generalized Lithology Representing Sediments Beneath the Western Dog Pens Area.

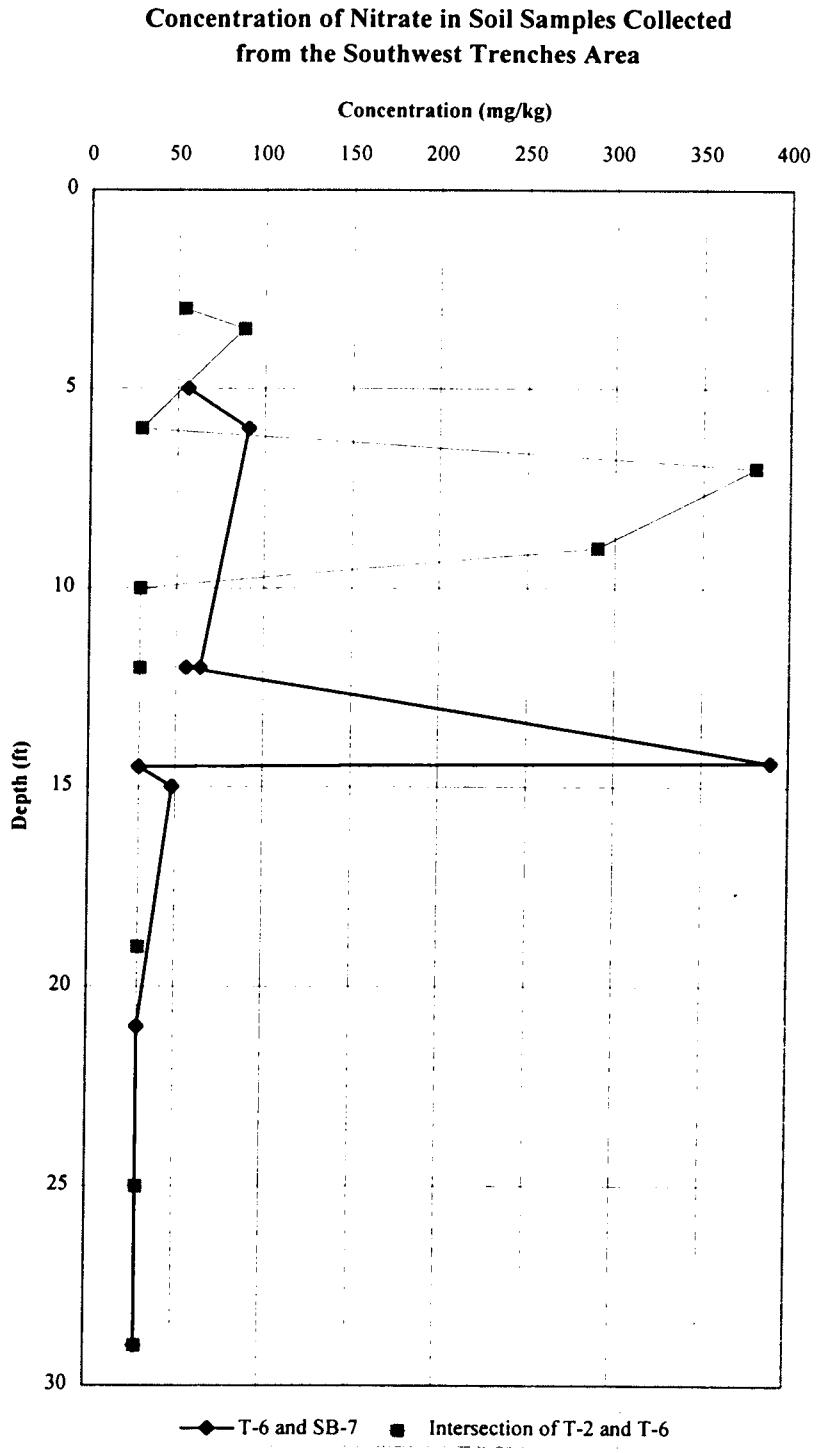
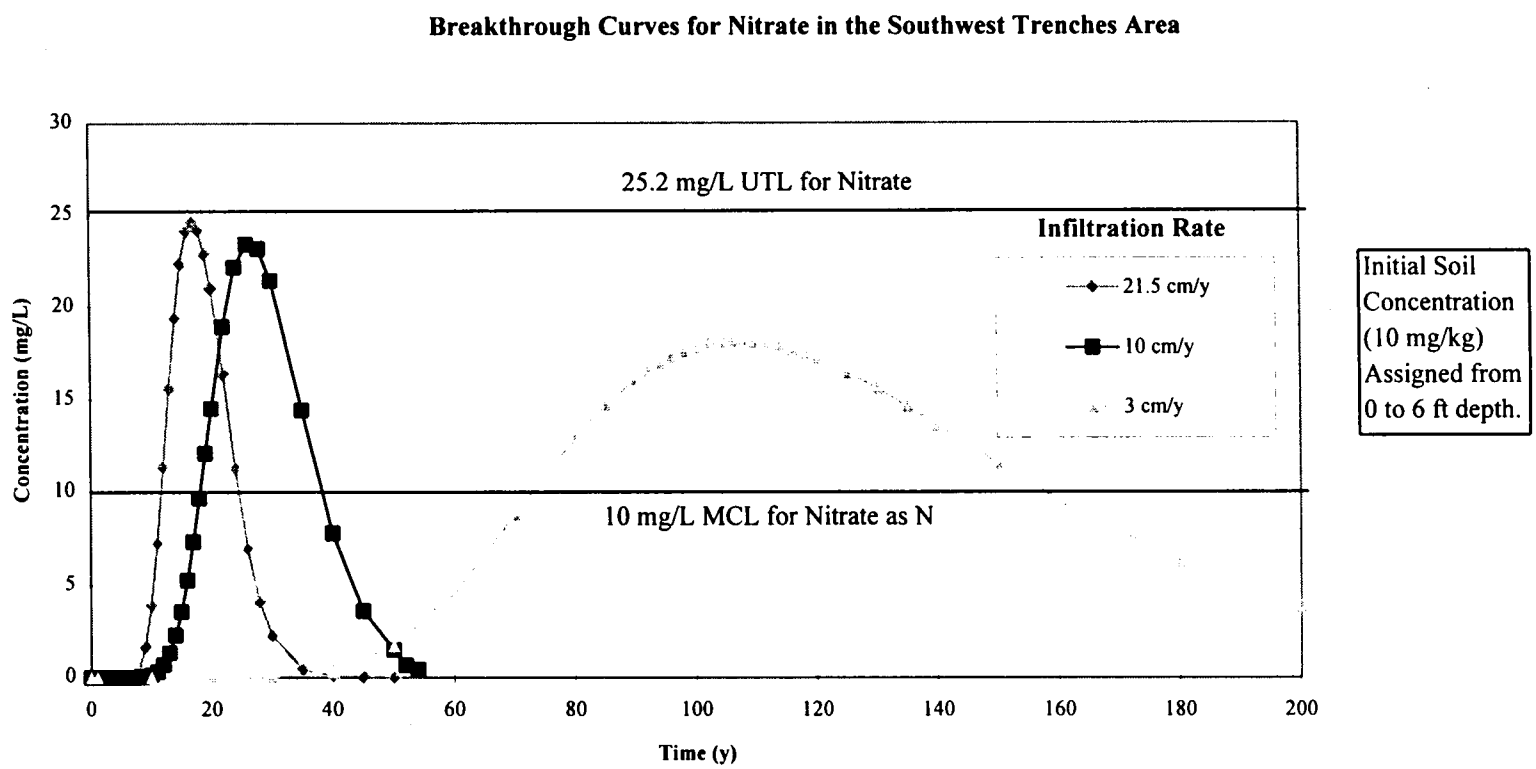


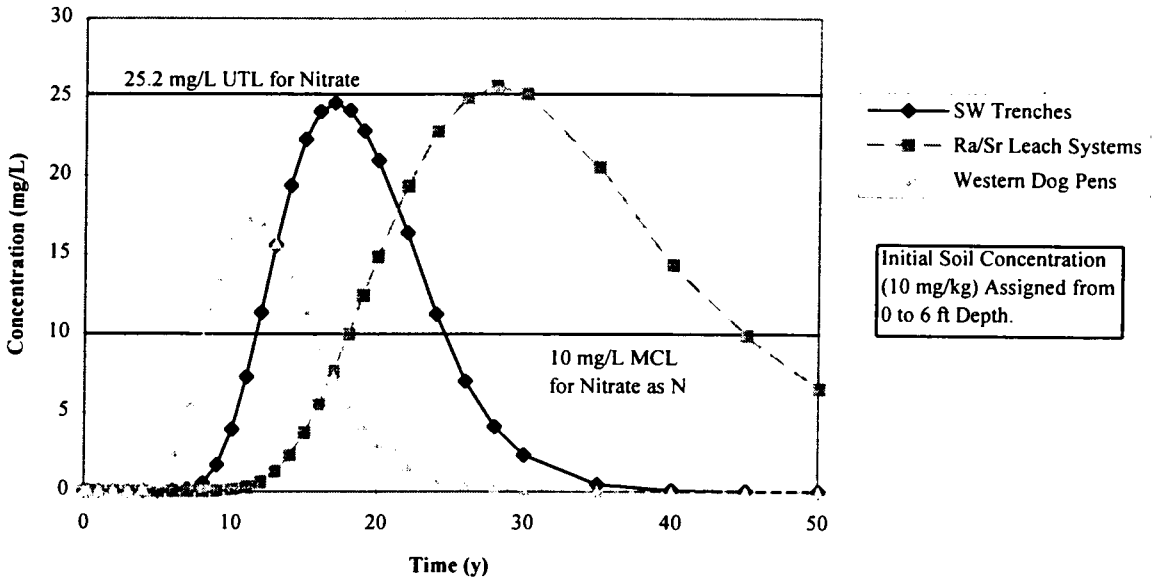
Figure 8. Nitrate Concentrations in Soil Beneath the Southwest Trenches Area.



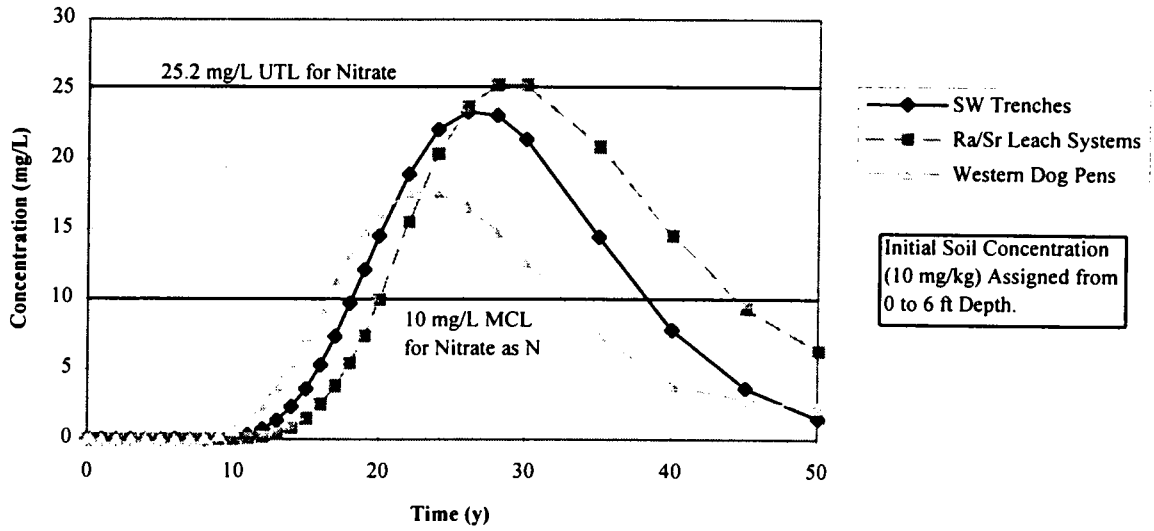
MCL = Maximum Contaminant Level, EPA Region 9, Drinking Water Standards and Health Advisory Table, 1996.
UTL = 95% Upper Tolerance Limit based on analytical results of ground water samples from HSU-1 (Stewart *et al.*, 1996).

Figure 9. Nitrate Breakthrough Curves from the Infiltration Rate Sensitivity Analyses.

Breakthrough Curves for Nitrate when Infiltration Rate is 21.5 cm/y



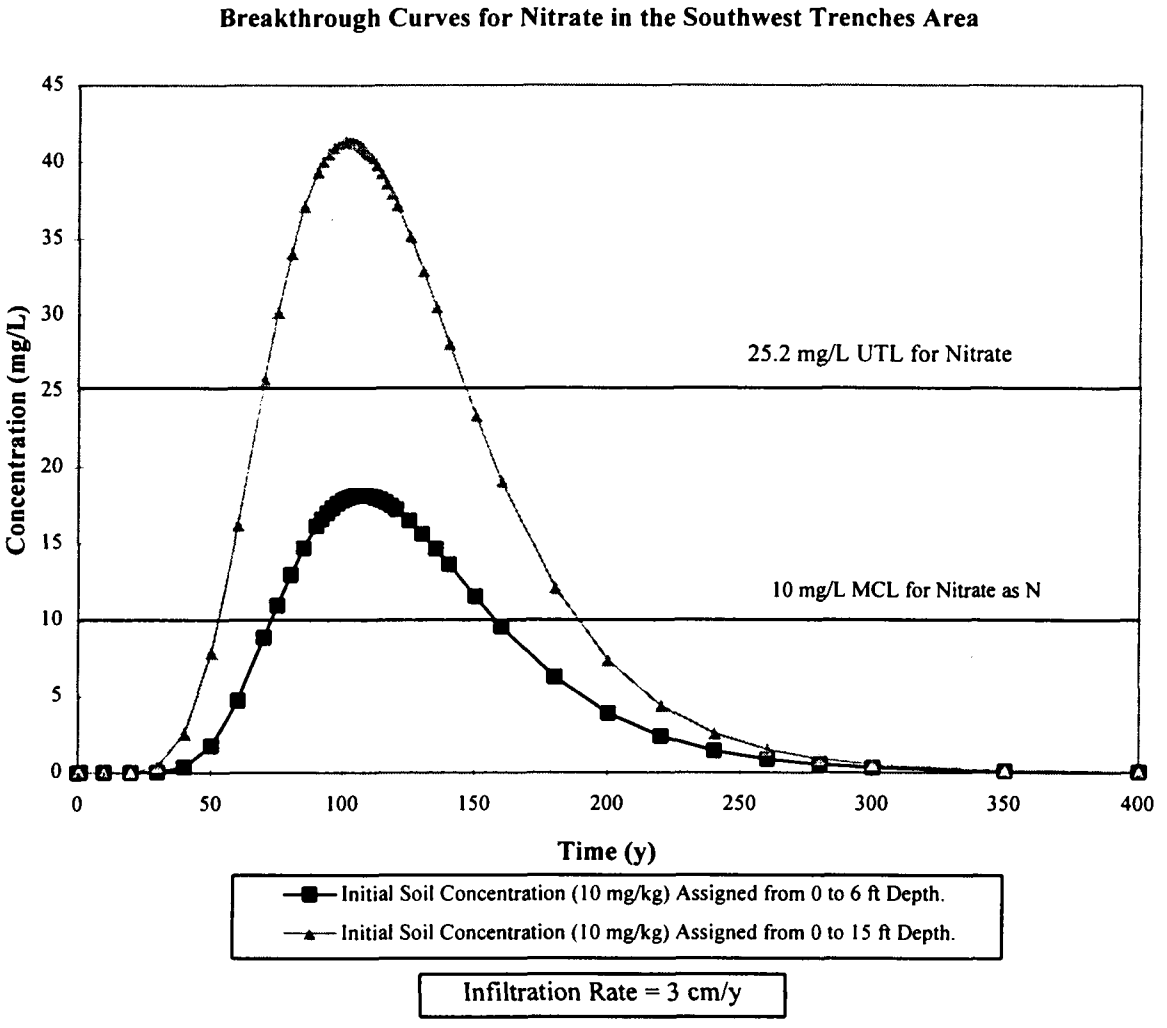
Breakthrough Curves for Nitrate when Infiltration Rate is 10 cm/y



MCL = Maximum Contaminant Level, EPA Region 9, Drinking Water Standards and Health Advisory Table, 1996.

UTL = 95% Upper Tolerance Limit based on analytical results of ground water samples from HSU-1 (Stewart et al., 1996).

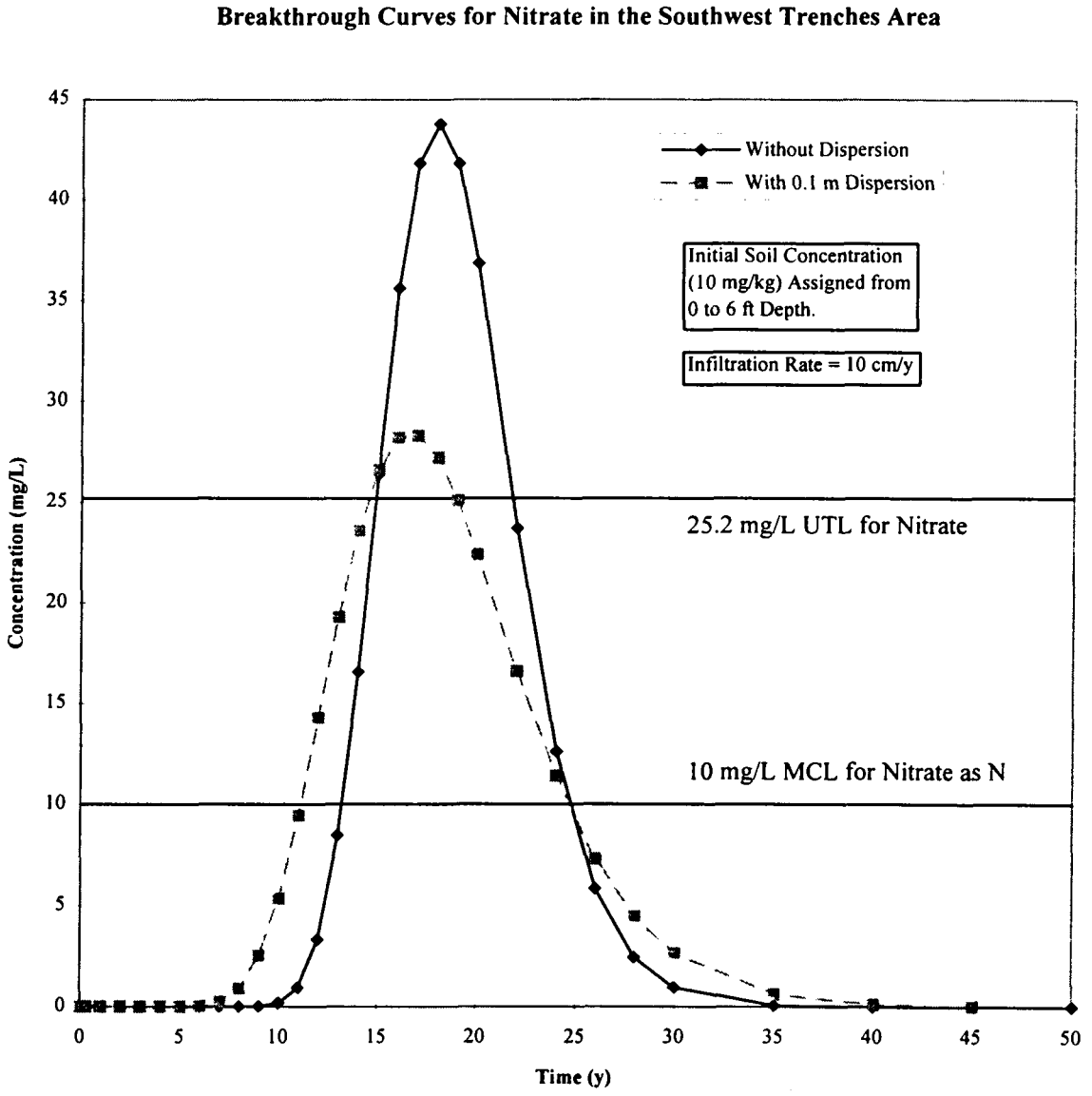
Figure 10. Nitrate Breakthrough Curves for the Southwest Trenches, Ra/Sr Leach Systems, and the Western Dog Pens Areas.



MCL = Maximum Contaminant Level, EPA Region 9, Drinking Water Standards and Health Advisory Table, 1996.

UTL = 95% Upper Tolerance Limit based on analytical results of ground water samples from HSU-1 (Stewart et al., 1996).

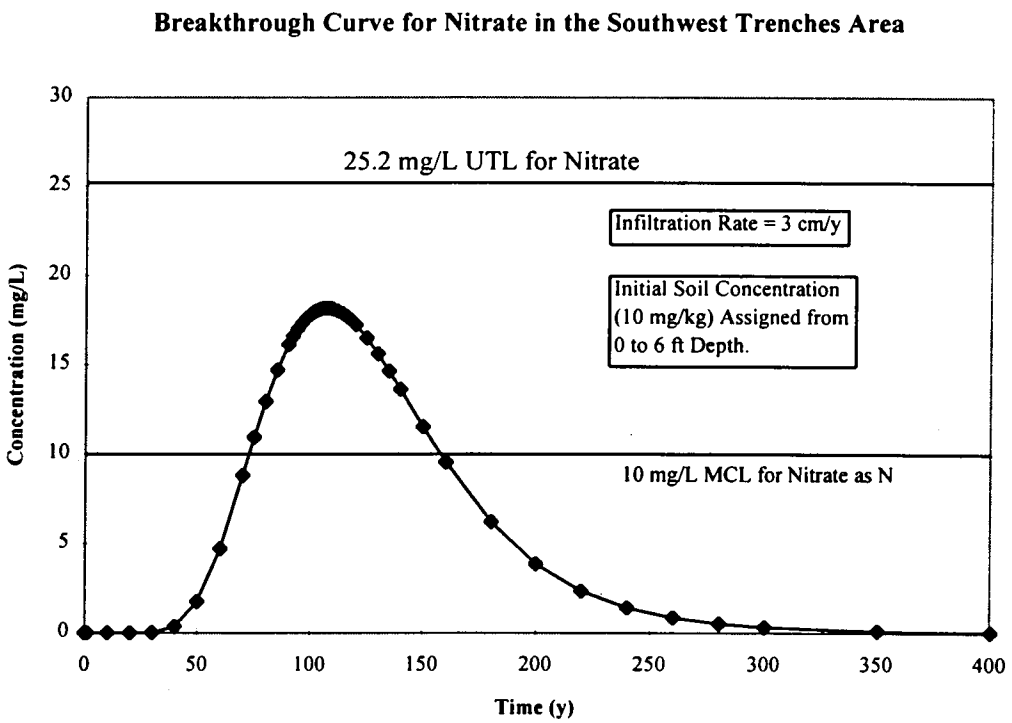
Figure 11. Nitrate Breakthrough Curves for Contaminant Inventory Sensitivity Analyses.



MCL = Maximum Contaminant Level, EPA Region 9, Drinking Water Standards and Health Advisory Table, 1996.

UTL = 95% Upper Tolerance Limit based on analytical results of ground water samples from HSU-1 (Stewart et al., 1996).

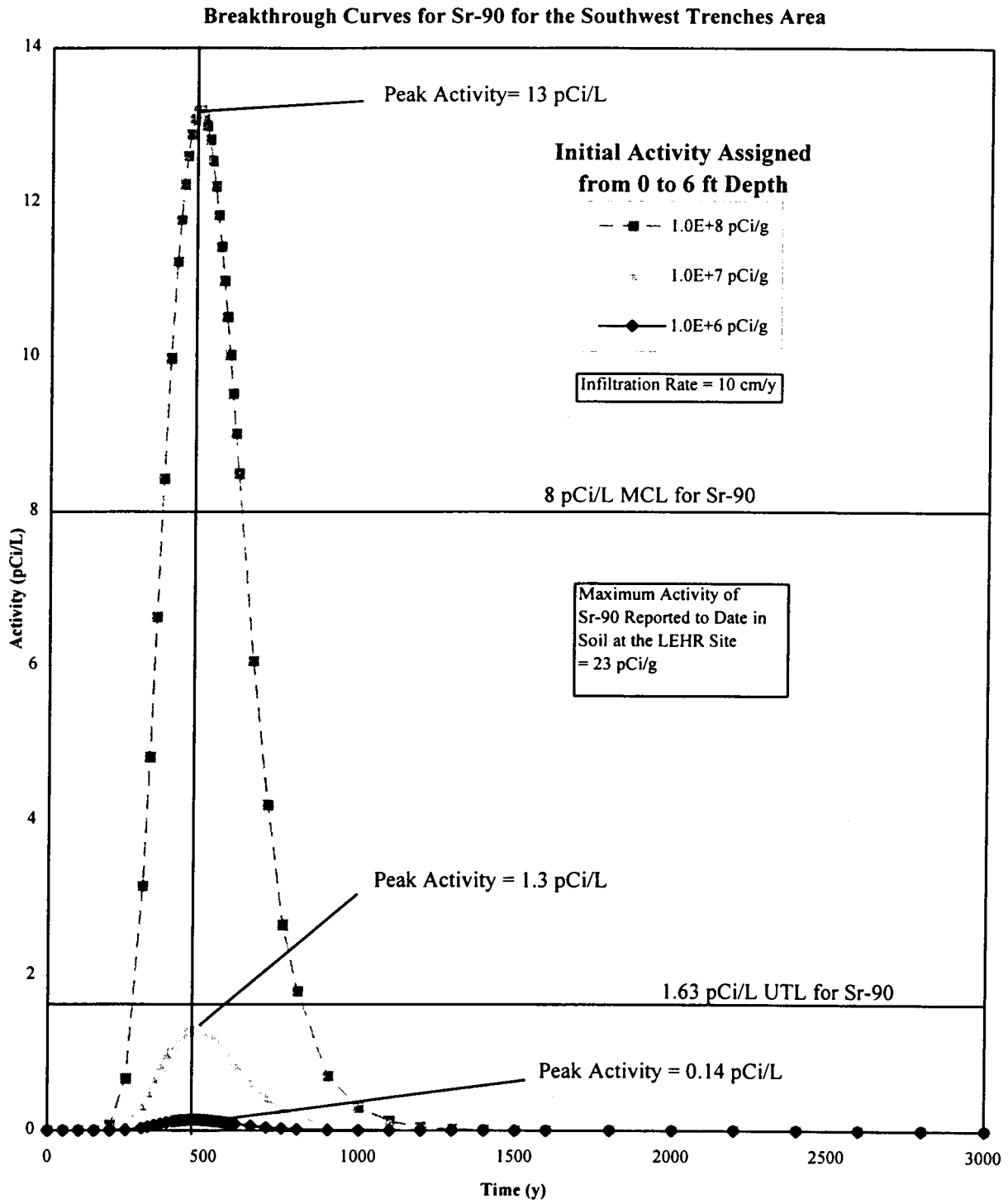
Figure 12. Nitrate Breakthrough Curves for the Southwest Trenches Area for the Dispersion Sensitivity Analysis.



MCL = Maximum Contaminant Level, EPA Region 9, Drinking Water Standards and Health Advisory Table, 1996.

UTL = 95% Upper Tolerance Limit based on analytical results of ground water samples from HSU-1 (Stewart et al., 1996).

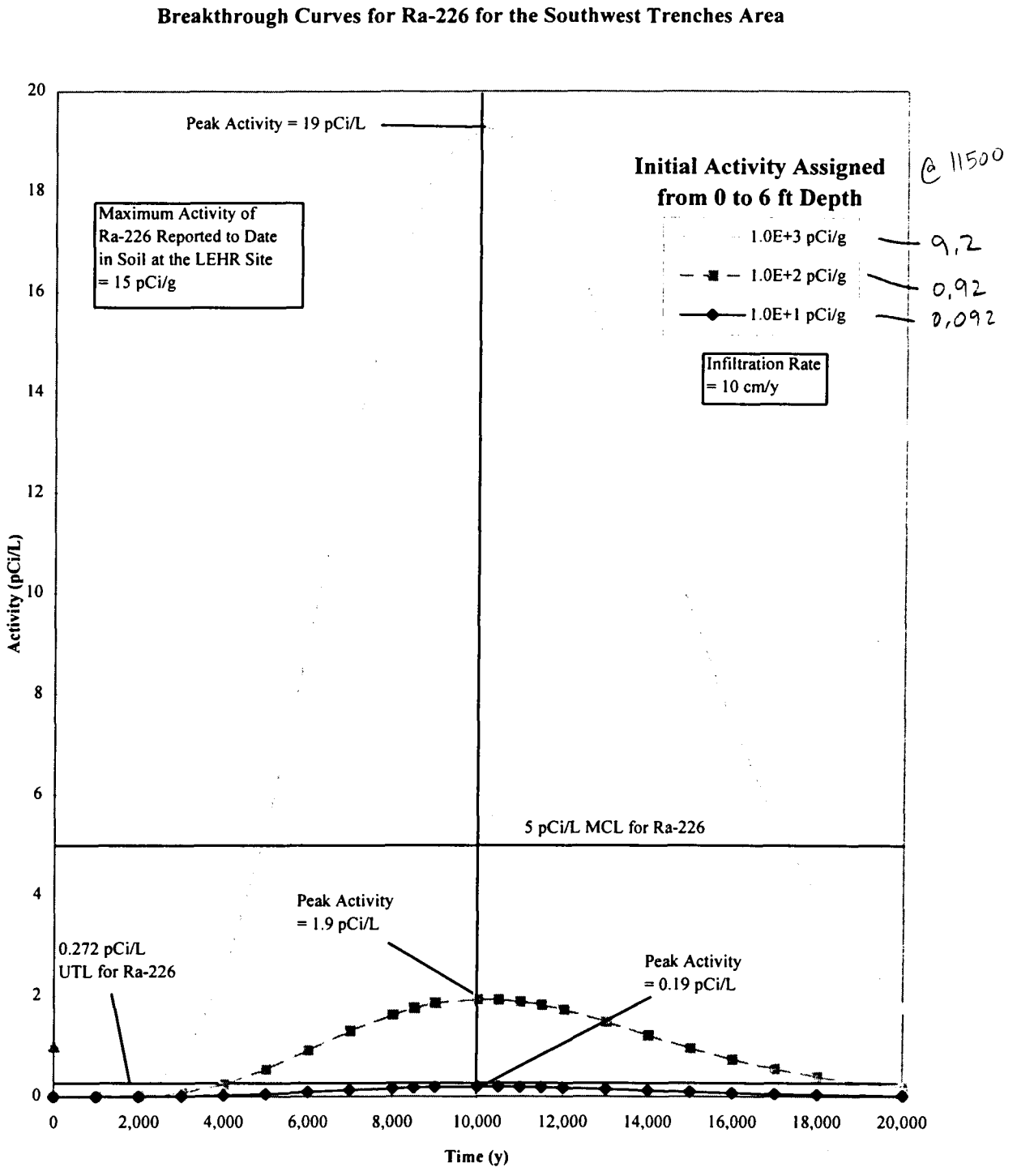
Figure 13. Nitrate Breakthrough Curve for the Southwest Trenches Area.



MCL = Maximum Contaminant Level, EPA Region 9, Drinking Water Standards and Health Advisory Table, 1996.

UTL = 95% Upper Tolerance Limit based on analytical results of ground water samples from HSU-1 (Stewart et al., 1996).

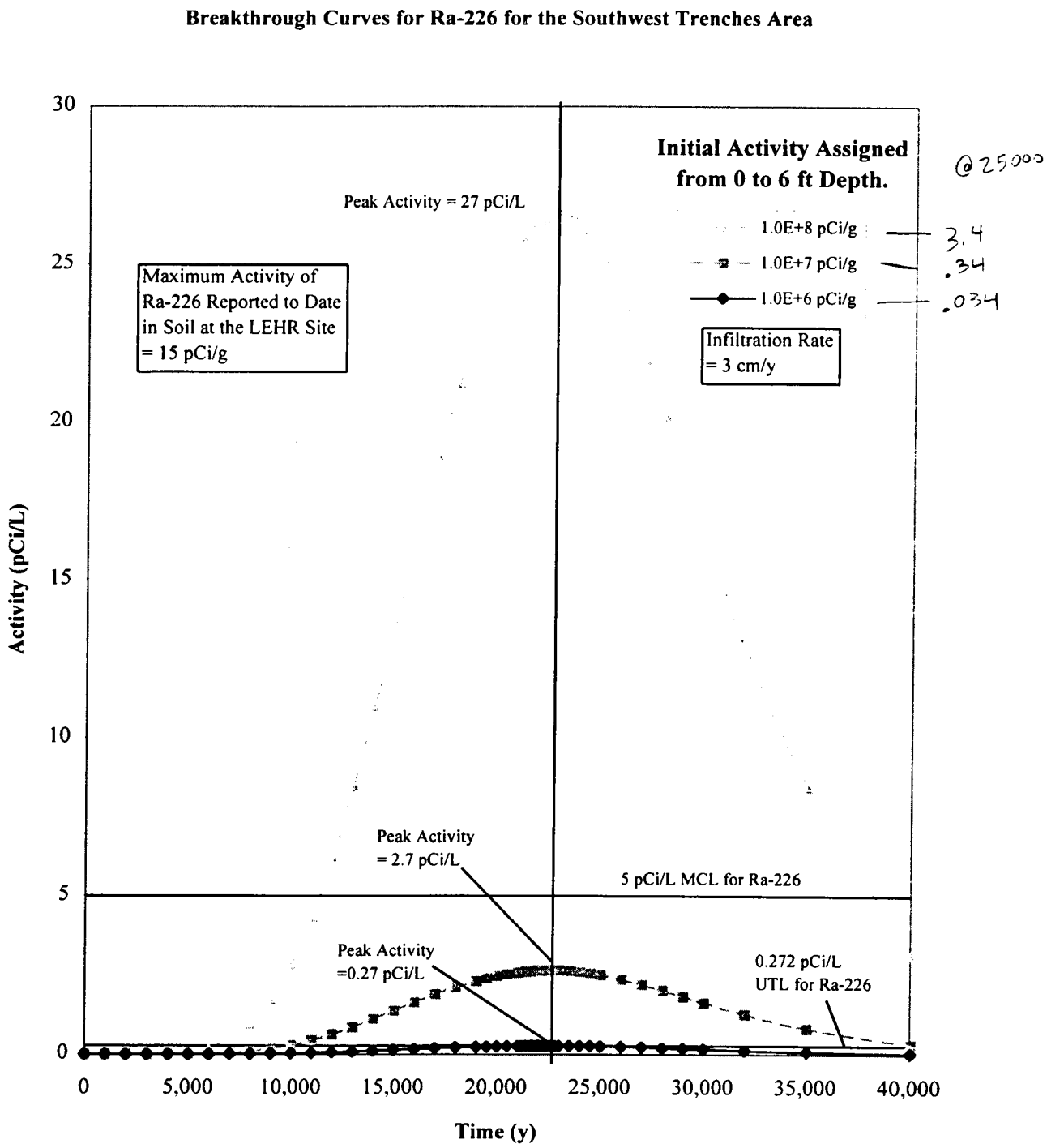
Figure 14. Strontium 90 (Sr-90) Breakthrough Curves for the Southwest Trenches Area.



MCL = Maximum Contaminant Level, EPA Region 9, Drinking Water Standards and Health Advisory Table, 1996.

UTL = 95% Upper Tolerance Limit based on analytical results of ground water samples from HSU-1 (Stewart et al., 1996).

Figure 15. Radium 226 (Ra-226) Breakthrough Curves for the Southwest Trenches Area Assuming 10 cm/y Infiltration Rate.



MCL = Maximum Contaminant Level, EPA Region 9, Drinking Water Standards and Health Advisory Table, 1996.

UTL = 95% Upper Tolerance Limit based on analytical results of ground water samples from HSU-1 (Stewart et al., 1996).

Figure 16. Radium 226 (Ra-226) Breakthrough Curves for the Southwest Trenches Area Assuming 3 cm/y Infiltration Rate.

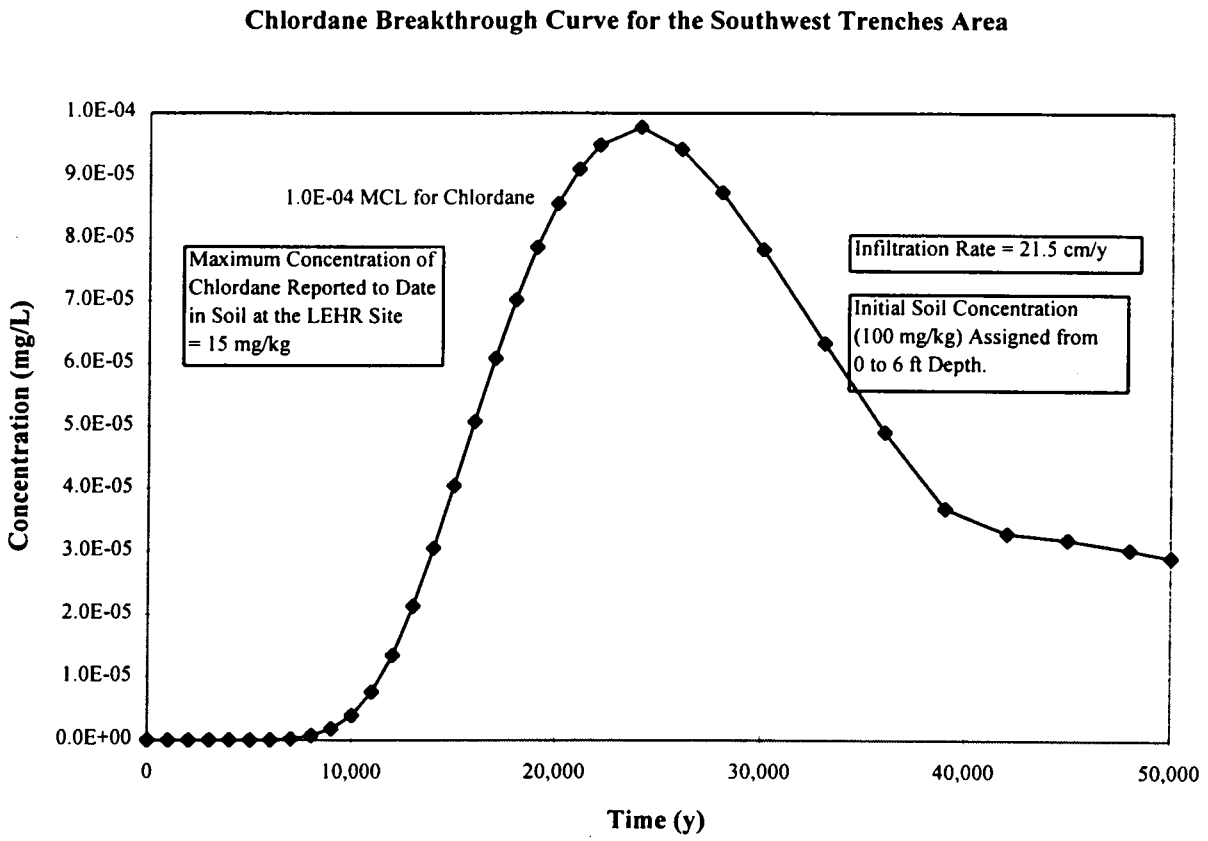
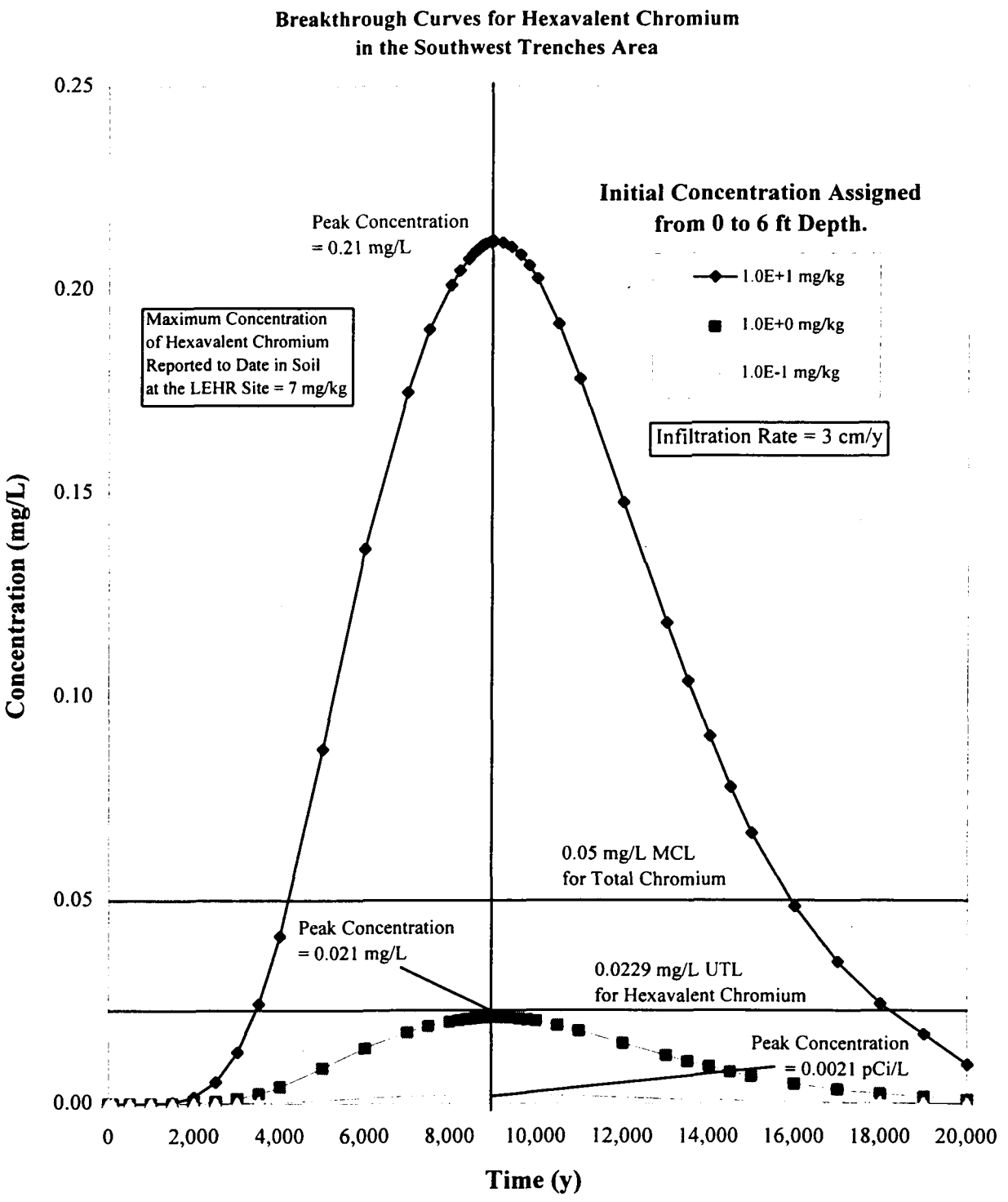


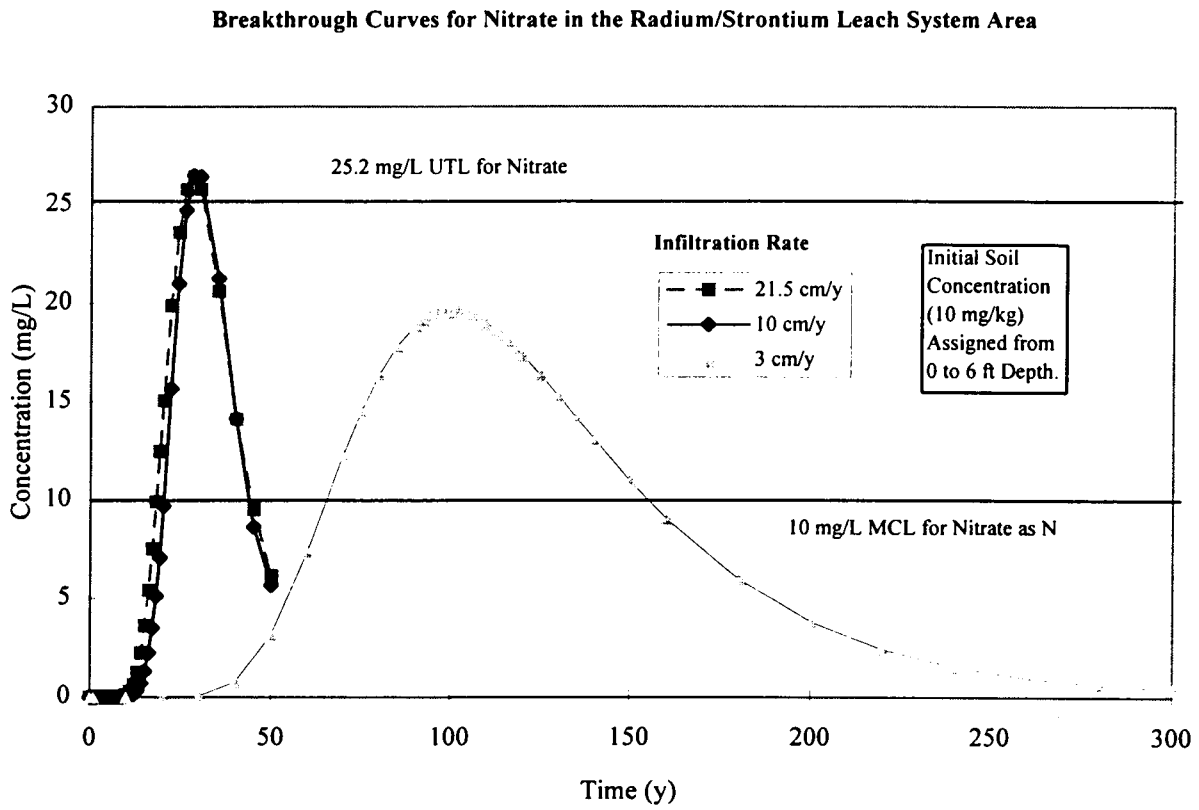
Figure 17. Chlordane Breakthrough Curve for the Southwest Trenches Area.



MCL = Maximum Contaminant Level, EPA Region 9, Drinking Water Standards and Health Advisory Table, 1996.

UTL = 95% Upper Tolerance Limit based on analytical results of ground water samples from HSU-1 (Stewart et al., 1996).

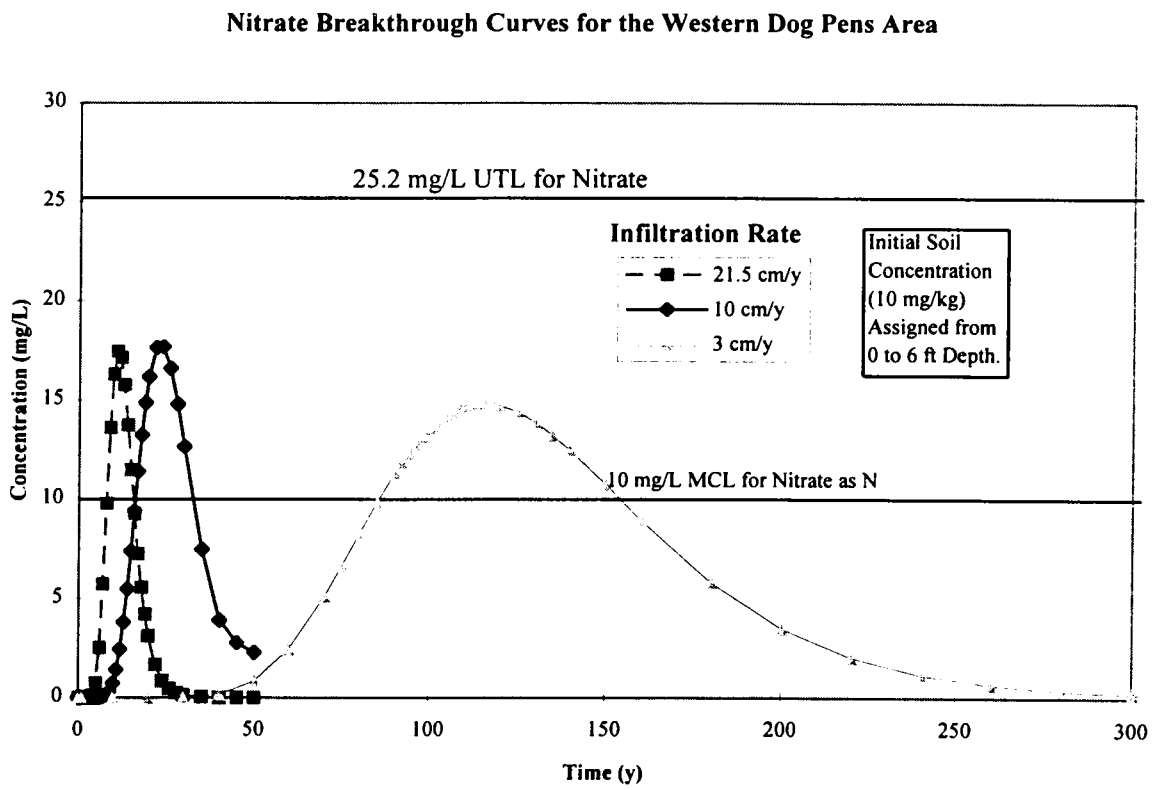
Figure 18. Hexavalent Chromium Breakthrough Curves for the Southwest Trenches Area.



MCL = Maximum Contaminant Level, EPA Region 9, Drinking Water Standards and Health Advisory Table, 1996.

UTL = 95% Upper Tolerance Limit based on analytical results of ground water samples from HSU-1 (Stewart et al., 1996).

Figure 19. Nitrate Breakthrough Curves for the Radium/Strontium Leach System Area.



MCL = Maximum Contaminant Level, EPA Region 9, Drinking Water Standards and Health Advisory Table, 1996.

UTL = 95% Upper Tolerance Limit based on analytical results of ground water samples from HSU-1 (Stewart et al., 1996).

Figure 20. Nitrate Breakthrough Curves for the Western Dog Pens Area.

Table 1. Areas Investigated for the Vadose Zone Modeling at the LEHR Facility.

Area Number[a]	Area Name	Corresponding Operable Unit
1	Southwest Trenches	OU-1
2	Ra/Sr Leach Systems	OU-2
3	Western Dog Pens	OU-3
4	Septic Tanks	OU-4

[a]Numbers shown on Figure 1.

Table 2. Boring Logs from the LEHR Site Used to Compile Composite Logs.

Operable Unit	Area	Boring Logs Used to Compile Generalized Log
OU-1	Southwest Trenches	UCD1-4, UCD2-15, SB-6, -7, -8[a]
OU-2	Radium/Strontium Leach Fields	UCD1-6, -22, SB-1, -2, -3, -4[a]
OU-3	Western Dog Pens	UCD1-3, -5, -20, -21, -23

[a]Borings (SB-#) drilled during the 1996 Characterization Investigation (Weiss Associates, 1997).

Table 3. Rationale for Excluding Contaminants Detected at LEHR as Indicator Constituents for the Vadose Zone Modeling.

Constituent	Rationale for Exclusion
Actinium 228	Limited vertical and horizontal distribution.
Alpha BHC	Limited vertical and horizontal distribution.
Beryllium	Limited vertical and horizontal distribution.
Bismuth 214	Limited vertical and horizontal distribution.
Carbon 14	Limited vertical and horizontal distribution. Reported values generally near background levels.
Cesium 137	Limited vertical and horizontal distribution. K_d similar to that of Ra-226.
Chloride	Limited vertical and horizontal distribution.
Chromium (Total)	Limited vertical and horizontal distribution. Limited to shallow depths. K_d similar to that of Sr-90.
Chromium VI	Limited horizontal distribution.
Cobalt 60	Limited vertical and horizontal distribution. Values only slightly above background. K_d similar to that of Sr-90.
Copper	Limited horizontal distribution. Reported values generally near background levels.
DDD	Reported values are generally low.
DDE	Limited vertical and horizontal distribution. Limited to shallow depths.
Delta BHC	Limited vertical and horizontal distribution.
Dieldrin	Limited vertical and horizontal distribution.
Endosulfan	Limited vertical and horizontal distribution.
Formaldehyde	Limited vertical and horizontal distribution.
Gamma BHC	Limited vertical and horizontal distribution.
Heptachlor	Limited vertical and horizontal distribution. Limited to shallow depths.
Iron	Limited vertical and horizontal distribution.
Lead	Limited vertical and horizontal distribution. Most reported values below or only slightly above background levels.
Lead 212	Limited vertical and horizontal distribution. Values only slightly above background. K_d similar to Sr-90 and Ra-226.
Lead 214	Limited vertical and horizontal distribution. K_d similar to that of Sr-90 and Ra-226.
Manganese	Limited vertical and horizontal distribution. K_d similar to that of Sr-90.
Mercury	Limited vertical and horizontal distribution.
Methylene Chloride	Limited vertical and horizontal distribution. Common analytical lab contaminant.
Potassium 40	Limited vertical and horizontal distribution.
Pyrene	Limited vertical and horizontal distribution.
Sulfate	Less widespread distribution and generally lower concentrations than nitrate.

K_d = Soil/Water Partioning Coefficient

Table 3. Rationale for Excluding Contaminants Detected at LEHR as Indicator Constituents for the Vadose Zone Modeling (continued).

Constituent	Rationale for Exclusion
SVOCs	Limited vertical and horizontal distribution.
Thallium 208	Limited vertical and horizontal distribution.
Thorium 232	Limited vertical and horizontal distribution.
Tritium	Limited vertical and horizontal distribution. Reported values within range of observed background concentrations.
Vanadium	Limited vertical and horizontal distribution. Reported values within range of observed background concentrations.
Zinc	Reported values near background levels.

K_d = Soil/Water Partioning Coefficient

Table 4. Lateral and Vertical Distribution of Indicator Constituents at the LEHR Facility.

Indicator Constituent	Lateral Distribution[a]	Vertical Distribution[a]
Southwest Trenches - Solid Waste		
Strontium 90	Detected in nearby soil at least 7 ft from waste.	Detected at 7 ft and 12 ft bgs.
Radium 226	Does not spread laterally to soil. ND in nearby soil samples.	Solid waste detected only at 6 to 7 ft bgs.
Chlordane	Minor detections in soil samples within a few feet.	Does not significantly spread vertically. Detected at 0 to 3 ft, and 6.5 ft bgs.
Nitrate	Not observed to spread laterally to soil.	Appears to spread below waste to soil. Detected from 2.5 to 6.5 ft bgs.
Southwest Trenches - Soil		
Strontium 90	Not limited to disposal areas, detections at least 7 ft from waste.	Limited to upper 3 ft, and 6 to 15 ft bgs.
Radium 226	Confined to disposal pits and trenches.	Confined to and immediately below waste. Detected at 6 to 14 ft bgs.
Chlordane	Not confined to waste, minor detections in soil within a few feet.	Detected from 2 to 4 ft, and 19 ft bgs.
Nitrate	Confined to disposal trenches and pits.	Confined within and below waste. Detected at 0 to 15 ft bgs.
Ra/Sr Treatment System		
Strontium 90	Not confined laterally, exists in Ra and Sr Areas.	Attenuates with depth, except near 2 of 3 dry wells. Detected from 8 to 15 ft and 25 to 29 ft bgs.
Radium 226	Confined to Ra dry wells, piping, & leach line.	Decreasing activity with depth. Detected from 6 to 18 ft bgs in Ra Leach System area.
Chlordane[b]	ND	ND
Nitrate	Not observed to spread laterally.	Detected from 4 to 14 ft bgs. Some downward migration indicated.
Dog Pens Area		
Strontium 90	Detections in many Dog Pens Area surface samples.	Not well constrained. Detected at 0 ft and 6 ft bgs.
Radium 226	Not well constrained, generally limited distribution.	Detected at 6 ft and 21 ft bgs.
Chlordane	Detections in many Dog Pens Area surface samples.	Attenuates sharply with depth. No detections below 2.5 ft bgs.
Nitrate	Confined to dog pens row E and N and Chemical Dispensing Area.	Confined to surface. No detections below 2 ft bgs.

bgs = below ground surfaces
ND = Not Detected
[a]Lateral and vertical distribution determined by plotting concentration/activities vs. depth for various areas (Appendix A). These plots were then compared to information presented in the Draft Final Characterization Report (Weiss Associates, 1997).
[b] Chlordane was not detected in the Ra/Sr Source Area during the Characterization Investigation.

Table 5. Summary of Vadose Zone Model Indicator Constituents, Associated Levels, and Input Parameter Values.

RADIOLOGICAL COMPOUNDS

Indicator Constituent	Background[a] in soil	95% UTL in water[b]	MCL[c]	Maximum soil activity reported at site[d]	Partitioning coefficient (K_d)	Molecular weight	Decay rate half-life
	(pCi/g)	(pCi/L)	(pCi/L)	(pCi/g)	(L/kg)	(g/mole)	(y)
Radium 226	1.50	0.272	5	15	100	226.0254	1,600
Strontium 90	0.52	1.63	8	23	10	87.62	29

NON-RADIOLOGICAL COMPOUNDS

Indicator Constituent	Background[a] in soil	95% UTL in water[b]	MCL[c]	Maximum soil concentration reported at site[d]	Partitioning coefficient (K_d)	Molecular weight	Henry's Law constant
	(mg/kg)	(mg/L)	(mg/L)	(mg/kg)	(L/kg)	(g/mole)	(atm-m^3/mole)
Chlordane	NA	NA	0.0001	15	650/1230[e]	409.8	1.9E-03[f]
Hexavalent Chromium	0.16	0.0229	0.05	7	10	52	0
Nitrate (as N)	29.1	25.2	10	390	0	14.0067	0

[a]Background = 95% Upper Confidence Level (UCL) for 24 background samples collected at 0, 4, 20, and 40 ft below ground surface at six locations within one-half mile of the LEHR facility (Weiss Associates, 1997).
[b]Based on analytical results of ground water samples from HSU-1. UTL = Upper Tolerance Limit (Stewart *et al.*, 1996, *1995 Annual Water Monitoring Report*, LEHR Environmental Restoration, University of California at Davis).
[c]MCL = EPA Region 9, Maximum Contaminant Level, Drinking Water Standards and Health Advisory Table, 1996.
[d]Based on analytical results of soil samples from the LEHR site taken as part of the 1996 Characterization Investigation (Weiss Associates, 1997).
[e]Values assuming 10% and 20% organic carbon content, respectively (Strenge *et al.*, 1989).
[f]Calculated from vapor pressure (VP) and solubility (S) [H=VP/S].
NA = Not Available

Table 6. Summary of Physical and Hydraulic Properties for Representative Vadose Zone Model Soil Types at the LEHR Facility.

Model Soil Type Name	Sediment Description	Porosity	Saturated Hydraulic Conductivity	Dry Bulk Density	Particle Density	van Genuchten Parameters	
						alpha	N
		(-)	(cm/s)	(g/cm^3)	(g/cm^3)	(cm^{-1})	(-)
NCLYSLT	clayey sandy silt	0.35	7.08E-05	1.7	2.57	2.11E-02	1.03
NSAND	sand	0.31	1.27E-04	1.8	2.63	6.39E-02	1.42
GEO1	sandy gravel	0.29	4.70E-03	1.9	2.71	8.50E-02	1.90
GRVLFLL	gravel fill	0.25	1.00E-02	2.1	2.70	1.20E-01	1.90
NGEO6	silty clay	0.39	5.56E-06	1.6	2.70	2.41E-02	1.17
GEO2	sandy clay	0.37	6.70E-05	1.7	2.68	3.30E-02	1.30
GRVLCL	gravelly clay	0.40	1.00E-07	1.7	2.70	7.00E-04	1.80
CLYGRVL	clayey gravel	0.40	1.00E-07	1.8	2.70	7.00E-04	1.80
GEO5	organic-rich clay	0.41	1.00E-08	1.6	2.69	1.00E-03	2.00

Table 7. Initial Model Soil Concentrations, MCLs, and Model Results for the LEHR Site.

RADIOLOGICAL COMPOUNDS	MODEL INPUT				MODEL RESULTS	
Indicator Constituent (and Area)	Initial Soil Concentration	Infiltration Rate	Ground Water MCL[a]	95% UTL Background in Ground Water[b]	Peak Ground Water Concentration	Arrival Time
	(pCi/g)	(cm/y)	(pCi/L)	(pCi/L)	(pCi/L)	(y)
Strontium 90 (SW Trenches)	1.0E+6	10.0	8	1.63	0.14	470
Strontium 90 (SW Trenches)	1.0E+7	10.0	8	1.63	1.3	470
Strontium 90 (SW Trenches)	1.0E+8	10.0	8	1.63	13	470
Radium 226 (SW Trenches)	1.0E+6	3.0	5	0.272	0.27	23,000
Radium 226 (SW Trenches)	1.0E+7	3.0	5	0.272	2.7	23,000
Radium 226 (SW Trenches)	1.0E+8	3.0	5	0.272	27	23,000
Radium 226 (SW Trenches)	1.0 E+1	10.0	5	0.272	0.19	10,000
Radium 226 (SW Trenches)	1.0 E+2	10.0	5	0.272	1.9	10,000
Radium 226 (SW Trenches)	1.0 E+3	10.0	5	0.272	19.0	10,000

[a]MCL = Maximum Contaminant Level, EPA Region 9 Drinking Water Standards and Health Advisory Table, 1996.
[b]Based on analytical results of ground water samples from HSU-1. UTL = Upper Tolerance Limit (Stewart *et al.*, 1996, *1995 Annual Water Monitoring Report*, LEHR Environmental Restoration, University of California at Davis).
[c]Initial concentration applied from 0 to 15 ft below ground surface (bgs). Initial concentrations applied from 0 to 6 ft bgs for all other simulations.
NA = Not Available

Table 7. Initial Model Soil Concentrations, MCLs, and Model Results for the LEHR site (continued).

NON-RADIOLOGICAL COMPOUNDS	MODEL INPUT				MODEL RESULTS	
Constituent and Area	Initial Soil Concentration	Infiltration Rate	Ground Water MCL[a]	95% UTL Background in Ground Water[b]	Peak Ground Water Concentration	Arrival Time
	(mg/kg)	(cm/y)	(mg/L)	(mg/L)	(mg/L)	(y)
Nitrate (SW Trenches)	10	3.0	10	25.2	18	107
Nitrate (SW Trenches)	10	10.0	10	25.2	23	26
Nitrate (SW Trenches)	10	21.5	10	25.2	25	17
Nitrate (SW Trenches)[c]	10	10.0	10	25.2	55	26
Nitrate (Ra/Sr Area)	10	3.0	10	25.2	15	116
Nitrate (Ra/Sr Area)	10	10.0	10	25.2	26	28
Nitrate (Ra/Sr Area)	10	21.5	10	25.2	26	28
Nitrate (W. Dog Pens)	10	3.0	10	25.2	20	100
Nitrate (W. Dog Pens)	10	10.0	10	25.2	18	24
Nitrate (W. Dog Pens)	10	21.5	10	25.2	17	11
Chlordane (SW Trenches)	100	21.5	1.0E-4	NA	1E-4	24,000

[a]MCL = Maximum Contaminant Level, EPA Region 9 Drinking Water Standards and Health Advisory Table, 1996.
[b]Based on analytical results of ground water samples from HSU-1. UTL = Upper Tolerance Limit (Stewart *et al.*, 1996, *1995 Annual Water Monitoring Report*, LEHR Environmental Restoration, University of California at Davis).
[c]Initial concentration applied from 0 to 15 ft below ground surface (bgs). Initial concentrations applied from 0 to 6 ft bgs for all other simulations.
NA = Not Available

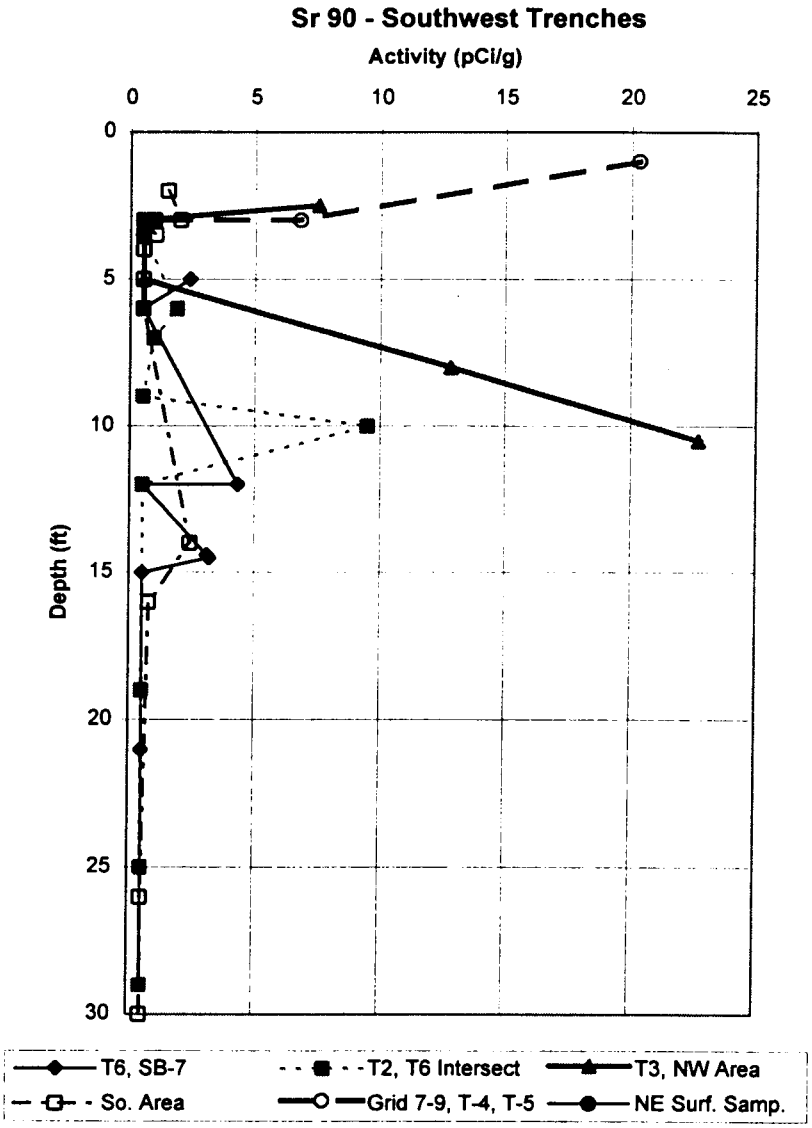
Table 7. Initial Model Soil Concentrations, MCLs, and Model Results for the LEHR site (continued).

METALS	MODEL INPUT				MODEL RESULTS	
Constituent	Initial Soil Concentration	Infiltration Rate	Ground Water MCL[a]	95% UTL Background in Ground Water[b]	Peak Ground Water Concentration	Arrival Time
	(mg/kg)	(cm/y)	(mg/L)	(mg/L)	(mg/L)	(y)
Hexavalent Chromium (SW Trenches)	10	3.0	0.05	0.0229	0.21	9,000
Hexavalent Chromium (SW Trenches)	1.0	3.0	0.05	0.0229	0.021	9,000
Hexavalent Chromium (SW Trenches)	0.1	3.0	0.05	0.0229	0.0021	9,000
Hexavalent Chromium (SW Trenches)	10	10.0	0.05	0.0229	0.33	1,630
Hexavalent Chromium (SW Trenches)	1.0	10.0	0.05	0.0229	0.033	1,620
Hexavalent Chromium (SW Trenches)	0.1	10.0	0.05	0.0229	0.0032	1,640
Hexavalent Chromium (Ra/Sr Area)	10	3.0	0.05	0.0229	0.23	8,800
Hexavalent Chromium (Ra/Sr Area)	1.0	3.0	0.05	0.0229	0.023	8,800
Hexavalent Chromium (Ra/Sr Area)	0.1	3.0	0.05	0.0229	0.0023	8,800
Hexavalent Chromium (W. Dog Pens)	10	10.0	0.05	0.0229	0.21	1,610
Hexavalent Chromium (W. Dog Pens)	1.0	10.0	0.05	0.0229	0.021	1,610
Hexavalent Chromium (W. Dog Pens)	0.1	10.0	0.05	0.0229	0.0021	1,610

[a]MCL = Maximum Contaminant Level for total chromium, EPA Region 9 Drinking Water Standards and Health Advisory Table, 1996.
[b]Based on analytical results of ground water samples from HSU-1. UTL = Upper Tolerance Limit (Stewart *et al.*, 1996, *1995 Annual Water Monitoring Report*, LEHR Environmental Restoration, University of California at Davis).
[c]Initial concentrations applied from 0 to 6 ft bgs for all simulations.

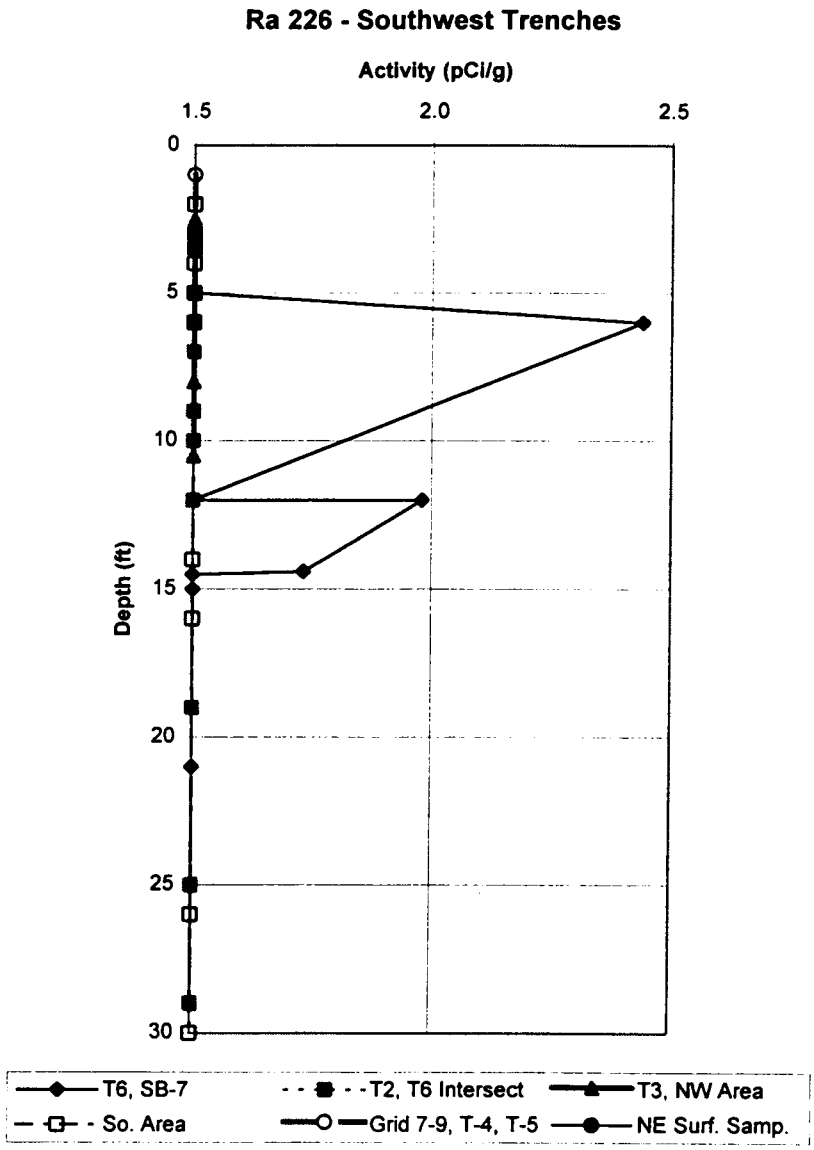
APPENDIX A

VERTICAL DISTRIBUTION OF LEHR SITE INDICATOR CONSTITUENTS



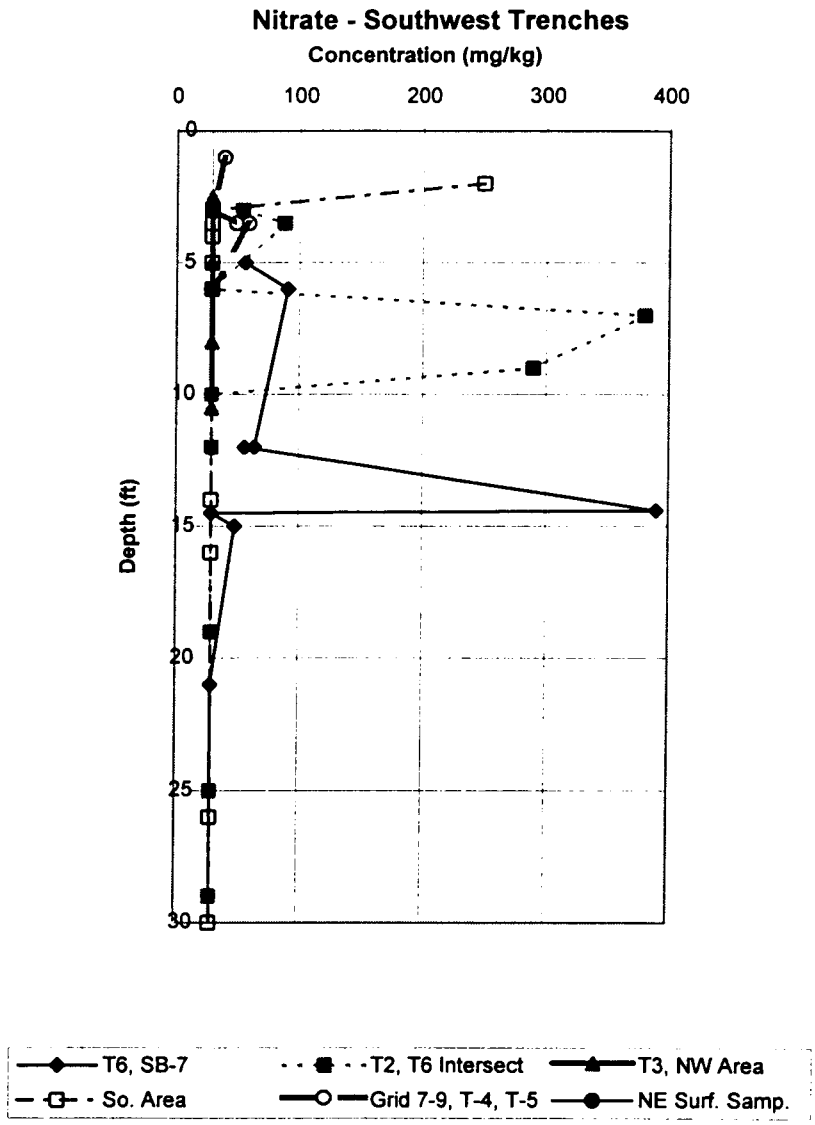
Activities below preliminary soil background levels are presented at background levels.
Preliminary background = 0.52 pCi/g (Weiss Associates, 1997)

Figure A-1. Strontium-90 Activity in Soil Beneath the Southwest Trenches Area.



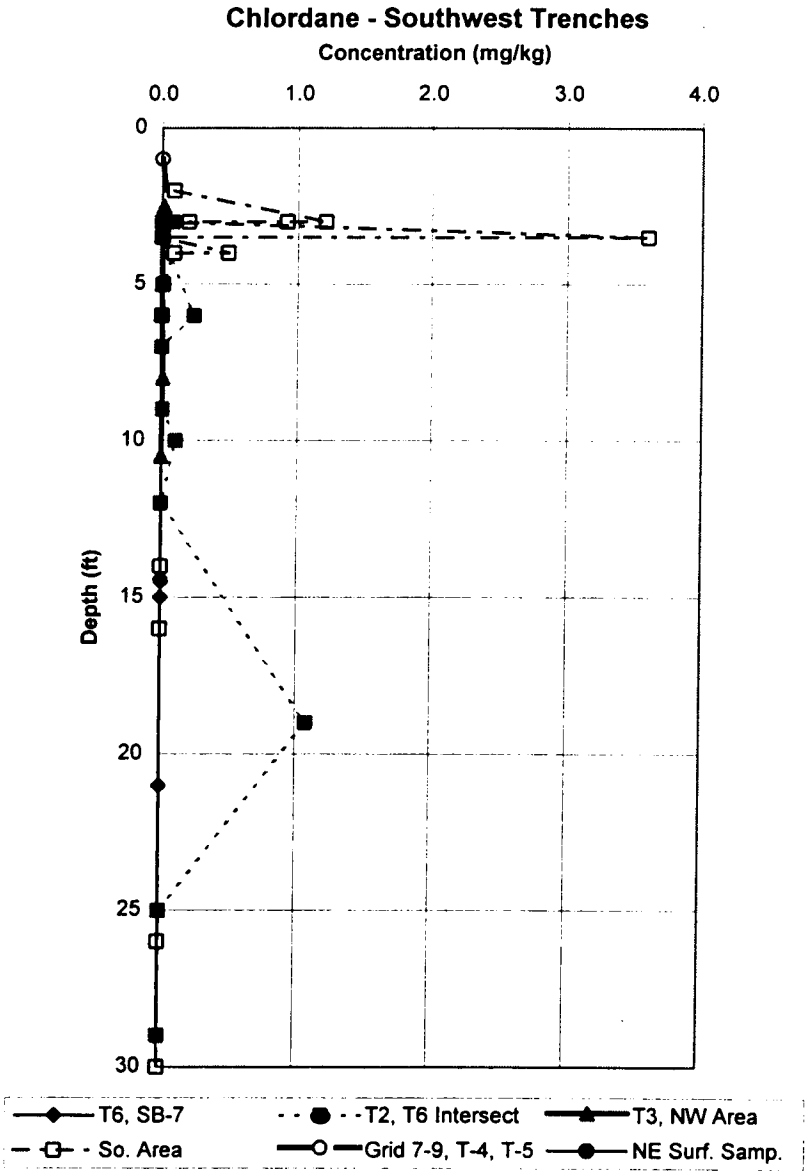
Activities below preliminary soil background levels are presented at background levels.
Preliminary background = 1.50 pCi/g (Weiss Associates, 1997)

Figure A-2. Radium-226 Activity in Soil Beneath the Southwest Trenches Area.



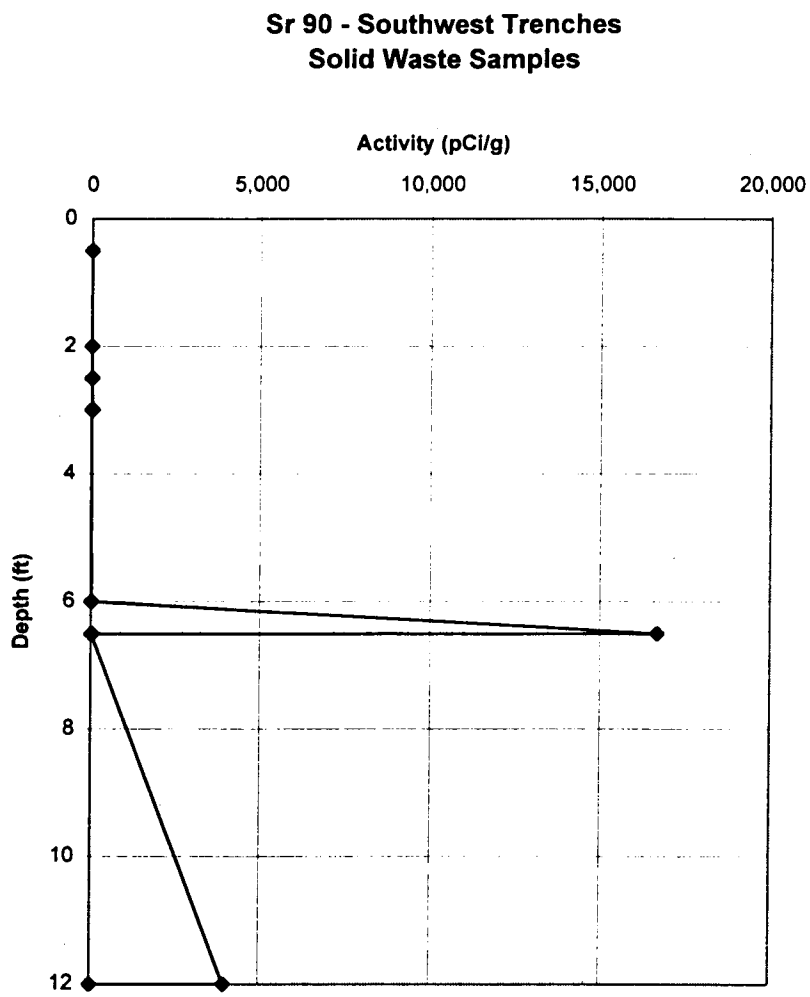
Concentrations below preliminary soil background levels are presented at background levels.
Preliminary background = 29.1 mg/kg (Weiss Associates, 1997)

Figure A-3. Nitrate Concentration in Soil Beneath the Southwest Trenches Area.



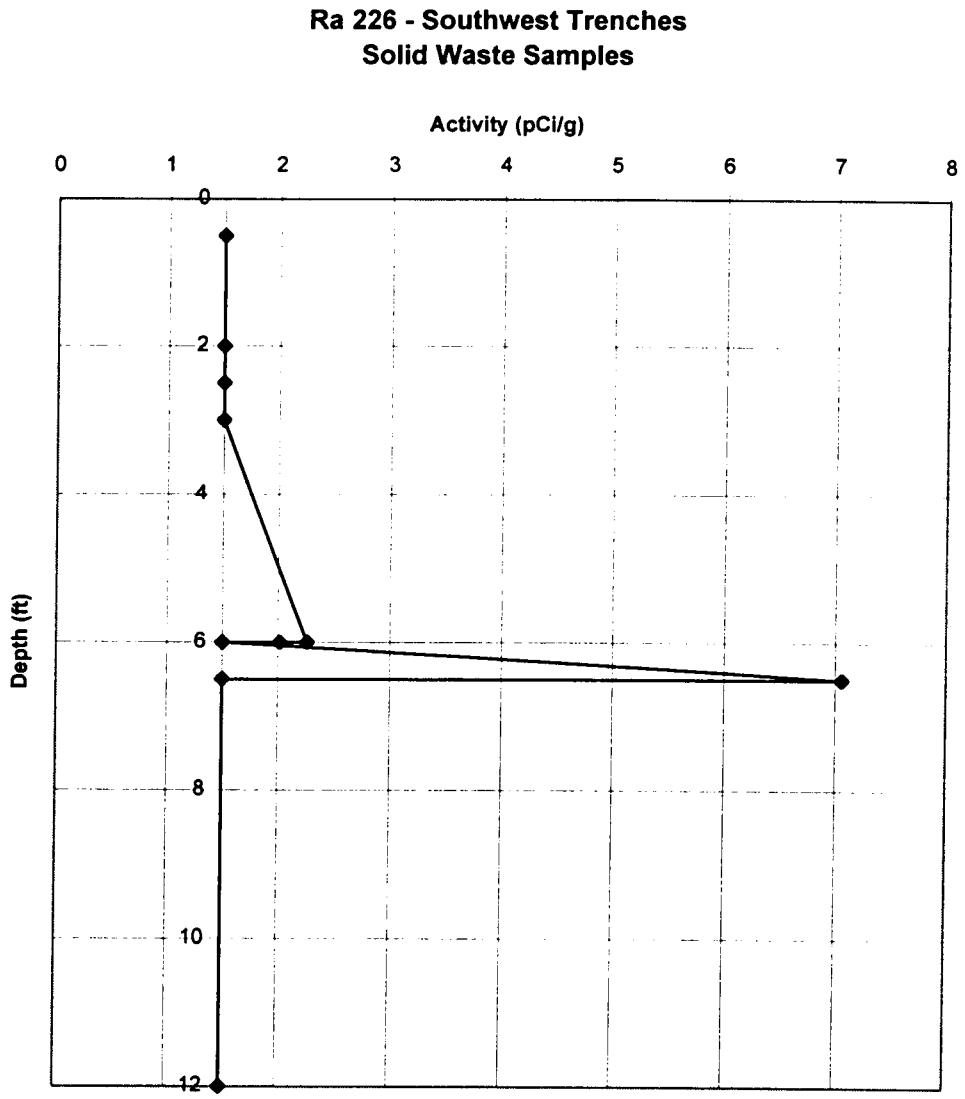
All concentrations detected are presented.
Non-detections plotted as 0 mg/kg.

Figure A-4. Chlordane Concentration in Soil Beneath the Southwest Trenches Area.



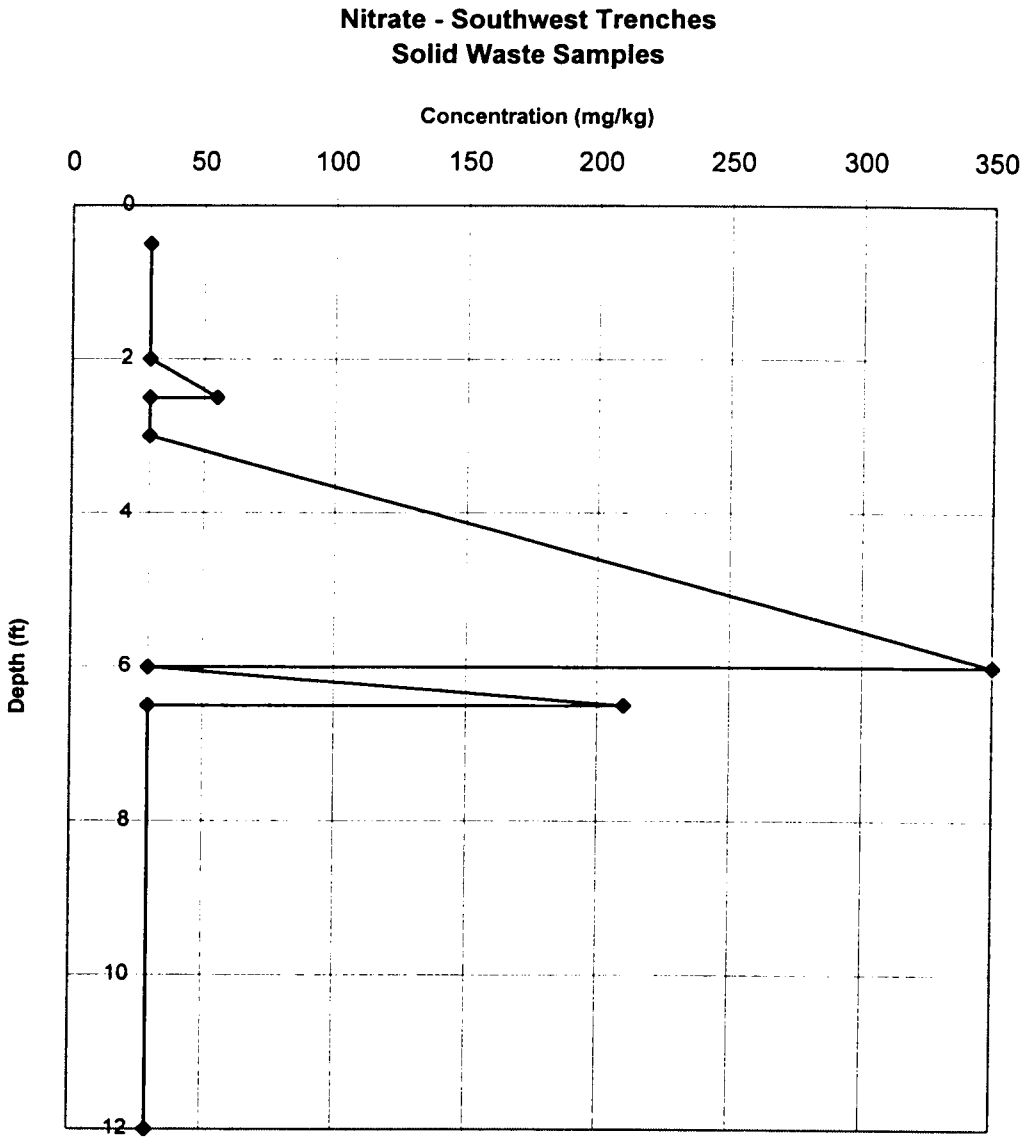
Activities below preliminary soil background levels are presented at background levels.
Preliminary background = 0.52 pCi/g (Weiss Associates, 1997)

Figure A-5. Strontium-90 Activity in Solid Waste Beneath the Southwest Trenches Area.



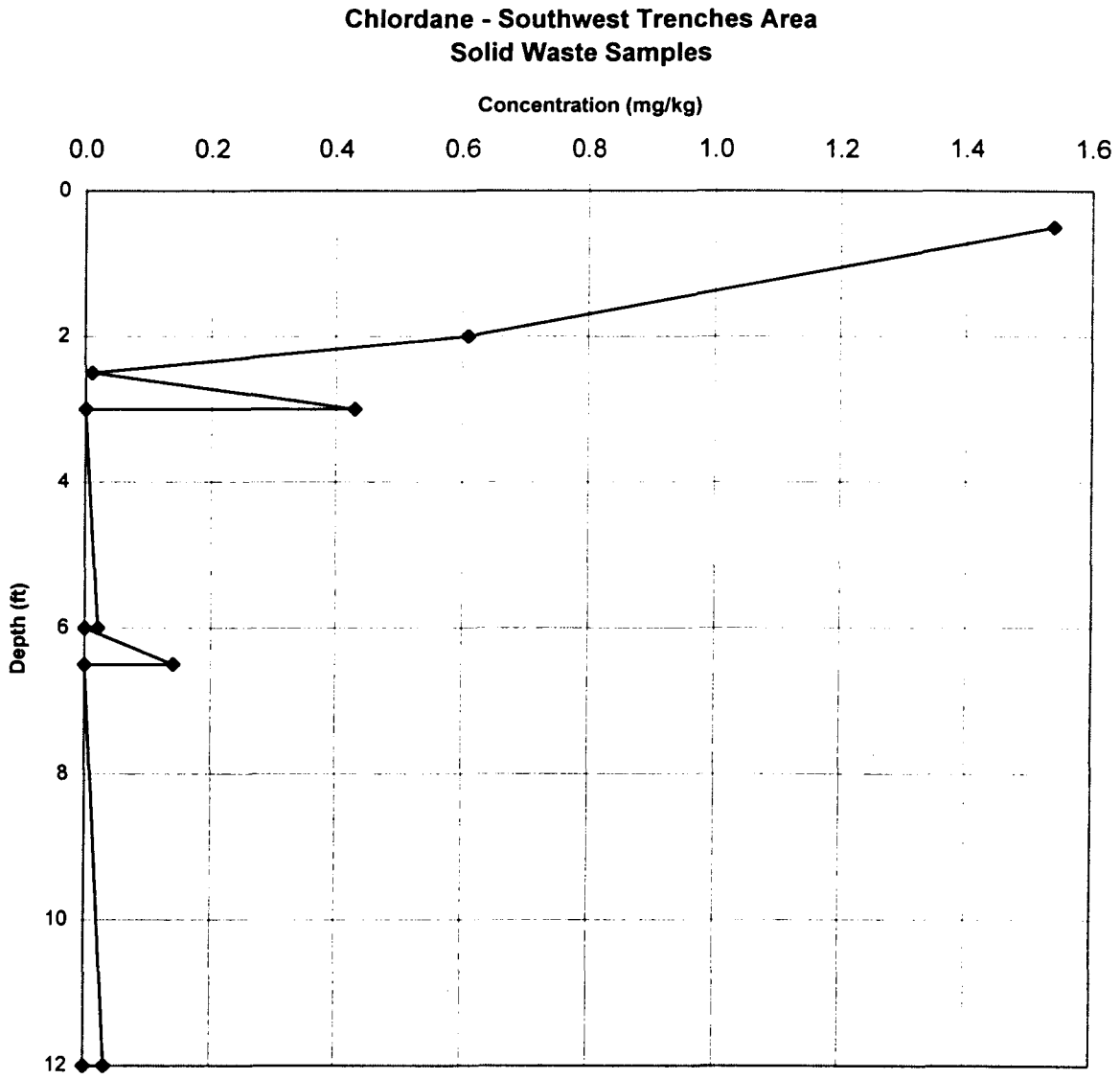
Activities below preliminary soil background levels are presented at background levels.
Preliminary background = 1.50 pCi/g (Weiss Associates, 1997)

Figure A-6. Radium-226 Activity in Solid Waste Beneath the Southwest Trenches Area.



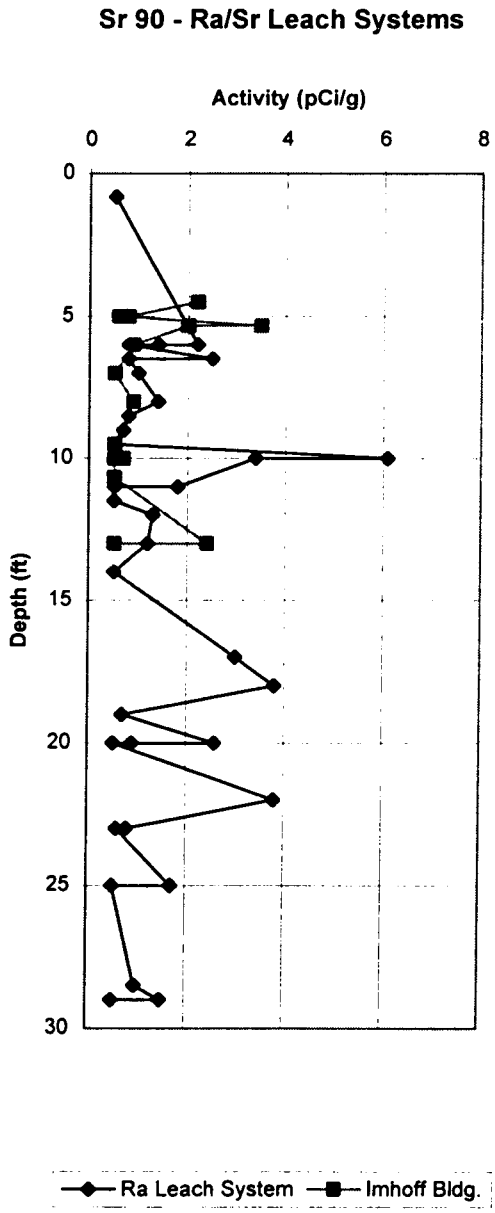
Concentrations below preliminary soil background levels are presented at background levels.
Preliminary background = 29.1 mg/kg (Weiss Associates, 1997)

Figure A-7. Nitrate Concentration in Solid Waste Beneath the Southwest Trenches Area.



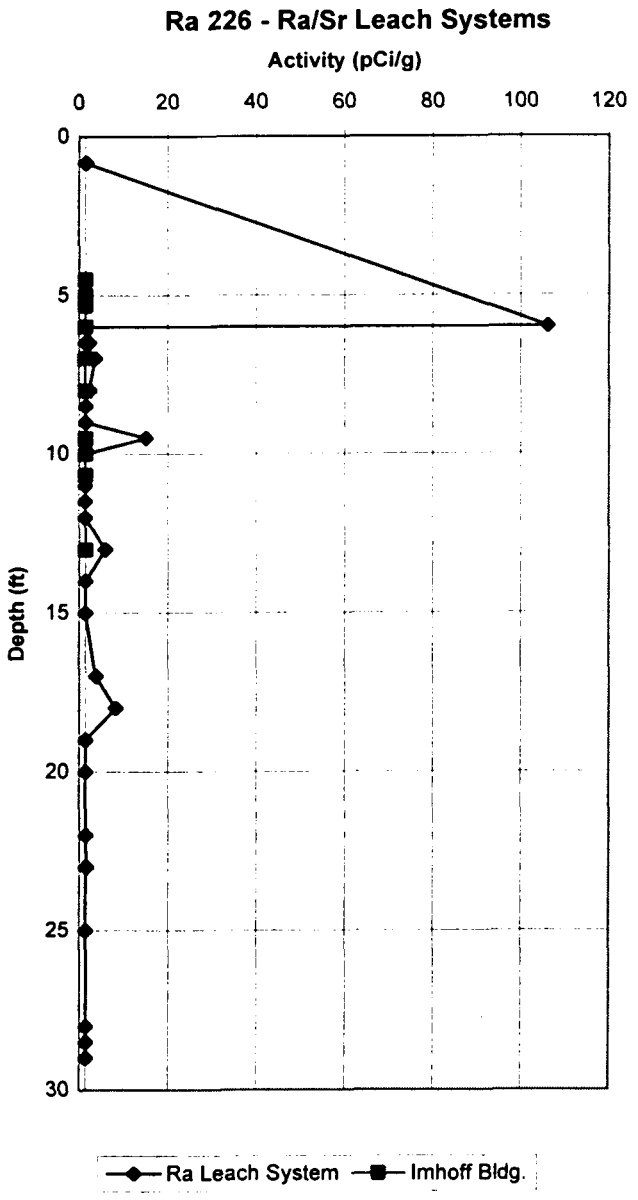
All concentrations detected are presented.
Non-detections plotted as 0 mg/kg.

Figure A-8. Chlordane Concentration in Solid Waste Beneath the Southwest Trenches Area.



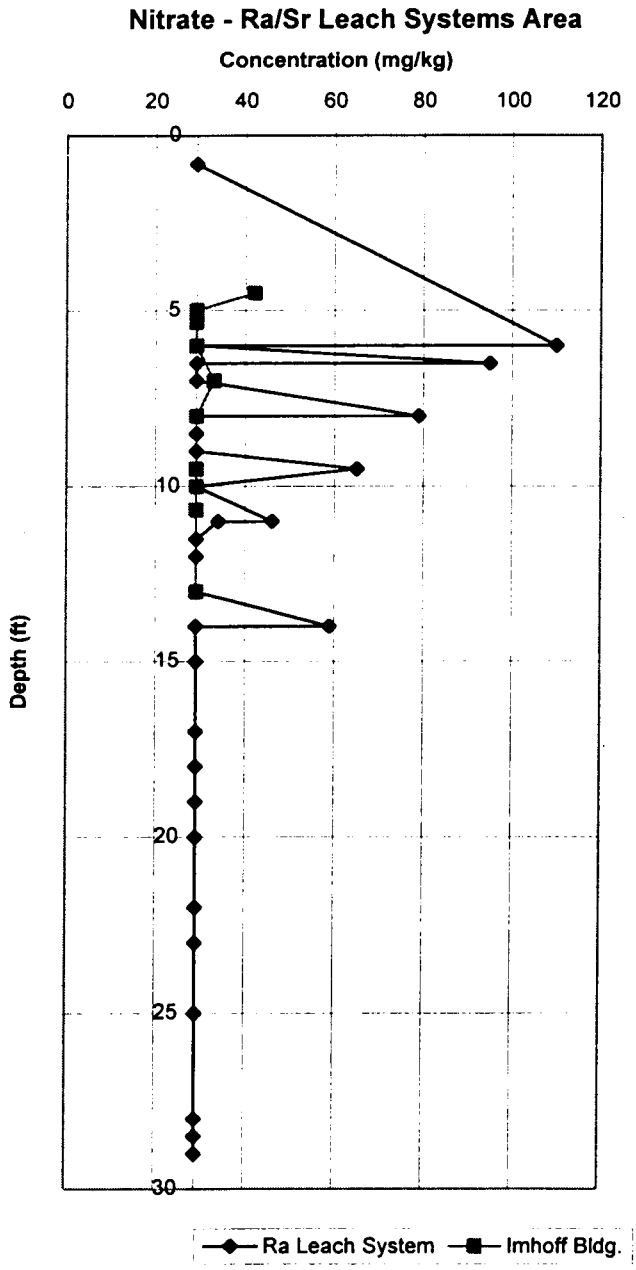
Activities below preliminary soil background levels are presented at background levels.
Preliminary background = 0.52 pCi/g (Weiss Associates, 1997)

Figure A-9. Strontium-90 Activity in Soil Beneath the Ra/Sr Leach Systems Area.



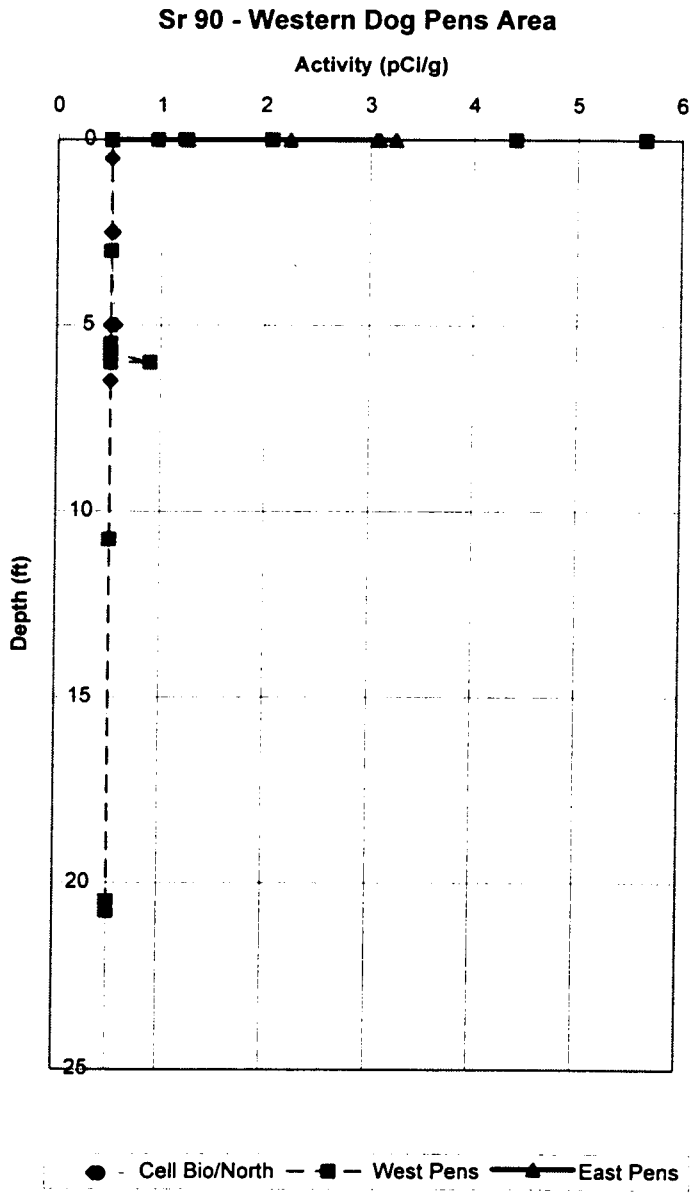
Activities below preliminary soil background levels are presented at background levels.
Preliminary background = 1.50 pCi/g (Weiss Associates, 1997)

Figure A-10. Radium-226 Activity in Soil Beneath the Ra/Sr Leach Systems Area.



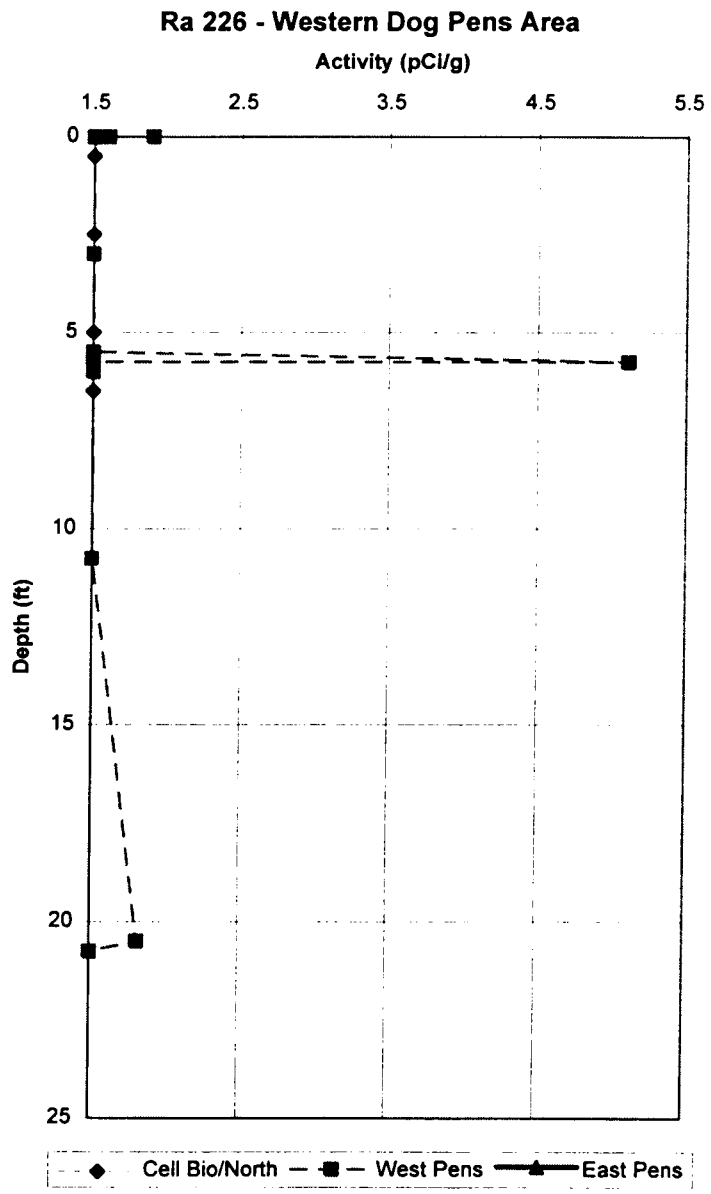
Concentrations below preliminary soil background levels are presented at background levels.
Preliminary background = 29.1 mg/kg (Weiss Associates, 1997)

Figure A-11. Nitrate Concentration in Soil Beneath the Ra/Sr Leach Systems Area.



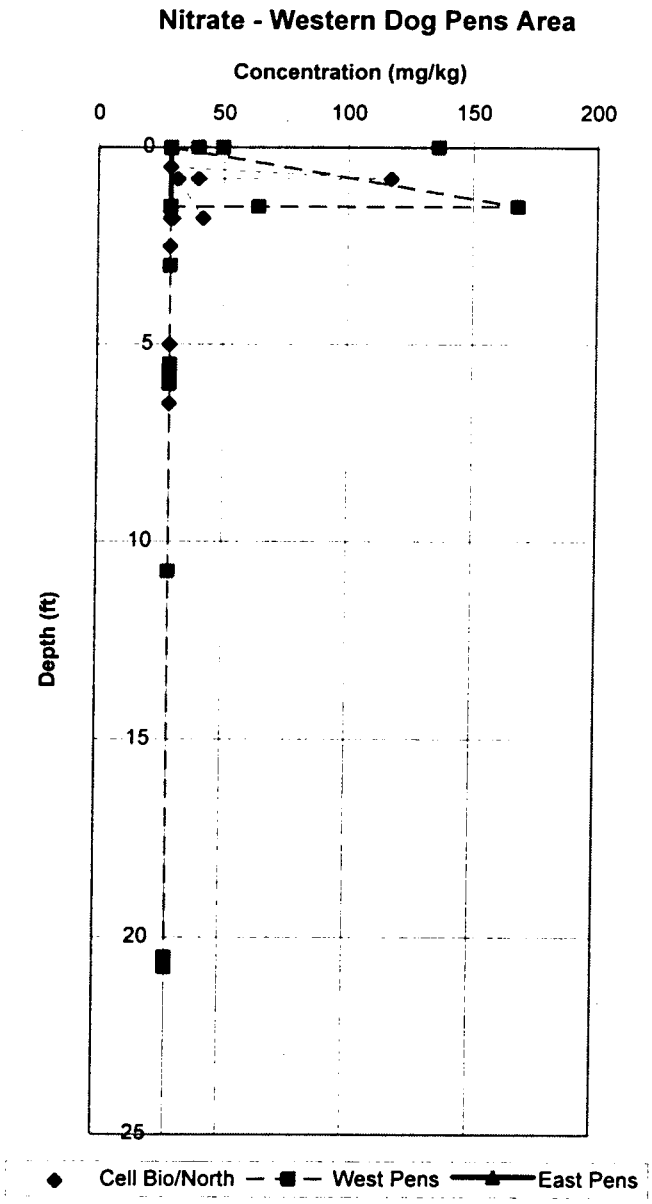
Activities below preliminary soil background levels are presented at background levels.
Preliminary background = 0.52 pCi/g (Weiss Associates, 1997)

Figure A-12. Strontium-90 Activity in Soil Beneath the Western Dog Pens Area.



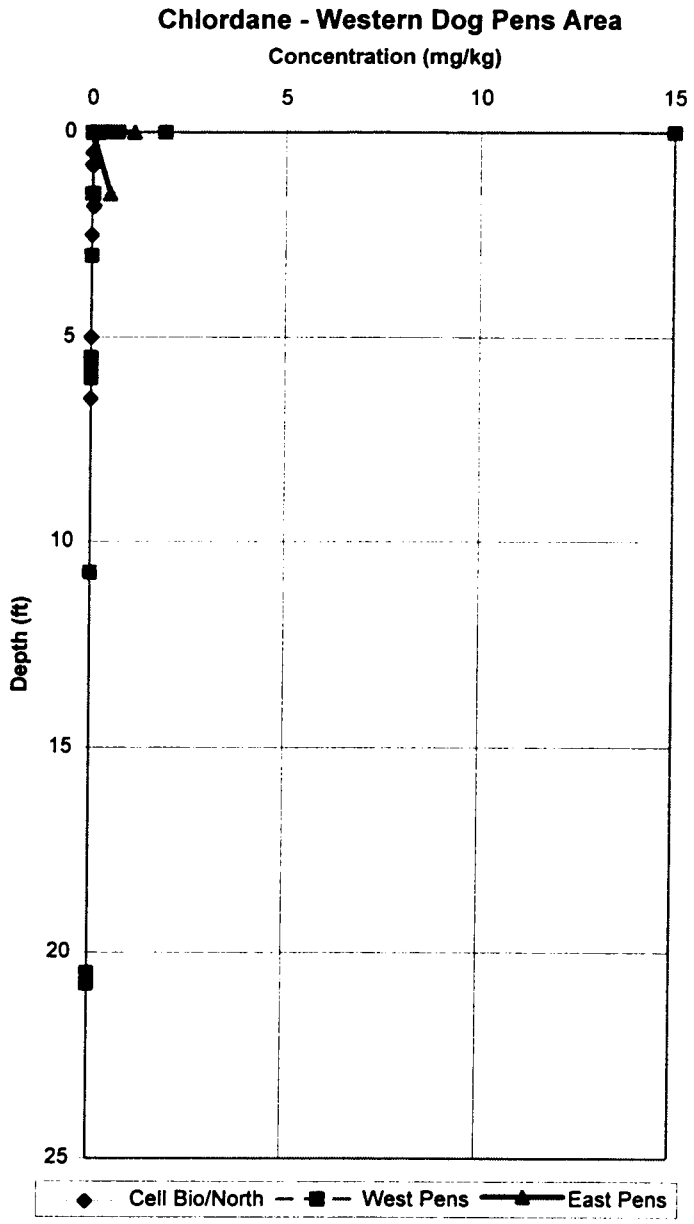
Activities below preliminary soil background levels are presented at background levels.
Preliminary background = 1.52 pCi/g (Weiss Associates, 1997)

Figure A-13. Radium-226 Activity in Soil Beneath the Western Dog Pens Area.



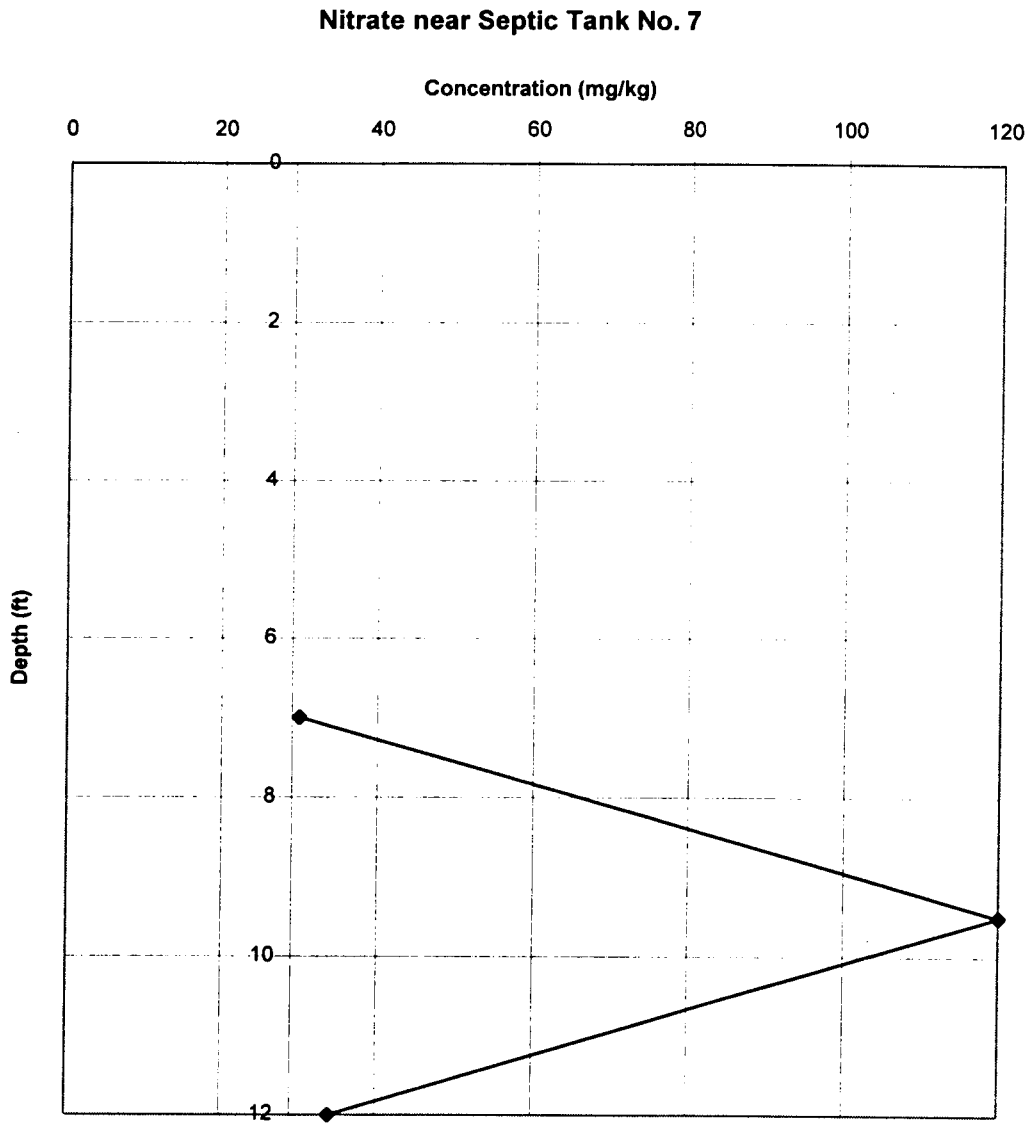
Concentrations below preliminary soil background levels are presented at background level
Preliminary background = 29.1 mg/kg (Weiss Associates, 1997)

Figure A-14. Nitrate Concentration in Soil Beneath the Western Dog Pens Area.



All concentrations detected are presented.
Non-detections plotted as 0 mg/kg.

Figure A-15. Chlordane Concentration in Soil Beneath the Western Dog Pens Area.



All concentrations detected are presented.
Preliminary background = 29.1 mg/kg (Weiss Associates, 1997)

Figure A-16. Nitrate Concentration in Soil Near Septic Tank Number Seven.