Analysis of Past Leaks from Waste Management Area C, Hanford, Washington-17525

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ABSTRACT

Waste Management Area C (WMA C) at the Hanford Site was actively used for several decades for storing radioactive waste in tanks, and therefore is alternatively termed a “waste management area,” or a “tank farm.” During its operational life, a number of documented leaks occurred within or near to the WMA. The largest ones were associated with leaks in pipelines and diversion boxes, with the inlets or outlets of the tanks, or with leaks from the tanks themselves. Contaminants associated with these leaks were released to the soil, and mobile ^{99}Tc has reached the groundwater exceeding drinking water standards.

An analysis of the impact of past leaks on groundwater resources has been undertaken as part of the overall process of closing the tank farm. The analysis of leaks was carried out using a suite of scoping cases to evaluate alternative conceptual models for the leak behavior to identify those that are in reasonable agreement with observed concentrations of ^{99}Tc in groundwater.

Comparisons of the scoping cases with available ^{99}Tc observations indicate the following.

- Several of the scoping cases produced results that are inconsistent with observations, indicating that the assumptions in those cases may not be representative of conditions in WMA C. These negative results are valuable in improving the understanding of the migration of ^{99}Tc from WMA C.
- The remaining scoping analyses produced comparable results to each other, and none were obviously superior to others in terms of explaining the ^{99}Tc observations. When uncertainties in groundwater fluxes were taken into account, these scoping analyses were capable of producing both arrival times and concentrations consistent with observed data for ^{99}Tc.

A representative model was used to implement a forward projection of a suite of contaminants of concern to show how the contamination associated with past leaks can be expected to evolve in the future. This paper presents these results and discusses their implications on groundwater contamination at WMA C.

INTRODUCTION

The U.S. Department of Energy, Office of River Protection (DOE-ORP) is pursuing closure of Waste Management Area C (WMA C) at the Hanford Site, which requires the facility to meet a variety of Federal and State regulatory requirements. WMA C is part of the Single-Shell Tank system. WMA C is in the Central Plateau, near the eastern edge of the 200 East Area (Fig. 1). WMA C was one of the first tank farms built; it was constructed in 1944 and 1945.

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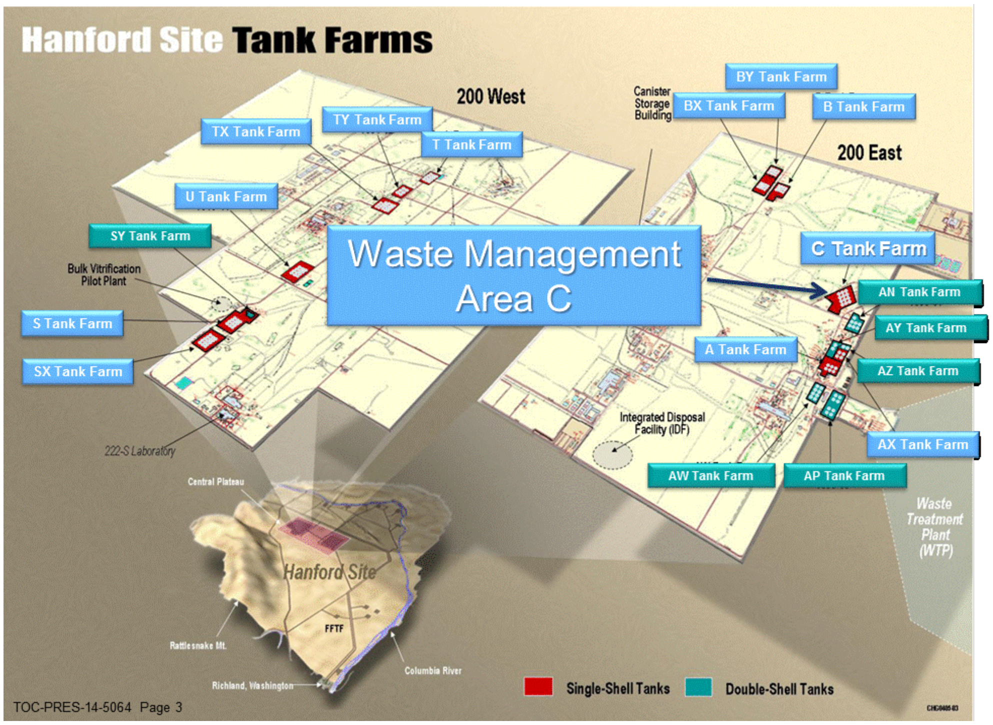

Fig. 1. WMA C is located in the Central Plateau, near the eastern edge of the 200 East Area.

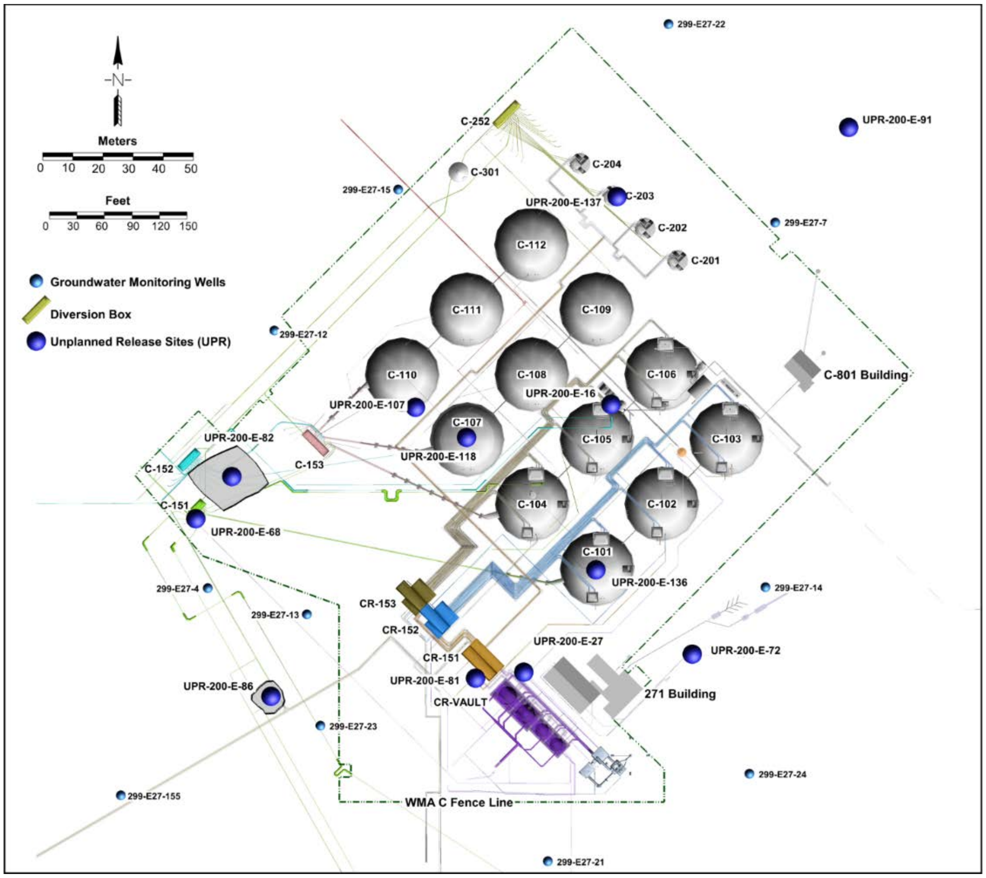

Fig.2. WMA C tanks, infrastructure, associated Leaks, and monitoring wells.

Contaminants associated with these waste leaks and losses were released to the the underlying vadose zone sediments. The volume, timing and radionuclide content of the leaks are all uncertain, but estimates have been established by taking account of site observations and process knowledge. While a variety of contaminants were released in the leaks, mobile ^{99}Tc has reached the groundwater in excess of it's drinking water standard (e.g. 900 pCi/l) and is a key contributor to groundwater contamination at the site [1]. It is also the only contaminant that is unambiguously the result of releases from WMA C. Therefore, the focus of this paper will be on ^{99}Tc contamination, although analyses have been conducted for other contaminants of potential concern as well. Estimates of the inventory, volumes, and timing of the leaks are presented in Table I.

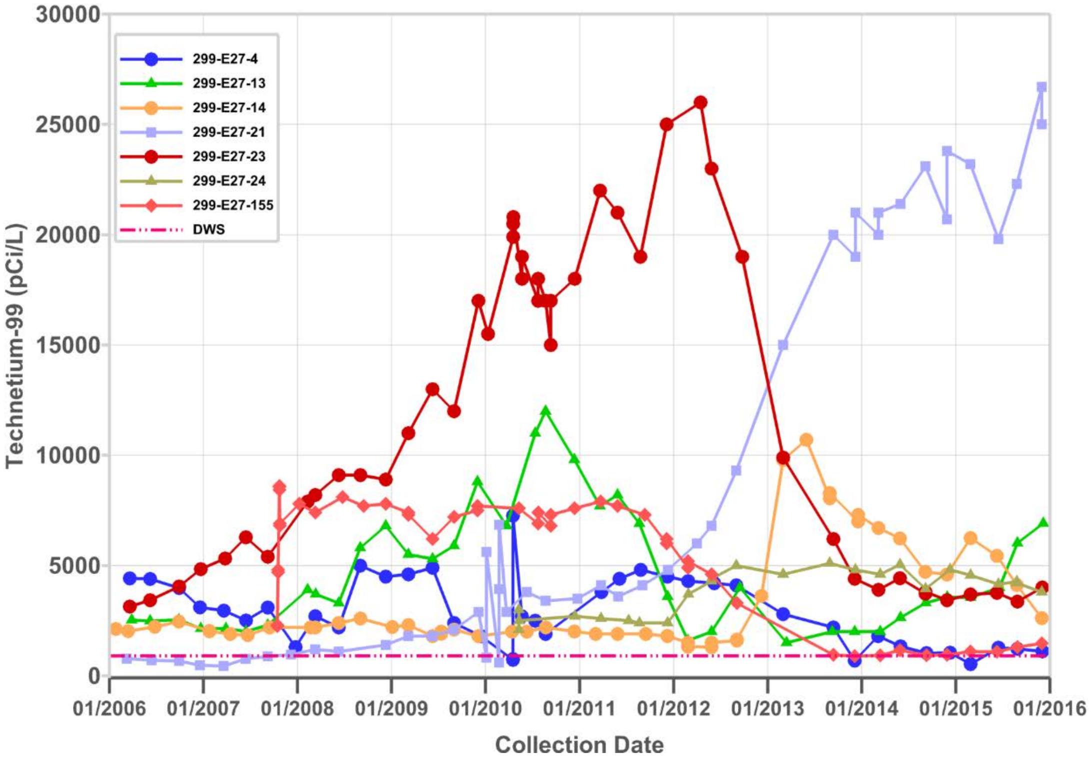

Fig.3. Technetium-99 Concentrations WMA C Monitoring Wells from January 2006 through December 2015. Also shown on the figure is the drinking water standard (DWS) for ^{99}Tc.

TABLE I. Estimates of the Inventory of Technetium-99, volumes, and timing for the leaks.

Tank/Unplanned Release	Waste Release Volume, L (gal in parenthesis)	^{99}Tc, Ci (GBq in parenthesis)	Time of release
241-C-101	140,600 (37,000)	0.25 (9.3)	Continuous release 1965 – 1969
241-C-104	106,400 (28,000)	0.03 (1.1)	Acute release 1965
241-C-105	7,600 to 77,900 (2,000 to 20,500)	1.0 – 9.8 (37 – 360)	Continuous release 1963 – 1967
241-C-108	68,400 (18,000)	0.02 (0.74)	Acute release 1965
241-C-110	7,600 (2,000)	3.4 (1.3)	Continuous release 1971 – 1972

Tank/Unplanned Release	**Waste Release Volume, L (gal in parenthesis)**	**^{99}Tc, Ci (GBq in parenthesis)**	**Time of release**
241-C-112	26,600 (7,000)	0.0075 (0.28)	“prior to 1972” taken as acute release 1965
UPR-200-E-81	136,800 (36,000)	0.1 (3.7)	Acute release 1969
UPR-200-E-82	98,800 (2,600)	1.3 (48)	Acute release 1969
UPR-200-E-86	64,600 (17,000)	2.7 (100)	Acute release 1971
Surface Releases	3,800 (1,000)	0.001 (0.04)	“Unknown” taken as acute release 1965
216-C-8	121,600 (32,000)	0.0 (0.0)	Continuous release 1960 – 1965
Total	169,100	17.5 (648)	

As part of the closure process, analyses have been conducted to simulate the evolution of the groundwater plumes, and to determine their long term environmental impact. The purpose of this paper is to present the results of these analyses, and to discuss the implications of these results for groundwater contamination near WMA C.

KEY FEATURES OF THE ANALYSIS

Vadose-Zone Features

The vadose zone underlying WMA C consists of heterogeneous layers of sediments that spatially vary in thickness. These layers under WMA C are generally sands and gravelly sands. Several alternative conceptual models for the stratigraphy and spatial variability have been proposed. One of these alternative models is depicted in Fig. 4.

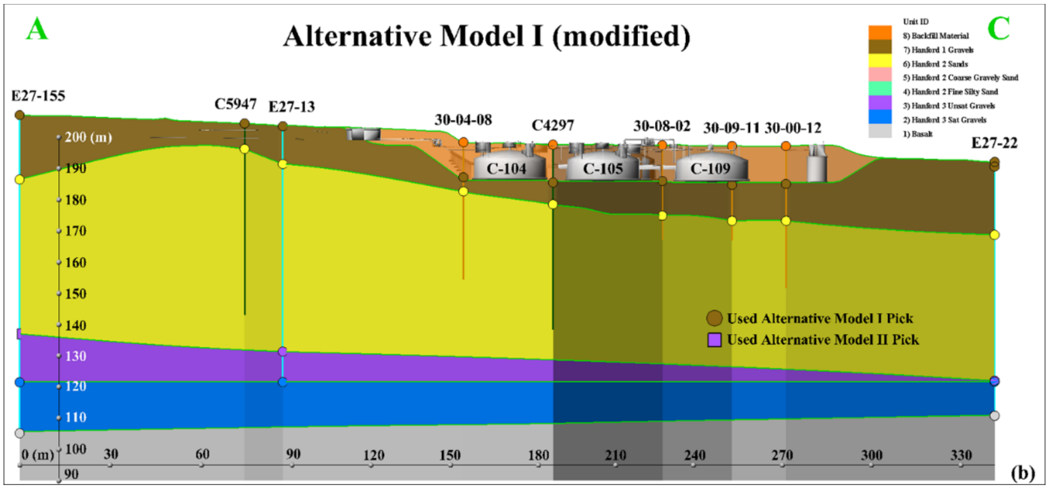

Fig. 4. Representation of the stratigraphy of the vadose zone below WMA C.

Features such as clastic dikes and man-made structures (i.e., monitoring wells) have the potential to allow water and contaminants to bypass parts of the vadose zone. There are no known clastic dikes under WMA C, but an alternative conceptual model has been evaluated to consider the potential for an undetected dike. Similarly, an alternative conceptual was evaluated for an unsealed well, to evaluate whether such a feature has the potential to significantly alter the migration of contaminants.

Saturated-Zone Features

The groundwater in the aquifer system in the vicinity of WMA C has been studied extensively as part of site characterization activities. Groundwater flow beneath WMA C has been historically difficult to measure because the hydraulic gradient is very small and the hydraulic conductivity is very high in this region of the Hanford Site. In addition, the water table continues to recover from large operational liquid discharges in the vicinity of WMA C, unassociated with WMA C itself. These discharges resulted in a substantial mound in the water table, with associated changes in the magnitude and direction of the aquifer gradient. Once operational discharges in the Central Plateau ceased, the mound in the water table began to relax to a natural state. As a consequence, the water table under WMA C declined, as shown in Fig. 5.

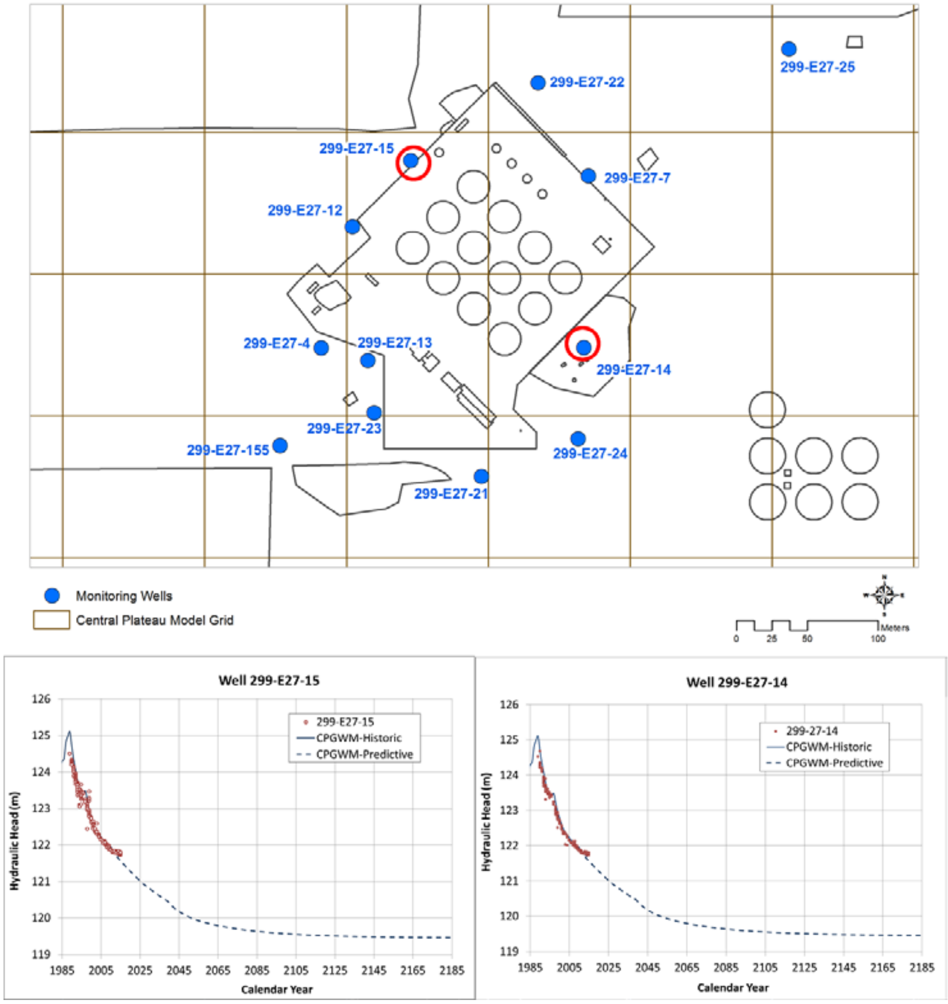

Fig. 5. Decline in the water table following cessation of operational discharges in the Central Plateau. The figure shows a comparison of the calibrated Central Plateau Groundwater Model (CPGWM) with measured heads adjacent to WMA C.

Regionally, the decline in the water table elevation was associated with change in the direction of groundwater flow. In Fig. 6, the evolution of the gradient as measured between 2005 and 2013 in a specialized low-gradient monitoring network is shown. This network at the Low-Level Waste Management Area (LLWMA) is northwest of WMA C by about 2 km; similar measurements at WMA C are unavailable. Similar evolution is believed to have occurred at WMA C, but the specifics of the timing and magnitude of the changes are unknown. The data (black dots) in Fig. 6 show that prior to January 2007 the direction of the gradient was to the North (azimuth approximately 360 degrees). From 2007 until 2011 the data are ambiguous, and the gradient is difficult to distinguish from zero. Following 2011, the direction of the aquifer is to the South (azimuth approximately 180 degrees).

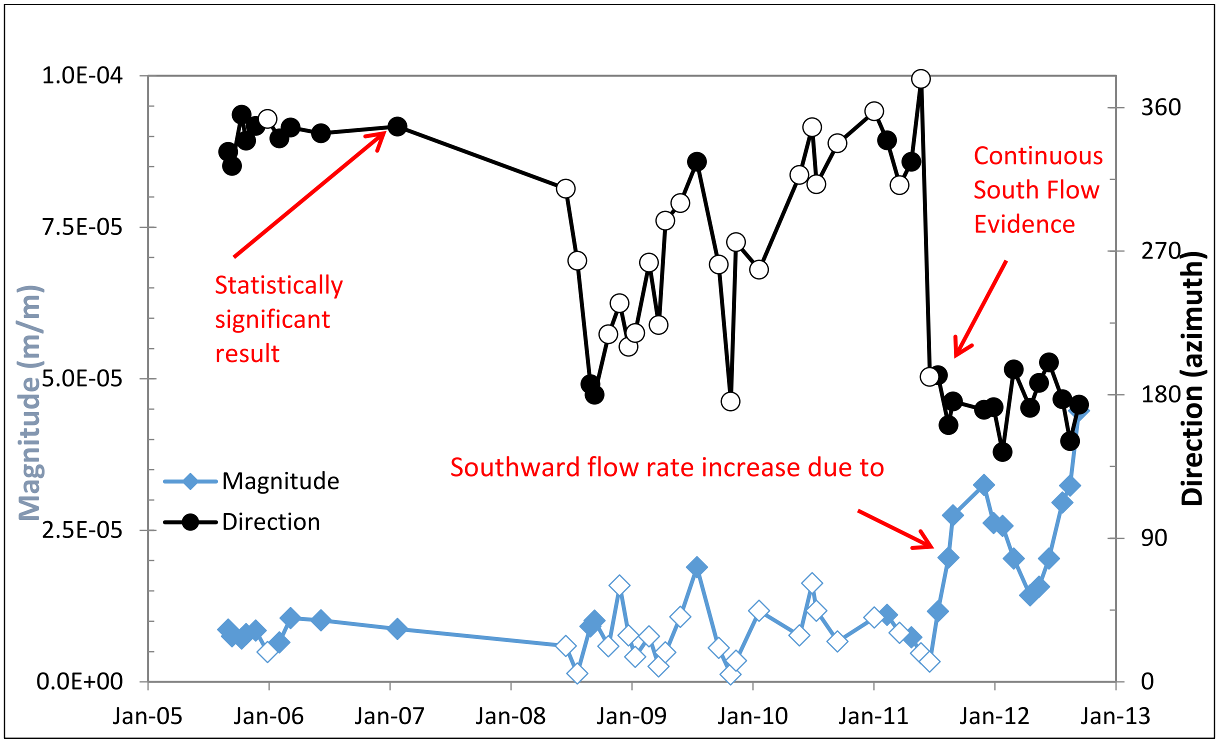

Fig. 6. Evolution of the Groundwater Gradient in the Low-Level Waste Management Area-1 Monitoring Network. The gradient at the nearby WMA C is believed to have evolved in a similar manner and timescale. Filled circles indicate statistically significant results; open circles are not statistically significant.

The projected equilibrium state of the aquifer gradient is expected to be similar to its pre-Hanford direction, generally northwest to southeast.

TECHNICAL APPROACH

An analysis of the impact of past leaks on groundwater resources has been undertaken as part of the overall process of closing the tank farm. The strategy for this analysis of leaks has been to define and analyze a suite of-scoping cases to evaluate the uncertainties associated with past leaks. These scoping cases were used to investigate alternative conceptual models for the leak behavior to develop a band of analyses that produce results that are in reasonable agreement with observed concentrations in groundwater monitoring wells. For these comparisons, the model results have been compared to ^{99}Tc concentrations in groundwater. Technitium-99 is a key risk driver, and the contamination levels observed in groundwater monitoring wells are unambiguously the result of WMA C past leaks. The ^{99}Tc concentration data observed in groundwater monitoring wells have been compared to scoping case results for the arrival times and concentration levels of ^{99}Tc observed historically in the vicinity of WMA C.

The starting point for the analyses was a model developed for the postclosure performance assessment of WMA C to evaluate compliance with requirements under DOE Order 435.1 [2]. Modifications were made to this model

- to introduce leak inventories at appropriate times and locations
- to accommodate the higher water table (shorter vadose zone travel path) during the operational period
- to accommodate time dependent aquifer gradient variability during the operational period

STATIC WATER TABLE RESULTS

Static water table analyses were conducted to evaluate uncertainties associated with the leaks themselves and with the vadose zone. In these analyses the aquifer gradient was oriented to its expected long-term post-closure orientation, generally northwest to southeast. Since the direction of the aquifer gradient in these analyses does not match the orientation and transient behavior of the aquifer in the time scale of interest, the model results are not directly comparable to data at the location of the wells. Descriptions of the scoping analysis cases and their intended application are presented in Table II.

TABLE II. Scoping analysis cases conducted using a static water table.

Scoping Case	Scoping Case Description and Purpose
Case 1a	Base case model with elevated water table and 9.8 Ci (360 GBq) ^{99}Tc, 77,900 L (20,500 gal) C-105 leak
Case 1b	Same as Case 1a but with the lower bound inventory of 1 Ci (37 GBq) and volume 7,570 L (2,000 gals) developed for tank C-105.
Cases Related to Changes in Groundwater Flux Rates	
Case 2a	Same as Case 1a but with the aquifer flux set at 10th percentile values for aquifer flow producing minimal aquifer dilution.
Case 2b	Same as Case 1a but with the aquifer flux set at 90th percentile values for aquifer flow producing higher aquifer dilution.
Cases Related to Changes in Recharge Rates	
Case 3a	Same as Case 1a but with a recharge rate of 150 mm/yr applied for the tank farm area.

Scoping Case	**Scoping Case Description and Purpose**
Case 3b	Same as Case 1a but with a recharge rate of 100 mm/yr for areas within the WMA C model domain but outside the tank farm to evaluate effect of increased anthropogenic recharge outside of the tank farm area on past releases.
Case 3c	Same as Case 1a, but with local changes at UPRs-E-81, -82, and -86 to represent the past practice of applying water from a firehose to remediate these UPRs. The hoses are assumed to have applied 1140 L/min (300 gal/min) of wash water for 4 hours at the time of release. Twenty years later, gunite caps were applied to UPRs 82 and 86, which are assumed to have changed the infiltration to 1 mm/y (UPR-81 does not have a gunite cap).
Cases Related to Changes in Vadose Zone Parameters/Conceptualizations	
Case 4a	Same as Case 1a but with Alternative Geologic Model II.
Case 4b	Same as Case 1a, but with Heterogeneous Alternative Model geology
Case 4c	Same as Case 1a, but with median hydraulic properties in the vadose zone
Case 4d	Same as Case 1a, but with 95th percentile hydraulic properties in the vadose zone
Case 4e	Same as Case 1a but with a hypothetical clastic dike placed below tank C-105.
Case 4f	Same as Case 1a, but with a hypothetical inadequately sealed borehole, located near the past tank leak near C-105.

Results of these analysis cases are presented in Fig. 7. Three scoping analysis cases produced results in which the arrival time of the calculated plume is substantially earlier than the observations in the wells. These scoping analysis cases are

- Case 3a, in which the recharge was increased to 150 mm/y,
- Case 4b, in which the spatial variability of the vadose zone properties was represented by an alternative heterogeneous representation, and
- Case 4d, in which the flow properties of the vadose zone soil were set to their 95th percentile values.

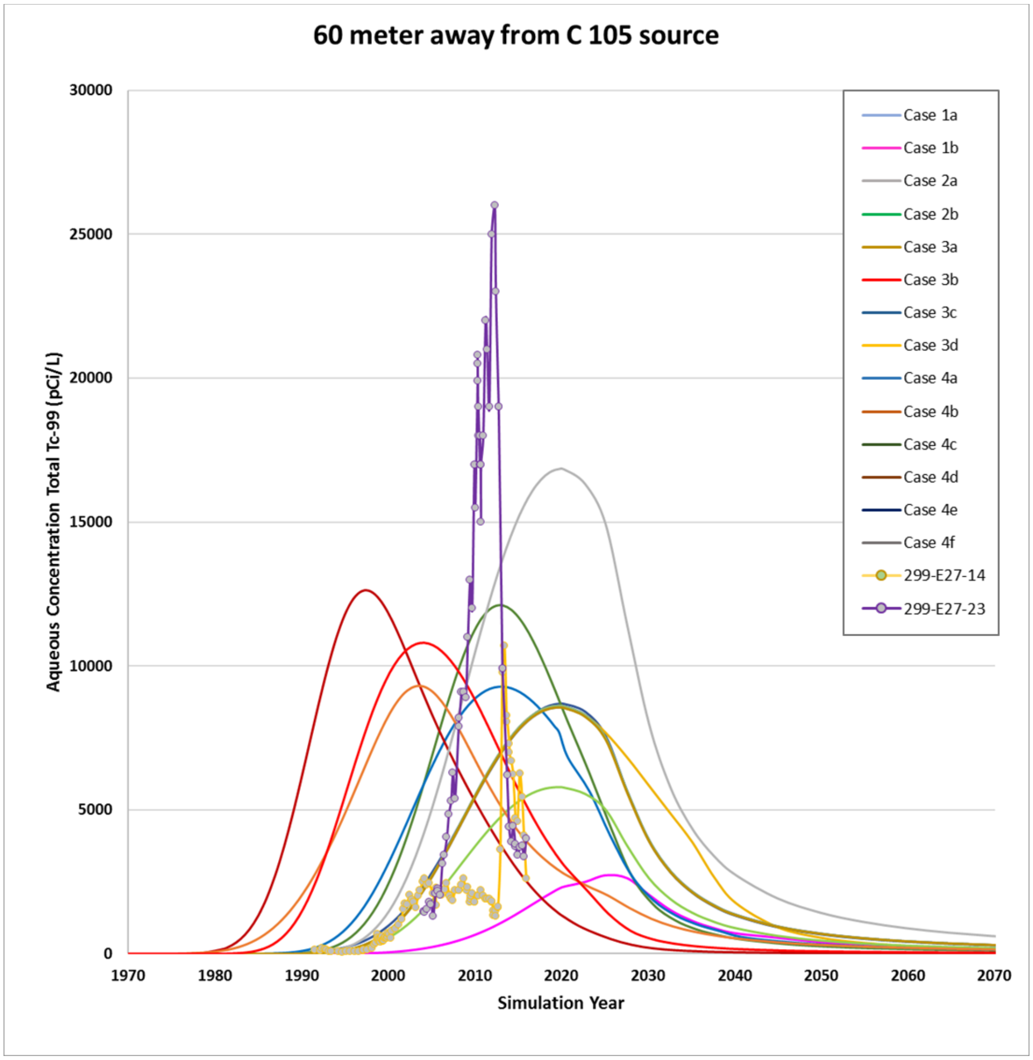

Fig. 7. Results of analysis cases conducted using a static water table. Also shown on the figure are data from two key monitoring wells.

The remaining scoping analysis cases shown in Fig. 7 produced results that are in reasonable agreement with arrival time of the plume at 60 m downgradient (the approximate distance from the C-105 leak to well 299-E27-23). None of these static water table results were obviously superior to others in terms of explaining the peak concentrations at 299-E27-23, nor do they represent the sharp rise and fall of the observation well data. When uncertainties in groundwater fluxes were taken into account, these scoping analyses were capable of producing both arrival times and concentrations consistent with observed monitoring well data for ^{99}Tc.

TRANSIENT WATER TABLE RESULTS

An analysis case was performed with a transient water table, to represent the transition of the aquifer gradient as discussed above and shown in Fig. 6. Since the timing of the changes and magnitude of the gradients were unknown during the times of interest, these were treated as adjustable variables in the model; consequently, the results are best regarded as fitted results rather than predictive. The data were suggestive of a counter-clockwise rotation of the orientation of the gradient, as shown in Fig. 8.

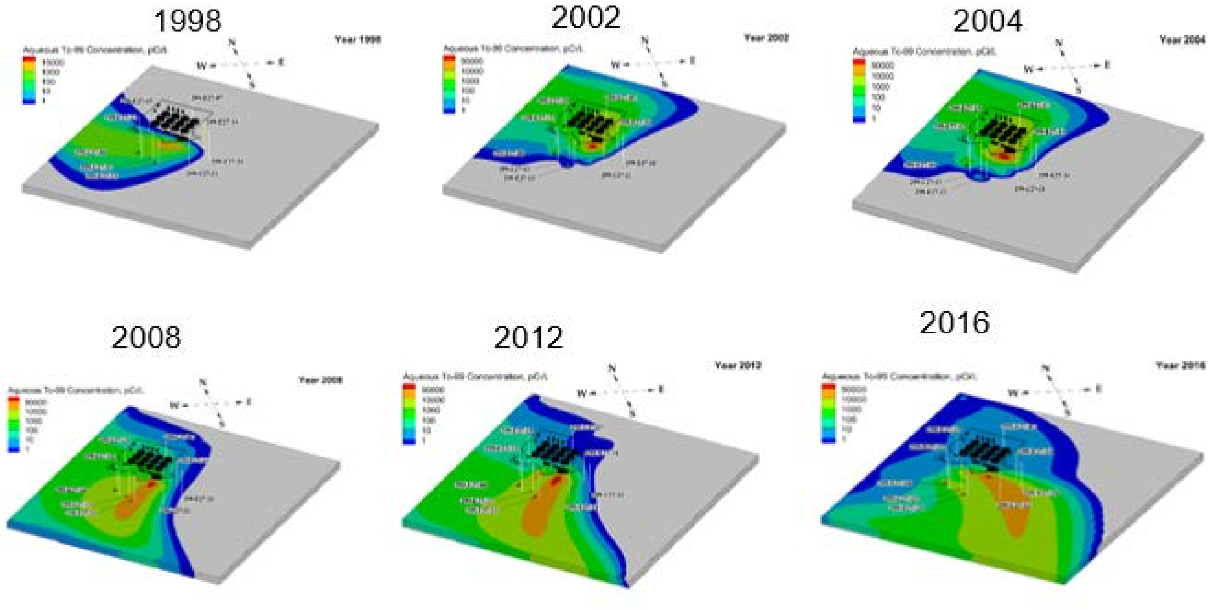

Fig. 8. Depiction of the ^{99}Tc plume evolution as the gradient changes from a northwest to southeast orientation. A counterclockwise rotation of the gradient direction was assumed.

Results of this analysis case are directly comparable to data at wells near WMA C; such comparisons are shown in Figs. 9 and 10. Given the uncertainties in the analysis, the model produces good agreement with the observed groundwater concentrations and the timing of the arrival of the peaks in most of the wells. Furthermore, the model demonstrates the ability to reproduce qualitative features of the trends in the well data, such as the multiple peaks in well 299-E27-04 (Fig. 9), the sharp spike in well 299-E27-07 (Fig. 9), and the sharp decline in concentrations in well 299-E27-23 (Fig. 10). These observations lead to a conclusion that the transition in the aquifer gradient is a primary factor in explaining the observed trends in the groundwater data at WMA C. These trends are associated with the decline in the water table as the operational groundwater mound dissipates, and are not relevant features of the system as it progresses into the future.

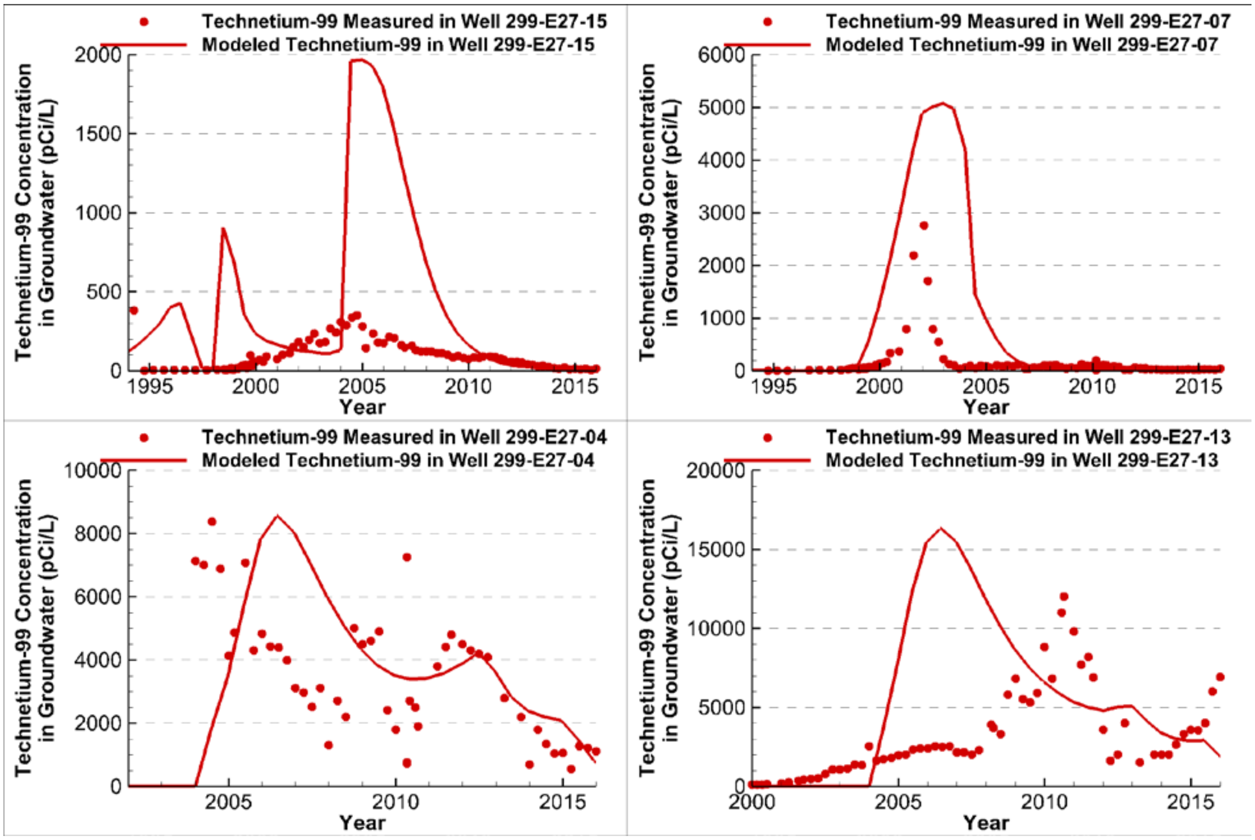

Fig. 9. Transient water table analysis compared to observed groundwater concentrations in wells northeast, northwest, and southwest of WMA C.

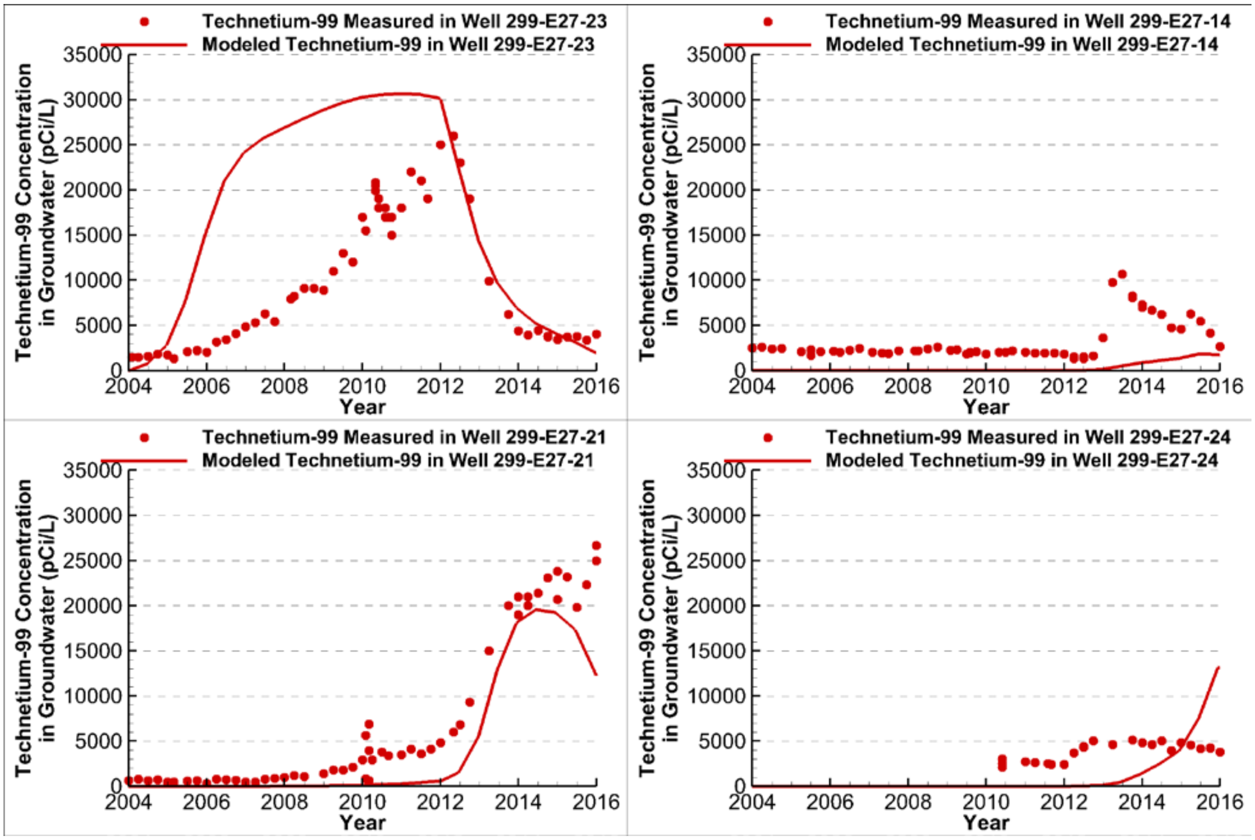

Fig. 10. Transient water table analysis compared to observed groundwater concentrations in wells south, southwest, and southeast of WMA C.

FUTURE PROJECTIONS

The utility of this set of analyses is its ability to project the consequences of past leaks into the future, in support of decision-making about potential actions needed to support closure of WMA C. Therefore, the model was used to project concentrations of contaminants of potential concern (COPCs) into the future. The approach to these analyses has been to use the static water table version of the model, discussed above. Concentrations were calculated at the WMA C fence line and at 100 m downgradient. The future projections were calculated for 100 m for consistency with the points of location in the residual waste performance assessment [3]. In keeping with the focus of the current paper, only ^{99}Tc results are discussed here, but similar analyses have been carried out for other COPCs. Results of Case 1a projected ^{99}Tc concentrations 100 m downgradient are shown in Fig. 11. The concentration of ^{99}Tc is dominated by contributions from the C-105 leak. It peaks in between about years 2015 and 2020, after which it undergoes a decline as the source entering the aquifer depletes and the contamination disperses downgradient of the facility.

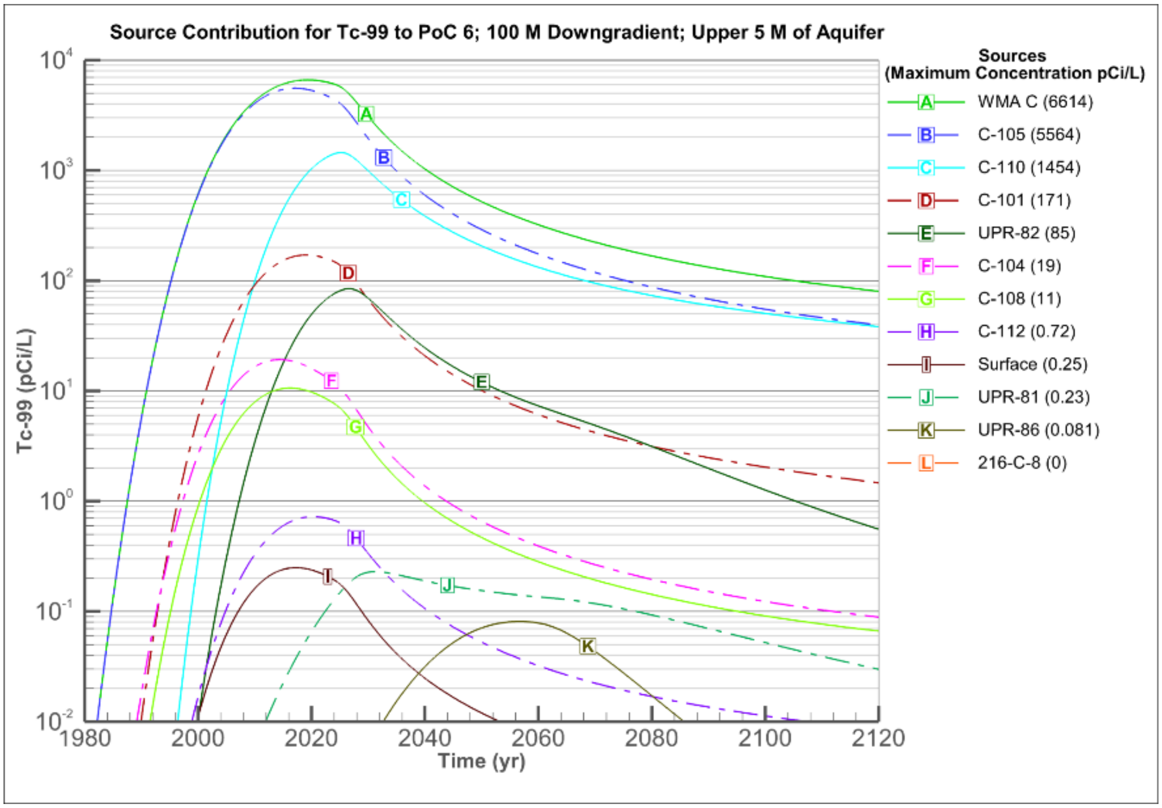

Fig. 11. Forward projection of ^{99}Tc concentration 100 m downgradient of WMA C, showing the contribution of different leaks to the total concentration.

CONCLUSIONS

The scoping analysis cases identified several assumptions that are inconsistent with data:

- The lower estimate results for the C-105 leak were inconsistent with data, therefore all other analyses were conducted using the upper estimate of 9.8 Ci (360 GBq).
- The upper estimate of recharge (150 mm/y) case results were inconsistent with the plume arrival time inferred from monitoring data.
- The case results with vadose-zone flow properties set to their 95th percentile values were inconsistent with plume arrival time.
- The highly heterogeneous vadose zone conceptual model results were inconsistent with plume arrival time.

The forward projection results lead to several observations, as follows.

- Model results indicate that current high concentrations of ^{99}Tc below WMA C are expected to decline over the next several decades as the contamination plume disperses in the aquifer.
- Concentrations decrease significantly with distance.

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