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Subsidence Study for Non-Crushable Containers in Slit Trenches at the Savannah River Site

by

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Abstract

This study addresses the issue of waste and cover subsidence caused by corrosion of the non-crushable waste containers defined as containers with significant void space that will not be stabilized by dynamic compaction of the E-area Slit Trenches at the Savanaah River Site. Concentrations at the hypothetical 100-m well were evaluated for 1,000 years and compared with the base case value for compliance. To generalize the results, a hypothetical, no-decay radionuclide characterized by a Kd (5 ml/g) that would be most problematic was selected. Although the non-crushable containers will not be stabilized by dynamic compaction, these containers will gradually corrode, eventually collapse after placement of the final closure cap and cause the cap to subside resulting in an increase of the infiltration rates. The vadose zone model estimated the contaminant fluxes that were input to the aquifer model for prediction of concentrations at the 100-m well.

To study the potential effect of trench subsidence on the well concentrations within the 1000-year time window, two high-impact cases were considered. In the first case, trenches subsided right after dynamic compaction (i.e., at 125 years). In the second case, trenches subsided at 419 years to make the peak concentrations from both the subsided and unsubsided area align in space and time. The study shows that the first case presented no compliance problem for the subsidence of up to two trenches. In the second case, even a single trench subsidence caused the well concentration to be out of compliance. The peak concentration exceeded the base case value by as much as 15%. This paper discusses the general modeling approach and presents the study results.

INTRODUCTION

The E-Area Low Level Waste Facility (LLWF) at the SRS was constructed in October 1989 and began radiological operations in 1994. The current E-Area LLWF area developed for disposal consists of approximately 100 acres (0.4 km^2). Disposal units within the footprint of LLWF include the Slit Trenches, Engineered Trenches, Component-In-Grout (CIG), the Low Activity Waste (LAW) Vault, the Intermediate Level (IL) Vault, and the Naval Reactor Component Disposal Areas (NRCDAs). Figure 1 shows the location of different facilities within the E-Area LLWF.

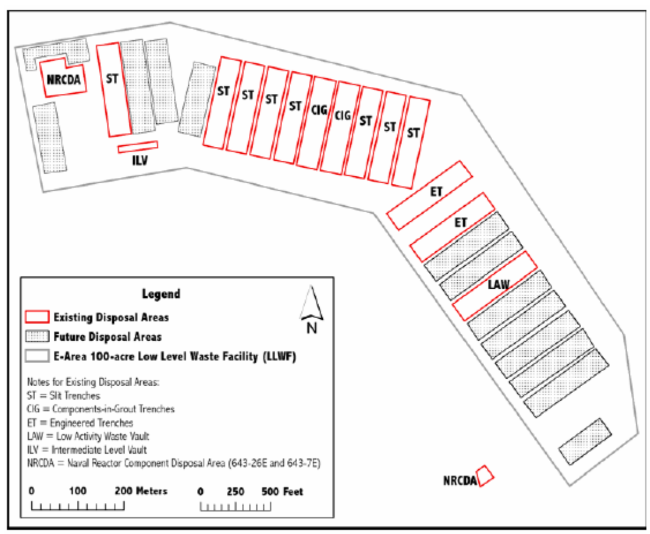

Figure 1. Location of Facilities within the E-Area LLWF

Slit Trenches are below grade earthen disposal units with essentially vertical side slopes. The excavated soil is stockpiled for later placement over disposed waste. Slit Trenches are generally 20 feet (6.1 m) deep, 20 feet (6.1 m) wide, and 656 feet (200 m) long. Ten feet (3 m) of undisturbed soil separates each trench. A set of five 20-foot (6.1 m) wide Slit Trenches are grouped together within a 157-foot (47.8 m) wide by 656-foot (200 m) long footprint.

Seven such footprints, designated Slit 1 through 7, have been currently sited and waste has been placed within all seven units. Fourteen additional Slit Trenche footprints have been designated for future disposals. Figure 1 above provides the layout of the seven existing and fourteen future Slit Trence footprints relative to other E-Area LLWF disposal unit types.

During the 25-year operational period, low-level waste consisting of soil, debris, rubble, wood, concrete, equipment, and job control waste is disposed within the Slit Trenches. The waste may be disposed as bulk waste or contained within B-25 boxes, B-12 boxes, 55-gallon drums, Sealand containers, and other metal containers. At the end of the operational period, an interim runoff cover will be installed and maintained during the 100-year institutional control period (i.e. interim closure). The interim runoff cover will involve the placement of up to an additional 2-foot of soil over the Slit Trenches, that is graded to promote even greater drainage off the trenches. Final closure of the Slit Trenches will take place at final closure of the entire E-Area LLWF, at the end of the 100-year institutional control period. Static surcharging and/or dynamic compaction of the Slit Trenches will be conducted at the end of the 100-year institutional control period, when the efficiency of the subsidence treatment will be greater due to container corrosion and subsequent strength loss. Final closure will consist of the installation of an integrated closure system designed to minimize moisture contact with the waste and to provide an intruder deterrent. The integrated closure system will consist of one or more closure caps installed over all the disposal units and a drainage system. Figure 2 provides the Slit Trench closure cap configuration.

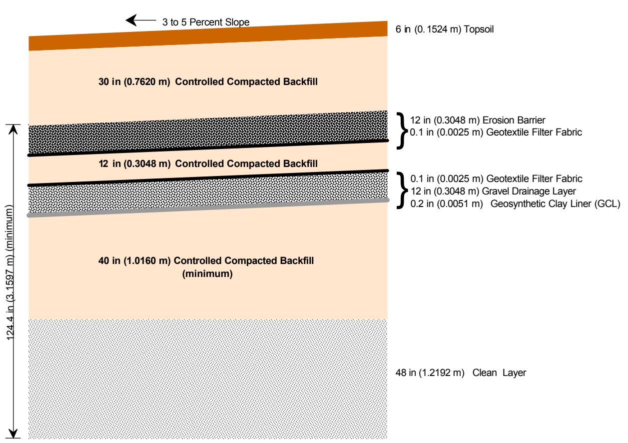

Figure 2. Slit Trench Closure Cap Configuration

The Closure Plan for the E-Area low-level waste facility (Cook et al. 2004) assumes that dynamic compaction performed at the end of the 100-year institutional control period will adequately stabilize all waste in Slit Trenches. However, some non-crushable waste containers with significant void space will not be stabilized by dynamic compaction. These non-crushable containers will gradually corrode, eventually collapse and cause the final closure cap to subside resulting in an increase of the infiltration rates (Phifer 2004). After subsidence occurs, the waste zone will be significantly reduced to concentrate waste in the lower portion of the slit trench, therefore increasing waste concentration. The trench subsidence may have an adverse impact on the 1000-year compliance specified in DOE Order 435.1 (US DOE 1999).

This study addresses the issue of trench subsidence, evaluates the resulting concentrations at the hypothetical 100-m well, and provides the maximum number of trenches that can subside without causing the well concentrations to be out of compliance.

MODEL APPROACH

A Slit Trench disposal unit currently consists of a set of five slit trenches with each trench being 20 feet wide by 656 feet long with a 10-ft space between trenches. A set of two Slit Trench disposal units was considered in this subsidence study. The arrangement for each slit trench set is illustrated in Figure 3. All scenarios were simulated using PC-based PorFlow™ Version 5.97. PorFlow™ solves problems involving transient and steady-state fluid flow, heat and mass transport in multi-phase, variable saturation conditions, porous or fractured media flow, and dynamic changes in phases. The porous/fractured media may be anisotropic and heterogeneous. Arbitrary sources (injection or pumping wells) may be present, and chemical reactions or radioactive decay may take place in the model (ACRi, 2002). PORFLOW™ has been widely used at the SRS and in the DOE complex to address major issues related to the groundwater and radioactive waste management.

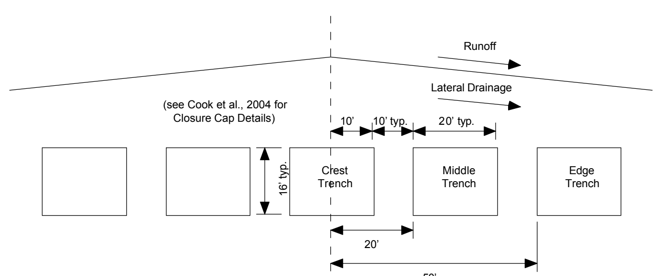

Figure 3. Slit Trench Arrangement

Vadose Zone Model

Using the HELP model (US EPA 1994a; US EPA 1994b), infiltration rates for each trench (i.e., edge trench, middle trench and crest trench) were estimated for intact and subsided conditions over a 10,000-year period. The vadose zone model uses the highest infiltration rates in each time interval after 125 years. This approach would produce more conservative results. Table 1 shows the modeled infiltration rates in all time intervals up to 1,025 years. Note that the first scenario in Table 1 (i.e., without any subsidence) represents the intact condition. The total simulation time was selected to be the 1,000-year time of compliance specified in DOE Order 435.1. Applying these infiltration rates, the steady-state flow fields were generated using PorFlow™ for each time interval of all scenarios listed in Table 1.

Table 1. Modeled infiltration rates and time intervals

Subsided Trench			Infiltration (in/yr)				
Crest	Midde	Edge	0-25 yrs†	25-125 yrs††	125-325 yrs	325-575 yrs	575-1025 yrs
No	No	No	11.26	0.36	3.05	7.90	12.04
Yes	No	No	11.26	0.36	15.91	15.91	15.91
No	Yes	No	11.26	0.36	27.36	24.97	20.80
Yes	Yes	No	11.26	0.36	21.27	20.20	18.36
No	No	Yes	11.26	0.36	47.77	41.18	29.28
Yes	No	Yes	1126	0.36	40.85	35.59	26.36
No	Yes	Yes	11.26	0.36	21.27	20.20	18.36
Yes	Yes	Yes	11.26	0.36	21.27	20.20	18.36

(†: Initial uncapped period; ††: Institutional control period; ≥125 years: Failed period)

The vadose zone analyses incorporated the effects of dynamic compaction and subsidence. As shown in Figure 3, the space between trenches is 10 feet. The outer side of the edge trench is ~23 ft away from a vertical drain/barrier combination. Hence, to better account for the difference in geometry between the edge trench and the middle or crest trench, two modeling grid layouts were generated as shown in Figure 4 and Figure 5. These figures display distances in cm as used in the PorFlow™ vadose zone models. The two distinct grid layouts would provide more accurate trench flow fields and activity fluxes. The waste zone thickness was modeled as a variable: the initial waste zone (16 ft thick) and the final waste zone (2.5 ft thick) that was assumed to occur after a trench subsidence. The material properties data used for the vadose zone flow and transport analyses are shown in Table 2. Bold values in Table 2 highlight the change in properties before and after subsidence.

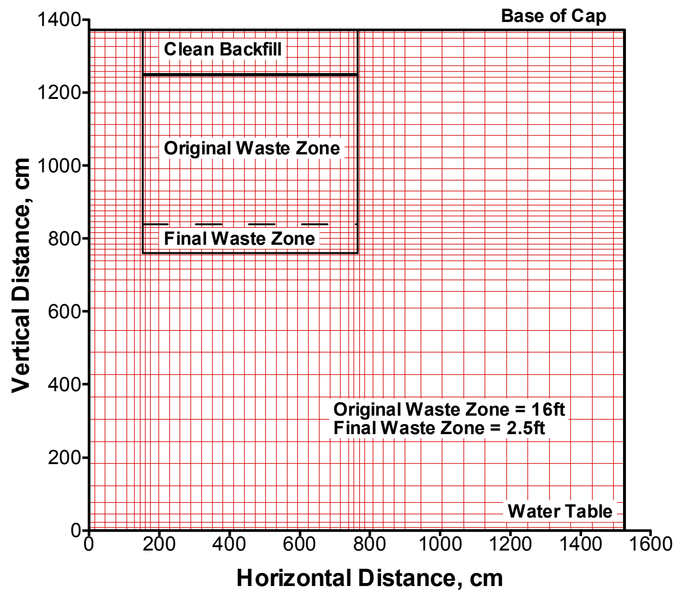

Figure 4. Vadose zone modeling grid for edge trench

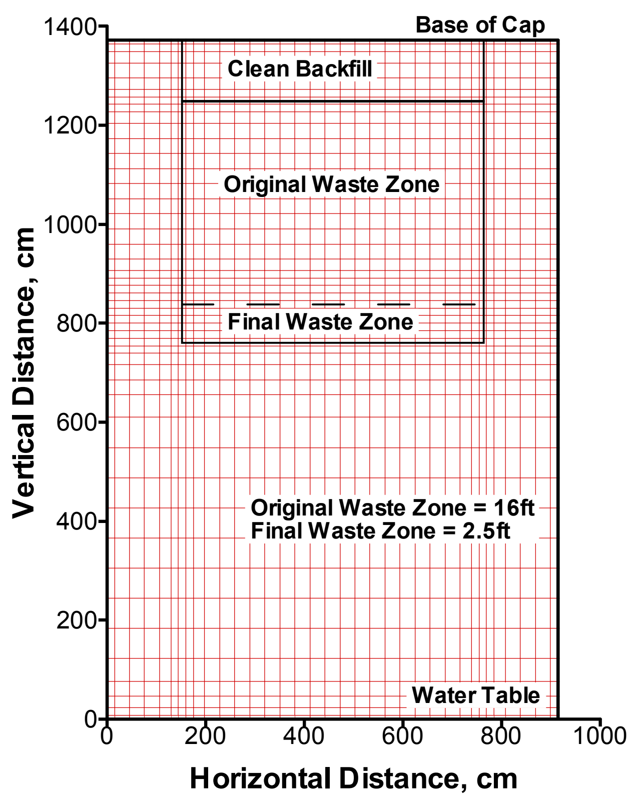

Figure 5. Vadose zone modeling grid for middle/crest trench

Table 2. Material properties for vadose zone flow and transport analyses

Properperties	Clean Backfill	Top 13.5 ft Waste Zone	Bottom 2.5 ft Waste Zone	Native Soil
Particle density (g/cc)	2.65	2.65	2.65	2.65
Porosity (cc/cc) • Initial • After subsidence	 0.51 0.51	 0.38 **0.51**	 0.38 0.38	 0.42 0.42
Saturated hydraulic conductivity (cm/yr) • Intial • After subsidence	 3.154E4 **3.154E3**	 3.154E5 **3.154E3**	 3.154E5 **6.3072E3**	 3.154E2 3.154E2
Diffusion coefficient (cm^2/yr)	1.578E2	1.578E2	1.578E2	1.578E2
Dispersivity (cm)	0	0	0	0

In order to generalize the results, a hypothetical, no-decay radionuclide characterized by a specific Kd was selected. Without decay the transport of the radionuclide throughout the modeling domain is primarily affected by infiltration. Therefore, the impact of trench subsidence on the well concentrations can be isolated for study.

To select a Kd, several runs for the intact condition with no dynamic compaction were made in which Kd values were varied from 0 to 100 ml/g. An increase in Kd would cause more retardation, resulting in a slower mass transport of the radionuclide in the fluid phase. Consequently, the time at which the flux at the water table peaks increases with increasing Kd. Figure 6 displays the effect of Kd on the fractional flux calculated at the water table. Note that no flux for a Kd of 100 ml/g is visible within 1,000 years. Since a late peak time of the flux may result in a well concentration that peaks after 1,000 years, an early flux peak time would be preferable to provide flexibility to analyze the potential effect of trench subsidence within the 1,000-yr time window of interest. With a zero Kd, the fractional flux peaks at 7 years. Subsidence will not have any significant impact on the well concentrations if the flux peaks prior to placement of the final cap at 125 years. Hence, a Kd of 5 ml/g was selected in this study.

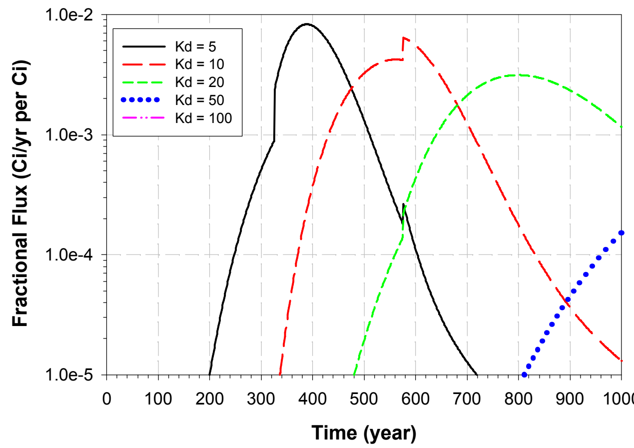

Figure 6. Effect of Kd on the fractional flux at the water table (Edge trench)

Aquifer Model

The aquifer model was designed to accurately represent the locations in the aquifer where the contamination from the vadose zone would first enter. For a better representation of the waste footprint, a mesh of 20 ft x 20 ft in plan view was generated. The mesh allows precise allocation of contaminant source cells into each individual slit trench. As a result, this allocation scheme makes analyses of any partial or total subsidence of any trench or a combination of trenches among the 10 slit trenches possible. Figure 7 provides a plan view of the aquifer model including the two sets of slit trenches (i.e., Slit 1 and Slit 2) and the 100-m buffer. Figure 8 shows the plan view of the aquifer model with stream traces generated from the aquifer flow field. Circles on stream traces are 5-year pore velocity markers that start from 4 corners of the 10-trench footprint. The big box containing stream traces in Figure 8 outlines the modeling domain.

Trench segments were defined by SRS Solid Waste as portions of the five slit trenches that form disposal units Slit Trench 1 and Slit Trench 2. Figure 9 displays the modeled footprint of Slit Trench 1 and Slit Trench 2. The dots in Figure 9 represent the allocated source cells. This study used a simple notation to identify each trench of two Slit Trench sets. In this notation, the trench order within each trench set increases toward the SRS north. For example, ST1-1 and ST1-5 are the lower and the upper edge trench of Slit Trench set 1, respectively.

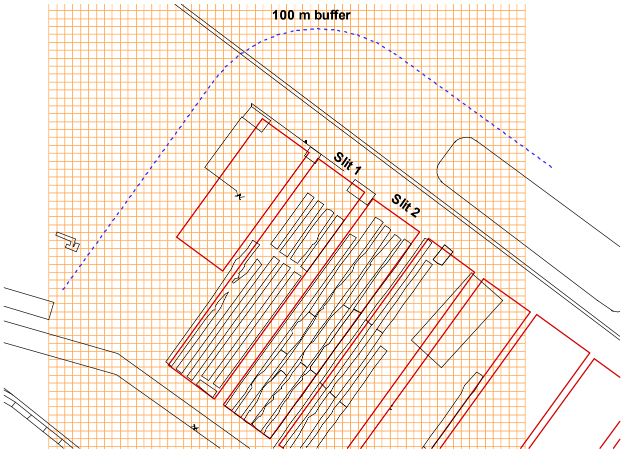

Figure 7. Plan view of the aquifer model

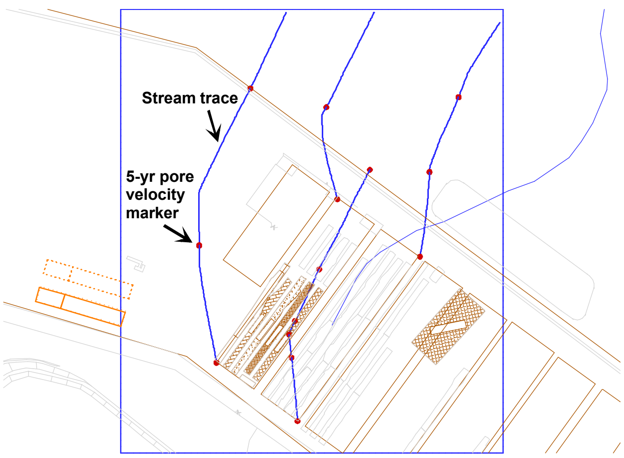

Figure 8. Aquifer model with stream traces

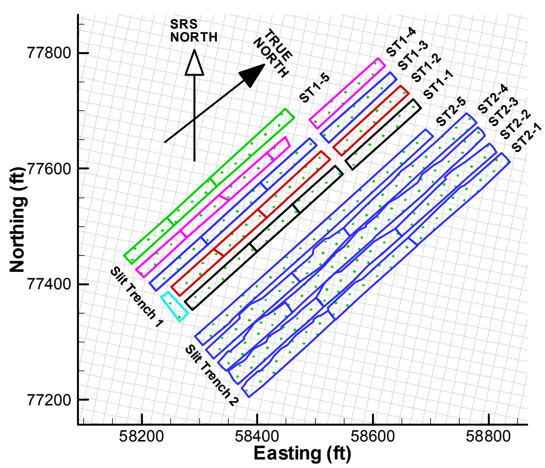

Figure 9. Mapping footprint of slit trenches onto aquifer model source cells

TEST SCENARIOS

There are two high-impact cases that could be considered for studying the potential effect of trench subsidence on the 100-m well concentrations within 1,000 years. In the first case, the subsided area alone produces a peak concentration that is greater than the peak concentration for the base case. In the second case, the peak concentrations from the subsided area and the unsubsided area align in space and time, resulting in a combining peak concentration exceeding the base case peak concentration.

To analyze these high-impact cases, PorFlow™ simulations were performed as outlined below. In all simulations, a hypothetical, no-decay radionuclide with a Kd of 5 ml/g was selected. For all cases, the assumption was made that the waste is uniformly distributed and was placed in the trenches at the beginning of the simulation.

1. Case 1: The first case was to establish a base case for comparison. Simulation was performed with dynamic compaction at 125 years and the waste zone was compacted from 16 ft to 2.5 ft with no trench subsidence.

2. Case 2: Trench subsidence occurs right after dynamic compaction (i.e., at 125 years). Simulations were performed by increasing the number of subsided trenches until the well peak concentration exceeds the base case value.

3. Case 3: Trench subsidence occurs at the earliest time that would make the peak concentrations from the subsided area and the unsubsided area align in space and time. Again, simulations were performed by increasing the number of subsided trenches until the well peak concentration exceeds the base case value.

For Cases 2 and 3, trench subsidence was selected so that it would have the largest impact on contaminant concentrations in the aquifer. That could be achieved when the subsided trenches are closest to the location on the perimeter of the two slit trench disposal units at which the contaminant concentration from the unsubsided area peaks. If the subsided area is closest to the location of the peak concentration from the unsubsided area, the bulk of its contaminant concentration would pass through that location, hence resulting in the possibly highest combining concentration peak. To determine the peak concentration location, a PorFlow™ simulation was performed for the intact condition without dynamic compaction. The

PorFlow™ command 'STATistics' was utilized to provide information about the peak concentration and its location over time along the Slit Trench perimeter. The peak concentration location obtained from this analysis is shown in Figure 10. The peak time at this location was determined to be 420 years. This location seems logical with respect to the direction of stream traces in Figure 9. The following trenches were selected for subsidence: (1) ST1-5 for one subsided trench, and (2) ST1-5 and ST1-4 for two subsided trenches.

In Case 3, the time at which trenches subsided was adjusted to make the vadose zone flux at the water table peak at the same time as the peak aquifer concentration in the Slit Trench perimeter location discussed above. This subsidence time was determined to be 419 years.

The vadose-zone contaminant flux to the water table was obtained for each individual trench based on an initial 1-Ci trench inventory. Because of the difference in geometry as shown in Figure 4 and Figure 5, the edge trench flux differs from the middle or crest trench flux even for the same infiltration rate. All contaminant fluxes were appropriately assigned to the aquifer source cells shown in Figure 9.

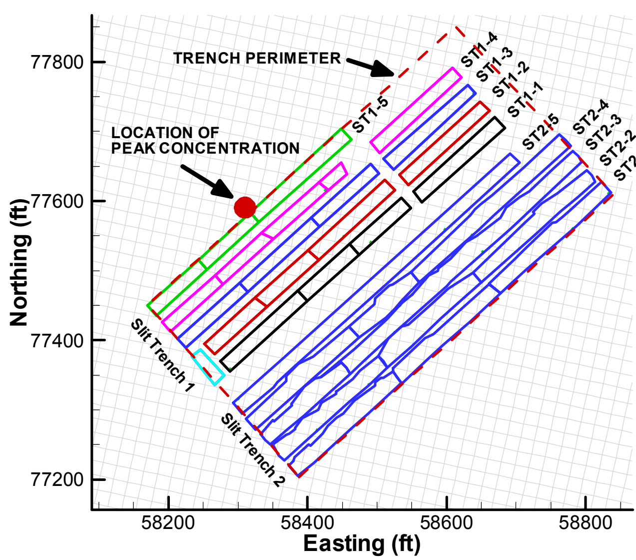

Figure 10. Location of peak concentration on the Slit Trench perimeter

RESULTS

The fractional contaminant fluxes (i.e., fluxes per initial Ci inventory) at the water table (from the vadose zone models) and the concentration at the hypothetical 100-m well where the maximum concentration occurs (from the aquifer model) are illustrated in Figure 11 and Figure 12 for the base case. Figure 11 confirms the difference between the edge and crest/middle trench fluxes due to dissimilar flow fields. PorFlow™ simulation results revealed that starting with a 1 Ci initial inventory the inventories remaining in the trench at 125 years were 2.63E-2 Ci for the edge trench and 5.89E-2 Ci for the crest/middle trench. The inventories remaining in the total modeling domain at 1,025 years were 4.98E-6 Ci and 1.97E-5 Ci for the edge trench and the crest/middle trench, respectively. These results clearly indicate that contaminants move out of the trench to the water table faster in the case of the edge trench, hence resulting in an earlier peak flux of the edge trench as confirmed by Figure 11. Figure 11 and Figure 12 also show that from the time of the peak flux at the water table (~400 years) it took ~100 years for the well concentration to peak. Note that the well concentrations are expressed in pCi/L/Ci per disposal unit (i.e., set of 5 trenches). The concentration results obtained from PorFlow™ were in Ci/ft^3. Because the initial inventory is 1 Ci per trench, resulting in a total inventory of 10 Ci for two Slit Trench sets, the well concentrations per Slit Trench inventory are calculated from PorFlow™ results as follows:

$$\text{Concentration (pCi/L/Ci)} = \text{C (Ci/ft}^3\text{)} * \text{1E+12 (pCi/Ci)} * [\text{2 (Disposal Units)} / \text{10 Ci}] / \text{28.31685 (L/ft}^3\text{)}$$

For Case 2 in which trench subsidence occurs at 125 years the well concentrations are shown in Figure 13. Subsidence of a single trench (Edge trench ST1-5) and two trenches (Edge trench ST1-5 and middle trench ST1-4) were simulated. For each type of subsidence, the calculated well concentrations exhibit two peaks resulting from the subsided area (first peak) and the unsubsided area (second peak). The second peaks align in time with the peak from the base case that was simulated with no trench subsidence. A single trench subsidence presented no compliance problem, since the peak well concentrations were less than the base case peak value. When two trenches subsided, the first peak concentration was slightly higher than the base case value. Note that the second well-concentration peak was much lower than the first, because less contaminant remained in the modeling domain when the second peak occurred. In Figure 13, to capture the peak concentration values, the well concentrations were monitored at different well locations. As a result, the different behavior was observed between cases.

In Case 3, the impact of trench subsidence at a later time after dynamic compaction was studied. The aquifer concentration from the unsubsided area peaked at the trench perimeter location shown in Figure 10. The peak time was determined to be 420 years. For the vadose zone flux at the water table to peak at 420 years, the subsidence time of 419 years was selected. In case of a single trench (Edge trench ST1-5) subsidence, the subsided area contributed ~30% of the peak well concentration (see Figure 14). Figure 15 indicates when the peak concentrations from the subsided area and the unsubsided area align in space and time, even a single trench subsidence would cause the well concentration to be out of compliance.

Peak values and peak times for the 100-m well concentration are summarized in Table 3 for all scenarios. The extent (in %) to which the peak well concentration exceeded the base case value is also provided.

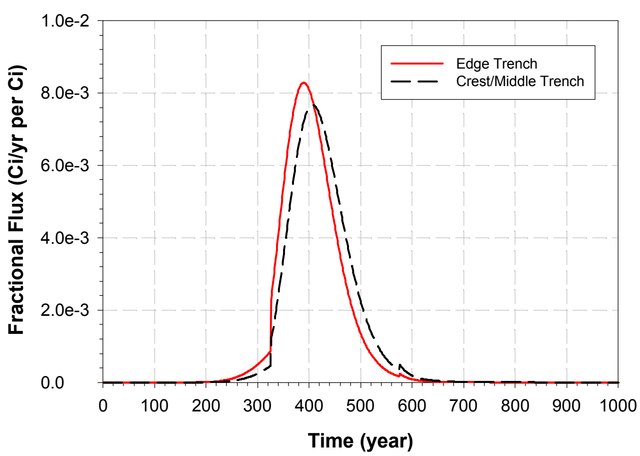

Figure 11. Fractional fluxes at the water table (Base case)

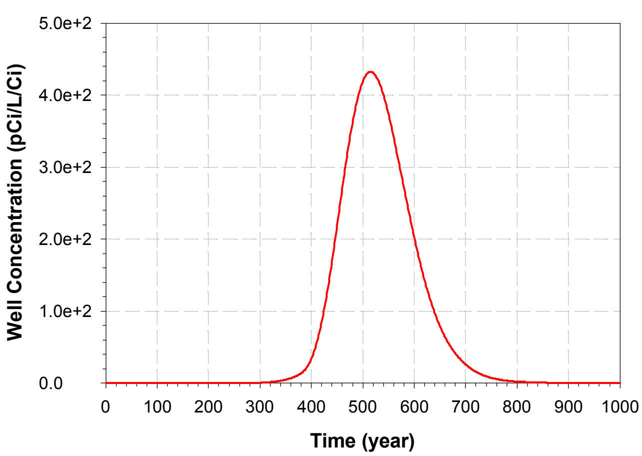

Figure 12. Well concentration (Base case)

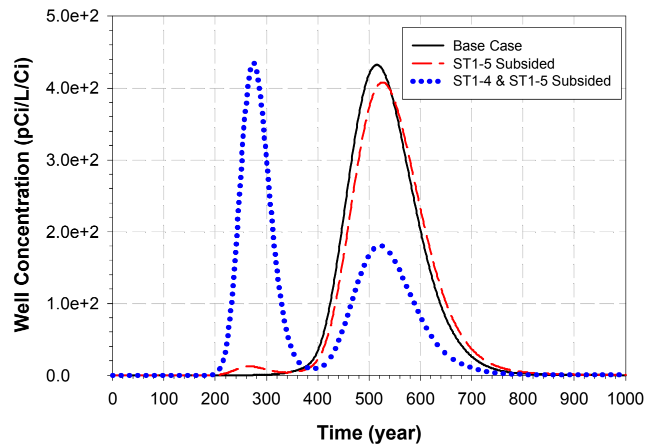

Figure 13. Well concentration (Trench subsidence at 125 years)

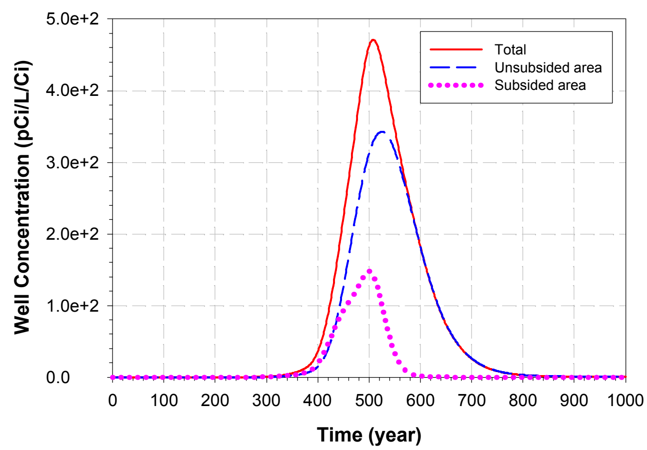

Figure 14. Well concentration (ST1-5 subsidence at 419 years)

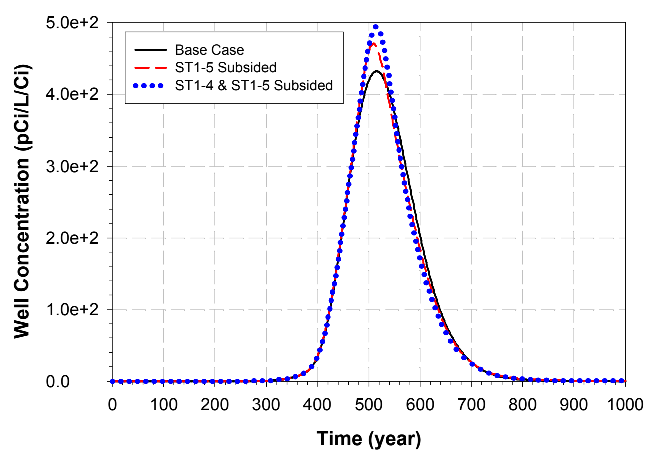

Figure 15. Well concentration (Trench subsidence at 419 years)

Table 3. Summary of peak well concentrations

	Peak Time (yr)	**Peak Concentration (pCi/L/Ci)**	**% of Peak Concentration exceeding Base Case Value†**
Base case (Case 1)	515	432	-
Subsidence @ 125 years (Case 2):			
• One-trench subsidence (Trench 14-5)	526	408	-
• Two-trench subsidence (Trenches 14-4 and 14-5)	274	435	0.7
Subsidence @ 419 years (Case 3):			
• One-trench subsidence (Trench 14-5)	508	471	9
• Two-trench subsidence (Trenches 14-4 and 14-5)	514	495	15

† $100*(C-C_{\text{Base Case}})/C_{\text{Base Case}}$

CONCLUSIONS

Two scenarios were considered as the high-impact cases for studying the potential effect of trench subsidence on the 100-m well concentrations within 1,000 years. In the first case, trenches subsided right after dynamic compaction (i.e., at 125 years) in order to study when the peak from the subsided area alone would exceed the results from the base case. In the second case, trenches subsided at 419 years to make the peak concentrations from both the subsided and unsubsided areas align in space and time. The simulation results showed that in the first case the subsidence of up to two trenches presented no compliance problem. In the second case, even a single trench subsidence caused the well concentration to exceed the base case value.

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