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Summary of TA53 Borehole Tritium Analysis

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Introduction

This report summarizes the analysis of tritium and corresponding water saturation data from boreholes located in the vicinity of the TA-53 surface impoundments. The data are used to constrain simulations of tritium transport in the subsurface. The simulations are designed using the current conceptual model for how tritium and water move through the subsurface of the Pajarito Plateau. The simulations use the process based porous flow and transport code FEHM (Zyvoloski et al., 1997) to explore a range of possible scenarios for how water and tritium have migrated beneath the impoundments. Simulations are presented to show that the most recent observations of tritium and water saturation beneath the impoundments can be explained within the framework of the current conceptual model allowing for uncertainty in site specific variables. Finally, the most recent data are used to initiate a simulation that shows that the current tritium plume is likely to attenuate to below levels of concern within less than 100 years.

Conceptual Model of Tritium Transport within the Pajarito Plateau

The conceptual model of tritium release from the wet lagoons and transport through the dry host rock assumes that the majority of tritium was released in the form of liquid water over a specific period of time. Tritium is radioactive hydrogen (half-life = 12.4 years) and thus forms 'heavy' water, which behaves nearly identically to normal water with respect to transport in the environment. Being intimately bound to water, tritium is migrating as liquid water and as water vapor in the soil air (Knight 1996, 70152).

Liquid effluent, mainly water, has infiltrated the dry rock beneath the lagoons and is moving under the forces of gravity and capillary suction. Gravity pulls water down while capillary suction pulls water from areas of high saturation to areas of low saturation. During the period of active infiltration from the surface, high saturations allow liquid water to move more quickly to depth. After the source is removed, capillary forces will continue to spread the subsurface effluent into regions of lower saturation leading to a much slower liquid flow rate. When liquid flow is reduced, vapor transport becomes more important (Fetter, 1999).

Within the porous media, equilibrium between water and water vapor is assumed (a well mixed model) because diffusive transport is slow relative to the rate of tritium exchange between pore water and pore gas (Smiles et al. 1995, 70153). Any tritium in the vapor phase would become incorporated into the residual liquid pore water before diffusing through the air-filled pore space (Smiles et al. 1995, 70153). Migration of tritium due to water vapor transport is important in regions with low moisture content. Vapor transport becomes the dominant transport mechanism as the liquid effluent is spread out by capillary suction after the source is removed. Finally, the short half-life of tritium causes a large reduction in the inventory during the time needed to migrate from the source.

Numerical Model of Tritium Transport

A site-specific tritium transport model was developed to support decisions regarding placement of boreholes to determine the maximum horizontal and lateral extent of tritium released beneath the TA-53 surface impoundments (Stauffer et al., 2002). The model used the porous-flow simulator FEHM (Finite Element Heat and Mass Transfer), which was developed by the DOE and Nuclear Regulatory Commissoin (NRC) to demonstrate compliance with EPA regulations at the Yucca Mountain high-level waste repository (Zyvoloski et al. 1997, 70147). The conceptual model of dual-phase tritium transport described above was simulated by means of enhanced liquid phase diffusion coefficient (Smiles et al. 1995, 70153). Site-specific data and general Pajarito Plateau hydrologic data (Birdsell et al. 2000) were used to develop a numerical grid that simulated the land surface to the water table and encompassed a lateral area centered on the impoundments (Figure 1). The grid was generated using GEOMESH grid generation software (Gable et al. 1995, 70148) and incorporates information from the LANL site-wide geologic model (Carey et al.1999, 66782). Important uncertainties in the site data that were varied in these simulations include (1) infiltration rate and area, (2) volume of infiltration, (3) concentration of tritium in the effluent, and (4) the diffusion coefficient for tritium. Many of the details discussed in Stauffer et al. (2002) are applicable to the current discussion, however for brevity, are not included here.

Figure 1 shows the location of the seven boreholes drilled in 2002. These boreholes were drilled to delineate the extent of the tritium plume. Figure 1 also shows the lateral extent of the numerical grid used to calculate tritium transport. For this report, a limited number of simulations were performed to determine if uncertain parameters could be adjusted within the bounds of the conceptual model to explain the most recent data from the boreholes drilled in 2002.

Best-Fit Simulation for the 2002 data

The simulation is run for a period of 85 years. The first 15 years (1977–1992) represents the active "wet" leaking phase at the site with enhanced infiltration and high tritium concentrations in the effluent. The last 70 years represent the period after removal of the effluent source. Site data on tritium and water discharge from the TA-53 surface impoundments (working volume of each northern impoundment is 1.6 million gal) are available for the years 1978 to 1989 (TA-53 RFI, Appendix D, LANL 1998, 58841). During this 15 year period 60 million gallons containing approximately 187 Ci of tritium was discharged from the outfall.

Input parameters that were varied for this report are (1) infiltration rate (2) volume of infiltration, (3) concentration of tritium in the effluent, and (4) the diffusion coefficient for tritium. The best fit simulation from the current limited sensitivity has the following attributes.

(1) The enhanced infiltration used to simulate the active wet period of operation was 1 meter/year over an area of 10,000 ft^2. This area is roughly equivalent in size to the northeast quadrant of the southern surface impoundment, where the old

unlined outfall channel was located. The simulated injection is equal to a volume of 490,722 gal/year. This infiltration rate is nearly 5 times higher than in-situ estimates (23 centimeters/yr) based on measured saturations in borehole 53-6 (Rogers et al. 1996).

(2) The total volume of the simulated infiltration, 7.4 million gallons represents a significant fraction of the total estimated discharge (60 million gal) at the site.

(3) The simulated source concentration in the injected water (1 million pCi/L) was chosen to represent the average concentration of the effluent . The total simulated injection of tritium activity is 27.9 Ci and represents 15% of the total reported tritium discharged from the impoundments.

(4) For this study, the assumed vapor diffusion coefficient for tritium was lowered by a factor of 10 from the worst case scenario of Stauffer et al (2002) to help match the 2002 data. Stauffer et al (2000) showed that for TCA at MDA L the apparent diffusion coefficient for water is on the order of 4e-6 m2/s, which at 5% volumetric moisture is a factor of 10 times lower than used in the current simulations. Further sensitivity analysis to this important parameter will help to bound uncertainty in the calculations of future plume behavior, however is beyond the scope of this report. FEHM has recently been improved to handle diffusion as a function of water content and this new capability should be used to analyze the data further analysis is undertaken in the future.

Best Fit Simulation Results

Tritium

Figure 2 compares the 2002 borehole tritium data (converted to pCi/L) to the simulated tritium concentrations with depth for the year 2002 under the western injection point for the best-fit simulation. The location of this injection node is quite close to Borehole 7 from the 2002 data. The simulation is able to capture the general character of the Borehole 7 tritium data. Both data and model show very little tritium moving below the Qbt 1v-Qbt 1g contact. Data from Boreholes 4, 5, and 6 support the conceptual model for transport mechanisms because measured tritium was found to be quite low on the perimeter of the impoundments, especially to the north. Boreholes 1 and 2 also support simplified site history and most likely location of major tritiated water input to depth being along the old unlined drainage ditch. These holes help to show that the northern impoundments probably did not allow significant tritiated water to move past the clay liner. However, tritium in Borehole 6 shows that some water may have leaked through the geotechnical liner of the southern impoundment. Additionally, data from the 50' deep Borehole 3 show increasing tritium at 50' with a value approaching 400,000 pCi/L. This borehole was drilled in the overflow drainage. Increased infiltration of tritium was not included in the simulations for this region, thus the model does not match data from this borehole. The model could easily be changed to include infiltration from the beginning of the outfall along the path of the drainage leading of the east side of the mesa. Although such additional simulations would allow a better fit to the Borehole 3 data, such an effort would do little to affect the conclusions of this report.

Saturation

Figure 3 shows the best-fit simulated saturation profile below the western injector located just north of Borehole 7 on Figure 1. This figure also includes data from Birdsell et al. (2000) for ranges of saturation found on Mesita del Buey, a similar mesa. The background simulation that is used as the initial state for the tritium analysis is also shown in Figure 3, showing that the model is honoring the saturation data at the beginning of the tritium calculations.

Comparison of the 2002 data with the saturation ranges shows increased liquid saturation to 100' in all boreholes except Borehole 6. Below 100' increased saturation is seen in Borehole 7 from 150-250', while Borehole 4 appears to have elevated saturation between 150-170 '. The best-fit simulation over-estimates the saturation in borehole 7 above 150'. However the simulated saturation spike seen at 150' is quite similar to the data and implies that Borehole 7 has seen liquid migration carrying to this depth. Although saturation in Borehole 7 from 150-250' appear to be elevated above background, the tritium values associated with this water are relatively low and suggest that the source of this water was not from the high concentration south lagoon, but may be from deep infiltration of sanitary waste. Major ion analysis supports this conclusion, and future analysis of nitrogen isotopes should help to fingerprint the source of nitrate found at this depth.

Future Plume growth and water movement

Figures 4 and 5 show calculated concentrations and saturations below the western injector for the year 2072. By 2072, the maximum tritium concentration has been reduced to less than 20,000 pCi./L by radioactive decay and dilution. Figure 5 shows that the large amount of water introduced to the system moves downward. Interestingly, the saturation profile in the year 2072. is very similar to the Borehole 7 saturation data below 150'. This suggests that the water at depth in Borehole 7 either traveled laterally at depths of approximately 150' from a very wet region nearby, or leaked from the location of Borehole 7 early in the site history and had sufficient time to drain from the upper 125'.

Conclusions

Results from simulations of tritium transport below the TA-53 surface impoundments suggest that data collected during 2002 fit within the conceptual model of transport at this site. The simulations show that, in the context of the conceptual model, the data can be used to delineate the extent of the tritium plume beneath TA-53. The simulations are also used to show that the plume is expected to dissipate, through natural attenuation in less than 100 years.

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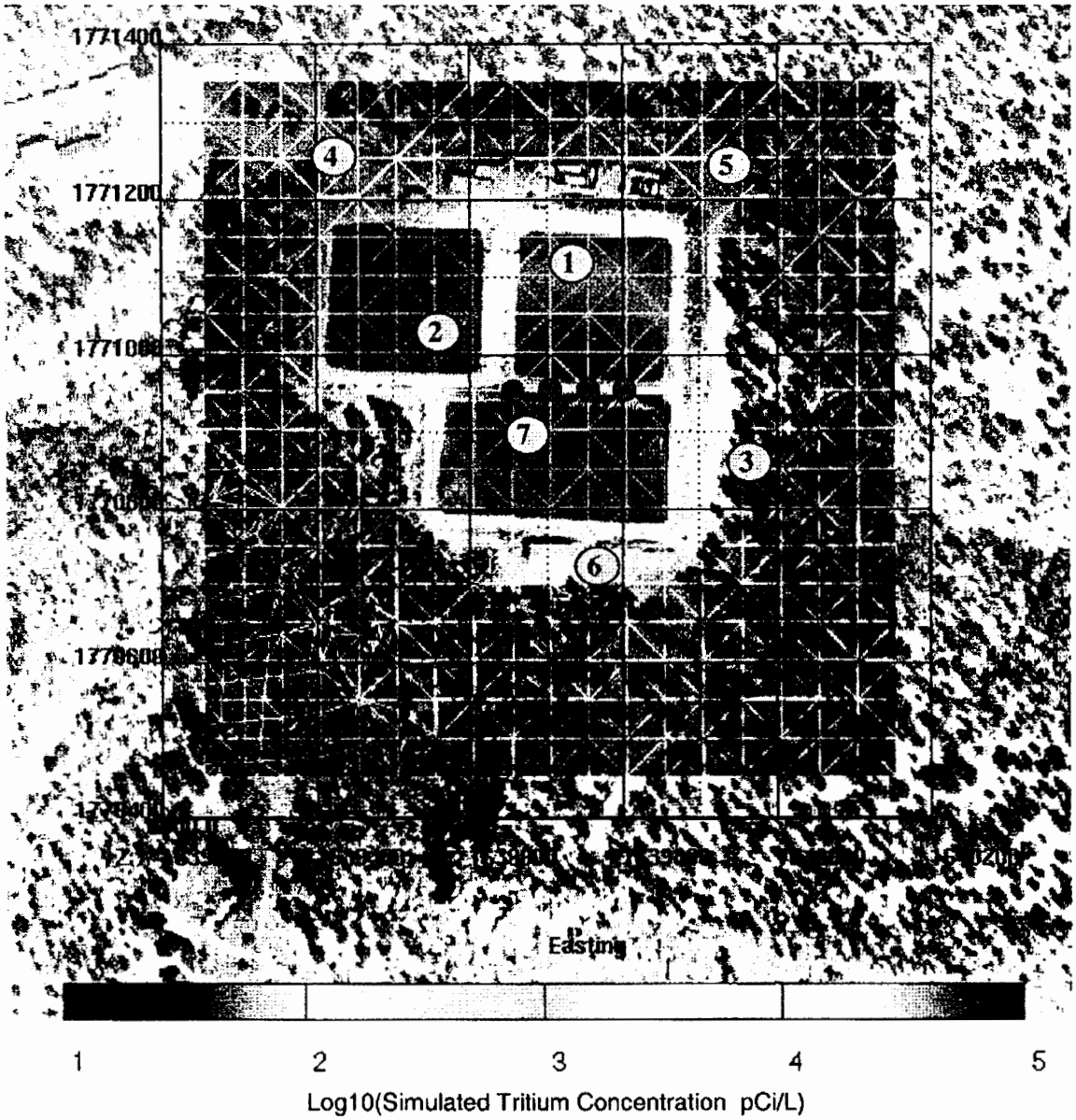

Log10(Simulated Tritium Concentration pCi/L)

Figure 1 Image of the surface impoundments before they were removed. The numerical grid is overlain on the photo. The color contours are the simulated tritium plume for the worst case simulation from Stauffer et al. (2002). The four pink dots show the location of the simulated injection. The green circles are the approximate locations of Boreholes 1-7 from the 2002 drilling.

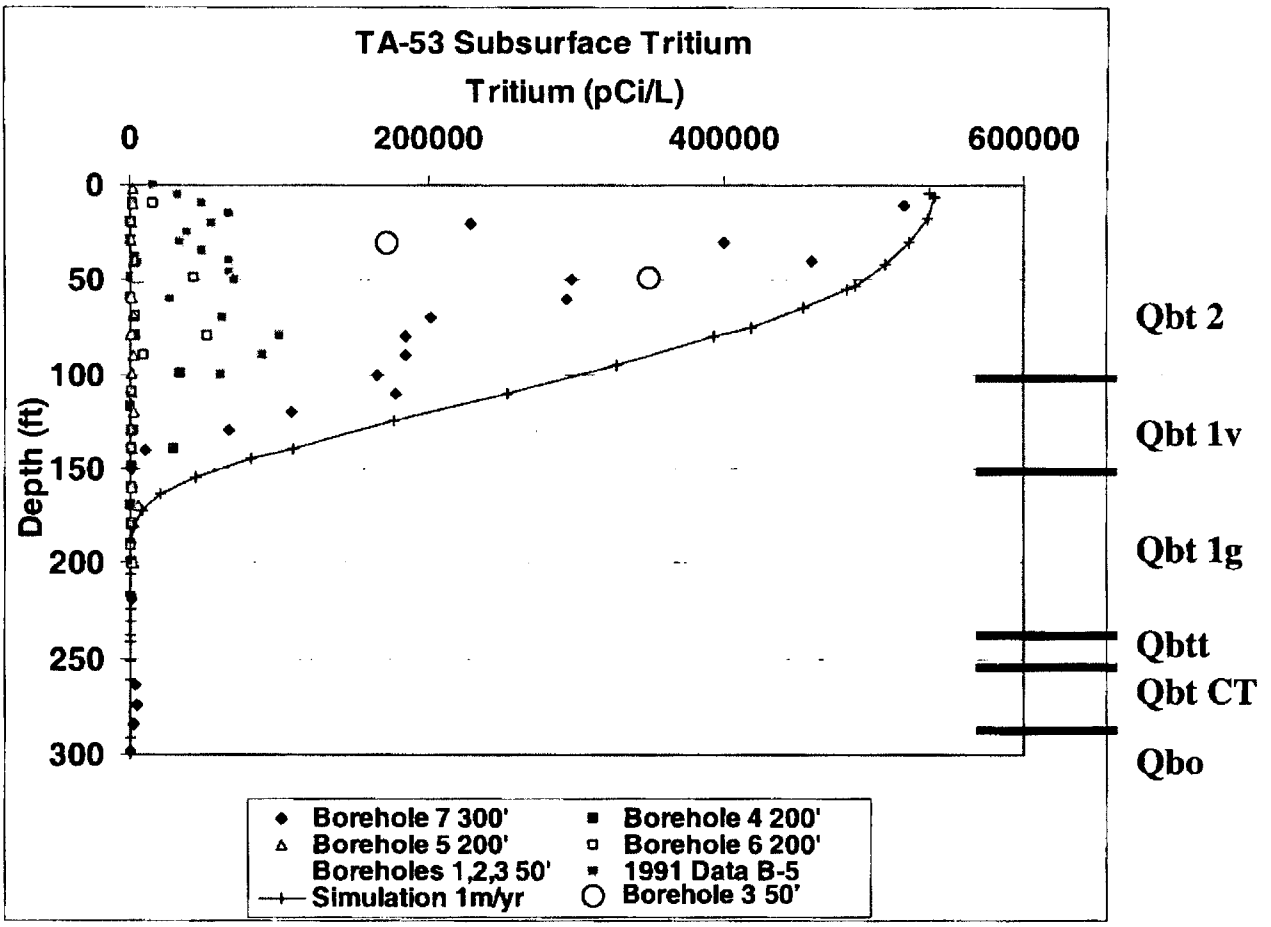

Figure 2 Simulated tritium concentration for the year 2002. The simulated concentrations are located directly beneath the western injection node and are close to the location of Borehole 7.

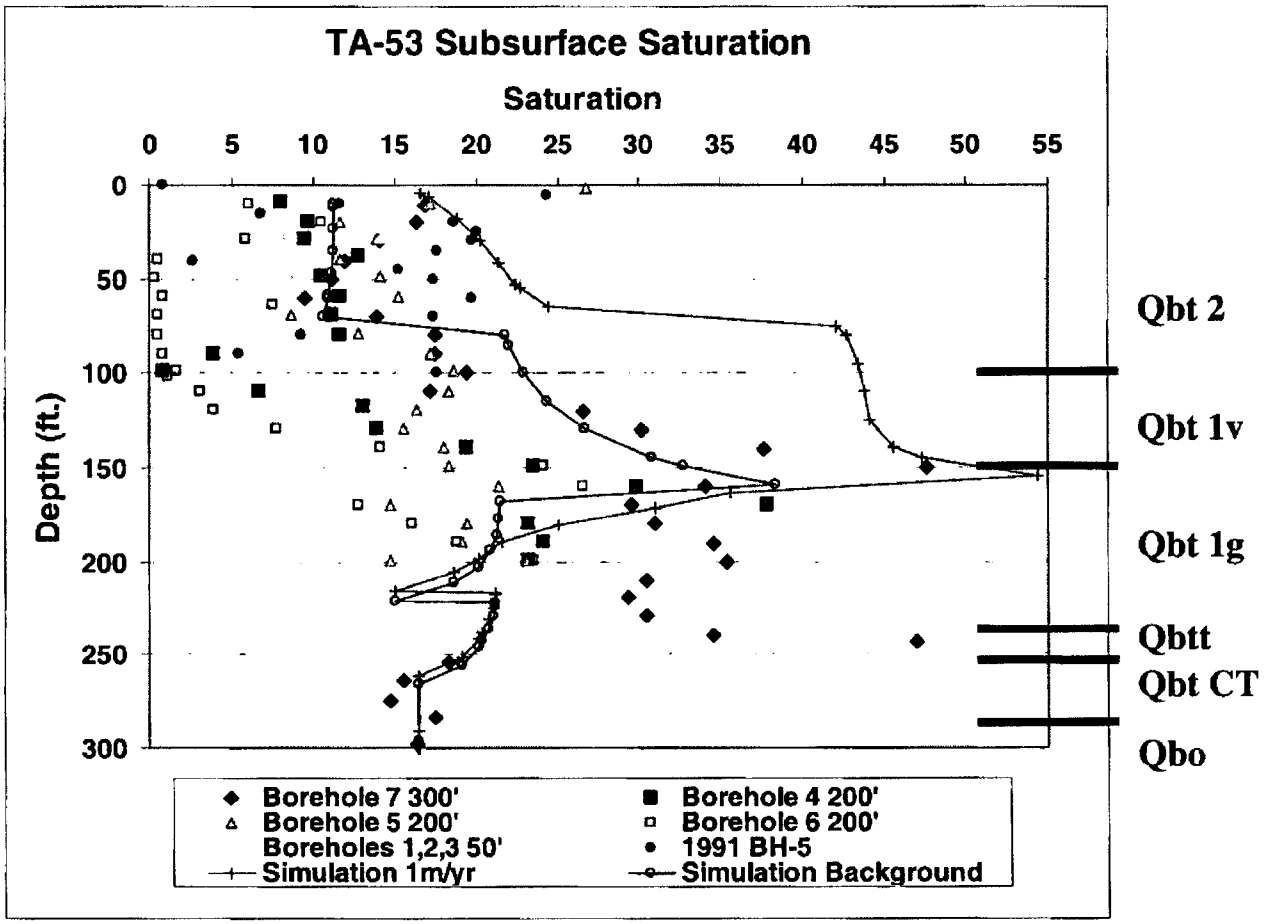

Figure 3 Simulations of saturation compared to site data. The transparent beige rectangles are 1 sigma saturation ranges seen in data from Area G.

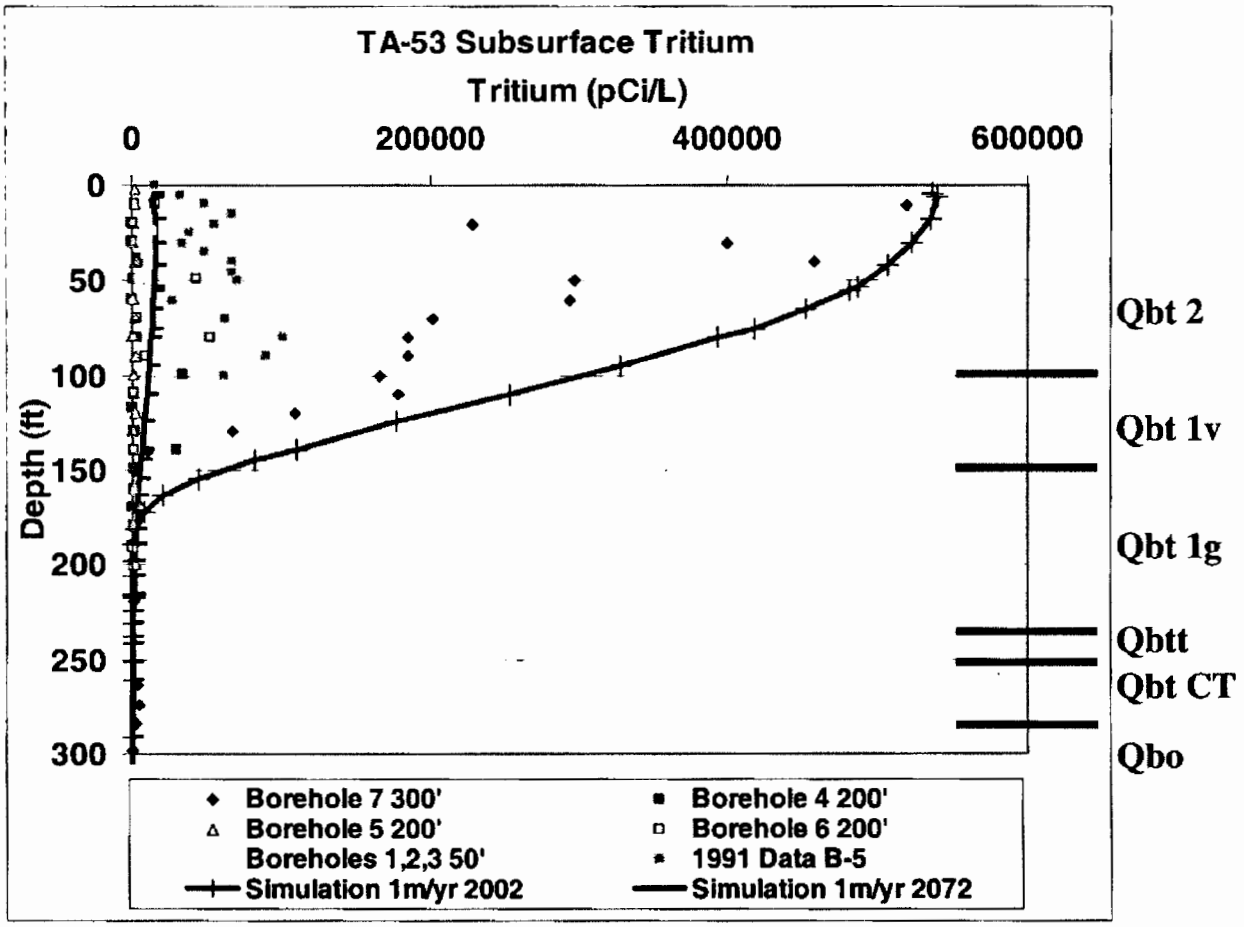

Figure 4 Simulated tritium below the source region for the year 2002 and 2072 compared to the site borehole data.

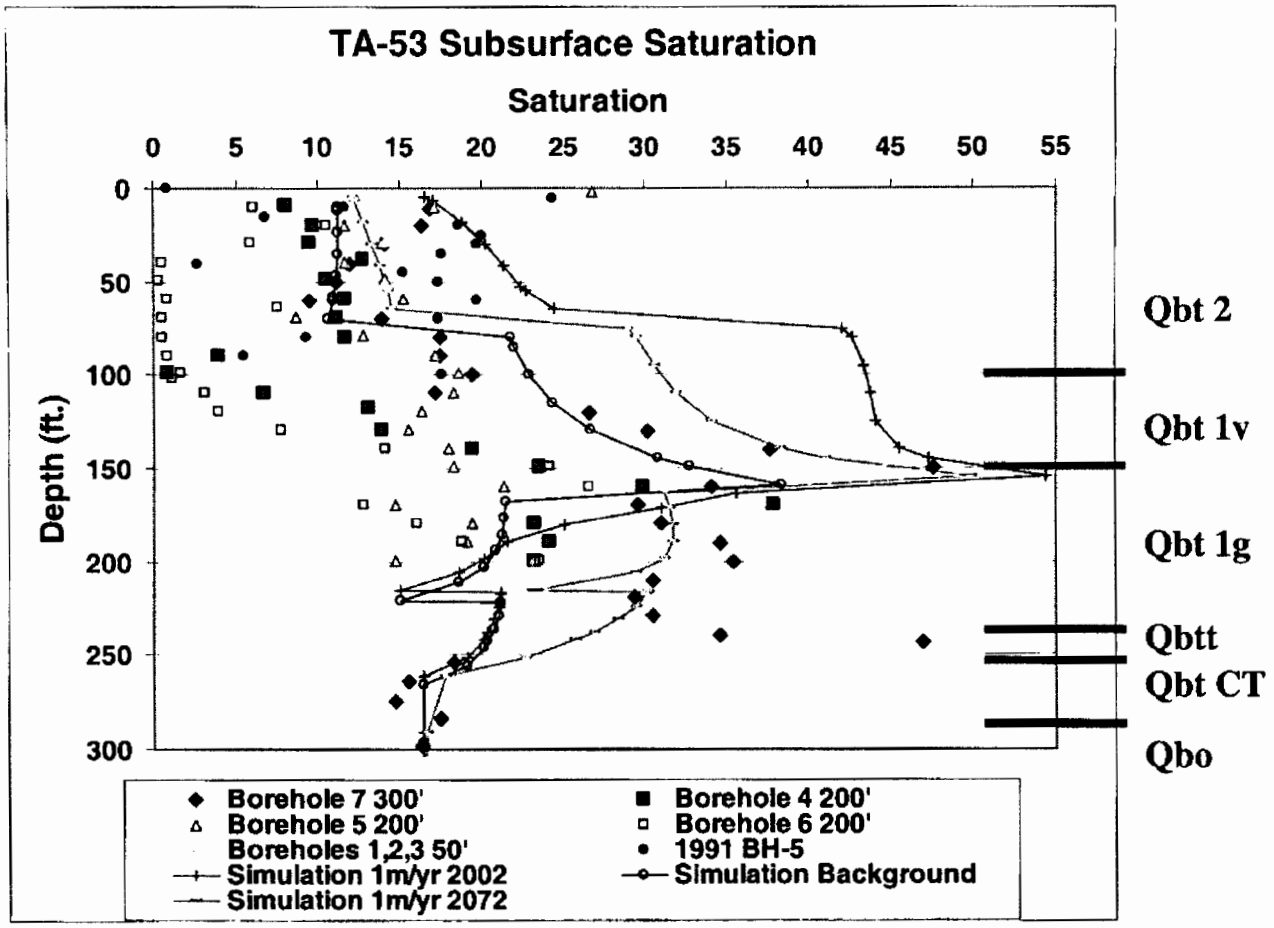

Figure 5 Simulated saturation profiles for the background, best fit to the 2002 tritium data, and at 75 years from the current compared to the site borehole data.