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Revision 0

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COMPARISON OF THE CENTRAL PLATEAU GROUNDWATER MODEL WITH TRITIUM MIGRATION FROM 200 WEST AND THE 1956-57 DYE TRACER TESTS AT NRDWL

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
under Contract DE-AC06-08RL14788

CH2MHILL
Plateau Remediation Company

P.O. Box 1600
Richland, Washington 99352

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APPROVED
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ENVIRONMENTAL CALCULATION COVER PAGE

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ENVIRONMENTAL CALCULATION COVER PAGE (Continued)

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ENVIRONMENTAL CALCULATION COVER PAGE (Continued)

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Terms

CHPRC	CH2M HILL Plateau Remediation Company
CPGWM	Central Plateau Groundwater Model
ECF	environmental calculation file
F&T	fate and transport
HISI	Hanford Information System Inventory
SIM	Soil Inventory Model
SWL/NRDWL	Solid Waste Landfill/Nonradioactive Dangerous Waste Landfill

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1 Purpose

This analysis compares the result of transport modeling to field data measured at the Hanford Site. There are two sets of field data: tritium breakthrough at wells in 200-UP-1, and a set of historical tracer studies conducted near the Solid Waste Landfill/Nonradioactive Dangerous Waste Landfill (SWL/NRDWL) (HW-60601, *Aquifer Characteristics and Ground-Water Movement at Hanford*). These two sets of data were compared to transport modeling done using the Central Plateau Groundwater Model (CPGWM) (CP-47631, *Model Package Report: Central Plateau Groundwater Model, Version 8.4.5*).

The comparison for transport in 200-UP-1 was completed using particle tracking and transport simulations. Particles were released from the generalized tritium source area during the years the cribs received waste and simulated through 2016 to assess the general flow paths from the sources to the wells, as well as the feasibility of the sources' contribution to the tritium measured at the breakthrough wells. Tritium transport in the CPGWM was compared to the observed activity at selected wells. Two transport scenarios were considered: one that assumed a lag in arrival of the waste to the water table, and one that assumed instantaneous transport of the waste to the water table. The lag considered in the former scenario is due to transport through the vadose zone.

The historical tracer studies near SWL/NRDWL were simulated using the CPGWM. Three transport simulations were performed. The first made no changes to the CPGWM, except those required for simulating the injection of the tracer. The second transport simulation used an alternative flow model wherein the region with high hydraulic conductivity paleochannel properties was expanded laterally and vertically. The third transport model used the CPGWM flow model but changed the porosity and longitudinal dispersivities in the transport model.

2 Background

2.1 Tritium Breakthrough in 200-UP-1

A tritium plume exists in groundwater in the 200-UP-1 Operable Unit, as seen in Figure 2-1. Tritium breakthrough was observed at wells 299-W19-2, 699-35-70, 699-35-66A, 699-32-62, and 699-36-61A (SGW-60511, *Central Plateau Groundwater Tracer Study Work Plan*), among others. The most significant sources of tritium in this area, according to DOE/RL-2009-122, *Remedial Investigation/Feasibility Study for the 200-UP-1 Groundwater Operable Unit*, are seven cribs: 216-S-1, 216-S-2, 216-S-7, 216-S-21, 216-S-25, 216-U-8, and 216-U-12. Figure 2-1 depicts the locations of these cribs. The cribs received waste from 1952 through 1980, with the majority of the tritium being released in the 1950s and 1960s. Table 2-1 shows the years during which each crib received waste, along with the total amount of curies of tritium received. Appendix B has the breakdown of the curies of tritium received per waste site per year.

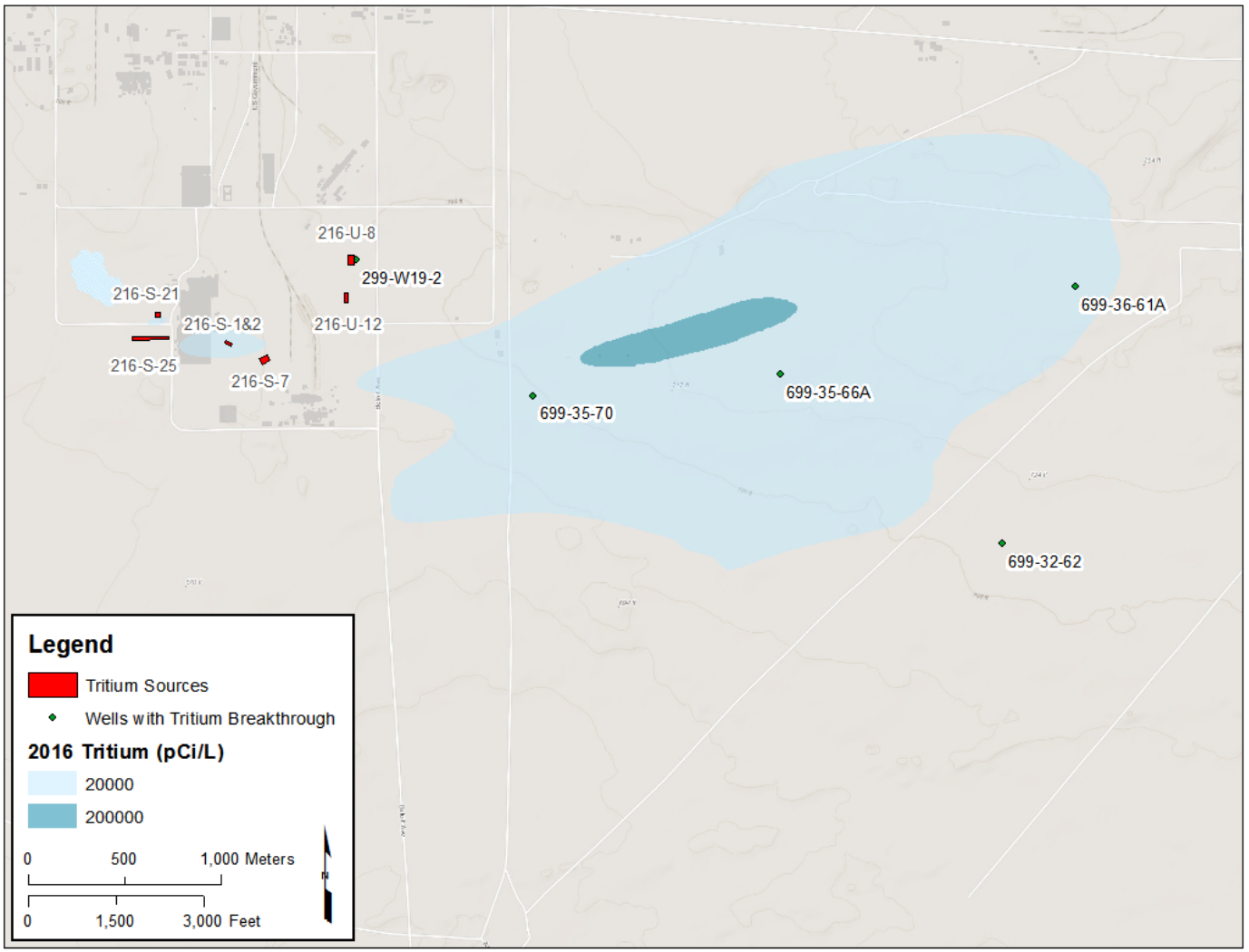


Figure 2-1. A Map of the 2016 Tritium Plume, the Source Areas, and the Wells with Breakthrough Discussed in SGW-60511 and this Report

Table 2-1. Tritium Released in 200-UP

Waste Site	Years Active	Total Curies of Tritium Released*
216-S1&2	1952–1956	35,200
216-S-7	1956–1965	81,300
216-S-21	1954–1969	22,800
216-S-25	1973–1980, 1985	14,100
216-U-8	1952–1960	60,100
216-U-12	1960–1972, 1981-1988	20,200

Reference: RPP-26744, *Hanford Soil Inventory, Rev. 1.*

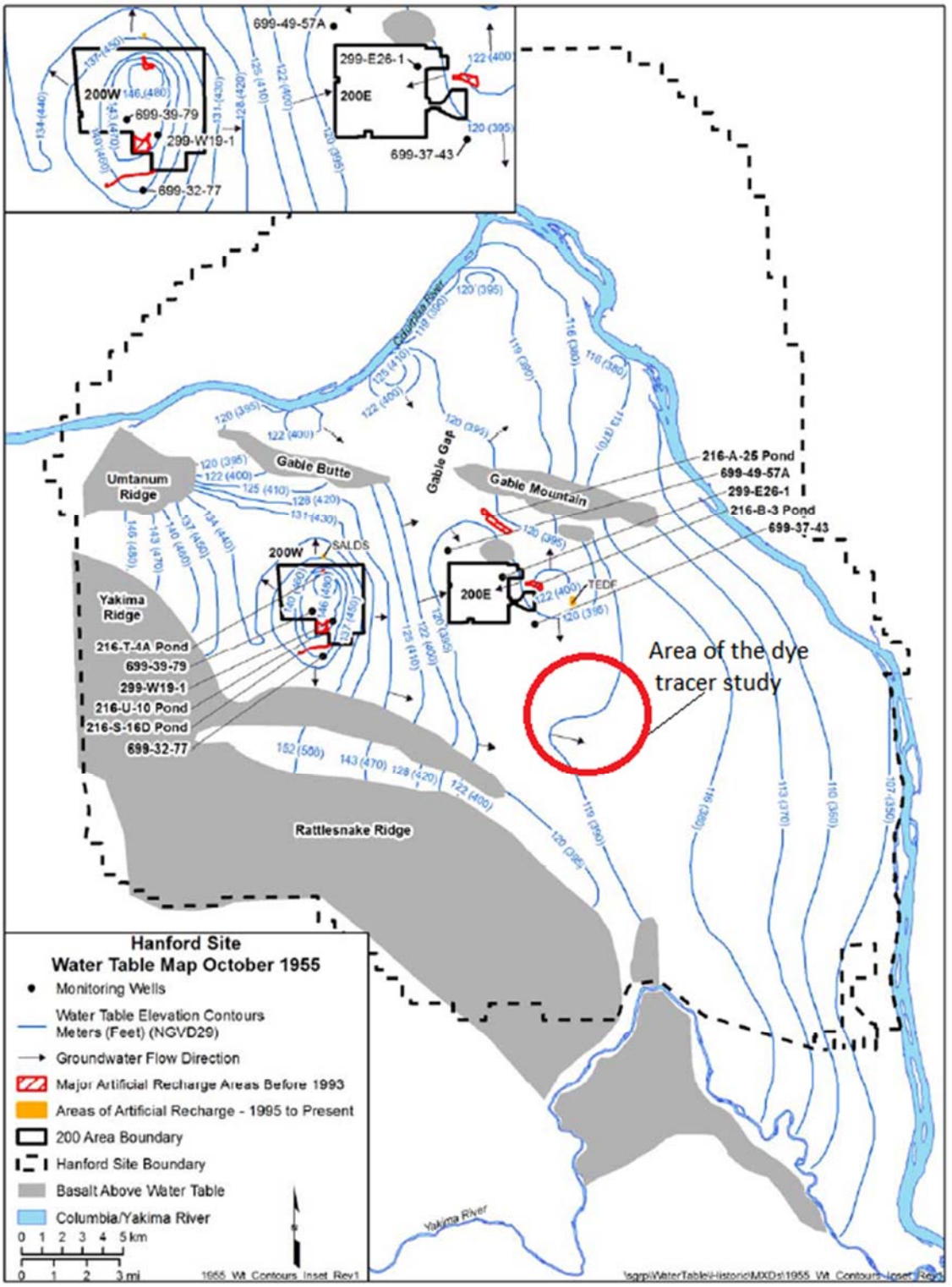
*Tritium values reported in RPP-26744 are decayed to 01/01/2001. The values in this table were undecayed to the release year.

2.2 Historical Dye Tracer Studies

Groundwater tracer studies were conducted in 1956 and 1957 near SWL/NRDWL (HW-60601). Figure 2-2 shows the general location of the tracer studies overlain on the 1955 water table map. In these studies, a solution of 100 pounds of sodium fluorescein dye in 100 gallons of water was injected into a well, and samples were taken at downgradient wells to capture the breakthrough curve. Injection occurred at 699-28-40 (HW-60601 refers to this well as 699-28-41) in 1956, and 699-24-33 in 1957. The injection and observation wells for each of these studies can be seen in Reference: SGW-60511, Central Plateau Groundwater Tracer Study Work Plan

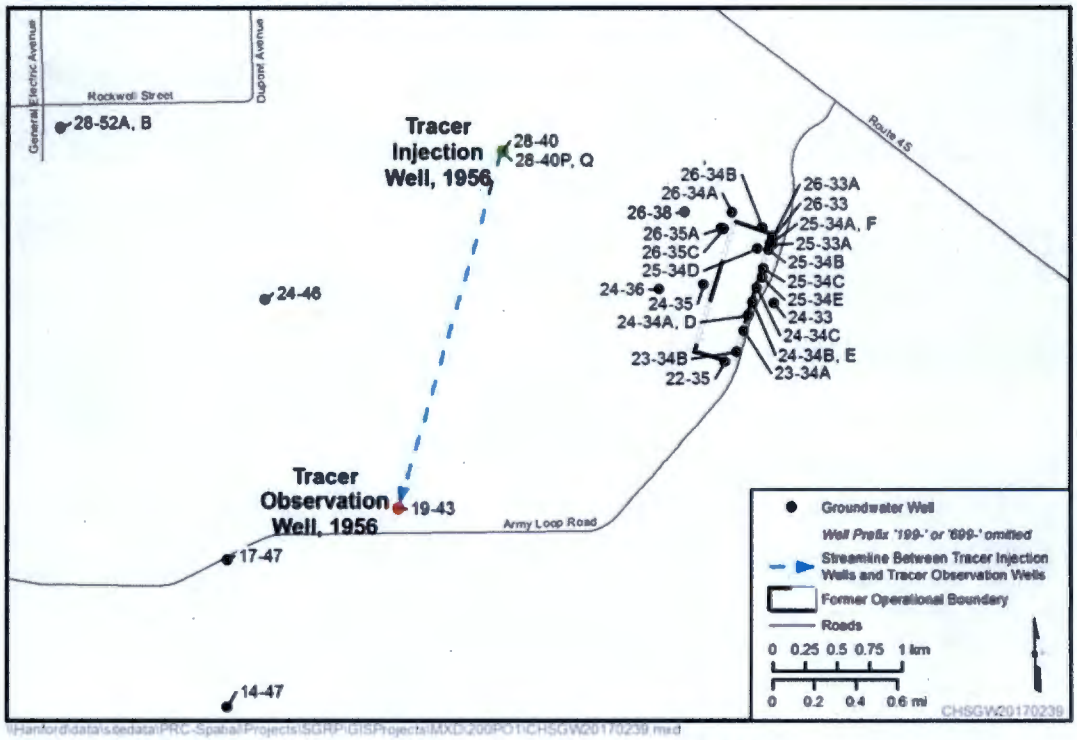
Figure 2-3 and Reference: SGW-60511, Central Plateau Groundwater Tracer Study Work Plan

Figure 2-4. Table 2-2 shows the results of the tracer tests from HW-60601. The results of these tracer studies indicated velocities ranging from 85 to 130 m/day (280 to 440 ft/day) for the 1956 study, and 26 to 59 m/day (85 to 195 ft/day) for the 1957 study.



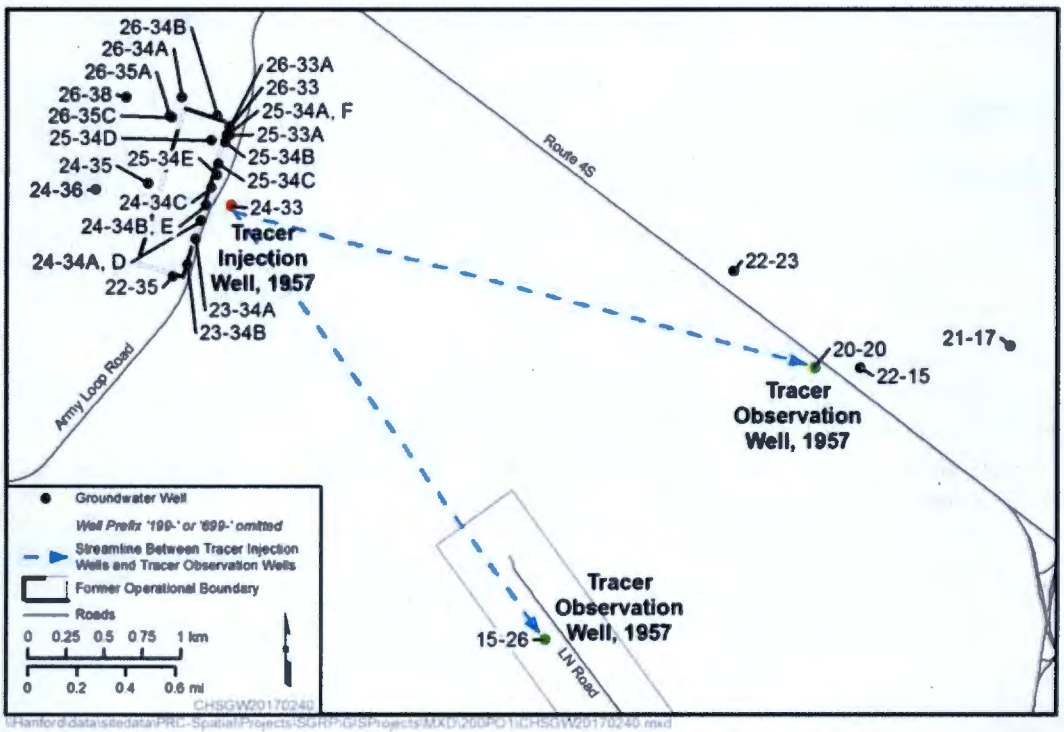
Modified from: SGW-60338, *Historical Changes in Water Table Elevation and Groundwater Flow Direction at Hanford: 1944 to 2014*

Figure 2-2. Area of Dye Tracer Study Overlain on the 1955 Water Table Map



Reference: SGW-60511, *Central Plateau Groundwater Tracer Study Work Plan*

Figure 2-3. Map of the Injection and Observation Wells in the 1956 Dye Tracer Study



Reference: SGW-60511, *Central Plateau Groundwater Tracer Study Work Plan*

Figure 2-4. Map of the Injection and Observation Wells in the 1957 Dye Tracer Study

Table 2-2. Historical Tracer Study Results

Observation Well Name	Distance from Injection Well (m [ft])	Travel Time in Days		Velocity (m/day [ft/day])	
		First Detection	Peak	First Detection	Peak
699-19-43	2,860 (9,383)	20	31	130 (440)	85 (280)
699-15-26*	3,510 (11,500)	67	134	52 (170)	26 (85)
699-20-20	4,020 (13,200)	67	129	59 (195)	30 (100)

Reference: HW-60601, *Aquifer Characteristics and Ground-Water Movement at Hanford.*
*Well 699-15-26 was formerly identified and reported as 699-14-27 in HW-60601.

3 Methodology

The flow and transport results computed with the CPGWM were compared to the data measured in the field. Alternative simulations with slightly different flow and transport properties were also tested. This section outlines the ways in which the CPGWM and associated alternative simulations were compared against the field observations. Because the field observations occurred in disparate parts of the model, the modeling work was split into two categories: modeling related to the tritium breakthrough at 200-UP-1 and modeling related to the historical tracer tests near SWL/NRDWL.

3.1 Modeling Tritium in 200-UP-1

Fate and transport (F&T) related to the tritium plume in 200-UP-1 was analyzed using particle tracking and transport modeling. The particle tracking visualized the modeled flow paths from the tritium sources to the wells. The transport modeling compared the simulated tritium breakthrough from the CPGWM against observed values.

3.1.1 Particle Tracking in 200-UP-1

Forward particle tracking was conducted in 200-UP-1 to visualize the flow paths from the tritium source area to the wells with tritium breakthrough. The CPGWM was used as the flow model. One particle per cell was released in the area depicted in Figure 3-1 starting in 1952 and once every five years through 1987. The area in Figure 3-1 allows a buffer of at least 400 m around each source, to get a general understanding of flow at the site.

The major sources of tritium at 200-UP-1 are cribs 216-S-1, 216-S-2, 216-S-7, 216-S-21, 216-S-25, 216-U-8, and 216-U-12 (RPP-26744, *Hanford Soil Inventory, Rev. 1*, hereinafter referred to as the Soil Inventory Model [SIM]). It was assumed that some spatial redistribution of the tritium occurred in the vadose zone. Figure 3-2 shows the source locations and the grid cells over which the spatial distribution was assumed to have taken place.

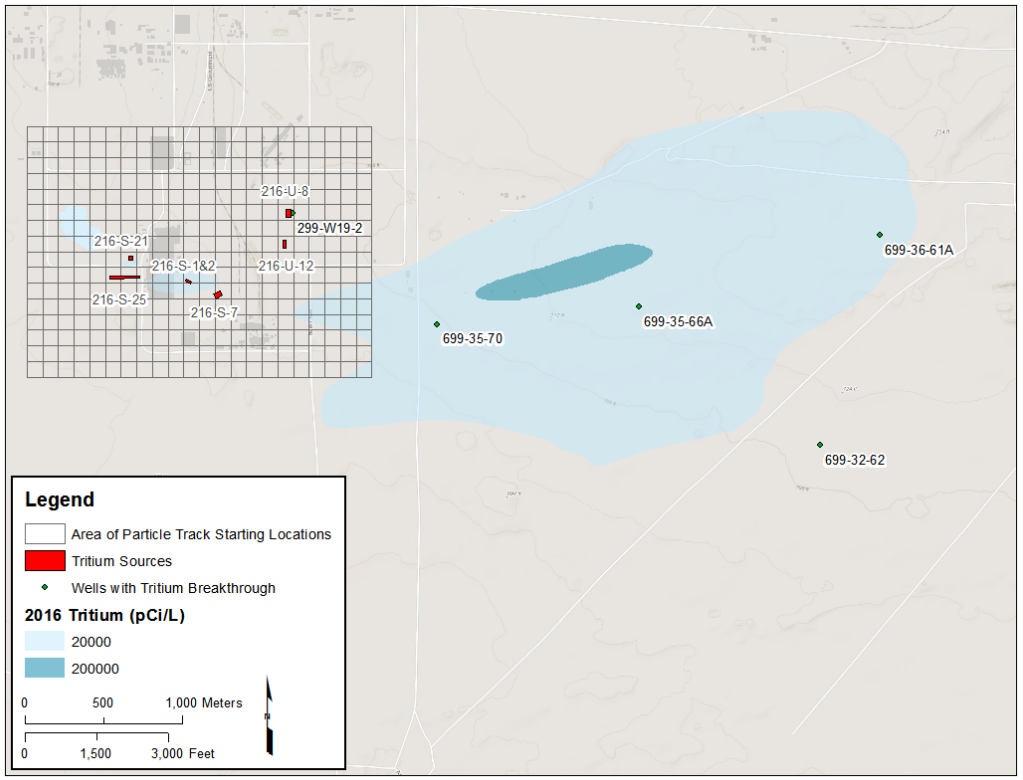


Figure 3-1. Particle Starting Locations

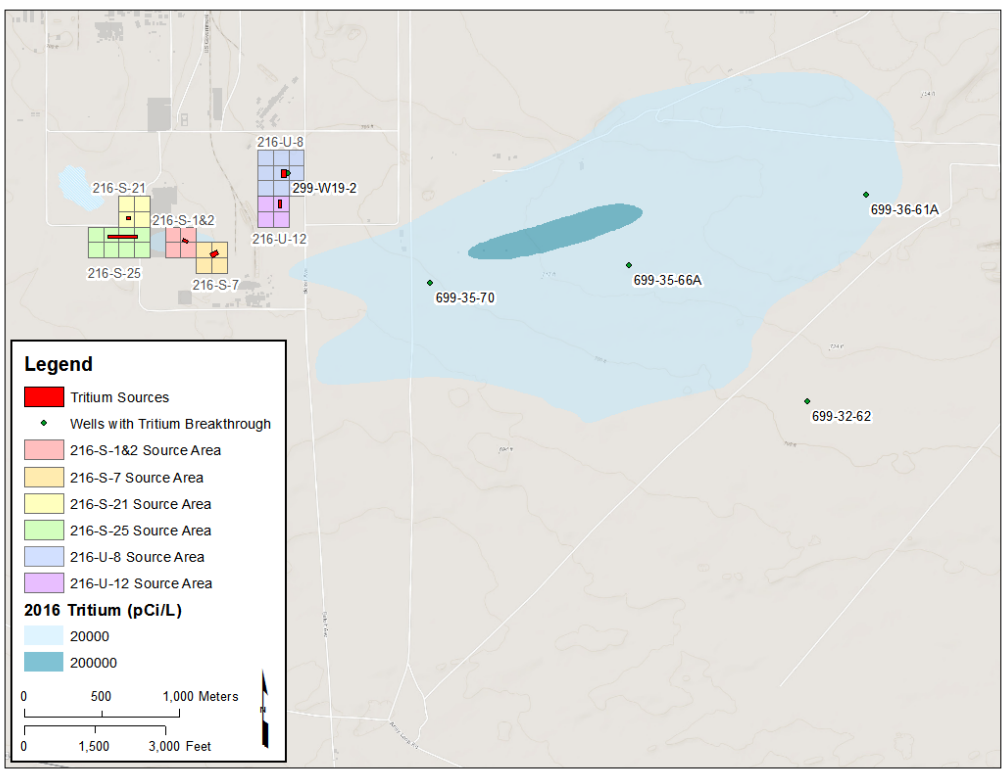


Figure 3-2.Tritium Source Areas Used in Transport Modeling

3.1.2 Transport Simulations

Two transport simulations were considered: one that assumed a lag between waste release and arrival at the water table and one that assumed instantaneous arrival of waste at the water table. The CPGWM flow model was used for both the transport simulations. The transport scenario that assumed a lag in arrival times was completed for and documented in CP-47631. The steps for building the transport scenario that did not assume a lag are outlined as follows:

First, the major tritium sources in the area of interest were identified. Then, the inventories for these sources were retrieved from the SIM. The SIM reports the inventories released from each waste site for each year, where the inventories for radionuclides have been decayed to their values on January 1, 2001. For use in the transport modeling scenario, the tritium values were undecayed to the midpoint of the year in which they were released (Appendix B). The tritium sources were applied over several grid cells in the model, as seen in Figure 3-2, to simulate lateral spreading of the source.

The observed tritium concentrations for the wells seen in Figure 2-1 were compared against the modeled tritium concentrations.

3.2 Modeling the Historical Dye Tracer Study

Transport modeling of the historical dye tracer studies was conducted. All modeled scenarios were based on the CPGWM. Two flow scenarios were modeled and three transport scenarios were modeled. One flow scenario used the CPGWM unmodified, except that one-hour timesteps at the beginning of 1956 and 1957 were added to allow for injection of the tracer. This flow scenario is referred to as the base case scenario in this document. The second flow scenario used the CPGWM as a template and changed the hydraulic conductivity in two ways: first, the hydraulic conductivity of the paleochannel and surrounding high-conductivity values near the injection wells were copied from layer 2 to layer 3; second, an inter-channel area in the paleochannel of layer 3 was changed to match paleochannel properties. This flow scenario is referred to as the alternative hydraulic conductivity scenario in this document.

HW-60601 stated that the high groundwater velocities of the tracer tests were due to their placement in the high-conductivity paleochannel. In the CPGWM, paleochannel properties are present in this area in layer 2. Layer 2 goes intermittently dry through the duration of this model. Layer 3 does not go dry during the simulation, so the paleochannel properties were copied to layer 2 in the area of interest. Figure 3-3 is a map of the hydraulic conductivity of the layer 2 sediments in the model. Note that the paleochannel sediments, which have a hydraulic conductivity of 15,000 m/day, split upgradient of the 1957 injection well (699-24-33), leaving a section of low (compared to the paleochannel values) conductivity that envelops both well 699-24-33 and the likely flow paths to the downstream wells. Figure 3-4 is a map of the unaltered hydraulic conductivity of layer 3 of the CPGWM. The paleochannel is not present in this area in this layer and low hydraulic conductivity values are present in the southeast corner. The hydraulic conductivity in layer 3 for the alternative flow model is seen in Figure 3-4. The paleochannel sediments have been inserted to the north of the injection wells and the inter-channel area has been filled with paleochannel sediments. Channel properties were copied from layer 2 into layer 3 because layer 2 intermittently goes dry and layer 3 does not.

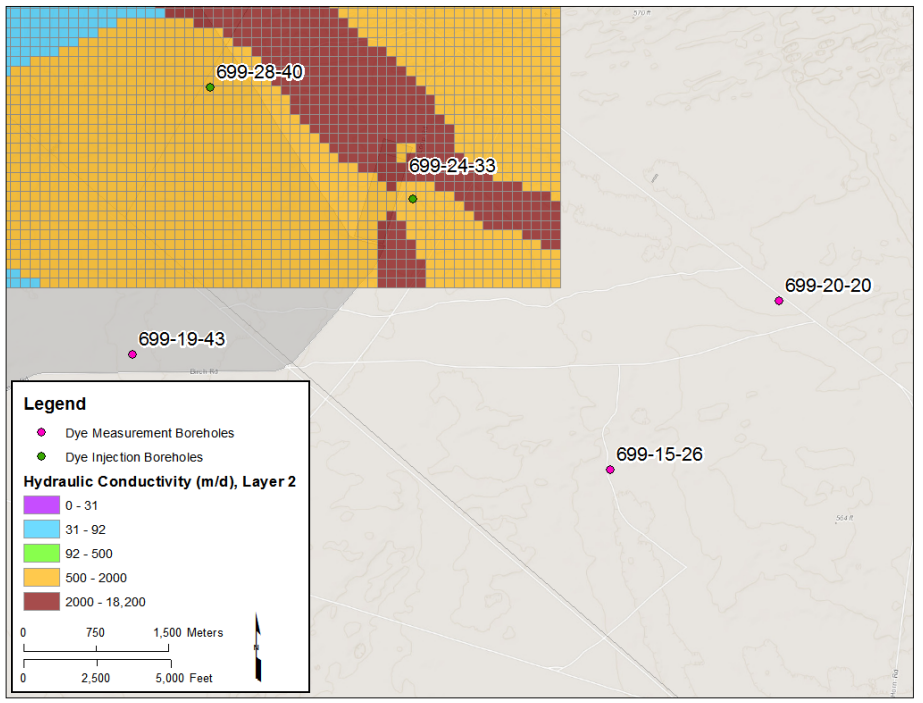


Figure 3-3. Map of Hydraulic Conductivity in Layer 2 of the CPGWM in the Region of the Dye Tracer Study

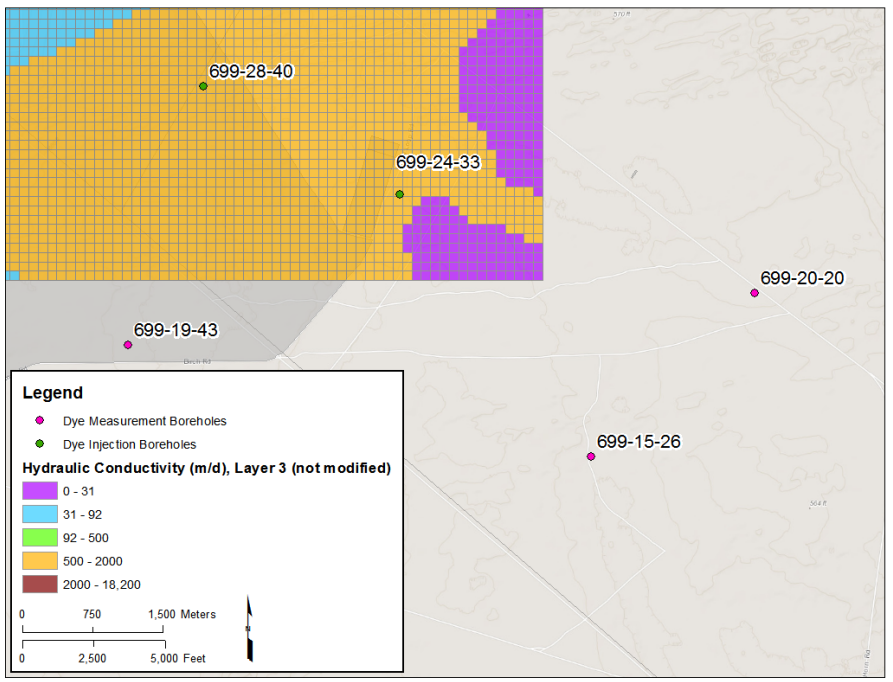


Figure 3-4. Map of Hydraulic Conductivity in Layer 3 of the CPGWM in the Region of the Dye Tracer Study

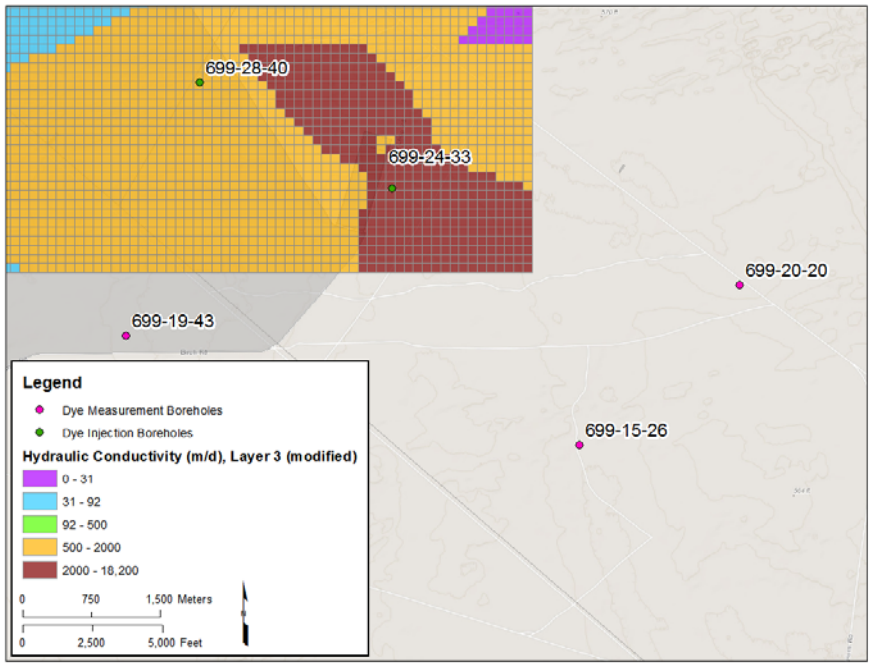


Figure 3-5. Map of Hydraulic Conductivity in Layer 3 of the Second Flow Scenario when Modeling the Dye Tracer Study

Three transport simulations were performed. The CPGWM tracer dye transport simulation was calculated once using the CPGWM flow model with the base case scenario and once using the flow scenario with altered hydraulic conductivity seen in Figure 3-5. The third transport simulation used the CPGWM flow model base case scenario and altered the porosity and longitudinal dispersivity in layer 3. For a sensitivity analysis, the porosity of the layer was changed to 0.09 and the longitudinal dispersivity of the layer was changed to 20 m to enhance lateral migration. This transport scenario is referred to in this document as the alternative transport properties scenario.

HW-60601 calculated groundwater velocities and hydraulic conductivity based on the dye tracer studies. The hydraulic gradient used to calculate the hydraulic conductivity was not included in HW-60601. The average hydraulic gradient was calculated in this document using water levels contemporaneous to the dye tracer study in wells 699-19-43, 699-24-33, and 699-28-40. The wells used in a three-point calculation to calculate the hydraulic gradient and gradient direction are seen in Figure 3-6.

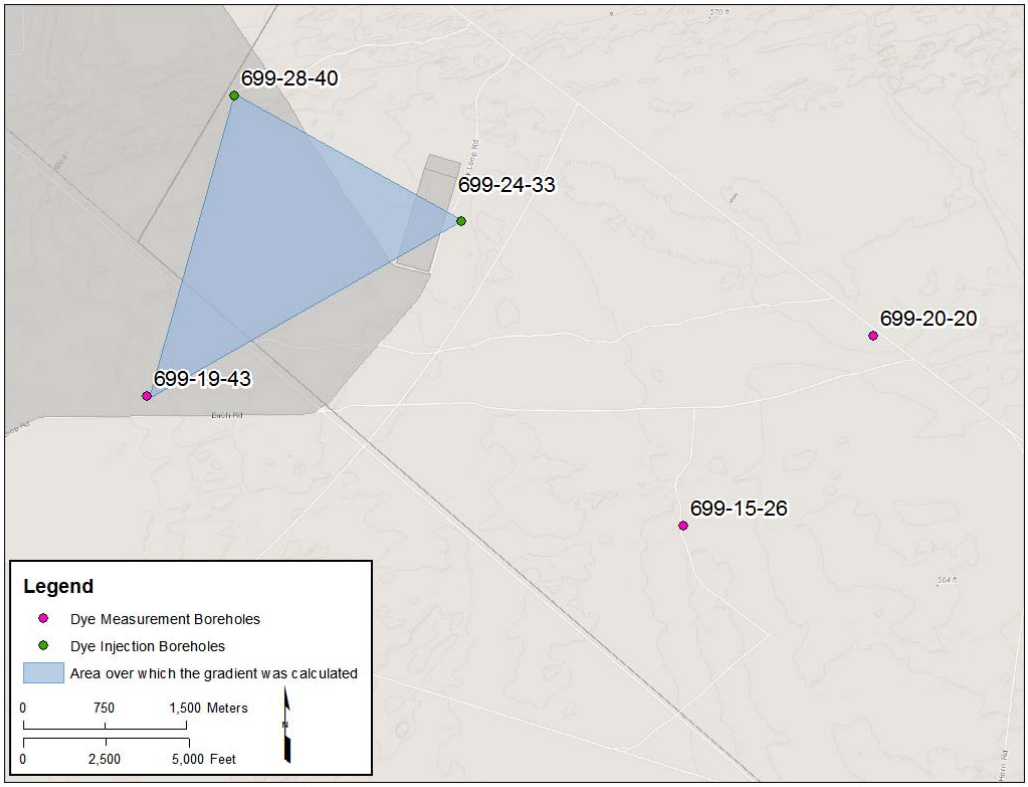


Figure 3-6. Map of the Wells Used to Calculate the Hydraulic Gradient

The hydraulic gradient and gradient direction were calculated for May, October, and December 1956, and January, February, March, April, May, June, and August 1957 using a three-point solution (Table 3-1). The direction of flow was calculated to be approximately 180 degrees, or due south, consistent with the observed migration of the dye tracer from 699-28-40 to 699-19-43. Therefore, the calculation done by this document is for the velocity of the dye tracer from 699-28-40 to 699-19-43. The average gradient magnitude determined from the water-level measurements is 2.4e-04. Using the calculated average gradient of 2.4e-04, the hydraulic conductivity of 4,280 m/day reported in HW-60601, the effective porosity of 0.1 reported in HW-60601, and the distance between the wells of 2,860 m (9,383 ft), the travel time calculated was 260 days, a velocity of 10 m/day.

HW-60601 calculated the hydraulic conductivity at each observation well based on the arrival of the dye. One hydraulic conductivity was calculated based on the first arrival of dye at the well, and the second was based on the arrival of the peak concentration. The slower of the two is the arrival of the peak concentration. The hydraulic conductivity calculated in HW-60601 using the arrival of the peak concentration at well 699-19-43 was 4,280 m/day. Table 2-2 indicates HW-60601 reported a travel time of 31 days for the peak concentration for well 699-19-43. To reproduce the velocities indicated by the dye tracer study using the hydraulic conductivity reported in HW-60601, the hydraulic gradient would need to be about an order of magnitude higher than observed in the water-level data. The reason for this inconsistency is not known.

Table 3-1. Water Levels at Wells in the Dye Tracer Study Area and Hydraulic Gradient and Gradient Direction Calculated using those Water Level Data

Well Name	Measurement Date	Water Level Elevation (NAVD88 m)	Hydraulic Gradient	Gradient Direction (azimuth)
699-19-43	4/19/1956	120.709	1.8E-04	165.8
699-24-33	5/29/1956	120.859		
699-28-40	5/29/1956	121.15		
699-19-43	10/15/1956	120.806	2.8E-04	171.3
699-24-33	10/15/1956	121.124		
699-28-40	10/20/1956	121.528		
699-19-43	12/19/1956	120.925	2.6E-04	180.6
699-24-33	12/21/1956	121.343		
699-28-40	12/21/1956	121.634		
699-19-43	1/28/1957	120.983	2.5E-04	181.1
699-24-33	1/28/1957	121.401		
699-28-40	1/28/1957	121.683		
699-19-43	2/15/1957	120.977	2.7E-04	182.8
699-24-33	2/15/1957	121.444		
699-28-40	2/8/1957	121.726		
699-19-43	3/14/1957	121.056	2.6E-04	175.8
699-24-33	3/14/1957	121.423		
699-28-40	3/14/1957	121.768		
699-19-43	4/15/1957	121.169	2.4E-04	176.9
699-24-33	4/15/1957	121.517		
699-28-40	4/15/1957	121.823		
699-19-43	5/16/1957	121.224	2.3E-04	177.7
699-24-33	5/16/1957	121.566		
699-28-40	5/16/1957	121.851		
699-19-43	6/27/1957	121.279	2.2E-04	178.4
699-24-33	6/24/1957	121.612		
699-28-40	6/24/1957	121.878		

Table 3-1. Water Levels at Wells in the Dye Tracer Study Area and Hydraulic Gradient and Gradient Direction Calculated using those Water Level Data

Well Name	Measurement Date	Water Level Elevation (NAVD88 m)	Hydraulic Gradient	Gradient Direction (azimuth)
699-19-43	8/23/1957	121.291	2.2E-04	180.4
699-24-33	8/23/1957	121.648		
699-28-40	8/23/1957	121.9		

NAVD88, *North American Vertical Datum of 1988.*

4 Assumptions and Inputs

The particle tracking calculation ignored tritium sources other than the seven main sources and assumed that tritium spread laterally in the vadose zone. The assumed lateral spread at each of the sources is seen in Figure 3-2. The CPGWM considered many sources and accounted for delay of inventory as the sources moved through the vadose zone (CP-47631).

The dye tracer modeling assumed all the dye arrived at the water table in the span of an hour. The dye slug modeled had the same concentrations reported in HW-60601: 45 kilograms (100 pounds) of sodium fluorescein dye in 0.38 cubic m (100 gal) of water. When the alternative flow scenario was considered, only a portion of the hydraulic properties from layer 2 were copied to layer 3, as to not cause issues with the model functioning. The alternative transport properties considered changed to values that would increase transport speed while still remining plausible transport property values.

5 Software Applications

Software was used in this calculation compliant with procedure PRC-PRO-IRM-309, *Controlled Software Management*, which implements the requirements of DOE O 414.1D, *Quality Assurance*. Software used is to be registered on the Hanford Information System Inventory (HISI) and identified as approved for use. Use of approved software graded as safety software is logged in HISI.

5.1 Approved Software

PRC-PRO-IRM-309 requires that the following information be reported for use of approved software.

5.1.1 MODFLOW-2000-MST

MODFLOW-2000-MST is an approved calculation software (CHPRC-00258, *MODFLOW and Related Codes Software Management Plan*). The single-precision executable was used to calculate the capture zone analysis, and the double-precision executable was used to calculate the flow for the F&T simulations.

- Software Title: MODFLOW-2000-MST
- Software Version: MODFLOW-2000, modified by S.S. Papadopulos and Associates for minimum saturated thickness and to use the ORTHOMIN Solver. Approved as CH2M HILL Plateau Remediation Company (CHPRC) Build 8 using executable file mf2k-mst-0008dpl.x (for Linux) or mf2k-mst-0008dpl.exe (for Microsoft Windows), both compiled to default double precision for real variables.
- HISI Identification Number: 2517

- Workstation type and property number: Personal computer, PSC-XENON, 00857
- Authorized User: M Weber
- Software Vendor Documents:
  - Harbaugh et al. (2000), *MODFLOW-2000, the U.S. Geological Survey Modular Ground-Water Model – User Guide to Modularization Concepts and the Ground-Water Flow Process*
- CHPRC Software Control Documents:
  - CHPRC-00257, *MODFLOW and Related Codes Functional Requirements Document*
  - CHPRC-00258, *MODFLOW and Related Codes Software Management Plan*
  - CHPRC-00259, *MODFLOW and Related Codes Software Test Plan*
  - CHPRC-00260, *MODFLOW and Related Codes Requirements Traceability Matrix*
  - CHPRC-00261, *MODFLOW and Related Codes Acceptance Test Report*

5.1.2 MT3DMS-2000-MST

MT3DMS-2000-MST is an approved calculation software (CHPRC-00258). The single-precision executable was used to calculate the particle track analysis, and the double-precision executable was used to calculate the transport for the F&T simulations.

- Software Title: MT3DMS-2000-MST
- Software Version: MT3DMS, modified by S.S. Papadopulos and Associates for minimum saturated thickness and to use the ORTHOMIN Solver. Approved as CHPRC Build 8 using executable file mt3d-mst-0008dpl.x (for Linux) or mt3d-mst-0008dpl.exe (for Microsoft Windows), both compiled to default double precision for real variables.
- HISI Identification Number: 2518
- Workstation type and property number: Personal computer, PSC-XENON, 00857
- Authorized User: M Weber
- Software Vendor Documents
- Zheng, C. and Wang, P.P. (1999), *MT3DMS: A Modular Three-Dimensional Multispecies Transport Model for Simulation of Advection, Dispersion, and Chemical Reactions of Contaminants in Groundwater Systems; Documentation and User's Guide*

5.1.3 MODFLOW and Related Codes Support Software

CHPRC-00257 distinguishes calculational software from supporting software because these two groups of software are classified and graded differently. The basis for the difference is that calculational software, including MODFLOW-2000-MST, calculate results that will be used to support decision-making and, as such, constitute safety software graded to level C. In contrast, supporting software includes graphical interfaces, visualization, and input preparation support but not calculation of results that directly support decision-making, and are, therefore, not rated as safety software. The support software items identified in CHPRC-00258 and used in this calculation follow:

- ArcGIS®[1]: Provided visualization for assessing simulated plume distributions, processing particle track shapefiles, creating maps, and pre-processing some input files.
- Groundwater Vistas: Used graphical tools for model input/output review. Used for pre-processing some input files.
- Microsoft Excel®[2]: Used for post-processing calculations and creating graphs of results.
- MODPATH: USGS version of MODPATH version 6.0.0.1 was used for forward particle tracking.
- Perl: Used for post-processing results.
- R: Used for editing the hydraulic conductivity for the alternative flow simulation.

5.1.4 Software Installation and Checkout

Safety Software (MODFLOW-2000-MST and MT3DMS-MST) was checked out and installed in accordance with procedures specified in CHPRC-00259. Executable files were obtained from the CHPRC software owner, installation tests identified in CHPRC-00259 were performed and confirmed, and required Software Installation and Checkout Forms were completed and approved for installations used to perform model runs reported in this environmental calculation file (ECF). A copy of the Software Installation and Checkout Forms for the authorized user and authorized workstation for software used in this calculation is provided in Appendix A to this ECF.

5.1.5 Statement of Valid Software Application

The preparers of this calculation attest that the software identified above and used for the calculations described in this document is appropriate for the application and used within the range of intended uses for which it was tested and accepted by CHPRC.

6 Results

6.1 Tritium Forward Particle Tracking Results

Particles were released from the area depicted in Figure 3-1 at 5-year intervals beginning in 1952 and ending in 2016 to observe the flow paths from the tritium sources to the wells. Particles that passed within a 100 m radius of the wells seen in Figure 3-1 were considered to have come close enough to the well to feasibly have contributed to tritium at the well. Figure 6-1 through Figure 6-8 show the evolution of the paths of particles that reach the wells with tritium breakthrough. The maps have filtered the particle track data such that only the tracks that come within the 100 m radius around the wells are visible. Those tracks are color-coded according to which well they reach. Figure 6-1 through Figure 6-8 indicate the general source areas for each of the wells. Wells 699-35-66A and 699-36-61A are only reached by particles released in the 1950s. To the south of the observed tritium plume, there is a section of high-conductivity Cold Creek unit gravel deposits in the CPGWM flow model that creates a preferential flow path. This flow path is visible in the tracks of the particles that reach well 699-32-62 (Figure 6-1 through Figure 6-6). These particles are pulled to the south, and have abrupt, angular turns when entering and exiting the high-conductivity unit.

[1] ArcGIS is a registered trademark of ESRI.

[2] Excel is a registered trademark of Microsoft Corporation in the United States and in other countries.

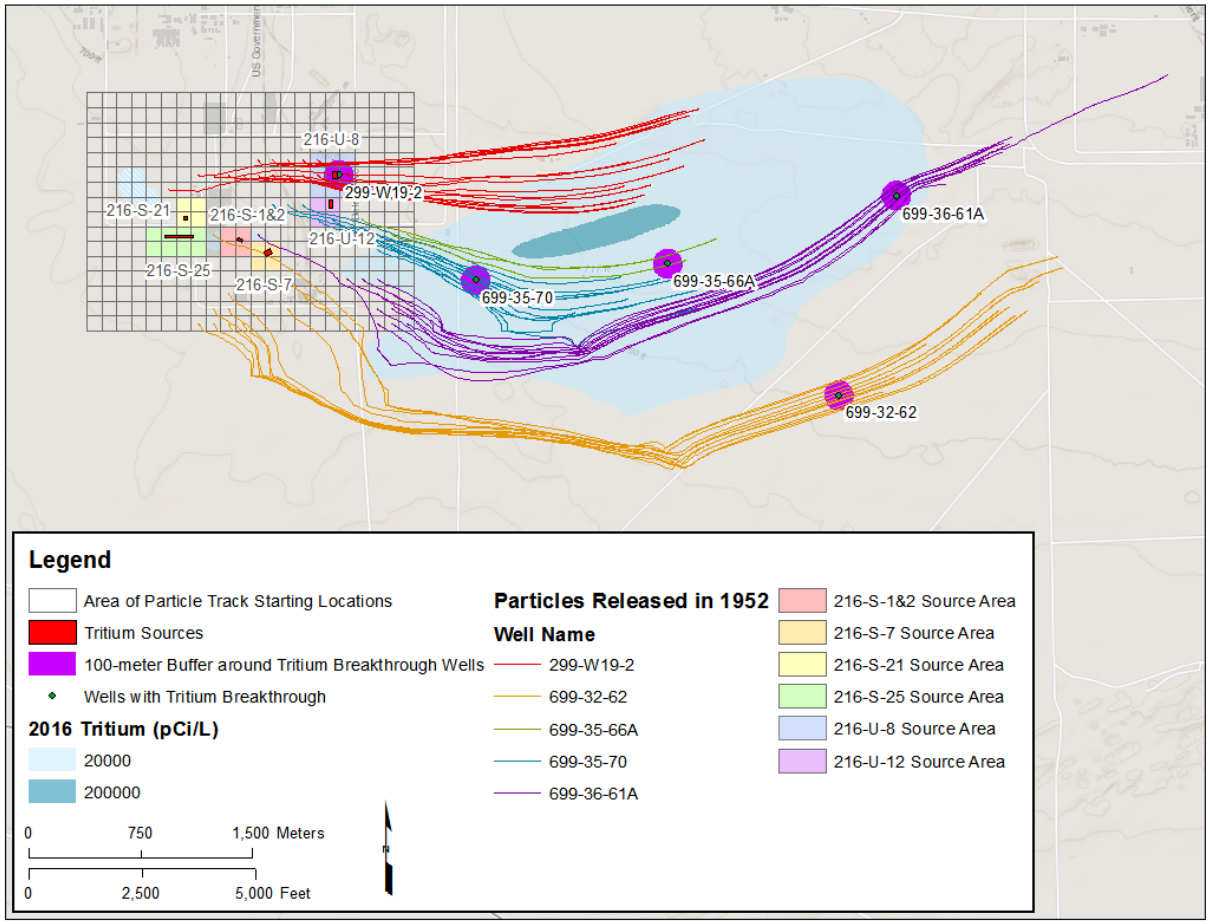


Figure 6-1. Particles Released in 1952 that Reach Selected Wells with Observed Tritium Breakthrough

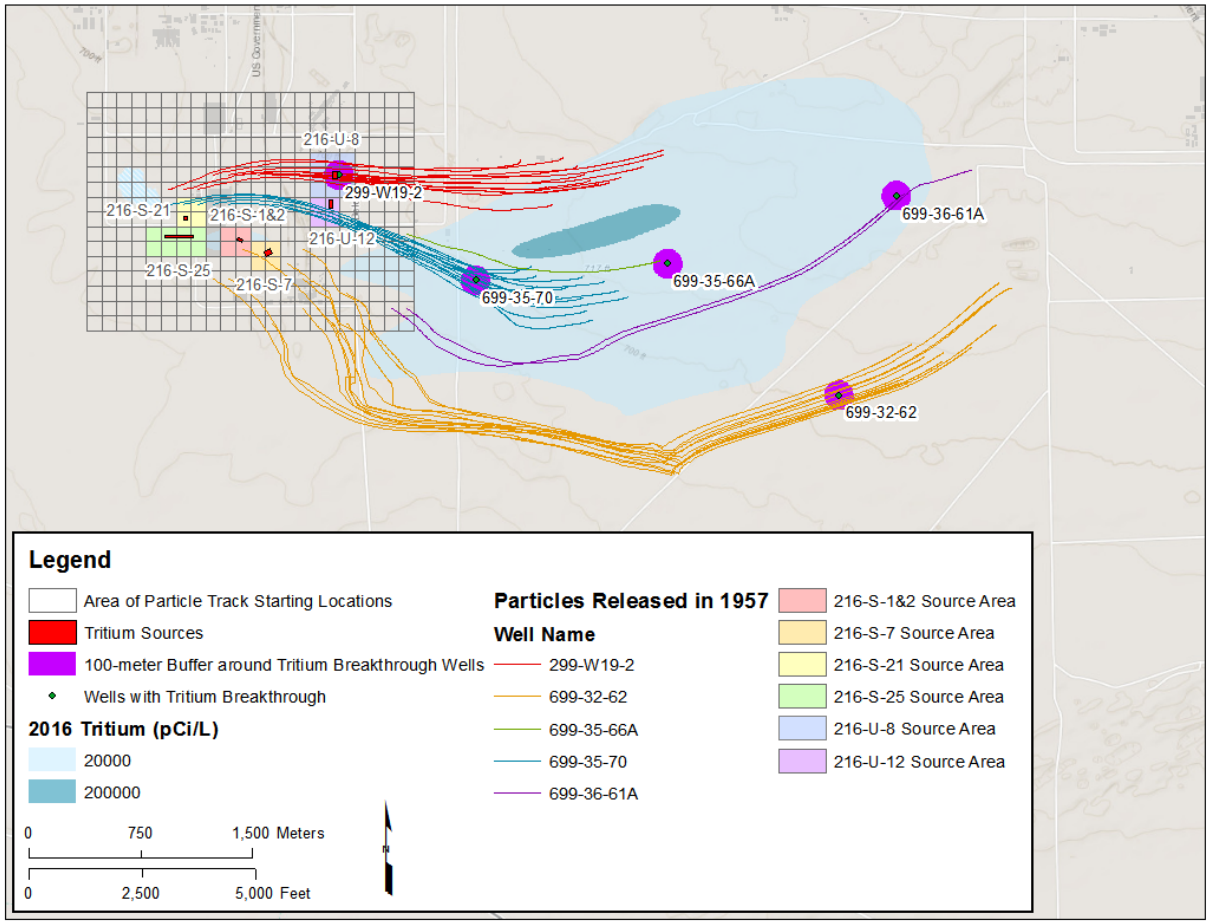


Figure 6-2. Particles Released in 1957 that Reach Selected Wells with Observed Tritium Breakthrough

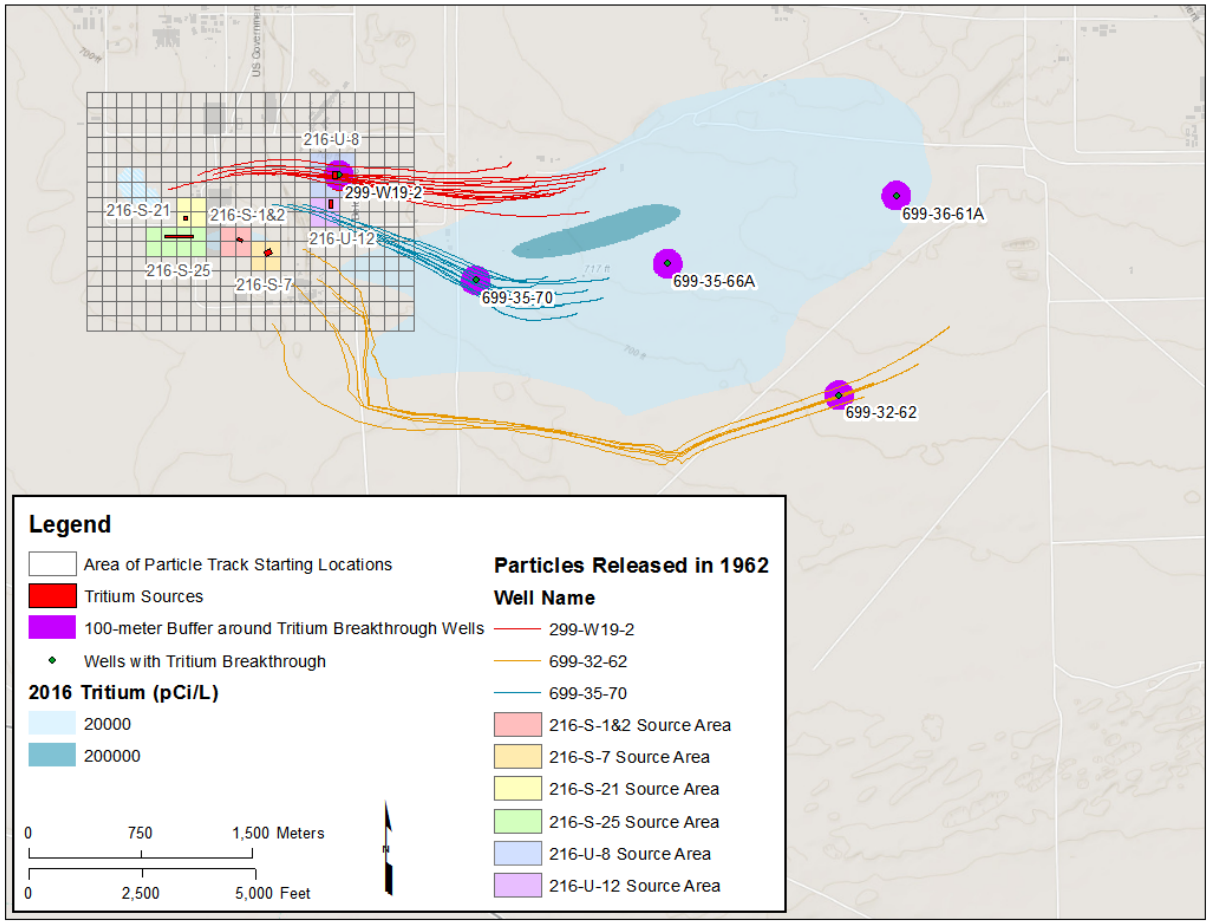


Figure 6-3. Particles Released in 1962 that Reach Selected Wells with Observed Tritium Breakthrough

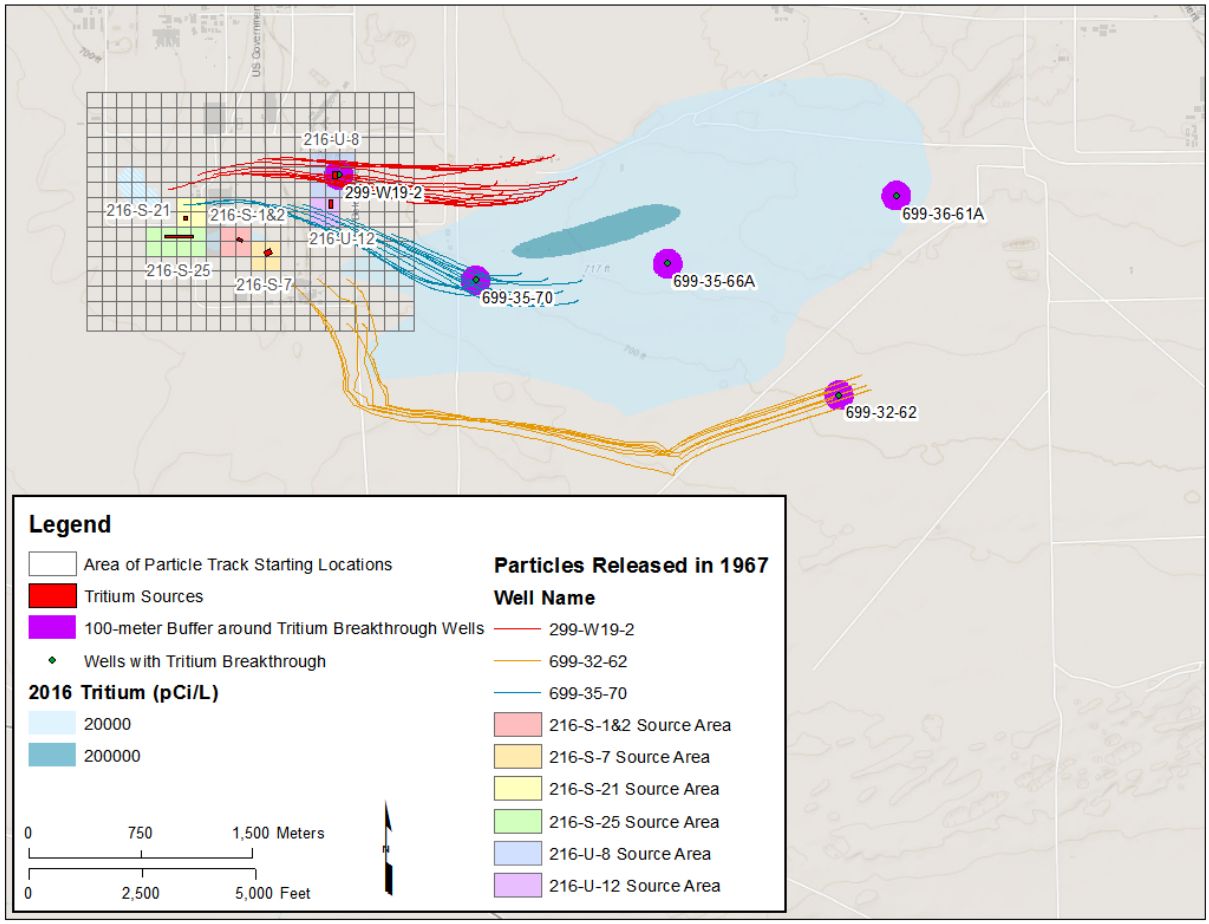


Figure 6-4. Particles Released in 1967 that Reach Selected Wells with Observed Tritium Breakthrough

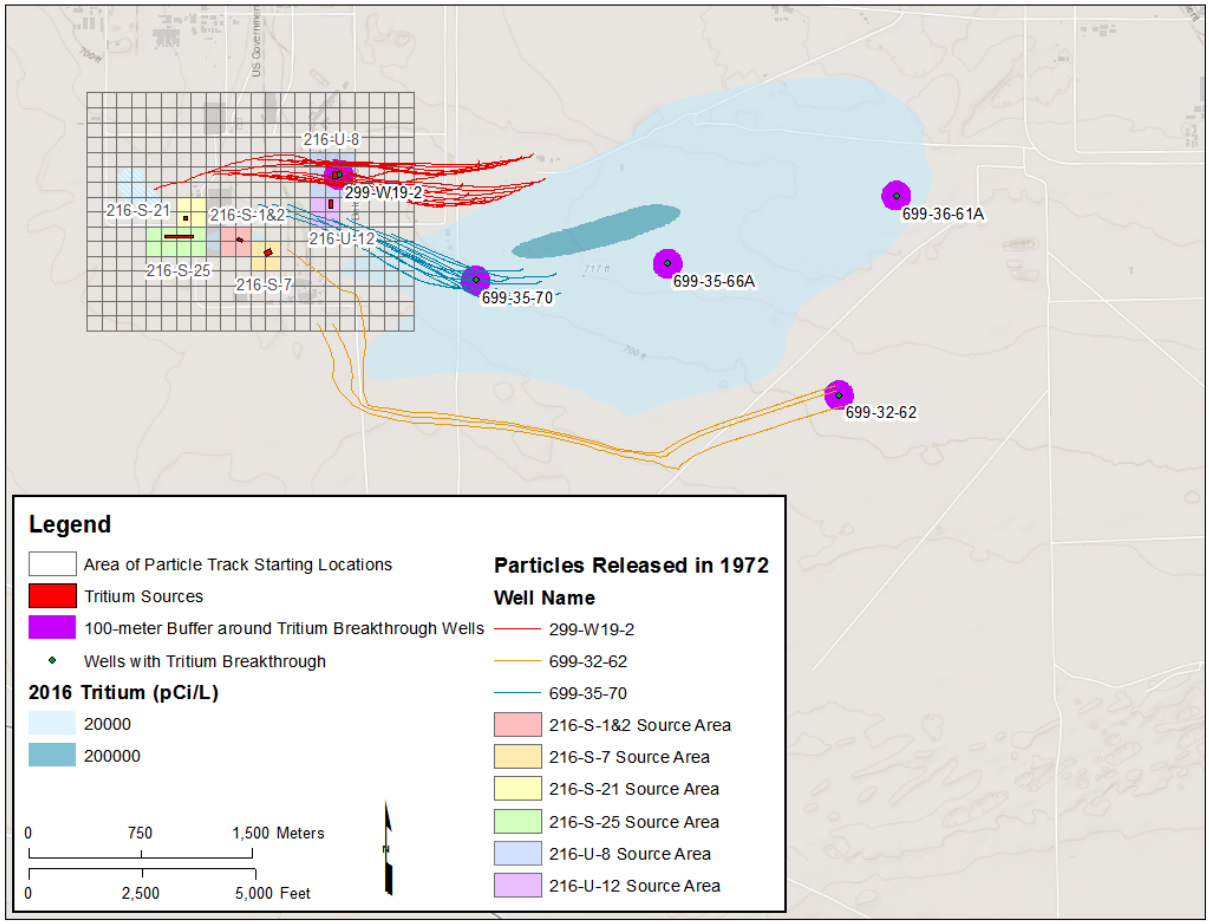


Figure 6-5. Particles Released in 1972 that Reach Selected Wells with Observed Tritium Breakthrough

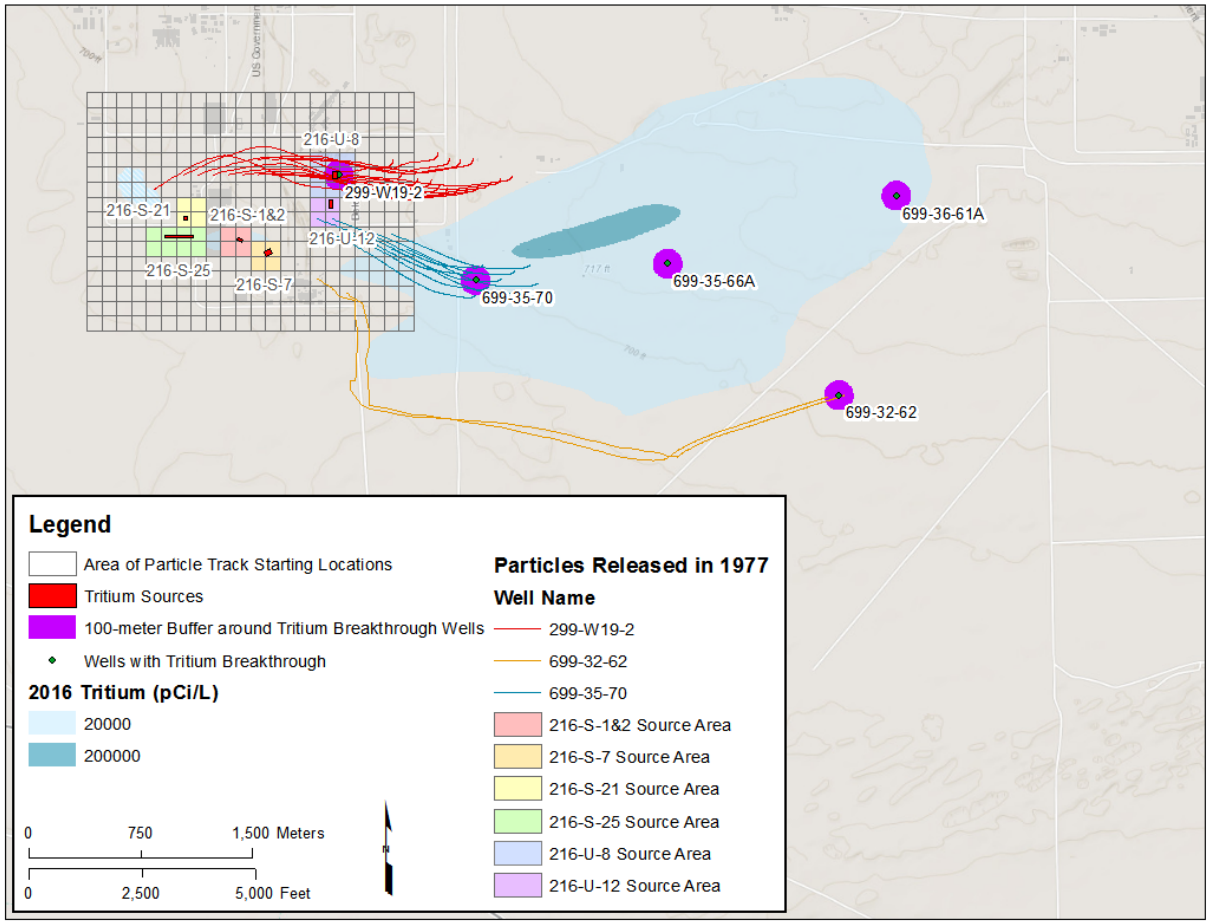


Figure 6-6. Particles Released in 1977 that Reach Selected Wells with Observed Tritium Breakthrough

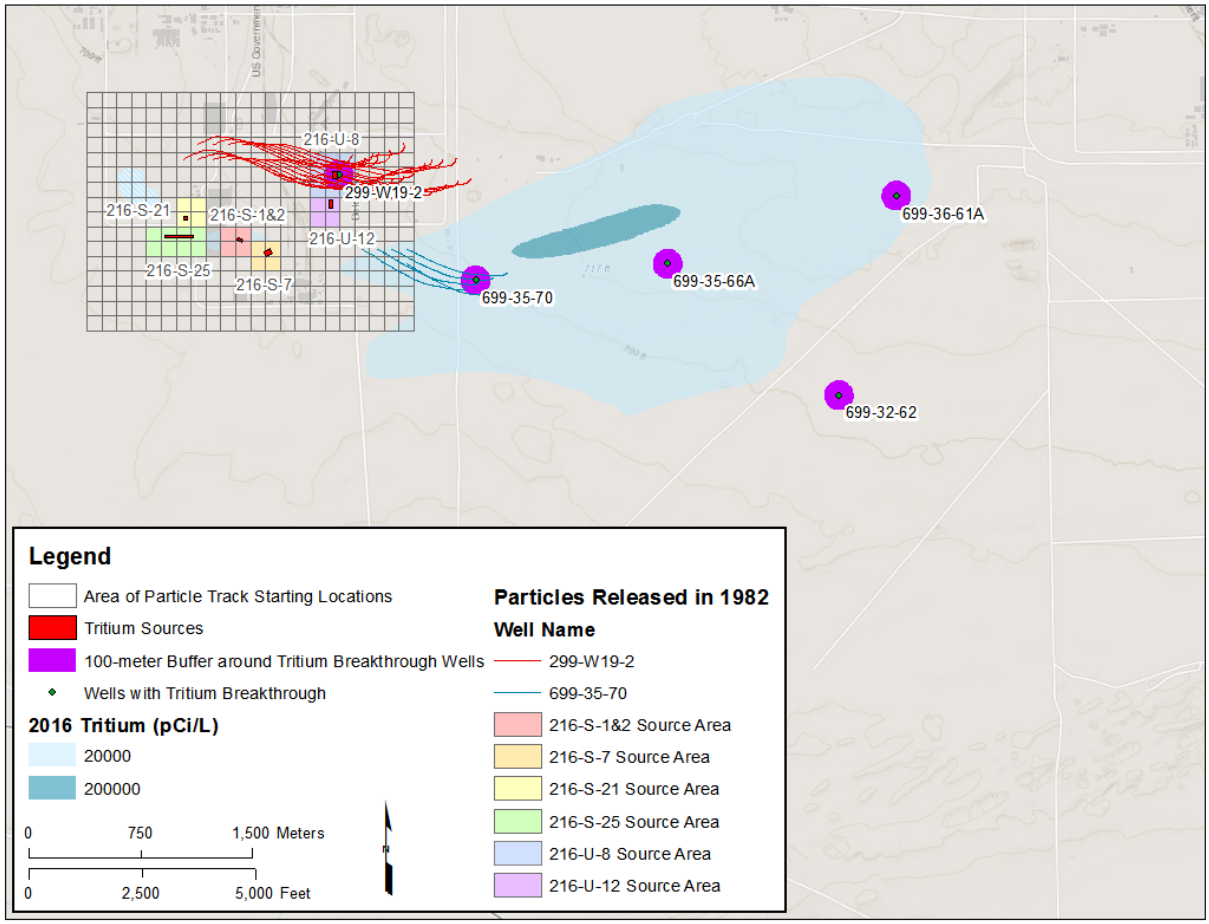


Figure 6-7. Particles Released in 1982 that Reach Selected Wells with Observed Tritium Breakthrough

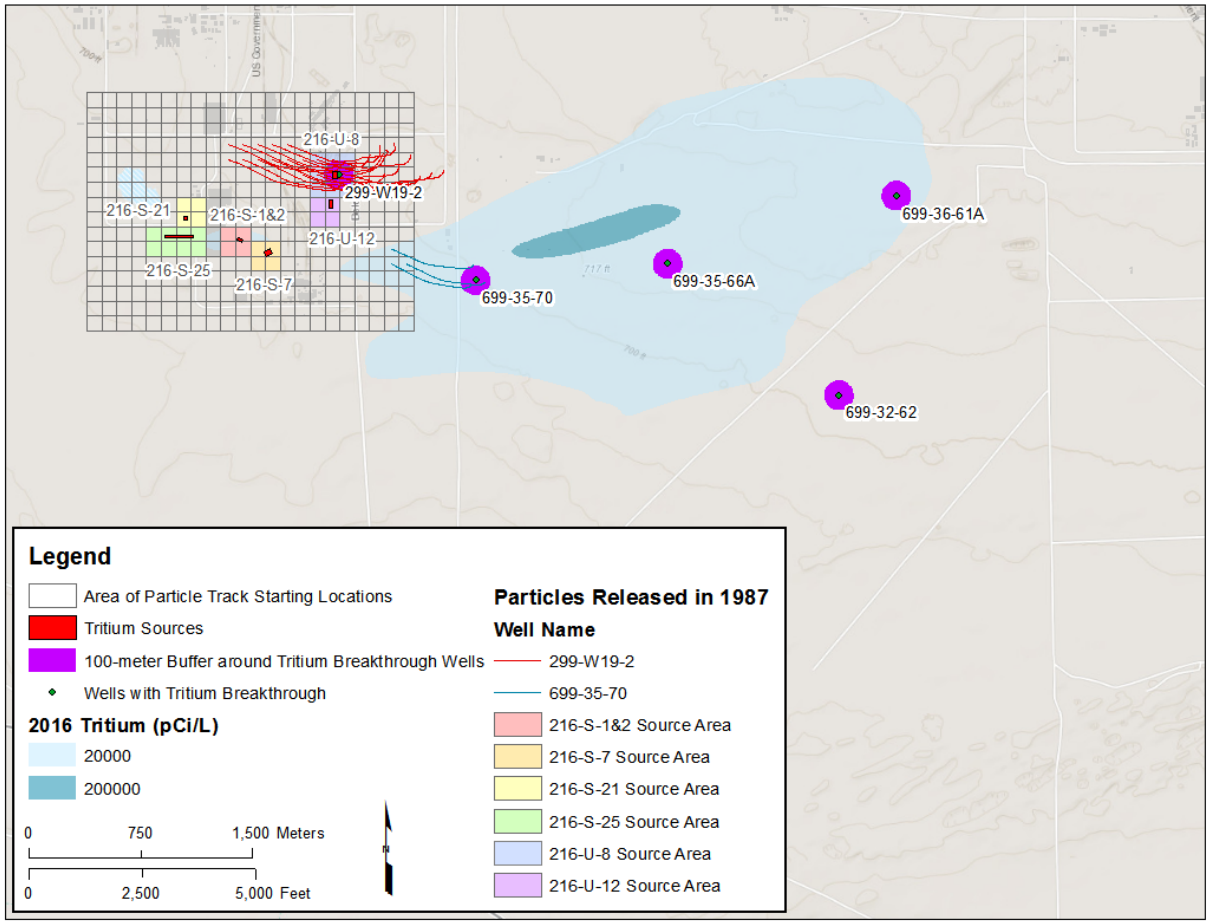


Figure 6-8. Particles Released in 1987 that Reach Selected Wells with Observed Tritium Breakthrough

6.2 Tritium Transport Modeling Results

Graphs comparing the modeled tritium concentration values for the observation wells to the observed tritium concentration at those wells are seen in Figure 6-9 through Figure 6-13. Overall, when a lag was assumed, the modeled concentrations tended to be lower and breakthrough tended to occur later than observed well concentrations.

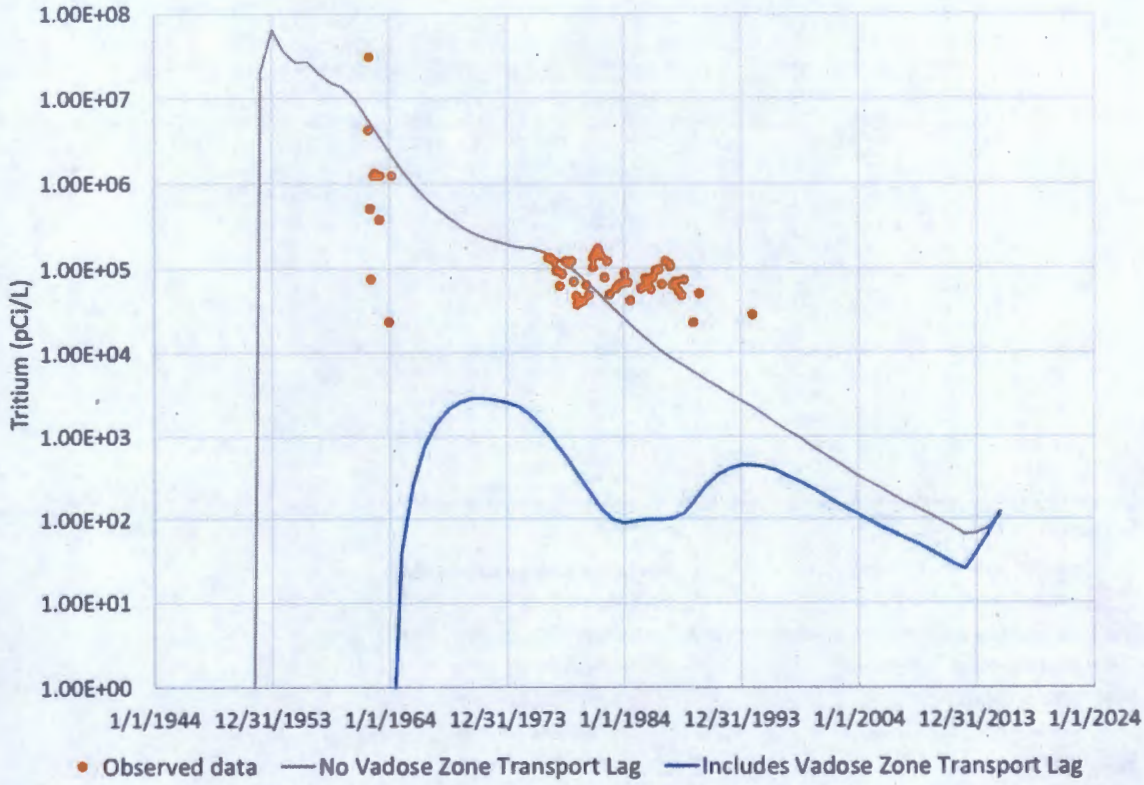


Figure 6-9. Modeled Tritium Breakthrough Compared to Observed Tritium Breakthrough at Well 299-W19-2

Well 299-W19-2 measures concentrations almost directly underneath waste site 216-U-8. There are no tritium sample results available for well 299-W19-2 during the time of the earliest waste releases, but sample results from the early 1960s have high tritium activity, as do the model results when no lag is assumed. When lag is assumed, the simulated peak concentration of tritium is lower than observed, and it occurs in the late 1960s. Both of the modeled scenarios appear to have a peak, a decline, then a second peak, which occur 20 years apart. This effect is more obvious in the model results with lag than the results without lag, and it occurs later. This second peak may be due to contamination coming from 216-U-21; particle tracks show a flow path from just north of the 216-S-21 source area to near 299-W19-2 (Figure 6-1 through Figure 6-8). The observed tritium concentrations appear to be slightly decreasing from the mid-1970s to 1990s, consistent with the model results without lag, which exhibit decreasing concentrations in that well. The model results with the vadose zone transport lag have steady-to-increasing concentrations during that time.

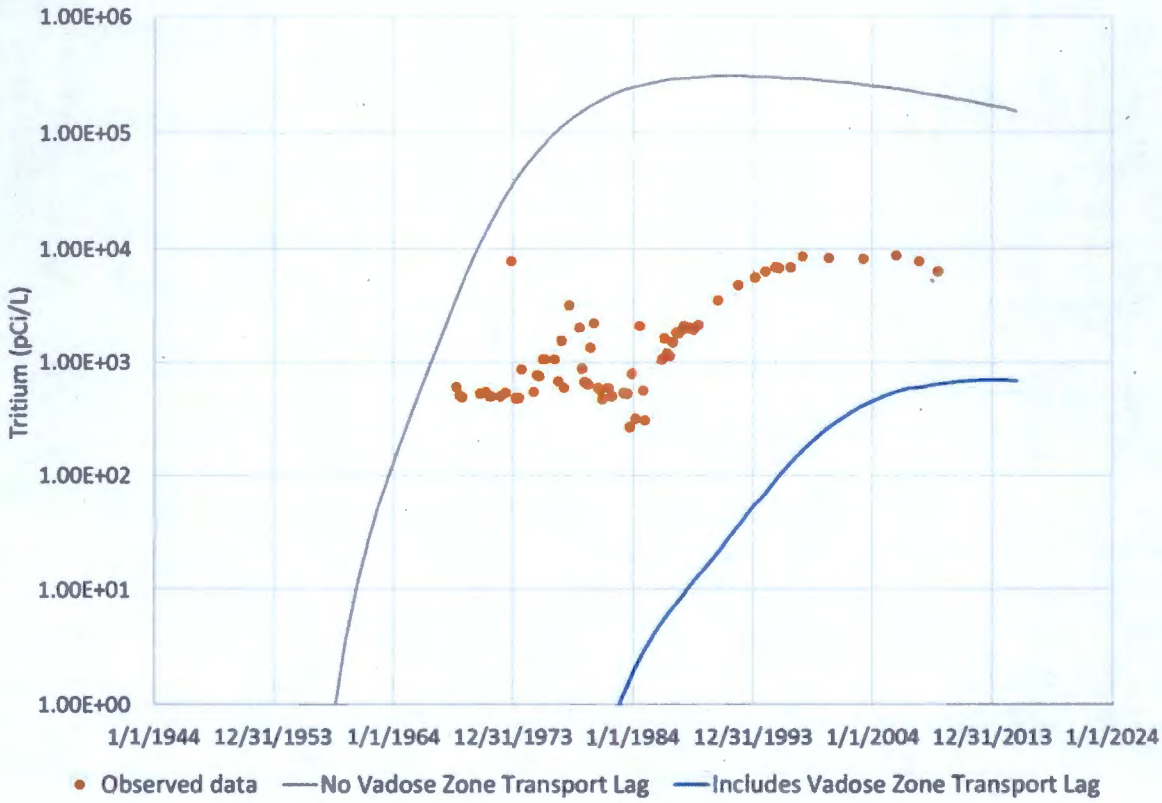


Figure 6-10. Modeled Tritium Breakthrough Compared to Observed Tritium Breakthrough at Well 699-32-62

Well 699-32-62 is to the south of the observed tritium plume. A clear breakthrough curve was not observed at this well. The scenario that did not include vadose zone lag has higher concentrations than observed. These elevated concentrations may be due to the preferential pathline created by the high-conductivity Cold Creek unit gravel deposits in the CPGWM flow model. This high-conductivity unit may divert more water—and move that water at a higher speed—than what occurs in the field, resulting in elevated modeled concentrations. The scenario that did include vadose zone lag has lower concentrations than observed and a breakthrough that occurs after the observed values had first indicated elevated values.

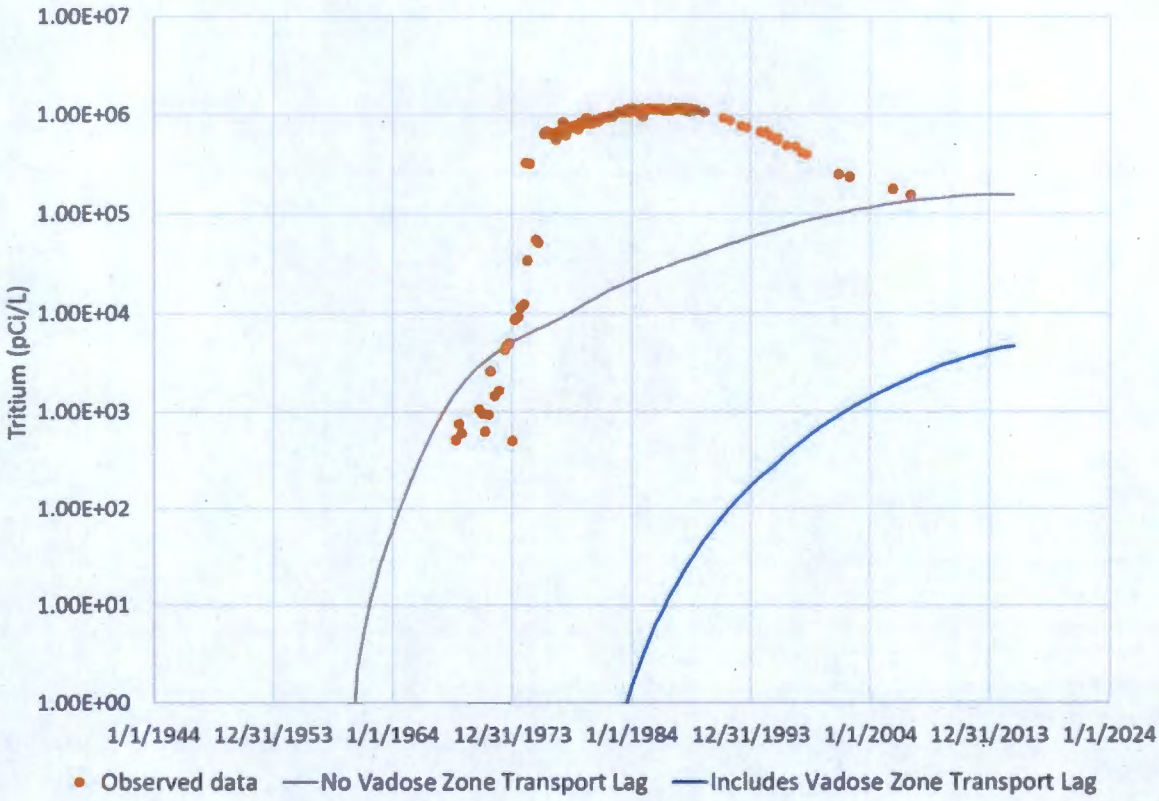


Figure 6-11. Modeled Tritium Breakthrough Compared to Observed Tritium Breakthrough at Well 699-35-66A

Well 699-35-66A lies near the axis of the plume. A clear observed breakthrough occurs around the mid-1970s, with concentrations peaking in the mid-to-late 1980s, and then trailing off. The transport scenario that did not include the vadose zone transport lag shows a breakthrough occurring around the mid-to-late 1960s, with concentrations rising steadily since. The transport scenario that included the vadose zone transport lag had a more gradual breakthrough occurring around the 1990s, with concentrations rising to the end of the simulation period. Both modeled scenarios tended to have lower concentrations than the observed values, but the scenario with the vadose zone lag was the lowest.

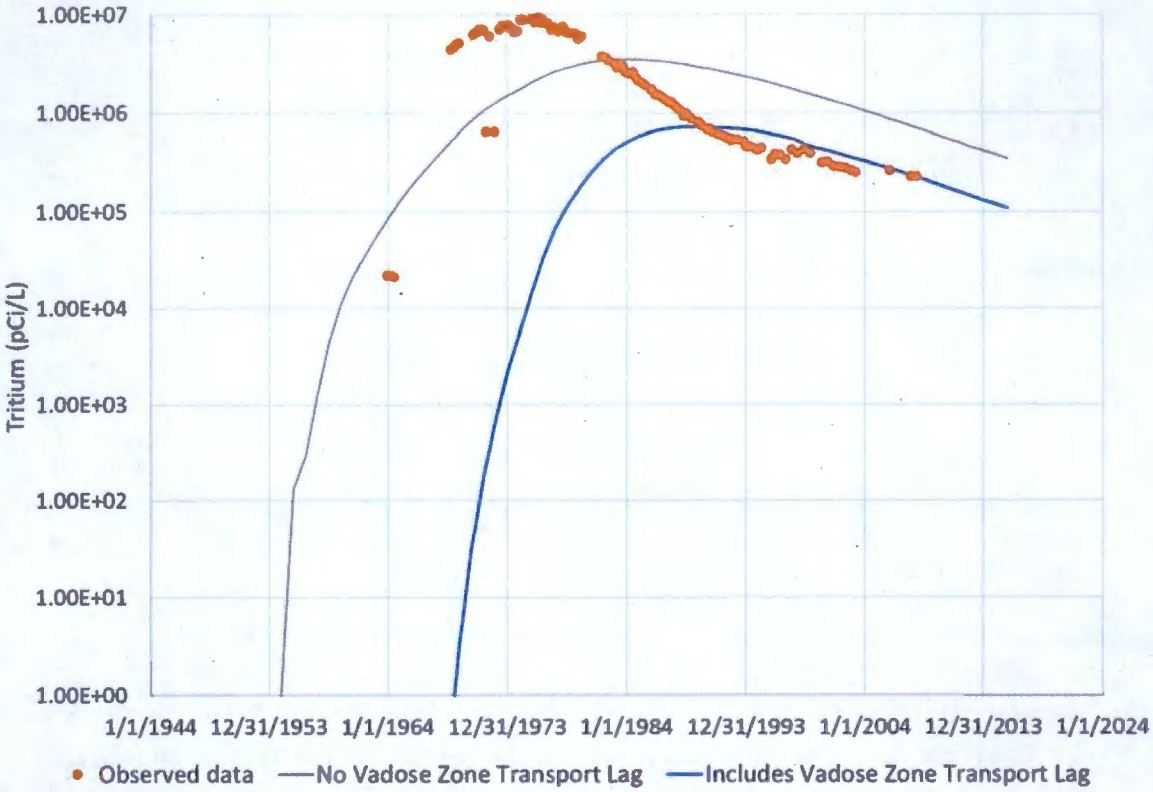


Figure 6-12. Modeled Tritium Breakthrough Compared to Observed Tritium Breakthrough at Well 699-35-70

Well 699-35-70 also lies near the axis of the plume, but closer to the sources than 699-35-66A. Breakthrough appears to have been observed in the late 1960s to early 1970s. The timing of the breakthrough in the model that does not include vadose zone lag appears to have occurred around the same time, but the peak occurred about a decade later than observed and, thereafter, the modeled concentrations declined at a slower rate than the observed values. When vadose transport lag was considered, the peak occurred later and at a lower concentration than the observed values or the scenario without the lag, but the reduction in concentration after the peak occurred at a similar rate in both scenarios.

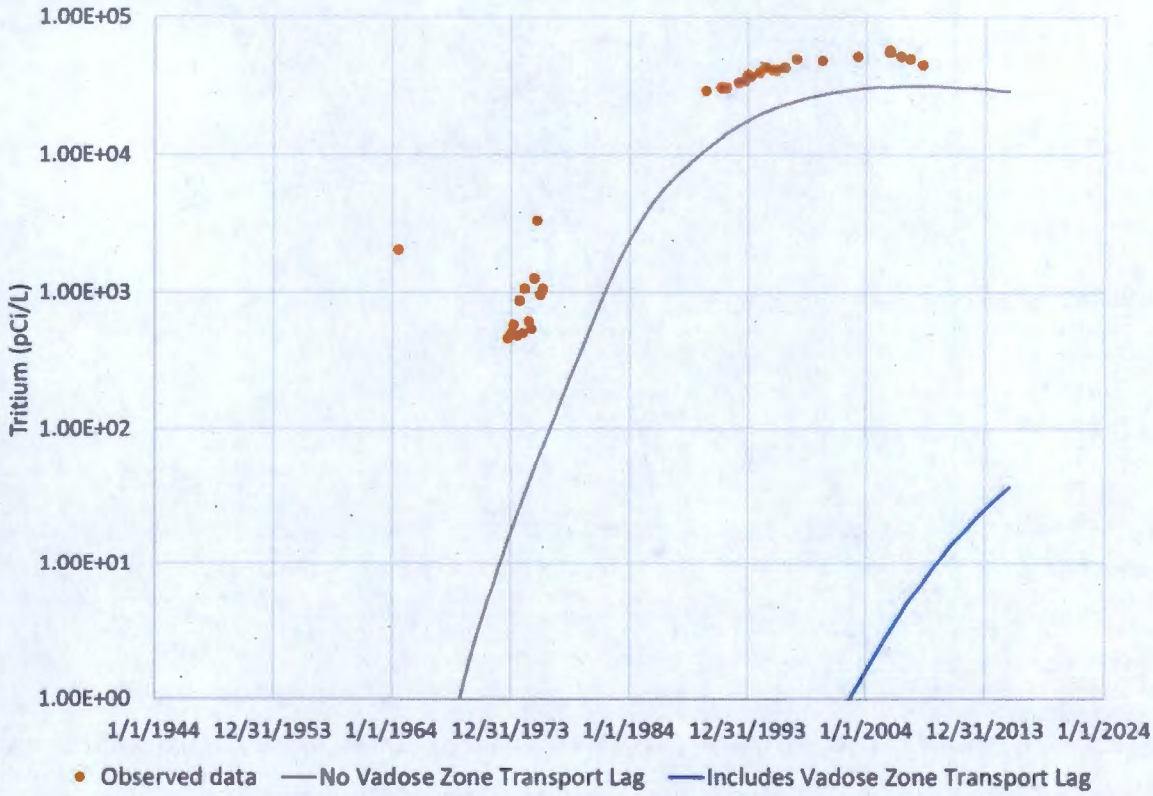


Figure 6-13. Modeled Tritium Breakthrough Compared to Observed Tritium Breakthrough at Well 699-36-61A

Well 699-36-61A is on the far east end of the plume. The scenario with the vadose zone lag has a later breakthrough with lower concentrations, similar to the other wells considered. The observed values are very similar in timing and concentration to the scenario with no vadose transport lag, though the modeled concentrations are slightly lower. At farther distances from the sources, on the advective edge of the plume, the effect of any individual source is lessened and concentrations are more a result of the cumulative effect of all the sources. This results in a relatively smooth breakthrough curve, as shown in Figure 6-13. This is in contrast to samples taken closer to the sources (e.g., 299-W19-2 in Figure 6-9), which tend to be affected most by nearby sources and temporal variations in the source terms.

6.3 Modeled Dye Tracer Study Results

Modeling the dye tracer study in the CPGWM could not reproduce the reported velocities or flow directions in HW-606010. For all three scenarios, the dye for the 1956 tracer test flowed to the east, not southwest to the well where it was observed, and the dye for the 1957 tracer test moved toward 699-20-20, but did not move toward 699-15-26 (Figure 6-14 through Figure 6-22). In the unaltered CPGWM scenario, seen in Figure 6-14 through Figure 6-16, the dye injected in well 699-28-40 forms a shape that is slightly longer in the east-west direction than the north-south direction. The dye injected into 699-24-33 forms a tight, cigar-shaped plume. The leading edges of the plumes end up approximately 1 km (0.6 mi) away from the injection site at the end of 1958. When the hydraulic conductivity in layer 3 is altered (as seen in the results in Figure 6-17 through Figure 6-19), the plume shapes become more oval: the 699-28-40 plume is less round and the 699-24-33 plume is rounder and less cigar-shaped. The plume at 699-24-33 has moved 200 m (656 ft) farther to the east at the end of 1958 than it did when the baseline CPGWM was used. Results of the dye tracer study with alternative transport properties are seen in Figure 6-20 through Figure 6-22. The plumes in this scenario are larger and travel faster than the plumes in the other scenarios. The plume at 699-28-40 has traveled approximately 2 km (1.2 mi), while the 699-24-33 plume traveled approximately 1.5 km (0.9 mi). By rough approximation, the fastest velocity for the plumes in this analysis is approximately 2 m/day (6.5 ft/day), measuring by the advective edge of the plume. By comparison, the slowest calculated velocity measured in HW-60601 is approximately 26 m/day (85 ft/day), when measuring by the peak of concentration, and 52 m/day (170.6 ft/day) when measuring by first arrival.

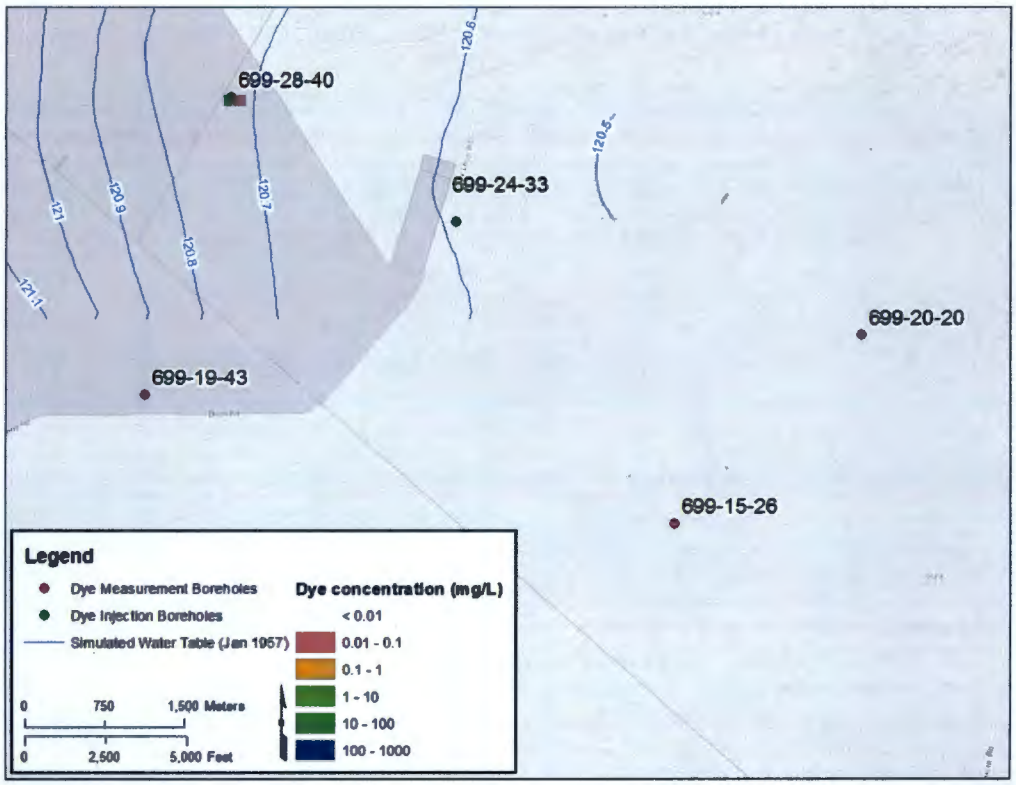


Figure 6-14. Modeled Dye Tracer Study Results, Base Case Scenario, 1956

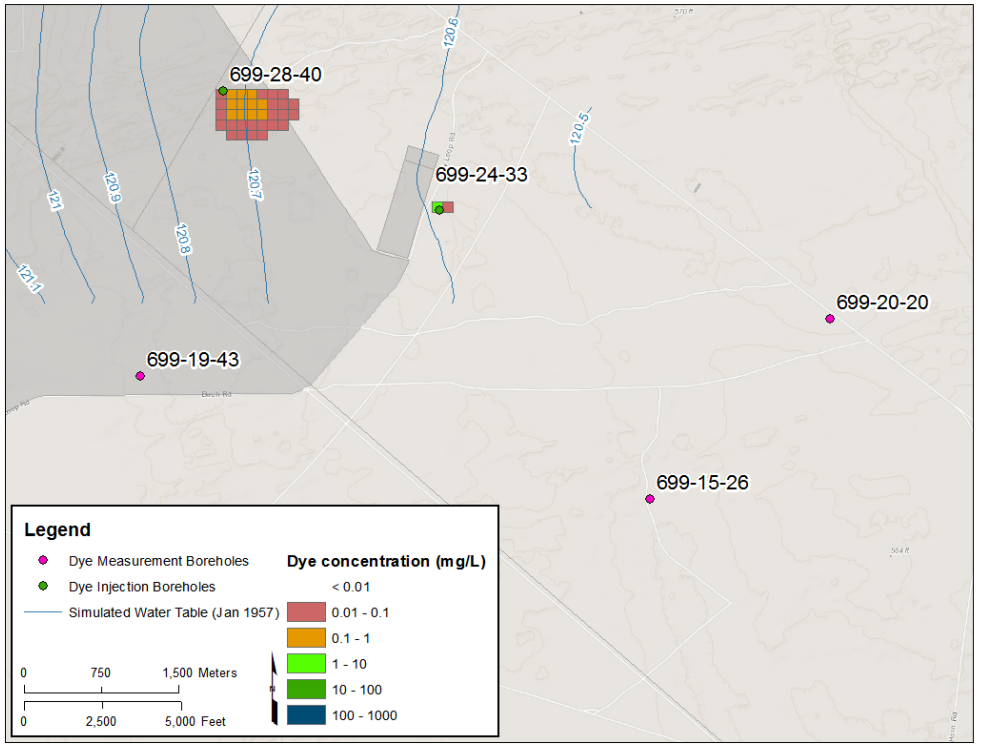


Figure 6-15. Modeled Dye Tracer Study Results, Base Case Scenario, 1957

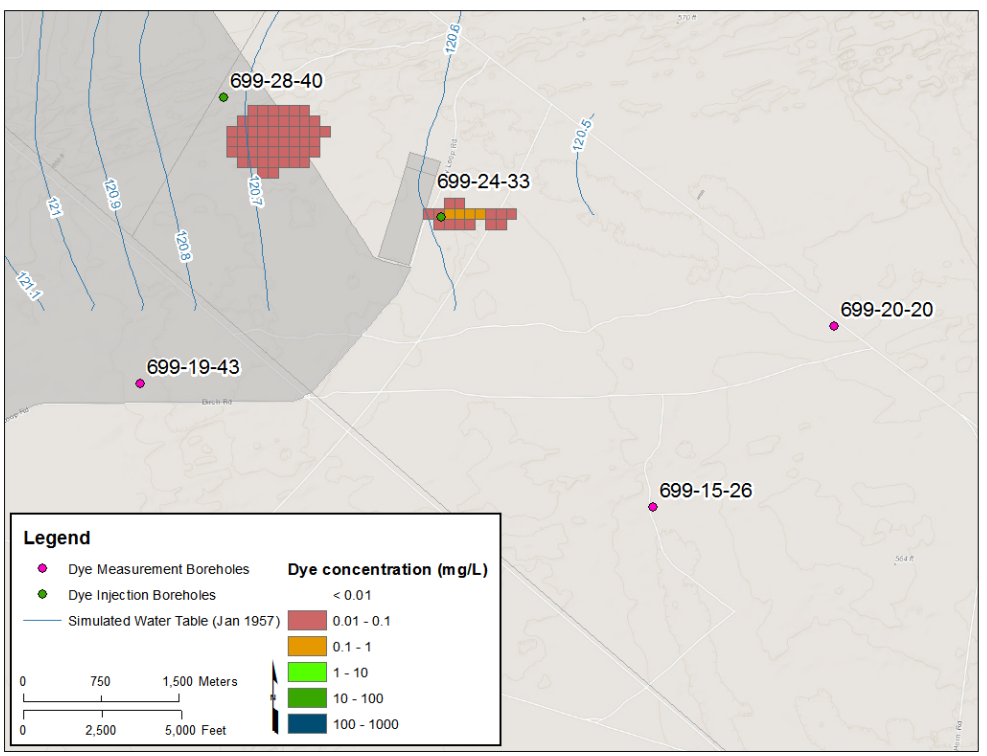


Figure 6-16. Modeled Dye Tracer Study Results, Base Case Scenario, 1958

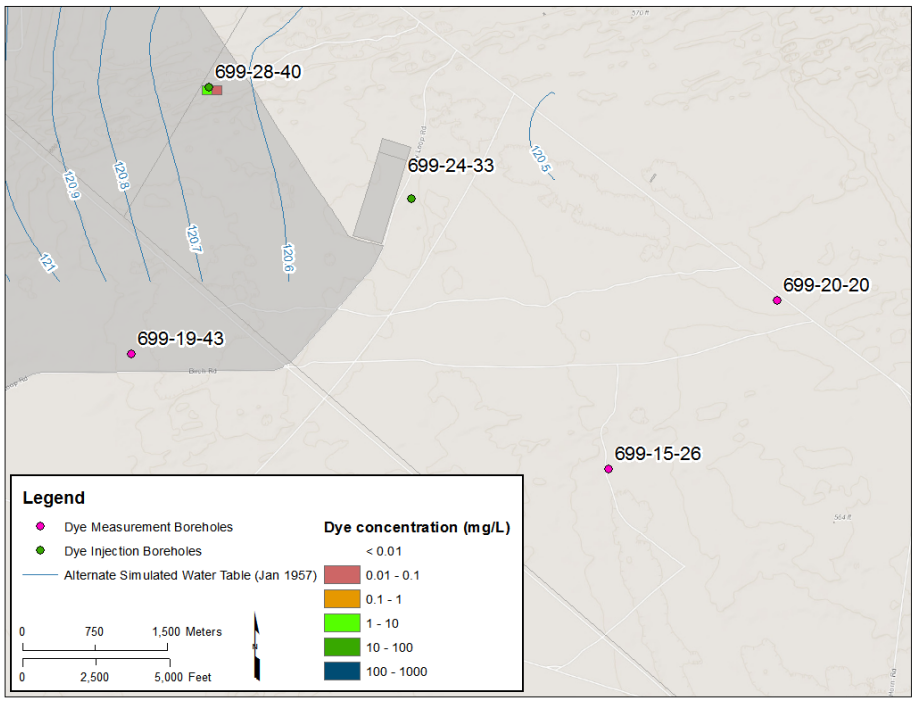


Figure 6-17. Modeled Dye Tracer Study Results, Modified Hydraulic Conductivity Scenario, 1956

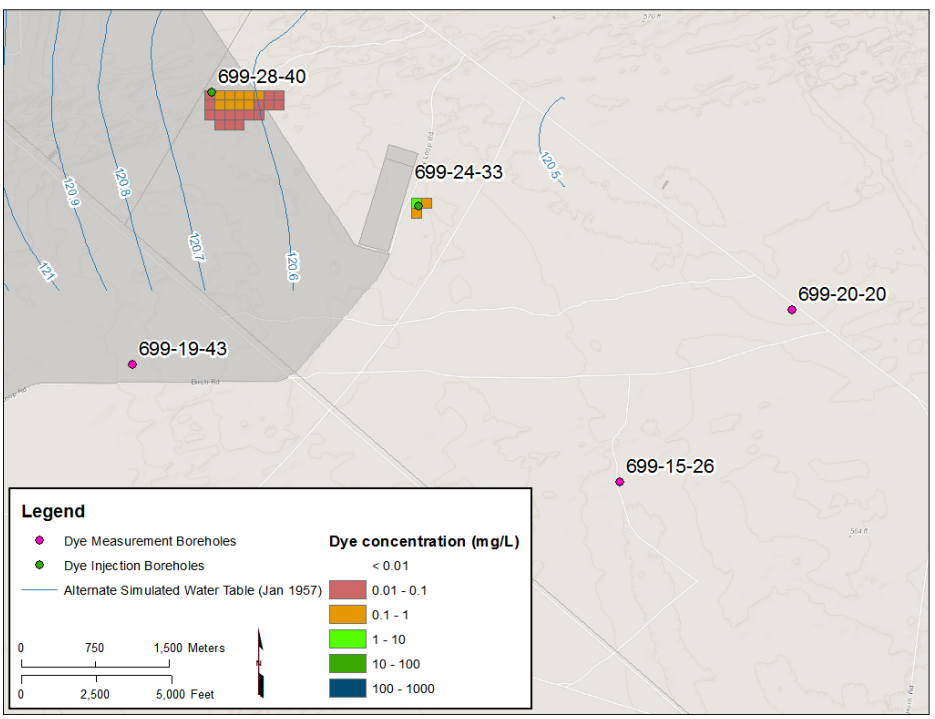


Figure 6-18. Modeled Dye Tracer Study Results, Modified Hydraulic Conductivity Scenario, 1957

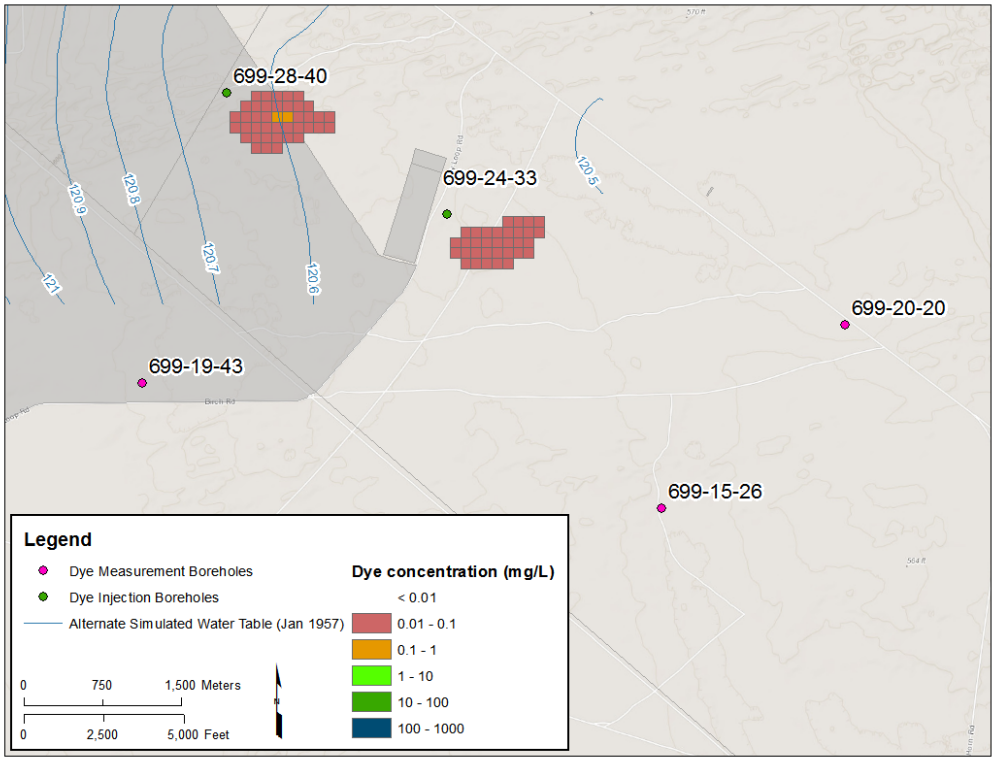


Figure 6-19. Modeled Dye Tracer Study Results, Modified Hydraulic Conductivity Scenario, 1958

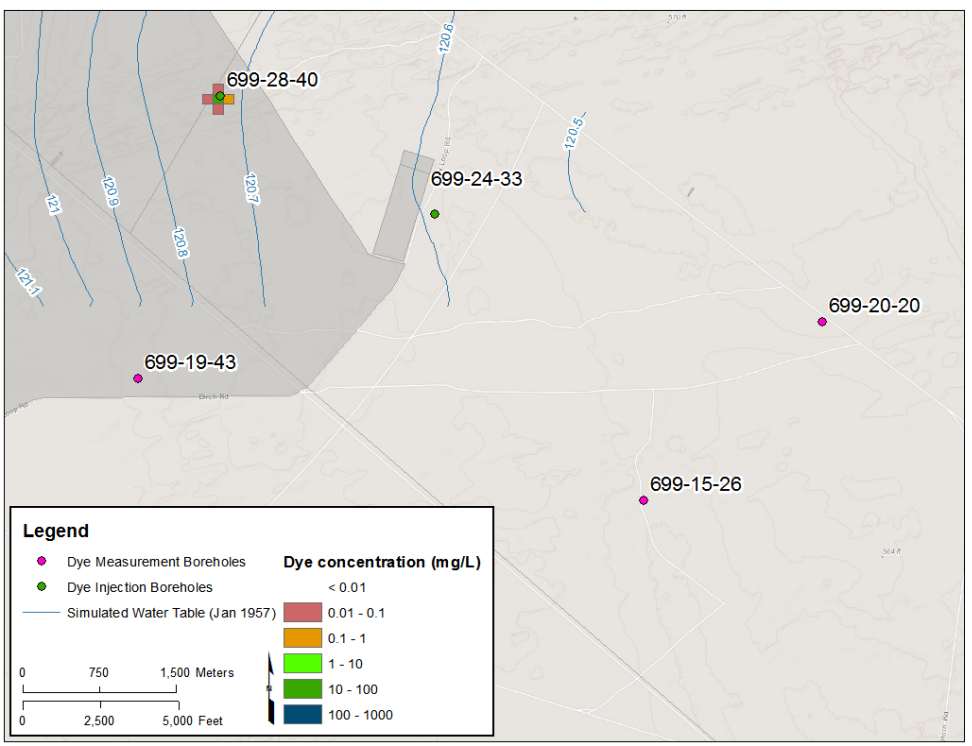


Figure 6-20.Modeled Dye Tracer Study Results, Alternative Transport Properties Scenario, 1956

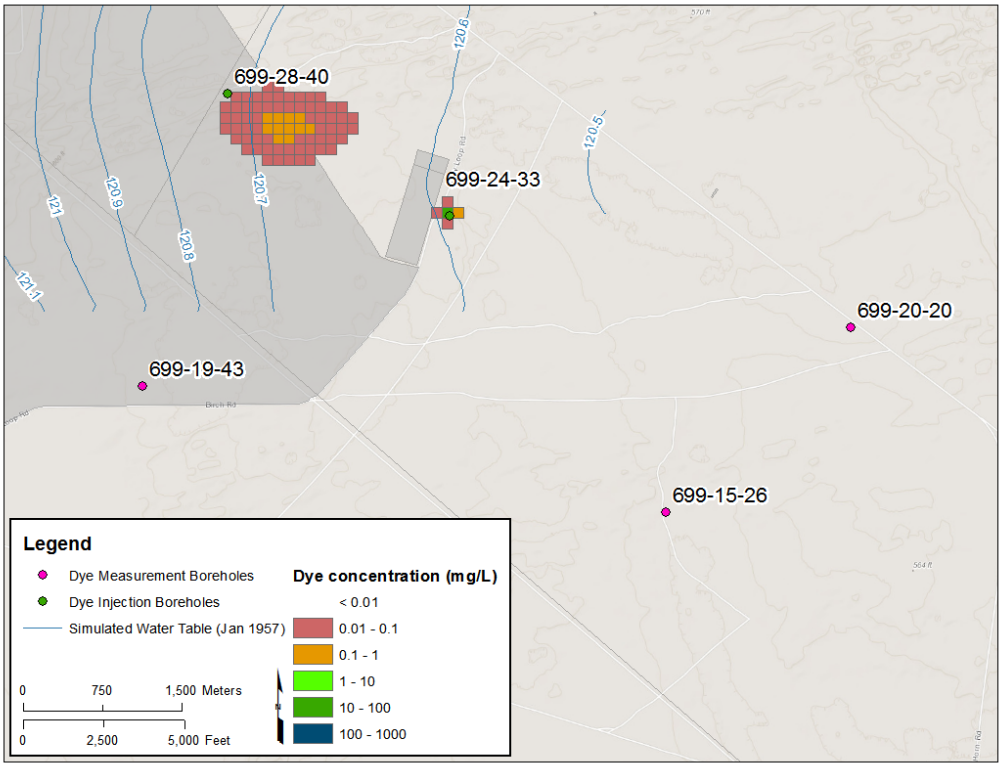


Figure 6-21. Modeled Dye Tracer Study Results, Alternative Transport Properties Scenario, 1957

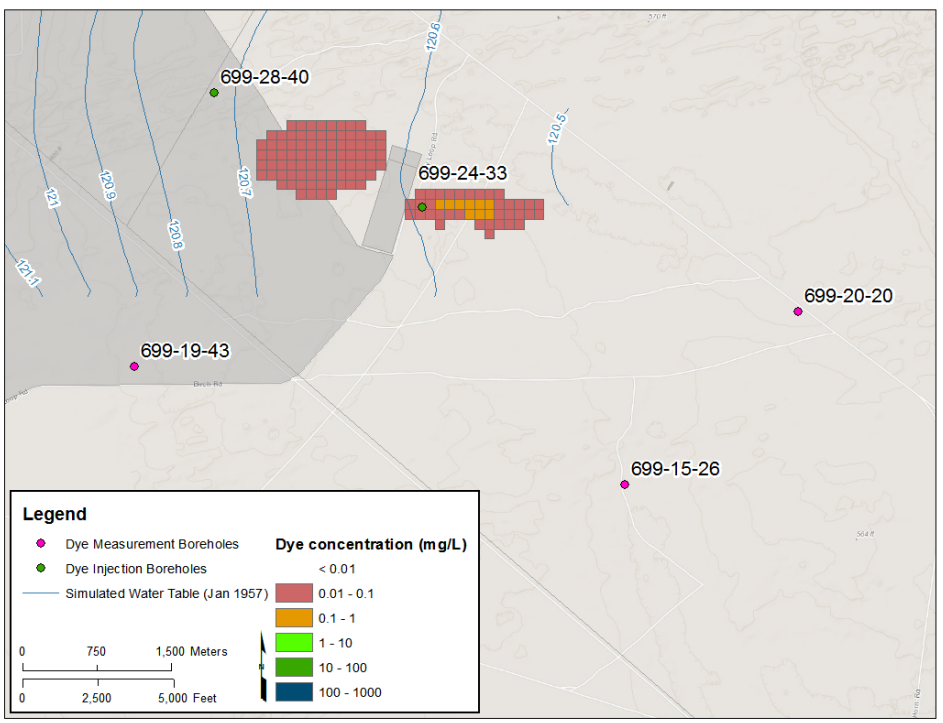


Figure 6-22. Modeled Dye Tracer Study Results, Alternative Transport Properties Scenario, 1958

The discrepancy in the groundwater flow direction between the modeled data and observed data may be due to the intended use of the CPGWM and the location of the dye tracer study relative to the model boundaries. First, the CPGWM's intended use is on the scale of regional flow patterns. Figure 2-2 shows the water table map of the Hanford Site in 1955. The overall regional flow around the area of the dye tracer study is to the southeast. However, a local effect can be seen in the tracer study area, the area highlighted by the red circle. This local effect shows some groundwater flowing due south, which is consistent with the hydraulic gradient calculated using water levels in Section 3.2. It is possible that this local effect is what was represented by the dye tracer study, instead of the regional trend of groundwater flowing to the southeast. This local change in groundwater flow may be on too small a scale for the CPGWM to model, as it models regional, not local, trends. Second, the dye tracer study was conducted near the edge of the CPGWM. The general head boundaries, which were created to represent regional flow, may be overriding any local trends in the hydrogeology.

In addition to the direction of movement, the velocity of dye tracer movement was different in the CPGWM than the velocity reported in HW-60601.When the travel time of the historical dye tracer study was calculated using historical water-level data in Section 3.2, the calculated velocity was approximately 10 m/day (32.8 ft/day)(a travel time of 260 days to reach 699-19-43 from 699-28-40), whereas the center of the peak concentration from 699-28-40 to 699-19-43 was reported in HW-60601 as having a velocity of approximately 87 m/day (285 ft/day) (a travel time of 31 days). Using porosity and hydraulic conductivity reported by HW-60601 and historical water levels to calculate the hydraulic gradient, the reported velocities in HW-60601 could not be reproduced.

7 References

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Appendix A

Software Installation and Checkout Forms

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CHPRC SOFTWARE INSTALLATION AND CHECKOUT FORM

Software Owner Instructions:
Complete Fields 1-13, then run test cases in Field 14. Compare test case results listed in Field 15 to corresponding Test Report outputs. If results are the same, sign and date Field 19. If not, resolve differences and repeat above steps.

Software Subject Matter Expert Instructions:
Assign test personnel. Approve the installation of the code by signing and dating Field 21, then maintain form as part of the software support documentation.

GENERAL INFORMATION:

1. Software Name: MODFLOW and Related Codes Software Version No.: Bld 8

EXECUTABLE INFORMATION:

2. Executable Name (include path):

Following executable files in directory: _____

MD5 Signature (unique ID)	Executable File Name	
		MODFLOW-2000 double precision
		MODFLOW-2000 single precision
		MODFLOW-2000-MST single prec
		MODFLOW-2000-MST double prec
		MT3DMS double precision
		MT3DMS single precision
		MT3DMS-MST double precision
		MT3DMS-MST single precision

3. Executable Size (bytes): MD5 signatures listed above uniquely identify executable files

COMPILATION INFORMATION:

4. Hardware System (i.e., property number or ID):

Vendor Provided (SSP&A)

5. Operating System (include version number):

Vendor Provided (SSP&A)

INSTALLATION AND CHECKOUT INFORMATION:

6. Hardware System (i.e., property number or ID):

PSC-Xenon; Intera Property Number 00857

7. Operating System (include version number):

Windows 10

8. Open Problem Report? ◉ No ○ Yes PR/CR No.

TEST CASE INFORMATION:

9. Directory/Path:

10. Procedure(s):

CHPRC-00259 Rev 3, MODFLOW and Related Codes Software Test Plan

11. Libraries:

N/A (static linking)

12. Input Files:

MF-ITC-1 and MT-ITC-1 inputs

13. Output Files:

MF-ITC-1 and MT-ITC-1 outputs

CHPRC SOFTWARE INSTALLATION AND CHECKOUT FORM (continued)

1. Software Name: MODFLOW and Related Codes — Software Version No.: Bld 8

14. Test Cases:

MF-ITC-1 (both standard and MST versions of MODFLOW)- run for single & double precision
MT-ITC-1 - run for single and double precision

15. Test Case Results:

FC: no differences encountered x8 – PASS.

16. Test Performed By: Mary Weber

17. Test Results: (●) Satisfactory, Accepted for Use ( ) Unsatisfactory

18. Disposition (include HISI update): INSTALLATION ADDED TO APPROVED USER LISTS FOR HISI #2517 (MODFLOW) AND #2518 (MT3DMS). [illegible]

Prepared By:

19. [signature] — WE Nichols — 13 FEB 2017
Software Owner (Signature) — Print — Date

20. Test Personnel:

[signature] — M Weber — 13 FEB 2017
Sign — Print — Date

Sign — Print — Date

Sign — Print — Date

Approved By:

21. NA — N/R (CHPRC-00258 Rev 3) — NA
Software SME (Signature) — Print — Date

A-6005-149 (REV 0)

Appendix B

Inventory Data from RPP-26744

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Inventory Data from RPP-26744

Site	Year	Mean inventory estimate (Curies of tritium)*
216-S-1&2	1952	3,470
	1953	10,800
	1954	10,800
	1955	10,200
	1956	5.04
	Summation	35,200
216-S-7	1956	10,800
	1957	9,070
	1958	11,900
	1959	8,470
	1960	7,430
	1961	7,270
	1962	6,990
	1963	7,970
	1964	8,340
	1965	3,040
	Summation	81,300
216-S-21	1954	55.7
	1955	1,720
	1956	1,350
	1957	2,410
	1958	2,520
	1959	1,510
	1960	1,530
	1961	1,240
	1962	1,060
	1963	1,240
	1964	1,470
	1965	2,600
	1966	2,760
	1967	1,210
	1968	2.71
	1969	151
	Summation	22,800
216-S-25	1973	433
	1974	4,190
	1975	2,770
	1976	2,030
	1977	1,370
	1978	667

Inventory Data from RPP-26744

Site	Year	Mean inventory estimate (Curies of tritium)*
	1979	1,010
	1980	1,070
	1985	536
	Summation	14,100
216-U-8	1952	4,260
	1953	13,500
	1954	11,100
	1955	10,700
	1956	11,000
	1957	4,190
	1958	2,340
	1959	2,340
	1960	684
	Summation	60,100
216-U-12	1960	1,340
	1961	2,050
	1962	1,890
	1963	1,800
	1964	2,090
	1965	1,590
	1966	1,150
	1967	1,010
	1968	2,000
	1969	1,540
	1970	620
	1971	1,140
	1972	687
	1981	1.77
	1982	19.4
	1983	108
	1984	436
	1985	352
	1986	278
	1987	43
	1988	6.73
	Summation	20,200

*Tritium values reported in RPP-26744 are decayed to 01/01/2001. The values in this table were undecayed to the release year.