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Pacific Northwest
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Evaluation of the Fate and Transport of Tritium Contaminated Groundwater from the 618-11 Burial Ground

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P. E. Dresel
E. J. Freeman
R. E. Peterson
P. D. Thorne

August 2005

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Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

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Richland, WA 99352

Executive Summary

Tritium transport simulations conducted during this modeling effort indicate that mechanisms associated with dilution, dispersion, and radioactive decay have, in the past, and continue to attenuate the tritium plume from the 618-11 Burial Ground and limit the risk to the primary receptors (the Columbia River and Energy Northwest water supply wells). Before running predictive simulations over the full period of interest, model predictions at two locations downgradient from the burial ground were compared with observed concentrations to evaluate model fit. This process was conducted in an iterative fashion, with the distribution of tritium residuals (the difference between observed and simulated values) guiding the development of alternative conceptual models that would address unacceptably high residual values and ultimately provide a reasonable fit to the observed tritium concentration trend data.

A comparison of simulated and observed tritium concentration at two downgradient monitoring wells indicated that the model provided a reasonable representation of the tritium concentration trend immediately downgradient from the site (699-13-3A) and near the leading edge of the plume (699-13-0A). This relatively good match increased confidence in the conceptual model, its numeric implementation, and the validity of predictive simulations of tritium fate and transport.

Three tritium release scenarios were investigated to measure the impact expected at the primary receptor locations under different release conditions. The three cases include 1) a pulse release of tritium from the burial ground that provided the best fit between observed and simulated tritium concentrations and 2) two alternative release scenarios designed to evaluate the effects of increasing mass release on predicted tritium concentration. The alternative release scenarios include a continuing, decaying source beneath the burial ground through 2015, the milestone for source removal under the River Corridor Closure Contract, and a pulse release, like the best fit case, but at twice the concentration.

In the best fit case, the model predicts that the maximum tritium concentration will decline to below the drinking water standard of 20,000 pCi/L by 2031. For the two alternative release scenarios, maximum tritium concentrations will decline to below the drinking water standard by 2040 and 2037, respectively. Simulations also indicate that tritium from the 618-11 Burial Ground is not expected to migrate to the primary receptor locations (the Columbia River and Energy Northwest water supply wells MW-31 and -32) at concentrations exceeding the drinking water standard. These simulations did not consider pumping from the Energy Northwest water supply wells, which, if sustained at high rates for long periods of time, could increase the observed concentration at this location.

Acknowledgments

The authors wish to thank PNNL staff who provided invaluable assistance in the important areas of data processing, model data input preparation and final report preparation. Contributors include Chris Newbill and Mark Williams. Mike Truex provided technical peer review and Sheila Bennett provided technical editing support.

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1.0 Introduction

The 618-11 Burial Ground is located in the eastern part of the U.S. Department of Energy (DOE) Hanford Site (Figure 1.1). After a marked increase in tritium concentration (January 2000) was detected in monitoring well 699-13-3A, installed immediately downgradient of the burial ground to evaluate impacts on groundwater quality, a field investigation was initiated to determine the nature and extent of tritium contamination in groundwater. A preliminary investigation was conducted in February 2000 (Dresel et al. 2000) that consisted of sampling existing monitoring wells near the 618-11 Burial Ground and analyzing the samples for a variety of radionuclides and other potential contaminants of concern. A second investigation was completed in fiscal year 2001[(a)] that provided detailed information on the spatial distribution of tritium, including a measure of the downgradient, lateral, and vertical extent. Data from these investigations were used to develop a conceptual model for tritium contamination downgradient of the burial ground and formed the basis of a preliminary evaluation of the potential impact of the 618-11 tritium plume on the Columbia River.[(b)] Although this preliminary evaluation indicated that the impact to the river from the 618-11 tritium plume would be minimal, the evaluation was based on simplified analytical and numerical approaches that limited the amount of confidence that could be placed in the results.

The record of decision (ROD) for the 300-FF-5 operable unit (EPA 1996) describes the selected interim action remedy as 1) continued monitoring of groundwater that is contaminated above health-based levels to ensure that concentrations continue to decrease and 2) institutional controls to ensure that groundwater use is restricted to prevent unacceptable exposure to groundwater contamination. Contaminants of concern for the 618-11 Burial Ground, as identified in the explanation of significant difference (EPA 2000), are limited to tritium. The fate and transport model described in this report incorporates the most current hydrogeologic conceptual model of the site and provides a tool for assessing the impact of the 618-11 tritium plume on potential downgradient receptors (e.g., the Columbia River). The modeling results provide an improved technical basis for evaluating the suitability of the current remedy for the tritium plume.

The scope of this report is to perform a detailed evaluation of the fate and transport of the 618-11 tritium plume and its potential impact on downgradient receptors. Section 2 of this report provides general background information and a history of site investigations. Section 3 summarizes the current status of contaminants of concern and provides a discussion of how well the

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(a) Letter report from JV Borghese, WJ McMahon, and RW Ovink, CH2M HILL, to U.S. Department of Energy, Richland, Washington. 2001. *Tritium Groundwater Investigation at the 618-11 Burial Ground, September 2001.*
(b) Letter Report from PE Dresel and MP Bergeron, PNNL, to U.S. Department of Energy, Richland, Washington. 2001. *Evaluation of the Impact of Tritium Contamination in Groundwater from the 618-11 Burial Ground at the Hanford Site.*

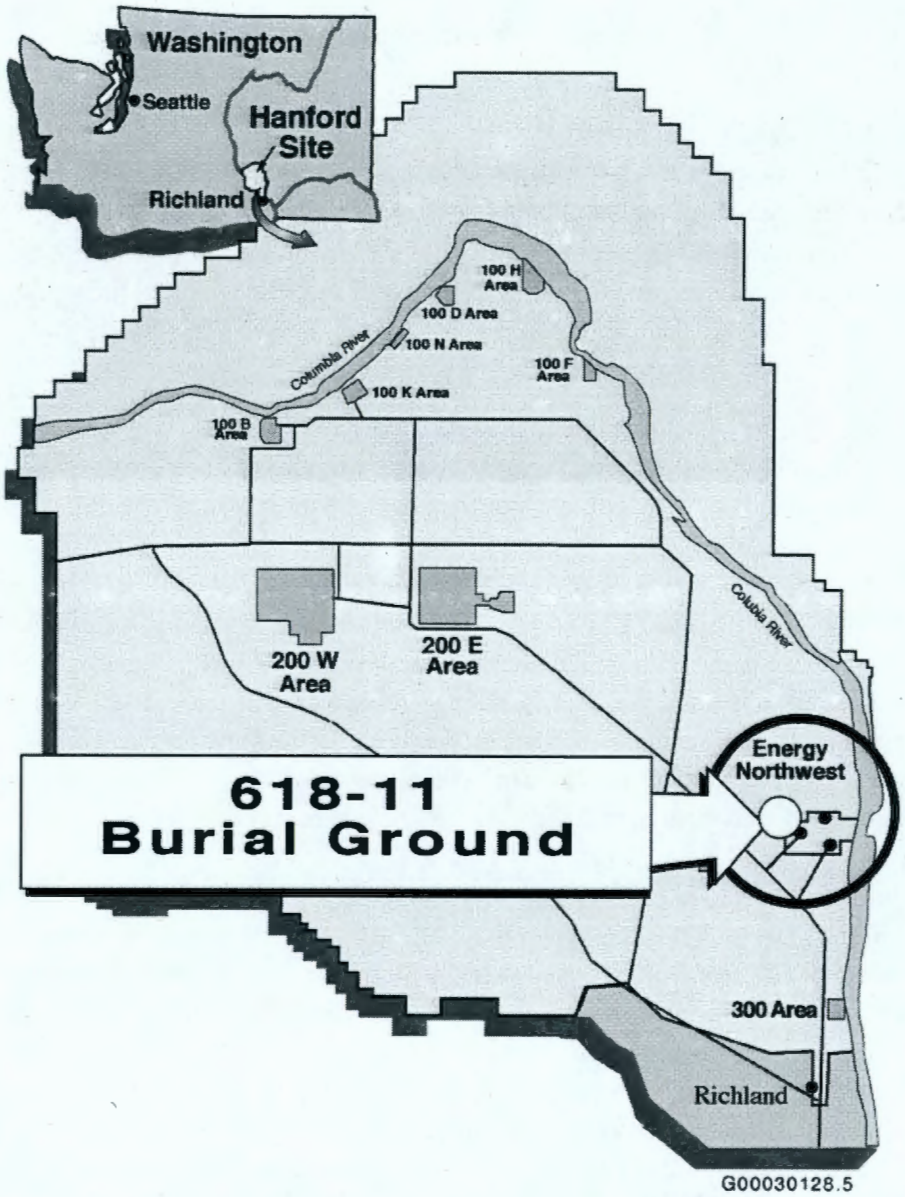

Figure 1.1. Location of the 618-11 Burial Ground, Hanford Site, Washington

monitoring objectives of the selected interim remedy (i.e., continued monitoring) are being met. Section 4 describes the groundwater flow and contaminant transport model that was developed for this effort, and Section 5 provides a discussion of the 618-11 tritium plume fate and transport evaluation. Section 6 summarizes the main conclusions resulting from this modeling effort, and Section 7 lists cited references.

2.0 Background

Development of a detailed conceptual model of site hydrogeology and contaminant distribution in the vicinity of the 618-11 Burial Ground is an essential element of evaluating of the future impact of the tritium plume on potential receptors such as the Columbia River. This section presents the background for development of the site conceptual model, which formed the basis of the groundwater flow and contaminant transport model developed during this effort.

2.1 Site Description

The 618-11 Burial Ground received waste between March 1962 and December 1967 (Demiter and Greenhalgh 1997). The site consists of three trenches, two to five large-diameter caissons, and fifty vertical pipe storage units. It covers an area of 3.5 hectares (8.6 acres) approximately 300 m (1,000 ft) west of Energy Northwest Plant 2 (WNP-2). The trenches are 274.3 m (900 ft) long by 15.2 m (50 ft) wide. The vertical pipe units are five 208-L (55-gal) drums welded together end-to-end and are approximately 4.6 m (15 ft) long by 55.9 cm (22 in.) in diameter. The caissons are metal pipes 2.4-m (8-ft) in diameter, 3 m (10 ft) long, and buried vertically 4.6 m (15 ft) below grade. They are connected to the surface by offset 91.4-cm-(36-in.-) diameter pipe with a dome-type cap. All vertical pipe units and caissons were capped with concrete and covered with native sediment as they were filled.

Waste was sent to the 618-11 Burial Ground from the 324, 325 and 327 Building hot cells and the Plutonium Recycle Test Reactor in the 300 Area. Inventories of the waste do not specifically state that tritium was disposed there, although hydrogen gas (a possible misnomer) was identified. Shortly after the site was closed, it was covered with 1.2 m (4 ft) of soil. In 1983, the surface of the site was stabilized with an additional 0.6 m (2 ft) of clean material and planted with wheatgrass. The bottoms of the trenches and caissons are estimated to be approximately 9.1 m (30 ft) below grade, while the bottoms of the vertical pipe units are estimated to be 6.4 m (21 ft) below grade. The site perimeter is fenced and identified by concrete markers. Plants in the area show no obvious signs of vegetative stress that would indicate radiological or chemical constituent uptake from either the waste site or the unplanned releases that have occurred there.

The mechanisms controlling tritium release from the 618-11 Burial Ground are not well understood or have not been well characterized; thus, developing a detailed conceptual model of historic releases from the site is not possible. There are two components of contaminant transport between the 618-11 waste forms and the water table: 1) release of contaminants from containment structures (vertical storage pipes and caissons) and 2) migration of contamination through the vadose zone to the water table. Factors controlling transport for the first component include waste form and container integrity, condition of containment structures, and transport mechanisms within the unsaturated zone. The primary driver controlling transport of con-

taminants through the vadose zone and into the unconfined aquifer is surface recharge. Though surface recharge on the Hanford Site is relatively low, and estimates for the 618-11 Burial Ground vicinity are on the low end of the range (5 to 10 mm/yr) (Fayer and Walters 1995), episodic occurrences of elevated recharge may cause increased infiltration through the vadose zone and pulsed release of tritium to groundwater. Examples of increased recharge events include the application of water to establish the wheatgrass groundcover during the 1983 stabilization effort, atypical winter weather conditions that result in significant quantities of snow, and occasional rain on snow events that significantly increase the short-term natural recharge rate.

Groundwater contamination from the 200 East Area extends over a large portion of the Hanford Site to areas adjacent to the 618-11 Burial Ground. Contamination from the 200 East Area in this region consists predominantly of tritium with associated nitrate and iodine-129 (which is generally below detection limits near the burial ground). However, as indicated in Figure 2.1, an area of anomalously low tritium has been noted east of the burial ground when compared to the surrounding plume from the 200 East Area. This tritium distribution is thought to be the result of hydrogeologic controls that dominate this portion of the groundwater flow system.

The Energy Northwest reactor complex was constructed east of the 618-11 Burial Ground. The WNP-2 reactor initially went critical in January 1984 (Washington Public Power Supply System 1985); the other two power plants, WNP-1 and WNP-4, were never completed. Some tritium is produced during reactor operations by ternary fission. Several instances of release of tritium and other radionuclides to the environment have been documented (Washington State Department of Health 1999). Release locations include the WNP-2 Sanitary Waste Treatment Facility and the storm drain outfall.

2.2 Hydrogeologic Setting

The 618-11 Burial Ground and the Energy Northwest nuclear power plant complex are constructed on suprabasalt sediments of Miocene to Pleistocene age (Figure 2.2). The stratigraphic column includes, in ascending order from oldest to most recent, the Columbia River Basalt Group, Ringold Formation coarse-grained facies of the Cold Creek unit, and Hanford formation. In addition, a thin, regionally discontinuous veneer of Holocene alluvium and eolian sediment overlies the principal geologic units. Lindsey (1995) describes the regional geology of the Hanford Site. The hydrogeologic description of the Hanford Site is provided in Hartman (2000).

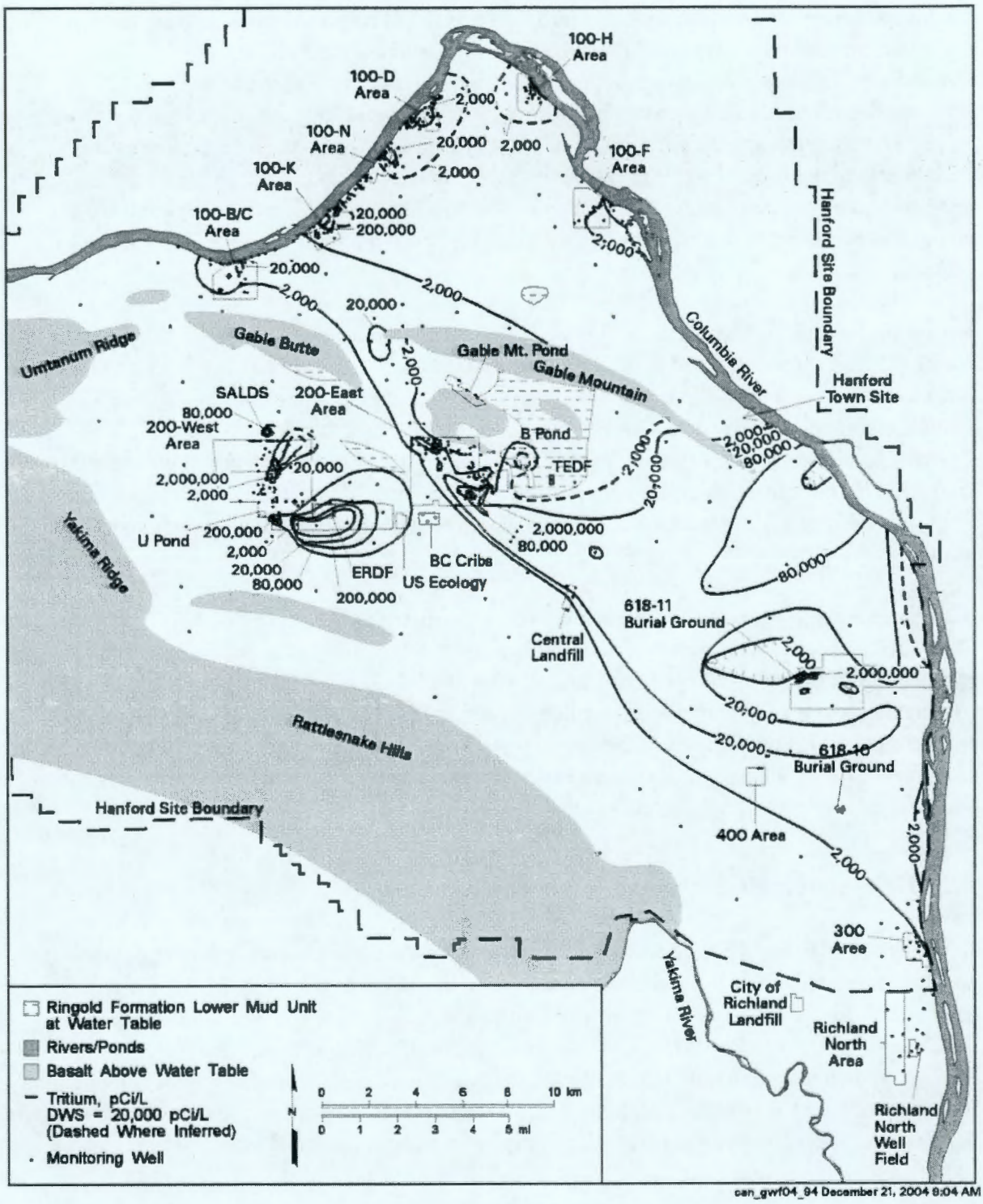

Figure 2.1. Tritium Concentrations at Top of Unconfined Aquifer, Hanford Site, FY 2004

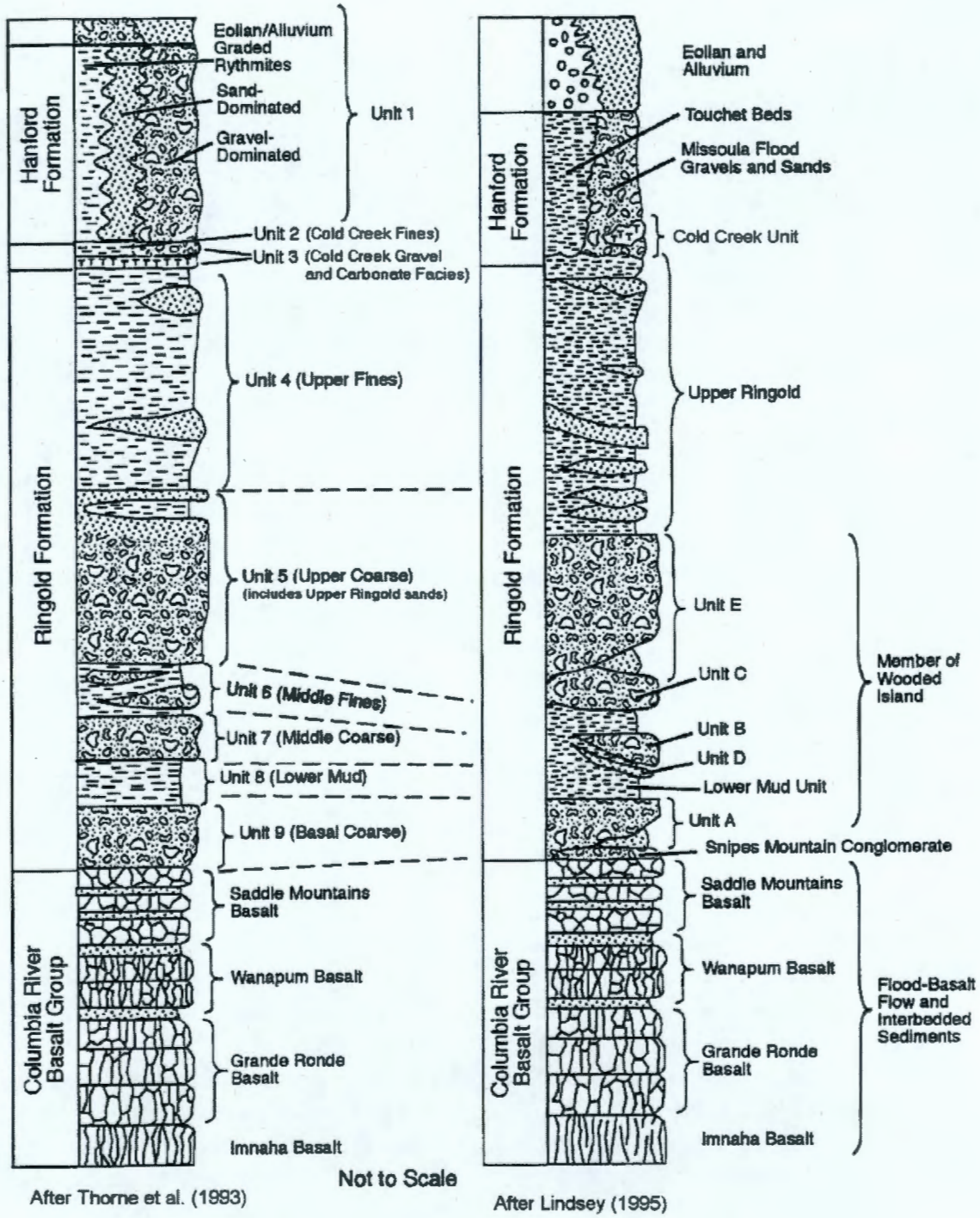

Figure 2.2. Generalized Hydrogeologic and Geologic Stratigraphy

The suprabasalt sediments are the most significant hydrogeological units in terms of contaminant transport beneath the area because they form the uppermost aquifer system. This aquifer system is the primary groundwater contaminant pathway to the Columbia River. The upper aquifer system consists of an upper unconfined aquifer and deeper zones that have confined to semi-confined aquifer conditions. The Elephant Mountain Member basalt forms the bottom of this uppermost aquifer system more than 150 m (500 ft) beneath the surface. Confined aquifer conditions exist beneath the Elephant Mountain Member basalt. The confined aquifer system is used for water supply at WNP-1 (two wells) and for emergency supply at WNP-2 (one well). Information obtained from well drilling records, and recent water level measurements confirm that the basalt-confined aquifers have a higher water level (potentiometric surface) than the uppermost unconfined aquifer, resulting in upward flow if any leakage occurs between the two aquifers. This condition significantly reduces the possibility of a downward movement of tritium into the lower, deeper confined aquifer.

The Pliocene-age Ringold Formation, which overlays the Elephant Mountain Member basalt, is a mix of variably cemented and consolidated gravel, sand, silt and clay. Overlying the Ringold Formation is the coarse-grained facies of the Cold Creek unit and the Hanford formation. The Hanford formation is mostly unconsolidated gravel, sand, and silt deposited by a series of catastrophic glacial floods. The fluvial coarse-grained facies of the Cold Creek unit gravel underlies the Hanford formation in some areas of the Hanford Site. Cold Creek gravel is hard to distinguish from Hanford gravel; however, efforts have been made recently to better define this contact (Vermeul et al. 2003). Available aquifer testing data and well completion pumping results from similar lithologies west of the burial ground indicate that the Hanford formation is significantly more permeable (possibly by multiple orders of magnitude) than the underlying Ringold Formation sediment.

An accurate mapping of the configuration of the Ringold and Hanford formations is important for understanding groundwater and tritium flow paths to the river because of the differences in permeability between the Ringold Formation and Hanford formation sediments. The water table may be found within the Hanford formation, the Cold Creek gravel unit, or the Ringold Formation in the vicinity of the 618-11 Burial Ground because of structural features created at the top of the Ringold Formation by cataclysmic flooding, fluvial reworking, and erosion by the Columbia River. Areas where saturated Hanford formation sediments are thin or absent are expected to provide barriers to flow or to significantly decrease groundwater velocity. Ringold Formation sediments are interpreted to exist above the water table beneath the 618-11 Burial Ground and in some areas east (i.e., no saturated Hanford sediments are present; see discussion in Section 4.1).

The current water table surrounding the 618-11 Burial Ground is elevated compared to pre-Hanford conditions. At a maximum, the water table was elevated more than 4.6 m (15 ft) from pre-Hanford conditions due to infiltration of a large volume of artificial recharge to the aquifer in the 200 Areas west of the site. Water level measurements more representative of pre-Hanford

conditions are available from wells drilled in the 1950s. These older water level measurements suggest that the pre-Hanford water table near the 618-11 Burial Ground was close to where the Ringold Formation contacts the overlying Hanford/Pre-Missoula gravel and sand sequences. This regionally stable water table condition likely existed because the water table could not be sustained in the high hydraulic conductivity Hanford formation sediments above this contact under the low natural recharge conditions.

2.3 History of Site Investigations

In 1978, Pacific Northwest Laboratory (PNNL) conducted geophysical surveys and core drilling and sampling near the 618-11 Burial Ground (Phillips et al. 1980). According to Phillips et al., wells "were located to enable drilling beneath the structure where radiocontaminated leachate, if present, would be intercepted, rather than drilling into the structure." Two soil samples were collected from depths of 8.8 and 9.4 m (29 and 31 ft). Gross alpha, gross beta, and other natural occurring radionuclides were reported to be within background range. A small concentration of cesium-137 (0.16 pCi/g) was found at a depth of 8.8 m (29 ft) but was not judged to be a concern.

An Environmental Impact Statement (EIS) was issued in 1987 that analyzed the effect of strategies for the final disposal of high-level, transuranic, and tank waste generated during national defense activities and stored at the Hanford Site (DOE 1987). The EIS also evaluated waste that was disposed at the Hanford Site before 1970, when the transuranic category was established, that would be considered transuranic if generated today. Because the 618-11 Burial Ground was used between 1962 and 1967 for disposal of laboratory waste (including remote-handled hot cell waste) from 300 Area operations, it was specifically included in the scope of the EIS under the classification "pre-1970 Buried Suspect Transuranic-Contaminated Solid Wastes."

Several disposal alternatives were studied in the EIS (DOE 1987). Based on the conclusions of that study, a preferred alternative for deferral of disposal decisions pending additional development and evaluation was selected for the single-shell tanks, transuranic-contaminated soil sites, and the pre-1970 buried suspect transuranic-contaminated solid waste sites. Before decisions could be made on final disposition of these wastes, alternatives would be analyzed in subsequent environmental documentation, including a supplement to the EIS. These decisions were documented in a corresponding ROD (53 FR 12449) and implementation plan (DOE 1988). The EIS and associated ROD included one exception to the preferred alternative, the 618-11 Burial Ground. A decision was made to proceed with removal and processing of waste from the 618-11 Burial Ground based on 1) its location outside of the 200 Area plateau, 2) concerns over potential flooding, and 3) a DOE desire to consolidate the pre-1970 buried transuranic-contaminated waste at the 200 Area plateau for a reasonable cost.

In 1992, the U.S Environmental Protection Agency (EPA) and Washington State Department of Ecology (Ecology) directed that an engineering evaluation/cost analysis be performed to consider expedited response action (ERA) alternatives for the 618-11 Burial Ground. The evaluation analyzed options that included no action, increased monitoring, removal and monitored storage, and a demonstration/feasibility study. The proximity of buried waste to the water table and the potential for migration of contaminants were a concern based on the limited information about the waste inventory.

Increased monitoring was the selected option, as documented in the ERA proposal (DOE 1993). A removal action was eliminated as an immediate need based on the absence of data to identify a threat to human health and the environment and the lack of operating facilities to receive, process, and/or dispose of excavated high-activity transuranic material. To support the ERA recommendation, a new well (699-13-3A) was installed in 1995 to monitor groundwater adjacent to the burial ground. Groundwater samples from this well were analyzed for radioactive and hazardous chemical constituents of concern on an annual basis.

Tritium was not identified as a constituent of concern for the burial ground, so it was not included in the analyte list until January 1999. No follow-on action was taken regarding the 1,860,000 pCi/L result from the January sampling (reported in May 1999) until January of 2000. The high tritium value from the January 1999 and January 2000 samples triggered an off-normal event report (RL-PNNL-PNNLBOPER-2000-0003) that was submitted on February 3, 2000. Following this event, a preliminary investigation was conducted of elevated tritium in groundwater near the 618-11 Burial Ground (Dresel et al. 2000). This Phase 1 investigation consisted of sampling existing monitoring wells in the vicinity of the 618-11 Burial Ground and analyzing the samples for a variety of radionuclides and other potential contaminants of concern.

During the Phase 1 investigation, existing monitoring wells near the 618-11 Burial Ground were sampled. This sampling event included wells upgradient and downgradient from the burial ground and Energy Northwest water supply and monitoring wells. The samples were analyzed for a variety of radionuclides and chemicals, including water quality parameters and potential contaminants. Sampling was conducted in February 2000.

The Phase I investigation confirmed the elevated tritium levels in a single well downgradient from the burial ground. Other wells contained tritium at low levels similar to the plume emanating from the 200 East Area. The well with the elevated tritium contained no other contaminants at levels that could be clearly tied to a source in the burial ground. Constituents detected at elevated levels in the sampling area include nitrate, uranium, technetium-99, and carbon tetrachloride. Levels of technetium-99 and carbon tetrachloride were below drinking water standards. The nitrate and uranium did not appear to be related to the 618-11 Burial Ground,

based on the distributions and chemical correlations. Not enough information was available to define the source of technetium-99, but it is a known contaminant within the plume from the 200 East Area.

The distribution of tritium pointed strongly to a probable source within the 618-11 Burial Ground. Other sources considered included the tritium plume from the 200 East Area and Energy Northwest operations. However, the tritium levels were too high to be explained by either of these sources. The distribution was inconsistent with the 200 East Area plume. The highest tritium concentration was upgradient from the Energy Northwest WNP-2 reactor, so known discharges from Energy Northwest were unlikely to be the source. The Phase 1 investigation did not define the extent of the elevated tritium levels in groundwater, but available data suggested the plume was relatively narrow. Data on the vertical extent of contamination were sparse, but no tritium was detected in the confined aquifer samples.

To obtain additional information on the extent of tritium contamination, a second investigation was conducted in 2001. Six boreholes were drilled, four of which were completed as monitoring wells. To aid in the delineation of the tritium plume, helium-3/helium-4 ratios were measured in soil gas samples collected near the burial ground and along downgradient transects oriented both longitudinally and transverse to the direction of groundwater flow. Results from this investigation indicated that the source of the tritium was the 618-11 Burial Ground, as evidenced by the high helium-3/helium-4 ratio soil gas results in the vadose zone, high tritium in groundwater grab samples, and low tritium values from upgradient wells. In addition, the soil gas and groundwater concentration data indicated that the plume was relatively narrow, with the highest tritium concentrations showing a limited downgradient extent (Figure 2.3).

In addition to the downgradient and lateral extent of the plume, this investigation conducted depth discrete sampling during the installation of one borehole to provide some measure of the vertical extent of tritium contamination. At this location (Borehole C3254, completed as monitoring well 699-13-2D), stratification of the tritium concentration profile was observed. At the water table within the Hanford formation and across the Hanford/Ringold contact and upper few feet of the Ringold formation, tritium concentrations ranged from 630,000 to 690,000 pCi/L. Samples collected deeper in the Ringold Formation (18 to 37 ft below the water table) essentially doubled to 1.3 million pCi/L, while the last sample, collected 42 ft below the water table and just above the Ringold Mud Unit, measured 503,000 pCi/L. Although a limited amount of depth extent data were collected, they provide some indication of the degree of stratification within the aquifer. The observed stratification may be an artifact of pumping in wells 699-13-1A and 699-13-1B during the 1970s. These wells were installed in 1972 and used for water production during construction of the Energy Northwest power plants.

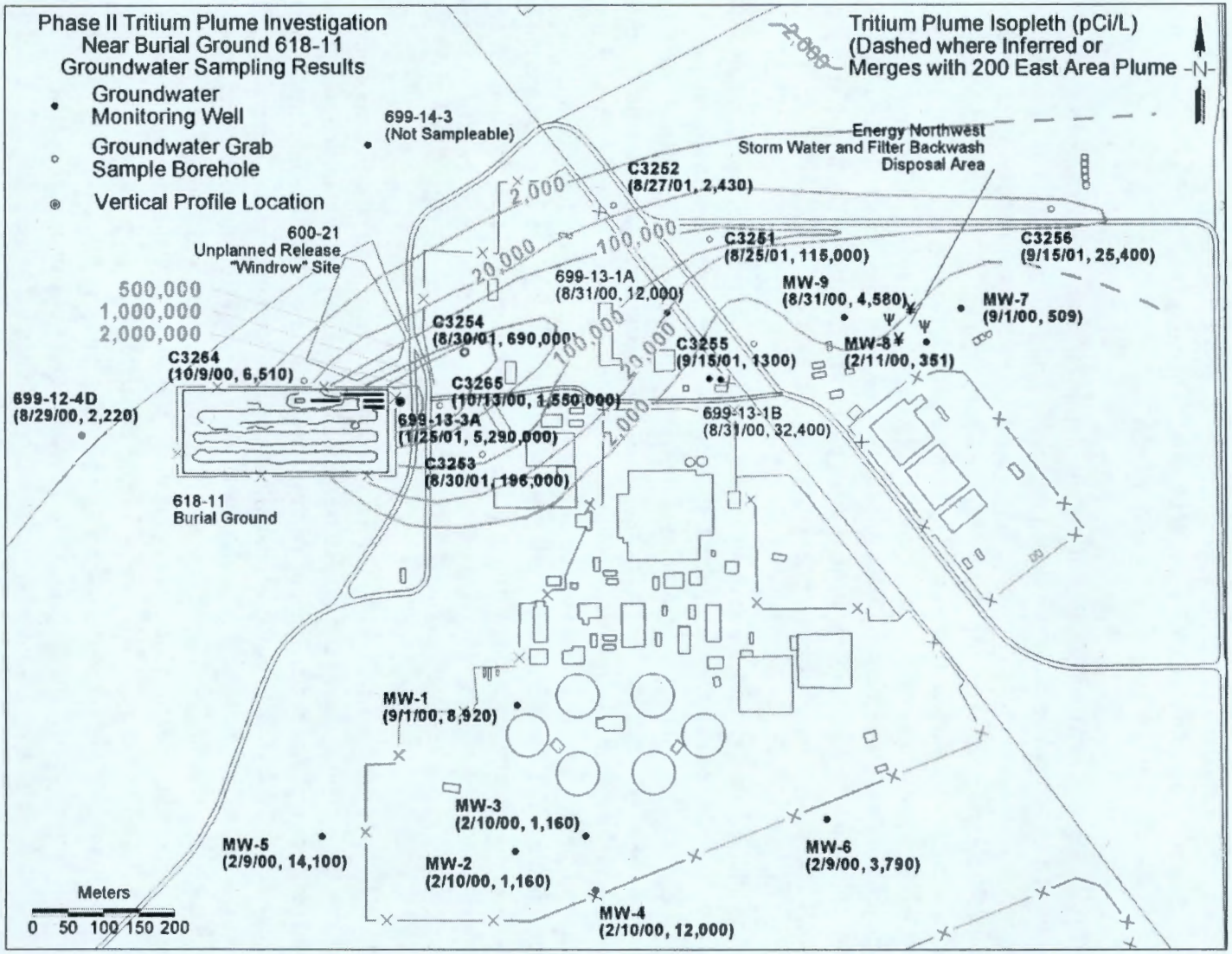

Figure 2.3. Tritium Plume Resulting from 618-11 Burial Ground[a]

(a) Borghese JV, WJ McMahon, and RW Ovink. September 2001. "Tritium Groundwater Investigation at the 618-11 Burial Ground." Letter report, CH2M HILL, to U.S. Department of Energy, Richland, Washington.

2.4 Preliminary Evaluation of Tritium Plume Fate and Transport

Data from the investigations discussed in Section 2.3 were used to develop a conceptual model for the tritium contamination downgradient of the 618-11 Burial Ground and formed the basis of a preliminary evaluation of the potential impact of the 618-11 tritium plume on the Columbia River.[(a)] Three separate approaches were presented for estimating the amount of time required for the plume to migrate to the river, the concentration at the river, and the flux of tritium expected when the plume discharges to the river. These approaches included estimates base on 1) the conceptual model of plume migration over the available period of record, 2) average hydraulic properties, and 3) an evaluation using a simplified implementation of the Hanford Site wide groundwater model. Results from these analyses provided estimates of travel time to the river that ranged from 43 to 166 year, with a maximum concentration at the river of from 730,000 to 700 pCi/L, respectively. Although this preliminary evaluation resulted in a relatively wide range in estimated values, the authors indicated that the future impact at the river for the 618-11 tritium plume was expected to be minimal. However, it should be noted that this evaluation was based on simplified analytical and numerical approaches that limit the amount of confidence that could be placed in the results.

(a) Dresel PE and MP Bergeron. 2001. "Evaluation of the Impact of Tritium Contamination in Groundwater from the 618-11 Burial Ground at the Hanford Site." Letter report, Pacific Northwest National Laboratory, Richland, Washington.

3.0 Current Status of Contaminants of Concern

This section presents an interpretation of the monitoring results that have become available since the original ROD for the 300 FF 5 Operable Unit (EPA 1996) and its subsequent update to include the 618-11 Burial Ground (EPA 2000). Of particular interest are the most recent data and their relationship to those collected during the 618-11 field investigations discussed in Section 2.3. These groundwater data have been collected to meet the ROD requirement of continued monitoring during a period of interim remedial action (i.e., before selecting a final remedy) to ensure that concentrations of contaminants of concern continue to decrease.

Contaminants of concern for the 618-11 Burial Ground, as identified in the explanation of significant difference (EPA 2000), are limited to tritium. Several other constituents have exceeded the EPA drinking water standard in groundwater near the 618-11 Burial Ground or are useful indicators of contamination, and are therefore carried as contaminants of potential concern in the operable unit. Following is a brief discussion of available monitoring results, which is summarized from Peterson et al. (2005).

3.1 Tritium

The general shape of the tritium plume has remained nearly constant since the first maps were drawn in 2000 (Figures 3.1 through 3.3). Both groundwater concentration data and mapped geologic controls (i.e., the Hanford/Ringold contact) were considered when the tritium plume maps were developed.

Tritium concentrations near the 618-11 Burial Ground show a decreasing trend since the peak in 2000, but current levels (~2.3 M pCi/L) still exceed the drinking water standard (Table 3.1). The decrease in concentration close to the source cannot be entirely accounted for by radioactive decay, indicating that transport processes are affecting tritium concentrations and suggesting dispersal of a "pulse" release that was first observed in 1999~2000 (Table 3.1 and Figures 3.4 and 3.5). Relatively constant or gradually increasing trends have been seen at wells along the downgradient flow path from the burial ground, indicating a relatively slow downgradient migration of the tritium plume (Figures 3.6 through 3.8).

3.2 Gross Beta

Gross beta levels at most plume monitoring locations are below the 50-pCi/L EPA drinking water standard (Table 3.1). Elevated gross beta values have been observed at three sites near the eastern perimeter e of the burial ground: well 699-12-2C (maximum 98 pCi/L in 2002); 699-13-3A (maximum value 84 pCi/L in 2001); and borehole C3265 (maximum 271 pCi/L in 2000); because it is a weak beta emitter, tritium is an unlikely source of the observed gross beta levels.

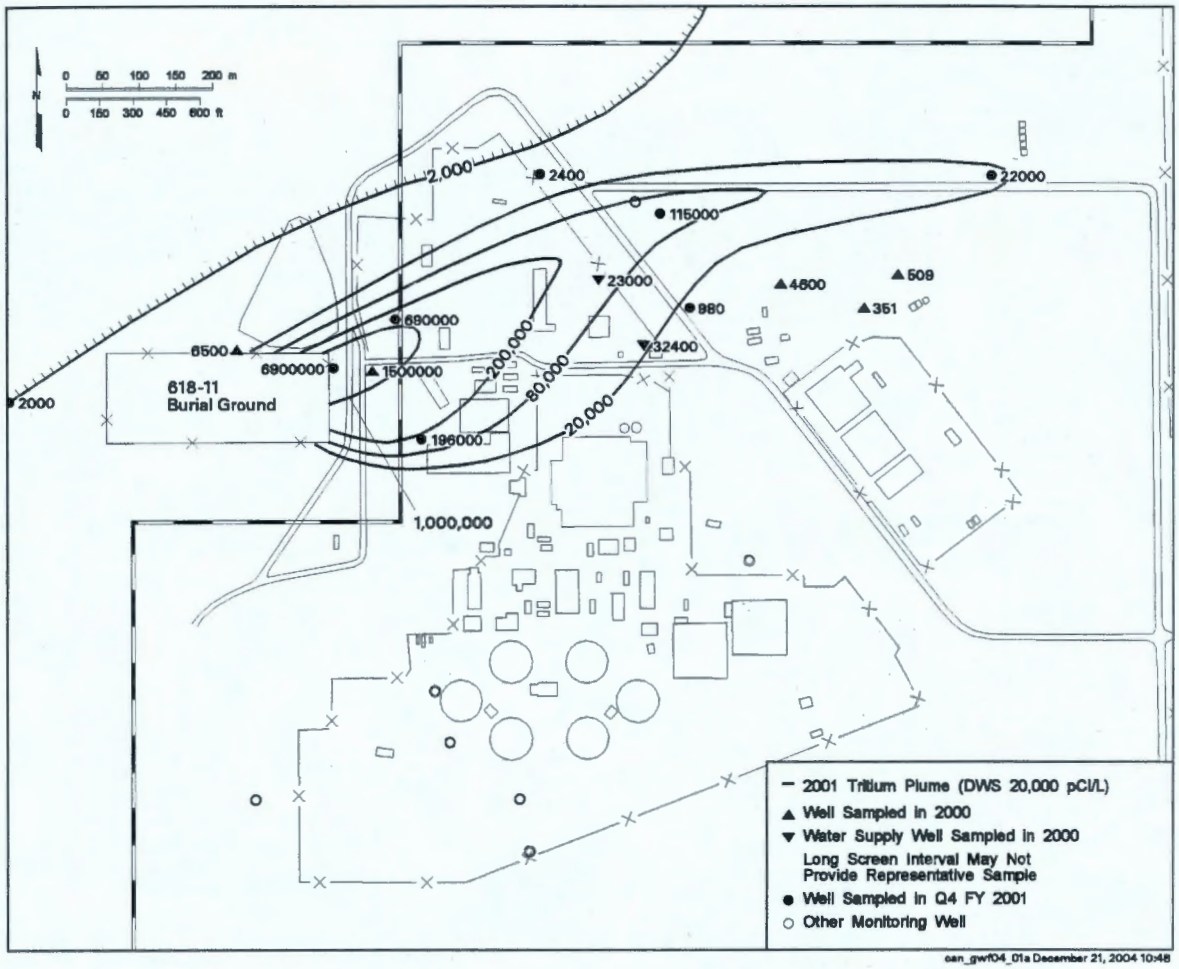

Figure 3.1. Tritium Plume Downgradient of 618-11 Burial Ground, 2001 Conditions

3.3 Uranium

Uranium concentrations in 618-11 monitoring wells are all well below the 30-ug/L EPA drinking water standard (Table 3.1) and probably reflect natural background levels in the sediment. There is no evidence to suggest releases from the burial ground.

3.4 Technetium-99

The only other known beta emitter in the 618-11 area is technetium-99. The few results available for the wells listed in Table 3.1 suggest concentrations of ~320 pCi/L, which could account for the gross beta values.

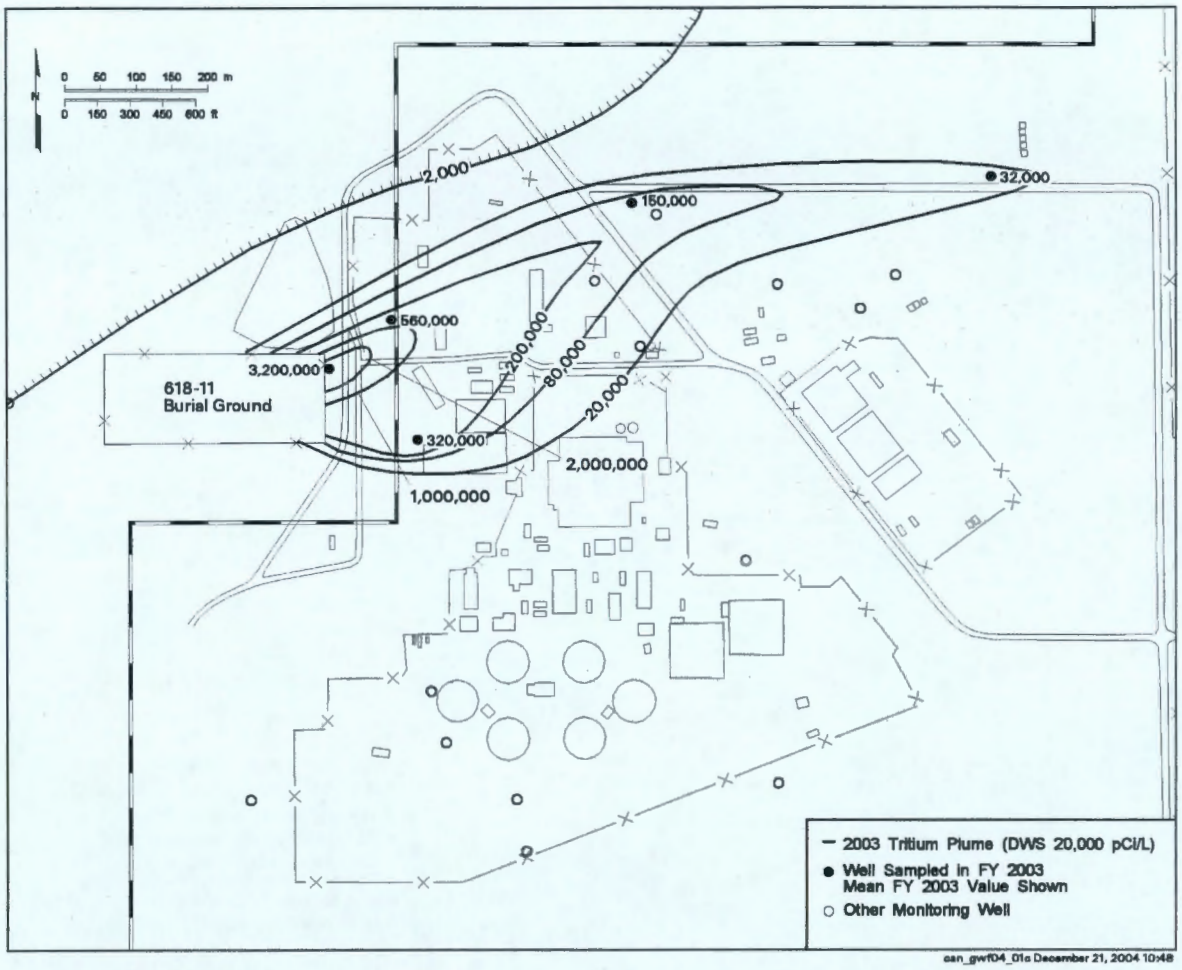

Figure 3.2. Tritium Plume Downgradient of 618-11 Burial Ground, 2003 Conditions

Technetium-99 migrates into the area via the site-wide plume but at low concentrations in recent years. For example, concentrations near the 618-10 Burial Ground, which is near the leading edge of the site-wide plume, currently fall in the range 20~40 pCi/L.

The possibility exists that the few elevated results near 618-11 (i.e., ~320 pCi/L; Table 3.1) represent small patches of higher concentrations that migrated into the area during earlier periods, perhaps during the 1970s and 80s, when gross beta data indicate the possibility of site-wide plume techneticium-99 in the range 900~1,800 pCi/L at several wells northwest of the burial ground (699-26-15A and 699-20-20). All three of the elevated results were from samples collected at locations where the lower-permeability Ringold Formation is present at the water table (i.e., Hanford formation exists only above the water table).

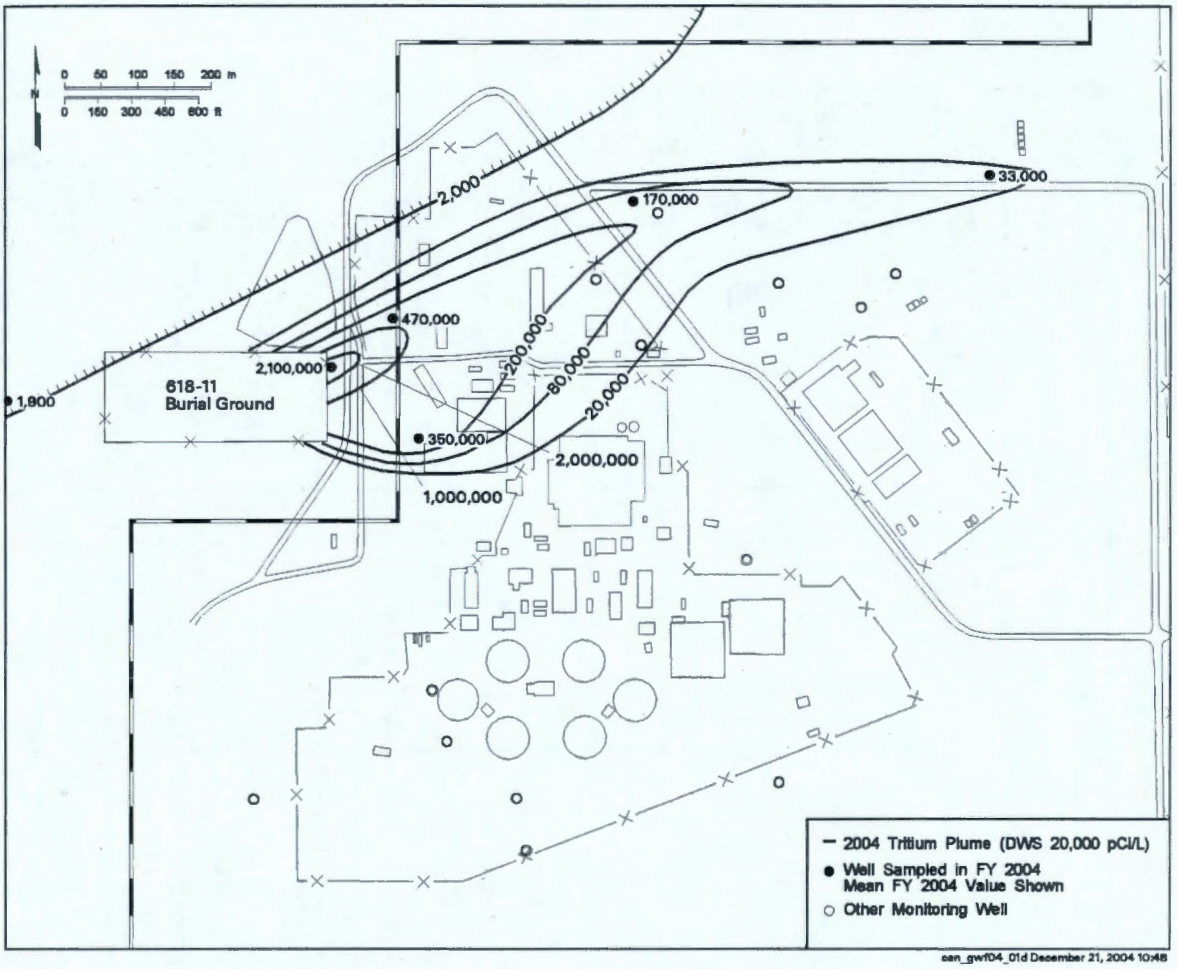

Figure 3.3. Tritium Plume Downgradient of 618-11 Burial Ground, 2004 Conditions

Table 3.1. Maximum Observed Concentrations from Wells near the 618-11 Burial Ground[a,b,c,d,e]

Well Name	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004[f]
Gross Beta (pCi/L; MCL = 50)											
699-12-2C									98	86	81
699-12-4D		9	11				9				
699-13-0A								30	12	12	11
699-13-1A		33	21				10	11			
699-13-1B		27	29				18				
699-13-1C							7	7		4	
699-13-1D								20			
699-13-1E									25	23	20
699-13-2C								33			
699-13-2D								25	41	37	31
699-13-3A		14	19	18	25	30	38	84	23	20	20
C3252								22			
C3255								26			
C3264							ND				
C3265							271				
ENW-MW-7							6				
ENW-MW-8							8				
ENW-MW-9							22				
ENW-MW-31							7				
ENW-MW-32							8				
Tritium (pCi/L; MCL = 20,000)											
699-12-2C									313,000	353,000	363,000
699-12-4D							2,220	2,010			1,870
699-13-0A								21,600	35,500	36,400	35,000
699-13-1A							23,300	16,400			
699-13-1B							32,400				
699-13-1C	770	ND					ND	25		32	
699-13-1D								116,000			
699-13-1E									123,000	184,000	168,000

Table 3.1 (contd)

Well Name	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004[f]
Tritium (contd)											
699-13-2C								196,000			
699-13-2D								1,390,000	639,000	587,000	480,000
699-13-3A						1,860,000	8,380,000	5,290,000	4,230,000	3,620,000	2,320,000
699-14-E6S		ND									
C3252								2,770			
C3255								1,040			
C3264							6,510				
C3265							1,550,000				
ENW-MW-7							509				
ENW-MW-8							351				
ENW-MW-9							4,580				
ENW-MW-31							ND				
ENW-MW-32							ND				
Uranium (µg/L; MCL = 30)											
699-12-2C									10	11	10
699-12-4D		6	5				6				
699-13-0A									6	6	6
699-13-1A		6	5				4				
699-13-1B		8	10				10				
699-13-1E									8	9	9
699-13-2D									11	11	11
699-13-3A		8	10	9	9	12	11	11	10	10	9
ENW-MW-7							2				
ENW-MW-9							31				

Table 3.1 (contd)

Well Name	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004[f]
Gross Alpha (pCi/L; MCL = 15)													
699-12-2C											6	8	9
699-12-4D				4	4				3				
699-13-0A										ND	7	6	3
699-13-1A				5	4				4	3			
699-13-1B				6	5				6				
699-13-1C									ND	ND		ND	
699-13-1D										ND			
699-13-1E											6	5	6
699-13-2C										ND			
699-13-2D										4	7	8	6
699-13-3A				5	8	5	8	5	9	2	5	8	15
C3252										10			
C3255										ND			
C3264									ND				
C3265									ND				
ENW-MW-7									ND				
ENW-MW-8									6				
ENW-MW-9									23				
ENW-MW-31									ND				
ENW-MW-32									2				
Nitrate (µg/L; MCL = 45)													
699-12-2C											88	134	80
699-12-4D				26	25				28	30			28
699-13-0A											17	20	18
699-13-1A				48	24				7	5			
699-13-1B				43	61				41				
699-13-1C	1		0	ND					0	ND		0	
699-13-1E											43	53	60
699-13-2D											54	66	271
699-13-3A				36	39				103		78	100	101

Table 3.1 (contd)

Well Name	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004[f]
Nitrate (contd)													
C3264									35				
C3265									48				
ENW-MW-7									4				
ENW-MW-8									2				
ENW-MW-9									149				
ENW-MW-31									0				
ENW-MW-32									0				
Technetium-99 (µg/L; MCL = 900)													
699-12-2C												319	
699-12-4D									ND				
699-13-0A										ND			
699-13-1A									30				
699-13-1B									28				
699-13-1C									ND				
699-13-1D										ND			
699-13-2C										9			
699-13-2D										10			
699-13-3A									124			12	26
C3252										ND			
C3255										ND			
C3264									ND				
C3265									332				
ENW-MW-7									ND				
ENW-MW-8									ND				
ENW-MW-9									ND				
ENW-MW-31									ND				
ENW-MW-32									ND				

(a) Maximum values for constituents at 618-11 Burial Ground wells.
(b) Monitored units were at the top of the unconfined aquifer.
(c) Blanks indicate no results.
(d) Values in blue are below EPA drinking water standard.
(e) ND indicates not detected.
(f) Partial year results for 2004.

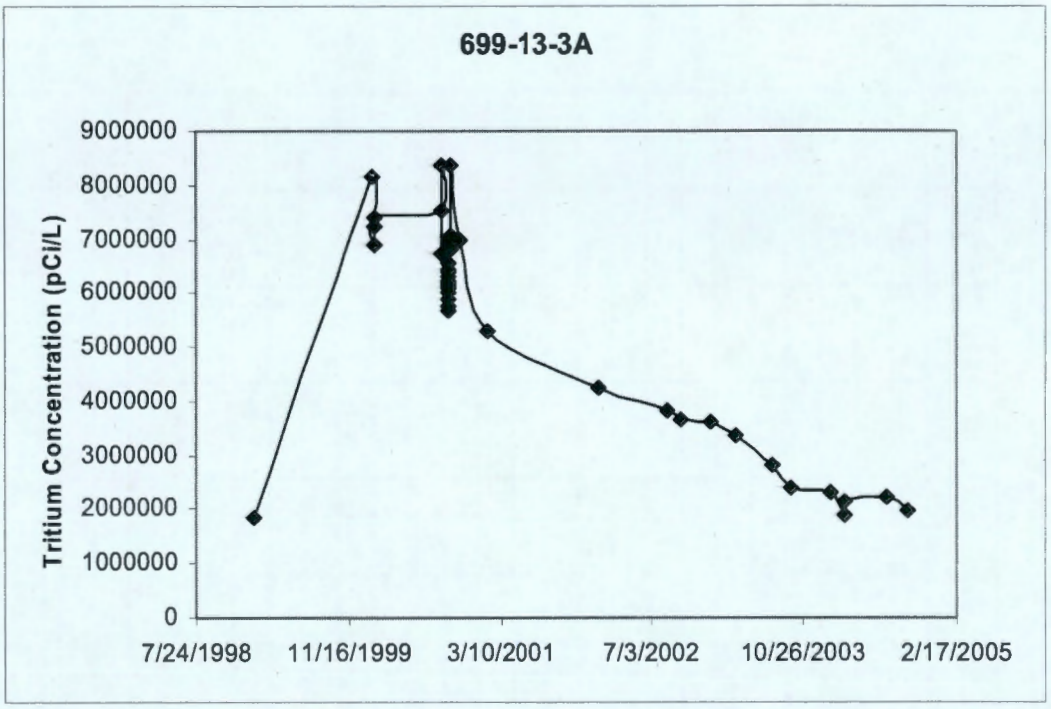

Figure 3.4. Tritium Concentration Trend Plot for Monitoring Well 699-13-3A

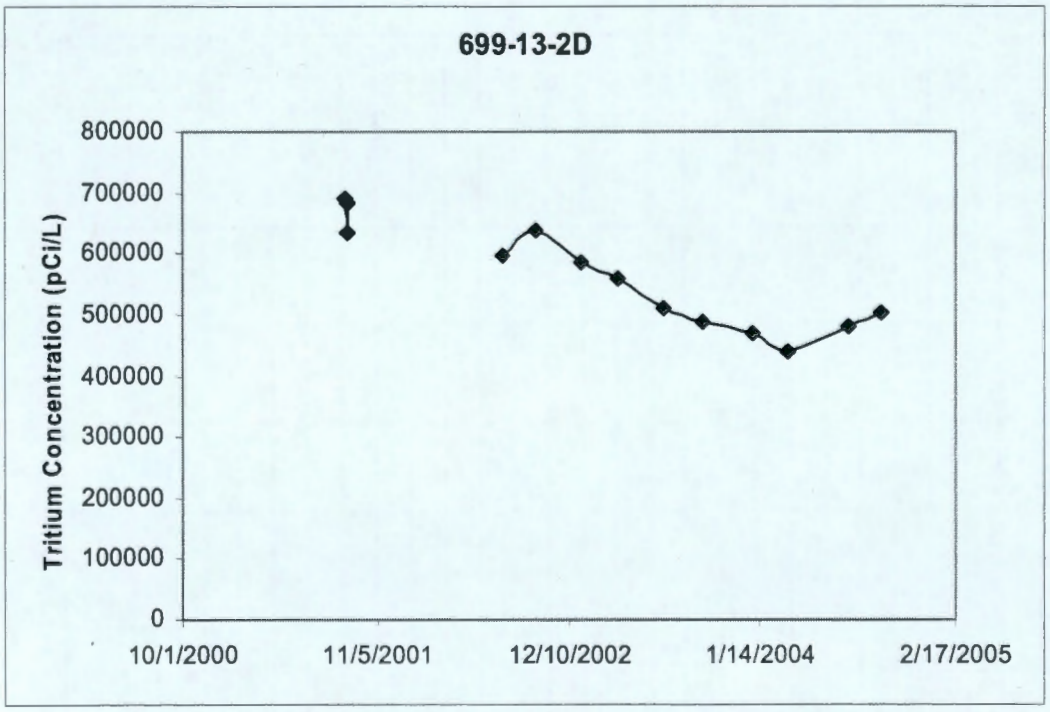

Figure 3.5. Tritium Concentration Trend Plot for Monitoring Well 699-13-2D

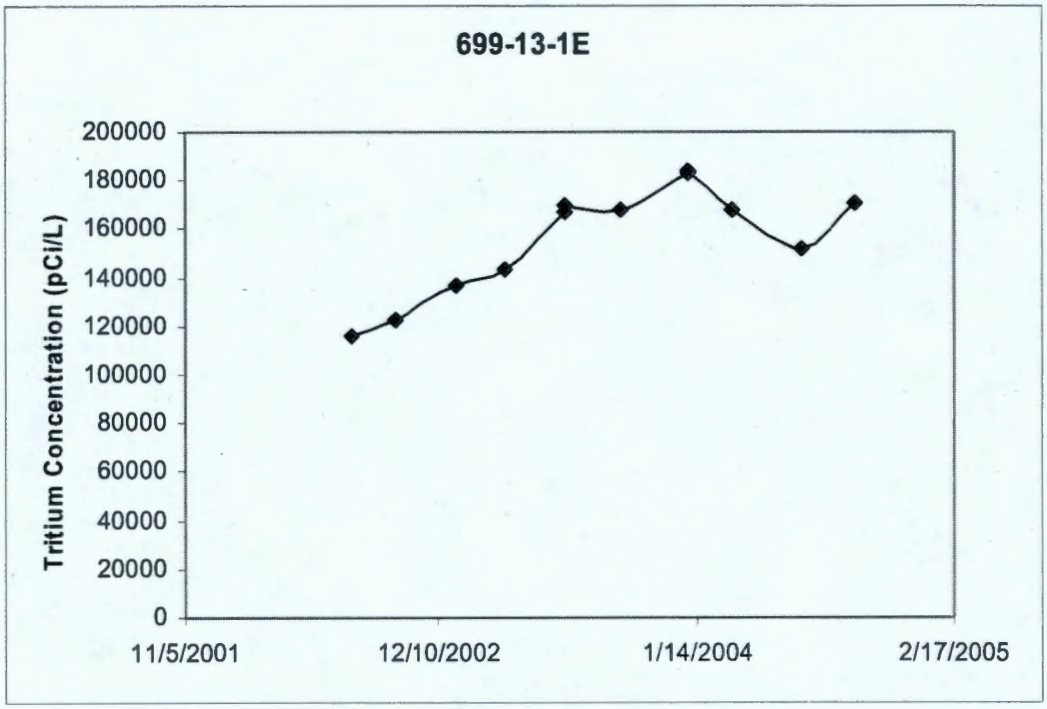

Figure 3.6. Tritium Concentration Trend Plot for Monitoring Well 699-13-1E

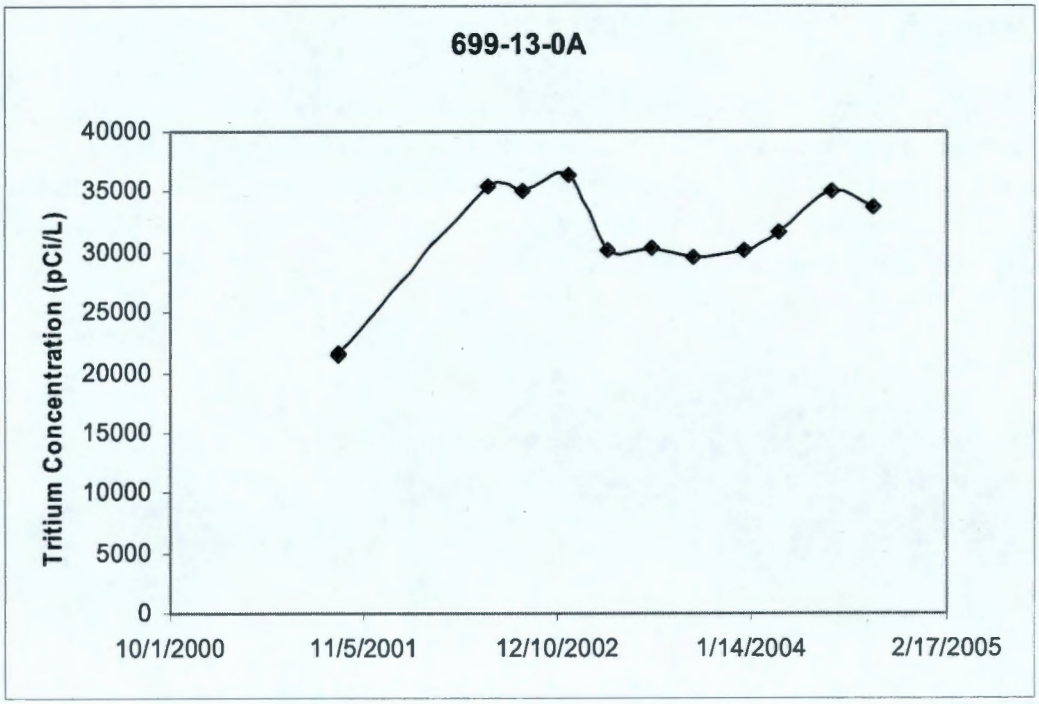

Figure 3.7. Tritium Concentration Trend Plot for Monitoring Well 699-13-0A

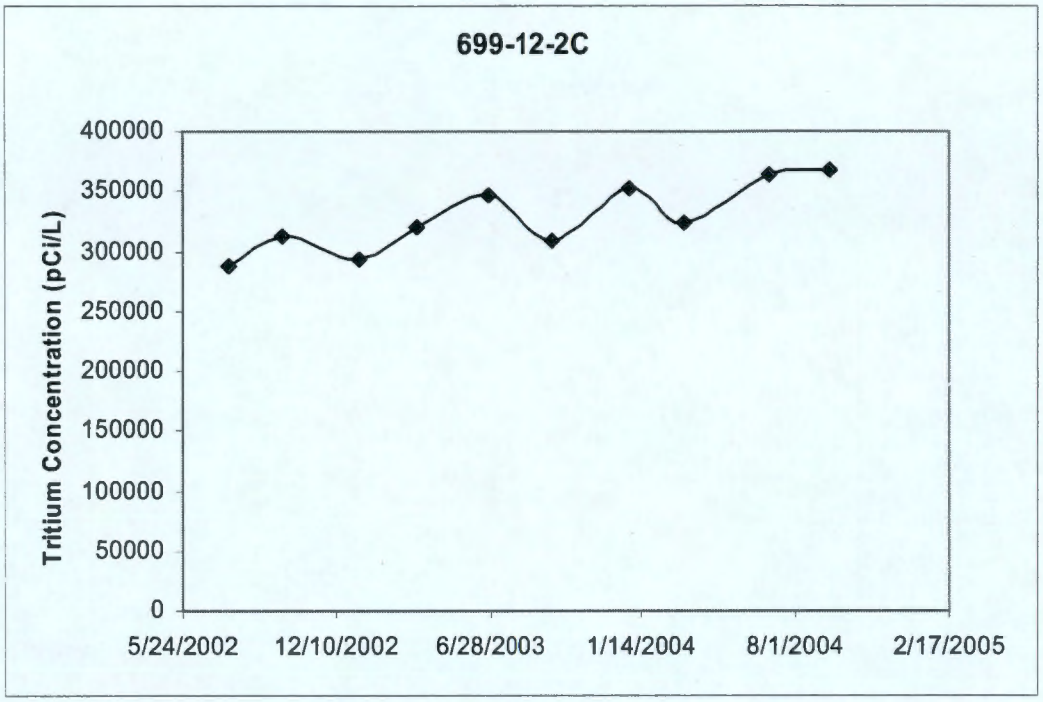

Figure 3.8. Tritium Concentration Trend Plot for Monitoring Well 699-13-0A

3.5 Gross Alpha

Gross alpha concentrations, which typically reflect uranium, fall below the 15 pCi/L EPA drinking water standard at 618-11 monitoring wells (Table 3.1) with one possible exception: a recent sample from 699-13-3A, adjacent to the east fence of the burial ground, yielded a result of 15.4 pCi/L during 2004. This value is somewhat higher than the well-established historical trend for the well and may be an outlier.

3.6 Nitrate

Nitrate exceeds the 45 mg/L EPA drinking water standard at several wells in the 618-11 monitoring network (Table 3.1). The source of nitrate is unknown, but it is possibly related to the site-wide plume.

3.7 Regulatory Status

The regulatory status of the 618-11 subregion of the 300-FF-5 Operable Unit is described in the explanation of significant difference (EPA 2000) to the initial record of decision (EPA 1996) for the operable unit. The interim action remedy selected under these decision documents

involves continued monitoring and institutional controls. Interim action is likely to continue until source cleanup actions have been completed.

During interim action, monitoring and characterization activities are performed, following the operations and maintenance plan for the operable unit (DOE 2002). That plan identifies three monitoring objectives, and the following paragraphs describe how well those objectives are being met. The contaminant of concern, as identified in the explanation of significant difference to the record of decision (EPA 2000), is tritium. Other Hanford Site contamination indicators are detected but are associated with site-wide contaminant plumes and are typically at concentrations below drinking water standards. These site-wide constituents include gross alpha and beta, technetium-99, uranium, and nitrate.

- *Objective: Verify that natural attenuation reduces groundwater contamination concentrations to drinking water maximum contaminant levels over a reasonable time.*

  Summary Statement:

  - Tritium concentrations near the 618-11 Burial Ground show a decreasing trend since peak values occurred during 2000. Current levels (~2 M pCi/L) still greatly exceed the drinking water standard.
  - The decrease in concentration close to the source cannot be entirely accounted for by radioactive decay, indicating that transport processes are impacting tritium concentrations and suggesting dispersal of a "pulse" release that was first identified in 1999~2000.
  - Relatively constant or gradually increasing trends are observed at wells along the downgradient flow path from the burial ground, indicating a relatively slow downgradient migration of the tritium plume
  - The general shape of the tritium plume has remained nearly constant since the first maps were drawn in 2000.
  - Tritium has a half-life of 12 years.

- *Objective: Confirm that contaminant concentrations in the river seeps do not exceed ambient water quality criteria or established remediation goals (drinking water standards).*

  - The tritium plume associated with the burial ground has not reached the Columbia River, based on initial groundwater travel time estimates.

- Previous screening-level analysis of tritium fate and transport[a] was not conclusive in determining whether tritium concentrations from the 618-11 plume would reach the river at levels of concern.
- Updated modeling results indicate that tritium will not reach the river at concentrations above the drinking water standard.

- *Objective: Validate contaminant fate and transport conceptual models.*
  - Previous fate and transport analysis was not sufficiently detailed to provide a good basis for comparison to temporal plume data.
  - The updated groundwater model was compared to the available temporal plume data and was a good match. Based on this favorable comparison, the model was used to predict future tritium fate and transport.

(a) Dresel PE and MP Bergeron. 2001. "Evaluation of the Impact of Tritium Contamination in Groundwater from the 618-11 Burial Ground at the Hanford Site." Letter report to DOE, Pacific Northwest National Laboratory, Richland, Washington.

4.0 Description of the Groundwater Flow and Contaminant Transport Model

4.1 Hydrogeologic Conceptual Model

The three-dimensional representation of major hydrogeologic units in the vicinity of the 618-11 Burial Ground was based on information from borehole logs and knowledge of the depositional environment at the site. The hydrogeologic interpretation was also influenced by information on the movement of tritium from the burial ground. Hydrogeologic units were delineated to reflect differences in hydraulic properties of sediments such as effective porosity and hydraulic conductivity. These properties are related to sediment texture, which is a function of grain-size distribution, sorting, and consolidation/cementation. In developing the model, an effort was made to identify major textural units that influence groundwater flow directions and contaminant transport.

4.1.1 Sedimentary Geologic Units

Major sedimentary units (see Figure 2.2) that overlie basalt in the vicinity of the 618-11 Burial Ground are, in ascending order, the Ringold Formation, the coarse-grained facies of the Cold Creek unit, and the Hanford formation (informal name). These are described below.

4.1.1.1 Ringold Formation

After the last major eruption of basalt, the fluvial-lacustrine Ringold Formation was deposited in generally east-west trending valleys by the ancestral Columbia River and its tributaries. Fluvial deposits of the Ringold Formation include gravel and associated sand and silt deposited by the migrating river system, and the overbank sand, silt, and clay deposits that resulted from flooding beyond the influence of the main river channels. The fluvial units are separated by relatively thick layers of laminated mud with minor sand that were deposited periodically when the river channels were blocked causing lakes to develop.

The alternating fluvial and lacustrian deposits within the Ringold Formation form distinct hydrogeologic units that have been identified in boreholes and correlated over distances of several kilometers. Identification of these hydrogeologic units was based on the facies associations defined by Lindsey (1995). These facies associations reflect differences in geologic characteristics and depositional environment that affect groundwater flow properties. Based on the distribution of dominant facies, three informal members of the Ringold Formation were defined by Lindsey (1995).

Ringold sediments on the Hanford Site are dominated by the lowermost "member of Wooded Island." This member is divided into fluvial gravel-dominated units designated, in ascending order, as A, B, C, D, and E by Lindsey (1995). The gravel and sand units are vertically separated by mud-dominated overbank and lacustrian deposits, including the extensive unit referred to as the Ringold lower mud that stratigraphically lies above gravel unit A.

The "member of Taylor Flat" lies stratigraphically above the unit E gravel and is dominated by fluvial sands and overbank fines. This member, referred to as the upper Ringold unit, has been removed from most of the central and southern portions of the Hanford Site by post-Ringold erosion. The upper Ringold unit is not present at the burial ground but is found between the burial ground and the Columbia River.

4.1.1.2 Cold Creek Unit

The coarse-grained facies of the Cold Creek unit consists of rounded clast-supported pebble- to cobble-sized gravel. It is generally coarser and less consolidated than the Ringold Formation and has a lower percentage of basalt clasts than the Hanford formation. It generally displays hydraulic conductivity that is greater than the underlying Ringold gravels but less than the over-lying Hanford formation. The coarse-grained facies of the Cold Creek unit represents main-stream alluvial deposits of the ancestral Columbia-Clearwater-Salmon River system (DOE 2002). Deposition occurred after a period of down-cutting into the Ringold Formation and may define the former course of the Columbia River southeastward through Gable Gap. The facies is narrow through Gable Gap and widens across the east-central portion of the Hanford Site, just north of the 618-11 Burial Ground. In some areas, some or all of the Cold Creek unit was removed during the Ice Age flooding that deposited the Hanford formation.

4.1.1.3 Hanford Formation

The informally named Hanford formation sediments are generally coarser and less consoli-dated than those of the Ringold Formation. The Hanford formation was deposited by a series of cataclysmic floods that inundated the Pasco Basin during the last ice age, beginning as early as 2.5 million years ago (DOE 2002). The last major flood sequence is dated about 13,000 years ago by the presence of Mount St. Helens "S" tephra interbedded with the flood deposits. The number and timing of cataclysmic floods continues to be debated but may be as high as 100 (DOE 2002). The largest and most frequent floods came from glacial Lake Missoula in north-western Montana. Cataclysmic floodwaters entering the Pasco Basin quickly became impounded behind Wallula Gap, which was too restrictive for the volume of water involved. Floodwaters formed temporary lakes, which lasted only a few weeks or less.

The floods caused massive erosion of both earlier sediments and the basalt bedrock (DOE 2002). They also resulted in rapid deposition of flood-borne sediments (Hanford formation) in

low-lying areas. Cobbles, gravels and coarse sand were deposited in the main flood channels with finer sand and silt being deposited on the fringes. Hanford formation sediments are continuous across the model area. However, in some places the water table lies below the bottom of the Hanford formation.

Hanford formation sediments in the vicinity of the 618-11 Burial Ground predominantly belong to the gravel-dominated facies. Facies classifications and depositional environments of the Hanford formation are discussed in DOE (2002). Gravel-dominated strata consist of coarse-grained sand and up to boulder-sized, clast-supported gravel. The gravels can have an open matrix with large pore spaces and very high permeability. Lenticular sand and silt beds are intercalated throughout the facies. Gravel clasts are generally dominated by basalt (50 to 80%). The gravel-dominated facies was deposited by high-energy floodwaters in or immediately adjacent to the main channel of cataclysmic floodways (Reidel et al. 1992). Because of their coarse texture and lack of consolidation/cementation, the Hanford formation gravels are much more permeable than the Ringold sediments and tend to dominate groundwater flow where they exist below the water table.

4.1.2 Hydrogeologic Framework of the 618-11 Groundwater Model

Numbered units defined for the model generally correlate to the geological units described above and shown in Figure 2.2. The hydrogeologic conceptual model used to construct the 618-11 groundwater model is described as follows:

- Unit 1: Hanford formation
- Unit 3: Coarse-grained facies of the Cold Creek unit
- Unit 4: Upper Ringold unit overbank fines (muds)
- Unit 5: Ringold gravel units C and E combined with overlying upper Ringold unit sands (where present)
- Unit 6: Predominantly Ringold overbank deposits with variable lenses of sand and gravel
- Unit 7: Ringold gravel units B and D, which occur at different locations
- Unit 8: Lower Ringold mud
- Unit 9: Ringold unit A gravel.

The hydrogeologic framework of the Hanford Site-wide groundwater model (Cole et al. 2001b) was used for the initial configuration of major units within the 618-11 submodel. Geological information from 14 additional boreholes was compiled and used to refine the configuration of units in the vicinity of the 618-11 Burial Ground. Figure 4.1 shows the locations of

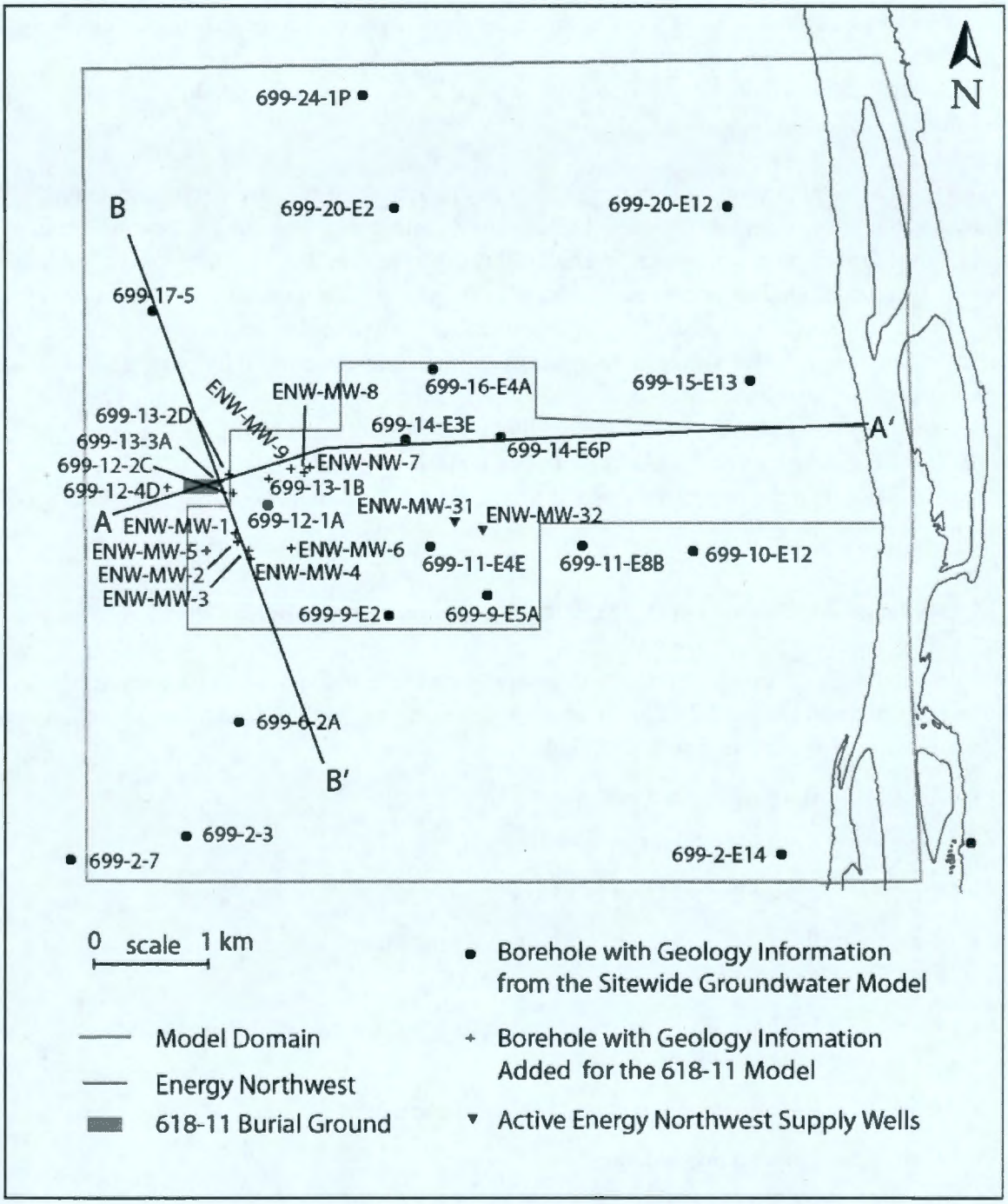

Figure 4.1. Locations of Boreholes Used to Define the Hydrogeologic Conceptual Model

boreholes with interpretations from the Site-wide conceptual model and the 14 additional boreholes. Cold Creek unit sediments were not identified in any of the additional boreholes. The Cold Creek unit is found at a borehole about 1400 m north of the burial ground. The contact between the Hanford formation and underlying Ringold gravel Unit E was identified in all 14 of

the added boreholes. These data helped define the bottom of the Hanford formation sediments near 618-11. The position of the bottom of the Hanford formation relative to the water table is important in controlling groundwater flow and contaminant transport because of its relatively high permeability. The configuration of the Ringold/Hanford contact was also influenced by information regarding movement of the tritium plume from the 618-11 Burial Ground.

Figure 4.2 shows the saturated thickness of the Hanford formation (Unit 1) based on the 2001 water table. Data points used in defining the bottom of the Hanford formation are shown. Contours of the tritium plume measured in 2001 are also shown on the figure. The saturated Hanford formation gravels north of the burial ground appear to reflect a channel formed during

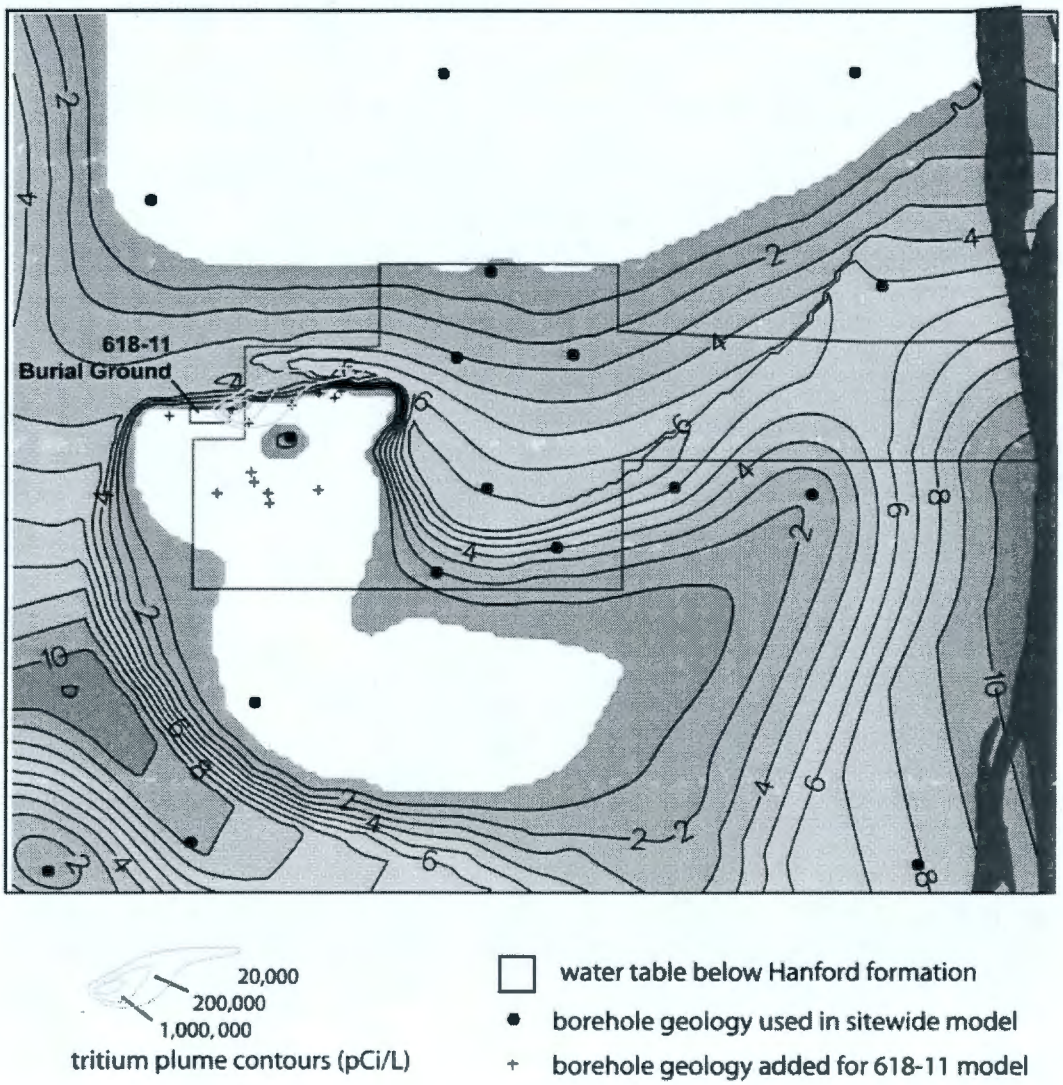

Figure 4.2. Hanford Formation (Unit 1) Saturated Thickness (m) Based on 2001 Water Table

the ice-age floods. The highest concentrations of tritium are found where the Hanford formation is above the water table (i.e., where only the Ringold Formation is saturated). When the tritium migrates northward into the area with saturated Hanford formation gravels, the plume appears to move eastward at a higher rate than observed within Ringold Formation sediments. Given the difference in hydraulic properties between these two units, this type of response would be expected. The saturated thickness of Unit 3, the coarse-grained facies of the Cold Creek unit, based on the 2001 water table is shown in Figure 4.3.

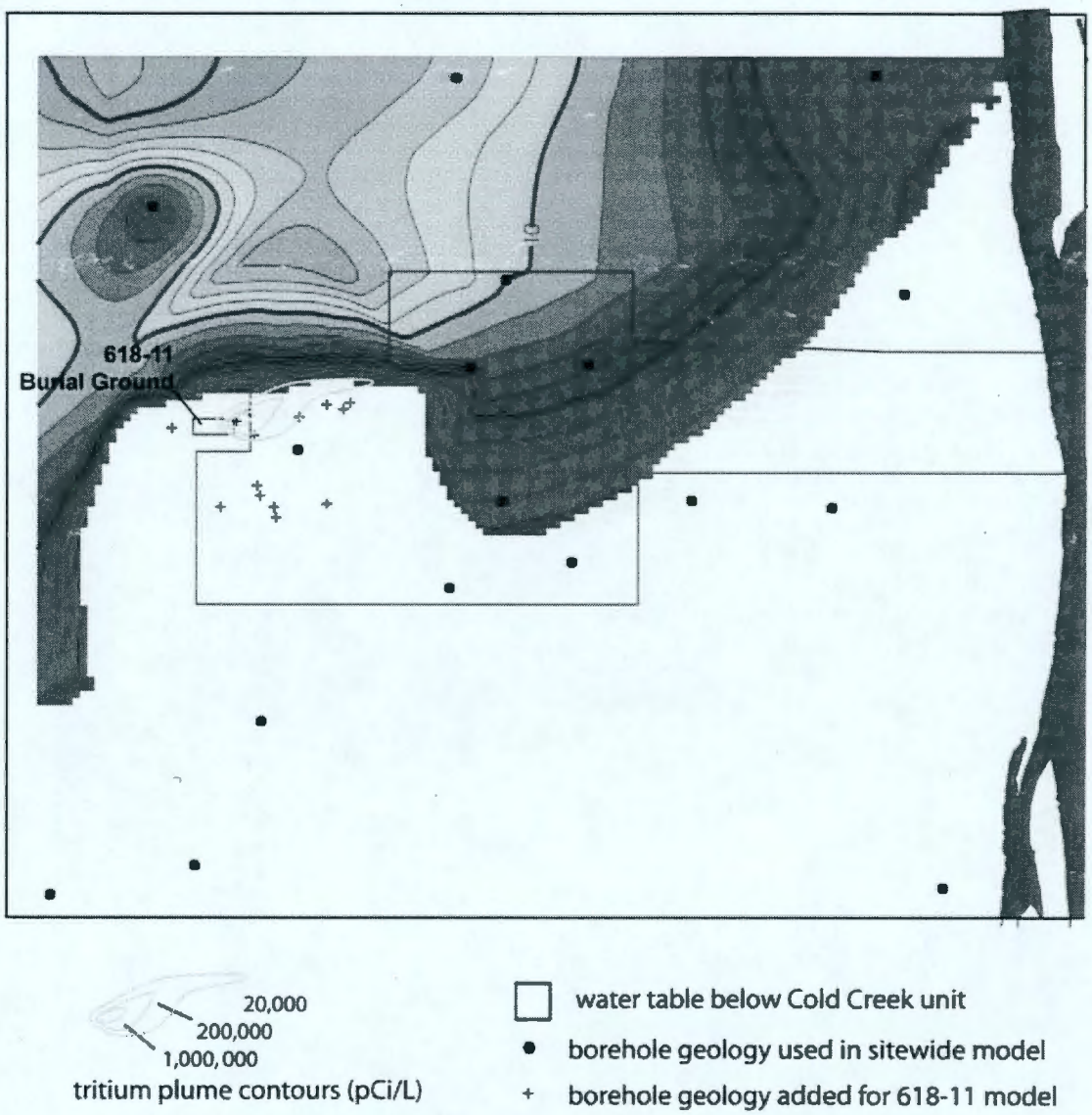

Figure 4.3. Saturated Thickness (m) of the Coarse-Grained Facies of the Cold Creek Unit (Unit 3) Based on the 2001 Water Table

Beneath the 618-11 Burial Ground, the water table is below the bottom of the Hanford formation and in the less permeable Ringold Unit E gravel. Near the burial ground, this unit is

approximately 60 m thick. However, during a field investigation in fiscal year 2001,[a] a Ringold mud unit was encountered while installing well 699-13-2D approximately 14 m below the water table. Because relatively few wells in this area are deep enough to encounter this unit, the areal extent of this feature is not well characterized. Based on geologic logs from other wells, two of which show a similar feature (699-13-1A and 699-13-1B), this mud unit is thought to be a relatively discontinuous feature (see Figures 4.4 through 4.6).

The cross sections shown in Figures 4.4 and 4.5 include the hydrogeologic units that make up the current geologic conceptual model of the site relative to the 2001 water table. Cross-section transects are shown in Figure 4.1. Figures 4.7 through 4.13 depict three-dimensional views of the upper surface of each hydrogeologic unit above the Ringold lower mud unit. Borehole data points for each hydrogeologic unit are also shown in these figures.

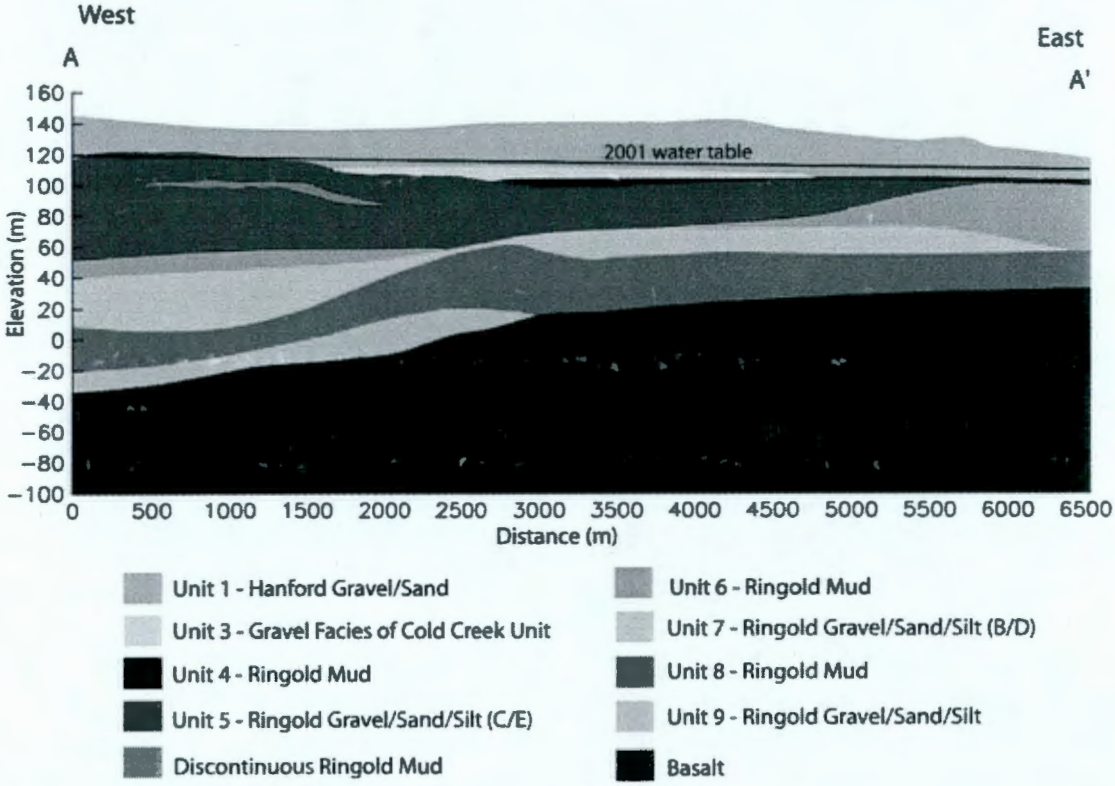

Figure 4.4. West-to-East Cross Section Through the Model Showing Hydrogeologic Units (transverse shown in Figure 4.1)

(a) Borghese JV, WJ McMahon, and RW Ovink. 2001. *Tritium Groundwater Investigation at the 618-11 Burial Ground, September 2001*. Letter report to U. S. Department of Energy from CH2M HILL, Richland, Washington.

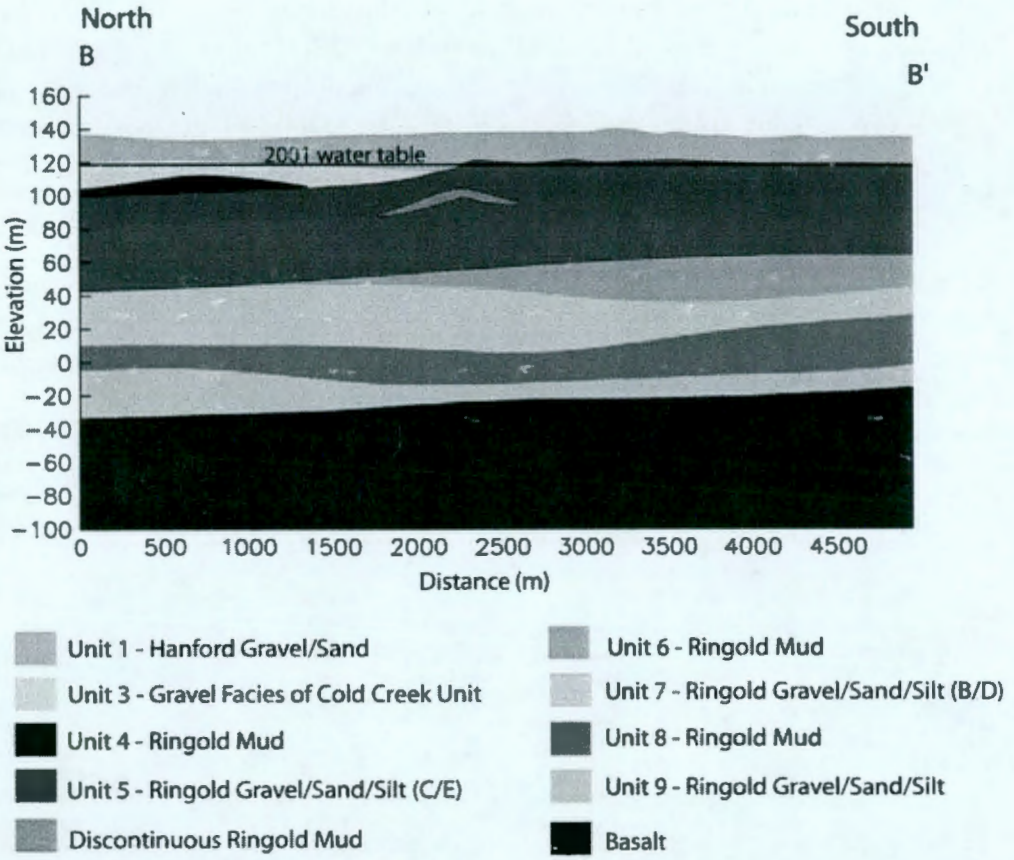

Figure 4.5. North-to-South Cross Section Through the Model Showing Hydrogeologic Units (transverse shown on Figure 4.1)

4.1.3 Hydraulic Properties of Hydrogeologic Units

Hydraulic properties, including horizontal and vertical hydraulic conductivity (Kh and Kv), storativity (S), and specific yield (Sy), are important components of the hydrogeologic conceptual model. Hydraulic conductivity controls the rate of groundwater flow through a unit thickness of aquifer at a given hydraulic gradient. Storativity and specific yield determine the change in water table elevation that occurs in response to a change in the volume of water stored in the aquifer.

Hydraulic property data for the Hanford Site unconfined aquifer have been derived mainly from aquifer pumping tests and, in a few cases, laboratory permeameter tests. These results have been documented in dozens of published and unpublished reports over the past 50 years. A summary of available data for the unconfined aquifer was provided in DOE (1988) and an updated summary Thorne and Newcomer (1992) along with an evaluation of selected pumping test analyses.

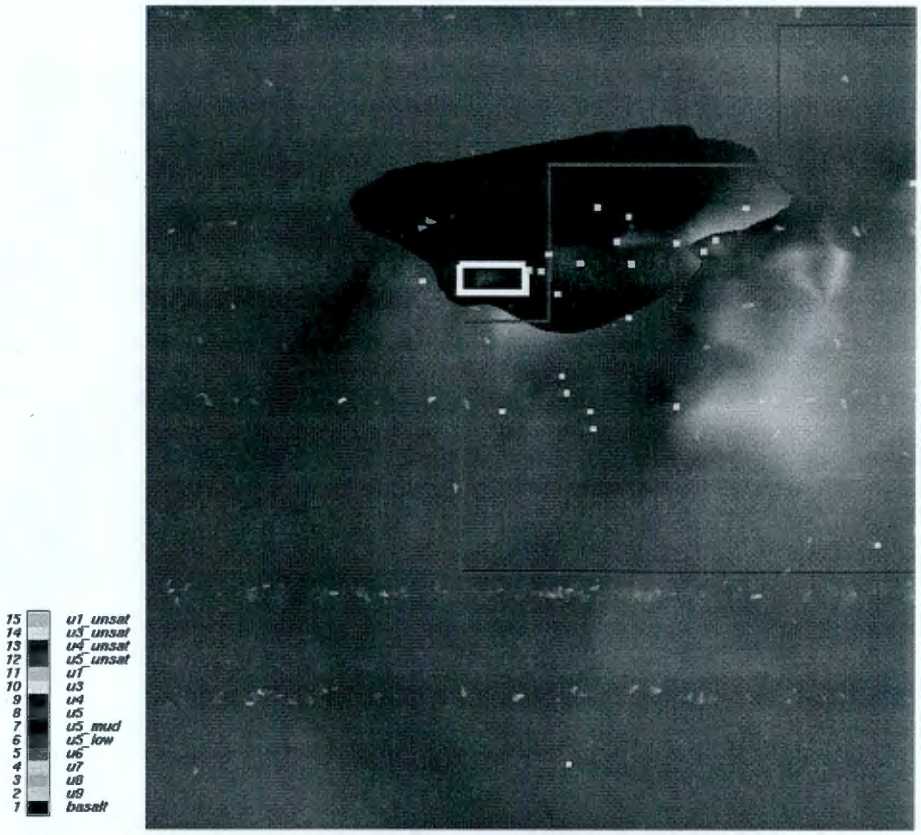

Figure 4.6. Estimated Areal Extent of the Discontinuous Ringold Mud Unit

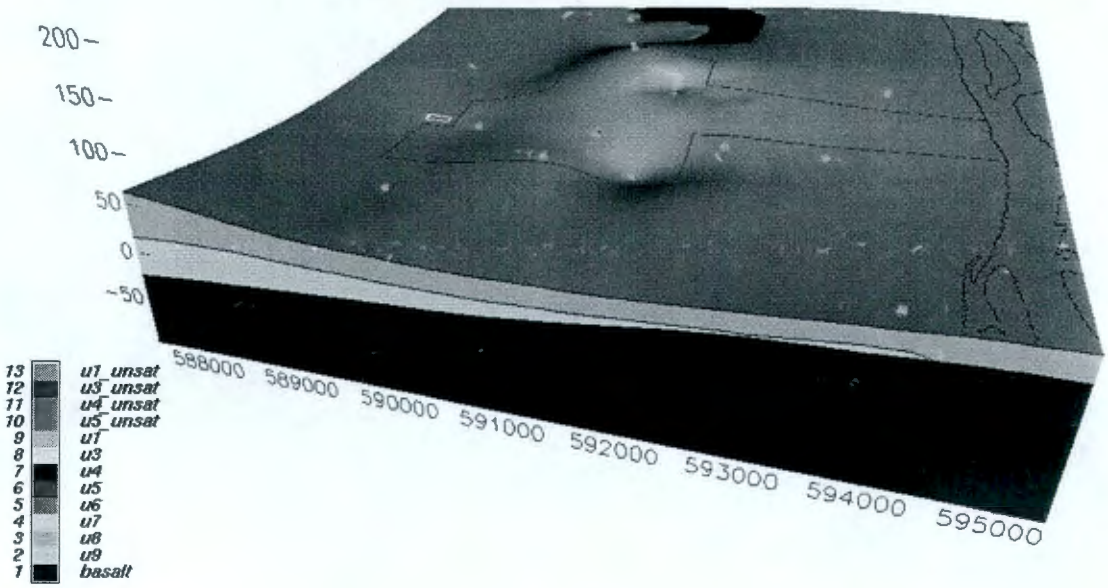

Figure 4.7. Top of Model Unit 8 (Lower Ringold Mud) Showing Borehole Data

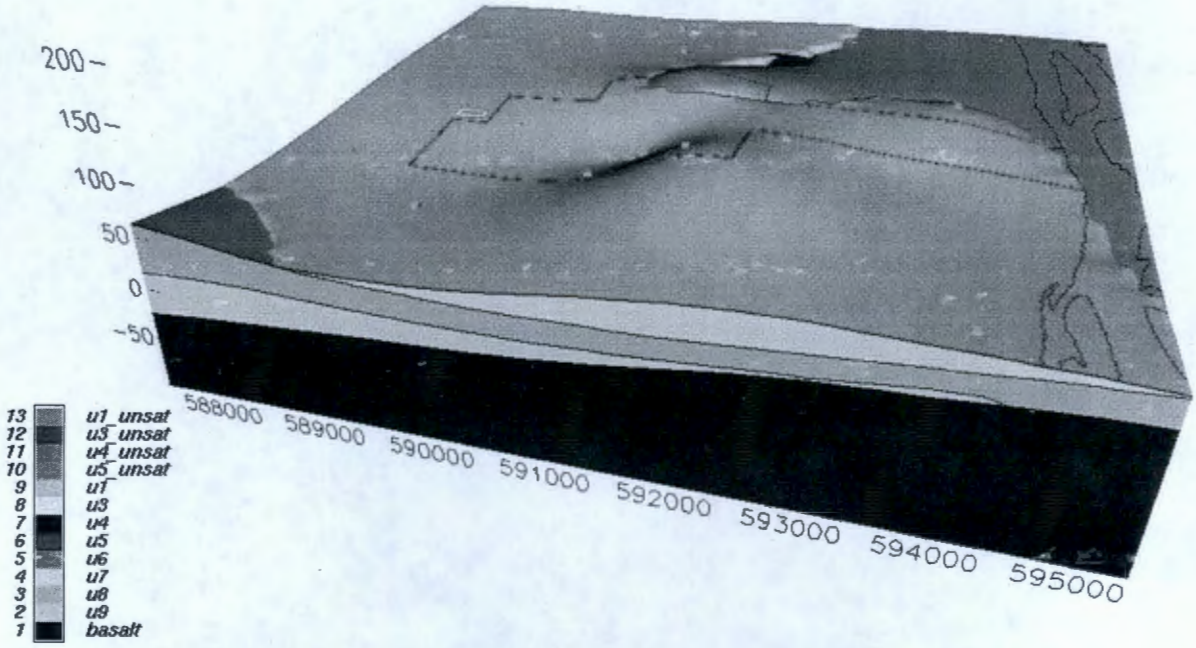

Figure 4.8. Top of Model Unit 7 (Ringold Gravel) Showing Borehole Data

Figure 4.9. Top of Model Unit 6 (Ringold Overbank Mud) Showing Borehole Data

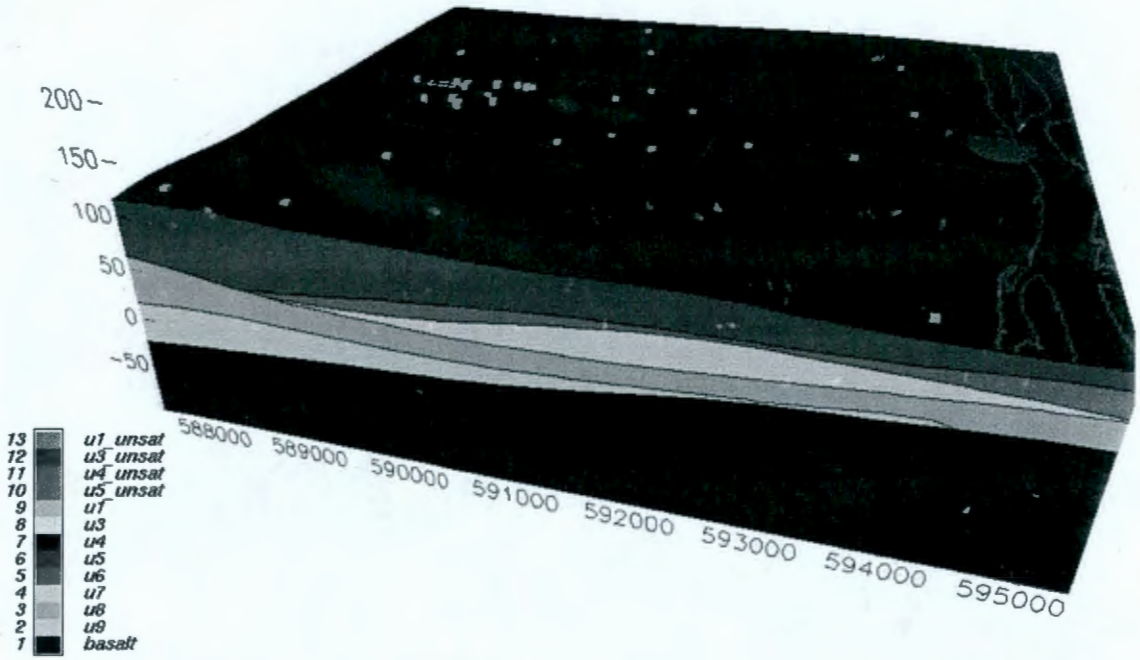

Figure 4.10. Top of Model Unit 5 (Ringold Gravel) Showing Borehole Data

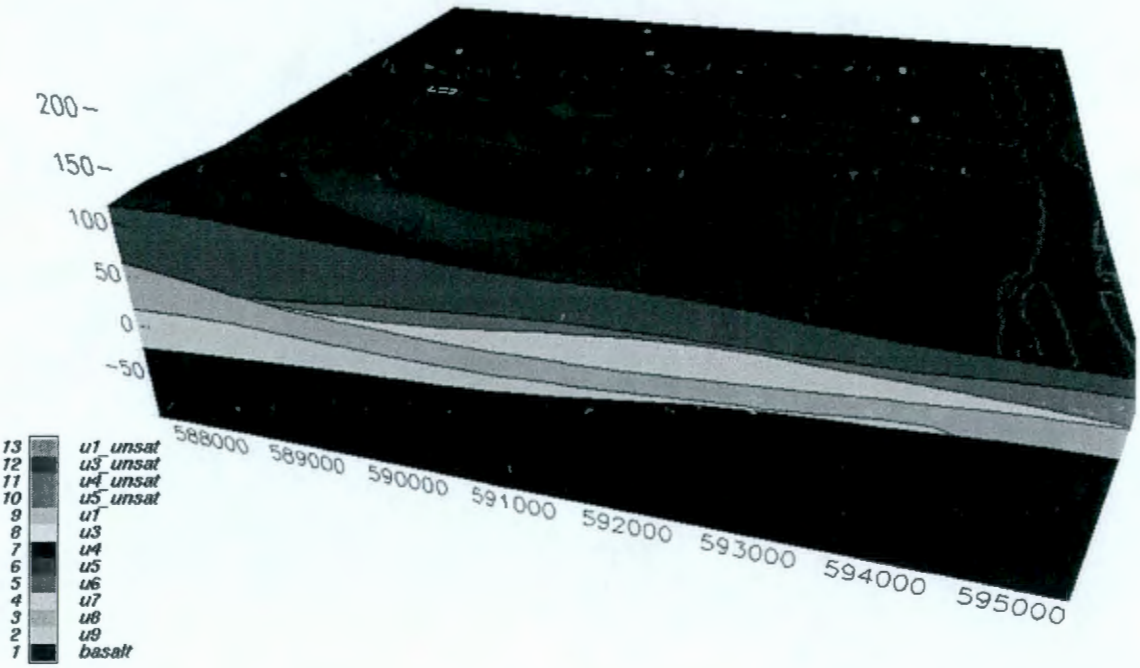

Figure 4.11. Top of Model Unit 4 (Upper Ringold Mud) Showing Borehole Data

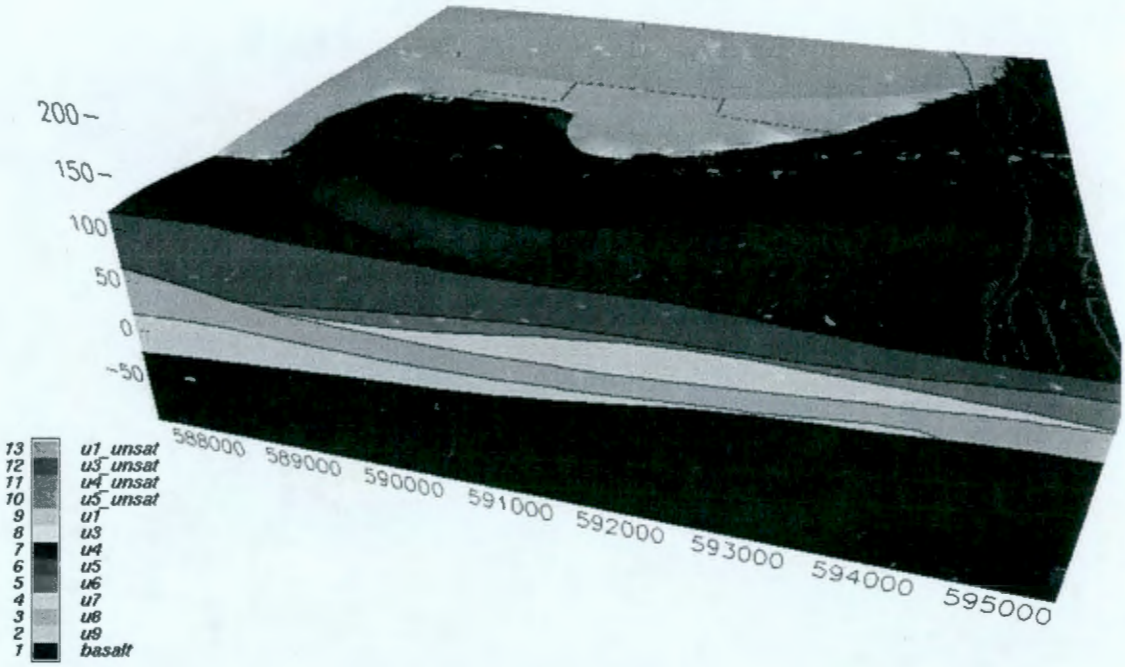

Figure 4.12. Top of Model Unit 3 (Coarse-Grained Cold Creek Unit) Showing Borehole Data

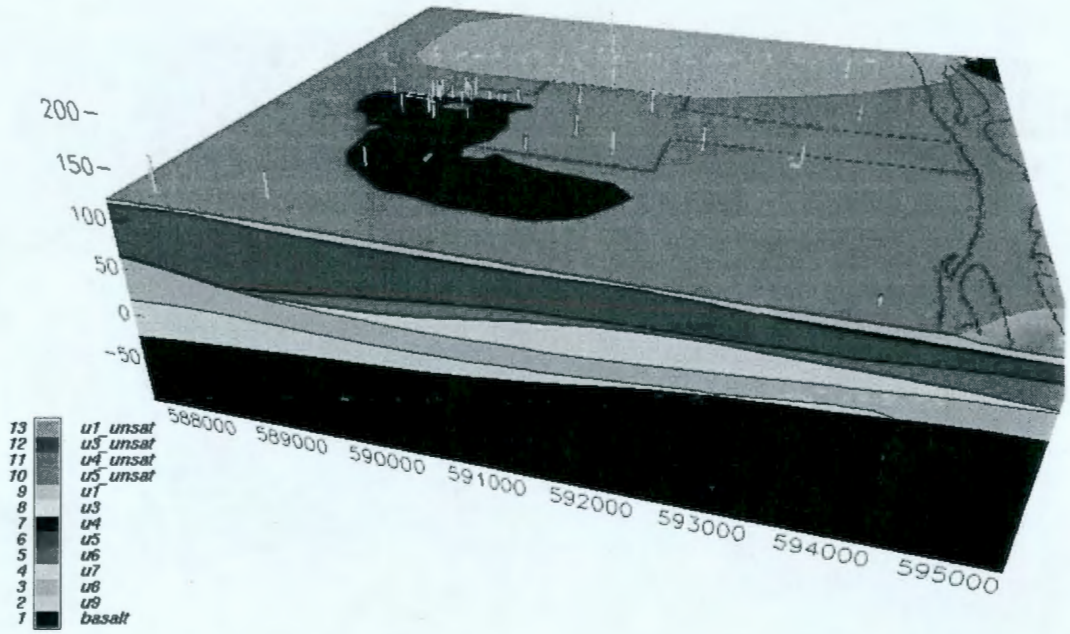

Figure 4.13. Top of Saturated Model Unit 1 (Hanford formation) Based on 2001 Water Table Showing Borehole Data

Hydraulic property measurements from aquifer pumping tests are not available from the wells in the immediate vicinity of the 618-11 Burial Ground. Across the Hanford Site, aquifer tests indicate that the Kh of the Hanford formation varies from 1 to 10,000 m/d (DOE 1988, Thorne and Newcomer 1992). However, the maximum hydraulic conductivity that can be measured by an aquifer test is limited by well efficiency and the flow rate that can be pumped with available equipment. As a result, the upper limit of Kh for coarse gravel flood deposits of Unit 1 is probably greater than that interpreted from existing field tests. The ratio of Kv to Kh (vertical anisotropy) for the Hanford formation has been measured in a few multiple well pumping tests at 0.2 to 0.5, but it may approach 1.0 in relatively clean gravel zones where stratified layers of fine-grained material are not present. Ringold gravel units (model units 5, 7, and 9) consist of sand to muddy sandy gravel with varying degrees of consolidation or cementation. Measured Kh values of these units vary from about 0.1 to 200 m/d. The average Kh value measured from aquifer pumping tests in Ringold gravel is about 20 m/d; the geometric mean is about 7.5 m/d. A few multiple well aquifer tests suggest vertical anisotropy is in the range 0.01 to 0.1. Therefore, the range of Kv is estimated to be about 0.001 to 20 m/d.

Few hydraulic test results are available for Ringold mud-dominated units (model units 4, 6, and 8). These few tests yielded hydraulic conductivity values of 0.0003 to 0.09 m/d. Some of the results are from laboratory tests. Because of a tendency to complete wells only in zones that are likely to produce water, these values may represent the higher range of Kh for the mud units. Test results for model unit 6 indicate higher Kh than unit 4 (upper Ringold fines). This is expected because of the sand and gravel layers included in unit 6. Unit 8 is expected to have even lower hydraulic conductivity than unit 4 because it contains more clay. Freeze and Cherry (1979) give a hydraulic conductivity range of 0.001 to 1 m/d for silt and loess and as low as 10^{-7} m/d for clay. This range is partially based on data compiled by Davis (1969).

Storativity and specific yield can be calculated from multiple-well aquifer tests. Specific yield values from these tests ranged from 0.11 to 0.2 for Ringold gravels and 0.2 to 0.37 for Hanford gravels. The average specific yield was 0.15 for Ringold gravels and 0.27 for Hanford gravels. The only test conducted on the coarse-grained facies of the Cold Creek unit resulted in a specific yield of 0.15. However, some test results are highly uncertain because of non-ideal test conditions such as partially penetrating wells and aquifer heterogeneity. These conditions can have a more significant effect on storage properties than on transmissivity. Moench (1997) demonstrated that these conditions can affect specific yield calculated from type-curve analysis of aquifer pumping tests and usually result in low calculated values.

Based on information in Cole et al. (2001b), specific yield for Unit 1 is estimated to range from about 0.1 to 0.3. The specific yield is expected to be higher for coarse, well-sorted gravels than for poorly sorted mixtures of sand and gravel. Storativity is estimated to range from 0.0001 to 0.0005. Specific yield is estimated to range from 0.05 to 0.2 for the generally poorly sorted sediments of Units 5, 7, and 9, and storativity from 0.0001 to 0.001 for these units.

4.2 Tritium Plume Conceptual Model

Contaminant distribution data collected during previous field investigations (Sections 2.3 and 2.4) were used to develop a conceptual model for the tritium contamination downgradient from the 618-11 Burial Ground. These data form the basis of the tritium concentration initial conditions used in this evaluation of potential impacts of the 618-11 tritium plume on the Columbia River. As discussed in Section 2.1, the mechanisms controlling tritium release from the 618-11 Burial Ground are neither well understood nor well characterized; thus, development of a detailed conceptual model of historic releases from the site is not possible. Due to these limitations, a release history from the burial ground and transport of tritium from the burial ground to the groundwater was not incorporated into the numerical model. Instead, the preliminary model configuration used initial conditions (tritium source configurations) based on the distribution of tritium in the groundwater near the burial ground in 2001. Simulations were conducted with different potential source configurations as part of model development to identify the best fit to current plume data. This best-fit model was used for predictive simulations.

Beneath the burial ground the water table is within the Ringold Formation, and the Hanford formation is completely above the water table. However, the tritium plume moves into saturated Hanford and Cold Creek gravels immediately downgradient from the burial site (Figure 4.2). As tritium migrates north into the area with saturated Hanford gravels, the plume appears to move eastward at a higher rate than within Ringold Formation sediments. Given the difference in hydraulic properties between these two units, this type of response would be expected.

Only limited information is available on the vertical distribution of tritium contamination near the 618-11 Burial Ground. Borghese et al. collected samples at discrete depths in borehole C3254, completed as monitoring well 699-13-2D (Figure 2.3), and analyzed for tritium.[(a)] Results are shown in Table 4.1. The higher concentration of tritium deeper in the aquifer is thought to result from downward movement of groundwater in response to pumping during construction of the WPS-1 power plant.[(a)] Based on this information, tritium concentration 5 to 10 m below the water table in the Ringold Formation was assumed to be twice as high as in the upper 5 m of the aquifer. The concentration from 10 to 15 m below the water table was assumed to be the same as that in the upper 5 m and was assumed uncontaminated 15 m or more below the water table. This distribution was only applied to the Ringold gravel portion of the aquifer. In the saturated portion of the Hanford formation and Cold Creek Unit, the tritium distribution was assumed to be constant over the entire thickness. A three-dimensional (3-D) view of the initial condition plume implemented in the 618-11 model is shown in Figures 4.14 and 4.15 along with the deeper 3-D hydrogeologic layering.

Table 4.1. Tritium Measured at Discrete Depths in Borehole C3254

Distance below Water Table (m)	Tritium (pCi/L)
0.1	690,000
2.7	634,000
5.7	1,330,000
11.4	1,300,000
12.9	503,000

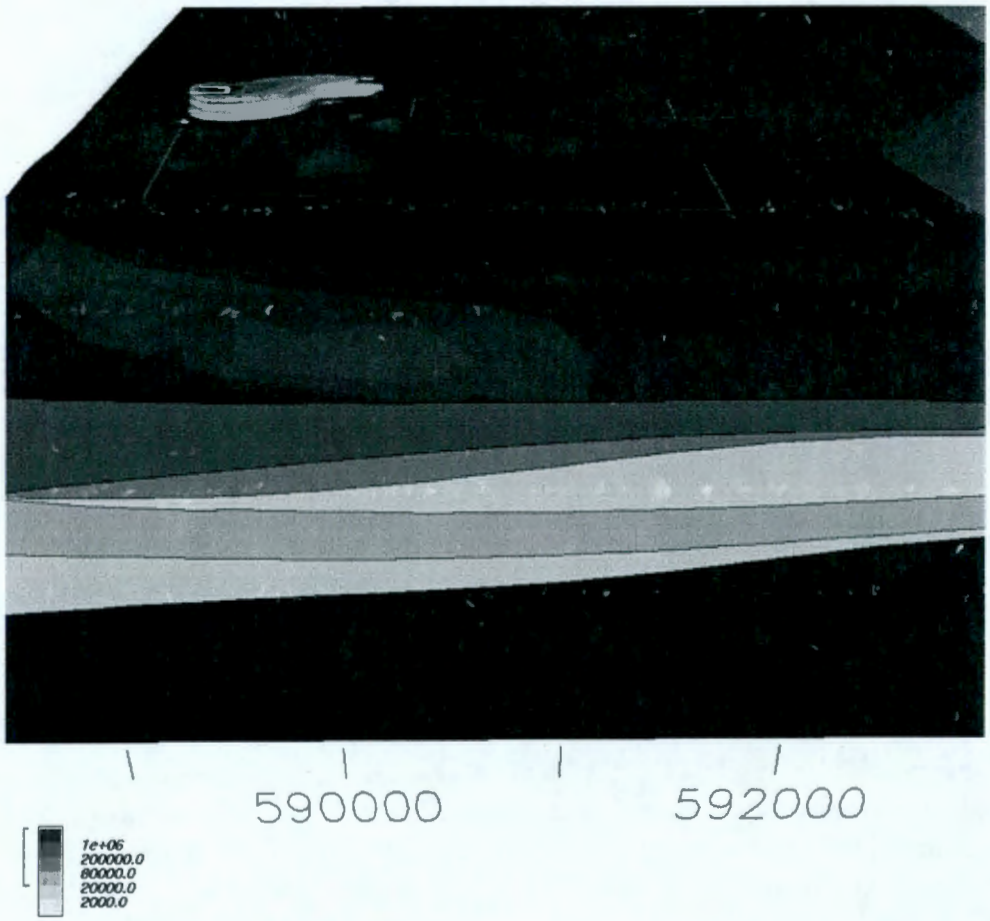

Figure 4.14. Initial Condition Tritium Plume Implemented for the 618-11 Model

(a) Borghese JV, WJ McMahon, and RW Ovink. 2001. *Tritium Groundwater Investigation at the 618-11 Burial Ground, September 2001*. Letter report to U. S. Department of Energy from CH2M HILL, Richland, Washington.

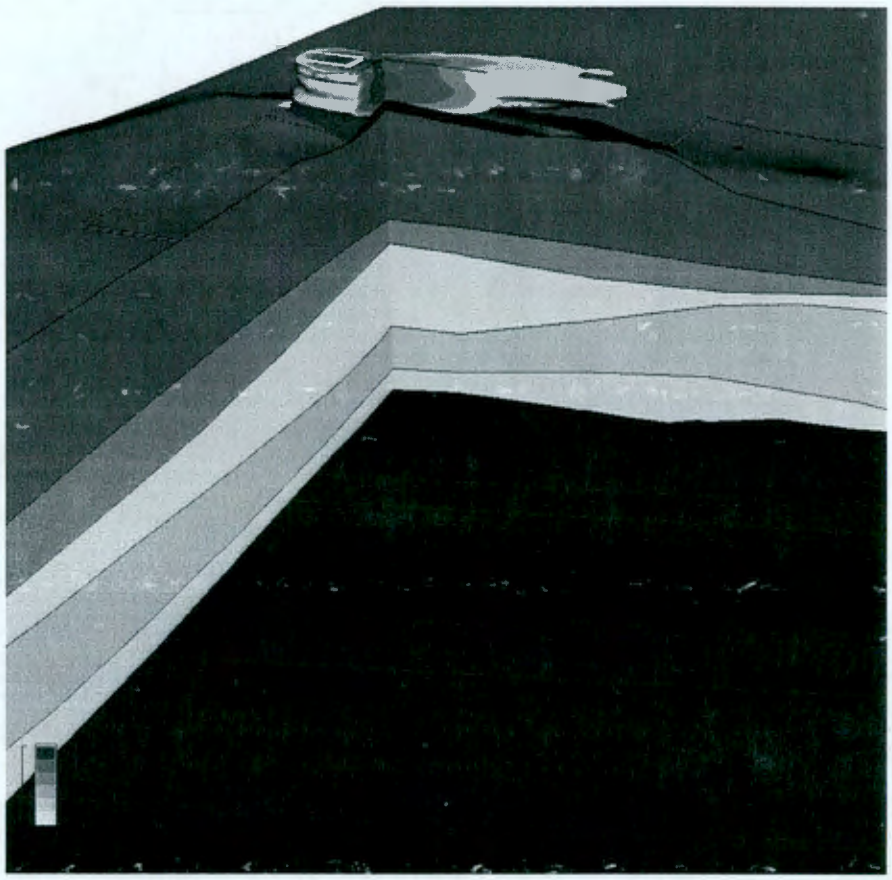

Figure 4.15. Initial Condition Tritium Plume Implemented for the 618-11 Model

4.3 Model Implementation

The fate and transport model for the 618-11 Burial Ground tritium plume is a refinement of the Hanford groundwater model (Vermeul et al. 2003). The regional grid covering the local scale model region was extracted and used as the starting point for the refinement process. Two sequential subgrid refinements of the grid were performed. Figure 4.16 shows the refined local scale grid used in this model implementation.

The grid spacing of the regional groundwater model corresponds to the large square grids that measure 250 m on a side. The region of highest refinement has grid spacing of 28 m. The complete model consists of 4759 surface nodes and 4702 surface elements. The model domain measures approximately 6900 m along the east and north directions, for a total area of 4.761E+7 m^2. The finely discretized portion of the grid encompasses the initial 618-11 Burial Ground plume extent. The subsurface domain was divided into 40 layers, with the upper 16 m

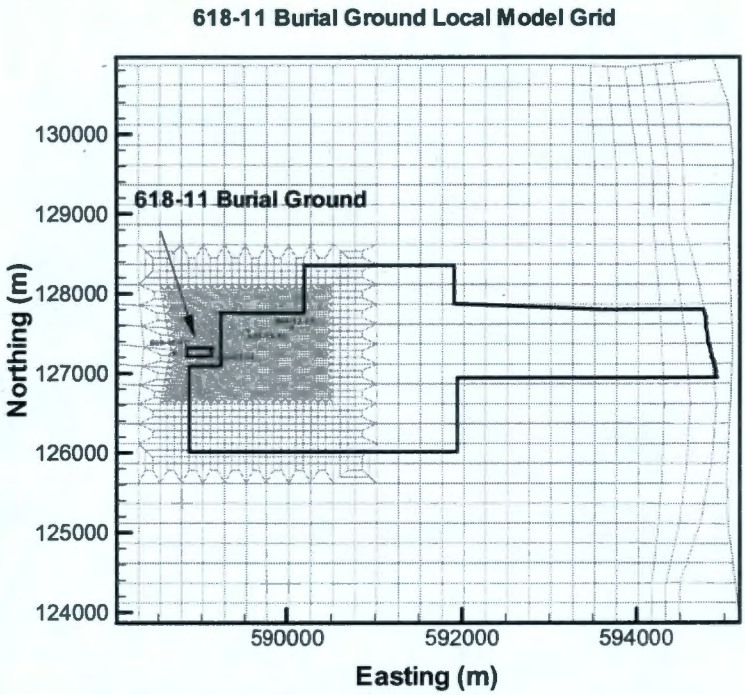

Figure 4.16. 618-11 Burial Ground Model Grid

represented by 2-m-thick sublayers. Figure 4.17 shows a vertical cross section through the model domain that represents the general groundwater flow direction to the northeast and approximately represents a line through wells 699-13-3A and 699-13-0A. The vertical profile shows the vertical model grid discretization and vertical hydrostratigraphic distribution. A discontinuous mud unit underlies the upper 16 m of the Ringold formation directly beneath the burial ground. Groundwater exiting the 618-11 Burial Ground flows into the coarse, more permeable Hanford formation as it moves downgradient along this transect.

The 618-11 model was implemented using the Coupled Fluid, Energy, Solute Transport (CFEST) code (Cole et al. 1988), which is a 3-D, finite element, numerical model that describes fluid flow and contaminant transport in porous media. Three primary input files are used to define model parameters: 1) the control file, which identifies all input file names and other general options required for the simulation; 2) the LP1 file, which contains physical and hydraulic property data, initial conditions, node assignments, and element connectivity information and is generated using the GEOFEST code (Williams et al. 1996); and 3) the L3I file, which contains information pertaining to time stepping, model flux assignments, and time varying source/sink assignments. A detailed description of the LP1 and L3I files is provided in the CFEST users' manual (Cole et al. 1988).

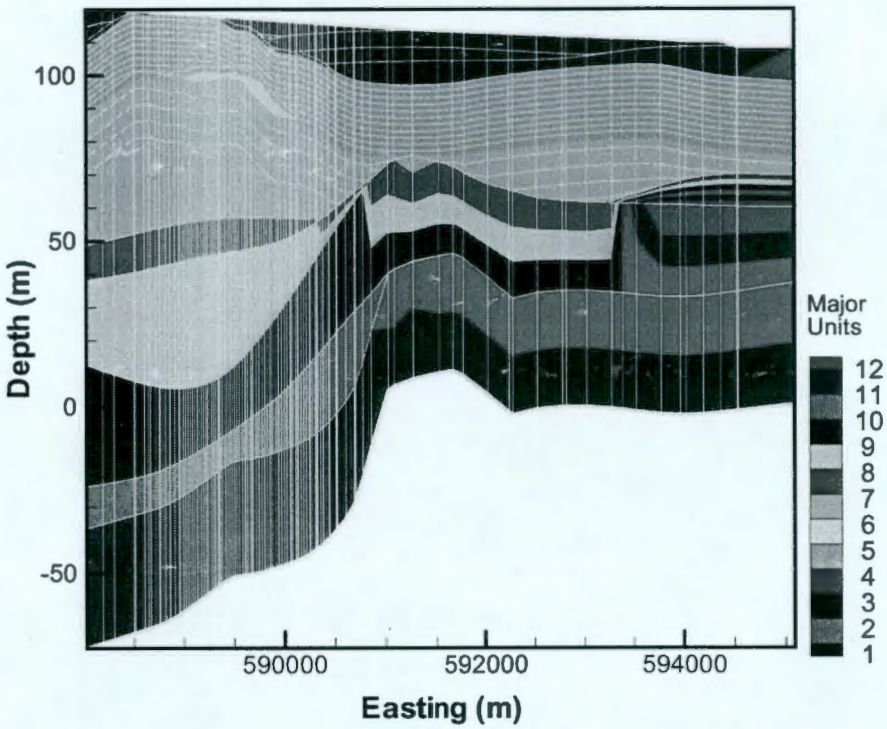

Figure 4.17. Vertical Cross Section Through the Model Domain Showing Model Discretization and Hydrostratigraphic Distribution

The GEOFEST utility reads in the model node list, element connectivity, boundary conditions, hydrogeologic layering for the model grid, hydraulic properties for specific hydrogeologic units, a list of the hydrogeologic units and the model layers they correspond to, and initial head and concentration conditions at model nodes. The hydrogeologic unit distributions used to build the LP1 file is generated from well log data that were interpolated to a spatial grid using EarthVision software. The hydrogeologic conceptual model implemented in this local scale numerical model is discussed in detail in Section 4.1.

Boundary conditions were developed to approximate groundwater flow conditions through and downgradient from the site over the simulation period (2001 through 2076). Average Columbia River stage was used to define the eastern held-head boundary condition, which remained fixed throughout the simulation period. River stage was held at 108.65 m at the northeastern corner of the model domain and at 106.80 m in the southeast corner.

During development of the local scale model, the north and south model boundaries were located so that they were parallel to groundwater flow based on available water level contour maps. This allowed the northern and southern boundaries of the model to be represented by a no-flow boundary condition.

The western boundary of the model was initially assigned a constant head value based on measurements in observation wells in 2001 (i.e., the start of the simulation period) and subsequent contouring along the boundary. The water table was initially held at an elevation of 120.75 m in the southwest corner and approximately 2 m lower in the northwest corner of the model domain. As the 200 Area groundwater mound continues to dissipate over time, the water level at the western boundary of the 618-11 model is also expected to decline. The rate of decline over the period of simulation was derived from a previous System Assessment Capability (SAC) regional groundwater model (Cole et al. 2001a) that was run through the year 2400. The water level decline at the northwest corner of the model domain is shown in Figure 4.18. The rate of decline was calculated using an interpolation approach for segments of this hydrograph. Discrete segments were selected to represent major changes in the decline rate. The time intervals referenced for the calculation correspond to the time step interval used for the model.

All nodes along the western boundary are reduced by the same extent at each time step. Therefore, the south to north water table slope is retained throughout the simulation as the water table declines in a uniform fashion. The period of steepest descent occurs within the time period encompassed by this modeling effort.

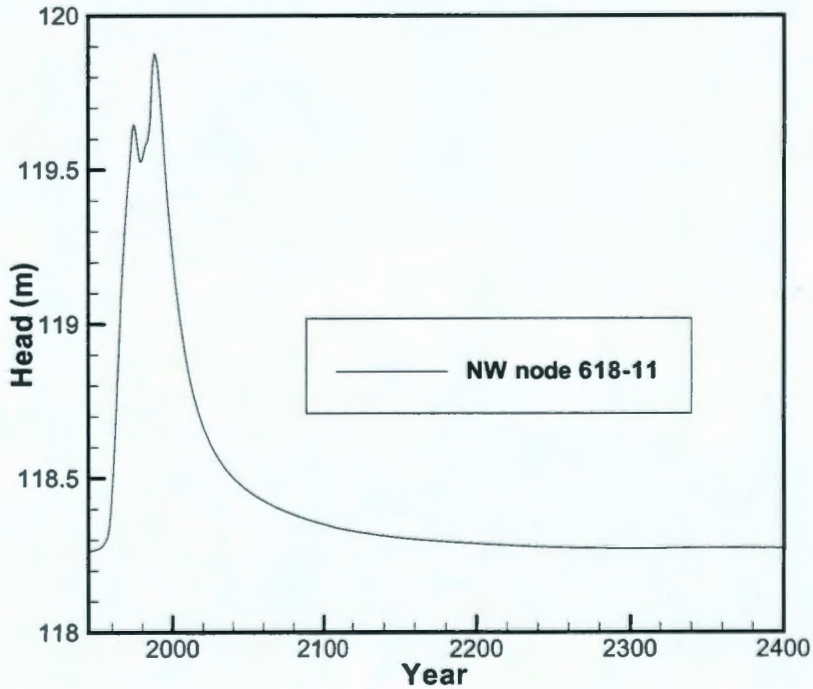

Figure 4.18. Water Level Decline at NW Model Boundary Node

4.3.1 Initial Conditions

Another requirement for model implementation was that initial conditions for water level and tritium concentrations be established within the model domain. The initial water table was set based on a water table map template for the Hanford Site. Upon execution of the model, the boundary conditions are invoked and the water table is recalculated to achieve a steady-state condition with the established boundary conditions. Subsequent time steps reflect the water table change as the western boundary declines. The initial tritium concentration was calculated from measurements at monitoring wells near the 618-11 Burial Ground (Section 4.2). Tritium concentration is interpolated to the model grid in the lateral and vertical directions. Tritium associated with the larger-scale 200 East Area plume was not included in the initial tritium distribution so that the path defined by the 618-11 Burial Ground plume was clearly defined. In the instance where the 200 East Area plume was not excluded, the 618-11 plume merged with the larger-scale plume downgradient from the site, and the lower-concentration portion of the 618-11 plume became indistinguishable within the simulated period. The initial conditions for water table elevation and tritium concentrations are shown in Figure 4.19.

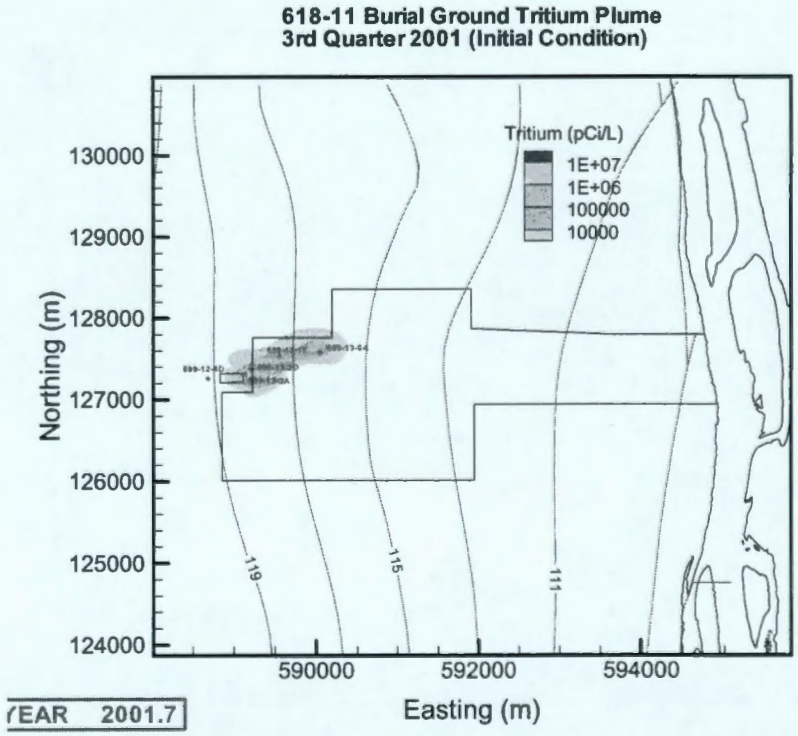

Figure 4.19. Initial Water Table Elevation and Tritium Concentrations

4.3.2 Flow and Transport Properties

The hydrostratigraphic distribution for the model domain is derived from interpolation of the geologic units between existing boreholes (Section 4.1.2). Hydraulic properties are derived for specific hydrostratigraphic units from a regional groundwater model that applied inverse techniques to optimize parameter values to honor field-measured data (Vermeul et al. 2003). Hydraulic conductivity, porosity, dispersivity, and molecular diffusivity values used in the model are listed in Table 4.2.

Table 4.2. Flow and Transport Properties for Hydrostratigraphic Units that Make up the Local Scale Model

	Kx (m/d)	Ky (m/d)	Kz (m/d)	Porosity	A_L (m)	A_T (m)	D_m (m^2/d)
Unit 1	363.0	363.0	36.3	0.25	7.0	1.40	1.73E-4
Unit 2	1.0E-4	1.0E-4	1.0E-5	0.15	7.0	1.40	1.73E-4
Unit 3	297.0	297.0	29.7	0.30	7.0	1.40	1.73E-4
Unit 4	5.0E-4	5.0E-4	5.0E-5	0.40	7.0	1.40	1.73E-4
Unit 5	10.6	10.6	1.06	0.20	4.5	0.70	1.73E-4
Unit 6	1.0E-2	1.0E-2	1.0E-3	0.40	4.5	0.70	1.73E-4
Unit 7	1.0	1.0	0.1	0.15	4.5	0.70	1.73E-4
Unit 8	1.0E-5	1.0E-5	1.0E-6	0.15	4.5	0.70	1.73E-4
Unit 9	1.0	1.0	0.1	0.15	4.5	0.70	1.73E-4

Vertical hydraulic conductivity (Kz) is an order of magnitude lower than the horizontal (Kx, Ky) and reflects resistance of flow perpendicular to the stratigraphic layers. Porosity is assigned so the finer matrix materials (clay/silt) have the highest porosities and the coarser materials the lowest. Hydrostratigraphic distribution of the model domain at the water table, based on 2001 water levels, is shown in Figure 4.20. The position of the initial plume and the burial ground boundaries are also shown.

Transport and plume attenuation mechanisms accounted for in the numerical model include dilution, dispersion, molecular diffusion, and radioactive decay. The longitudinal dispersivity (A_L) is assigned to honor the Peclet condition of $\Delta x=4A_L$, or ¼ of the smallest grid spacing. The transverse dispersivity (A_T) is assumed to be 20% of the longitudinal dispersivity term. Molecular diffusion is assumed to be the same for all hydrostratigraphic units. To implement the effects of radioactive decay, mass at each time step is calculated by the exponential decay equation:

$$N = N_0 e^{-kt}$$

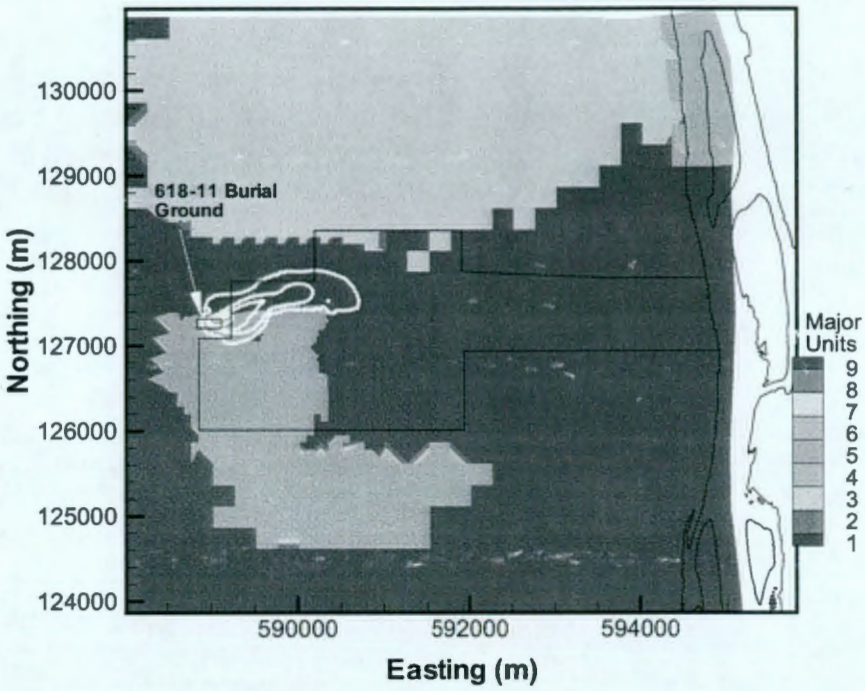

Figure 4.20. Hydrostratigraphic Unit Distribution at the Water Table for the 618-11 Burial Ground Model

where N_0 is the initial mass beneath the 618-11 Burial Ground, k is the decay coefficient ($\ln 2/t_{1/2}$), $t_{1/2}$ is the half-life of tritium (12.32 yr), and t is the time since start (yr). Consequently, the tritium mass within the plume will decrease by half every 12.32 years. Figure 4.21 shows the rate of decay for an initial tritium source concentration of 7,000,000 pCi/L.

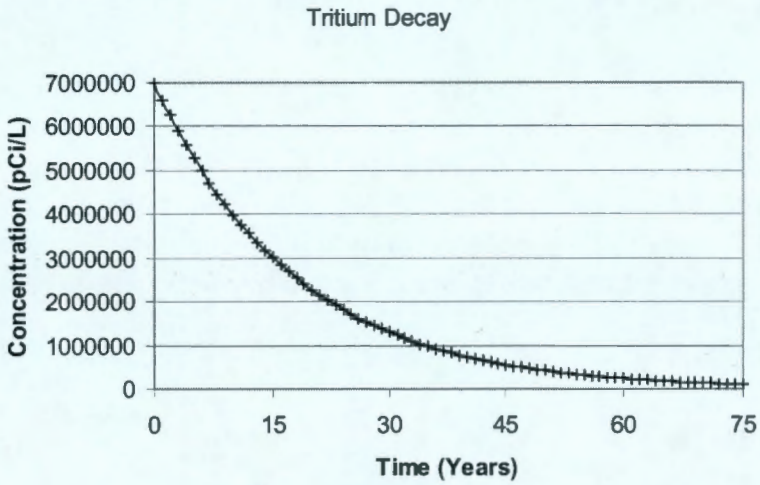

Figure 4.21. Simple Tritium Decay for a 7,000,000 pCi/L Source over 75 Years

4.4 Transport Model Calibration

The objective of the transport model calibration was to determine the most appropriate conceptual model for the 618-11 tritium plume initial conditions and release history and develop a flow and transport model that could provide a reasonable fit to observed tritium distributions. Tritium concentration data were available from five wells down gradient from the 618-11 Burial Ground to support this evaluation. As discussed in Section 4.3, the initial 618-11 local scale model implementation was based on a refined version of a regional groundwater model that applied inverse techniques to optimize parameter values. During model calibration, simulated tritium concentrations were compared with observations at monitoring wells. These data were evaluated and used to modify the hydrogeologic and tritium plume conceptual models in a stepwise fashion to improve overall model fit. During this process, several components of the model were candidates for modification, including the flow field, contaminant distribution, and hydrostratigraphic material distribution.

Two conceptual models of tritium release were evaluated during this modeling effort. The first model assumed that the tritium source was a pulse release (i.e., noncontinuing source) that migrates away from the facility after the initial condition is set at the beginning of the simulation. Although elevated tritium concentrations will persist in the low-conductivity Ringold (Unit 5) sediments more than they do in the high-conductivity Hanford gravel (Unit 1) in this scenario, no additional contaminant mass is applied to the system after the simulation is initiated. The second conceptual model represents the source area beneath the facility as continuous, decaying at a rate commensurate with the half-life of the tritium. Under this scenario, the continuing decaying source is implemented in the model by assigning a variable tritium concentration at the model surface nodes within the boundaries of the burial ground as the simulation progresses. The initial concentration is that defined by the tritium concentration initial condition. At each successive time step, the decay equation is applied at each surface node within the burial ground boundary to reassign a new concentration. The source strength at any time step is therefore a function of the time since the beginning of the simulation.

Tritium initial conditions are discussed in Section 4.2 and shown in Figures 4.14 and 4.15. After the first time step, head conditions were redefined as steady state for the up- and down-gradient boundary conditions, and the tritium mass was redistributed to represent migration in the first time step. As the simulation progressed, the western head boundary was lowered as defined by the function described in Section 4.3.1. The tritium plume concentrations change in response to radioactive decay, hydrodynamic dispersion, and diffusion processes. Maximum tritium concentration within the model domain was identified for discrete time steps throughout the simulation to determine when tritium concentration drops below the drinking water standard (20,000 pCi/L). Maximum concentrations along the Columbia River and at the Energy Northwest water supply wells were evaluated to assess potential impacts.

4.4.1 Observed Plume Migration

Figure 4.22 shows the flow velocity vectors and initial tritium plume configuration. Groundwater flow direction is to the northeast in the western end of the burial ground and east-northeast in the eastern half of the burial ground. Groundwater velocities beneath the burial ground are on the order of 0.12 m/d. Directly north of the burial ground, groundwater velocity is approximately 2.20 m/d. The difference in velocity reflects the nature of the geologic materials at the site. The Ringold Formation sediments that exist at the water table beneath the facility are less conductive and more cemented than the unconsolidated sediments of the Hanford formation to the north. Consequently, groundwater is expected to flow preferentially in this direction, and much of the tritium plume would be expected to migrate to the northeast. This phenomenon is inferred from the tritium concentration trends observed in the closest downgradient monitoring well (699-13-3A). Given the initial plume dimensions and Ringold velocities, if the plume moved primarily within the Ringold Formation and toward this well, observed concentrations would remain relatively constant (except for losses associated with radioactive decay) as the plume migrated through the area. However, observations in well 699-13-3A show a decrease in concentration that cannot be accounted for by radioactive decay alone, indicating that the tritium plume center of mass is not moving directly through this well location. The northward flow of mass into the high-conductivity Hanford formation could account for the observed decrease in concentration. Alternative conceptual models of plume initial conditions and their effect on the simulated concentration trends in downgradient monitoring wells are evaluated in Section 4.4.2.

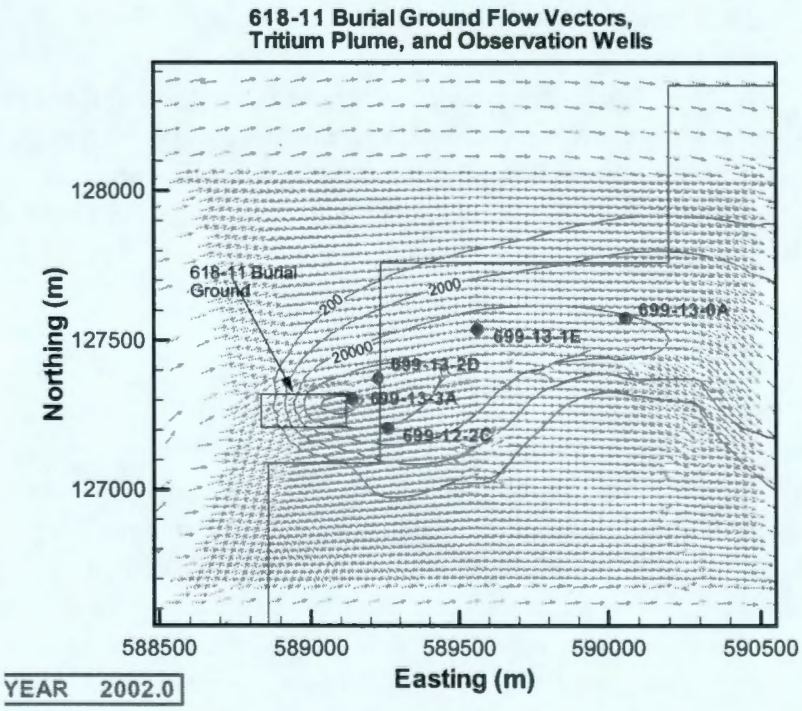

Figure 4.22. Velocity Field and Tritium Plume at the 618-11 Burial Ground

Tritium concentrations from two observation wells downgradient from the burial ground were used to identify the most likely conceptual model of initial plume configuration and release history that could adequately represent observed concentration trends. The closest downgradient monitoring well (699-13-3A) is about 50 m from the burial ground boundary. The farthest monitoring well (699-13-0A) is about 1000 m downgradient from the burial ground and within the anticipated path of the tritium plume. The river is approximately 5000 m downgradient from the burial ground.

The time history for five observation wells down gradient of the burial ground is shown in Figure 4.23. These are the same data shown in Figures 3.4 through 3.8 plotted at a common reference scale. Figure 4.22 shows the well locations relative to the burial ground. The downgradient wells closest to and farthest from the burial ground were used during the first phase of this modeling effort, which is discussed in detail Section 4.4.2.

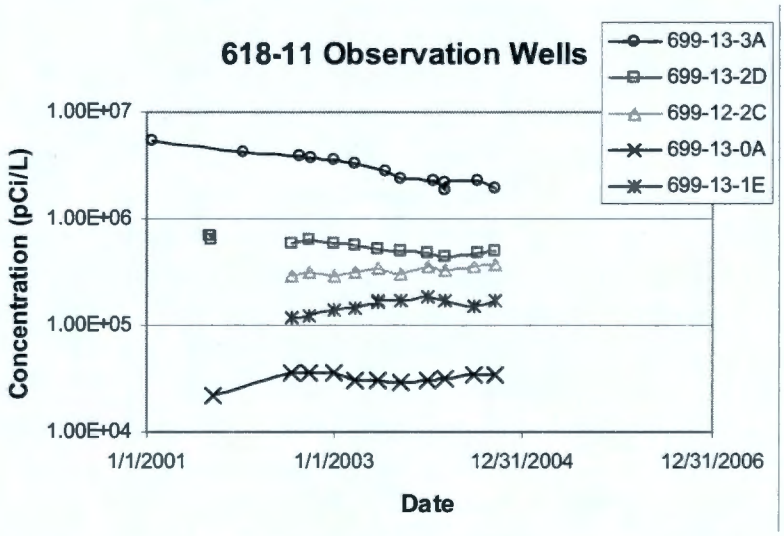

Figure 4.23. Burial Ground 618-11 Observation Wells

4.4.2 Comparison of Observed and Model Predicted Tritium Concentrations

The tritium plume fate and transport was simulated for four distinct plume configurations and release conditions. The intent of this approach was to evaluate conditions that best reproduce observed concentration trends at the two downgradient wells. Critical factors considered during this evaluation included simulated versus observed tritium concentrations at each well at each time and overall trends in the tritium concentration data. The different cases reflect a progression of conditions that were thought to be the most appropriate conceptual models for the 618-11 tritium plume initial conditions and release history and the most likely to provide a reasonable fit to measured data. The four cases below are discussed in detail in subsequent sections.

- Case 1: Original plume, pulse release
- Case 2: Original plume, continuous decaying source
- Case 3: Extended plume, pulse release
- Case 4: Extended plume, continuous decaying source.

The original plume is generated from hand contours of observation points derived from previous publications. The plume configuration was based on existing monitoring wells that do not exist within burial ground boundaries. Methods used to correct discrepancies between the model and observed results include revising the geologic model, including a continuous, decaying source at the water table, extending the high-concentration mass beneath the burial ground, and adjusting the water table elevation along the west boundary.

The 3-D hydrostratigraphy assigned to the model is derived from borehole logs that are interpolated onto the model grid in both the horizontal and vertical directions. The hydrostratigraphy was originally established for 250-m grid spacing. Upon grid refinement, assignment of hydrogeologic units was interpolated from the larger to the smaller scale. The resulting hydrogeologic distribution to the finer grid was unable to adequately reproduce the fine scale features and processes at the observation wells; therefore, manual adjustment of the geology was necessary to match observations. Adjustments that were required included removing anomalous geologic units that caused unrealistic flow fields, extending the Ringold formation so the plume dynamics were adequately represented, and adjusting unit thickness, particularly in the thin Hanford formation between the burial ground boundary and the far observation well.

The water table elevation specified for the western boundary was initially based on water table contours defined from widely spaced, sparse observations. A general description of water table elevation along the length of this boundary was derived from this information. The water table elevation at the south end of the western boundary was set at 120.75 m above MSL and decreased to the north. The net result of this prescribed boundary slope was to shift the path of the tritium plume to the north. Early simulation results showed that the tritium plume mass did not move far enough to the north and did not migrate to the far observation well. This problem was resolved by increasing the thickness of the high-conductivity Hanford formation, the water table elevation, and the slope angle of the western boundary.

4.4.2.1 Case 1: Original plume, pulse release

The initial case investigated was based on the tritium plume conceptual model developed using contaminant distribution data collected during previous field investigations (Section 4.2). Because the tritium plume was delineated using groundwater concentration data from monitoring wells outside the burial ground boundary (no data are available from wells within the burial ground), the highest concentration contour was centered near well 699-13-3A, immediately east

of the burial ground's eastern boundary (Figure 3.1). The concentration is projected vertically to a depth of 15 m, as discussed in Section 4.2. The concentration at the initial time step represents the total tritium mass released to the aquifer for this simulation. Transport mechanisms contributing to attenuation of the tritium plume during the simulation include advection, dispersion, dilution, and radioactive decay.

The observed and simulated tritium concentration trends at wells 699-13-3A and 699-13-0A are shown in Figures 4.24 and 4.25, respectively. Simulated concentrations were significantly less than measured values, indicating that, assuming the model incorporates a representative hydrogeologic model, the Case 1 tritium plume conceptual model provides insufficient tritium mass to account for observed concentration trends. The peak tritium concentration in Figure 4.25 does appear to approximate the peak arrival time observed in the measured data, indicating that the simulated travel time to this well is of the same order of magnitude.

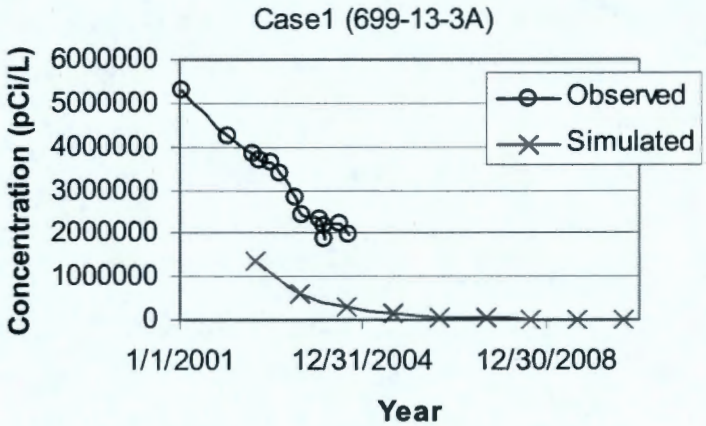

Figure 4.24. Case 1: Tritium Concentration at Well 699-13-3A

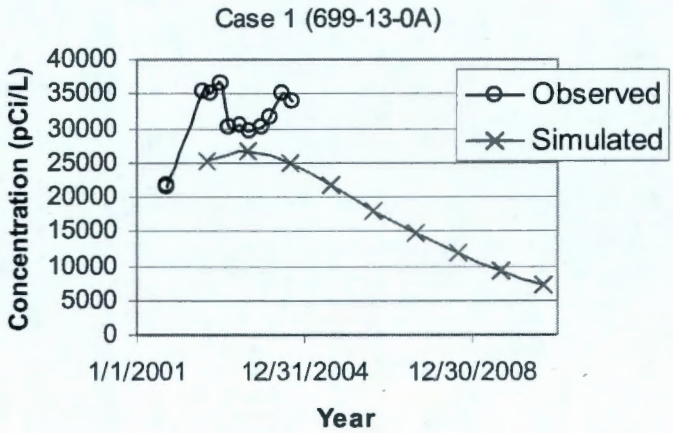

Figure 4.25. Case 1: Tritium Concentration at Well 699-13-0A

4.4.2.2 Case 2: Original plume, continuous decaying source

The continuous source simulation differs from Case 1 in that the source concentration is maintained at the surface nodes within the boundaries of the burial ground during the entire simulation period and is reduced at each time step to reflect radioactive decay. The net result is that the mass is added at each time step for those nodes within the burial ground boundaries for the duration of the simulation. The observed and simulated tritium concentration trends at wells 699-13-3A and 699-13-0A are shown in Figures 4.26 and 4.27, respectively. Like Case 1, simulated concentrations were significantly less than measured values at these wells. The most notable difference is the long tail in the predicted concentration trend at each location. Based on available data, including the continuous source does little to improve model fit.

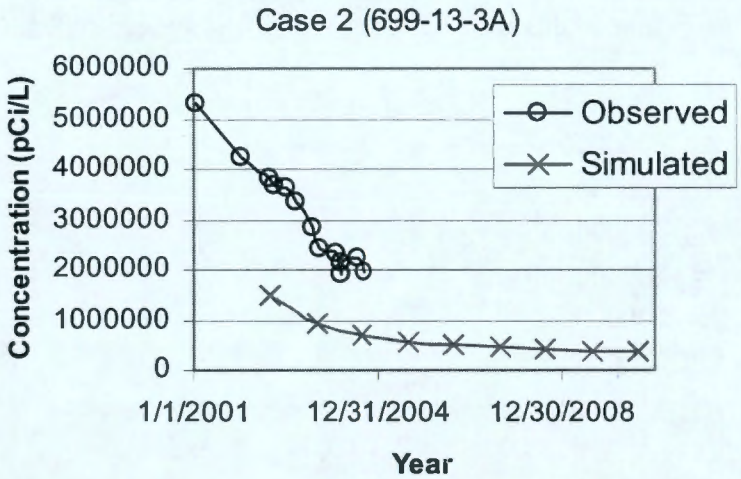

Figure 4.26. Case 2: Tritium Concentration at Well 699-13-3A

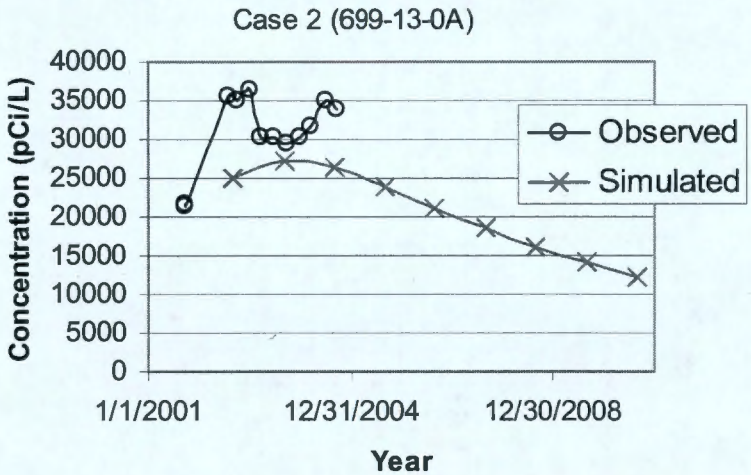

Figure 4.27. Case 2: Tritium Concentration at Well 699-13-0A

4.4.2.3 Case 3: Extended plume, pulse release

The apparent discrepancy in observed versus simulated tritium concentrations in the first two cases resulted in a reevaluation of the adopted tritium plume initial conditions to determine whether an increase in mass near the source area was warranted. As discussed previously, the initial tritium plume was based on measurements taken outside the burial ground boundaries. However, it is reasonable to assume that elevated tritium concentrations also exist inside the burial ground boundaries. Therefore, the maximum concentration was extended west to the approximate midpoint of the burial ground. Like Case 1, no additional mass was introduced into the model domain after the initial conditions were established.

The observed and simulated tritium concentration trends at wells 699-13-3A and 699-13-0A are shown in Figures 4.28 and 4.29, respectively. The fit of the simulated concentration to the measured concentration for both well locations is relatively good. The far well also shows a peak arrival time for the simulation that corresponds to the observed peak, indicating that flow velocities and hydrostratigraphic distribution used in the model are able to reproduce observed trends reasonably well. The observed difference between simulated and observed values can be attributed to any remaining discrepancies between the hydrogeologic/tritium plume conceptual models and actual site conditions, averaging of heterogeneities inherent to the numerical model implementation, variance of the boundary conditions from actual, and resolution of the average mass in the model relative to the mass measured at any particular point in the aquifer (i.e., the discrete interval monitored at a given well location).

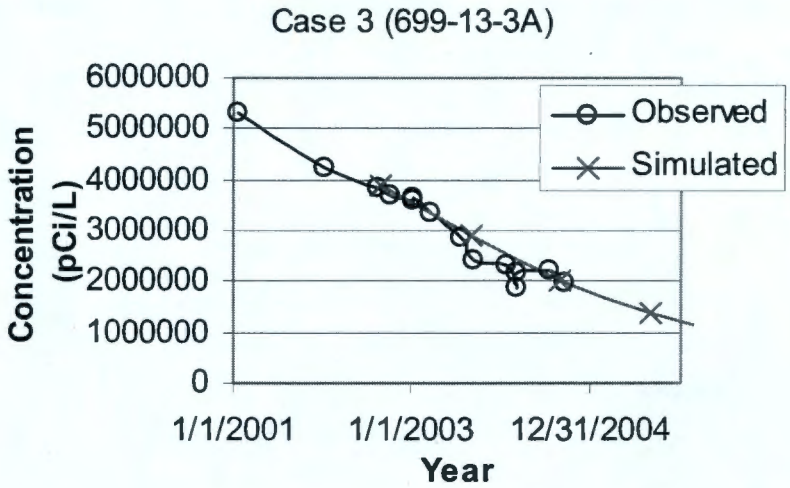

Figure 4.28. Case 3: Tritium Concentration at Well 699-13-3A

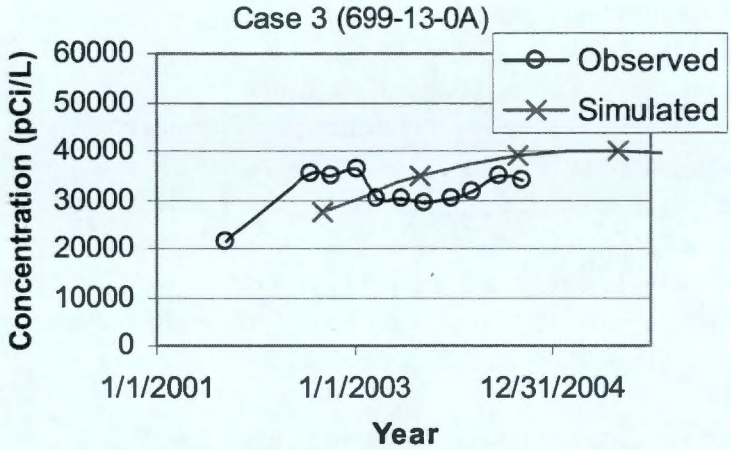

Figure 4.29. Case 3: Tritium Concentration at Well 699-13-0A

4.4.2.4 Case 4: Extended plume, continuous decaying source

Case 3 simulation results fit the observed tritium concentration trends relatively well. However, Case 4 was investigated to determine whether these results could be improved upon by including a continuously decaying source. Like Case 2, the source is maintained within the burial ground boundaries at the surface nodes only. The observed and simulated tritium concentration trends at wells 699-13-3A and 699-13-0A are shown in Figures 4.30 and 4.31, respectively. In both cases the simulation tends to overpredict the concentration at the observation wells at later times, though additional monitoring data are needed to better define the long-term trends at these wells. Another notable difference in Case 3 results is the long tail in the predicted tritium concentration trend at each location that was also observed in Case 2. Based on available monitoring data, including the continuous source does not appear to improve overall model fit relative to Case 3.

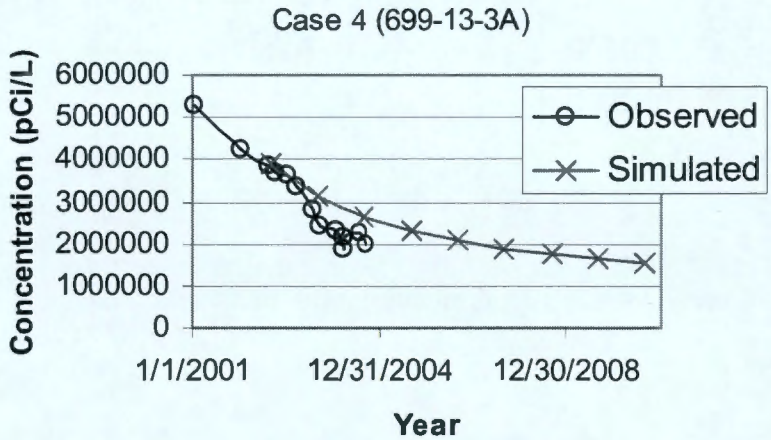

Figure 4.30. Case 4: Tritium Concentration at Well 699-13-3A

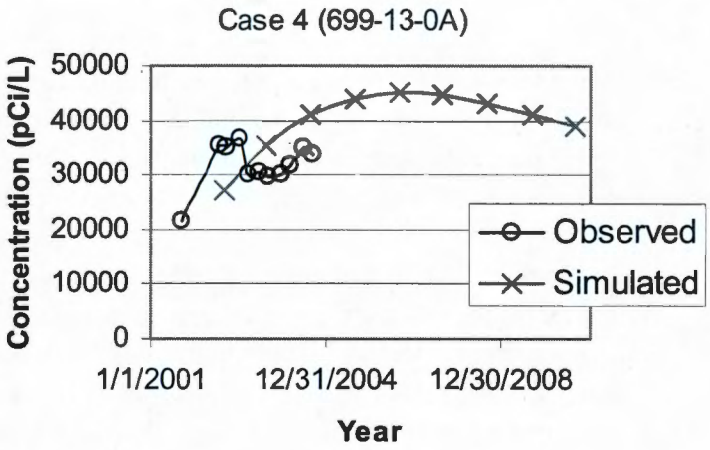

Figure 4.31. Case 4: Tritium Concentration at Well 699-13-0A

5.0 Evaluation of Tritium Plume Fate and Transport

The objective of the fate and transport modeling effort was to make long-term predictions concerning the fate and transport of the tritium plume associated with the 618-11 Burial Ground and provide a measure of the impact that might be expected at primary receptor locations under different release conditions.

Based on results from the first phase of this modeling effort, Case 3 (extended tritium plume beneath the burial ground and an instantaneous pulse release) provided the best fit to observed tritium concentration trends in monitoring wells downgradient from the 618-11 Burial Ground. In addition to this best-fit case, two alternative transport simulations were performed to determine the effects of increasing contaminant mass in the system relative to the base case. Alternative cases include 1) the extended plume, 14 year continuous decaying source followed by a pulse release (Case 5) and 2) the extended plume, pulse release, twice the initial concentration (Case 6).

5.1 Best Fit Tritium Plume Conceptual Model

This section presents the results from predictive simulations of tritium fate and transport for the best fit model. Model results are presented at five downgradient monitoring wells and the primary receptors (the Columbia River and Energy Northwest water supply wells), and an evaluation of the overall persistence throughout the aquifer is provided.

Figure 5.1 compares simulated versus observed tritium concentrations for the five downgradient observation wells that were used to track migration of the 618-11 plume. The observed tritium concentrations correspond to the data in Figures 3.4 through 3.8 and the composite in Figure 4.23. The simulated fit to the observed tritium concentration is relatively good for the closest (699-13-3A) and the farthest (699-13-0A) wells, which both lie along the centerline of the tritium plume. There is a distinct concentration signature for each of the five wells available for comparison that matches the simulated results (Figure 5.1). The difference between observed and simulated tritium concentrations can be attributed to a variety of imperfections in the numerical implementation of tritium fate and transport at the site. However, the generally good fit realized by this model indicates that it provides a useful tool for predicting tritium plume fate and transport associated with the 618-11 Burial Ground.

Figure 5.2 shows the maximum concentration within the model domain for the duration of the simulation. Tritium concentration falls below the drinking water standard of 20,000 pCi/L by 2031, about 30 years after the simulation start time. Figure 5.3 shows the peak tritium concentration at the Energy Northwest water supply wells (see well locations in Figure 4.1),

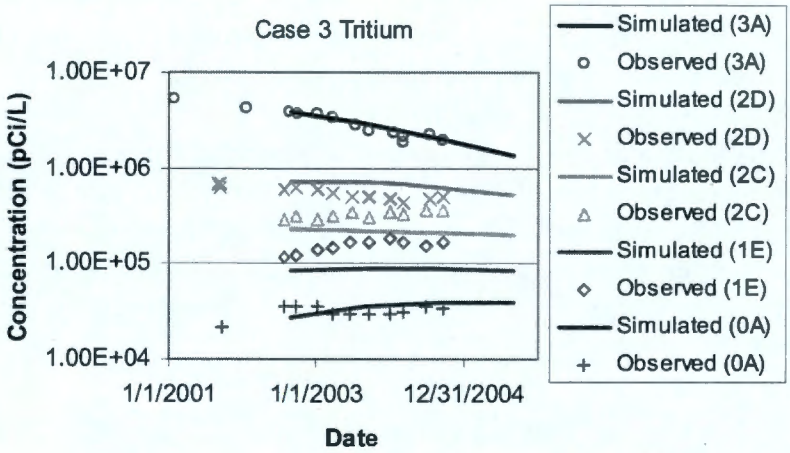

Figure 5.1. Case 3 Simulated Wells

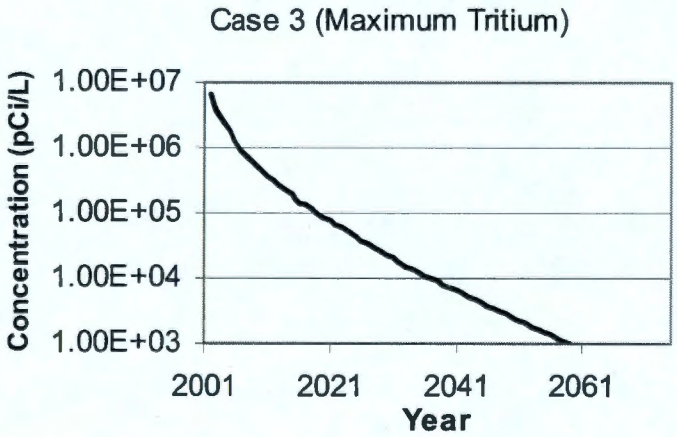

Figure 5.2. Case 3: Maximum Tritium Concentration in the Model Domain

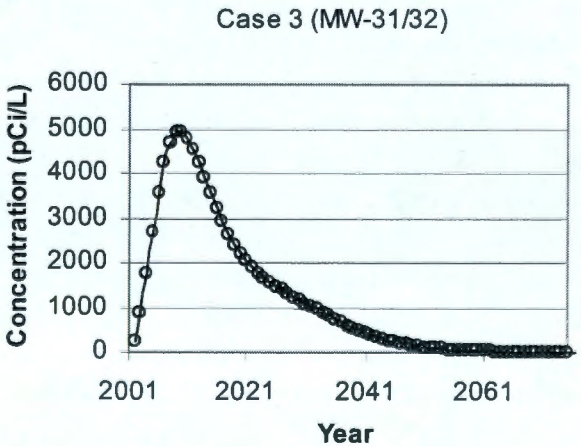

Figure 5.3. Case 3: Tritium Concentration at Energy Northwest Wells MW31 and MW32

which is predicted to occur in 2010 at 4,900 pCi/L. This simulation does not consider pumping from the Energy Northwest water supply wells, which, if sustained at high rates for long periods of time, could increase the observed concentration at this location.

Figure 5.4 shows the tritium arrival response at the Columbia River over the period of simulation. The peak concentration of 1000 pCi/L is reached in 2016, after which concentration declines steadily. This analysis does not account for potential dilution of the tritium plume that may occur as groundwater enters the near-river environment and is subjected to bank storage effects associated with changes in river stage. For all simulations the river is maintained as a held-head boundary.

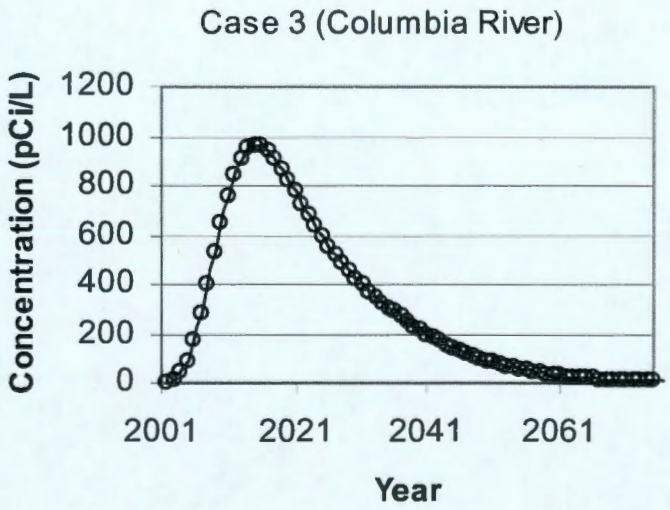

Figure 5.4. Case 3: Tritium Concentration at the Columbia River

Figures 5.5 through 5.8 show the tritium plume distribution at the water table at several times over the period of simulation for the best fit model (extended plume, pulse release). Figure 5.5 shows that initial tritium concentration used in this modeling effort, which is discussed in detail in Section 4.2, with subsequent discussion of modifications made to the tritium concentration initial conditions based on Phase 1 modeling results. The highest concentrations occur in the burial ground facility, up to 7,000,000 pCi/L. The trajectory of the plume at this time is toward the northeast and is controlled by the hydrogeology in the area.

Figure 5.6 shows the predicted tritium plume migration after six years. The center of the high concentration mass has migrated about 300 m from the burial ground boundary, indicating that the highest concentration portion of the plume is still moving through the low-conductivity Ringold formation. The maximum concentration in the Ringold Formation at this time is approximately 300,000 pCi/L. A large lobe of lower tritium concentration has migrated down-gradient in the higher conductivity Hanford formation. Once the plume enters the Hanford

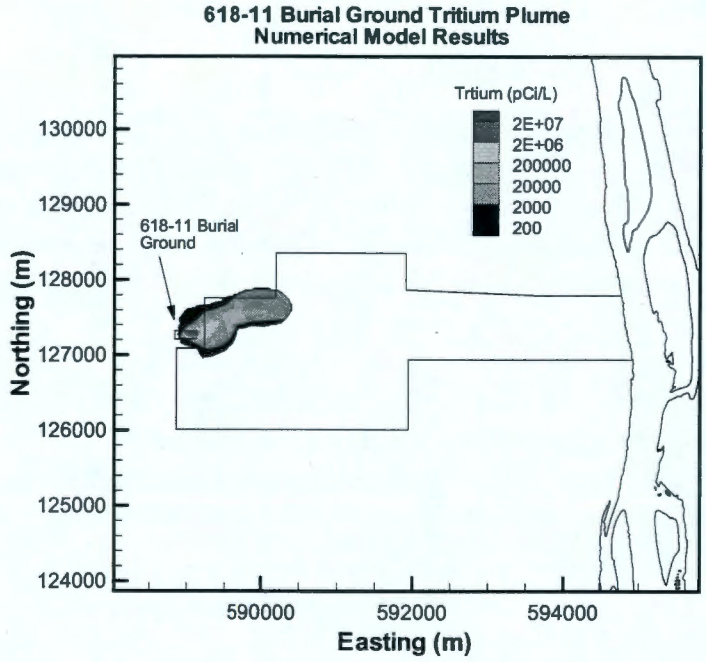

Figure 5.5. Tritium Concentration 2-D Flood Contour in 2001

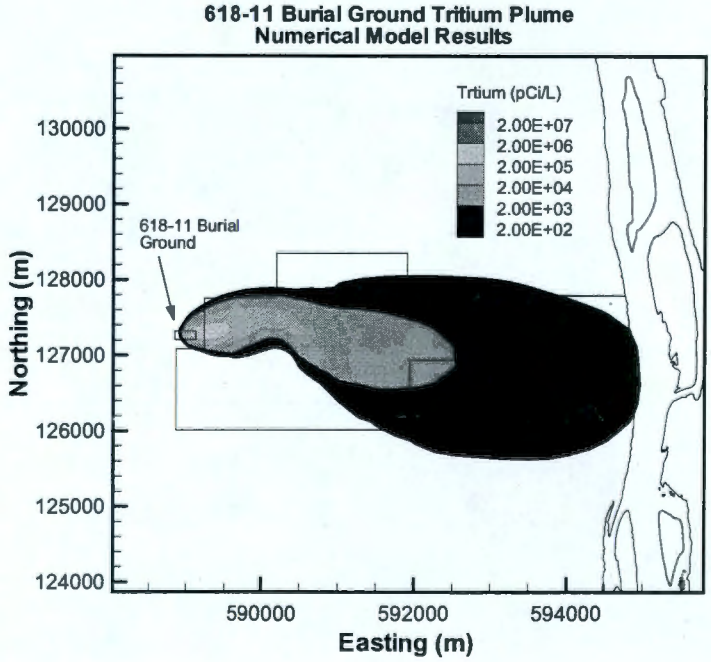

Figure 5.6. Tritium Concentration 2-D Flood Contour in 2007

formation, the trajectory changes to the Southeast and the plume spreads in the lateral direction. At this time, tritium concentrations greater than 200 pCi/L have not reached the Columbia River. Figure 5.7 shows the tritium plume 16 years after the simulation start time. The center of mass is approximately 750 m from the burial ground's east boundary. The average velocity within this highest concentration portion of the plume is 0.12 m/d, which is the reported average velocity of the Ringold formation. Maximum concentration in the plume remains at about 60,000 pCi/L and remains in the Ringold formation. The Tritium plume has reached the river and achieved a maximum concentration along the shoreline of approximately 1,000 pCi/L.

Figure 5.8 shows the tritium plume 31 years after the simulation start time, when the maximum concentration within the model domain has fallen below the drinking water standard of 20,000 pCi/L. By this point in the simulation, which has provided sufficient time for almost three half-lives of radioactive decay, most of the plume has dispersed or decayed to less than 2,000 pCi/L, and tritium concentration at the Columbia River is less than 200 pCi/L.

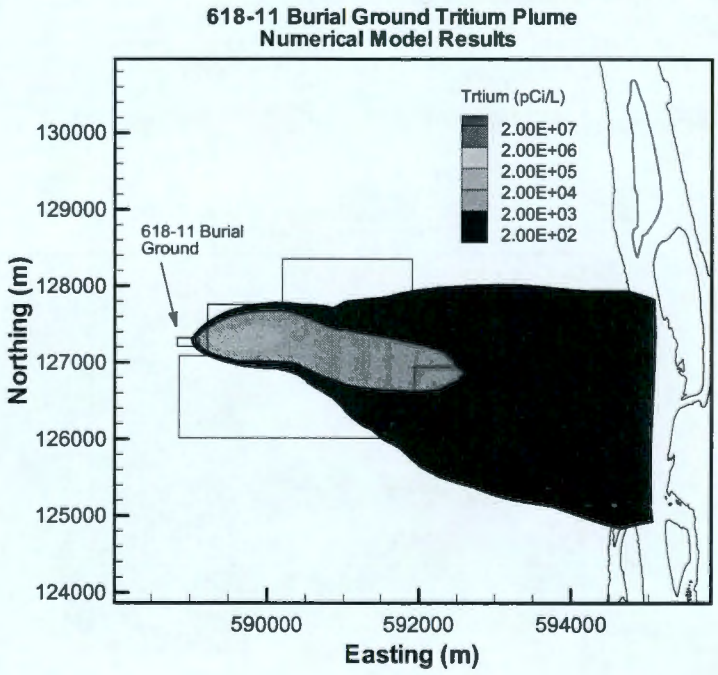

Figure 5.7. Tritium Concentration 2-D Flood Contour in 2017

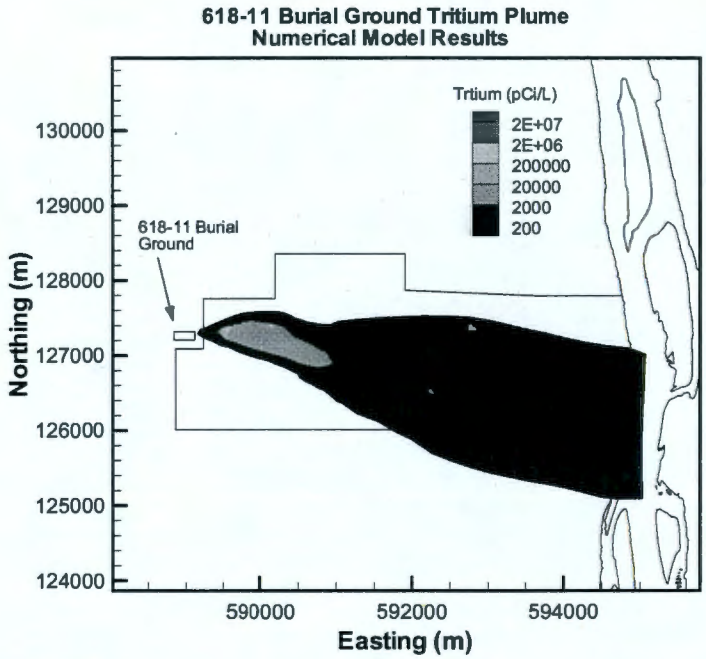

Figure 5.8. Tritium Concentration 2-D Flood Contour in 2027

5.2 Alternative Release Scenario 1: Continuing Source

The first alternative release scenario incorporated the initial plume conditions from the best-fit model and added a continuously decaying source that was maintained within the burial ground for 14 years (2015), then removed and the tritium plume released as a pulse. The continuous source was maintained through 2015 to coincide with the milestone for source removal at the burial ground under the River Corridor Closure Contract (Solicitation DE-RP06-04RL14655). For this alternative release scenario, predictive simulations indicate that the drinking water standard of 20,000 pCi/L was attained throughout the model domain in the year 2040, 39 years after the start of the simulated period (Figure 5.9) and nine years after that predicted for the best-fit model. The most distinctive feature of this plot is the "shelf" created by the initial slow reduction of mass followed by a rapid decrease after the source is discontinued. The additional time required to reach drinking water standards throughout the model domain (9 yr) is similar to that of the continuing source term (14 yr).

The peak tritium breakthrough occurs at the Energy Northwest water supply wells in 2013 (Figure 5.10), 12 years after the start of the simulated period, at a maximum concentration of 6,200 pCi/L. Peak arrival occurs three years after the best fit case and at a concentration about 1.2 times higher. The additional mass arrival predicted at this location is associated with the 14 years of continuing source assumed for this case. Peak tritium concentration at the

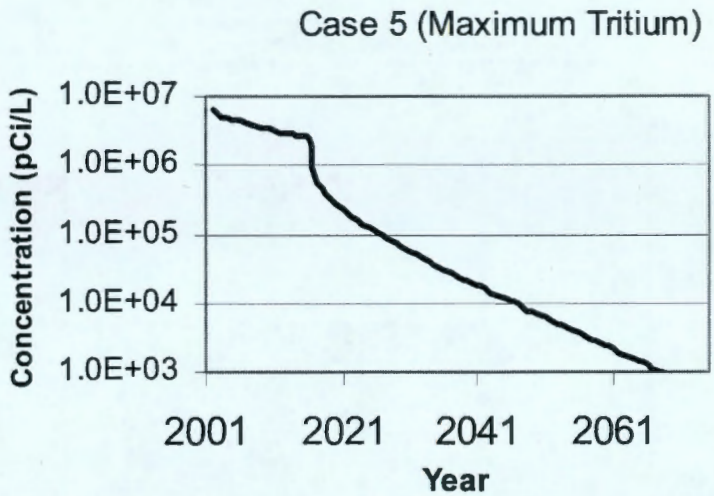

Figure 5.9. Case 5: Maximum Tritium Concentration in the Model Domain

Columbia River, shown in Figure 5.11, occurs in the year 2020, 19 years after the start of the simulated period, and reaches a peak concentration of 1,400 pCi/L. Relative to arrival response at the river for the best fit case, peak arrival for this case occurs four years later and at a concentration approximately 1.4 times higher.

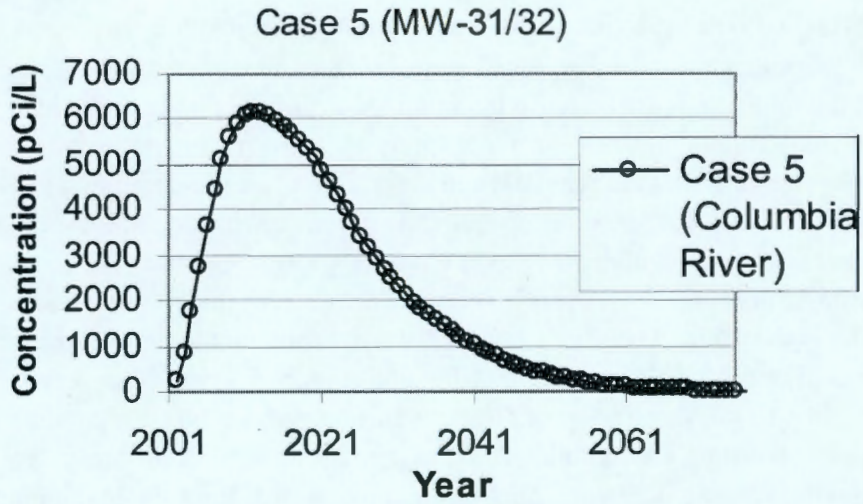

Figure 5.10. Case 5: Tritium Concentration at Energy Northwest Wells MW31 and MW32

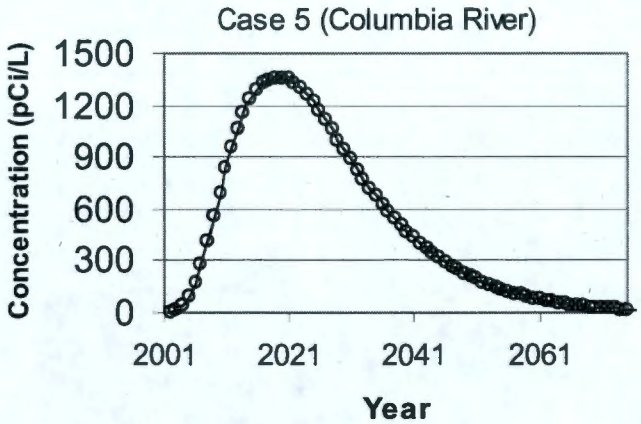

Figure 5.11. Case 5: Tritium Concentration at the Columbia River

Figures 5.12 through 5.14 are time-series contour plots of tritium concentration at the water table. The plot for the starting year is the same as for the best-fit case (Figure 5.5). The plots at later times show that the higher-concentration mass persists in the model longer, commensurate with the continuous source at the burial ground. The source term is removed after 14 years (in 2025), and then the high-concentration center can be seen migrating away from the burial ground (Figure 5.14). Because the release is continuous, the plume persists longer than predicted by the best-fit model. Figure 5.14 shows the tritium plume extent in 2040, the approximate time when the maximum tritium concentration within the model domain is predicted to fall below the drinking water standard of 20,000 pCi/L.

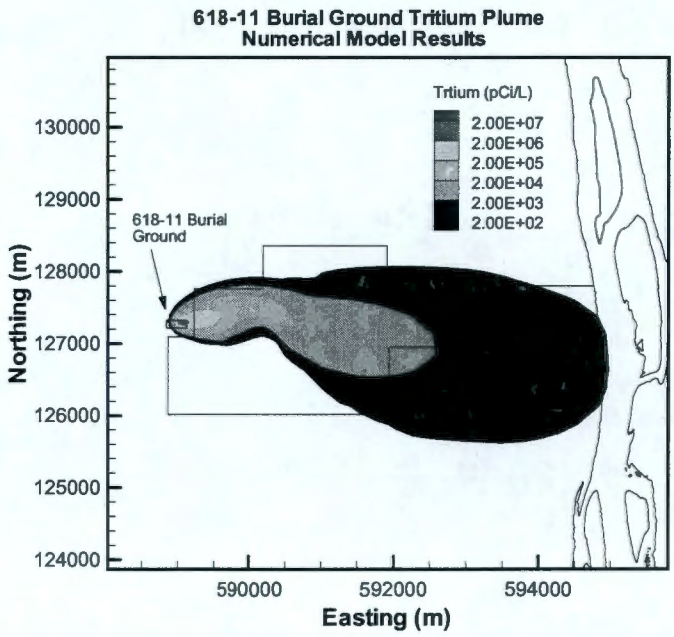

Figure 5.12. Case 5 Plume in 2007

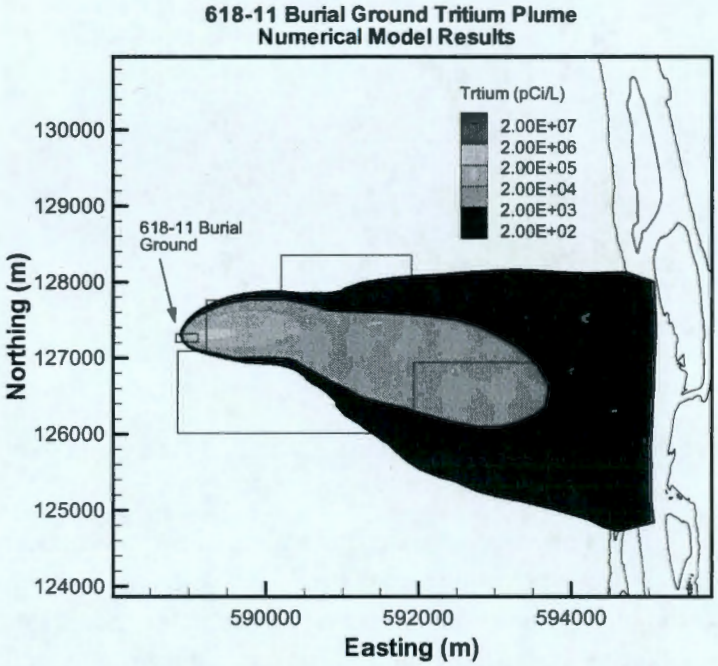

Figure 5.13. Case 5 Plume in 2017

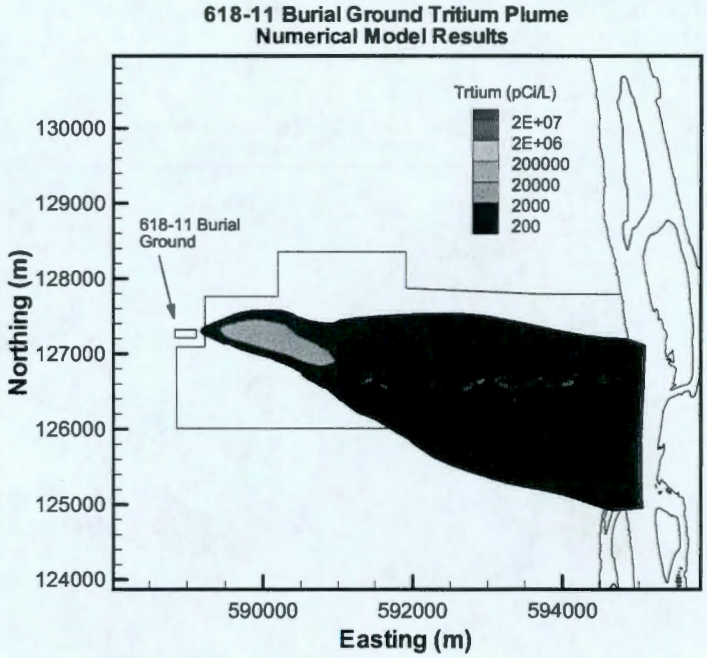

Figure 5.14. Case 5 Plume in 2040

5.3 Alternative Release Scenario 2: Twice the Initial Concentration

The second alternative release scenario incorporated the plume extent and pulse release used in the best-fit model but increased the initial tritium concentration by a factor of 2. This scenario was simulated to evaluate the impact associated with a higher concentration release from the burial ground on predicted arrival at downgradient receptor locations. For this alternative release scenario, predictive simulations indicate that the drinking water standard of 20,000 pCi/L is attained throughout the model domain in the year 2037, 36 years after the start of the simulated period (Figure 5.15) and six years after the time predicted for the best-fit model.

The peak tritium breakthrough occurs at the Energy Northwest water supply wells in 2010 (Figure 5.16), nine years after the start of the simulated period, and reaches a maximum concentration of 9,800 pCi/L. Peak arrival occurs in the same year as the best-fit case but at a

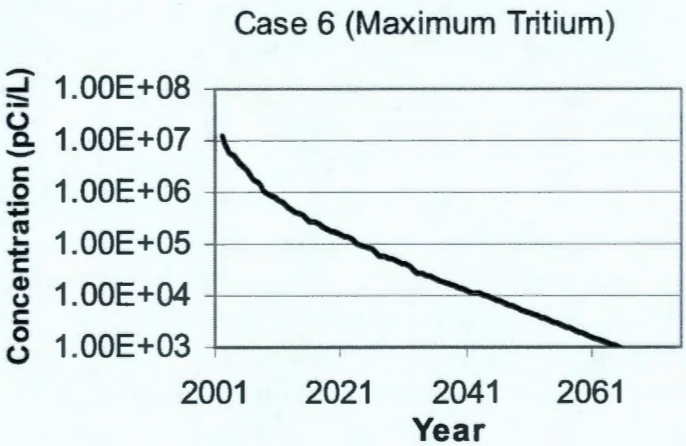

Figure 5.15. Case 6: Maximum Tritium Concentration in the Model Domain

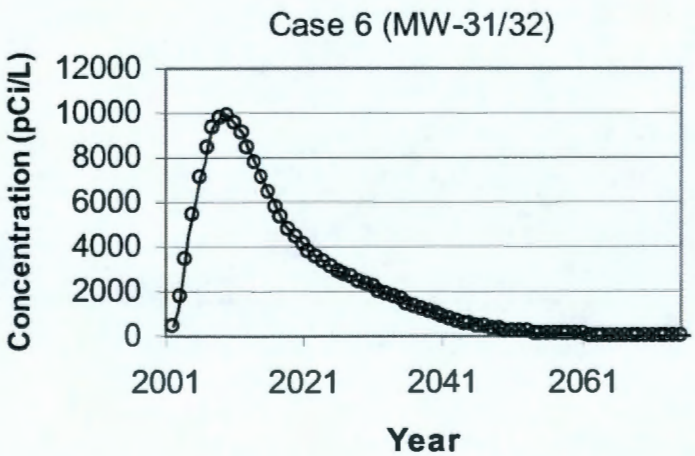

Figure 5.16. Case 6: Tritium Concentration at Energy Northwest Wells MW31 and MW32

concentration approximately twice as high. The additional mass predicted at this location is associated with the higher concentration specified for the tritium plume initial conditions. Peak tritium concentration at the Columbia River, shown in Figure 5.17, occurs in the year 2015, 14 years after the start of the simulated period, and reaches a peak concentration of 1,900 pCi/L. Relative to arrival response at the river for the best fit case, peak arrival for this case occurs one year sooner at a concentration approximately 1.9 times higher.

Figures 5.18 through 5.21 are time-series contour plots of tritium concentration at the water table. Figure 5.18 shows the initial tritium plume distribution after the plume used in the best-fit model (Case 3) was increased by a factor of 2. Comparing Figure 5.18 with Figure 5.5 shows that all of the high-concentration contours have increased in area. The overall size and shape of the plume does not change from the initial conditions used for the best fit model.

Figure 5.19 shows that the >2000 pCi/L contour is extended to the river and covers a larger area than that predicted for the best-fit case (Figure 5.6). The size of the other higher concentration contours is also more extensive than predicted by the best-fit model. Although the size and extent of the plume is greater for this case, the time of peak arrival at downgradient receptors is similar to that predicted by the best-fit model. This same type of plume extent relationship, relative to that predicted for the best fit model, was observed at subsequent time planes (see Figures 5.20 and 5.21). As was observed for the best fit case, during later times the highest concentration portions of the plume dissipate as the plume continues to expand and attenuate through radioactive decay. Throughout the simulated period, the highest tritium concentrations remain within the Ringold Formation sediments due to the relatively low groundwater velocities associated with these less-permeable materials. Figure 5.21 shows the tritium plume extent in 2037, the year when the maximum tritium concentration within the model domain is predicted to fall below the drinking water standard of 20,000 pCi/L.

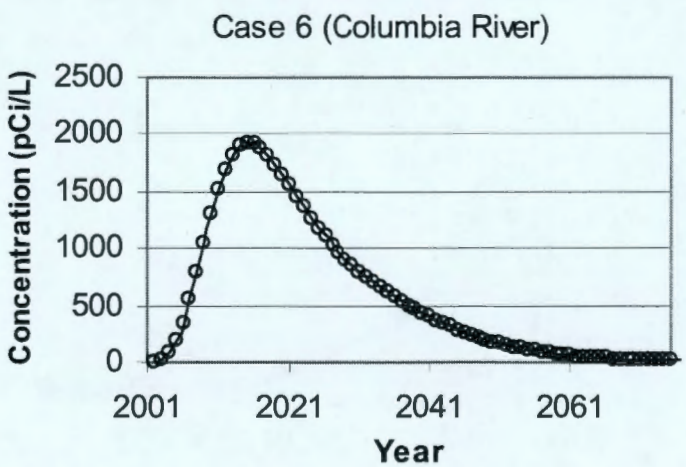

Figure 5.17. Case 6: Tritium Concentration at the Columbia River

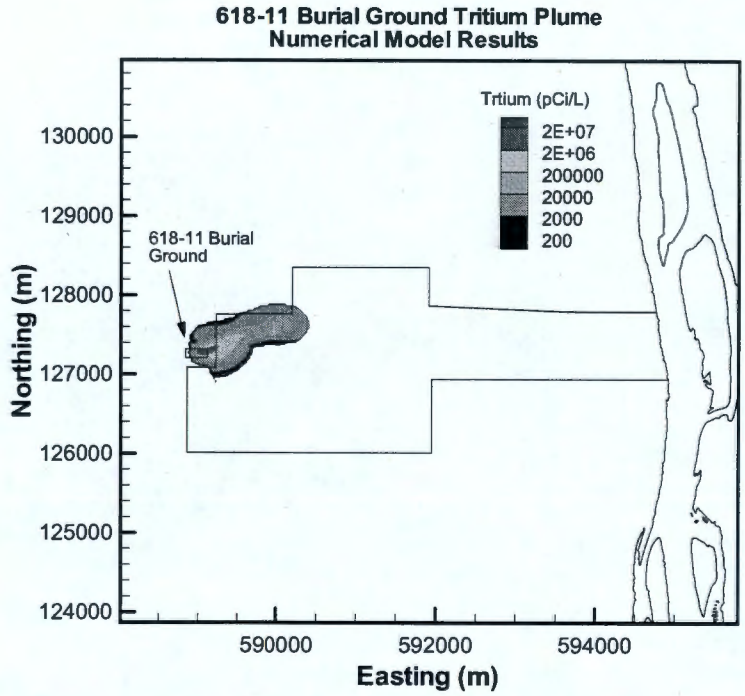

Figure 5.18. Tritium Concentration 2-D Flood Contour in 2001

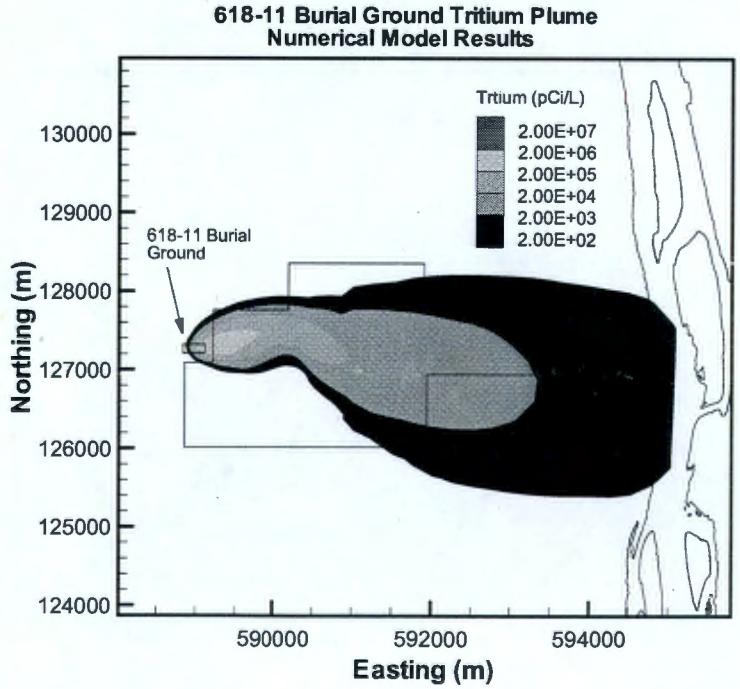

Figure 5.19. Tritium Concentration 2-D Flood Contour in 2007

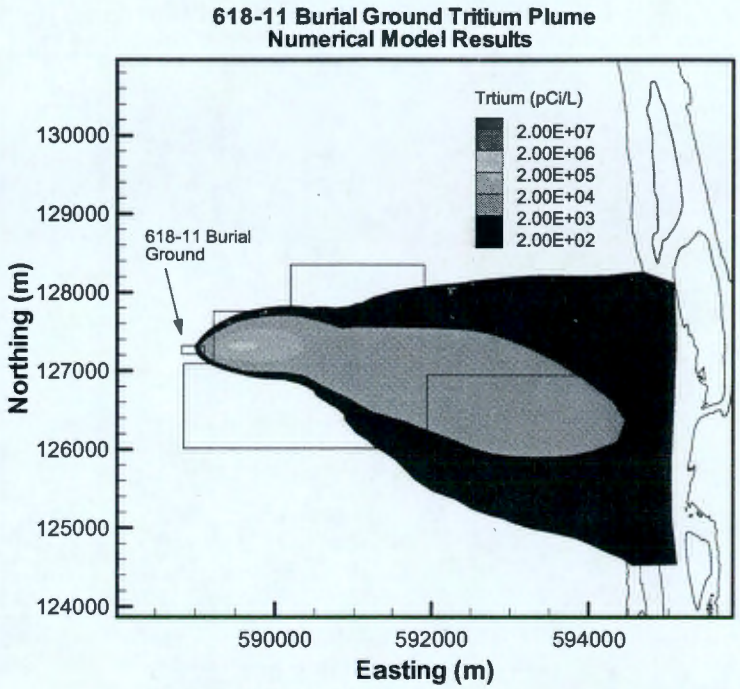

Figure 5.20. Tritium Concentration 2-D Flood Contour in 2017

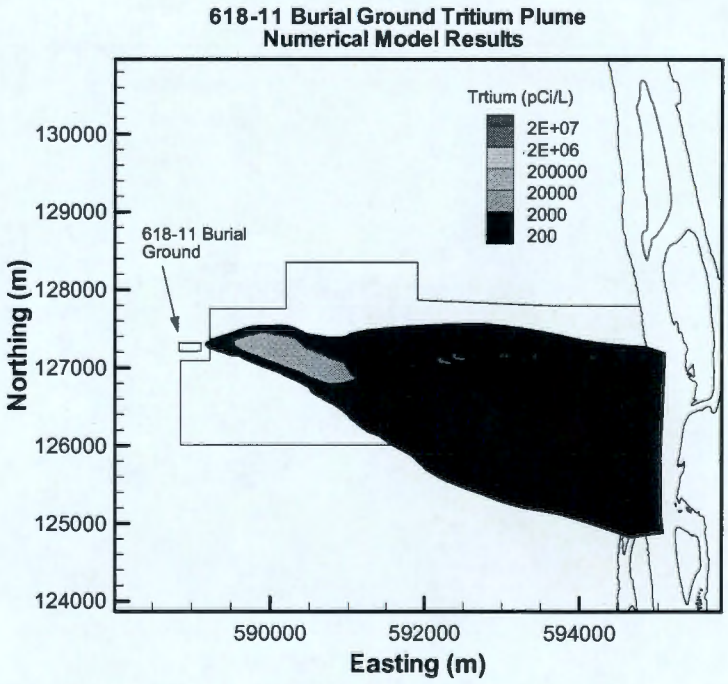

Figure 5.21. Tritium Concentration 2-D Flood Contour in 2037

6.0 Summary and Conclusions

A three-dimensional model of tritium transport associated with the 618-11-Burial Grounds was developed using the CFEST finite-element groundwater flow and transport code. The local-scale model is a refined submodel within the regional-scale Hanford Groundwater Model. Grid refinement entailed isolating a subdomain of the regional model and reducing the grid spacing for specific regions in the new model domain. This process includes superimposing the larger-scale hydrostratigraphic domain onto a smaller-scale, more refined grid. The hydrostratigraphy of the local-scale model was refined based on geologic information from additional boreholes located within the model domain and modified in a stepwise fashion using differences in simulated versus observed tritium concentrations downgradient from the burial ground to guide the calibration process. The objective of this initial phase of the modeling was to determine the most appropriate conceptual model for the 618-11 tritium plume initial conditions and release history and develop a flow and transport model that could provide a reasonable fit to observed tritium distributions.

The initial tritium plume conceptual model was modified during this process to achieve a reasonable match of the tritium plume at sequential time intervals. The first case investigated was based on the tritium plume conceptual model developed using contaminant distribution data collected during previous field investigations. Because the tritium plume was delineated using groundwater concentration data from monitoring wells outside the burial ground boundary (no well data are available from within the burial ground), the highest concentration contour was centered near well 699-13-3A, immediately outside the burial ground's eastern boundary. Initial model results showed that this plume configuration did not contain enough mass to match downgradient well measurements. Consequently, the high-concentration plume was extended beneath the burial ground to compensate for the observed deficit. Another aspect of the tritium plume conceptual model that was evaluated was the effect of a continuous decaying source. This release characteristic, which was implemented by maintaining the source concentration in surface nodes within the burial ground and reducing this held concentration at each time step to reflect radioactive decay, was investigated to determine its relative impact on tritium concentration trends in downgradient receptors.

The objective of Phase 2 of the modeling was, based on the best-fit model identified in Phase 1, to predict the long-term fate and transport of the tritium plume associated with the 618-11 Burial Ground. The best-fit model and two cases representing alternative release scenarios were evaluated to provide a measure of the impact that might be expected at primary receptors under different release conditions. For the best-fit model, which was based on a tritium plume conceptual model that incorporated a pulse release of the extended plume, simulation results indicate that tritium concentration will fall below the drinking water standard of 20,000 pCi/L by 2031, about 30 years after the start of the simulated period. Peak tritium concentration at the

Energy Northwest water supply wells is expected to occur in 2010 and at the Columbia River shoreline in 2016, at 4,900 pCi/L and 1,000 pCi/L, respectively.

The first alternative release scenario incorporated the plume initial conditions from the best-fit model but added a continuous decaying source that was maintained within the boundary of the burial ground for 14 years (2015); then it was removed and the tritium plume released as a pulse. The continuous source was maintained through 2015 to coincide with the milestone for source removal at the 618-11 Burial Ground under the River Corridor Closure Contract. For this alternative release scenario, predictive simulations indicate that the drinking water standard (20,000 pCi/L) was attained throughout the model domain in the year 2040, 39 years after the start of the simulated period and nine years after the best-fit model. Peak tritium concentrations at the Energy Northwest water supply wells are predicted to occur in 2013 and at the Columbia River shoreline in 2020, at concentrations of 6,200 and 1,400 pCi/L, respectively.

The second alternative release scenario incorporated the plume extent and pulse release used in the best-fit model but increased the initial tritium concentration by a factor of 2. This scenario was simulated to evaluate the impact of a higher-concentration release from the burial ground on predicted arrival at downgradient receptor locations. For this alternative release scenario, predictive simulations indicate that the drinking water standard of 20,000 pCi/L is attained throughout the model domain in the year 2037, 36 years after the start of the simulated period and five years after the best-fit model. Peak tritium concentrations at the Energy Northwest water supply wells and Columbia River shoreline are predicted to occur in 2010 and 2015, respectively, at concentrations of 9,800 and 1,900 pCi/L.

Predictive simulation results from this modeling effort indicate that tritium from the 618-11 Burial Ground is not expected to migrate to either of the two primary receptor locations, the Columbia River and Energy Northwest water supply wells MW-31 and -32, at concentrations exceeding the drinking water standard. These simulations do not consider pumping from the Energy Northwest water supply wells, which, if sustained at high rates for long periods of time, could increase the concentrations at this location.

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