RPP-RPT-59750, Rev. 0

Results of the Tritium Tracking and Groundwater Monitoring at the Hanford Site 200 Area State Approved Land Disposal Site, Fiscal Year 2016

Author Name:
P. L. Gassman

Washington River Protection Solutions, LLC
Richland, WA 99352
U.S. Department of Energy Contract DE-AC27-08RV14800

EDT/ECN:	DRCF	UC:	N/A
Cost Center:	N/A	Charge Code:	N/A
B&R Code:	N/A	Total Pages:	124

Key Words: Effluent Treatment Facility, Tritium, Wastewater discharges, State Approved Land Disposal Site, 200 Area, State Waste Discharge Permit Number ST0004500

Abstract: This report presents the results of groundwater monitoring of proximal wells and tracking wells for evidence of the tritium plume from the SALDS facility during FY 2016. This annual report addresses groundwater samples collected and analyzed from October 2015 through September 2016.

Results of Tritium Tracking and Groundwater Monitoring at the Hanford Site 200 Area State Approved Land Disposal Site, Fiscal Year 2016

Paul L. Gassman
Washington River Protection Solutions LLC

Date Published
November 2016

Prepared for the U.S. Department of Energy
Office of River Protection

Contract No. DE-AC27-08RV14800

EXECUTIVE SUMMARY

The 200 Area Effluent Treatment Facility (ETF) at the Hanford Site processes contaminated aqueous wastes derived from Hanford Site facilities and waste management areas. The ETF effluent wastewater is discharged to the soil column at the 200 Area State-Approved Land Disposal Site (SALDS), which is authorized to receive the discharge by *State Waste Discharge Permit Number ST0004500*[1] (Ecology, 2014) (hereafter referred to as the "Permit"). The ETF was inoperable for most of fiscal year (FY) 2015 and FY 2016 due to failure of the evaporator heat exchanger and consequently no ETF treated discharges occurred to the SALDS from February 2014 through May 2016. The heat exchanger was repaired in May 2016 and ETF operations resumed in June of 2016. From June to September of 2016, 14.7 million liters (3.88 million gallons) of ETF treated effluent was discharged to SALDS with a total tritium activity of 1.90 Ci.

The current monitoring network consists of two proximal (compliance) monitoring wells (699-48-77C, and 699-48-77D) and eight tritium-tracking wells. The proximal wells are sampled quarterly. Well 699-48-77A is nearly dry so it is only used occasionally for water-level monitoring. All of the tritium-tracking wells are sampled annually; several wells are sampled semi-annually.

Water-level measurements in the SALDS proximal and tracking wells indicate there is no longer a mound of heightened groundwater elevation beneath the SALDS resulting from ETF operational effluent discharges. Groundwater levels measured in March of 2016 show decreased elevations in all of the SALDS network wells relative to measurements from FY 2015. The largest decreases in water elevations is observed in the tracking wells 299-W6-6, 299-W6-11 and 299-W6-12, which lie south and southeast of the SALDS facility. These wells are close to deep injection wells from the 200-ZP-1 Pump and Treat (P&T) system. These decreased water levels correlate to the past few years of decreased injection volumes from the 200-ZP-1 P&T system.

The maximum tritium concentrations in the proximal wells were 51,600 pCi/L in 699-48-77C and 58,800 pCi/L in 699-48-77D. Tritium also continues to be detected in the tritium-tracking wells 299-W6-6, 299-W6-11, 299-W6-12, and 699-48-71. However, as noted in the FY 2015[2] report, tritium concentrations in these tracking wells are being influenced by 200-ZP-1 P&T system injections. This system discharges treated effluent containing tritium into an injection well located only 9.8 m (32 ft.) from well 299-W6-6. To date, tritium originating from ETF discharges to the SALDS has not been detected in any of the tritium-tracking wells.

The numerical groundwater flow and contaminant transport model of the SALDS tritium plume was last updated in FY 2011. The modeling results showed that some locations along the northern margin of the 200 West Area are expected to exhibit measurable concentrations of SALDS-derived tritium by the year 2030, although the model indicates that concentrations would be below the drinking water standard of 20,000 pCi/L. The eastern end of the tritium plume is also predicted to migrate to the south toward the 200-ZP-1 P&T system extraction wells by 2030. Measured tritium concentrations in the SALDS wells in FY 2016 are consistent with the predicted behavior obtained from the model, although the measurable concentrations of tritium are derived from the 200-ZP-1 P&T system.

---

[1] Ecology, 2014, *State Waste Discharge Permit Number ST0004500*, Washington State Department of Ecology, Kennewick, Washington. Available at: http://www.ecy.wa.gov/programs/nwp/permitting/WWD/PDF/ST4500/ST0004500.pdf.

[2] RPP-RPT-58908 Results of the Tritium Tracking and Groundwater Monitoring at the Hanford Site 200 Area State Approved Land Disposal Site, Fiscal Year 2015. This report is appended as Appendix B.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF TERMS

Abbreviations, Initialisms, and Acronyms

AEA	Atomic Energy Act of 1954
CCU	Cold Creek unit
CP	Central Plateau
DOE	U.S. Department of Energy
Ecology	Washington State Department of Ecology
ETF	Effluent Treatment Facility
FY	fiscal year
OU	operable unit
NAVD88	North American Vertical Datum of 1988
P&T	pump-and-treat
SALDS	State-Approved Land Disposal Site
TASL	Test America St. Louis
WMA	Waste Management Area

Units

µg/L	micrograms per liter
µS/cm	micro Siemens per centimeter
cm	centimeter
ft.	foot/feet
gal	gallons
in.	inch(es)
km	kilometers
L	liters
m	meters
mg/L	milligrams per liter
min	minutes
NTU	Nephelometric Turbidity Units
pCi/L	pico Curies per liter

1 Introduction

The 200 Area Effluent Treatment Facility (ETF) on the Hanford Site processes contaminated aqueous wastes derived from Hanford Site facilities and waste management areas (WMA). Treated water from ETF is discharged to the State-Approved Land Disposal Site (SALDS), which is authorized to receive the discharge by *State Waste Discharge Permit Number ST0004500* (Ecology, 2014) (hereafter referred to as the "Permit"). The Permit allows disposal of ETF effluents to the SALDS drain field, located 360 m (1,200 ft.) north of the 200 West Area (Figure 1-1). The Permit requires that groundwater samples be collected quarterly from the point of proximal compliance monitoring wells 699-48-77C and 699-48-77D located at the SALDS. Sampling of a third proximal well, 699-48-77A, was discontinued when the well became dry during FY 2012.[3] The current revision of the Permit requires that samples be analyzed for tritium only. However, samples are also analyzed for 16 other constituents per the current revision of the groundwater monitoring plan (RPP-ENV-59215, *Groundwater Monitoring and Tritium-Tracking Plan for the 200 Area State-Approved Land Disposal Site*). Water-level measurements are also collected.

The Permit addresses the tritium plume associated with ETF effluent discharges to SALDS. The ETF effluent disposed to SALDS contains tritium because no cost effective treatment technology exists to remove tritium from wastewater (DOE/RL-2014-10, 2014 *Evaluation of Tritium Removal and Mitigation Technologies for Wastewater Treatment*). The location of SALDS was chosen because of the resulting long travel time required for tritium to migrate from this location to the Columbia River. This allows tritium concentrations to decrease to below the drinking water standard (20,000 pCi/L) by dispersion and radiological decay before the plume reaches the river.

The U.S. Department of Energy (DOE) has taken the position that its groundwater monitoring and provision of data reporting to the State of Washington Department of Ecology (Ecology) is a matter of intergovernmental comity and cooperation, and that the Permit has no jurisdiction over radionuclides, which are regulated by DOE under Atomic Energy Act of 1954 (AEA) authority, in the same way that permits for wastewater discharge to surface waters issued by the Environmental Protection Agency under Section 402 of the Clean Water Act are preempted by the AEA from regulating radionuclides.[4] DOE shares its monitoring data with Ecology consistent with this policy of cooperation. The wells used to monitor the tritium plume and ensure it is migrating and dispersing as predicted are located farther from the facility than the proximal wells; they are referred to as the tritium-tracking wells. These wells are sampled either annually or semiannually. In accordance with the Permit, DOE also performs computer modeling of the tritium plume at least once every Permit cycle and submits an annual groundwater monitoring and tritium-tracking report to Ecology.

In addition to the annual report, results of groundwater sampling and analysis of proximal wells during FY 2016 were also reported in quarterly discharge monitoring reports submitted electronically to Ecology.[5] Details of the SALDS groundwater-monitoring program are described in the current groundwater monitoring plan (RPP-ENV-59215, *Groundwater Monitoring and Tritium-Tracking Plan for the 200 Area State-Approved Land Disposal Site*).

---

[3] The permit revision in 2014 removed well 699-48-77A as a required sampling point because the well is dry. No samples were taken from well 699-48-77D in the last two quarters of FY16 because of low water level. The well is expected to become dry sometime in FY17. The permit states that sampling of wells 699-48-77C and 699-48-77D are required until they no longer produce representative data.

[4] Clean Water Act, 40 CFR Section 122.2. Available at: http://www.gpo.gov/fdsys/pkg/CFR-2011-title40-vol22/pdf/CFR-2011-title40-vol22-sec122-2.pdf.

[5] Quarterly discharge monitoring reports can be obtained by accessing the Water Quality Permitting and Reporting Information System (PARIS) at Ecology's website (www.ecy.wa.gov) and searching for the permit number, "ST0004500."

1.1 Objective and Scope

This report presents the results of groundwater monitoring of proximal wells and tracking wells for evidence of the tritium plume from the SALDS facility during FY 2016. This annual report addresses groundwater samples collected and analyzed from October 2015 through September 2016.

This report also contains a summary of the most recent update to the numerical groundwater flow and contaminant transport model of the tritium plume, which was developed during FY 2011. DOE updates this model at least once every permit cycle. The most recent model, SGW-51085, *Results of Tritium Tracking and Groundwater Monitoring at the Hanford Site 200 Area State Approved Land Disposal Site, Fiscal Year 2011* is attached as Appendix B.

1.2 Background

Background information presented in this section is based on the previous version of the groundwater monitoring plan (PNNL-13121 *Groundwater Monitoring and Tritium-Tracking Plan for the 200 Area State-Approved Land Disposal Site*) published in 2000. The conceptual model, groundwater monitoring program, SALDS discharges, and plume modeling are presented.

1.2.1 Hydrogeologic Setting and Conceptual Model

The hydrogeologic setting and conceptual model for SALDS have been described in previous documents (e.g., SGW-38802, *Results of Tritium Tracking and Groundwater Monitoring at the Hanford Site 200 Area State-Approved Land Disposal Site Fiscal Year 2008*) and are not repeated here. Figure 1-2 shows the conceptual model and depicts ETF effluent migration through the sediment profile to groundwater. A key aspect of this conceptual model is the lateral migration of effluent in the vadose zone along the fine-grained Cold Creek unit (CCU), which dips toward the south. Most of the ETF effluent is interpreted to enter groundwater to the south of the SALDS, near monitoring well 699-48-77A.

1.2.2 Groundwater Monitoring Program

The primary objectives listed in the groundwater-monitoring plan (RPP-ENV-59215) are to compare groundwater-sampling results for nonradionuclides in the proximal wells to the Permit concentration limits and track migration of the tritium plume from the SALDS. The following objectives are also listed in the monitoring plan:

- Track changes in groundwater quality associated with SALDS discharges.
- Determine why changes (if any) have occurred.
- Compare model predictions with observed results to refine predictive model capability.
- Correlate discharge events at SALDS with analytical results from groundwater monitoring.
- Assess the hydraulic response of the aquifer to SALDS discharges.

The groundwater monitoring well network (Figure 1-3) was designed to address these objectives using existing wells shared with other monitoring programs and the dedicated proximal wells drilled specifically to monitor SALDS.

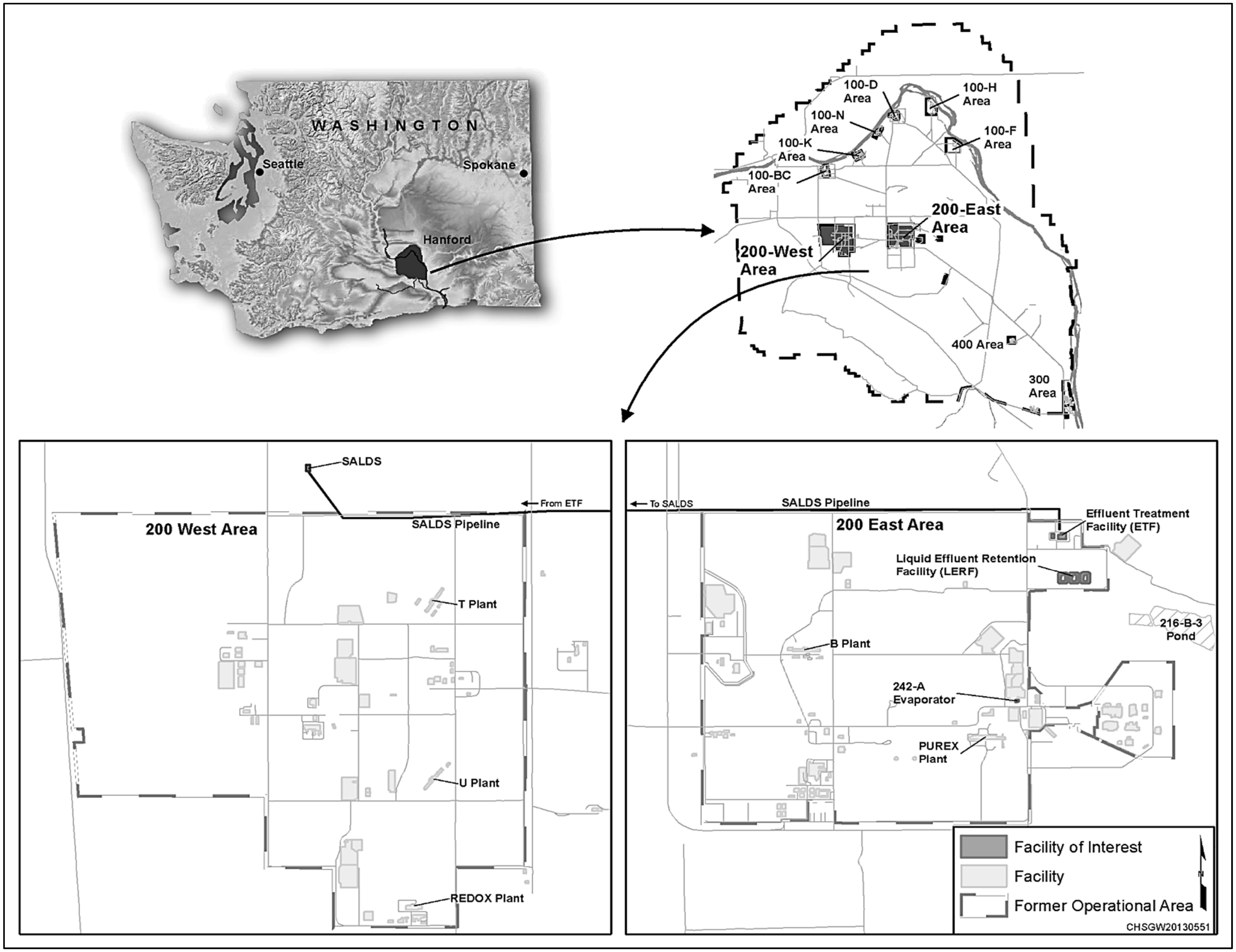


Figure 1-1. Location of SALDS and Related Infrastructure

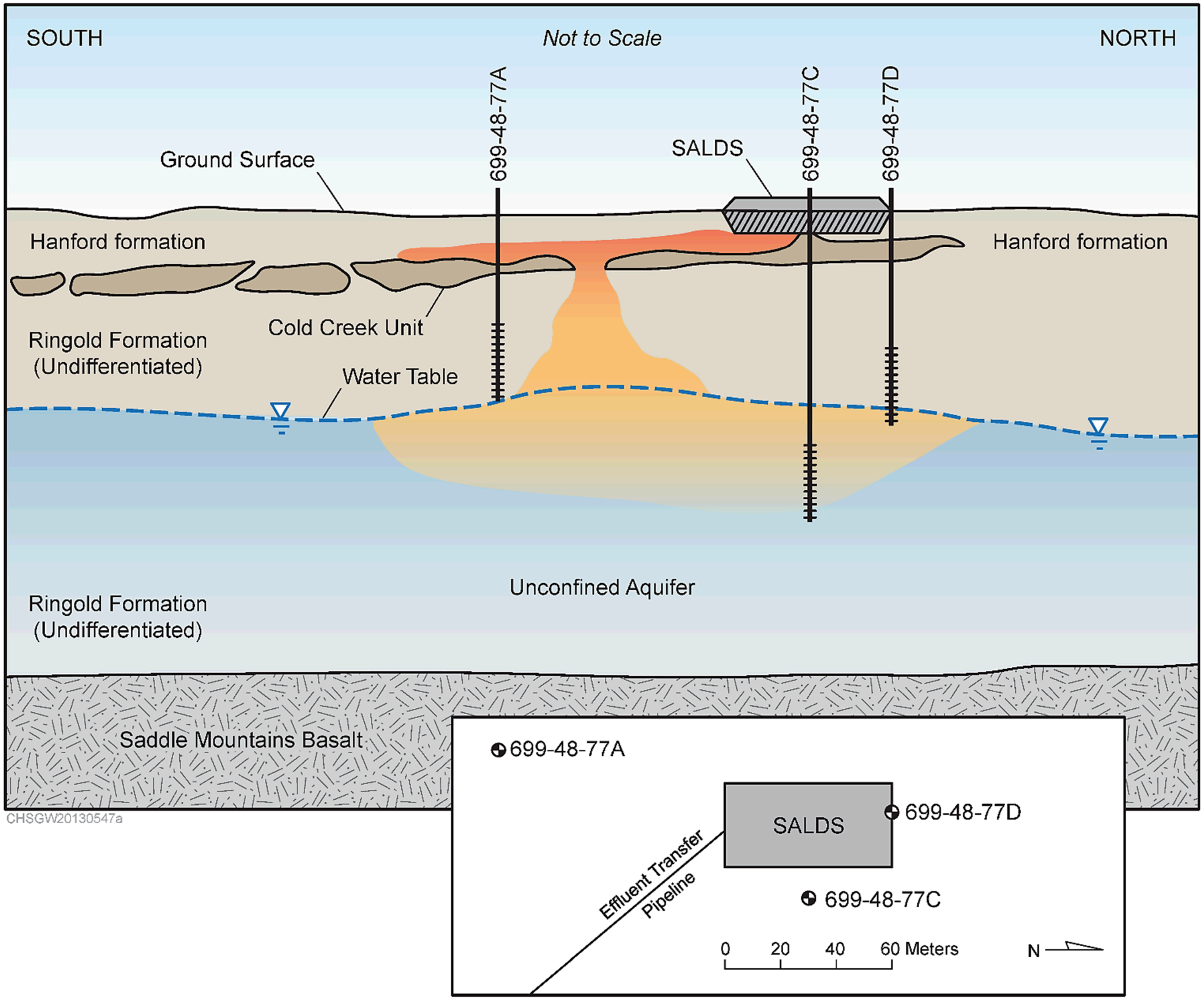


Figure 1-2. Conceptual Model Diagram of SALDS Operational Effects

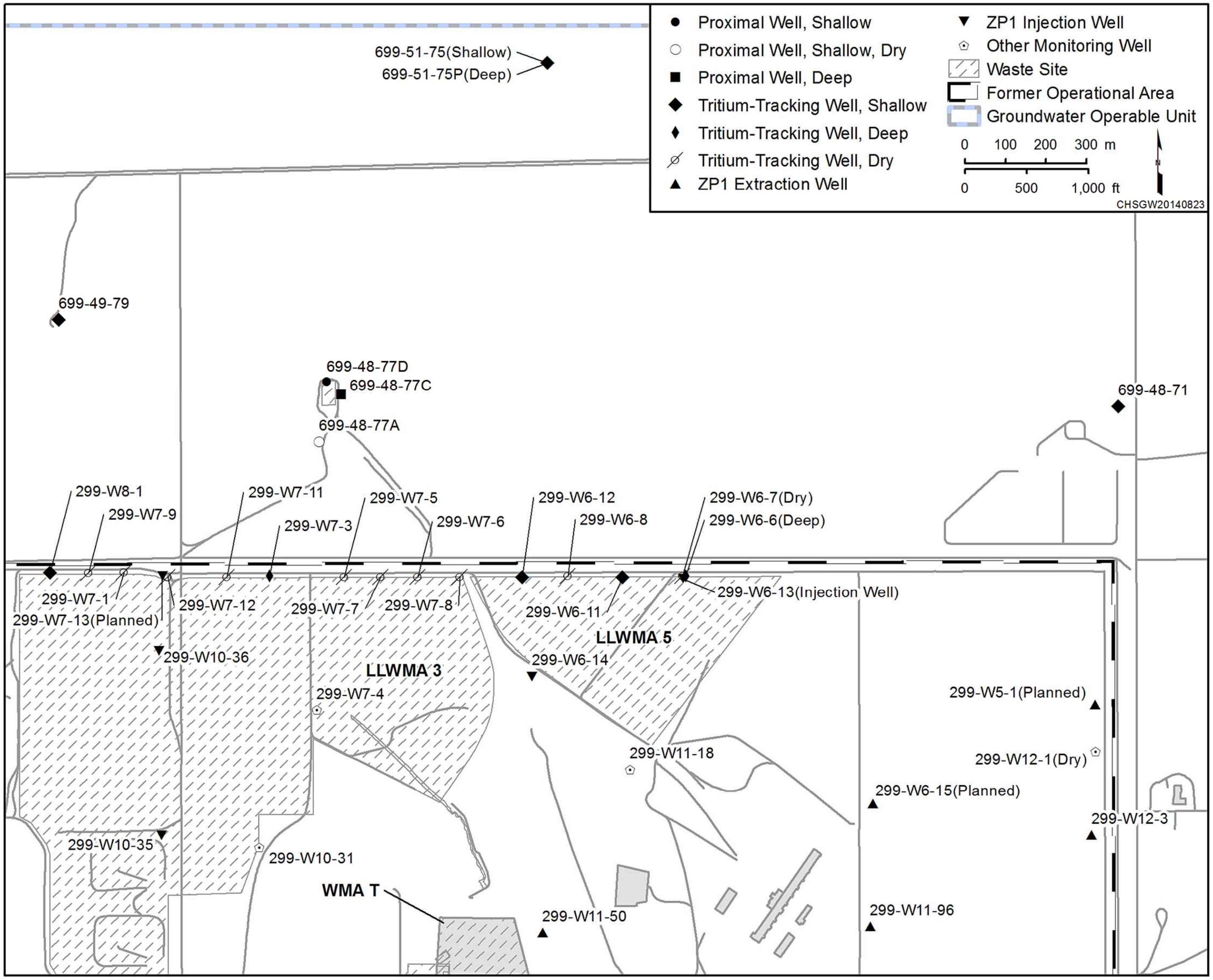


Figure 1-3. Locations of SALDS Groundwater Monitoring and Tritium Tracking Network Wells

1.2.3 Groundwater Modeling

DOE provides an update to the tritium plume numerical model at least once every Permit cycle to predict the distribution and movement of tritium in the aquifer as a result of discharges to SALDS. The Permit directs that the model be updated "within 6 months of detection of the tritium plume from SALDS in a new monitoring well," i.e., in a location not predicted by the most recent model run, or within a well not previously affected by SALDS-derived tritium. To date, no positive indications of SALDS-derived tritium have been detected in a new monitoring well. The groundwater model was last updated in 2011; Section 4 below provides a summary of the results, including the predicted tritium concentrations in groundwater near SALDS out to the year 2030. The model incorporated recent refinements to the Central Plateau (CP) groundwater model (DOE/RL-2009-38, *Description of Modeling Analyses in Support of the 200-ZP-1 Remedial Design/Remedial Action Work Plan*; CP-47631, *Model Package Report: Central Plateau Groundwater Model Version 3.3*) and included the SALDS discharge volume and tritium release information reported through June 2011. The model also included the latest information regarding the forecast operation of the 200-ZP-1 pump-and-treat (P&T) system located in the 200 West Area. The P&T system began operating during July 2012, and future model updates will include actual system operational parameters at the time the model update is performed. Appendix B of SGW-51085 provides a more detailed description of the modeling performed during 2011.

1.2.4 State-Approved Land Disposal Site Discharge Information

The ETF effluent infiltrates into the SALDS, which is a 35 m by 61 m (116 ft. by 200 ft.) rectangular drain field with 10.2 cm (4 in.) diameter porous pipe laterals coming from a 20.3 cm (8 in.) diameter header at 1.8 m (6 ft.) intervals. The drain field pipes are 15 cm (6 in.) below the surface of a 1.8 m (6 ft.) deep gravel basin. The gravel basin is covered by at least 30 cm (12 in.) of natural, compacted cover soil.

Discharge of tritium-laden water to SALDS began in December 1995, with 220 Ci of tritium released in the first 7 months (which amounted to approximately 51% of the total activity released to date). Discharge volumes from ETF were about 80 million L (21 million gal) each year until FY 2004. Discharges between March 2005 and August 2007 were sporadic and included intermittent ETF campaigns to treat 242-A evaporator process condensate and K Basins project waste streams, both of which supplied much of the tritium recently discharged to SALDS. Discharge volumes increased in September 2007 when ETF began treating groundwater from the interim action pump-and-treat system at the T Tank Farm; however, the tritium activity in this stream was low. The interim action pump-and-treat system was shut down on June 5, 2012 when the 200-ZP-1 P&T system began operating. Discharge volumes from August 2013 to January 2014 were again intermittent until the ETF evaporator heat exchanger failed in January 2014, shutting down the facility.

The ETF restarted in June 2016 following repair of the evaporator heat exchanger. Leachate waste from the Environmental Restoration Disposal Facility (ERDF), containing moderate tritium concentrations, was treated upon restart of the ETF with 14.7 million L (3.88 million gal) of effluent discharged to SALDS. The total discharge volume to SALDS, since startup in December 1995 through September 2016, is approximately 1,218 million L (322 million gal) (Figure 1-4).

Figure 1-5 shows the monthly and cumulative activity of tritium discharged to SALDS (not corrected for radioactive decay). The total quantity of tritium discharged in FY 2016 was 1.9 Ci. The total activity of tritium discharged to SALDS from December 1995 through September 2016 is 432 Ci.

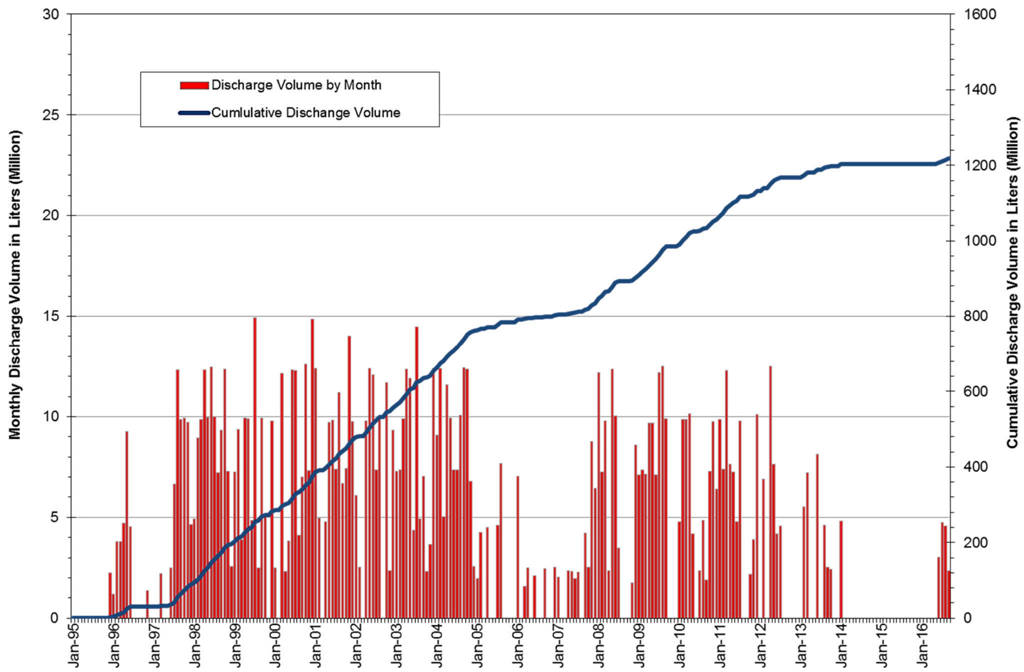


Figure 1-4. Monthly and Cumulative Discharge Volumes for SALDS from Inception through September 2016

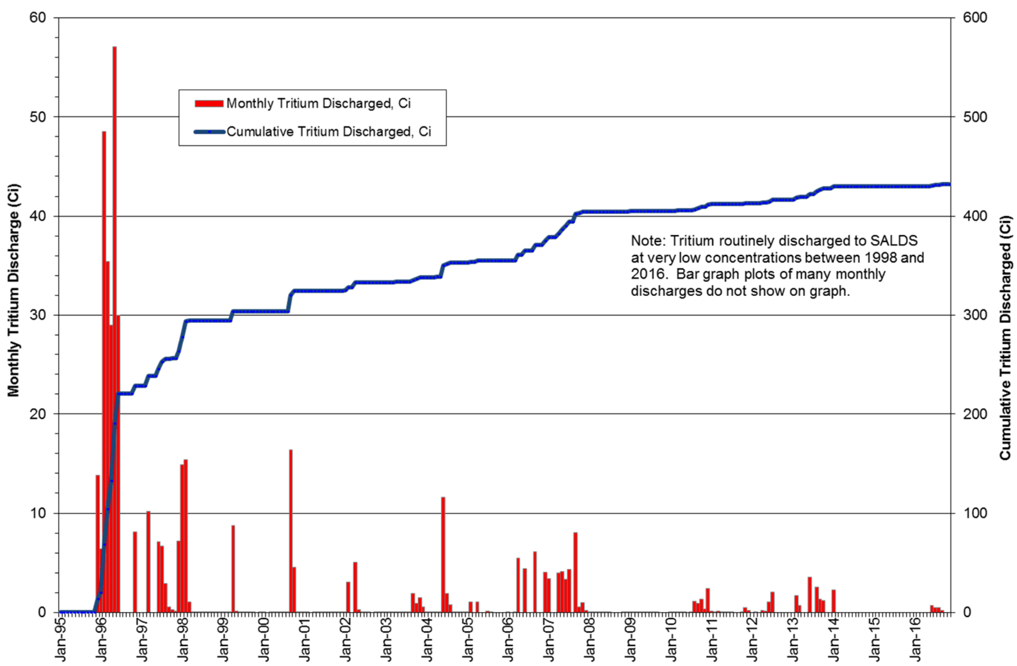


Figure 1-5. Monthly and Cumulative Tritium Activity Discharged to SALDS from Inception through September 2016

2 Results of Fiscal Year 2016 Water-Level Monitoring

Measurements of water levels in wells surrounding SALDS are performed to assess the hydraulic response of the aquifer to SALDS discharges, to interpret local and regional water table elevation changes, and determine the groundwater flow direction. These measurements are used in combination with groundwater chemistry analyses to update conceptual and predictive models and forecast the movement of tritium from the SALDS.

2.1 200-ZP-1 Operable Unit Pump-and-Treat System

The 200-ZP-1 P&T system continues to influence the water table in the SALDS vicinity. The system consists of extraction and injection wells, piping, transfer stations, and a treatment plant (200 West Groundwater Treatment Facility). The system began operating in July 2012 (DOE/RL-2014-26, *Calendar Year 2013 Annual Summary Report for the 200-ZP-1 and 200-UP-1 Operable Unit Pump-and-Treat Operations*) and has a capacity of 9,500 L/min (2,500 gal/min). The water is treated at the 200 West Groundwater Treatment Facility, located within the 200 West Area. This facility is designed to remove carbon tetrachloride, chromium, iodine-129, nitrate, technetium-99, and trichloroethylene from the extracted groundwater. Similarly to ETF, tritium is not removed because there is no cost effective treatment technology for tritium. As a result, the water injected into the aquifer contains tritium. The selected remedy for tritium in the 200-ZP-1 P&T system is monitored natural attenuation.

Several 200-ZP-1 extraction and injection wells are located along the north side of the 200 West Area and it is these wells that are primarily affecting the water table in the SALDS vicinity. The P&T system wells nearest to SALDS are injection wells 299-W6-13, 299-W6-14, and 299-W10-36 (Figure 1-3). In particular, injection well 299-W6-13 is located only 9.8 m (32 ft.) from tritium-tracking well 299-W6-6. Numerical modeling indicated that a slight water table elevation increase would occur in the SALDS vicinity due to operation of these injection wells (SGW-50907, *Predicted Impact of Future Water-Level Declines on Groundwater Well Longevity within the 200 West Area, Hanford Site*) and this has been confirmed by water-level measurements (see Sections 2.3 and 2.4). Three extraction wells; 299-W11-50, 299-W11-96, and 299-W12-3 are located 1.4 km (0.9 mi), 1.9 km (1.2 mi), and 2.2 km (1.4 mi) to the southeast of the SALDS well 299-W6-6. Two new extraction wells (299-W6-15 and 299-W5-1) have been installed approximately mid way between these extraction wells (Figure 1-3) and the SALDS well 299-W6-6. These new wells began extracting groundwater in late December of 2015.

2.2 Groundwater Flow

A set of water-level measurements across the 200 West Area were collected over the past year and the water table map constructed from these measurements for the northern portion of the 200 West Area is shown in Figure 2-1.[6] This map shows the effect of the 200-ZP-1 P&T system with groundwater mounds occurring where injection wells are located (circular features) and a large area where the water table has been drawn down occurs along the east side of the 200 West Area in response to groundwater extraction. This groundwater extraction has had an impact on the groundwater flow direction in the northeastern 200 West Area to be southeast toward the extraction wells, whereas prior to operation of the 200-ZP-1 P&T system, the flow direction was more toward the east-northeast. Due to the influence of the injection wells along the north side of the 200 West Area, the regional groundwater flow direction in the immediate vicinity of the SALDS continues toward the northeast.

---

6 All elevations in this document are in NAVD88, *North American Vertical Datum of 1988*.

In prior years, there has been hydraulic mounding around the SALDS. However, due to little or no discharges occurring over the last several years there is no noticeable mound, or impact, to the ground water elevation. When the groundwater mound was higher, such as during 2011 (SGW-51085), the groundwater flow indicated that effluent from SALDS may approach tritium-tracking wells located southeast of SALDS and may reach these wells if dispersion is taken into account. With no discharges in FY 2015 and only recent FY 2016 discharges, the situation is the same as in 2014, and conditions continue to indicate that groundwater from beneath SALDS will not be detected within the next six months in the tritium-tracking wells along the north side of the 200 West Area. Whether the tritium plume actually reaches these wells depends on future discharge volumes to SALDS and the influence of injection wells proximal to these wells. Predictions from the latest modeling are that the tritium plume will turn south toward the 200-ZP-1 extraction wells prior to reaching tritium-tracking well 699-48-71 (Section 4.2) located due east of the SALDS.

2.3 Water-Level Trends

Water level elevations are measured in SALDS wells prior to sampling events, and additional measurements are collected regularly in proximal wells (699-48-77A, 699-48-77C, and 699-48-77D) in accordance with the groundwater-monitoring plan (RPP-ENV-59215). The water table in the northern portion of the 200 West Area has declined in recent years to the point where a number of the SALDS tritium-tracking wells have become dry. The proximal well 699-48-77A has also become dry. Attempts to sample well waters are discontinued when wells are dry but water-level measurements are acquired when possible.

Water levels in all wells in the 200 West Area have exhibited declining trends since effluent discharges associated with process operations were terminated at U Pond in 1985 and at all nonpermitted facilities in 1995. Water elevation trends in proximal wells and tritium tracking wells are shown in Figures 2-2 through 2-7. Wells depicted on these graphs are grouped by relative geographic position to the SALDS well 299-48-77A.

Water elevations in the proximal wells continue to decline (Figure 2-2) due to an overall decline in the 200 West Area water table, decreased and interrupted discharges to SALDS, and fluctuations in the water table due to 200-ZP-1 P&T injection and extraction wells. There were no discharges from the ETF to the SALDS from January 2014 to May 2016 due to the ETF evaporator failure. From March 2015 to March 2016 water levels decreased in the proximal wells by 0.047 m (0.15 ft.) in 699-48-77A, by 0.580 m (1.90 ft.) in 699-48-77C, and 0.537 m (1.76 ft.) in 699-48-77D (Table 2-1). Comparable one year declines from July 2015 to July 2016 were 0.027 m (0.1 ft.), 0.271 m (0.9 ft.), and 0.561 m (1.8 ft.), respectively (not shown). Recent ETF discharges to SALDS in June, July, August and September of 2016 have not been observed to affect the water levels in the proximal wells and the general decline in water elevations in these wells continues (Table 2-1).

The one-year water level decrease in all three proximal wells averaged 0.388 m (1.27 ft.). The average one-year water-level change in the tritium-tracking wells was a decrease of 0.702 m (2.30 ft.). The average one-year decrease for all wells was 0.623 m (2.04 ft.).

The SALDS tritium-tracking wells also showed water elevation decreases. These decreases are directly attributable to decreased discharges from the 200 ZP-1 injection wells, particularly from wells 299-W6-13 and 299-W6-14 which lie very close to tritium tracking wells at the northern edge of the 200 West Area. When these injection wells are idle the water table drops dramatically as observed in the large one-year drops in the tracking wells 299-W6-6, 299-W6-11 and 299-W6-12 (Table 2-1).

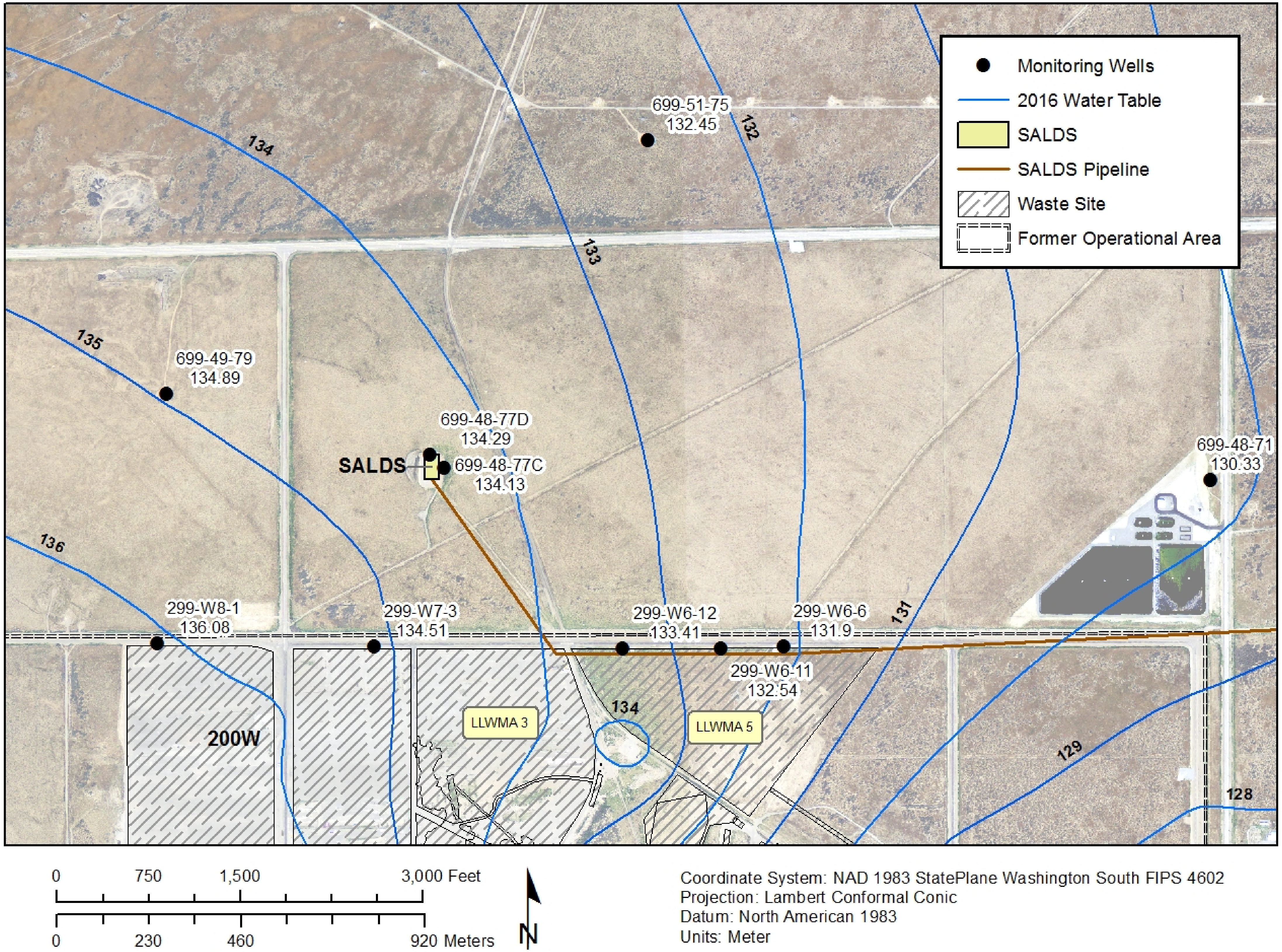


Figure 2-1. Water Table Map for the SALDS Area, March 2016

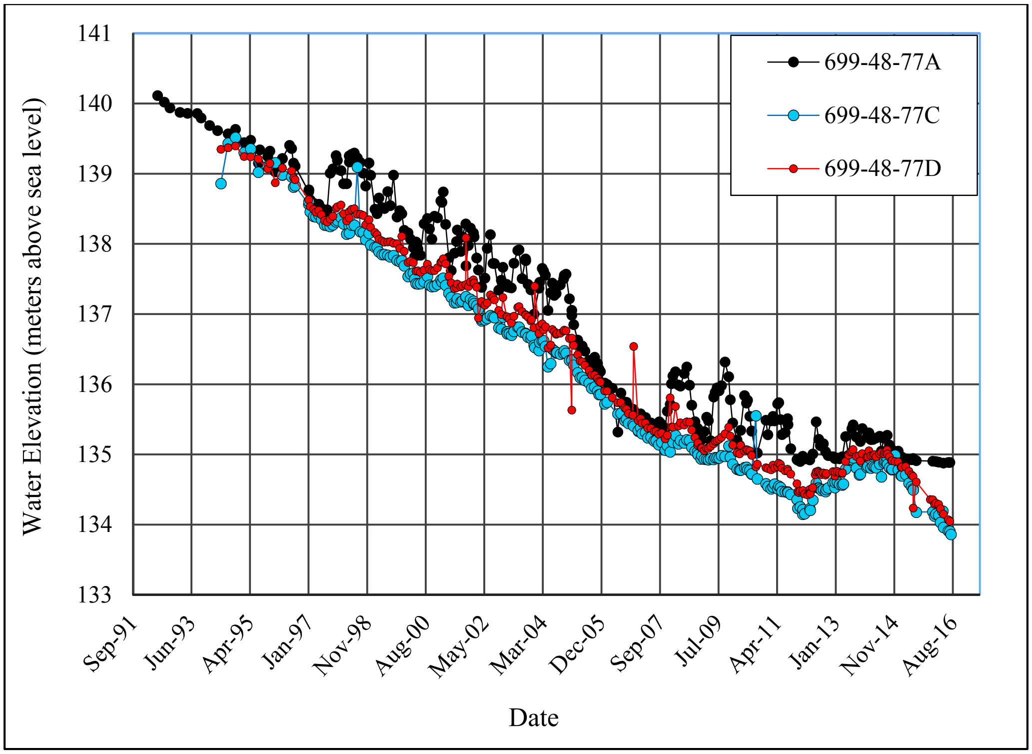


Figure 2-2. Water Levels in the SALDS Proximal Wells

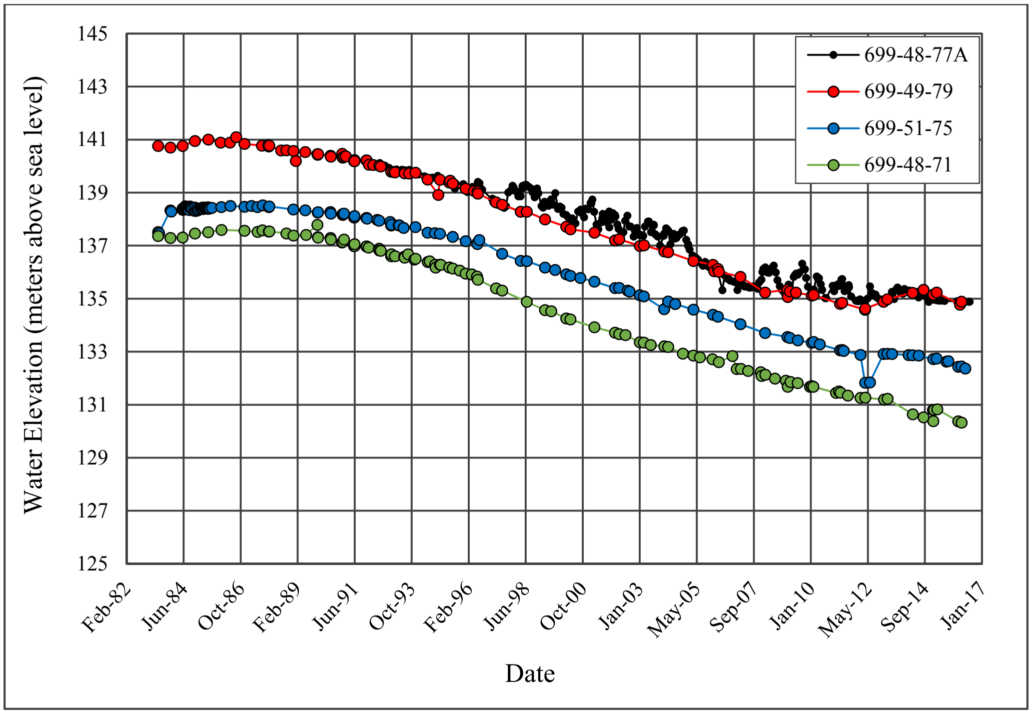


Figure 2-3. Water Levels in Tritium-Tracking Wells North, Northwest, and East of the Site Compared to Well 699-48-77A

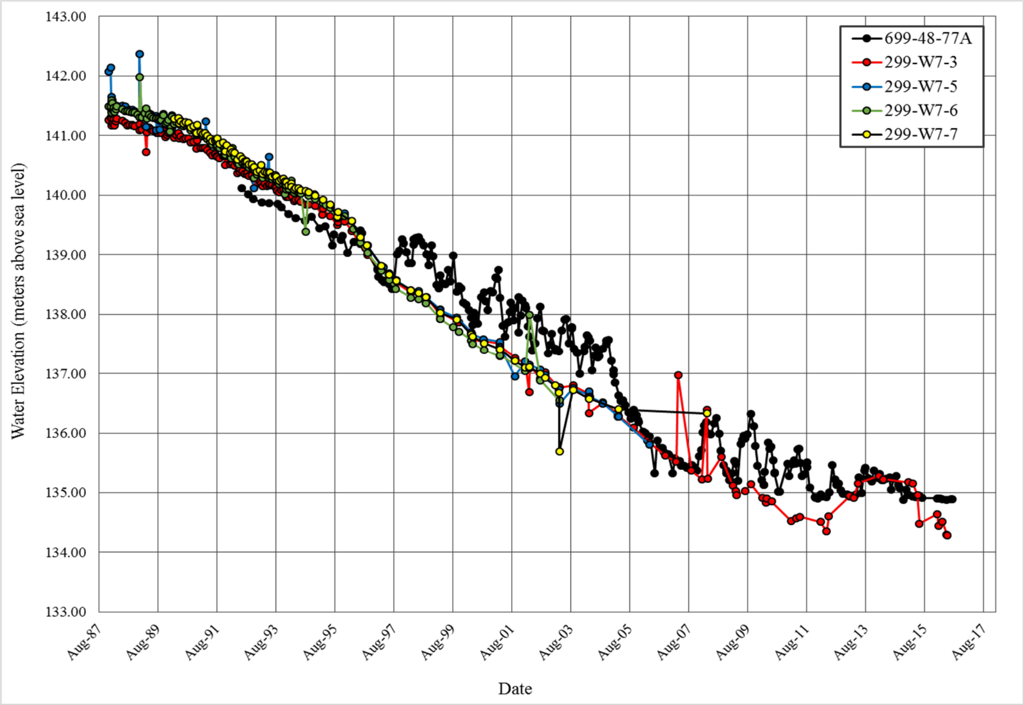


Figure 2-4. Water Levels in Tritium-Tracking Wells South of SALDS Compared to Well 699-48-77A

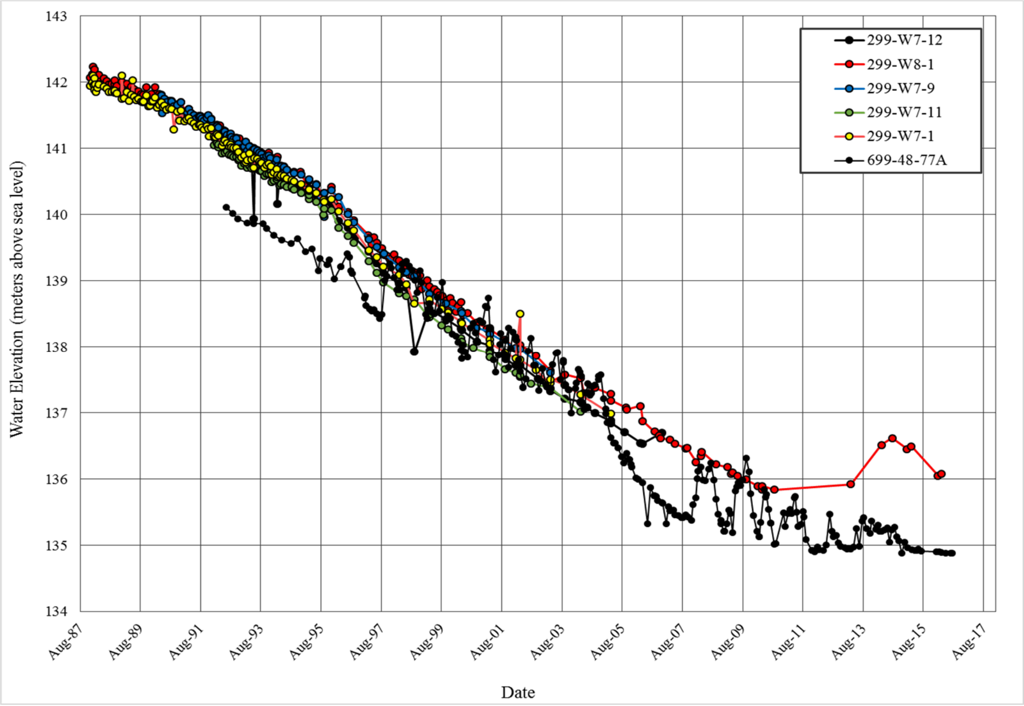


Figure 2-5. Water Levels in Tritium-Tracking Wells Southwest of SALDS Compared to Well 699-48-77A

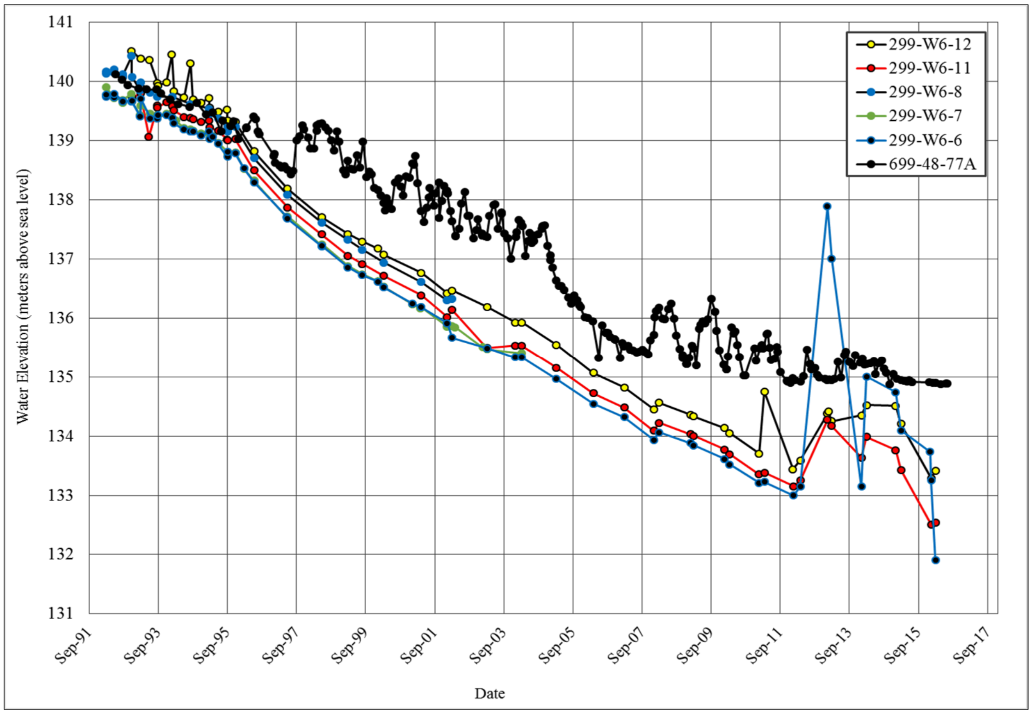


Figure 2-6. Water Levels in Tritium-Tracking Wells Southeast of SALDS Compared to Well 699-48-77A

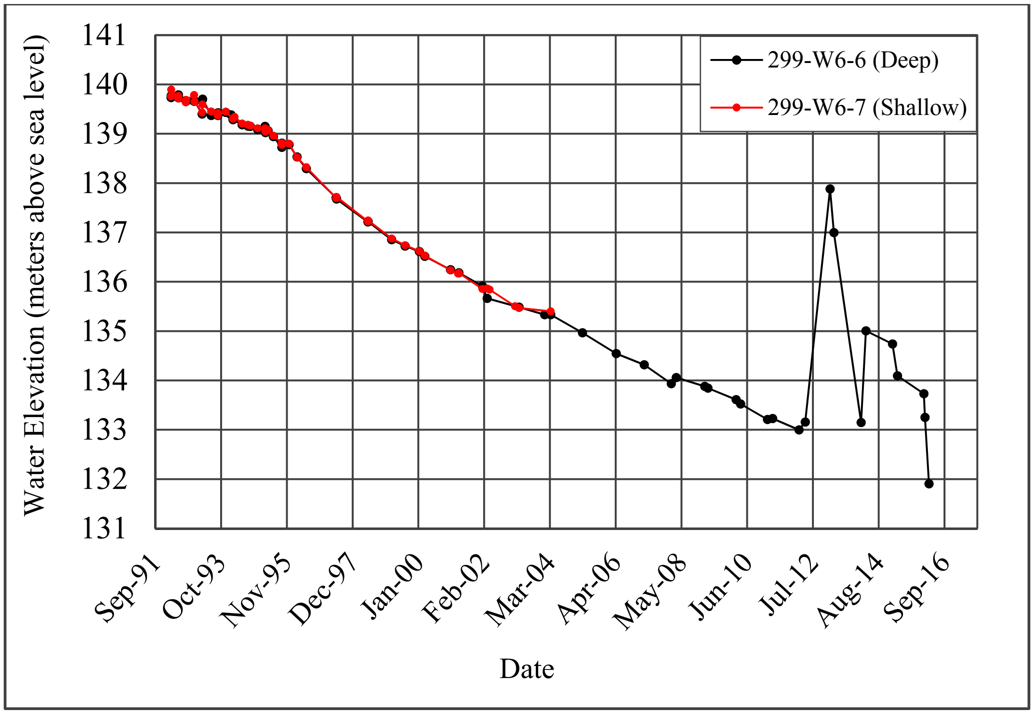


Figure 2-7. Water Levels in a Deep/Shallow Well Pair Southeast of SALDS

Table 2-1. Change in Water-Level Elevations

Well	March 2015 Elevation (m)	March 2016 Elevation (m)	Annual Rate of Change 2015 to 2016 (m/yr)
Proximal Wells			
699-48-77A	134.939	134.892	-0.047
699-48-77C*	134.714	134.134	-0.580
699-48-77D	134.827	134.290	-0.537
Tritium-Tracking Wells			
299-W6-6*	134.093	131.904	-2.189
299-W6-11	133.427	132.541	-0.886
299-W6-12	134.203	133.413	-0.790
299-W7-3*	135.152	134.513	-0.639
299-W8-1	136.492	136.080	-0.412
699-48-71	130.827	130.328	-0.499
699-49-79	135.234	134.888	-0.346
699-51-75	132.743	132.449	-0.294
699-51-75P*	132.755	132.495	-0.260
Average, All Wells (m/2 yr)			**-0.623**
Average, Tritium-Tracking Wells Only (m/2 yr)			**-0.702**
Average, Proximal Wells Only (m/2 yr)			**-0.388**

* Well has an open interval below the water table (i.e., deep completion).

2.4 Well Longevity

A groundwater modeling study was conducted in 2011 to assess the effects that the regional water table decline and operation of the 200-ZP-1 P&T system would have on groundwater levels in the 200 West Area and vicinity (SGW-50907). The model predicted future water levels, which were compared to well screen elevations of completed shallow wells in use at that time. The model identified wells that were predicted to become dry in the near future. This study represents the best forecast of well longevity through the year 2020 of the 200 West Area monitoring wells.

The modeling study indicated that between 2011 and 2013 water levels would increase in all but two of the shallow screened wells in response to the 200-ZP-1 P&T system. This prediction was confirmed by recent water-level measurements (Figures 2-2 through 2-7). Water elevation increases were predicted to range from 0.3 to 0.9 m (1 to 3 ft.). Water levels were not expected to increase in wells 699-48-71 and 699-51-75 which are farther from the 200-ZP-1 injection wells.

Thus, some wells that are becoming dry are expected to be usable a few years longer than they would have been without the 200-ZP-1 P&T system injections.

Predicted long-term well longevities of shallow-completed proximal and tritium-tracking wells are shown in Table 2-2. The model predicted there should be an overall drop in water levels and eight wells did decrease in elevation but they did not reach the levels predicted by the model. Two wells (699-48-71 and 699-49-79) increased contrary to model predictions. However, it is still expected that all but three of the shallow-screened monitoring wells in the SALDS network will become dry sometime in calendar year 2017. These wells (699-48-77D, 299-W6-11 and 299-W6-12) along with proximal well 699-48-77A (which became dry in 2011), are compared to actual water levels and screen bottom elevations in Figures 2-8 through 2-11. Actual water levels are lower than predicted in the two proximal wells (Figures 2-8 and 2-9). This is because actual discharge volumes to the SALDS have been lower than discharge volumes assumed for the modeling, so the groundwater mound beneath SALDS is lower than anticipated.

Actual water levels for wells 299-W6-11 and 299-W6-12 are in good agreement with the predicted water levels (Figures 2-10 and 2-11). These wells were forecast to become sample dry in 2015 or 2016. The water level at well 299-W8-1 increased more than model predictions, which allowed this well to be sampled beginning in 2014 after having been dry since 2010. This well will continue to be sampled until it becomes dry. Only three of the shallow-screened SALDS monitoring wells (tritium-tracking wells 699-48-71, 699-49-79, and 699-51-75) are predicted to have more than 0.3 m (1 ft.) of water after calendar year 2016 (Table 2-2). Four other wells in the SALDS network (299-W6-6, 299-W7-3, 699-48-77C, and 699-51-75P) are screened relatively deep in the aquifer and will be usable indefinitely.

Table 2-2. Well Open Interval Bottom Elevations Compared to Predicted Water Levels

Well	Open-Interval Bottom Elevation (m)	Most Recent Water-Level Measurement		Predicted Water Levels by Year (m NAVD88)				
		Meters (NAVD88)	Date	2016	2017	2018	2019	2020
299-W6-11	131.7	132.54	3/13/2016	132.07	131.76	131.51	131.28	131.07
299-W6-12	132.7	133.41	3/13/2016	132.85	132.54	132.29	132.07	131.85
299-W8-1	136.1	136.08	3/13/2016	135.49	135.23	135.01	134.80	134.56
699-48-71	124.5	130.33	3/17/2016	129.48	129.24	129.02	128.82	128.75
699-48-77A	135.1	134.89	3/13/2016	134.73	134.45	134.22	134.00	133.78
699-48-77D	134.2	134.29	3/13/2016	134.38	134.11	133.88	133.67	133.44
699-49-79	125.8	134.89	3/13/2016	134.28	134.04	133.83	133.63	133.42
699-51-75	127.7	132.45	3/13/2016	132.03	131.78	131.56	131.35	131.17

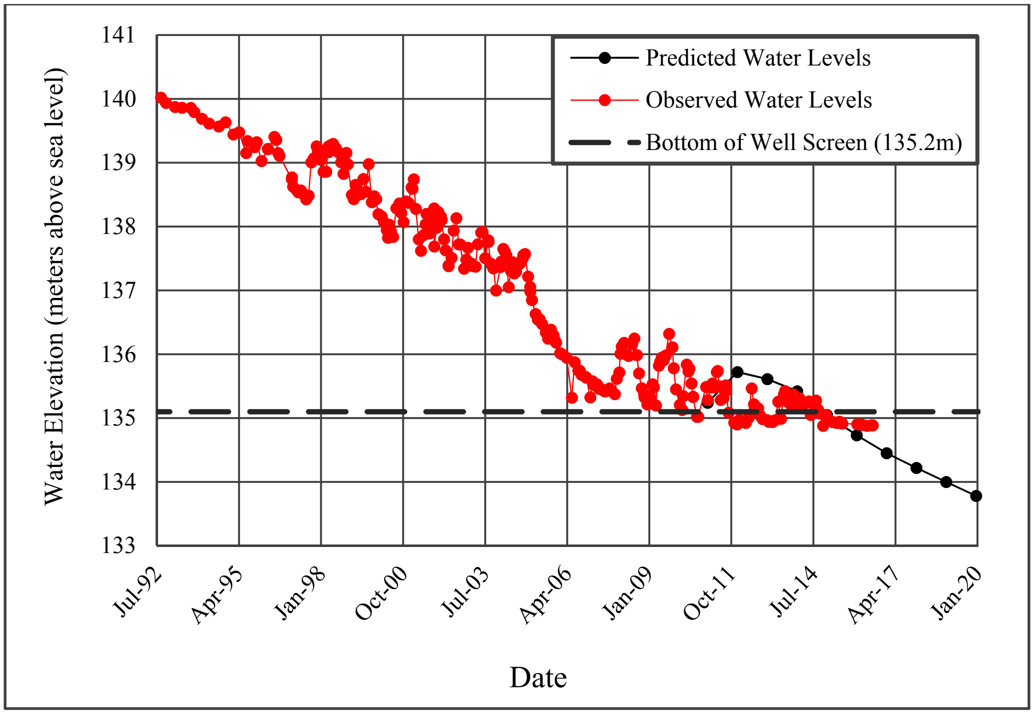


Figure 2-8. Water Remaining in Proximal Well 699-48-77A

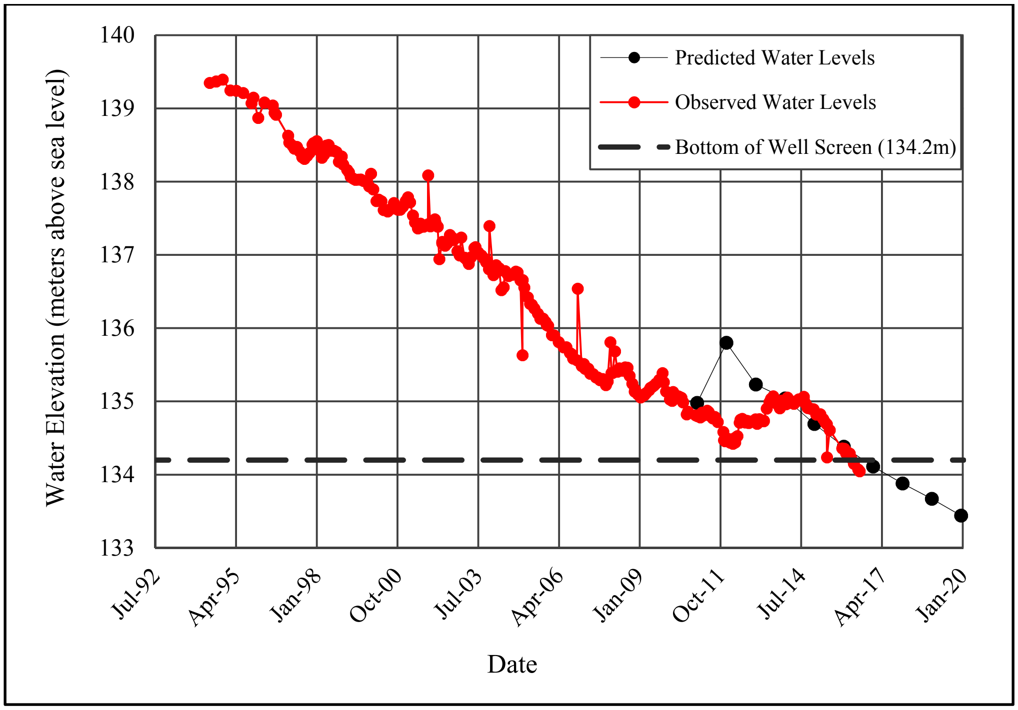


Figure 2-9. Water Remaining in Proximal Well 699-48-77D

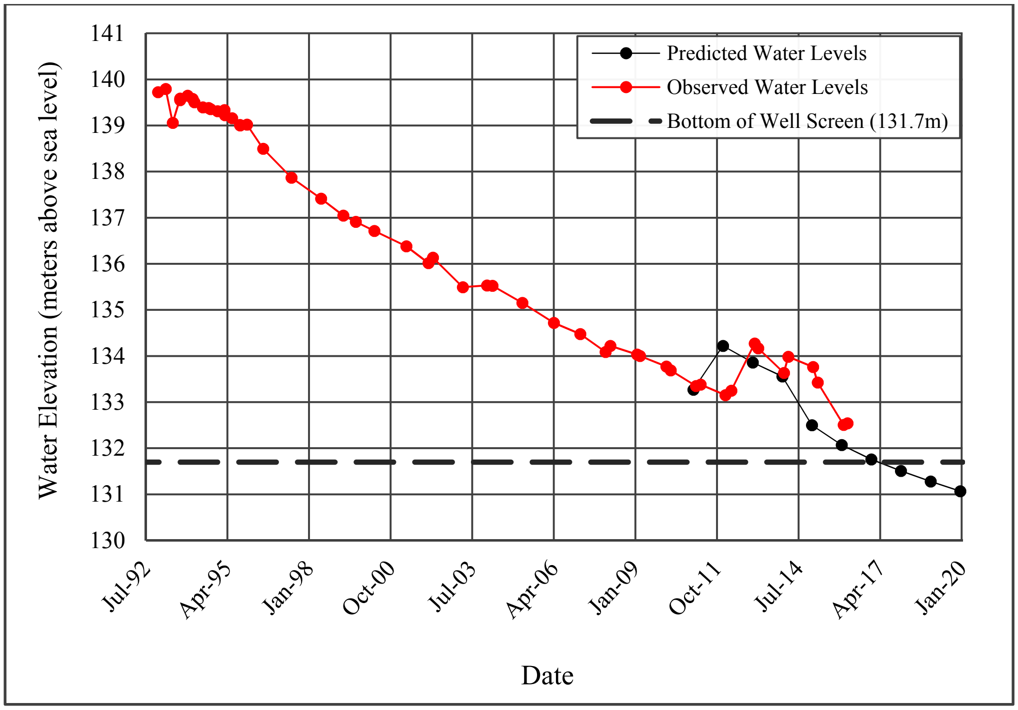


Figure 2-10. Water Remaining in Tritium-Tracking Well 299-W6-11

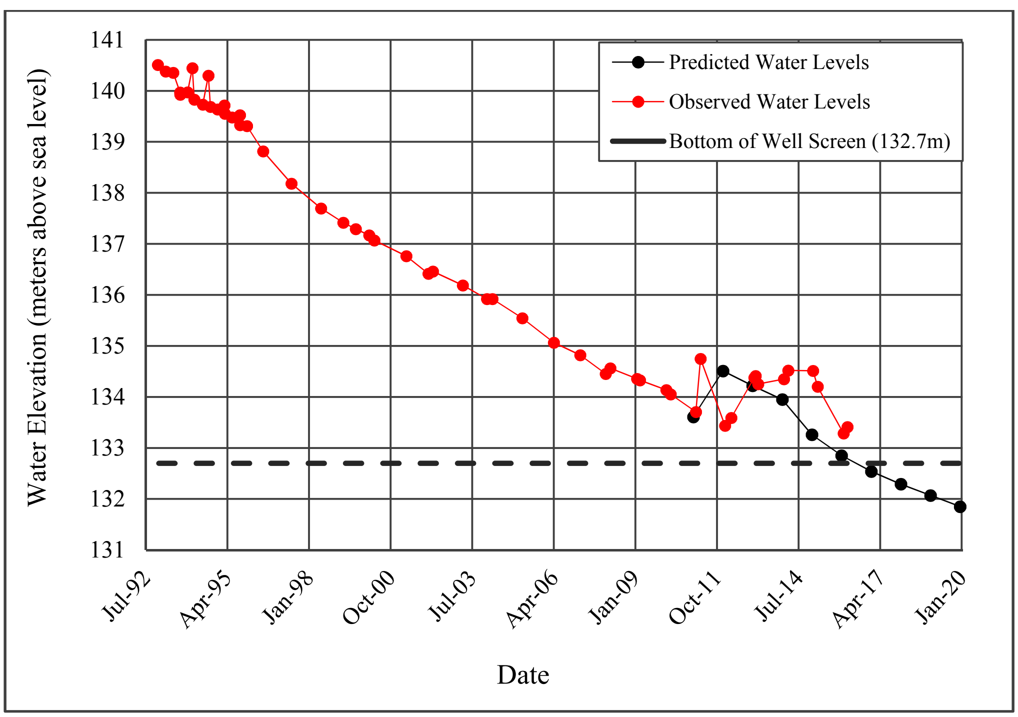


Figure 2-11. Water Remaining in Tritium-Tracking Well 299-W6-12

3 Results of Fiscal Year 2016 Groundwater Sampling

Groundwater sampling was scheduled quarterly in proximal wells 699-48-77C and 699-48-77D and annually to semiannually in tritium-tracking wells located in the SALDS vicinity. Proximal well 699-48-77A was not scheduled because it has too little water remaining to sample. Sampling of this well was removed from the Permit in 2014. Per the Permit, sampling of the SALDS proximal wells will continue only until they no longer produce representative data. Ecology has also agreed that no replacement wells are needed when a proximal well becomes dry because monitoring of ETF effluent provides assurance that the Permit discharge limits will not be exceeded (12-NWP-035). Although proximal well 699-48-77D was expected to become dry before FY 2017 it was successfully sampled in October 2015 and January 2016. Proximal well 699-48-77C is completed deeper in the aquifer and is not expected to go dry. Table 3-1 shows the FY 2016 sampling schedule.

Table 3-1. Sampling Schedule for Fiscal Year 2016

Well	Sampling Frequency/Months*	Other Sampling Programs	Comments
299-W6-6	A/January	Ringold Confined; 200-ZP-1 OU	Deep well Sampled in January 2016
299-W6-11	A/January	—	Sampled in January 2016
299-W6-12	A/January	—	Sampled in January 2016
299-W7-3	S/January, May	Ringold Confined; 200-ZP-1 OU	Deep well Sampled in January and May 2016
299-W8-1	A/July	—	Sampled in January 2016
699-48-71	A/January	200-ZP-1 OU	Sampled in January 2016
699-48-77C	Q/October, January, April, July	—	Sampled for 17 constituents/parameters listed in the Permit, including tritium. Sampled Oct 2015 and Jan, April, July 2016
699-48-77D	Q/October, January, April, July	—	Sampled for 17 constituents/parameters listed in the Permit, including tritium Sampled only in Oct 2015 and Jan 2016
699-49-79	A/January	—	Sampled in February 2016
699-51-75	S/January, May	—	Sampled in January and May 2016
699-51-75P	A/January	—	Deep piezometer in well 699-51-75. Sampled in January 2016

* Actual months of sampling may vary due to equipment failure, winter weather conditions, or accessibility restrictions caused by fire hazard; however, the sampling frequency is generally maintained.
A = annually
FY = fiscal year
OU = operable unit
Q = quarterly, S = semiannually

Samples collected this fiscal year were analyzed by either TestAmerica (Richland, Washington or St. Louis, Missouri) or GEL Laboratories (Charleston, South Carolina). TestAmerica Richland is typically used for anion and low-activity tritium analyses, while TestAmerica St. Louis (TASL) or GEL is used for all other analyses.

Section 3.1 summarizes FY 2016 groundwater sampling results for proximal wells 699-48-77C and 699-48-77D. Section 3.2 discusses results of the tritium analyses, including the tritium-tracking wells. Tritium concentrations in well samples are shown in Appendix A, Table A-1.

3.1 Proximal Well Sampling and Analyses for Fiscal Year 2016

Quarterly samples from proximal well 699-48-77C was analyzed for tritium and 16 other constituents/parameters listed in the groundwater-monitoring plan (RPP-ENV-59215). Well 699-48-77D was analyzed for tritium and 16 other constituents/parameters for the first two quarters of FY 2016, but samples were unobtainable from this well for the last two quarters. The earlier revision of the Permit from FY 2000 set concentration limits for acetone, benzene, cadmium (total), chloroform, copper (total), lead (total), mercury (total), field pH, sulfate, tetrahydrofuran, and total dissolved solids. Gross alpha, gross beta, strontium-90, tritium, specific conductance, and temperature were also listed in the Permit but were not assigned concentration limits; they were reported for informational purposes. Results for all of these parameters are reported quarterly in discharge monitoring reports in accordance with the Permit. Additional parameters (i.e., alkalinity, dissolved oxygen, turbidity, chloride, calcium and sodium) are used to determine general groundwater characteristics and verify the quality of analytical results. Table 3-2 lists measured concentrations of these constituents in proximal wells 699-48-77C and 699-48-77D and their sampling months in FY 2016. The limiting concentrations of each constituent which were listed under previous versions of the Permit, but which are not included in the current Permit, have been removed from Table 3-2.

Acetone, benzene, cadmium, chloroform, lead, mercury and tetrahydrofuran were reported below detection limits in both proximal wells for all samples collected in FY 2016. Very low concentrations of copper were detected in both wells in FY 2016. Unfiltered groundwater samples contained slightly higher copper concentrations than the filtered samples suggesting that a copper colloid may exist in equilibrium with the aqueous copper.

The sulfate concentration in well 699-48-77D was approximately 4 times higher than in well 699-48-77C. Sulfate concentrations were 4300 and 4200 µg/L in well 699-48-77C in FY 2016, respectively. Comparable concentrations in well 699-48-77D were 15,000 and 16,000 µg/L. The lower sulfate concentrations in well 299-48-77C were due to dilution by groundwater. Total dissolved solids (TDS) for the two proximal wells were 157,000 µg/L in 699-48-77C and 179,000 µg/L in 699-48-77D.

During FY 2016, gross beta results ranged from below detection limits to a maximum of 5.33 pCi/L in the proximal wells, which is below the Hanford Site background value of 9.73 pCi/L (95th percentile value provided in DOE/RL-96-61, *Hanford Site Background: Part 3, Groundwater Background*). Only one sample from well 699-48-77C and one from well 699-48-77D had detectable levels of gross alpha in FY 2016. Gross alpha measured 2.72 pCi/L in 699-48-77C and 2.40 pCi/L in April 2016 and October 2015, respectively. These results are also below the Hanford Site background value of 3.48 pCi/L (95th percentile) in DOE/RL-96-61. All of the strontium-90 analyses in the proximal wells were nondetects during FY 2016.

Table 3-2. Constituent Concentrations in Groundwater and Corresponding Sampling Month for the SALDS Proximal Wells, Fiscal Year 2016

Constituent	Well 699-48-77C	Well 699-48-77D
Measured Constituent Concentrations		
Acetone	3.0 (TU) [a]	3.0 (TU) [a]
Benzene	0.30 (U) [a]	0.30 (U) [a]
Cadmium, Total	0.11 (U) [a]	0.11 (U) [a]
Chloroform	0.30 (U) [a]	0.30 (U) [a]
Copper, Total	1.24 Oct 2015	4.16 Jan 2016
Lead, Total	0.5 (U) [a]	0.5 (U) [a]
Mercury, Total	0.067 (U) [a]	0.067 (U) [a]
Field pH, pH Units[b]	8.05 Apr 2016	8.10 Oct 2015
Sulfate	4,300 Oct 2014, July 2016	16,000 Jan 2016
Tetrahydrofuran	1.5 (U) [a]	1.5 (U) [a]
Total Dissolved Solids	157,000 July 2016	179,000 Jan 2016
Gross Alpha, pCi/L	2.72 Apr 2016	2.96 (U)[a]
Gross Beta, pCi/L	5.33 Apr 2016	4.38 Jan 2016
Strontium-90, pCi/L	1.98 (U) [a]	1.88 (U) [a]
Tritium, pCi/L	51,600 Oct 2015	58,800 Jan 2016
Field Specific Conductance, µS/cm[b]	194.2 July 2016	259 Oct 2015
Field Temperature, °C[b]	19.6 July 2016	18.7 Oct 2015
Alkalinity, mg/L	94.9 July 2016	106 Jan 2016
Dissolved Oxygen, mg/L[b]	9.21 - 9.26 July 2016	12.60 - 12.74 Oct 2015
Turbidity, NTU[b]	0.85 - 1.14 Oct 2015	4.07 – 4.30 Jan 2016
Chloride, µg/L	1,000 July 2016	5,700 Jan 2016
Calcium, µg/L	20,400 Apr 2016	26,400 Jan 2016
Sodium, µg/L	7,260 Apr 2016	9,070 Oct 2015

Note: All concentrations are reported in µg/L, unless otherwise indicated.
a. Not detected in any sample.
b. Four analyses were performed per sample event. Values reported are averages of the four analyses, except that maximum values are used for pH, specific conductance, and temperature.
J = detected at a value less than the contract-required detection limit but greater than or equal to the instrument detection limit/method detection limit, as appropriate (i.e., a low-level detection)
NTU = Nephelometric Turbidity Unit
TU = Spike and/or spike duplicate sample recovery is outside control limits, not detected
U = Not Detected; detection limits (for nonradionuclides) or minimum detectable activity (for radionuclides) are indicated, as applicable

3.2 Results of Tritium Analyses (Tritium Tracking)

As discussed in the preceding section, only proximal well 699-48-77C had sufficient water levels needed to collect quarterly samples which were analyzed for a suite of constituents, including tritium. Insufficient water levels in 699-48-77D prevented sampling the last two quarters of FY 2016. The other SALDS network monitoring wells are sampled annually or semiannually for tritium only (i.e., tritium-tracking wells). Nine tritium-tracking wells were sampled in FY 2016 along with the two proximal monitoring wells. Due to generally declining water levels throughout the 200 West Area, many tritium-tracking wells listed in the monitoring plan (RPP-ENV-59215) are dry and no longer in use. Six wells that were successfully sampled are screened in the upper portion of the aquifer near the water table. Three other wells are screened at greater depths, including well (699-51-75P), that is a nested piezometer within well 699-51-75 with an open interval 41 m (135 ft.) deeper in the aquifer. Three tritium-tracking wells were also sampled for other programs in FY 2016 (Table 3-1). In recent years, tritium concentrations in proximal wells and tritium tracking wells have declined due to an overall decrease in tritium released from SALDS and dispersion and radioactive decay. Tritium sample results for all of the network wells are provided in Appendix A, Table A-1.

3.2.1 Tritium in the Proximal Monitoring Wells

This section describes changes in tritium concentrations in the proximal wells due to SALDS discharges, including current concentrations and long term tritium trends. Temporal changes in tritium concentrations in proximal wells in FY 2016 are shown in Appendix A, Table A-1. Maximum tritium concentrations in the proximal wells are shown in Table 3-2.

3.2.1.1 Long-Term Trends of Proximal Wells

Groundwater in the proximal wells has been affected by tritium discharges since 1996 (Figure 3-1). Peak tritium concentrations occurred in September 1997 (2,000,000 pCi/L) and February 1998 (2,100,000 pCi/L) in wells 699-48-77A and 699-48-77D, respectively. These peak concentrations were in response to initial discharges to SALDS between December 1995 and June 1996. The tritium concentration trend in well 699-48-77C is attenuated and time-lagged compared to the other wells. The peak concentration in this well occurred in February 2001, which was 3 years after the peak occurred in 699-48-77D, and the concentration had decreased to 980,000 pCi/L. The lower concentration was caused primarily by dispersion. Well 699-48-77C is screened approximately 20 m (65 ft.) below the water table, and as the plume migrated to this depth, it mixed with uncontaminated groundwater. Radiological decay would have also contributed to the decreased concentration because tritium has a relatively short half-life (12.3 years). However, aqueous dispersion following peak discharge was the dominant cause of the decreased tritium concentration observed in well 699-48-77C.

Tritium concentrations have generally trended downward since the initial discharges to the SALDS in 1995 and 1996, although periods of increasing or fluctuating concentrations have occurred. From 1999 to 2005 concentration changes in well 699-48-77A were irregular (Figure 3-1) with periodic highs and lows of significant amplitude. These fluctuations were likely caused by the ETF performing annual campaigns to treat 242-A Evaporator wastewater containing elevated tritium concentrations. In April 2008 the tritium concentration in well 699-48-77A was 820,000 pCi/L, the highest level seen in a decade (Figure 3-2). This elevated tritium concentration was likely due to several intermittent ETF campaigns in 2006 and 2007 to treat wastewater from the K Basins project which contained tritium levels similar to the 242-A Evaporator wastewater. These intermittent campaigns restarted in FY 2010 with ETF again treating wastewater from the K Basins project. This is considered to be the basis for the fluctuation in tritium concentration observed during FY 2011, before well 699-48-77A became dry.

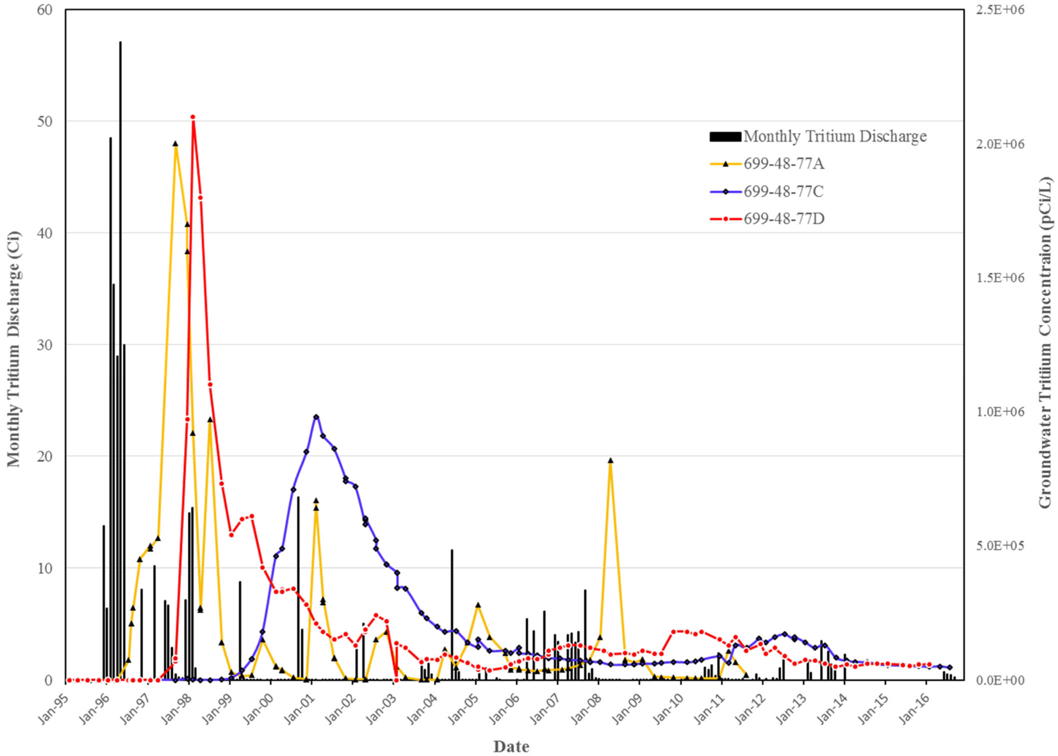


Figure 3-1. Tritium Releases and Concentration Trends in SALDS Proximal Wells from 1995 through July 2014

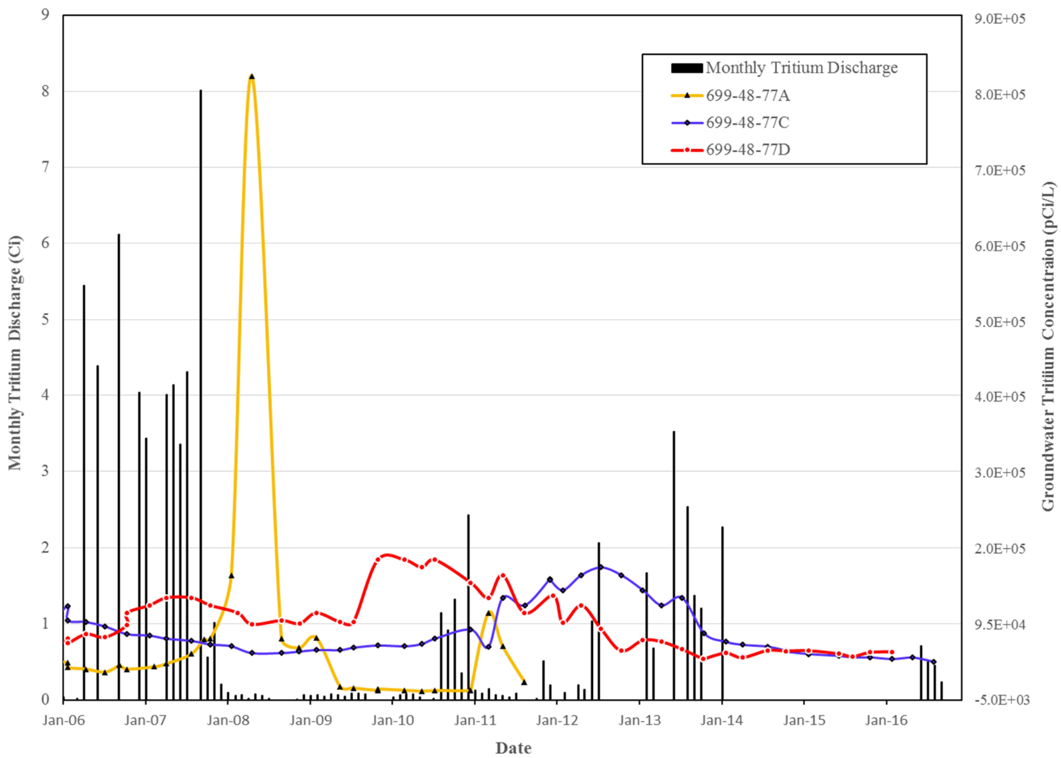


Figure 3-2. Tritium Releases and Concentration Trends in SALDS Proximal Wells from 2006 through June 2015

3.2.1.2 Current Trends of Proximal Wells

Tritium concentrations declined in the proximal wells in FY 2015 and FY 2016 reflecting the general decrease in concentrated discharges from ETF and interrupted discharges due to the failure of the ETF evaporator heat exchanger (Figures 3-1 and 3-2). The last ETF discharge to SALDS prior to the evaporator failure occurred in January 2014 with tritium concentrations gradually declining since then.

Neither proximal well showed evidence of a time-delayed pulse of tritium following the discharge in January of 2014. These delayed pulses of tritium from SALDS have been attributed to slow translocation of the plumes through the soil column and the vadose zone to the proximal wells. The translocation of plumes is also thought to be strongly influenced by the 200-ZP-1 P&T system, which injects very large volumes of effluent into the near surface environment with concomitant changes in the water table elevation. Interruptions in 200-ZP-1 P&T system discharges may be responsible for the apparent lack of time-lagged translocation and dispersion of tritium to the proximal wells. Proximity of these injection wells and their effect on water elevations in tritium-tracking wells is discussed below.

The tritium concentration in well 699-48-77C decreased from ~59,000 pCi/L in October 2014 to 51,300 pCi/L in August 2015. In FY 2016, tritium concentrations exhibited minor fluctuations but continued to decrease; decreasing from 51,400 to 45,700 pCi/L from October 2015 to July 2016. Similarly, tritium concentrations decreased in 699-48-77D from 60,500 pCi/L in July 2014 to 52,400 pCi/L in August 2015. From October 2015 to January 2016 the tritium concentration was essentially unchanged, measuring 57,900 to 58,800 pCi/L (1.5%), respectively.

3.2.2 Tritium-Tracking Wells

Sample analyses in FY 2016 continue to indicate that the tritium plume from SALDS has not reached any tritium-tracking wells. Tritium was not detected in wells 699-49-79 and 699-51-75, located west and northeast of SALDS, respectively (Figure 3-3). Similarly, tritium was not detected in two of the three deep tritium-tracking wells (299-W7-3 and 699-51-75P) located south and northeast of SALDS. Tritium, unrelated to the SALDS, was detected in tritium-tracking wells 299-W6-6, 299-W6-11, 299-W6-12 and 699-48-71 to the southeast and east of SALDS. The sources of this tritium was past waste disposal sites in the 200 West Area and active injection wells of the 200-ZP-1 P&T system.

As discussed in Section 2.1, the injection well 299-W6-13 for the 200-ZP-1 P&T system was installed only 9.8 m (32 ft.) from well 299-W6-6 (Figure 1-3). This injection well began operating in 2012 and continues to receive water from the 200-ZP-1 P&T system. Like the ETF, the 200-ZP-1 P&T system does not remove tritium from the effluent. In 2014 monthly tritium concentrations ranged from 2,550 to 3,180 pCi/L in the injected effluent. The average annual tritium concentration was 2,850 pCi/L (DOE/RL-2015-06). Injection of this effluent in well 299-W6-13 is causing tritium to appear in wells 299-W6-6, W6-11, W6-12 and 699-48-71. A second injection well, 299-W6-14, is also causing tritium to appear in tracking well 299-W6-12. Injection volumes in well 299-W6-14 have been approximately twice as large as the volumes injected in well 299-W6-13 since January 2014.

Migration of tritium from past wastewater disposal sites in the 200 West Area has also affected shallow tritium-tracking wells along the northern margin of the 200 West Area. Many of the shallow-screened wells in this area exhibited elevated tritium concentrations prior to the start of SALDS discharges (Figures 3-4 and 3-5), supporting the interpretation that this tritium originates from 200 West WMA's.

The deep tritium-tracking well 299-W6-6, located southeast of SALDS, contained 2,170 pCi/L of tritium when sampled in January 2015. The tritium concentration increased to 2730 pCi/L on January 13th, 2016 and decreased to 2,390 on January 25th, 2016. A second measurement on January 25th gave a tritium activity of 1,050 pCi/L but this measurement was considered anomalous (Table A-1).

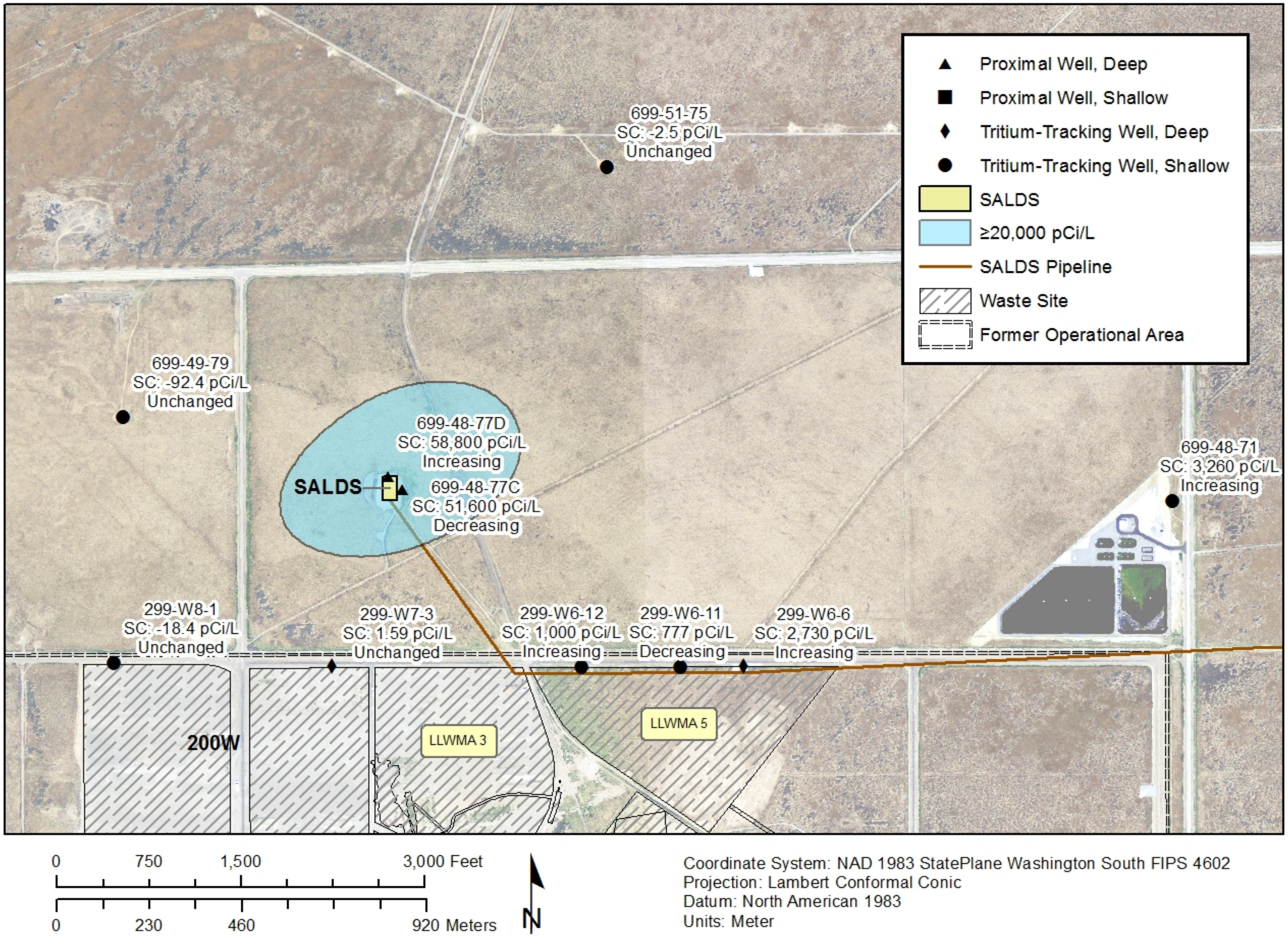


Figure 3-3. Tritium Activities in Groundwater from SALDS Tritium-Tracking Network in Fiscal Year 2016

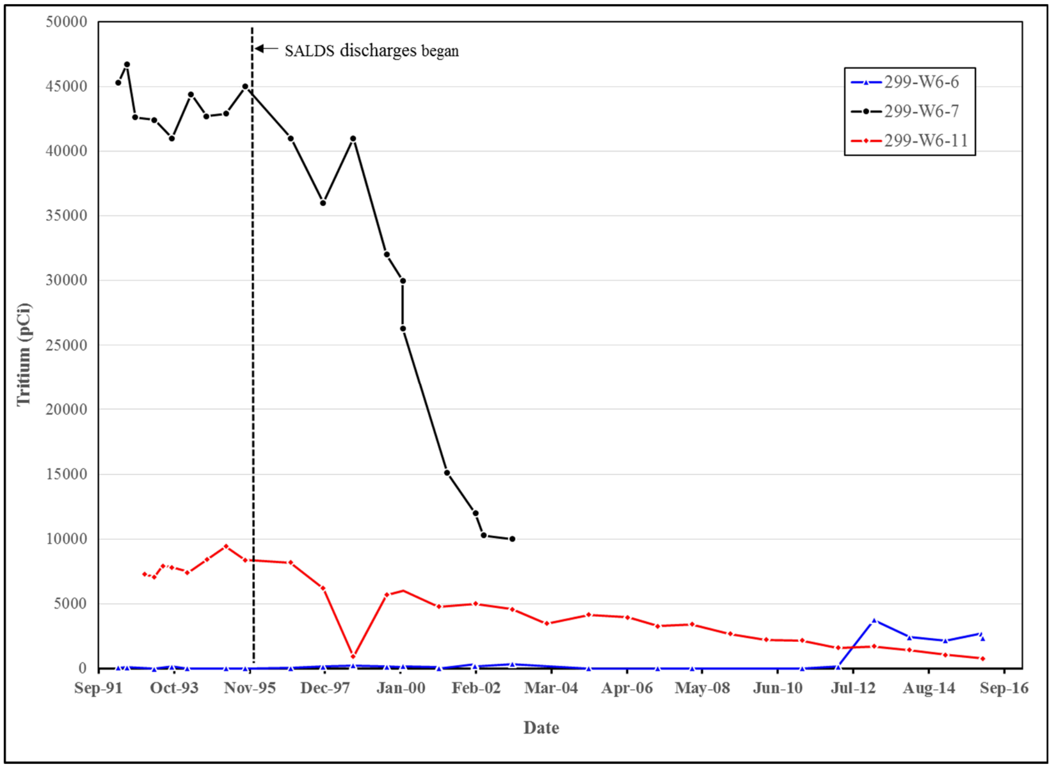


Figure 3-4. Tritium Activity Trends in Wells Southeast of SALDS Showing Remnant Effects of the Tritium Plume from the 200 West Area

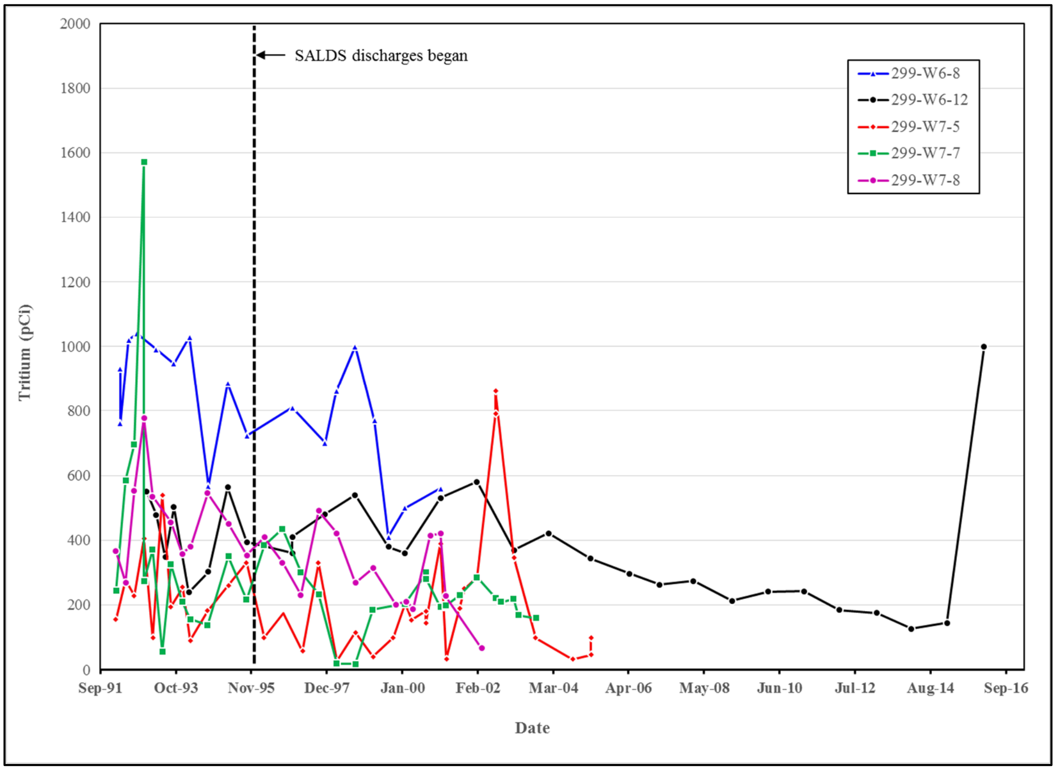


Figure 3-5. Tritium Activity in Wells South of SALDS Showing Remnant Effects of the Tritium Plume from the 200 West Area

The deep tracking well 299-W6-6 no longer provides useful information for tracking the tritium plume from SALDs due to the 200-ZP-1 injection wells and tritium contaminated groundwater migrating from 200 West WMA's. Another deep tritium-tracking well 299-W7-3 has not had measureable tritium since January 2008.

From FY 2015 to FY 2016, the shallow tracking well 299-W6-11 decreased from 1070 to 777 pCi/L while the nearby shallow tracking well 299-W6-12 increased sharply from 145 to 1000 pCi/L. As discussed above, this sharply increased tritium concentration is attributed to high volumes of effluent from the 200-ZP-1 P&T system being injected in well 299-W6-14 (Figure 1-3). This injection well lies 250 m (820 ft.) south of tracking well 299-W6-12 and 340 m (1115 ft.) southwest of tracking well 299-W6-11. For comparison, injection well 299-W6-13 lies 400 m (1315 ft.) east of well 299-W6-12. The proximity of injection well 299-W6-14 to tracking wells 299-W6-12 and 299-W6-11 is expected to increase tritium concentrations in both wells with continued injections from the 200-ZP-1 P&T system.

Well 699-48-71, located 1.5 km (0.97 mi) east of SALDS, has exhibited increasing tritium concentrations since 2004. Tritium concentrations in this well measured 2,390 pCi/L in FY 2014, 2,560 pCi/L in FY 2015, and 3260 and 2820 pCi/L in FY 2016. Although this well is located down gradient of the SALDS crib, the large distance to this well suggests that discharges from SALDS are not the source of tritium in groundwater at this location. This is supported by the tritium modeling results, which predict that the SALDS plume should not reach this well prior to the year 2030 (Figure 4-1).

3.3 Results of Other Constituent Analyses

After discharges began at SALDS, several anions and metals increased in concentration in the proximal wells and then rapidly declined. Specific conductance (a measure of total ions in solution) at well 699-48-77A shows a well-defined spike in the months after discharges to SALDS began in December 1995 (Figure 3-6), with values peaking at approximately 845 µS/cm in August 1996. This was likely due to transport of soluble mineral species that were dissolved from the vadose zone during initial percolation of effluents discharged to SALDS (PNNL-11633, *Origin of Increased Sulfate in Groundwater at the ETF Disposal Site,* PNNL-11665, *Tritium Monitoring in Groundwater and Evaluation of Model Predictions for the Hanford Site 200 Area Effluent Treatment Facility*). This spike in dissolved constituents was a temporary effect associated with initial effluent wetting and leaching of the emplaced sediments of the vadose zone beneath the SALDS.

Currently, specific conductance in the proximal wells is related to the volume of ETF effluent discharged to SALDS. ETF effluent is low in specific conductance with an average value for FY 2016 of 4.25 µS/cm. The Hanford Site groundwater background for specific conductance has a geometric mean of 348 µS/cm (DOE/RL-96-61). Thus, mixing of ETF effluent with groundwater decreases specific conductance in the monitoring wells because of dilution, and the amount of decrease depends on the volume of effluent released. Conversely, specific conductance in the SALDS wells increases during periods of decreased discharges. For example, between 2005 and 2007 specific conductance in shallow proximal wells 699-48-77A and 699-48-77D increased and peaked in late 2007 and early 2008 (Figure 3-6). A very small peak in specific conductance was observed during early 2011 in deep proximal well 699-48-77C, which is likely the attenuated, time-lagged response to the 2005 to 2007 period of decreased effluent discharges.

The tritium plume from SALDS is associated with low specific conductance in the groundwater because of the low specific conductance of the ETF effluent as shown in Figure 3-7. A region of high specific conductance occurs in the eastern part of the mapped area. This denotes the region of contamination originating from the 200 West Area. During FY 2016, the maximum specific conductance readings in the

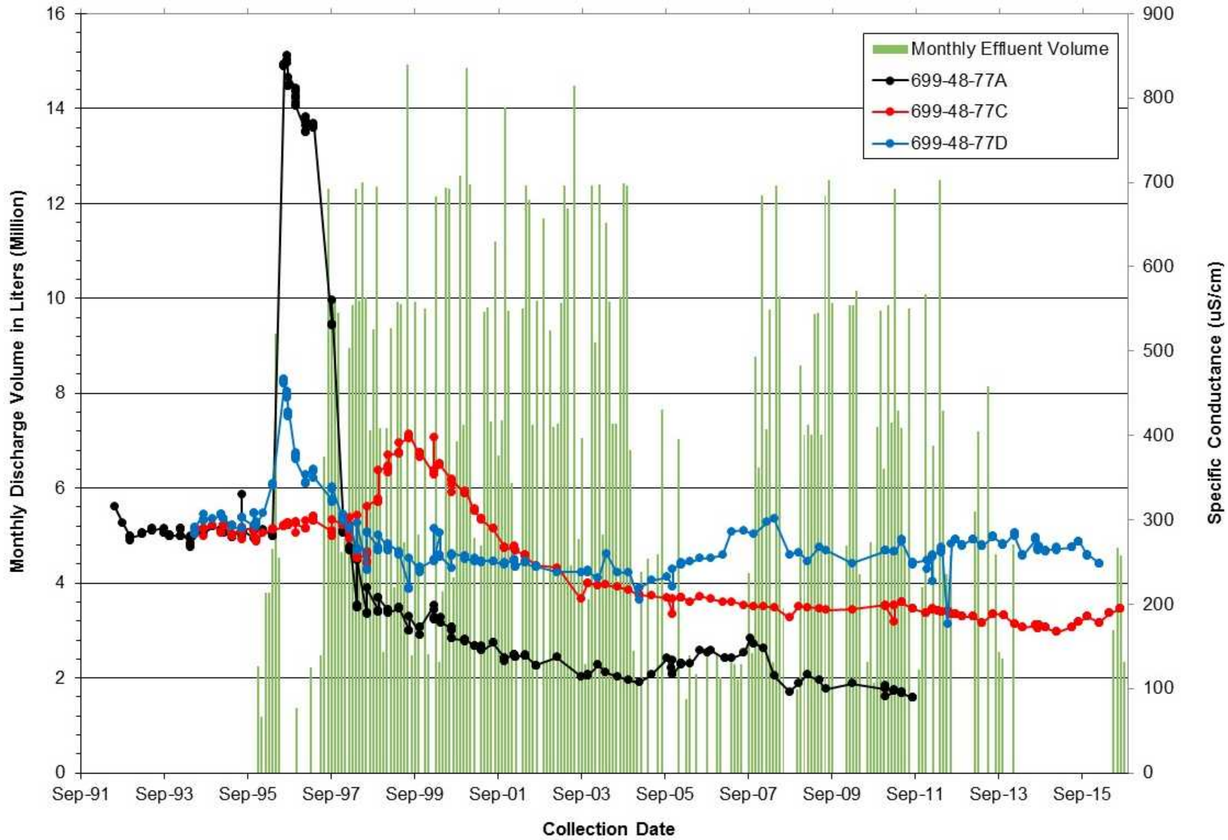


Figure 3-6. Specific Conductance in the SALDS Proximal Wells

proximal wells were 194 µS/cm in 699-48-77C and 259 µS/cm in 699-48-77D. Conductivity in well 699-48-77C is increasing slightly (Figure 3-6), which is likely in response to discontinued effluent discharges from February 2014 to June 2016. However, the shallow well 699-48-77D shows a slight decrease in specific conductance since August 2015.

During FY 2016, the maximum concentration of total dissolved solids in the proximal wells was 157 mg/L in 699-48-77C and 179 mg/L in 699-48-77D. Analytical results for total dissolved solids in both wells trended upward between 2011 and 2013, then changed to a downward trend during 2014, with the last samples collected indicating an upward movement (Figure 3-8). Specific conductance is an indirect measure of total ions in solution, so it is expected that total dissolved solids and specific conductance would trend together. However, recent trends in total dissolved solids (i.e., since 2011) do not correlate with trends in specific conductance (compare Figure 3-6 with Figure 3-8). The reason that recent specific conductance and total dissolved solids do not trend together is unknown.

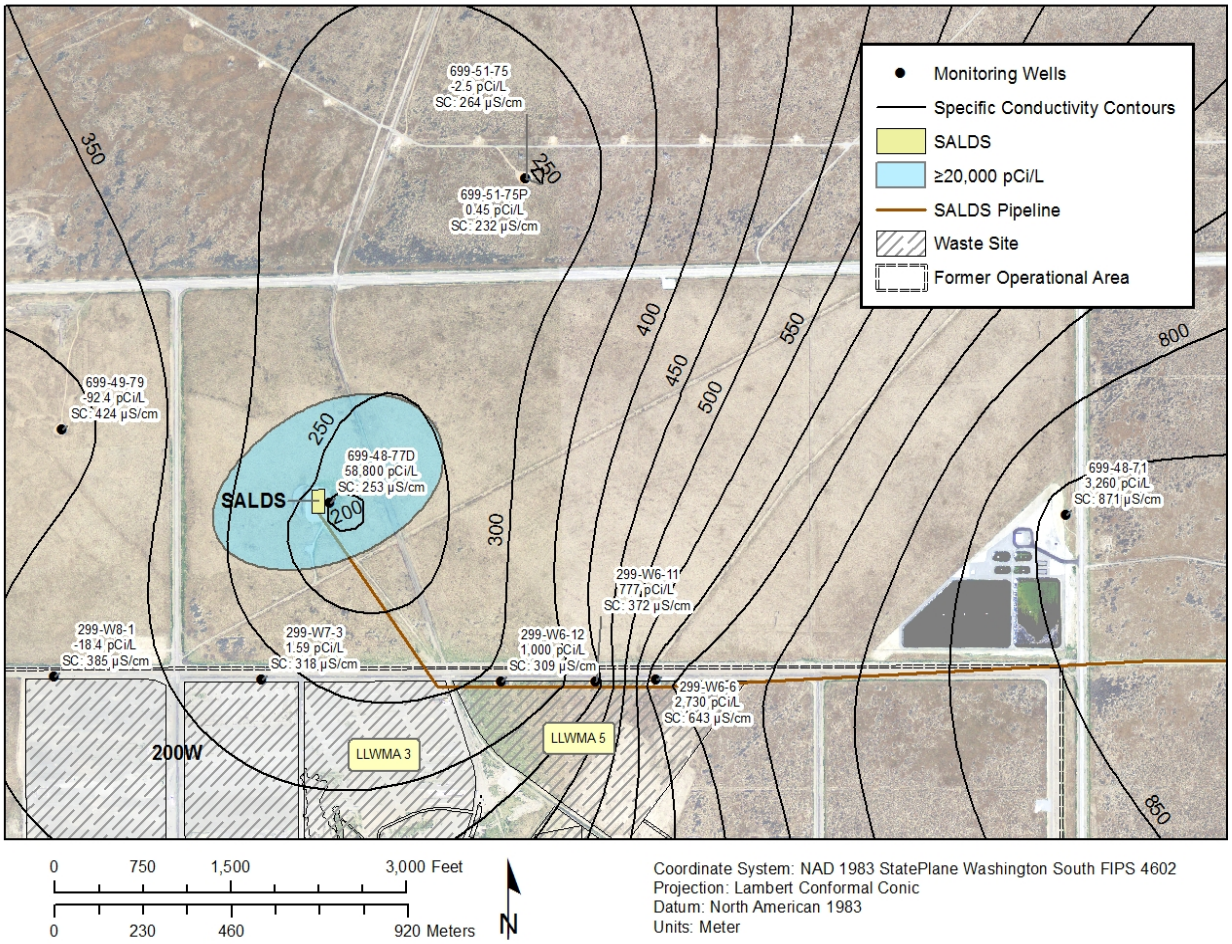


Figure 3-7. Specific Conductance and Tritium activity in the SALDS Vicinity

Figures 3-9 through 3-12 provide trend plots for chloride, sulfate, calcium, and sodium in the proximal wells. These constituents are leached from the soil, and they are naturally present in groundwater so the sample results are not representative of ETF effluent. However, these constituents provide useful information regarding the effect of discharges to SALDS on groundwater. Chloride, sulfate, and calcium exhibit the same trends as described previously for specific conductance. Sharp increases were observed in concentrations in the shallow proximal wells (699-48-77A and 699-48-77D) shortly after discharges began in 1995 due to leaching from the soil column. More recent trends exhibit an inverse relationship with discharge volume, indicating dilution in the aquifer of discharges to SALDS. The trends at deep well 699-48-77C exhibit the same attenuated, time-lagged response that was observed for specific conductance. The sodium trends also exhibit an increase in concentration shortly after the start of effluent discharges, but the relative increase was lower than for the other constituents (Figure 3-12). More recent sodium concentrations do not appear to trend with the other constituents, and there is no obvious relationship with effluent discharge volumes. This suggests that the effluent is continuing to leach sodium from the soil column, so the concentration in the leachate is similar to the concentration in groundwater.

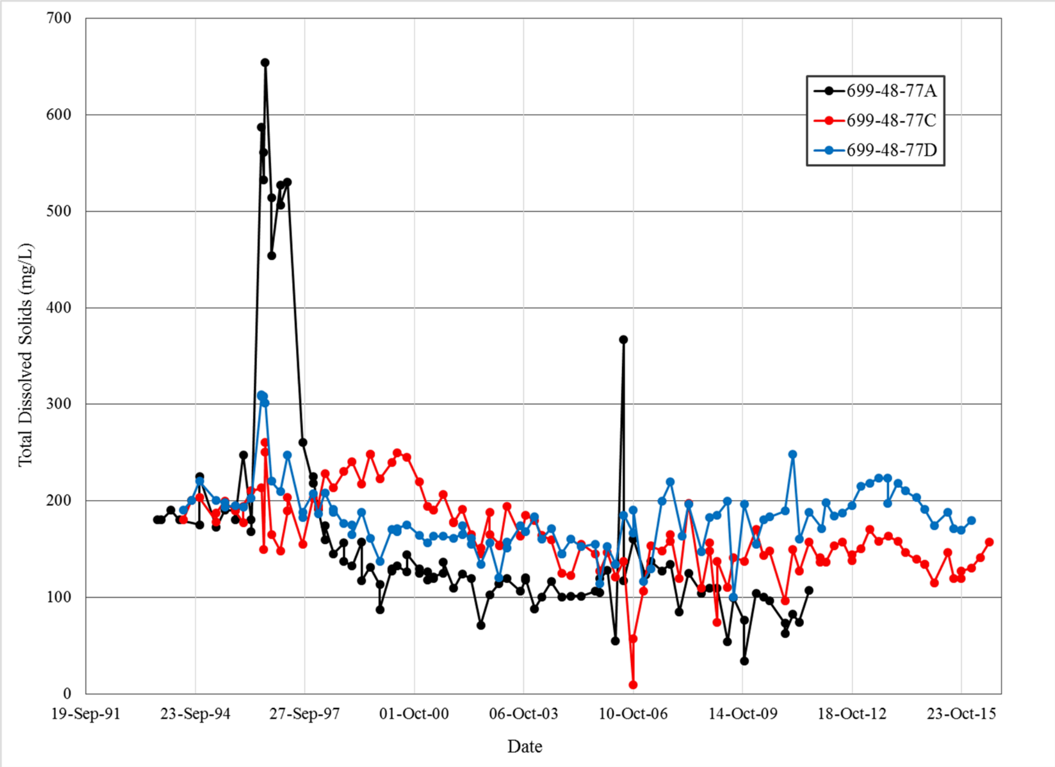


Figure 3-8. Total Dissolved Solids in the SALDS Proximal Wells

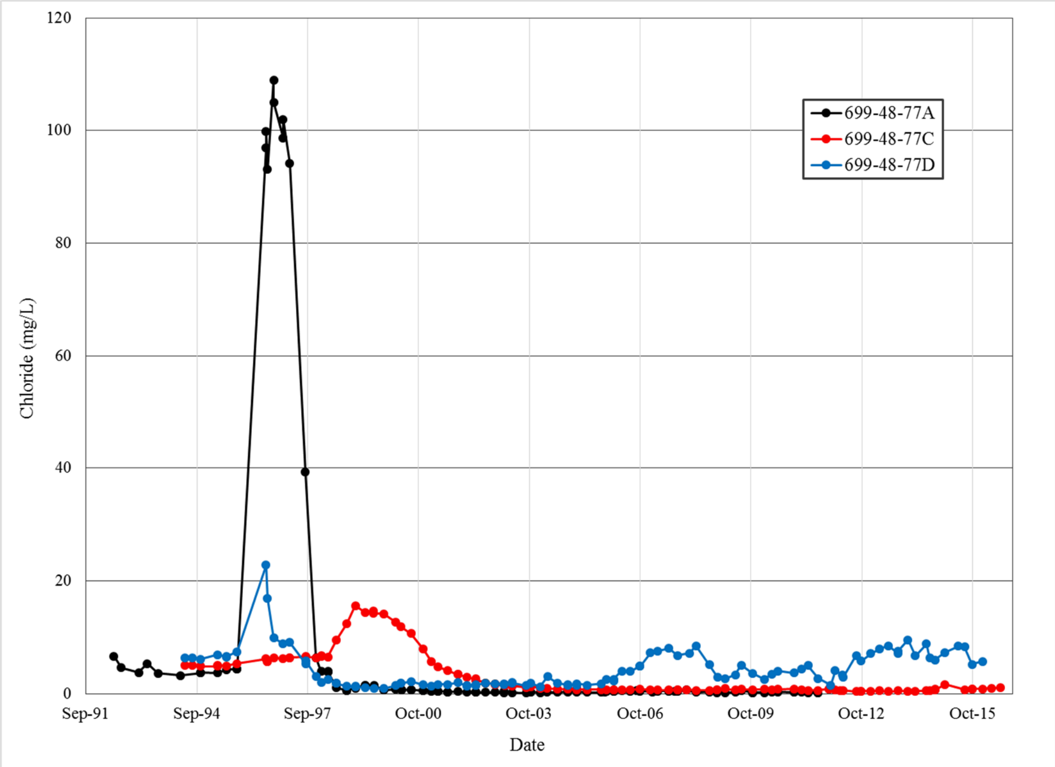


Figure 3-9. Chloride Concentrations in the SALDS Proximal Wells

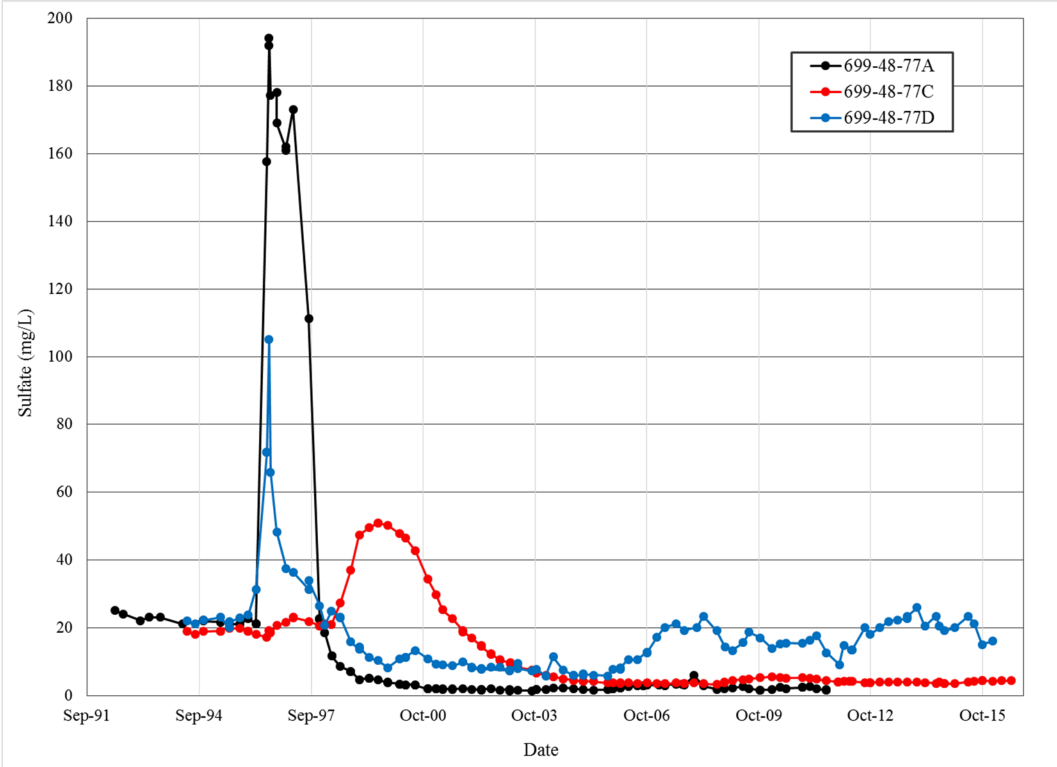


Figure 3-10. Sulfate Concentrations in the SALDS Proximal Wells

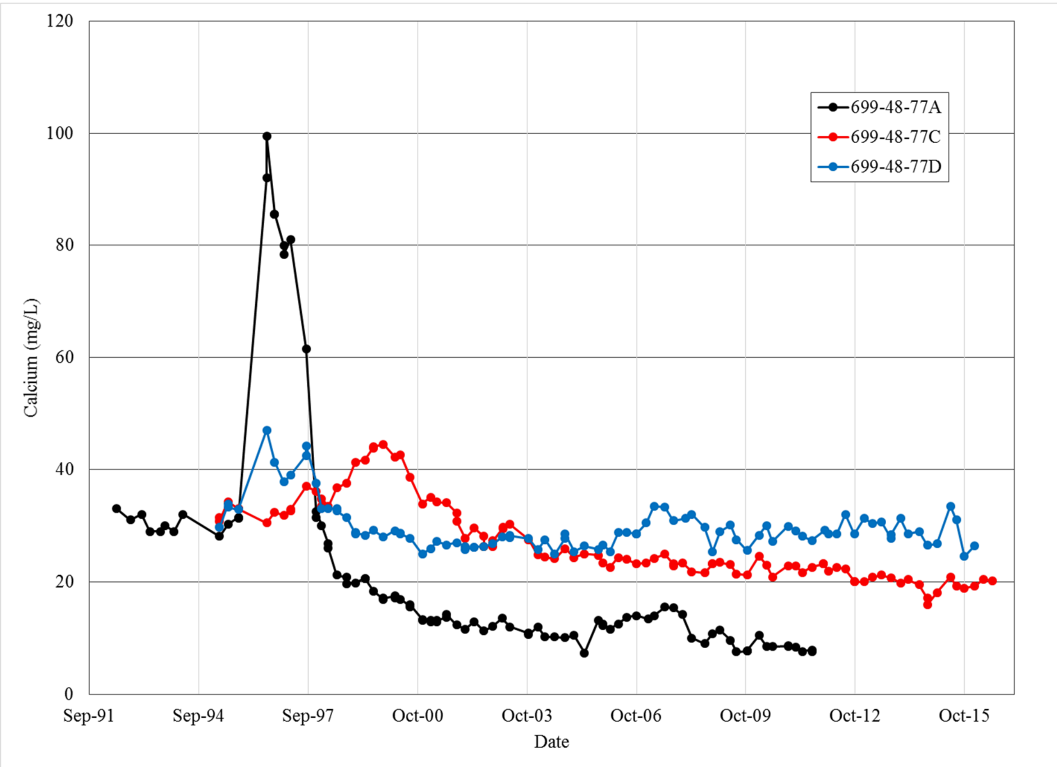


Figure 3-11. Calcium Concentrations in the SALDS Proximal Wells

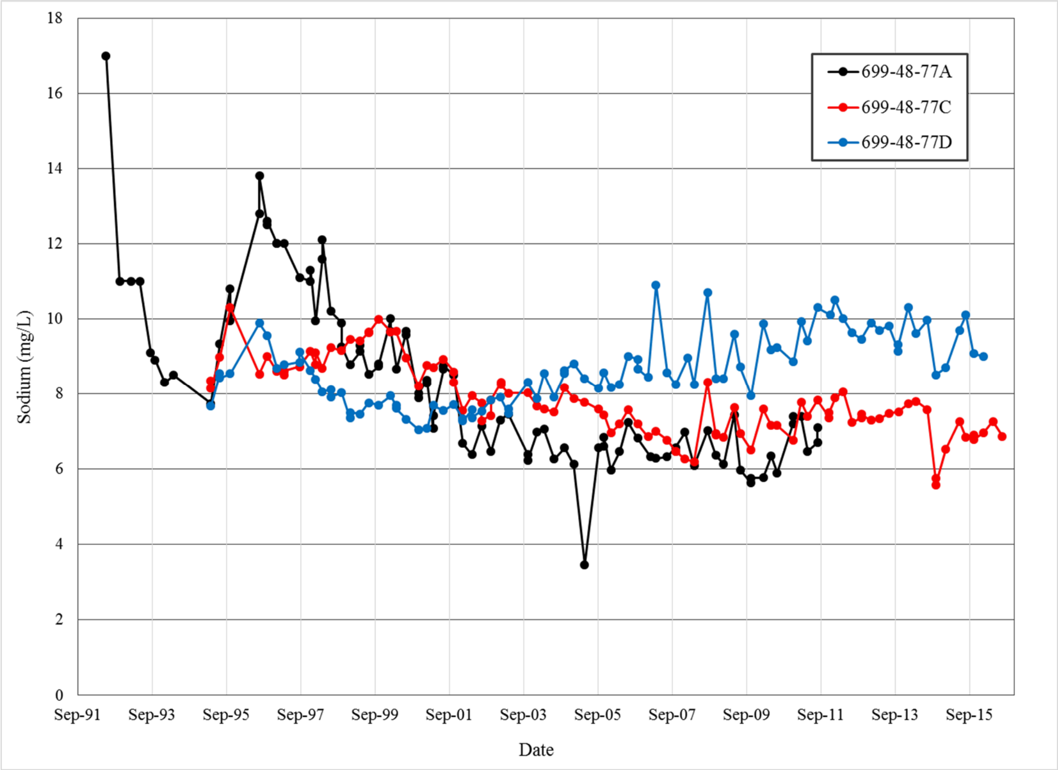


Figure 3-12. Sodium Concentrations in the SALDS Proximal Wells

4 Groundwater Modeling and Site Analysis

DOE performs numerical modeling of the tritium plume once per permit cycle. The model was last updated during FY 2011 (SGW-51085) and included tritium migration and fate predictions based on both the latest calibration of the groundwater model and the latest information regarding the forecast operation of the 200-ZP-1 P&T system. For convenience, the summary description of the modeling update that was provided in SGW-51085 is repeated in the remainder of this section. Additional details regarding the modeling are presented in Appendix B of SGW-51085.

4.1 Analysis Approach

Modeling was performed using the CP groundwater model that was first described in DOE/RL-2008-56, *200 West Area Pre-Conceptual Design for Final Extraction/Injection Well Network: Modeling Analyses*. The CP model simulates conditions from the 1940s through the present (calibration period) and is then used to simulate likely future conditions under assumed extraction and injection rates for the 200-ZP-1 P&T system. The CP model was updated in 2010 (ECF-HANFORD-10-0371, *Central Plateau Version 3 MODFLOW Model*; CP-47631) and included an improved calibration of the flow field to historical water-level measurements compared to previous versions of the model. The migration and fate of the SALDS tritium plume were simulated using historical tritium releases from the start of facility operation through June 2011, along with future projected tritium releases.

In addition to model simulations, analyses were completed using a water-level mapping and particle-tracking technique to verify that the flow field simulated by the CP model in the SALDS vicinity was in reasonable agreement with actual field conditions determined using water-level measurements. Results of this comparison are provided in SGW-51085.

4.2 Tritium Plume Migration and Fate

The CP model was used to simulate migration and fate of the SALDS tritium plume. Figure 4-1 shows results for the year 2030 (Appendix B in SGW-51085 shows the results for 2000 through 2030 at 5-year intervals). Modeling was completed using two effective porosity assumptions (0.13 and 0.18), and results for both are shown in Figure 4-1. Under either assumption, the tritium plume is not anticipated to reach tritium-tracking wells 699-51-75 or 699-48-71 by the year 2030. However, some locations along the northern margin of the 200 West Area are expected to exhibit measurable concentrations of SALDS-derived tritium by 2030, although the model indicates that concentrations would be below the drinking water standard of 20,000 pCi/L.

The results in Figure 4-1 differ slightly from results presented in the earlier model update performed in FY 2010 (SGW-47923, *Results of Tritium Tracking and Groundwater Monitoring at the Hanford Site 200 Area State-Approved Land Disposal Site, Fiscal Year 2010*) in that the distal end of the tritium plume is now simulated to migrate toward the south by the year 2030. The reason for this difference can be seen in Figure 4-2, which compares the FY 2010 and 2011 model update results for the year 2030 (for an effective porosity of 0.13) and shows the assumptions used for each update regarding the predicted operation of the 200-ZP-1 P&T system extraction and injection wells. The FY 2010 model update assumed uniform flow rates for all extraction and injection wells (depicted in Figure 4-2 by the uniform symbol size for the extraction and injection wells). The extraction and injection rates used for the FY 2011 model update resulted from an optimization analysis of the 200-ZP-1 P&T system to maximize the recovery of carbon tetrachloride (the principal contaminant being remediated) from the aquifer (SGW-50390, *FY 2011 Simulation-Optimization of the 200-ZP-1 Remedy Using the Central*

Plateau Model). The optimized flow rates are predicted to be higher in the eastern extraction wells compared to the western wells, resulting in a larger area of water table drawdown along the eastern margin of the 200 West Area, toward which the tritium plume is predicted to migrate.

It should be emphasized that the 200-ZP-1 extraction and injection rates used in both the FY 2010 and 2011 model updates are conjecture based upon current knowledge of the individual well and total system capacity of the P&T system. As such, actual flow rates may differ from those presented in either of these model updates. However, the modeling results do indicate that the ultimate fate of the SALDS tritium plume will be affected by operation of the 200-ZP-1 P&T system, as shown in Figure 4-2.

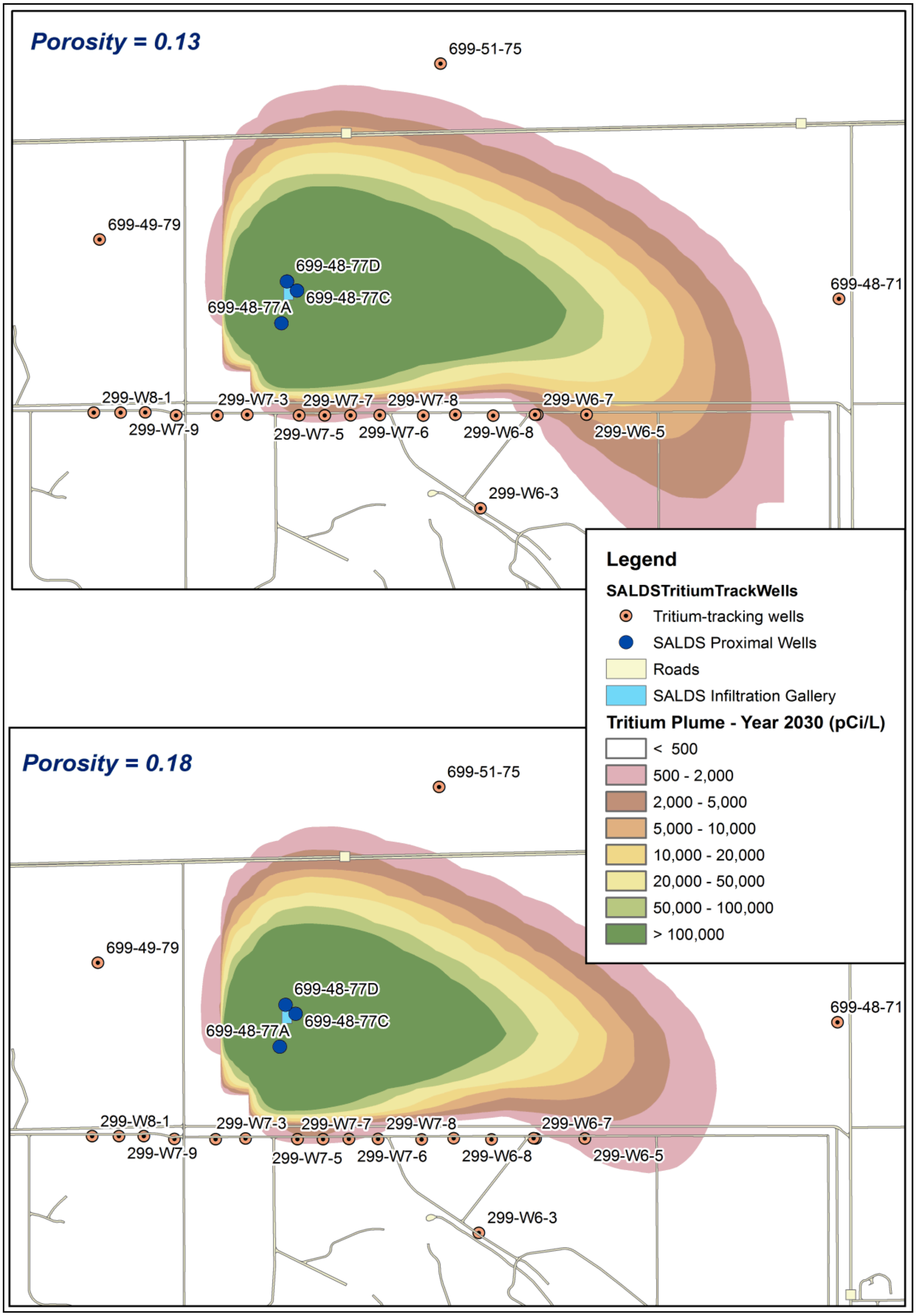


Figure 4-1. Simulated Tritium Distribution as a Result of SALDS Operation in Year 2030

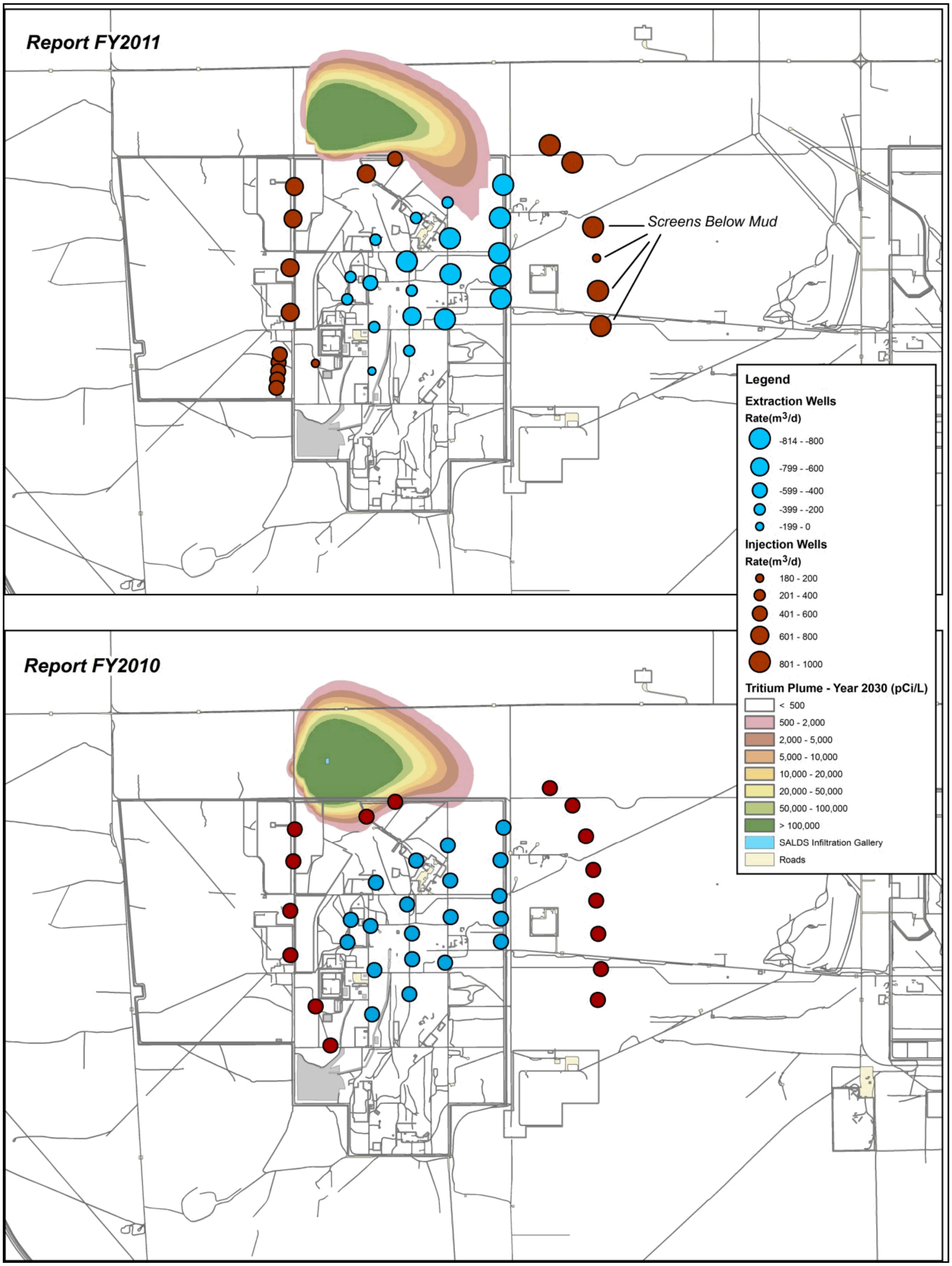


Figure 4-2. Comparison of Model Updates Performed in Fiscal Years 2010 and 2011 Along with Different 200 West P&T System Flow Rates Used in Simulations

5 References

12-NWP-035, 2012, "Status of Compliance Monitoring Wells at State Approved Land Disposal Site as Required by State Waste Discharge Permit ST-4500, Letter 12-EMD-0030, dated February 16, 2012" (letter to R.J. Corey, U.S. Department of Energy, Richland Operations Office, from R. Bond, Nuclear Waste Program), Washington State Department of Ecology, Richland, Washington, March 16. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=1203200658.

Atomic Energy Act of 1954, as amended, 42 USC 2011, Pub. L. 83-703, 68 Stat. 919. Available at: http://epw.senate.gov/atomic54.pdf.

CP-47631, 2011, *Model Package Report: Central Plateau Groundwater Model Version 3.3*, Rev. 0, CH2M HILL Plateau Remediation Company, Richland, Washington.

DOE/RL-96-61, 1997, *Hanford Site Background: Part 3, Groundwater Background*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=D197226378.

DOE/RL-2008-56, 2012, *200 West Area Pre-Conceptual Design for Final Extraction/Injection Well Network: Modeling Analyses*, Rev. 1, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-2009-38, 2009, *Description of Modeling Analyses in Support of the 200-ZP-1 Remedial Design/Remedial Action Work Plan*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0095363.

DOE/RL-2014-10, 2014, *2014 Evaluation of Tritium Removal and Mitigation Technologies for Wastewater Treatment*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0086036.

DOE/RL-2014-26, 2014, *Calendar Year 2013 Annual Summary Report for the 200-ZP-1 and 200-UP-1 Operable Unit Pump-and-Treat Operations*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0083706.

ECF-HANFORD-10-0371, 2010, *Central Plateau Version 3 MODFLOW Model*, Rev. 0, CH2M HILL Plateau Remediation Company, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0084305.

Ecology, 2014, *State Waste Discharge Permit Number ST0004500*, Washington State Department of Ecology, Kennewick, Washington. Available at: http://www.ecy.wa.gov/programs/nwp/permitting/WWD/PDF/ST4500/ST0004500.pdf

EPA, Section 402, *Clean Water Act, 40 CFR Section 122.2,* Environmental Protection Agency, Washington, District of Columbia. Available at: http://www.gpo.gov/fdsys/pkg/CFR-2011-title40-vol22/pdf/CFR-2011-title40-vol22-sec122-2.pdf.

NAVD88, 1988, *North American Vertical Datum of 1988*, National Geodetic Survey, Federal Geodetic Control Committee, Silver Spring, Maryland. Available at: http://www.ngs.noaa.gov/.

PNNL-11633, 1997, *Origin of Increased Sulfate in Groundwater at the ETF Disposal Site*, Pacific Northwest National Laboratory, Richland, Washington. Available at: http://www.osti.gov/energycitations/servlets/purl/548888-AscOkj/webviewable/548888.pdf.

PNNL-11665, 1997, *Tritium Monitoring in Groundwater and Evaluation of Model Predictions for the Hanford Site 200 Area Effluent Treatment Facility*, Pacific Northwest National Laboratory, Richland, Washington. Available at: http://www.osti.gov/energycitations/servlets/purl/554804-aEgmwz/webviewable/554804.pdf.

PNNL-13121, 2000, *Groundwater Monitoring and Tritium-Tracking Plan for the 200 Area State-Approved Land Disposal Site*, Pacific Northwest National Laboratory, Richland, Washington. Available at: http://www.pnl.gov/main/publications/external/technical_reports/PNNL-13121.pdf.

SGW-38802, 2008, *Results of Tritium Tracking and Groundwater Monitoring at the Hanford Site 200 Area State-Approved Land Disposal Site Fiscal Year 2008*, Rev. 0, CH2M HILL Plateau Remediation Company, Richland, Washington. Available at: http://www.osti.gov/scitech/servlets/purl/943300.

SGW-47923, 2010, *Results of Tritium Tracking and Groundwater Monitoring at the Hanford Site 200 Area State-Approved Land Disposal Site, Fiscal Year 2010*, Rev. 0, CH2M HILL Plateau Remediation Company, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=1011190085.

SGW-50390, 2011, *FY 2011 Simulation-Optimization of the 200-ZP-1 Remedy Using the Central Plateau Model*, Rev. 0, CH2M HILL Plateau Remediation Company, Richland, Washington.

SGW-50907, 2011, *Predicted Impact of Future Water-Level Declines on Groundwater Well Longevity within the 200 West Area, Hanford Site*, Rev. 0, CH2M HILL Plateau Remediation Company, Richland, Washington.

SGW-51085, 2011, *Results of Tritium Tracking and Groundwater Monitoring at the Hanford Site 200 Area State Approved Land Disposal Site, Fiscal Year 2011*, Rev. 0, CH2M HILL Plateau Remediation Company, Richland, Washington.

SGW-56210, *Results of Tritium Tracking and Groundwater Monitoring at the Hanford Site 200 Area State Approved Land Disposal Site, Fiscal Year 2014*, Rev. 0, CH2M HILL Plateau Remediation Company, Richland, Washington.

APPENDIX A

Table A-1. State-Approved Land Disposal Site Tritium Results for Fiscal Year 2015

Well	Date Sampled	2016 Tritium Analyses (pCi/L)	Lab Qualifier	2014 Tritium Maximum (pCi/L)	2015 Tritium Maximum (pCi/L)	Trend
299-W6-6	1/13/2016	2730	—	2,430	2,170	Increasing
	1/25/2016	1050	—			
	1/25/2016	2390	—			
299-W6-11	1/25/2016	770	—	1,450	1,070	Decreasing
299-W6-12	1/25/2016	1000	—	127	145	Increasing
299-W7-3	1/25/2016	<23.5	U	U	U	NA
	5/9/2016	<26.4	U			
299-W8-1	1/25/2016	<23.0	U	U	U	NA
699-48-71	1/19/2016	3260	—	2,390	2,560	Increasing
	1/25/2016	2820	—			
699-48-77C	10/19/2015	51,400	—	83,000	60,100	Decreasing
	10/19/2015	51,600	—			
	1/27/2016	49,200	—			
	4/27/2016	51,100	—			
	7/27/2016	45,700	—			
699-48-77D	10/19/2015	57,900	—	60,500	60,200	Unchanged
	1/27/2016	58,800	—			
699-49-79	2/22/2016	<26.0	U	U	U	NA
699-51-75	1/25/2016	<23.3	U	U	U	NA
	5/9/2016	<26.1	U			
699-51-75P	1/25/2016	<22.9	U	U	U	NA

Notes:

Increasing = 15% higher average concentration in FY 2016 than in FY 2015.

Decreasing = 15% lower average concentration in FY 2016 than in FY 2015.

Unchanged = FY 2016 average concentration within 15% of FY 2015 value.

FY = fiscal year

NA = not applicable

U = less than detection

RR = Awaiting client requested rerun of analysis

APPENDIX B

SGW-51085
Revision 0

Results of Tritium Tracking and Groundwater Monitoring at the Hanford Site 200 Area State Approved Land Disposal Site, Fiscal Year 2011

J.P. McDonald
CH2M HILL Plateau Remediation Company

M. Karanovic
M.J. Tonkin
S.S.Papadopulos & Associates, Inc.

Date Published
November 2011

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

J.E. Bratton 11/15/2011
Release Approval Date

Approved for Public Release;
Further Dissemination Unlimited

SGW-51085
Revision 0

Executive Summary

The Hanford Site's 200 Area Effluent Treatment Facility processes contaminated aqueous wastes derived from Hanford Site facilities. The treated wastewater discharge contains tritium because it is not cost effective to remove this constituent from the waste stream. The wastewater is discharged to the soil column at the 200 Area State Approved Land Disposal Site (SALDS), which is authorized to receive the discharge by *State Waste Discharge Permit Number ST 4500*[1] (Ecology, 2000; henceforth referred to as the "Permit"). During fiscal year (FY) 2011 (October 1, 2010 to September 30, 2011), 82.4 million L (21.8 million gal) of water containing 4.70 Ci of tritium were discharged to the SALDS. Groundwater monitoring for tritium and other constituents, as well as water-level measurements, are specified by the Permit. The objectives of the monitoring program are to evaluate constituent concentrations in the groundwater beneath the SALDS for compliance with limits specified in the Permit, and to track the migration of the tritium plume. The U.S. Department of Energy (DOE) has taken the position that its compliance with the permit is a matter of intergovernmental comity and cooperation and that the permit has no jurisdiction over radionuclides, which are regulated by DOE under its *Atomic Energy Act of 1954* authority.[2]

The current monitoring network consists of three proximal (compliance) monitoring wells and eight tritium-tracking wells. During the previous fiscal year, the network included nine tritium-tracking wells, but one well, 299-W8-1, went dry during FY 2011. Quarterly sampling of the proximal wells occurred in December 2010 and in March, May, and August 2011. The tritium-tracking wells were sampled in January, May, and June 2011.

Water-level measurements taken in the three proximal SALDS wells indicate that a small groundwater mound, resulting from operational effluent discharges, continues to be present beneath the facility. Measurements also indicate that water levels are continuing to decline and well usability is being affected. Two of the three proximal wells, 699-48-77A and 699-48-77D, have very little water left and may become dry at any time. The third proximal well, 699-48-77C, is screened deeper in the aquifer and will not

[1] Ecology, 2000, State Waste Discharge Permit Number ST 4500, Washington State Department of Ecology, Kennewick, Washington. Available at: http://www.ecy.wa.gov/programs/nwp/pdf/4500dp.pdf.

[2] *Atomic Energy Act of 1954*, 42 USC 2011, et seq. Available at: http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr0980/ml022200075-vol1.pdf.

become dry. Two of the eight remaining tritium-tracking wells are expected to become dry in four to six years. An expansion of the 200-ZP-1 Operable Unit pump-and-treat system is expected to become operational during FY 2012. Nearby injection wells may cause a water-level increase in the SALDS monitoring wells, so they may be useable for a few more years than they would be without the pump-and-treat system.

The proximal wells are sampled quarterly, and there were no exceedances of a groundwater concentration limit during FY 2011. Maximum tritium concentrations in the proximal wells ranged from 110,000 to 160,000 pCi/L. Compared to the previous fiscal year, average tritium concentrations declined in 699-48-77A and 699-48-77C and increased in 699-48-77D. To date, tritium from the SALDS has not been detected in the tritium-tracking wells.

The numerical groundwater flow and contaminant transport model of the SALDS tritium plume was updated for FY 2011 so that predictions of the migration and fate of the plume would be based on the latest calibration of the model and would include the latest information regarding the forecast operation of the expanded 200-ZP-1 pump-and-treat system. The modeling results show that some locations along the northern margin of the 200 West Area are expected to exhibit measurable concentrations of SALDS-derived tritium by the year 2030, although the model indicates that concentrations would be below the drinking water standard of 20,000 pCi/L. The eastern end of the tritium plume is also predicted to migrate to the south toward the 200-ZP-1 pump-and-treat system extraction wells by 2030.

Contents

Appendices

Figures

Tables

Terms

CCU	Cold Creek unit
CP	Central Plateau
DOE	U.S. Department of Energy
ERDF	Environmental Restoration Disposal Facility
ETF	Effluent Treatment Facility
FY	fiscal year
LERF	Liquid Effluent Retention Facility
LLBG	Low-Level Burial Ground
OU	operable unit
SALDS	State Approved Land Disposal Site

1 Introduction

The Hanford Site's 200 Area Effluent Treatment Facility (ETF) processes contaminated aqueous wastes derived from Hanford Site facilities. Treated water from the ETF is discharged to the 600-211 State Approved Land Disposal Site (SALDS), which is authorized to receive the discharge by *State Waste Discharge Permit Number ST 4500* (Ecology, 2000; henceforth referred to as the "Permit"). The Permit allows disposal of ETF effluents to the SALDS drain field, located 360 m (1,200 ft) north of the 200 West Area (Figure 1-1). The Permit requires that groundwater samples be collected quarterly from the point of compliance monitoring Wells 699-48-77A, 699-48-77C, and 699-48-77D (i.e., the proximal wells) located at the SALDS facility. It is required that the samples be analyzed for 17 constituents, 11 of which have groundwater limitations (i.e., concentration limits) specified in the Permit. The collection of water-level measurements is also required. The U.S. Department of Energy (DOE) has taken the position that its compliance with the permit is a matter of intergovernmental comity and cooperation and that the permit has no jurisdiction over radionuclides, which are regulated by DOE under its *Atomic Energy Act of 1954* authority.

Much of the effluent disposed to the SALDS contains tritium, because there is no cost-effective treatment technology to remove tritium from wastewater (DOE/RL-2009-18, *2009 Evaluation of Tritium Removal and Mitigation Technologies for Wastewater Treatment*). Thus, a tritium plume exists in groundwater beneath the SALDS and the Permit requires that this plume be tracked. The wells used for this purpose are located further from the facility than the proximal wells; they are referred to as the tritium-tracking wells. These wells are sampled either annually or semiannually. The Permit also requires that computer modeling of the tritium plume be performed, and that a groundwater monitoring and tritium-tracking report be submitted annually.

In addition to the annual report, the results of groundwater sampling and analysis of the proximal wells are also reported in the following quarterly discharge monitoring reports:

- CHPRC-1100679, "Quarterly Discharge Monitoring Reports for the 200 Area Effluent Treatment and Treated Effluent Disposal Facilities Covering the October 2010 Through December 2010 Reporting Period"
- CHPRC-1102245 , "Quarterly Discharge Monitoring Reports for the 200 Area Effluent Treatment and Treated Effluent Disposal Facilities Covering the January 2011 Through March 2011 Reporting Period"
- CHPRC-1103864 , "Quarterly Discharge Monitoring Reports for the 200 Area Effluent Treatment and Treated Effluent Disposal Facilities Covering the April 2011 Through June 2011 Reporting Period"
- CHPRC-1105426, "Quarterly Discharge Monitoring Reports for the 200 Area Effluent Treatment and Treated Effluent Disposal Facilities Covering the July 2011 Through September 2011 Reporting Period"

Details of the SALDS groundwater monitoring program are described in the current groundwater monitoring plan (PNNL-13121, *Groundwater Monitoring and Tritium-Tracking Plan for the 200 Area State-Approved Land Disposal Site*).

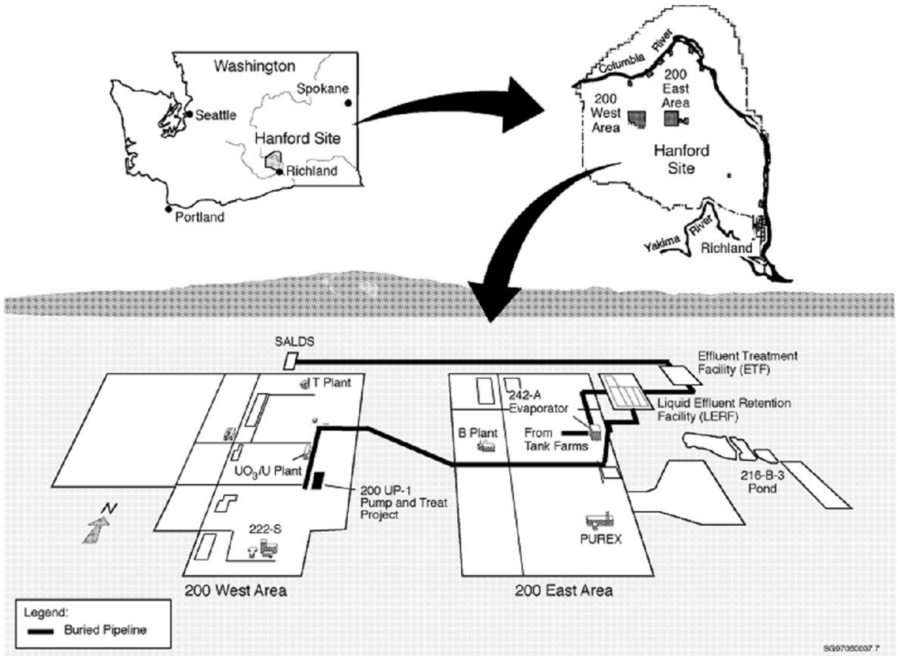


Figure 1-1. Location of the SALDS and Related Infrastructure

1.1 Objective and Scope

This report presents the results of groundwater monitoring of the proximal wells and tracking of the tritium plume from the SALDS facility during FY 2011. It also presents an update to the numerical groundwater flow and contaminant transport model of the tritium plume. Because 30 days are required for the laboratory to analyze and report groundwater sampling results, this annual report normally addresses groundwater samples collected only up to July 31 of the reporting period so that the report can be completed and submitted by the November 30th due date. However, the fiscal year (FY) fourth quarter sampling of the proximal wells, normally conducted during July, occurred in early August during 2011. The results of this sampling were available at the time this report was prepared and are also included.

1.2 Background

Background information presented in this section is based on PNNL-13121. It addresses the conceptual model, the groundwater monitoring program, plume modeling, and the SALDS' discharges.

1.2.1 Hydrogeologic Setting and Conceptual Model

The hydrogeologic setting and the conceptual model for the SALDS have been described in previous documents (e.g., SGW-38802, *Results of Tritium Tracking and Groundwater Monitoring at the Hanford Site 200 Area State-Approved Land Disposal Site Fiscal Year 2008*) and are not repeated here. Figure 1-2 shows the conceptual model and depicts effluent migration through the sediment profile to groundwater. A key aspect of this conceptual model is the lateral migration of the effluent in the vadose zone along the Cold Creek unit (CCU), which dips toward the south. Thus, much of the effluent is interpreted to enter the groundwater to the south of the drain field near monitoring Well 699-48-77A.

1.2.2 Groundwater Monitoring Program

The primary objectives of the groundwater monitoring plan (PNNL-13121) are to compare groundwater sampling results in the proximal wells to the Permit concentration limits and to track the migration of the tritium plume from the SALDS facility. Other objectives listed in the monitoring plan include the following:

- Track changes in groundwater quality associated with the SALDS discharges.
- Determine why changes (if any) have occurred.
- Compare model predictions with observed results to refine predictive model capability.
- Correlate discharge events at SALDS with analytical results from groundwater monitoring.
- Ensure that groundwater data are accurately interpreted.
- Assess the hydraulic response of the aquifer to SALDS' discharges.

The groundwater monitoring well network (Figure 1-3) was designed to address these objectives using existing wells shared with other nearby facilities (e.g., the Low-Level Burial Grounds [LLBGs]) and dedicated wells drilled specifically to monitor SALDS (i.e., the proximal wells).

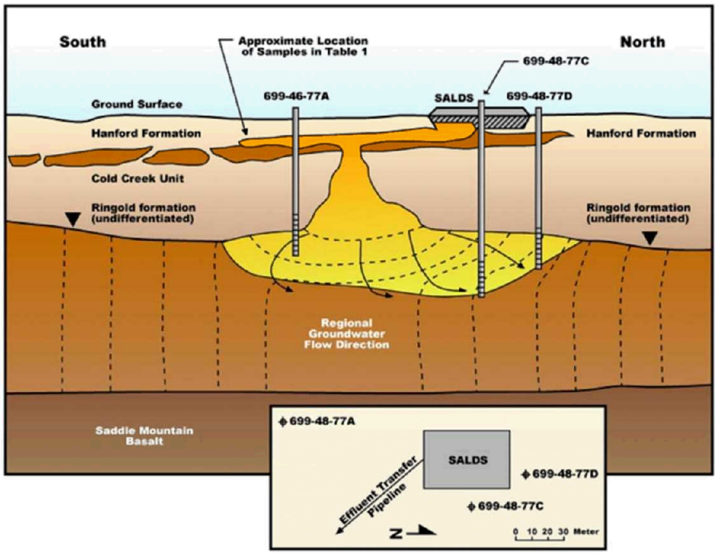


Figure 1-2. Conceptual Model Diagram of SALDS Operational Effects

1-4

SGW-51085, REV. 0

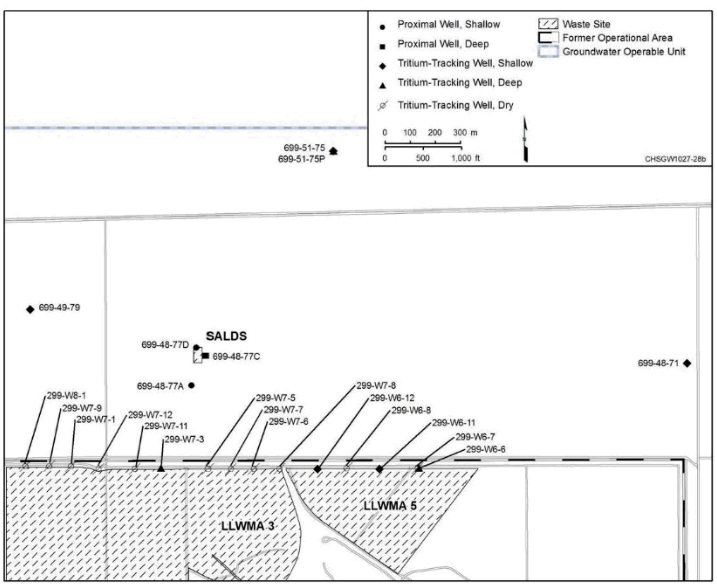


Figure 1-3. Locations of SALDS Groundwater Monitoring and Tritium-Tracking Network Wells

1-5

SGW-51085, REV. 0

1.2.3 Groundwater Modeling

The Permit requires an update to the tritium groundwater plume numerical model at least once during a five-year Permit cycle to predict the distribution and movement of tritium in the aquifer as a result of SALDS' discharges. The Permit also requires that the model be reapplied "within 6 months of detection of [the] tritium plume in a new monitoring well." This requirement indicates that the numerical model will be reapplied when the tritium plume associated with the SALDS is positively identified in a location not predicted by the most recent model run, or within a well not previously affected by SALDS-derived tritium. To date, no positive indications of SALDS-derived tritium have been detected in a new monitoring well.

The groundwater model was updated in 2011. Chapter 4 provides a summary of the results. Appendix B provides a more complete description of the model application. The model output graphically illustrates the predicted tritium concentrations in groundwater near the SALDS for five-year periods between 2000 and 2030. The model incorporates recent refinements to the Central Plateau (CP) groundwater model (DOE/RL-2009-38, *Description of Modeling Analyses in Support of the 200-ZP-1 Remedial Design/Remedial Action Work Plan*; CP-47631, *Model Package Report: Central Plateau Groundwater Model Version 3.3*), and includes the SALDS discharge volume and tritium release information reported through June 2011. Because the Permit requires that the modeling be updated once per permit cycle (i.e., every five years) and the previous model update was performed in 2010 (SGW-47923, *Results of Tritium Tracking and Groundwater Monitoring at the Hanford Site 200 Area State-Approved Land Disposal Site, Fiscal Year 2010*), it was not specifically required that the update be performed in 2011. However, the model update was performed so that the model predictions would be based on both the latest calibration of the model and the latest information regarding the forecast operation of the expanded 200-ZP-1 pump-and-treat system. The expanded pump-and-treat system is expected to begin operating in 2012, so this model update serves as a final benchmark prediction of the pump-and-treat system effects on the SALDS tritium plume prior to actual operation of the pump-and-treat system. Future model updates will include actual pump-and-treat system operational parameters at the time the model update is performed.

1.2.4 SALDS Discharge Information

The SALDS effluent infiltration gallery (i.e., 619-A Crib) is a 35 m by 61 m (116 ft by 200 ft) rectangular drain field with 4 in. diameter porous pipe laterals coming from an 8 in. diameter header at 1.8 m (6 ft) intervals. The drain field pipes are 15 cm (6 in.) below the surface of a 1.8 m (6 ft) deep gravel basin. The gravel basin is covered by a minimum of 30 cm (12 in.) of natural, compacted cover soil.

Discharge of tritium-laden water to the SALDS began in December 1995, with 220 Ci of tritium released in the first seven months (which amounted to approximately 52 percent of the total activity released to date). Discharge volumes until FY 2004 were about 95 million L (25 million gal) each year. Discharges between March 2005 and August 2007 were sporadic and included intermittent campaigns to treat 242-A Evaporator process condensate and K Basins project waste streams, both of which supplied much of the tritium recently discharged to the SALDS. Discharge volumes have increased since September 2007 when the ETF began treating wastewater from the interim-action pump-and-treat system at the T Tank Farm. However, the tritium activity in this stream is low.

During FY 2011, 82.4 million L (21.8 million gal) of water were discharged to the SALDS, compared to 48.0 million L (12.7 million gal) during FY 2010. The primary source of FY 2011 effluent was from ETF treatment of low-tritium-bearing groundwater streams from pump-and-treat systems at the 200-UP-1 Operable Unit (OU) and the T Tank Farm in the 200-ZP-1 OU. During the first six months of FY 2011, the 200-UP-1 OU pump-and-treat system pumped groundwater to the Liquid Effluent Retention

Facility (LERF) Basin 43 at an average rate of approximately 16.7 L/min (4.4 gal/min). The 200-UP-1 OU pump-and-treat system transfer to the LERF was discontinued on March 28, 2011. The pump-and-treat system was shut down due to low pumping rates from the extraction wells and the fact that the system had achieved its remedial action objectives. The system is not expected to operate in the future. The pumping rate from the T Tank Farm pump-and-treat system during FY 2011 was typically about 155 L/min (41 gal/min), but problems with frozen piping in December 2010 and January 2011 reduced the average flow to about 136 L/min (36 gal/min), not including downtime when the pipeline was used for transferring batches of leachate from the Environmental Restoration Disposal Facility (ERDF) to LERF. No discharges from the ETF to the SALDS took place in August and September 2011 due to a maintenance outage. The total discharge volume to the SALDS since startup in December 1995 is approximately 1,116 million L (295 million gal) (Figure 1-4).

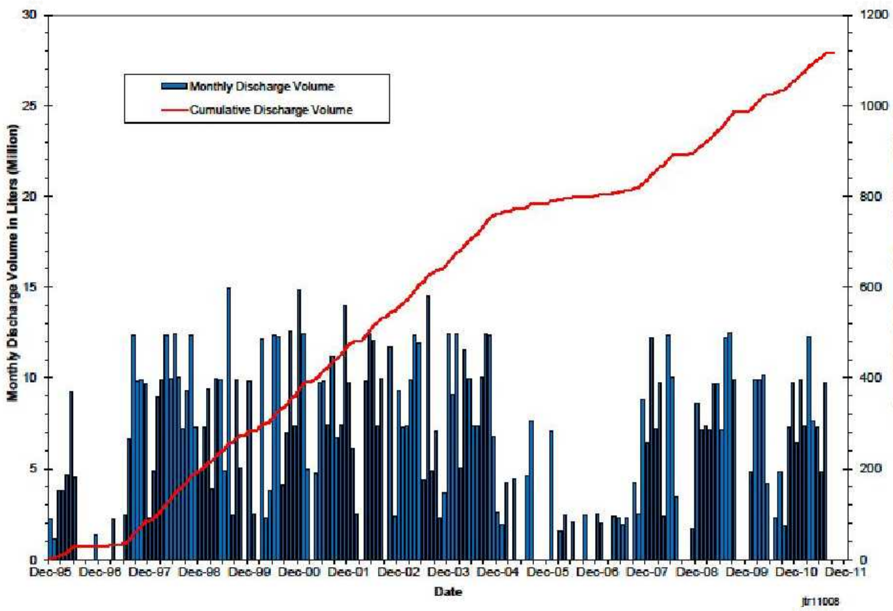


Figure 1-4. Monthly and Cumulative Discharge Volumes for the SALDS from Inception through September 2011

Figure 1-5 shows the monthly and cumulative activity of tritium discharged to the SALDS. The total quantity of tritium discharged to the SALDS during FY 2011was calculated to be 4.70 Ci based on sampling at the ETF prior to discharge, which is higher than the 2.42 Ci released during FY 2010 (SGW-47923). However, the FY 2011 calculation includes an apparent off-trend ETF sample result associated with discharges to the crib during December 2010. The result was 930,000 pCi/L, whereas samples of the effluent collected a few days before and after yielded on-trend results of 18,000 pCi/L. Even though the effluent being treated should not have contained a high tritium concentration, an analytical laboratory recheck indicated that the 930,000 pCi/L sample result was valid so it was used in the release inventory calculations. This yielded a release inventory of 2.42 Ci for December 2010, or over half the total calculated release during FY 2011. However, this is still a relatively small amount compared to historical releases (Figure 1-5). This reflects the relatively low concentration of tritium in the waste streams currently being treated. The total amount of tritium that has been discharged to the SALDS from December 1995 through mid-September 2011 is approximately 420 Ci.

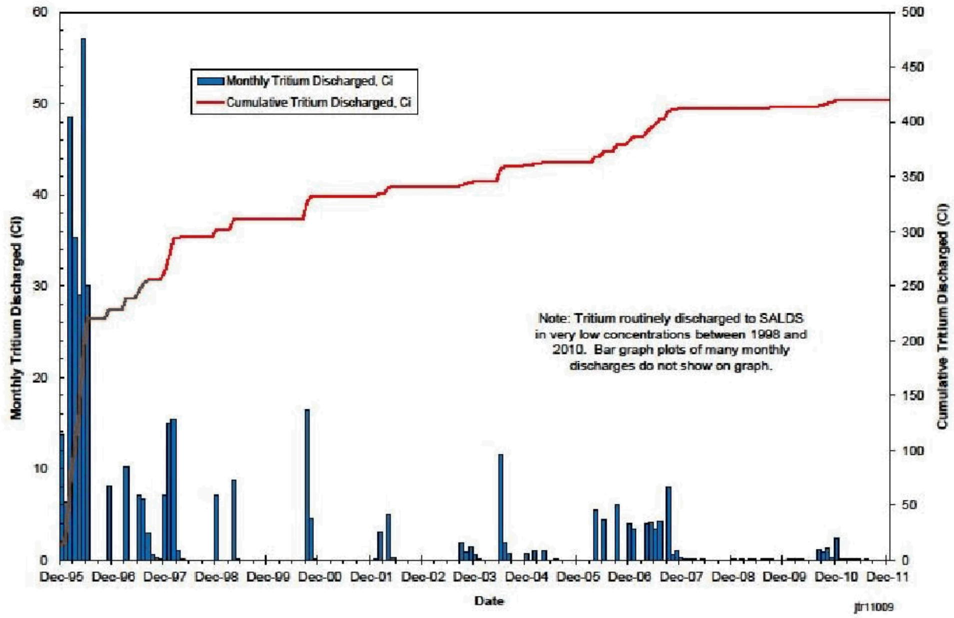


Figure 1-5. Monthly and Cumulative Tritium Activity Discharged to the SALDS from Inception through September 2011 (not adjusted for decay)

2 Results of FY 2011 Water-Level Monitoring

Measurements of water levels in wells surrounding the SALDS are necessary to assess the hydraulic response of the aquifer to SALDS' discharges, to interpret local and regional water table elevation changes, and to determine the groundwater flow direction. These measurements are used in combination with groundwater chemistry analyses to update conceptual and predictive models and forecast the movement of tritium from the SALDS facility.[3]

2.1 Water-Level Measurements

Water levels are measured in all wells prior to each sampling event, and additional measurements are collected monthly in the proximal wells (699-48-77A, 699-48-77C, and 699-48-77D) in accordance with the groundwater monitoring plan (PNNL-13121). The water table has declined in recent years to the point where a number of tritium-tracking wells have become dry (Figure 1-3). As this occurs, water-level measurements and sampling in these wells are discontinued.

Figures 2-1 through 2-6 present current hydrographs through July 2011 for the SALDS proximal and tritium-tracking wells. Wells depicted on these hydrographs are grouped by relative position to the SALDS. Water levels in all of the wells in the 200 West Area have generally exhibited declining trends since effluent discharges associated with process operations were terminated at U Pond in 1985 and later at all nonpermitted facilities in 1995. The water table in the 200 West Area is generally about 10 m (33 ft) higher than the estimated pre-Hanford Site water table elevation. However, water levels are expected to decline only another 3 to 5 m (10 to 16 ft) before stabilizing, because the water table is being affected by offsite irrigation activities to the west that were not occurring in pre-Hanford Site times (DOE/RL-2011-01, *Hanford Site Groundwater Monitoring Report for 2010*).

Most of the water-level measurements were collected during March 2011. Using measurements in both the proximal and tritium-tracking wells, the average decline of water levels in the SALDS area between March 2010 and March 2011 was 0.28 m (0.91 ft), as shown in Table 2-1. Because water levels in the proximal wells experience fluctuations in response to SALDS discharges, the decline of 0.28 m (0.91 ft) may not be representative of the regional water-level decline. For instance, Well 699-48-77A experienced a water-level increase between March 2010 and March 2011. A more representative regional decline can be determined by excluding water-level changes in the proximal wells. The calculation ("12-month average (excluding proximal wells)," Table 2-1) shows that the average regional decline of water levels in the area around the SALDS was 0.33 m (1.09 ft) between March 2010 and March 2011, which is larger than the average calculated for the previous 12 months (0.21 m [0.68 ft] reported in SGW-47923).

Water levels continue to be elevated at Well 699-48-77A compared to the other proximal wells, forming a mound on the water table (Figure 2-7). During March 2011, the water level in Well 699-48-77A was between approximately 0.9 m (3.0 ft) and 0.7 m (2.3 ft) higher than in proximal Wells 699-48-77C and 699-48-77D, respectively. Well 699-48-77A has generally had a higher hydraulic head than the surrounding wells due to movement of the discharge water to the south along the CCU and subsequent infiltration to the aquifer near this well.

During the period from March 1997 to March 2005, the SALDS received an average of 7.98 million L (2.1 million gal) of water per month, which yielded a 0.5 to 1.0 m (1.6 to 3.3 ft) high mound beneath the crib. During the period from March 2005 through March 2007, the average discharge rate was lower at approximately 1.15 million L (305,000 gal) per month. During this time, the groundwater mound was

[3] All elevations in this document are in the North American Vertical Datum of 1988.

much smaller. The discharge rate during the period from October 2010 through July 2011 averaged 8.2 million L (2.2 million gal) per month, and this resulted in an expansion of the mound to a similar extent as observed prior to March 2005.

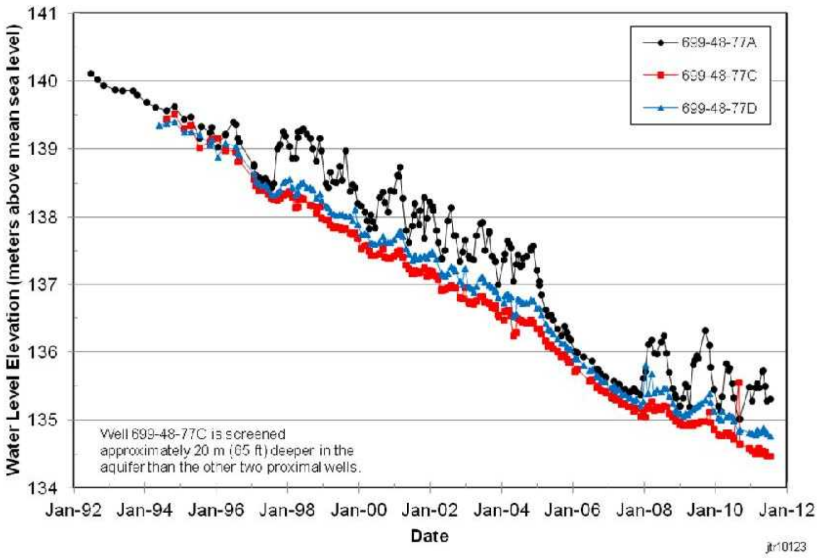


Figure 2-1. Water Levels in the SALDS Proximal Wells

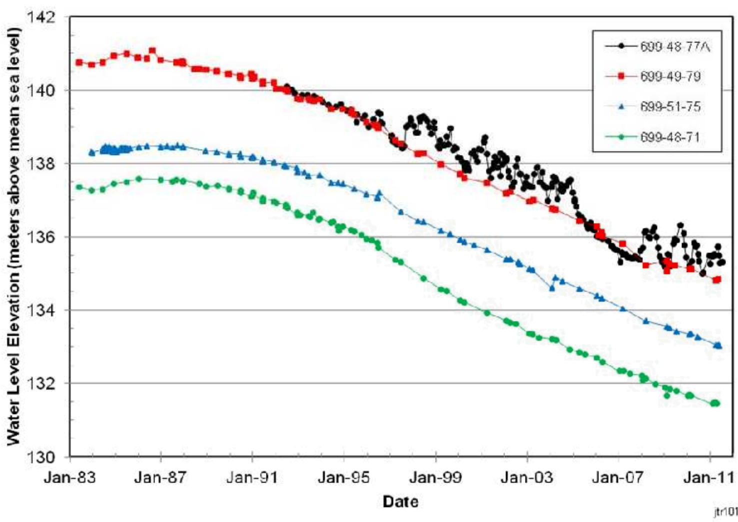


Figure 2-2. Water Levels in the Tritium-Tracking Wells North, Northwest, and East of the Site Compared with Well 699-48-77A

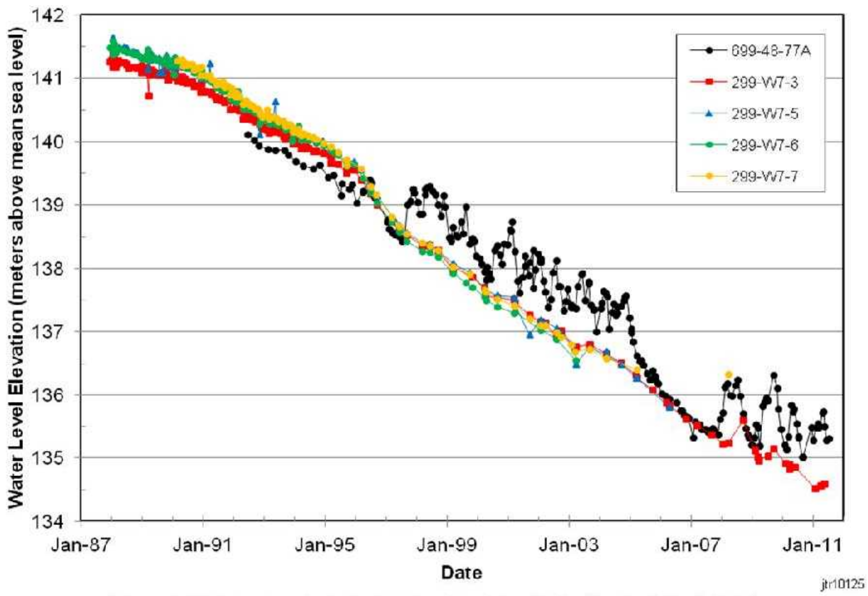


Figure 2-3. Water Levels in the Tritium-Tracking Wells South of the SALDS Compared with Well 699-48-77A

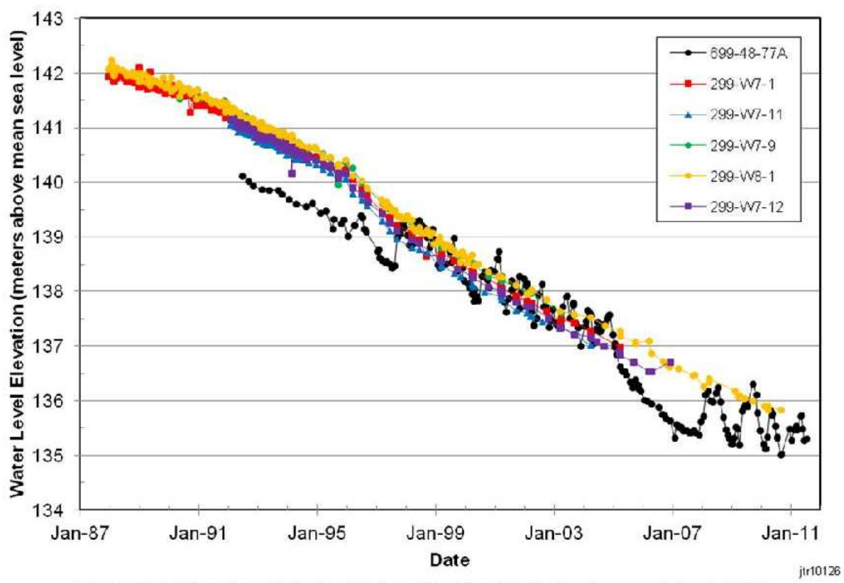


Figure 2-4. Water Levels in the Tritium-Tracking Wells Southwest of the SALDS Compared with Well 699-48-77A

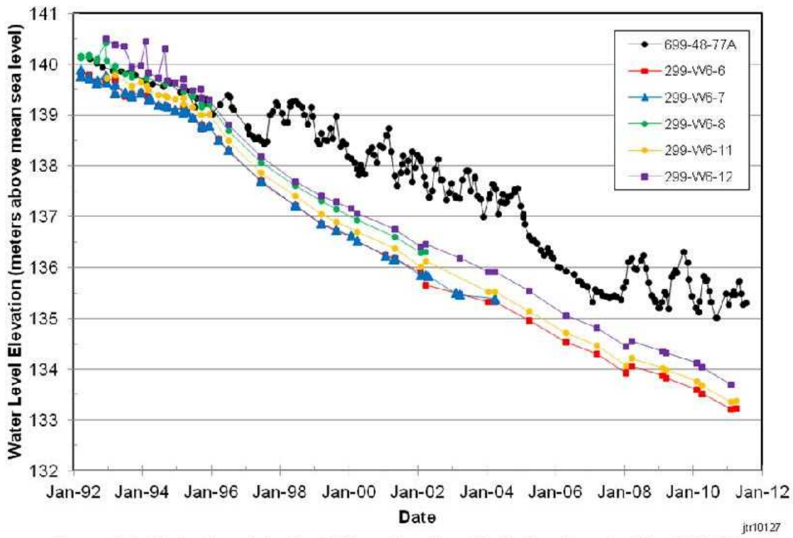
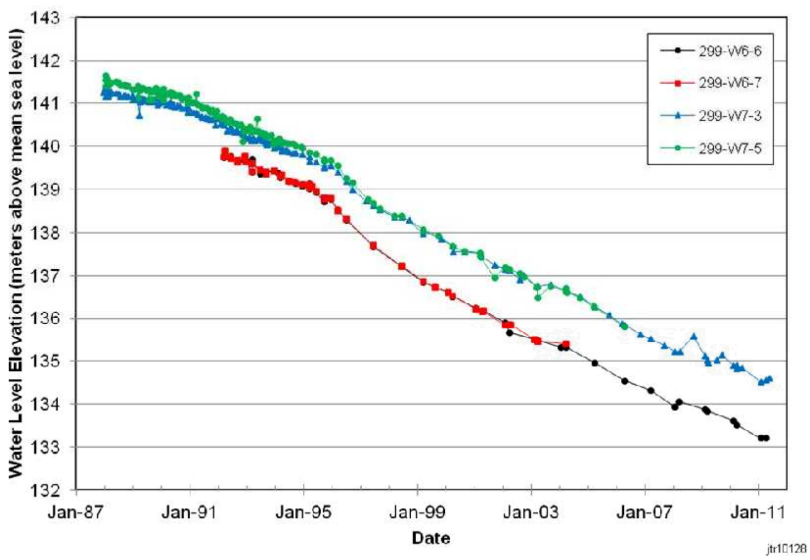


Figure 2-5. Water Levels in the Tritium-Tracking Wells Southeast of the SALDS Compared with Well 699-48-77A



Note: Well 299-W6-6 is completed approximately 51 m (167 ft) deeper in the aquifer than Well 299-W6-7.

Figure 2-6. Water Levels in the Tritium-Monitoring Wells Southeast of the SALDS Compared with Deep/Shallow Companion Wells

Table 2-1. Change in Water Table Elevation, March 2010 to March 2011

Well	March 2010 (m)	March 2011 (m)	One-Year Change (Normalized) (m)
699-48-77A[a]	135.345	135.480	+0.135
699-48-77C[a]	134.777	134.579	-0.198
699-48-77D[a]	135.130	134.808	-0.322
299-W6-11[b]	133.692	133.381	-0.311
299-W6-12[b]	134.052	133.706[c]	-0.415
299-W7-4[b]	134.954	134.604	-0.350
299-W10-22[b]	134.110[d]	133.526[e]	-0.539
299-W12-1[b]	132.184[f]	131.938	-0.227
699-48-71[b]	131.677	131.506	-0.158
699-49-79[b]	135.142	134.808	-0.334
699-51-75[b]	133.369	133.057	-0.312
		12-month average (all wells)	**-0.276**
		12-month average (excluding proximal wells)	**-0.331**
		12-month average (proximal wells only)	**-0.128**

Notes:
a. Proximal well.
b. Distal well.
c. Measured during January 2011.
d. Measured during April 2010.
e. Measured during May 2011.
f. Measured during February 2010.
SALDS = State Approved Land Disposal Site

Groundwater mounding near the SALDS creates a localized downward hydraulic gradient in the aquifer in the vicinity of the mound. However, deep and shallow tritium-tracking Wells 299-W6-6 and 299-W6-7, located 1.0 km (0.6 mi) southeast of the SALDS, have not indicated a vertical hydraulic gradient away from the vicinity of the SALDS (Figure 2-6). Well 299-W6-7 was completed at the water table, and Well 299-W6-6 was completed 51 m (167 ft) deeper in the aquifer. Well 299-W6-7 is currently dry and has been removed from the sampling schedule.

2.1.1 Well Longevity

Most of the tritium-tracking wells located south of the SALDS were constructed with 6.1 m (20 ft) screens. Many have gone dry, including 299-W8-1, which became dry during FY 2011. As shown in Table 2-2, the remaining tritium-tracking wells screened in the upper aquifer will be dry before the year 2020 if the water table continues to decline at the same rate observed between March 2010 and March 2011 (i.e., 0.33 m/yr [1.08 ft/yr]). Only Wells 299-W7-3 and 299-W6-6 (which are screened deeper in the aquifer) would continue to be useable past the year 2016 at the current rate of decline. The water-level trend plots for Wells 299-W6-11 and 299-W6-12 (Figures 2-8 and 2-9, respectively) show the elevation of the screen bottom in these wells and projects the future water-level decline using a longer period of data than used for the predictions in Table 2-2. The projected dry dates in Figures 2-8 and 2-9 are in general agreement with the dates in Table 2-2, differing by only a couple of years.

Figures 2-10 and 2-11 show the screen elevations and projected dry dates for proximal monitoring Wells 699-48-77A and 699-48-77D, respectively. The projections for 699-48-77A were done using multiple historical time periods (Figure 2-10), but this well may be dry in August 2014 using only water-level measurements since 2008 for the projection. Well 699-48-77D may be dry in September 2012 using measurements since 1994 for the projection. Due to different methods of extrapolation, these dates do not exactly match those calculated in Table 2-2, where it is assumed that the short-term rate of groundwater decline between March 2010 and March 2011 will remain constant in future years.

However, projections of future water-level declines based on historical water levels do not take into account the effect of the new 200-ZP-l OU pump-and-treat system, which is expected to start operation in 2012. Wells 299-W6-11, 299-W6-12, 699-48-77A, and 699-48-77D will likely be affected by this system. A modeling study was recently completed to assess the longevity of groundwater monitoring wells in the 200 West Area that considers the effects of the new pump-and-treat system (SGW-50907, *Predicted Impact of Future Water-Level Declines on Groundwater Well Longevity within the 200 West Area, Hanford Site*). Predictions from this study indicate the water level will increase slightly in wells 299-W6-11, 299-W6-12, 699-48-77A, and 699-48-77D due to the injection of treated water at nearby injection wells. Predictions from this study indicate that the water level in these four wells will decline to within 1 ft of the screen bottom between the years 2015 and 2017. Thus, the operation of the new pump-and-treat system may result in these wells being useable for a few more years than they would be without the pump-and-treat system.

2.2 Groundwater Flow

The arrows in Figure 2-7 denoting the interpreted groundwater flow paths indicate that effluent from the SALDS should approach wells located south and east of the facility, and may actually reach these wells if dispersion is taken into account. The maximum distance that effluent may travel from the SALDS to the south before turning east is not known precisely; however, based on both past and current model predictions, the distance by advection only (i.e., without considering dispersion) is assumed to be relatively short (i.e., approximately 300 to 350 m [1,000 to 1,150 ft]). Interpretation of the flow paths shown in Figure 2-7 indicates that Wells 699-51-75 and 699-48-71 (located 1.0 km [3,300 ft] northeast and 1.9 km [6,200 ft] east of the SALDS, respectively) are regionally downgradient of the facility and are in reasonable locations for intercepting SALDS effluent. Increasing concentration trends of carbon tetrachloride (and nitrate at Well 699-48-71), observed as part of the 200-ZP-1 OU monitoring (DOE/RL-2008-66, *Hanford Site Groundwater Monitoring for Fiscal Year 2008*) suggest a more northerly flow of these contaminants from the south and southwest. The increasing tritium concentration trend at Well 699-48-71 is also considered to be related to contaminated groundwater flowing from the south and southwest rather than from the SALDS facility. This is supported by the modeling which indicates the SALDS tritium plume should not reach Well 699-48-71 prior to the year 2030 (Figure 4-3 in Chapter 4).

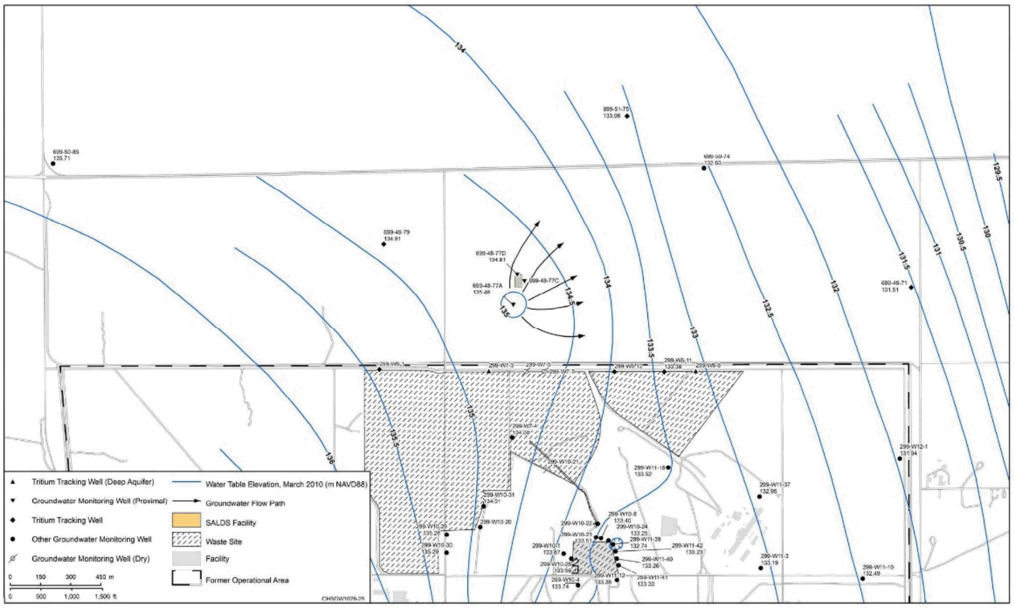


Figure 2-7. Water Table Map and Interpreted Groundwater Flow Directions in the SALDS Area, March 2011

This page intentionally left blank.

Table 2-2. Calculated Dry Dates for Tritium Monitoring Wells (Located Proximal to and South of the SALDS)

Well	Land Surface Elevation (m)	Depth to Screen Bottom (m)	Screen Bottom Elevation (m)	March 2011 Water Table Elevation (m)	Saturated Screen Thickness (m)	Saturated Screen Divided by 0.32 m/yr = Years Until Well Is Dry	Calculated Dry Well Date[a]
299-W6-6	216.503	130.9	85.6	133.227	47.6	144[b]	Not expected to go dry
299-W6-11	214.388	82.7	131.7	133.381	1.7	5[b]	2016
299-W6-12	211.219	78.4	132.8	133.706[c]	0.9	3	2014
299-W7-3	206.451	143.3	63.2	134.570	71.4	216	Not expected to go dry
299-W8-1	214.290	78.2	136.1	NM	Dry	n/a	Dry 2011
699-48-77A	205.922	70.8	135.1	135.480	0.4	1[d]	2012
699-48-77C	205.862	94.5	111.4	134.458	23.1	70[d]	Not expected to go dry
699-48-77D	205.698	71.5	134.2	134.808	0.6	2[d]	2013

Notes:

a. Calculated dry dates are not necessarily in agreement with the dates shown in Figures 2-8 through 2-11. The calculated dates are based on the short-term rate of change over a one-year period, while the dates shown in the figures are based on long-term trends over periods that extend from four to nineteen years.

b. Water-level decline is not expected to exceed approximately 6 m (20 ft).

c. Water level measured during January 2011.

d. Regional water level rate of decline (0.33 m/yr [1.08 ft/yr]) was used for these wells rather than the proximal well rate of decline (0.13 m/yr [0.43 ft/yr]) in order to provide a conservative estimate.

n/a = not applicable

NM = no measurement

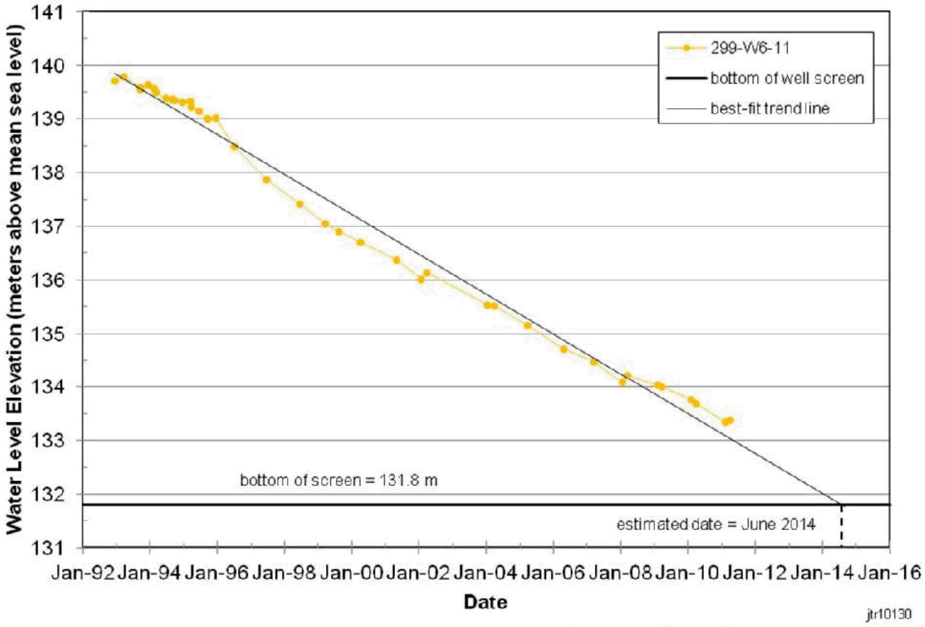


Figure 2-8. Water Remaining in Tritium-Tracking Well 299-W6-11

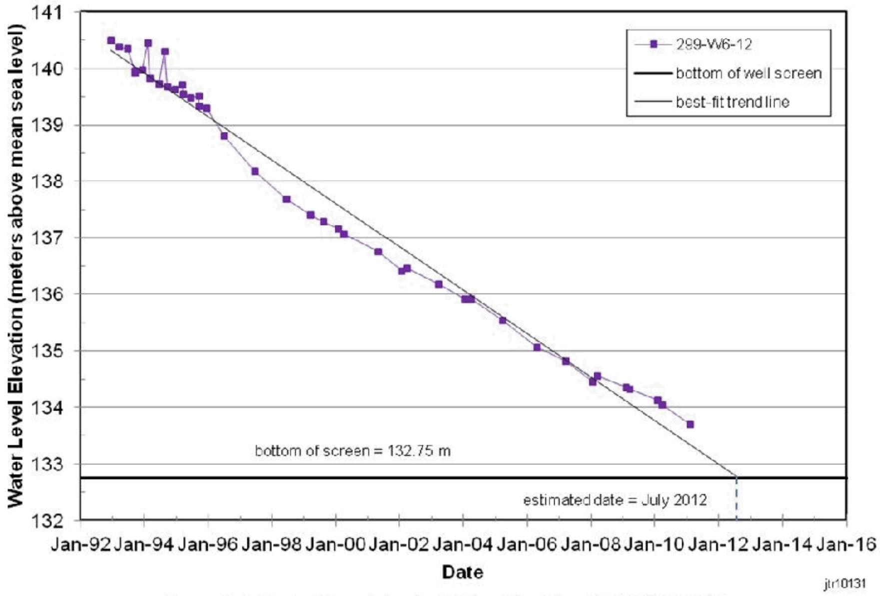


Figure 2-9. Water Remaining in Tritium-Tracking Well 299-W6-12

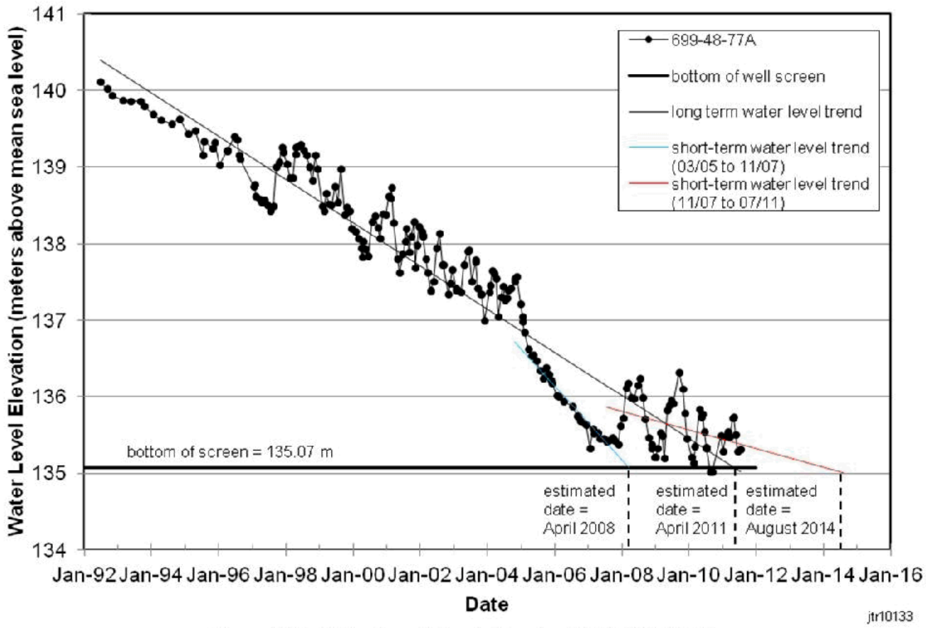


Figure 2-10. Water Remaining in Proximal Well 699-48-77A

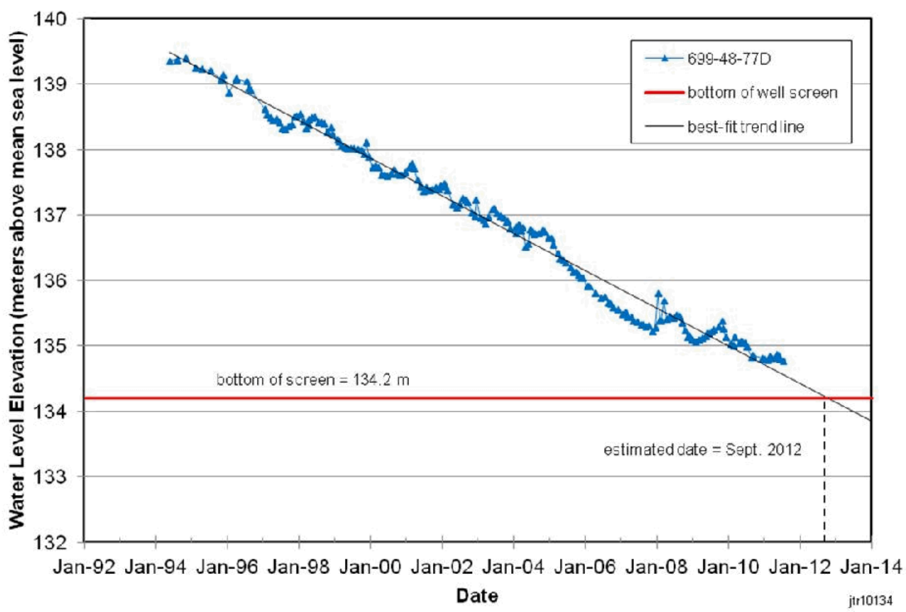


Figure 2-11. Water Remaining in Proximal Well 699-48-77D

3 Results of FY 2011 Groundwater Sampling

Groundwater is sampled quarterly in the SALDS proximal wells (699-48-77A, 699-48-77C, and 699-48-77D) and annually to semiannually in the tritium-tracking wells located in the vicinity of the SALDS. Table 3-1 shows the FY 2011 sampling schedule. Section 3.1 summarizes the FY 2011 groundwater sampling results for the proximal wells. Section 3.2 discusses the results of the tritium analyses (including the tritium-tracking wells) provided in Appendix A.

Table 3-1. FY 2011 Sampling Schedule

Well	Sampling Frequency/Months*	Other Sampling Programs	Comments
299-W6-6	A / January	--	Deep well. FY 2011 sample date: January 2011.
299-W6-11	A / January	--	FY 2011 sample date: January 2011.
299-W6-12	A / January	--	FY 2011 sample date: January 2011.
299-W7-3	S / January, May	--	Deep completion. FY 2011 sample dates: January and May 2011.
299-W8-1	A / January	--	FY 2011 sample date: attempted January 2011; unsuccessful; dry.
699-48-71	A / January	200-UP-1 OU	FY 2011 sample dates: January and July 2011.
699-48-77A	Q / November, February, May, August	200-UP-1 OU	Sampled for 17 constituents/parameters required by Permit, including tritium. FY 2011 sample dates: December 2010 and March, May, and August 2011.
699-48-77C	Q / November, February, May, August	--	Sampled for 17 constituents/parameters required by Permit, including tritium. FY 2011 sample dates: December 2010 and March, May, and August 2011.
699-48-77D	Q / November, February, May, August	--	Sampled for 17 constituents/parameters required by Permit, including tritium. FY 2011 sample dates: December 2010 and March, May, and August 2011.
699-49-79	A / January	--	FY 2011 sample date: May 2011.
699-51-75	S / January, May	--	FY 2011 sample dates: early and late May 2011.
699-51-75P	A / January	--	Deep piezometer in Well 699-51-75. FY 2011 sample date: June 2011.

* Actual months of sampling may vary slightly due to equipment failure, winter weather, or accessibility restrictions caused by fire hazard; however, the sampling frequency is generally maintained.

A = annually

FY = fiscal year

OU = operable unit

Q = quarterly

S = semiannually

3.1 Proximal Well Sampling and Analysis for FY 2011

Samples from the three proximal wells were collected in December 2010 and in March, May, and August 2011. The samples were analyzed for the 17 constituents/parameters, including tritium, required by the ST 4500 Permit, Special Condition S2(B) (Ecology, 2000). The Permit sets enforcement limits for acetone, benzene, cadmium (total), chloroform, copper (total), lead (total), mercury (total), field pH, sulfate, tetrahydrofuran, and total dissolved solids. Gross alpha, gross beta, strontium-90, and tritium are required by the Permit but are not assigned enforcement limits; they are reported for informational purposes. Specific conductance and temperature are also required by the Permit, and the results for all of these parameters are reported quarterly in discharge monitoring reports. Additional parameters (i.e., alkalinity, dissolved oxygen, laboratory pH, and turbidity) are used to determine general groundwater characteristics and to verify the quality of analytical results. Table 3-2 lists the maximum concentrations for these constituents in the proximal wells and the corresponding sample months for FY 2011.

Table 3-2. Constituent Maximum or Range of Concentrations in Groundwater and Corresponding Sample Month for the Proximal SALDS Wells, FY 2011

Constituent (Permit Limit)	Well 699-48-77A	Well 699-48-77C	Well 699-48-77D
Constituents with Permit Limits			
Acetone (160 µg/L)	<1.0 (U)[a]	<1.0 (U)[a]	<1.0 (U)[a]
Benzene (5 µg/L)	<1.0 (U)[a]	<1.0 (U)[a]	<1.0 (U)[a]
Cadmium, total (10 µg/L)	<0.1 (U)[a]	<0.1 (U)[a]	<0.1 (U)[a]
Chloroform (6.2 µg/L)	<1.0 (U)[a]	<1.0 (U)[a]	<1.0 (U)[a]
Copper, total (70 µg/L)	1.1; March and May 2011	0.76 (B); May 2011	1.78; May 2011
Lead, total (50 µg/L)	0.188 (B); March and May 2011	<0.1 (U)[a]	0.36 (B); May 2011
Mercury, total (2 µg/L)	<0.05 (U)[a]	<0.05 (U)[a]	<0.05 (U)[a]
Field pH, pH units (6.5 to 8.5)[b]	8.2 to 8.5	8.0 to 8.2	8.0 to 8.2
Sulfate (250,000 µg/L)	2,650; March 2011	5,220; December 2010	17,700; May 2011
Tetrahydrofuran (100 µg/L)	<2 (U)[a]	<2 (U)[a]	<2.0 (U)[a]
Total dissolved solids (500,000 µg/L)	107,000; August 2011	157,000; August 2011	248,000; March 2011
Other Constituents Required by the Permit			
Gross alpha, pCi/L	<1.9 (U)[a]	<2.1 (U)[a]	<2.3 (U)[a]
Gross beta, pCi/L	3.3; December 2010	3.5; May 2011	4.1; March 2011
Strontium-90, pCi/L	3.2; May 2011	1.4; May 2011	2.0; May 2011
Tritium, pCi/L	110,000; March 2011	130,000; May 2011	160,000; May 2011
Field specific conductance, µS/cm[b]	89 to 98	193 to 202	248 to 276
Field temperature, °C[b]	19.8 to 21.1	18.4 to 21.2	15.8 to 21.0

Table 3-2. Constituent Maximum or Range of Concentrations in Groundwater and Corresponding Sample Month for the Proximal SALDS Wells, FY 2011

Constituent (Permit Limit)	Well 699-48-77A	Well 699-48-77C	Well 699-48-77D
Additional Constituents not Required by the Permit			
Alkalinity, mg/L	47 to 51	94 to 97	110[c]
Dissolved oxygen, mg/L[b,d]	9.45 to 14.2	9.00 to 9.64	11.5 to 13.1
Laboratory pH, pH units	8.16 to 8.36	7.96 to 8.04	8.08 to 8.14
Turbidity, NTU[b]	3.2 to 10.2	0.5 to 1.4	1.6 to 11.3

Notes: All concentrations in µg/L, unless otherwise noted.

a. Not detected in any sample.

b. Four analyses performed per sample event. This table reports the range of the quarterly averages for FY 2011.

c. All quarterly results for alkalinity reported at 110 mg/L.

d. Dissolved oxygen not measured during December 2010.

(B) = Detected at a value less than the contract-required detection limit but greater than or equal to the instrument detection limit/method detection limit, as appropriate (i.e., a low-level detection).

NTU = Nephelometric Turbidity Unit

(U) = Not detected; detection limits (for nonradionuclides) or reported value (for radionuclides) are indicated, as applicable.

There were no exceedances of a Permit limit during FY 2011. Acetone, benzene, cadmium, chloroform, mercury, and tetrahydrofuran were reported below detection limits in each of the three proximal wells for each of the samples collected during FY 2011. Two target metals (i.e., lead and copper) were found at near detection-limit concentrations in one or more of the proximal wells. The maximum concentration of copper encountered was 1.78 µg/L at Well 699-48-77D. Copper concentrations in ETF effluent increased between 2008 and 2009, but concentrations in the effluent have been declining to mostly non-detect levels since then. At no time during this period did concentrations in the effluent exceed 1.0 µg/L. Copper has been detected in the SALDS wells since 1995, although generally at low levels. Copper levels in the proximal wells have generally been stable (with most values less than 4 µg/L) since analyses were first conducted in 2001. Lead is rarely detected in the proximal wells, and most of the detections that do occur are less than 2.0 µg/L.

Field pH measurements were within the 6.5 to 8.5 criterion in all samples collected from the proximal wells during FY 2011. The minimum value of 8.0 occurred in Wells 699-48-77C and 699-48-77D, and the maximum value was 8.5 in Well 699-48-77A. The maximum sulfate concentration was 17,700 µg/L in 699-48-77D, well below the permit limit of 250,000 µg/L. The maximum total dissolved solids value was 248,000 µg/L in 699-48-77D, below the 500,000 µg/L permit limit.

Gross beta results ranged from below detection limits to a maximum of 4.1 pCi/L in the proximal wells during FY 2011. All results were below the Hanford Site background value of 8.96 pCi/L (ninety-fifth percentile value provided in DOE/RL-96-61, *Hanford Site Background: Part 3, Groundwater Background*). Strontium-90 results ranged from below detection limits to a maximum of 3.2 pCi/L. The maximum value is above the Hanford Site background value of 0.020 pCi/L, but is below the 8 pCi/L drinking water standard. All the gross alpha analyses in the proximal wells yielded non-detect results during FY 2011. There are no permit limits associated with gross alpha, gross beta, or strontium-90.

3.2 Results of Tritium Analyses (Tritium Tracking)

While the proximal wells are sampled quarterly for a suite of constituents, the tritium-tracking wells are sampled annually or semiannually for tritium only. Eight tritium-tracking wells were sampled between January and July 2011. Due to generally declining water levels throughout the 200 West Area, 11 of the 19 tritium-tracking wells listed in the monitoring plan (PNNL-13121) have gone dry and are no longer in use. The attempt to sample tritium-tracking Well 299-W8-1 during January 2011 was not successful due to a lack of water; this well is now dry. Five of the wells sampled successfully are screened in the upper portion of the aquifer near the water table; the other three wells are screened at greater depths, including one well (699-51-75P) that is a piezometer nested within Well 699-51-75 but is completed 41 m (135 ft) deeper in the aquifer.

Two of the SALDS network wells, proximal Well 699-48-77A and tritium-tracking Well 699-48-71, are also sampled as part of monitoring for the 200-ZP-1 OU. The tritium results for this program, as well as the results collected specifically for the SALDS, are included in Appendix A. One tritium-tracking well (299-W7-3) was formerly sampled for LLBG monitoring (Low-Level Waste Management Area-3). A new LLBG monitoring plan was issued during 2010 (DOE/RL-2009-68, *Interim Status Groundwater Monitoring Plan for the LLBG WMA-3*). This plan reduced the number of wells monitored for the burial ground such that 299-W7-3 is no longer used for LLBG monitoring.

3.2.1 Tritium in the Proximal Monitoring Wells

Groundwater in the three proximal wells has been affected by tritium discharges since 1996 (Figure 3-1). From FY 2010 to FY 2011, average tritium activities increased (i.e., more than 20 percent change) in two of the three proximal monitoring wells in FY 2011 (699-48-77A and 699-48-77C) and decreased in the other well (699-48-77D) (Figure 3-2). The maximum tritium concentrations in the proximal wells during FY 2011, and the associated sample dates, are as follows:

- Well 699-48-77A: 110,000 pCi/L (March 2011)
- Well 699-48-77C: 130,000 pCi/L (May 2011)
- Well 699-48-77D: 160,000 pCi/L (May 2011)

3.2.1.1 Long-Term Trends

Figure 3-1 shows tritium concentrations in the proximal wells compared to the amount of tritium released at the SALDS. Peak tritium concentrations occurred in September 1997 (2,000,000 pCi/L) and February 1998 (2,100,000 pCi/L) in Wells 699-48-77A and 699-48-77D, respectively, in response to the initial discharges to the SALDS between December 1995 and June 1996. The peak concentration in Well 699-48-77C (980,000 pCi/L) was delayed until February 2001, likely because this well is screened approximately 20 m (65 ft) below the water table, and it took longer for the plume front to migrate to this depth. Additionally, tritium incursions to deeper Well 699-48-77C have been lower in magnitude, and cyclical variations are also absent. These differences are attributed to the deeper screen setting and the dilution and attenuation of the plume as it moves vertically through the aquifer.

Since the time of peak concentrations in the proximal wells, the tritium concentration trends have been generally downward. However, concentration changes in Well 699-48-77A are irregular (Figure 3-1) with what appears to be periodic highs and lows of significant amplitude (sometimes two order-of-magnitude changes) from 1999 to 2005. These fluctuations likely reflect the annual campaigns of the 242-A Evaporator wastewater, which is high in tritium. A more recent tritium analysis, 820,000 pCi/L in April 2008, is the highest level seen in Well 688-48-77A in a decade (Figure 3-2). This was likely due to several intermittent ETF campaigns in 2006 and 2007 to treat wastewater from the K Basins project, which had tritium levels similar to that of 242-A Evaporator wastewater. These intermittent campaigns restarted in FY 2010 with the ETF again treating wastewater from the K Basins project. This may explain the slight upward trend in tritium results in FY 2011.

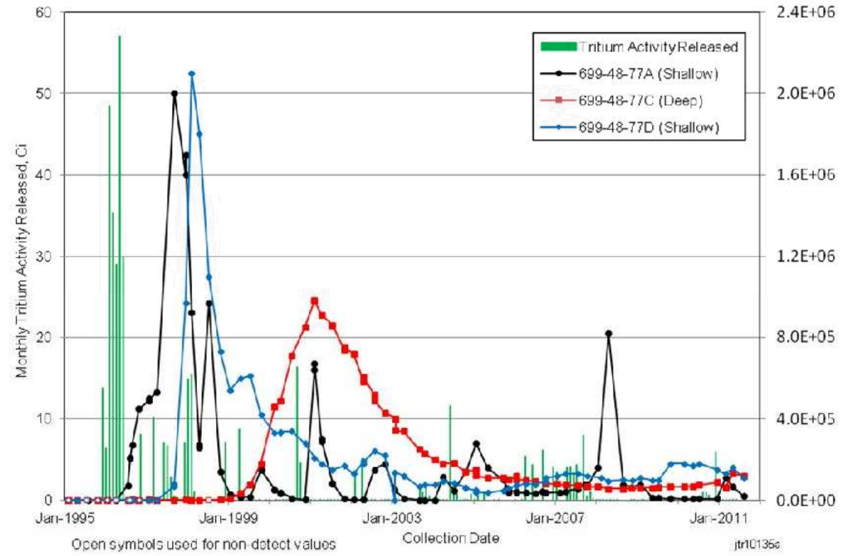


Figure 3-1. SALDS Tritium Releases and Concentration Trends in SALDS Proximal Wells from 1995 through August 2011

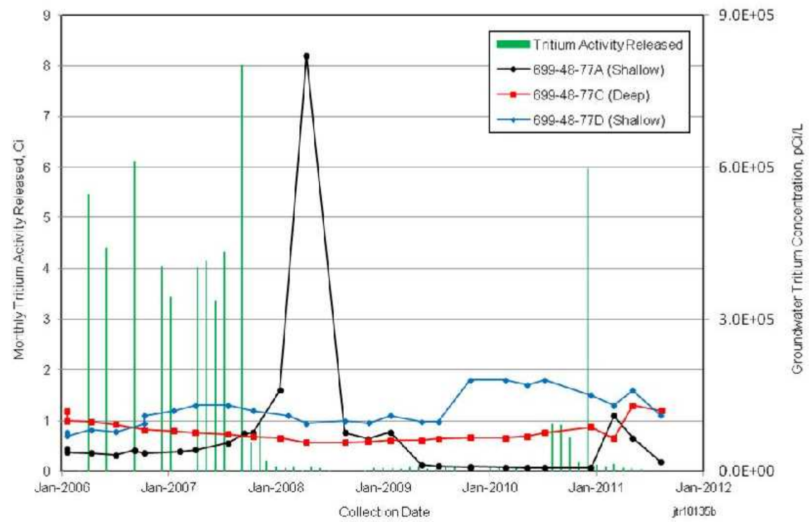


Figure 3-2. SALDS Tritium Releases and Concentration Trends in SALDS Proximal Wells from 2006 through August 2011

Well 699-48-77D is located nearest to the SALDS, yet the well showed a tritium concentration increase starting in September 1997, more than one year later than more distant Well 699-48-77A. There are two reasons for this delay: (1) the SALDS drain field fills from the southern end of the facility furthest away from Well 699-48-77D, and (2) discharged water initially moves to the south along the CCU which has a southward dip (Section 1.2.1). These two conditions direct the subsurface flow of effluent away from Well 699-48-77D so it actually reaches the groundwater nearer to Well 699-48-77A. This interpretation is consistent with the relatively low specific conductance values measured in Well 699-48-77A (ranging from 89 to 98 µS/cm during FY 2011), which indicates that a substantial portion of SALDS effluent has mixed with groundwater at this location.

3.2.1.2 Current Trends

The current tritium trends at the three proximal wells are mixed. All three wells exhibited a period of increasing concentrations during the fiscal year followed by declines in concentrations at the end of the fiscal year (Figure 3-2). Average concentrations for FY 2011 were higher than in FY 2010 for wells 699-48-77A and 699-48-77C, and lower for well 699-48-77D. Tritium concentration increases during the year at 699-48-77A and 699-48-77D may be attributed to increased tritium releases from August 2010 to January 2011 (Figure 3-2). Increases at 699-48-77C, screened deeper in the aquifer, may be attributable to the SALDS releases during 2006 and 2007 from ETF treatment of wastewater from the K Basins project.

3.2.2 Tritium-Tracking Wells

Tritium concentrations were little changed in the tritium-tracking wells compared to the previous year. Tritium was not detected in the three deep wells, 299-W6-6, 299-W7-3, and 699-51-75P (Figure 3-3). Tritium was also not detected in Wells 699-49-79 and 699-51-75, located west and northeast of the SALDS, respectively. All of these results are consistent with recent historical trends.

Wells located southeast of the SALDS have exhibited elevated tritium concentrations as a result of past wastewater disposal practices in the 200 West Area. Tritium activities in Well 299-W6-11 have slowly decreased over the past several years (Figure 3-4). Prior to becoming sample-dry in 2003, tritium concentrations in Well 299-W6-7 had declined steadily, from more than 40,000 pCi/L in 1993 to about 10,000 pCi/L in 2002. The maximum tritium concentration in Well 299-W6-11 occurred in March 1995 at 9,450 pCi/L. The FY 2011 tritium concentration was 2,180 pCi/L, a decrease of 3 percent from 2,240 pCi/L in FY 2010. The tritium concentration in Well 299-W6-12 was essentially unchanged from the previous year at 242 pCi/L (Figure 3-5). All three of these wells exhibited elevated tritium concentrations prior to the start of SALDS' discharges.

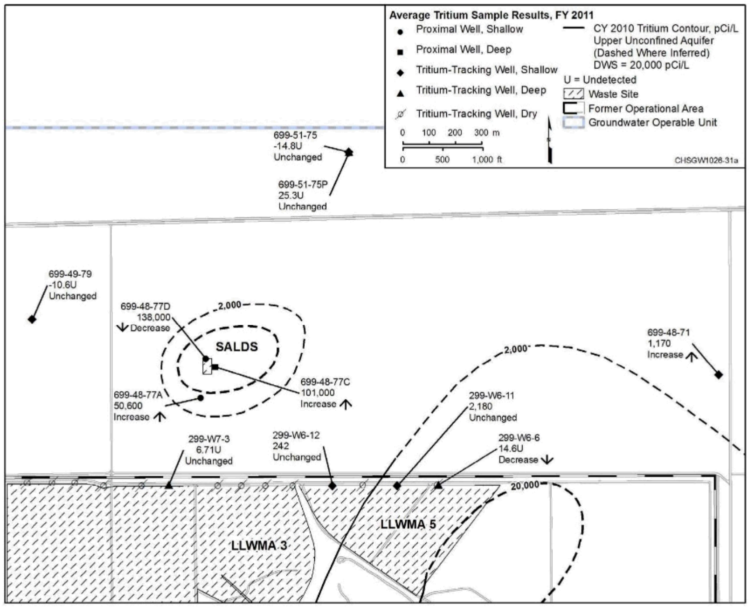


Figure 3-3. Average Tritium Activities in Groundwater for SALDS Tritium-Tracking Network for FY 2011

This page intentionally left blank.

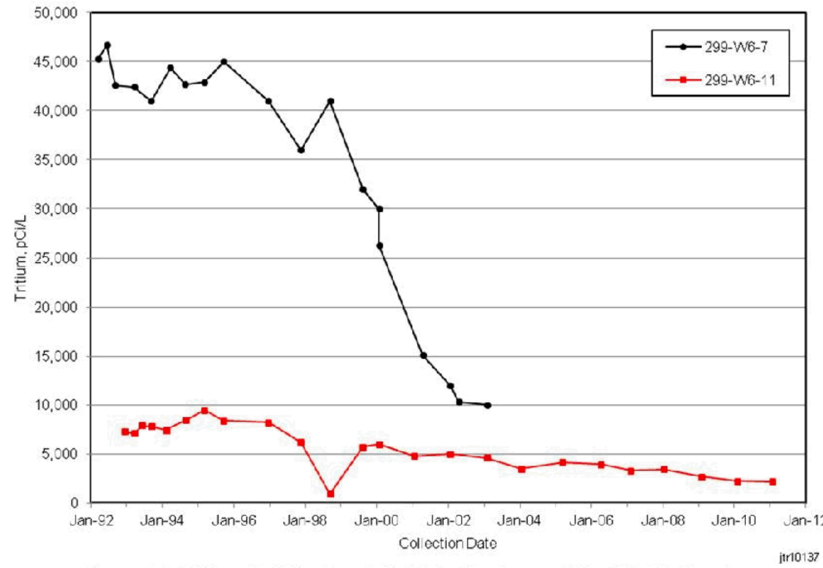


Figure 3-4. Tritium Activity Trends in Wells Southeast of the SALDS Showing Remnant Effects of the Tritium Plume from the 200 West Area

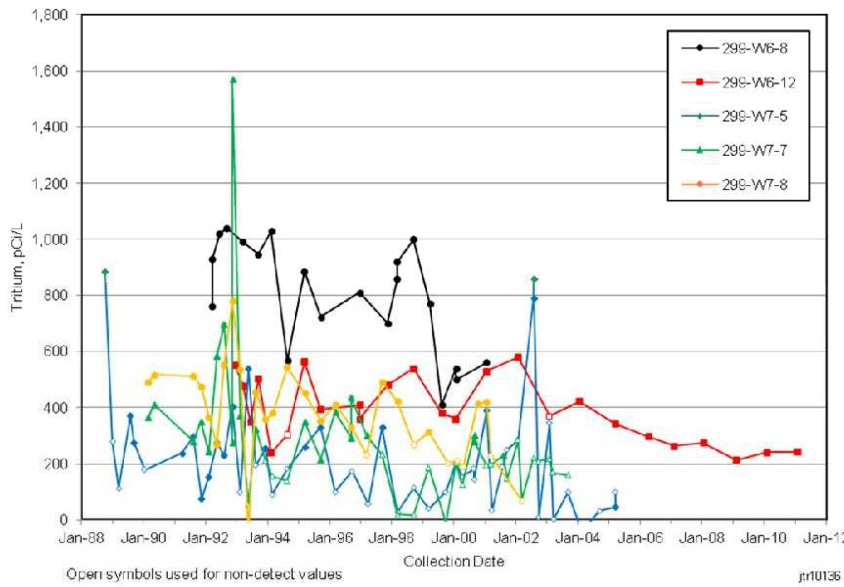


Figure 3-5. Tritium Concentrations in Wells South of the SALDS Showing Remnant Effects of the Tritium Plume from the 200 West Area

Well 699-48-71, located 1.9 km (1.2 mi) to the east of the SALDS crib, continued to show an increase in tritium concentration, from 850 pCi/L in FY 2010 to 1,170 pCi/L in FY 2011. Tritium concentrations have been increasing in this well since 2004. Although this well is downgradient of the SALDS crib, the distance involved suggests that discharges from the SALDS are not the source of tritium in groundwater at this location. This is also supported by the tritium modeling results, which predicts that the SALDS plume should not reach this well prior to the year 2030 (Section 4.3). The source of the tritium at 699-48-71 is interpreted to be an older plume from the 200 West Area (Figure 3-3).

3.3 Results of Other Constituent Analyses

Several anions and metals increased in concentration in the proximal wells after discharges began at the SALDS and then rapidly declined. The specific conductance at Well 699-48-77A (a measure of total ions in solution) clearly shows a well-defined spike in the months after SALDS discharge began in December 1995 (Figure 3-6), with values peaking at approximately 845 µS/cm during August 1996. This was likely due to transport of dissolved soluble mineral species in the vadose zone during initial percolation of SALDS effluents (PNNL-11633, *Origin of Increased Sulfate in Groundwater at the ETF Disposal Site*; PNNL-11665, *Tritium Monitoring in Groundwater and Evaluation of Model Predictions for the Hanford Site 200 Area Effluent Treatment Facility*). This spike in dissolved constituents was a temporary effect associated with the initial wetting of the vadose zone sediments beneath the facility. During FY 2011, the maximum field conductivity readings in the proximal wells were 98, 202, and 276 µS/cm in 699-48-77A, 699-48-77C, and 699-48-77D, respectively. Maximum total dissolved solids ranged between 107 and 248 mg/L (Figure 3-7).

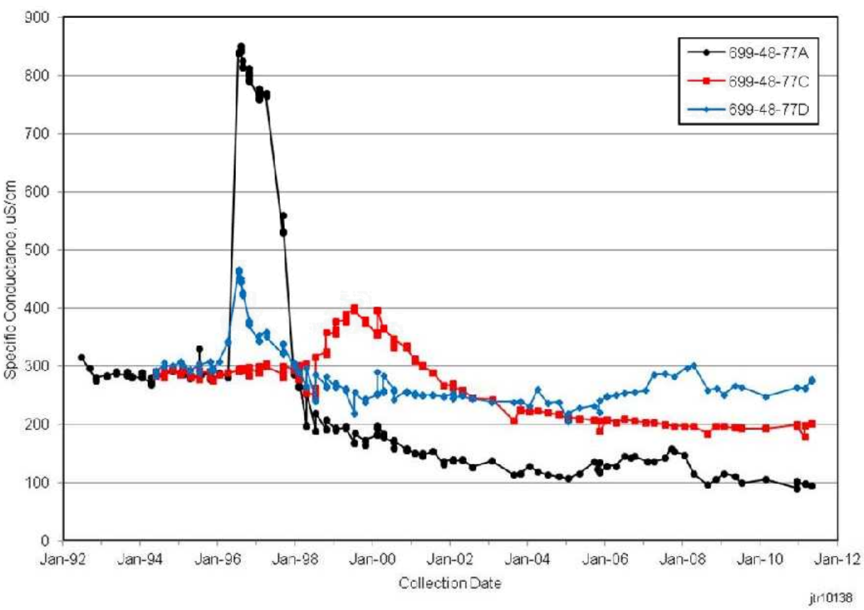


Figure 3-6. Specific Conductance in the SALDS Proximal Wells

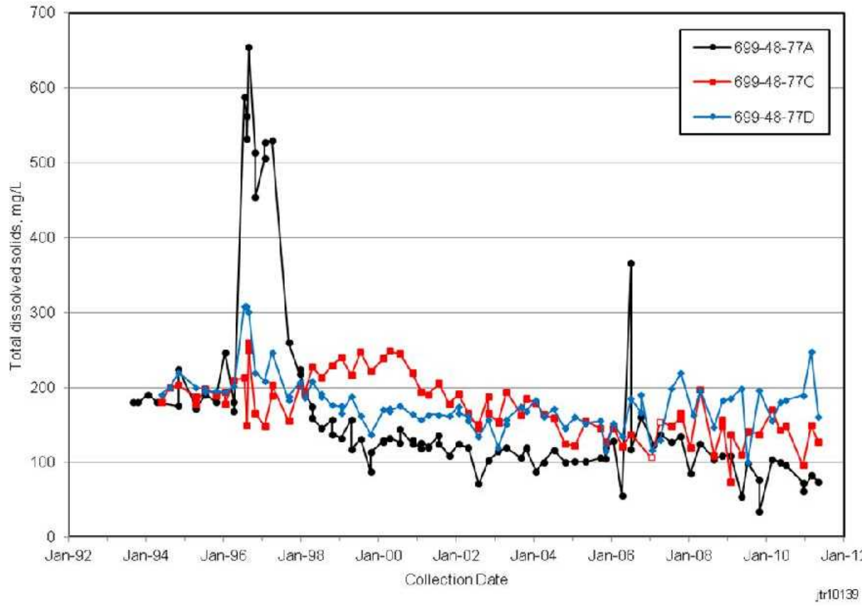


Figure 3-7. Total Dissolved Solids in the SALDS Proximal Wells

Well 699-48-77C is screened approximately 20 m (65 ft) below the water table. As previously discussed, constituent trends for 699-48-77C exhibit attenuated and time-lagged responses to SALDS discharges compared with the two shallow proximal wells. Specific conductance values gradually increased in Wells 699-48-77A and 699-48-77D when pumping ceased and a rebound study began at the 200-UP-1 pump-and-treat system in March 2005 (Figure 3-6). The specific conductance increase was caused by reduced effluent discharge volumes resulting in less mixing of effluent with the groundwater. Decreasing conductivities occurred in the shallow wells when effluent discharges increased in September 2007 due to resumption of pumping at 200-UP-1 as well as additional volumes of treated effluent from the T Tank Farm pump-and-treat system. However, these responses are not evident in the specific conductance trend in the deeper well, 699-48-77C. Specific conductance has only recently begun to increase in this well, perhaps in response to the reduction of discharges between 2005 and 2007.

Similar delayed behavior is seen in Figures 3-8 through 3-11 for chloride, sulfate, calcium, and sodium in the proximal wells. These constituents are leached from the soil, so the results are not directly representative of ETF effluent. Only sulfate analyses are required by the Permit, but all four of these constituents are useful for tracking groundwater movement. For example, the initial increase in sulfate concentration in Wells 699-48-77A and 699-48-77D in December 1995 occurred within six months after startup of disposal to the SALDS. Sulfate concentrations did not increase in Well 699-48-77C until late 1998, or three years after the startup of disposal. The ninety-fifth percentile background level for sulfate is 55 mg/L (DOE/RL-96-61). Concentrations of these four analytes began to increase at Well 699-48-77D in 2005. Since 2009, chloride, sulfate, and calcium have been generally stable in this well, while a slight increasing trend is noted for sodium. At Wells 699-48-77A and 699-48-77C, the concentrations of these four analytes are slowly declining or are stable.

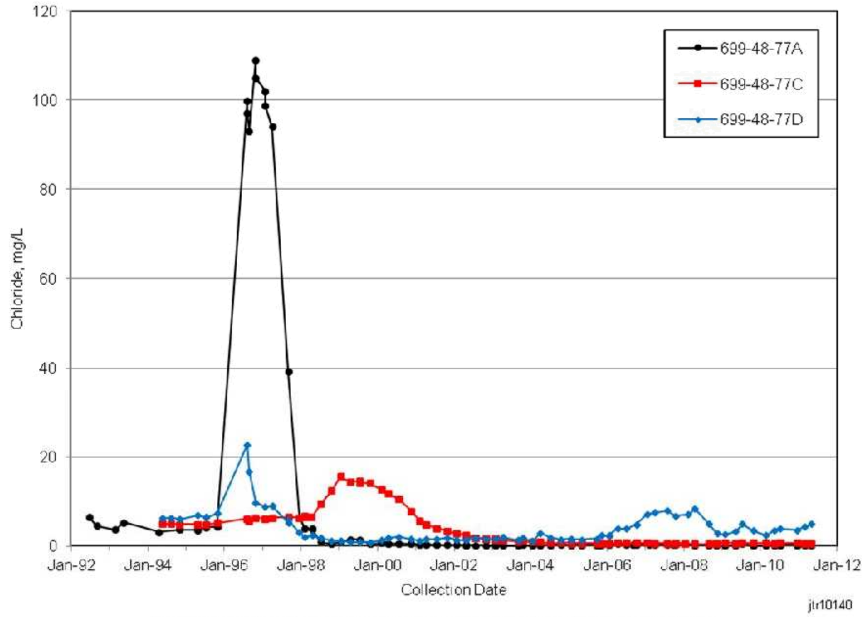


Figure 3-8. Chloride Concentrations in the SALDS Proximal Wells

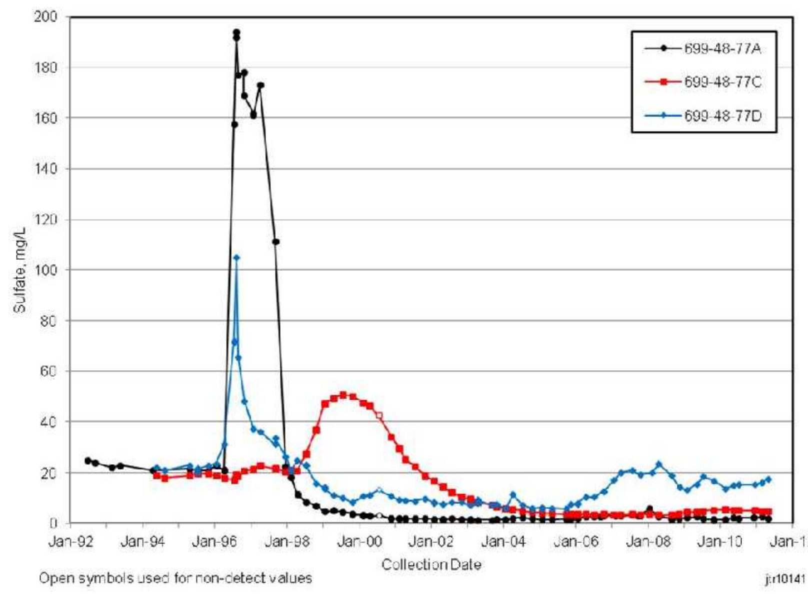


Figure 3-9. Sulfate Concentrations in the SALDS Proximal Wells

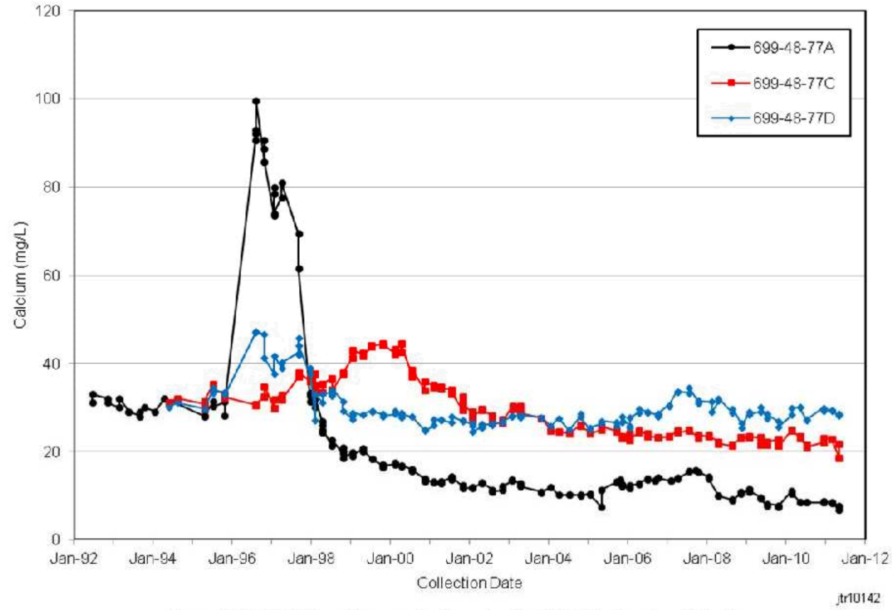


Figure 3-10. Calcium Concentrations in the SALDS Proximal Wells

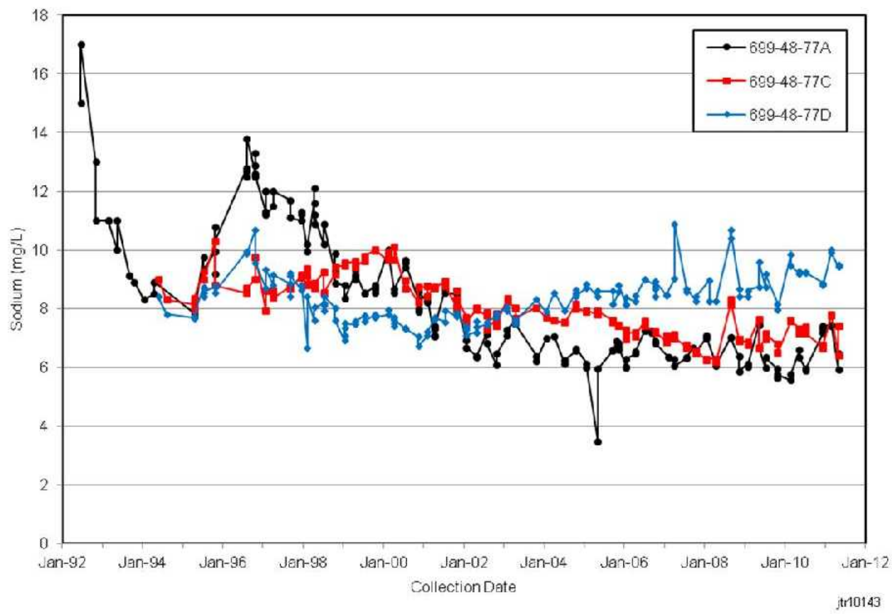


Figure 3-11. Sodium Concentrations in the SALDS Proximal Wells

4 Groundwater Modeling and Site Analysis

The groundwater modeling and site analysis was updated for this report. Although the model was updated for the previous annual report (SGW-47923), it was updated again for the current report so that the tritium migration and fate predictions would be based on both the latest calibration of the groundwater model and the latest information regarding the forecast operation of the expanded 200-ZP-1 pump-and-treat system. The expanded pump-and-treat system is expected to begin operating in FY 2012, so this model update serves as a final benchmark prediction of the pump-and-treat system effects on the SALDS tritium plume prior to actual operation of the expanded pump-and-treat system. This section provides a summary of the modeling results, which are discussed further in Appendix B.

4.1 Analysis Approach

The modeling was performed using the CP groundwater model that was first described in DOE/RL-2008-56, *200-West Area Pre-Conceptual Design for Final Extraction/Injection Well Network: Modeling Analyses*. The CP Model simulates conditions from the 1940s through to the present (calibration period) and is then used to simulate likely future conditions under assumed extraction and injection rates for the expanded 200-ZP-1 groundwater pump-and-treat system. The CP Model was most recently updated in 2010 (ECF-HANFORD-10-0371, *Central Plateau Version 3 MODFLOW Model*; CP-47631), and included an improved calibration of the flow field to historical water-level measurements compared to previous versions of the model. The migration and fate of the SALDS tritium plume was simulated using historical tritium releases from the start of facility operation through June 2011, along with future projected tritium releases.

In addition to the model simulations, analyses were completed using a water-level mapping and particle tracking technique to verify that the flow field simulated by the CP Model in the SALDS vicinity was in reasonable agreement with actual field conditions determined using water-level measurements. The mapping and particle-tracking analysis was performed using the program KT3D_H2O Version 3 (Karanovic et al., 2009, "KT3D_H2O: A Program for Kriging Water Level Data Using Hydrologic Drift Terms"). This software uses Kriging to generate gridded maps of water-level elevations taking the SALDS effluent discharges into account, and then uses the maps to compute particle movement paths. This analysis used seventeen sets of water level maps from 1995 through 2011.

4.2 Groundwater Flow

Figure 4-1 compares the results of conservative particle-tracking analyses through the year 2030, calculated using the CP Model and the water-level mapping technique. The two methods of evaluating the flow field yielded similar results; both techniques indicate a generally eastward movement of groundwater in the SALDS vicinity. The eastern end of the particle tracks differ in that the CP Model indicates a component of flow toward the south in later years. The model simulated the expected future effects of the expanded 200-ZP-1 pump-and-treat system in which flow turns southward toward the extraction wells, whereas for future projections, the water-level mapping technique used the 2011 water-level map that does not include future pump-and-treat system effects.

The particle tracks shown in Figure 4-1 are based on advection without dispersion. The software used for the water-level mapping particle tracks can simulate dispersion using a random-walk technique, and the results are shown in Figure 4-2. This figure suggests that when dispersion is taken into account, groundwater from the SALDS could reach wells located along the northern boundary of the 200 West Area by the year 2030. Using either method of particle-tracking analysis, the SALDS effluent is not predicted to reach Well 699-51-75, located 800 m (2,600 ft) to the northeast of the SALDS, or Well 699-48-71, located 1.9 km (1.2 mi) to the east, by the year 2030.

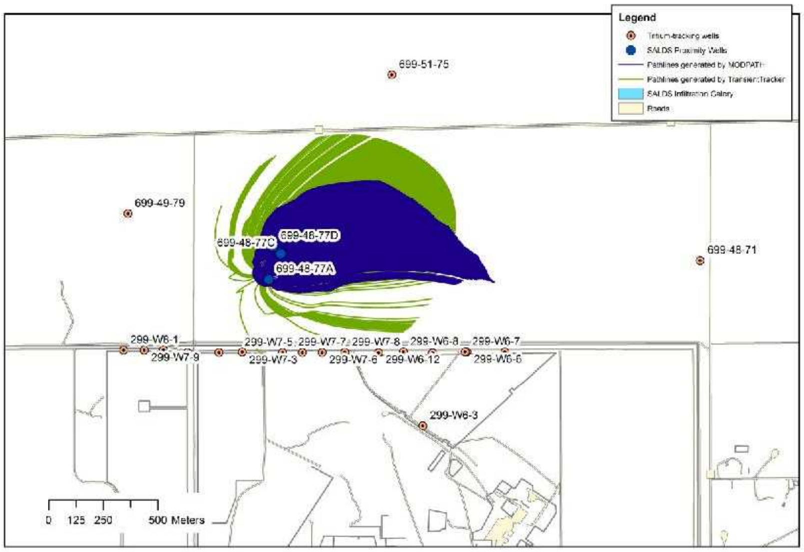


Figure 4-1. Particle Tracks through Year 2030 Calculated Using the Central Plateau Model and the Water-Level Mapping Technique

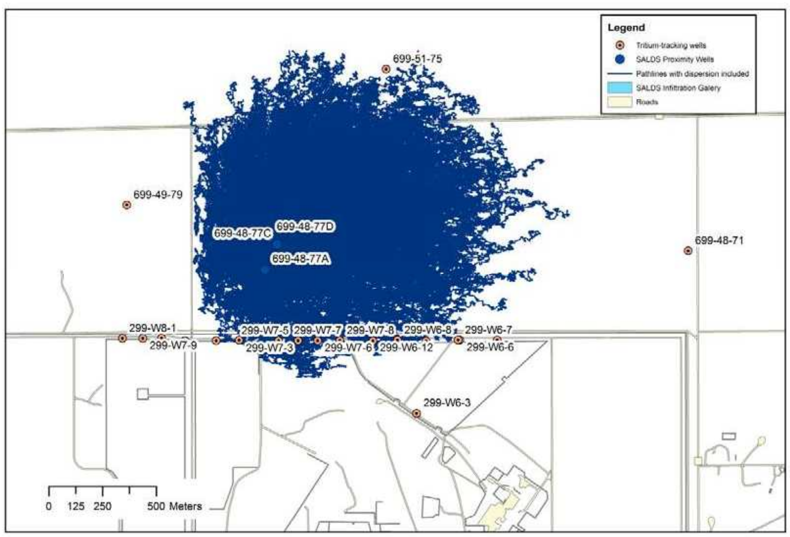


Figure 4-2. Particle Tracks with Dispersion Produced by the Water-Level Mapping Technique

4.3 Tritium Plume Migration and Fate

The CP Model was used to simulate the migration and fate of the SALDS tritium plume. Figure 4-3 shows the results for year 2030. Appendix B shows the results for 2000 through 2030 at five year intervals. The modeling was completed using two effective porosity assumptions, 0.13 and 0.18, and results for both are shown in Figure 4-3. Under either assumption, the tritium plume is not anticipated to reach tritium-tracking Wells 699-51-75 or Well 699-48-71 by the year 2030. However, some locations along the northern margin of the 200 West Area are expected to exhibit measurable concentrations of SALDS-derived tritium by 2030, although the model indicates that concentrations would be below the drinking water standard of 20,000 pCi/L.

The results in Figure 4-3 differ slightly from results presented in the earlier model update performed in FY 2010 (SGW-47923) in that the distal end of the tritium plume is now simulated to migrate toward the south by the year 2030. The reason for this difference can be seen in Figure 4-4, which compares the FY 2010 and FY 2011 model update results for year 2030 (for an effective porosity of 0.13) and shows the assumptions used for each update regarding the predicted operation of the expanded 200-ZP-1 pump-and-treat system extraction and injection wells. The FY 2010 model update assumed uniform flow rates for all extraction and injection wells (depicted in Figure 4-4 by the uniform symbol size for the extraction and injection wells). The extraction and injection rates used for the FY 2011 model update resulted from an optimization analysis of the pump-and-treat system to maximize the recovery of carbon tetrachloride (the principal contaminant being remediated) from the aquifer (SGW-50390, *FY 2011 Simulation-Optimization of the 200-ZP-1 Remedy Using the Central Plateau Model*). The optimized flow rates are predicted to be higher in the eastern extraction wells compared to the western wells, resulting in a larger area of water table drawdown along the eastern margin of the 200 West Area toward which the tritium plume is predicted to migrate.

It should be emphasized that the 200-ZP-1 extraction and injection rates used in both the FY 2010 and FY 2011 model updates are conjecture based upon current knowledge of the individual well and total system capacity of the 200-ZP-1 pump-and-treat system. As such, actual flow rates are expected to differ from those presented in either of these model updates. However, the modeling results do indicate that the ultimate fate of the SALDS tritium plume will be affected by operation of the pump-and-treat system, as is evident in Figure 4-4.

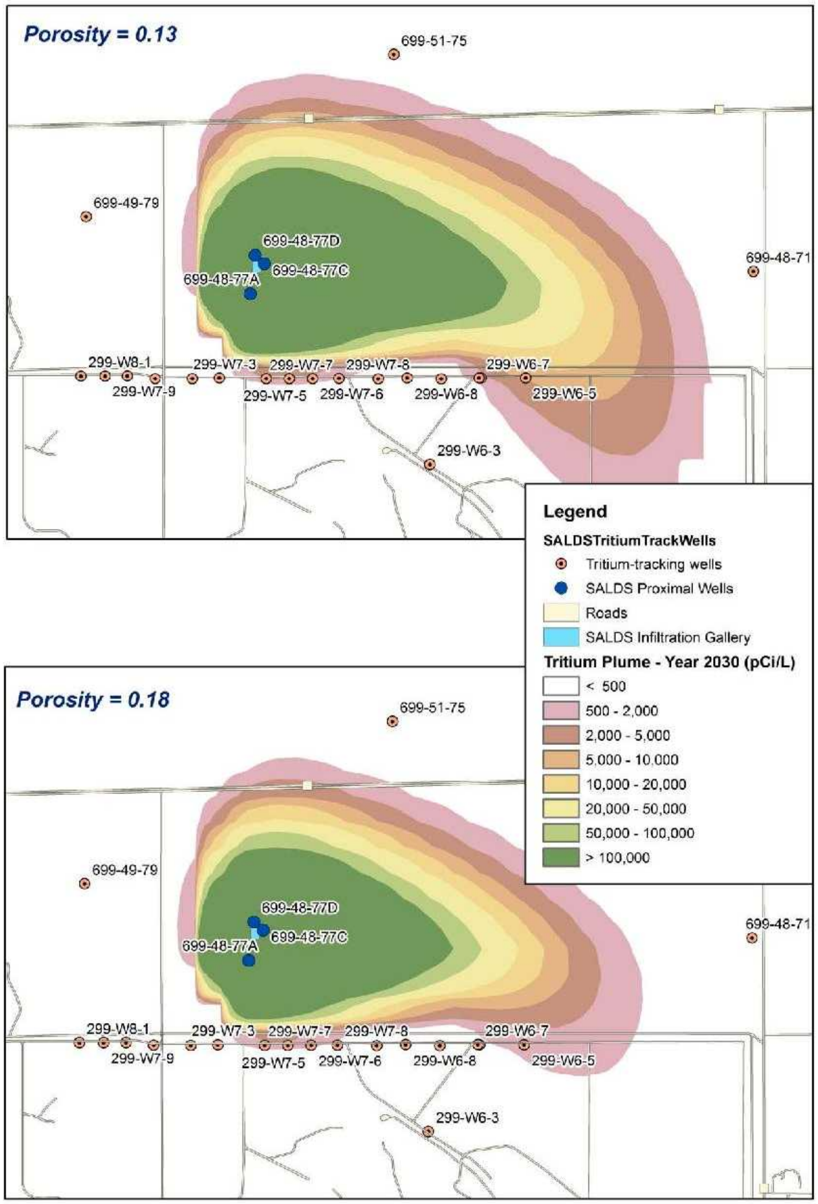


Figure 4-3. Simulated Tritium Distribution as a Result of SALDS Operation in Year 2030

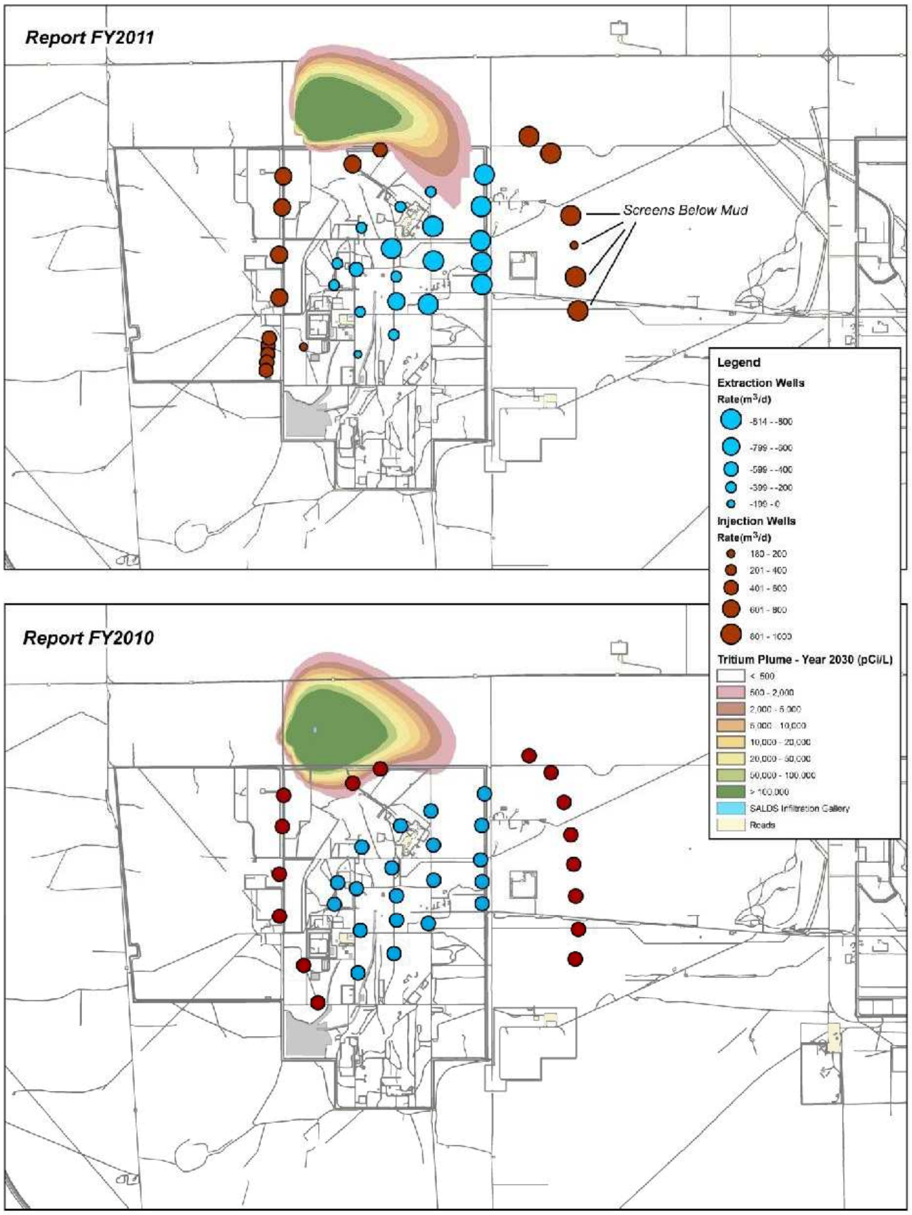


Figure 4-4. Comparison of the Model Updates Performed in FY 2010 and FY 2011 Along with the Different 200-ZP-1 Pump-and-Treat System Flow Rates Used in the Simulations

5 References

Atomic Energy Act of 1954, 42 USC 2011, et seq. Available at: http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr0980/ml022200075-vol1.pdf.

CHPRC-1100679, 2011, "Quarterly Discharge Monitoring Reports for the 200 Area Effluent Treatment and Treated Effluent Disposal Facilities Covering the October 2010 Through December 2010 Reporting Period," (letter to S.L. Nichols, Washington State Department of Ecology, from M.R. Kembel), CH2M HILL Plateau Remediation Company, Richland, Washington, February 11.

CHPRC-1102245, 2011, "Quarterly Discharge Monitoring Reports for the 200 Area Effluent Treatment and Treated Effluent Disposal Facilities Covering the January 2011 Through March 2011 Reporting Period," (letter to S.L. Nichols, Washington State Department of Ecology, from M.R. Kembel), CH2M HILL Plateau Remediation Company, Richland, Washington, May 10.

CHPRC-1103864, 2011, "Quarterly Discharge Monitoring Reports for the 200 Area Effluent Treatment and Treated Effluent Disposal Facilities Covering the April 2011 Through June 2011 Reporting Period," (letter to S.L. Nichols, Washington State Department of Ecology, from M.R. Kembel), CH2M HILL Plateau Remediation Company, Richland, Washington, August 10.

CHPRC-1105426, 2011, "Quarterly Discharge Monitoring Reports for the 200 Area Effluent Treatment and Treated Effluent Disposal Facilities Covering the July 2011 Through September 2011 Reporting Period," (letter to S.L. Nichols, Washington State Department of Ecology, from M.R. Kembel),CH2M HILL Plateau Remediation Company, Richland, Washington, pending.

CP-47631, 2011, *Model Package Report: Central Plateau Groundwater Model Version 3.3*, Rev. 0, CH2M HILL Plateau Remediation Company, Richland, Washington.

DOE/RL-96-61, 1997, *Hanford Site Background: Part 3, Groundwater Background*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://www5.hanford.gov/arpir/?content=findpage&AKey=D197226378.

DOE/RL-2008-56, 2009, *200-West Area Pre-Conceptual Design for Final Extraction/Injection Well Network: Modeling Analyses*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-2008-66, 2009, *Hanford Site Groundwater Monitoring for Fiscal Year 2008*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://www2.hanford.gov/arpir/?content=findpage&AKey=0905131281. http://www2.hanford.gov/arpir/?content=findpage&AKey=0905131282.

DOE/RL-2009-18, 2009, 2009 *Evaluation of Tritium Removal and Mitigation Technologies for Wastewater Treatment*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://www5.hanford.gov/arpir/?content=findpage&AKey=0904011630.

DOE/RL-2009-38, 2009, *Description of Modeling Analyses in Support of the 200-ZP-1 Remedial Design/Remedial Action Work Plan*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://www5.hanford.gov/arpir/?content=findpage&AKey=0095363.

DOE/RL-2009-68, 2010, *Interim Status Groundwater Monitoring Plan for the LLBG WMA-3*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://www2.hanford.gov/arpir/index.cfm?content=findpage&AKey=1103070711

DOE/RL-2011-01, 2011, *Hanford Site Groundwater Monitoring Report for 2010*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://www.hanford.gov/c.cfm/sgrp/GWRep10/start.htm

ECF-HANFORD-10-0371, 2010, *Central Plateau Version 3 MODFLOW Model*, Rev. 0, CH2M HILL Plateau Remediation Company, Richland, Washington. Available at: http://www2.hanford.gov/arpir/?content=findpage&AKey=0084305.

Ecology, 2000, *State Waste Discharge Permit Number ST 4500*, Washington State Department of Ecology, Kennewick, Washington. Available at: http://www.ecy.wa.gov/programs/nwp/pdf/4500dp.pdf.

Karanovic, M., M. Tonkin, and D. Wilson, 2009, "KT3D_H2O: A Program for Kriging Water Level Data Using Hydrologic Drift Terms," *Ground Water* 47(4):580-586.

PNNL-11633, 1997, *Origin of Increased Sulfate in Groundwater at the ETF Disposal Site*, Pacific Northwest National Laboratory, Richland, Washington. Available at: http://www.osti.gov/energycitations/servlets/purl/548888-AscOkj/webviewable/548888.pdf.

PNNL-11665, 1997, *Tritium Monitoring in Groundwater and Evaluation of Model Predictions for the Hanford Site 200 Area Effluent Treatment Facility*, Pacific Northwest National Laboratory, Richland, Washington. Available at: http://www.osti.gov/energycitations/servlets/purl/554804-aEgmwz/webviewable/554804.pdf.

PNNL-13121, 2000, *Groundwater Monitoring and Tritium-Tracking Plan for the 200 Area State-Approved Land Disposal Site*, Pacific Northwest National Laboratory, Richland, Washington. Available at: http://www.pnl.gov/main/publications/external/technical_reports/PNNL-13121.pdf.

SGW-38802, 2008, *Results of Tritium Tracking and Groundwater Monitoring at the Hanford Site 200 Area State-Approved Land Disposal Site Fiscal Year 2008*, Rev. 0, CH2M HILL Plateau Remediation Company, Richland, Washington. Available at: http://www.osti.gov/bridge/servlets/purl/943300-AbQLVi/.

SGW-47923, 2010, *Results of Tritium Tracking and Groundwater Monitoring at the Hanford Site 200 Area State-Approved Land Disposal Site, Fiscal Year 2010*, Rev. 0, CH2M HILL Plateau Remediation Company, Richland, Washington. Available at: http://www5.hanford.gov/arpir/?content=findpage&AKey=1011190085.

SGW-50390, 2011, *FY 2011 Simulation-Optimization of the 200-ZP-1 Remedy Using the Central Plateau Model*, Rev. 0, CH2M HILL Plateau Remediation Company, Richland, Washington.

SGW-50907, 2011, *Predicted Impact of Future Water-Level Declines on Groundwater Well Longevity within the 200 West Area, Hanford Site*, Rev. 0, CH2M HILL Plateau Remediation Company, Richland, Washington.

Appendix A

State Approved Land Disposal Site Tritium Results for Fiscal Year 2011

Table A-1. State Approved Land Disposal Site Tritium Results for Fiscal Year 2011

Well	Date Sampled	2011 Tritium Analyses (pCi/L)	Lab Qualifier	2010 Tritium Maximum (pCi/L)	2011 Tritium Maximum (pCi/L)	Trend
299-W6-11	1/31/2011	2,180		2,240	2,180	Unchanged
299-W6-12	1/31/2011	242		241	242	Unchanged
299-W6-6	1/31/2011	<27.2	U	27.4	U	Decreasing
299-W7-3	1/31/2011	<27.4	U	U	U	Unchanged
	5/17/2011	<29.4	U			
299-W8-1	Dry	N/A	N/A	23.8	N/A	N/A
699-48-71	1/31/2011	1,090		890	1,300	Increasing
	7/26/2011	1,200				
	7/26/2011	1,300				
699-48-77A	12/13/2010	7,400		9,600	110,000	Increasing
	12/13/2010	7,500				
	3/1/2011	110,000				
	5/4/2011	66,000				
	8/9/2011	19,000				
699-48-77C	12/13/2010	88,000		76,000	130,000	Increasing
	3/1/2011	65,000				
	5/4/2011	130,000				
	8/10/2011	120,000				
699-48-77D	12/13/2010	150,000		180,000	160,000	Decreasing
	3/1/2011	130,000				
	5/4/2011	160,000				
	8/9/2011	110,000				
699-49-79	5/2/2011	<26.0	U	U	U	Unchanged
699-51-75	5/2/2011	<24.8	U	U	U	Unchanged
	5/26/2011	<28.7	U			
699-51-75P	6/30/2011	<26.0	U	U	U	Unchanged

Table A-1. State Approved Land Disposal Site Tritium Results for Fiscal Year 2011

Well	Date Sampled	2011 Tritium Analyses (pCi/L)	Lab Qualifier	2010 Tritium Maximum (pCi/L)	2011 Tritium Maximum (pCi/L)	Trend

Notes:

Increasing = 20% higher average concentration in FY 2011 than in FY 2010.

Decreasing = 20% lower average concentration in FY 2011 than in FY 2010.

Unchanged = FY 2011 average concentration within 20% of FY 2010 value.

FY = fiscal year

N/A = not applicable

U = less than detection

Appendix B

Groundwater Modeling and Site Analysis

Contents

Figures

Terms

CP	Central Plateau
CFEST	Coupled Fluid, Energy, and Solute Transport
FY	fiscal year
HSS	Hydrocarbon Spill Source
OU	Operable Unit
PNNL	Pacific Northwest National Laboratory
SALDS	State Approved Land Disposal Site

B1 Groundwater Modeling and Site Analysis

This appendix discusses the groundwater modeling and site analysis for the State Approved Land Disposal Site (SALDS). The Central Plateau (CP) groundwater model was used, which was originally the 200-ZP-1 Groundwater Operable Unit (OU) groundwater model described in DOE/RL-2008-56, *200-West Area Pre-Conceptual Design for Final Extraction/Injection Well Network: Modeling Analyses*, as updated during 2009 and 2010 (DOE/RL-2009-38, *Description of Modeling Analysis in Support of the 200-ZP-1 Remedial Design/Remedial Action Work Plan*; ECF-HANFORD-10-0371, *Central Plateau Version 3 MODFLOW Model*). As described in the latter two reports, the CP Model simulates conditions from the 1940s through to the present (calibration period). It is then used to simulate likely future conditions under assumed extraction and injection rates for the 200-ZP-1 groundwater pump-and-treat (P&T) remedy (SGW-47651, *Final 200-ZP-1 Pump-and-Treat Remedy: Results of FY 2010 Groundwater Flow and Contaminant Transport Simulations*; SGW-50390, *FY 2011 Simulation-Optimization of the 200-ZP-1 Remedy Using the Central Plateau Model*).

Groundwater P&T operations within the 200-ZP-1 OU are expected to overlap in time with SALDS operations, and are expected to impact groundwater flow directions and rates in the vicinity of the SALDS. Since the evaluations presented here were undertaken using the CP Model, they incorporate the effects of projected 200-ZP-1 P&T operations ("Alternative 3" as presented in SGW-50390) on groundwater flow directions and rates throughout the CP Model domain. Over time, it is expected that additional information will become available about the actual operations at 200-ZP-1, the hydrostratigraphy, and the actual (measured) response of the groundwater system to pumping at 200-ZP-1. This information will be incorporated into future revisions of the CP Model. This is expected to improve the current conceptual model and parameter distributions for this site and result in higher confidence in model projections (NUREG/CR-6805, *A Comprehensive Strategy of Hydrogeologic Modeling and Uncertainty Analysis for Nuclear Facilities and Sites*).

B2 Background

Numerical simulations of groundwater flow and contaminant transport have been conducted for the SALDS since the planning stage of the facility began in 1991. The report, *Tritium Monitoring in Groundwater and Evaluation of Model Predictions for the Hanford Site 200 Area Effluent Treatment Facility* (PNNL-11665), presents a discussion of these groundwater models and of two relevant vadose zone flow models. Early two-dimensional (2D) models (e.g., WHC-MR-0276, *Groundwater Mounding and Plume Migration Analyses for Candidate Soil Column Disposal Sites, Hanford Site, Washington*) used conservatively high values for SALDS operations and assumed steady-state conditions. Some of these conservative models predicted that tritium would reach the Columbia River in 100+ years at concentrations near the drinking water standard of 20,000 pCi/L. Later models, such as those presented in BHI-00469, *Hanford Sitewide Groundwater Remediation Strategy – Groundwater Contaminant Predictions*, considered three-dimensional (3D) flow and transport, incorporating realistic operating scenarios for the SALDS, tritium decay, and transient flow conditions. These models suggested that the tritium plume generated by the SALDS would remain within about 2 km (1.2 mi) of the facility until the plume decayed.

Until about 2006, a Hanford Sitewide groundwater flow and contaminant transport model was used to predict future conditions of the unconfined aquifer due to the cessation of Hanford Site operations (e.g., determining which monitoring wells will become dry because of declining water levels). The Sitewide groundwater flow and transport model was also used to assess the potential for contaminants to migrate from the Hanford Site via the groundwater pathway and to address site-specific

B1 Groundwater Modeling and Site Analysis

This appendix discusses the groundwater modeling and site analysis for the State Approved Land Disposal Site (SALDS). The Central Plateau (CP) groundwater model was used, which was originally the 200-ZP-1 Groundwater Operable Unit (OU) groundwater model described in DOE/RL-2008-56, *200-West Area Pre-Conceptual Design for Final Extraction/Injection Well Network: Modeling Analyses*, as updated during 2009 and 2010 (DOE/RL-2009-38, *Description of Modeling Analysis in Support of the 200-ZP-1 Remedial Design/Remedial Action Work Plan*; ECF-HANFORD-10-0371, *Central Plateau Version 3 MODFLOW Model*). As described in the latter two reports, the CP Model simulates conditions from the 1940s through to the present (calibration period). It is then used to simulate likely future conditions under assumed extraction and injection rates for the 200-ZP-1 groundwater pump-and-treat (P&T) remedy (SGW-47651, *Final 200-ZP-1 Pump-and-Treat Remedy: Results of FY 2010 Groundwater Flow and Contaminant Transport Simulations*; SGW-50390, *FY 2011 Simulation-Optimization of the 200-ZP-1 Remedy Using the Central Plateau Model*).

Groundwater P&T operations within the 200-ZP-1 OU are expected to overlap in time with SALDS operations, and are expected to impact groundwater flow directions and rates in the vicinity of the SALDS. Since the evaluations presented here were undertaken using the CP Model, they incorporate the effects of projected 200-ZP-1 P&T operations ("Alternative 3" as presented in SGW-50390) on groundwater flow directions and rates throughout the CP Model domain. Over time, it is expected that additional information will become available about the actual operations at 200-ZP-1, the hydrostratigraphy, and the actual (measured) response of the groundwater system to pumping at 200-ZP-1. This information will be incorporated into future revisions of the CP Model. This is expected to improve the current conceptual model and parameter distributions for this site and result in higher confidence in model projections (NUREG/CR-6805, *A Comprehensive Strategy of Hydrogeologic Modeling and Uncertainty Analysis for Nuclear Facilities and Sites*).

B2 Background

Numerical simulations of groundwater flow and contaminant transport have been conducted for the SALDS since the planning stage of the facility began in 1991. The report, *Tritium Monitoring in Groundwater and Evaluation of Model Predictions for the Hanford Site 200 Area Effluent Treatment Facility* (PNNL-11665), presents a discussion of these groundwater models and of two relevant vadose zone flow models. Early two-dimensional (2D) models (e.g., WHC-MR-0276, *Groundwater Mounding and Plume Migration Analyses for Candidate Soil Column Disposal Sites, Hanford Site, Washington*) used conservatively high values for SALDS operations and assumed steady-state conditions. Some of these conservative models predicted that tritium would reach the Columbia River in 100+ years at concentrations near the drinking water standard of 20,000 pCi/L. Later models, such as those presented in BHI-00469, *Hanford Sitewide Groundwater Remediation Strategy – Groundwater Contaminant Predictions*, considered three-dimensional (3D) flow and transport, incorporating realistic operating scenarios for the SALDS, tritium decay, and transient flow conditions. These models suggested that the tritium plume generated by the SALDS would remain within about 2 km (1.2 mi) of the facility until the plume decayed.

Until about 2006, a Hanford Sitewide groundwater flow and contaminant transport model was used to predict future conditions of the unconfined aquifer due to the cessation of Hanford Site operations (e.g., determining which monitoring wells will become dry because of declining water levels). The Sitewide groundwater flow and transport model was also used to assess the potential for contaminants to migrate from the Hanford Site via the groundwater pathway and to address site-specific contaminant issues (e.g., SALDS). Developed by Pacific Northwest National Laboratory (PNNL), that model was based on the Coupled Fluid, Energy, and Solute Transport (CFEST) code (Gupta et al., 1987, *Coupled Fluid, Energy, and Solute Transport (CFEST) Model: Formulation and User's Manual*). Using that model, transient simulations were performed for the period of 1980 through 2100. The SALDS was assumed to receive effluent containing tritium from 1996 through 2025 and effluent with no tritium through the year 2034. Model results were illustrated as hydraulic head distributions, lateral tritium plume extents (plumes), and vertical distribution of tritium in the vicinity of the SALDS. In 2004, the report *Results of Groundwater Modeling for Tritium Tracking at the Hanford Site 200 Area State-Approved Land Disposal Site* (PNNL-14898) presented the results of numerical simulations that were performed using the sitewide CFEST model that had been updated from the model used in PNNL-11665.

Consistent with analyses performed in 2010 (as summarized in SGW-47923, *Results of Tritium Tracking and Groundwater Monitoring at the Hanford Site 200 Area State-Approved Land Disposal Site, Fiscal Year 2010*), this report uses three complementary methods to evaluate the likely migration of tritium to build confidence in the results obtained. These analysis methods are listed below, and their applications are described in the following sections:

- **Water-level mapping and particle tracking:** This analysis provides a preliminary understanding of likely groundwater flow directions and tritium migration rates in the vicinity of the SALDS to help validate the reasonableness of the groundwater modeling results.
- **Groundwater flow modeling and particle tracking:** This analysis provides estimates of likely groundwater flow directions and tritium migration rates in the vicinity of the SALDS for comparison with the estimates obtained using the water-level mapping approach.
- **Groundwater flow and contaminant transport modeling:** This analysis provides estimates of tritium migration rates and the likely future distribution of tritium concentrations in groundwater in the vicinity of the SALDS.

The site conceptual model that underpins these analyses is based primarily upon the work reported in PNNL-14898 and DOE/RL-2008-56. Model hydrostratigraphic layering and contact elevations are largely derived from PNNL-14753, *Groundwater Data Package for Hanford Assessments*. Hydrologic and geochemical parameters are largely derived from DOE/RL-2007-28, *Feasibility Study Report for the 200-ZP-1 Groundwater Operable Unit*. However, the CP Model has been updated on the basis of studies described in ECF-HANFORD-10-0371 and in CP-47631, *Model Package Report: Central Plateau Groundwater Model Version 3.3*. These documents constitute the principle basis for the conceptual and parametric model components. To identify the approximate location that the SALDS discharge reaches the unconfined aquifer water table, a superposition analysis was completed during 2009 (SGW-42604, *Results of Tritium Tracking and Groundwater Monitoring at the Hanford Site 200 Area State-Approved Land Disposal Site Fiscal Year 2009*). This analysis is summarized below to provide a basis for the water level mapping and groundwater modeling analyses that follow.

B3 Analyses of Groundwater Flow Using Superposition

Evidence suggests that the stratified geologic sequence encountered within the vadose zone beneath the SALDS facility results in SALDS discharge water intercepting the water table at a location laterally displaced from the facility (PNNL-13121, *Groundwater Monitoring and Tritium-Tracking Plan for the 200 Area State-Approved Land Disposal Site*). Groundwater chemical analyses indicate that Well 699-48-77A (the southernmost but upgradient proximal well furthest from the SALDS) responds to discharges several months earlier than Well 699-48-77D and about two to three years earlier than Well 699-48-77C, which is screened deeper in the aquifer. The interpretation of this pattern of well response is that the carbonate-cemented horizons of the Cold Creek unit occur within the vadose zone below the base of the SALDS drain field and lead to a lateral displacement of the discharged wastewater.

To investigate the approximate location where the SALDS water discharges to the water table (and hence, the location from which particles should be tracked and where tritium-laden wastewater should be loaded in the transport model), an analysis was completed using superposition. The analysis is detailed in SGW-42604. This was accomplished using a program that calculates transient potentiometric head surfaces by superimposing drawdown and/or mounding calculated using the Theis equation (Theis, 1935, "The Relation Between the Lowering of the Piezometric Surface and the Rate and Duration of Discharge of a Well Using Ground-Water Storage") on a uniform background gradient (DOE/RL-2007-28). The analysis comprised a calibration of the inputs to the program through comparison of measured water levels with those computed using the superposition approach. In this instance, the SALDS discharge times, rates, and location, as well as the aquifer transmissivity and storage, and background hydraulic gradient were considered fixed. The program was then used to calculate changes in water levels at the location of the three proximal SALDS monitoring wells (699-48-77A, 699-48-77D, and 699-48-77C). The easting and northing coordinates of the location that the discharge water reaches the water table were estimated. The results are detailed in Appendix B of SGW-42604. The estimated "best-fit" coordinates of the discharge location are 566395.40 m east and 137979.33 m north in the State Plane, Washington South FIPS 4602 (North American Datum of 1983). These coordinates were used in the following analyses as the assumed location of discharge to the water table. The coordinates were also used as the source of particles in particle-tracking analyses and the source of contaminants in the contaminant transport analyses.

B4 Water-Level Mapping and Particle Tracking

Water-level mapping was used with particle tracking to provide an understanding of likely groundwater flow directions and tritium migration rates based on measured water levels to help validate the reasonableness of the results obtained using the groundwater model. The mapping and particle-tracking analysis was performed using the program KT3D_H2O Version 3 (Karanovic et al., 2009, *KT3D_H2O: A Program for Kriging Water Level Data Using Hydrologic Drift Terms*), which is a graphical user interface that combines various programs to generate gridded maps of water-level elevations and to compute particle paths.

Water-level maps were prepared using a technique that combines universal kriging (i.e., kriging with a trend) with trend terms that describe the change in water levels (drawdown or mounding) in response to point sinks or sources of water (SGW-42305, *Collection and Mapping of Water Levels to Assist in the Evaluation of Groundwater Pump-and-Treat Remedy Performance*). When using this approach, the spatially varying mean or underlying trend in the water levels is calculated as a summation of a background gradient with the effects of wastewater discharge at the easting and northing coordinates corresponding to the estimated location at which the discharged water reaches the unconfined aquifer (described in Section B2). Use of universal kriging serves essentially the same purpose as the de-trending applied in the groundwater superposition analysis described in Section B2 and in SGW-42604.

Water-level maps were prepared using sixteen sets of average yearly water levels, collected from 1995 through 2010, plus one set of average water levels comprising the early months of 2011. For each of these averaged water level data sets, a point-source trend term was included in the kriging at the location of the estimated SALDS effluent discharge to the water table, with a magnitude equivalent to the annual average SALDS discharge rate. Together, the ensemble of maps calculated from 1995 through 2011 describe approximate groundwater water levels and flow directions and can be considered sequential annual "snapshots" of the actual transient conditions that occurred in the field. Particle tracking on these surfaces, reflecting changing groundwater conditions over time, can illustrate approximate migration directions and rates for water and dissolved contaminants discharged to the water table. To complete the particle tracking, the movement of a parcel of water and dissolved contaminants is tracked by calculating the gradient of the water-level surface, and assuming a representative hydraulic conductivity and effective (mobile) porosity for the aquifer. Particle tracking was accomplished using a program that implements the fourth-order Runge-Kutta (RK4) integration technique (Press et al., 1996, *Numerical Recipes in Fortran 90*) to calculate particle paths within the KT3D_H2O graphical user interface (DOE/RL-2007-28; Karanovic et al., 2009).

Figure B-1 illustrates the particle paths calculated from the assumed SALDS discharge location described above. The migration of each particle was calculated for 365 days on each of the calculated water-level surfaces from 1995 through the end of 2010, and for 21 years (2010 through 2030) on the map representing 2011 conditions. Hence, using the water level mapping approach, conditions existing in 2011 are assumed to exist until 2030. The particle paths presented in Figure B-1 were calculated assuming advective transport only, while Figure B-2 presents the particle paths calculated assuming a longitudinal dispersion of 30 m (98.4 ft) and transverse dispersion of 5 m (16.4 ft), calculated using the "random-walk" method for representing Fickian dispersion (Prickett et al., 1981, *A "Random-Walk" Solute Transport Model for Selected Groundwater Quality Evaluations*; Zheng and Bennett, 2002, *Applied Contaminant Transport Modeling*). Together, the results provide approximate depictions of the likely direction and distance traveled by the tritium discharged at the SALDS.

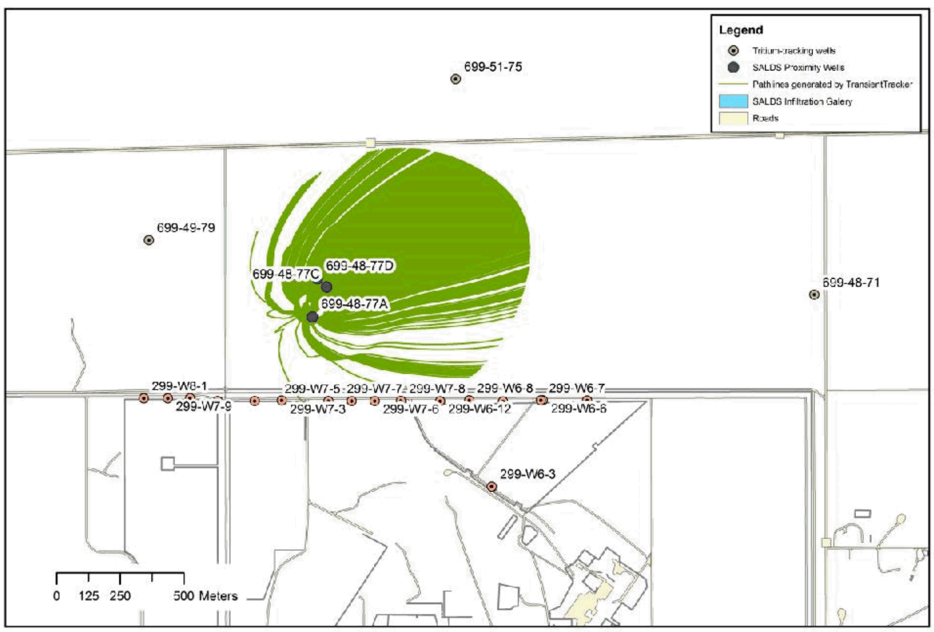


Figure B-1. Particle Traces Produced by Transient Tracker, a Utility of the KT3D-H2O Water-Level Mapping Program, Assuming Advection Only

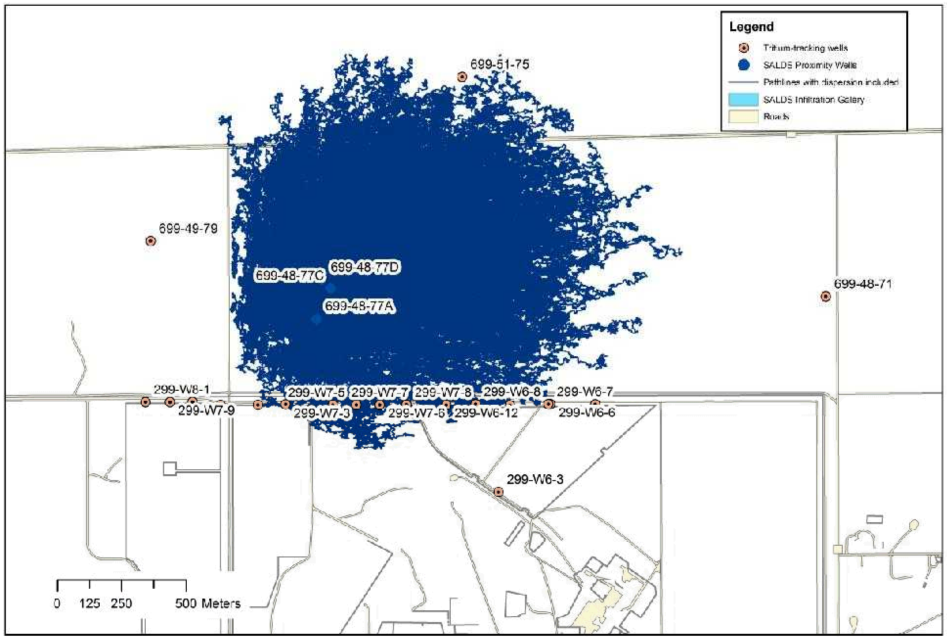


Figure B-2. Particle Traces Produced by Transient Tracker, a Utility of the KT3D-H2O Water-Level Mapping Program, Assuming Advection and Dispersion

B5 Groundwater Modeling

This section describes the use of the CP Model to provide an additional estimate of the direction and distance of tritium migration.

B5.1 Background

The CP Model, a groundwater flow and contaminant transport model developed to design and optimize the 200-ZP-1 OU groundwater P&T remedy, was used to complete additional analyses of the SALDS tritium injection. Details of the extents, discretization, and parameterization of this model can be found in several reports prepared for the 200-ZP-1 OU (DOE/RL-2008-56; DOE/RL-2009-38; SGW-47651), together with calculation briefs and associated reports that document revisions to, and calibration of, the model (ECF-HANFORD-10-0371; CP-47631). The CP Model uses the U.S. Geological Survey code, MODFLOW-2000, to simulate groundwater flow (McDonald and Harbaugh, 1988, *A Modular Three-Dimensional Finite-Difference Ground-Water Flow Model*; Harbaugh and McDonald, 1996, *User's Documentation for MODFLOW-96, an Update to the U.S. Geological Survey Modular Finite-Difference Ground-Water Flow Model*; 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*), and MODPATH to simulate particle paths (Pollock, 1994, *User's Guide for MODPATH/MODPATH-PLOT, Version 3: A Particle Tracking Post-Processing Package for MODFLOW, the U.S. Geological Survey Finite-Difference Ground-Water Flow Model*). In addition, the model uses MT3DMS to simulate contaminant migration (Zheng and Wang, 1999, *A Modular Three-Dimensional Multi-Species Transport Model for Simulation of Advection, Dispersion, and*

Chemical Reactions of Contaminants in Groundwater Systems; Documentation and User's Guide; Zheng, 2010, *MT3DMS v5.3: A Modular Three-Dimensional Multi-Species Transport Model for Simulation of Advection, Dispersion, and Chemical Reactions of Contaminants in Groundwater Systems – Supplemental User's Guide*).

The groundwater modeling analysis was completed in three steps. First, the flow model was used to simulate groundwater flow in the vicinity of the SALDS from 1995 through 2030. During this period, actual (historic) and projected annualized fluid volume discharges from the SALDS were applied at the water table at the location identified from the superposition analysis (in addition to the historic wastewater discharges at all discharge locations throughout the 200 West and 200 East Areas that were already incorporated in the model [ECF-HANFORD-10-0371]). Throughout this period, groundwater extraction and injection at the adjacent 200-ZP-1 OU was included in the flow model as described for Alternative 3 of the 2011 simulation-optimization analyses described in SGW-50390. After groundwater flow modeling was completed, the results were used to complete particle tracking and reactive transport analyses.

B5.2 Particle Tracking

Particle tracking was undertaken using MODPATH (Pollock, 1994) to estimate the likely groundwater flow directions and tritium migration rates in the vicinity of the SALDS for comparison with rates obtained using the water-level mapping technique and to provide confidence that the model reproduces patterns obtained through the mapping analysis prior to performing reactive-transport modeling.

Using the same particle starting locations, hydraulic conductivity, and mobile porosity used for the water level mapping path-line analysis, particle tracking was performed by releasing particles concentrically around the estimated discharge location and tracking their migration through to 2030. Figure B-3 presents a comparison of the advection-only particle-tracking results obtained using MODPATH and the flow field calculated by MODFLOW, with the results obtained using the RK4 particle-tracking scheme on the mapped water-level surfaces.

It is apparent from Figure B-3 that the two methods for calculating particle paths produce comparable results in terms of trajectory, distance travelled, and spread, although the particle paths calculated on the mapped surfaces travel and spread slightly farther than those calculated using MODPATH and the MODFLOW head solution. This may be due to the analytically continuous nature of the mapped surface versus the discretized nature of the MODFLOW solution, as well as the 2D nature of the mapped surface versus the 3D MODFLOW solution. Considering these structural differences in the methods, the comparison suggests that the groundwater model produces flow directions and rates that are suitable for use in reactive transport simulation of the migration and fate of the injected tritium.

B5.3 Reactive Transport Modeling

Reactive transport modeling provides estimates of tritium migration rates and the likely future distribution of tritium concentrations in groundwater in the vicinity of the SALDS.

The 3D, multi-species transport model, MT3DMS (Zheng and Wang, 1999) was developed for use with MODFLOW to simulate advection, dispersion, and chemical reactions. MT3DMS was used to evaluate the approximate directions and rates of migration of the tritium injected at the SALDS facility.
The simulations were performed using MT3DMS v5.3 (Zheng, 2010) and the CP Model flow results described above for the interval from 1995 through 2030. For all simulations, the sole source of tritium considered was the SALDS facility, and the MT3DMS reaction package was used to simulate a half-life for tritium of 12.3 years. Dispersion was not explicitly considered in the transport simulations, although

the implicit finite-difference scheme used to calculate the advection term of the transport equation may exhibit limited numerical dispersion. Two sets of transport simulations were performed, assuming effective (mobile) porosities of 0.13 and 0.18.

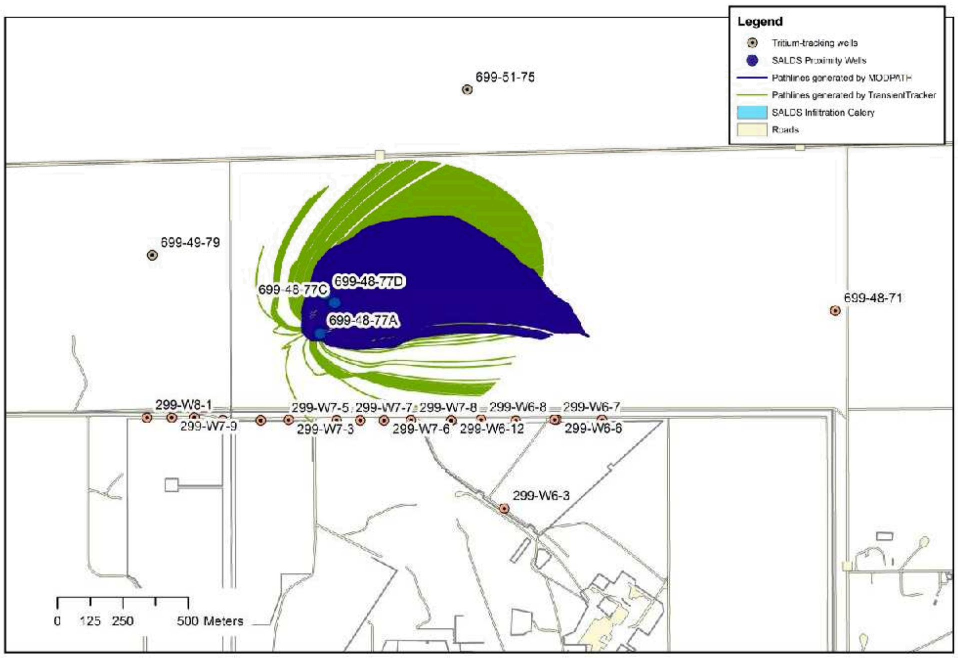


Figure B-3. Pathlines for 2030 Calculated Using the Central Plateau Model (MODPATH) and Water Level Mapping (Transient-Tracker)

For the historic period, the fluid volume discharge to the SALDS was applied in the MODFLOW model using annual stress periods, resulting in annual average discharge volumes – with the exception of years 2010 and 2011 for which monthly volumes were applied. The tritium discharged to the subsurface was simulated as a monthly averaged activity using the Hydrocarbon Spill Source (HSS) package developed for MT3DMS v5.3, which enables implicit loading of mass directly into the model on an arbitrary time interval (Zheng, 2009, "Recent Developments and Future Directions for MT3DMS and Related Transport Codes;" Zheng et al., 2010, *MT3DMS, A Modular Three-Dimensional Multispecies Transport Model – User Guide to the Hydrocarbon Spill Source (HSS) Package*). This combination of annual averaged flows and monthly averaged tritium activities preserves the total mass (activity) discharged, and reflects variations in tritium loading that persisted for relatively long periods of time (i.e., exceeding one month). As a result, the simulation results would be expected to match broad (longer term) changes in concentrations measured at monitoring wells but would not reflect localized (shorter term) changes in concentrations. For future time frames, both the fluid volume discharge and tritium mass (activity) released were simulated as annual average values based upon projections provided by CH2M HILL Plateau Remediation Company. Two sets of results are presented as output from this simulation:

- Graphs of calculated tritium versus time under historic conditions, for which tritium loading at the SALDS is known and tritium concentrations are available at monitoring wells
- Maps of calculated tritium distribution in groundwater under future conditions, assuming projected tritium loading rates at the SALDS

Figures B-4 through B-6 present measured and simulated tritium activities for Wells 699-48-77A, 699-48-77C, and 699-48-77D, respectively, from the startup of SALDS discharges through 2010. These figures suggest that the flow and transport model reasonably reproduces the pattern of changes in tritium concentration at these proximal SALDS monitoring wells, reflecting the broader (longer term) concentration patterns and the timing of arrival and departure of major peaks (with the possible exception of well 699-48-77A). Differences in the simulated tritium at these wells from that presented in SGW-42604 reflect the effect of calibration and re-parameterization of the CP Model during 2010, as described in ECF-HANFORD-10-0371 and CP-47631, which was focused on broader aspects of the 200 West Area flow system and not on the SALDS facility specifically. As expected, due to the method used for loading the fluid discharge to MODFLOW (annual average) and the discretization of the flow domain (100 m [328 ft] cell dimensions), the model does not reproduce relatively short-duration changes in tritium concentration. However, since the model reflects the broad patterns without explicit calibration, and the projected fluid and tritium discharge rates are annual averages, the model provides a suitable tool for making annual-averaged projections of the future disposition of tritium in the subsurface from the SALDS.

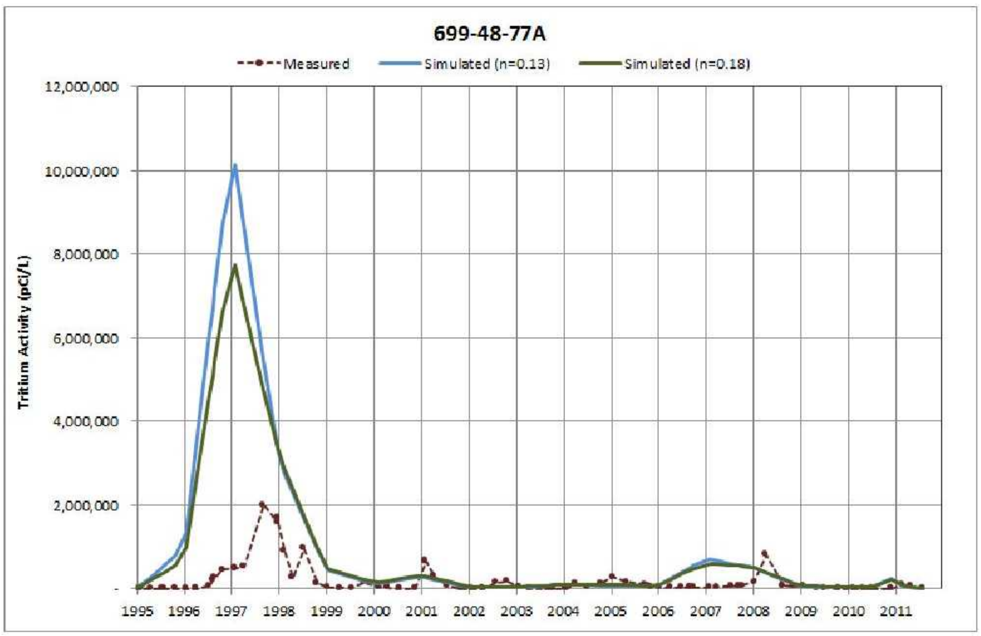


Figure B-4. Simulated and Modeled Tritium Activities for Well 699-48-77A

Figures B-7 through B-13 present the simulated tritium distribution in groundwater (model layer 2 as described in ECF-HANFORD-10-0371) at five-year intervals from 2000 through 2030, as a result of SALDS operations. Each figure presents two simulated plumes calculated assuming effective (mobile) porosities of 0.13 and 0.18. The results of these simulations are generally consistent with those presented in previous reports (e.g., PNNL-14898) in terms of size, orientation, and concentration pattern of tritium in the water table aquifer. Again, differences in the simulated disposition of tritium in groundwater from that presented in SGW-42604 and SGW-47923 largely reflect the effect of calibration and reparameterization of the CP Model during 2010, as described in ECF-HANFORD-10-0371 and CP-47631. However, some portion of the differences may be attributable to the different 200-ZP-1 pumping scheme used for this model update compared to that assumed in SGW-42604 (the FY 2009 annual report) and SGW-47923 (the FY 2010 annual report).

In SGW-47923, groundwater extraction and injection at the 200-ZP-1 groundwater remedy was assumed to be uniform (i.e., extraction wells recovering water at equivalent rates, and injection wells injecting water at equivalent rates). However, the extraction and injection rates used for the model update in this report represent the result of a simulation-optimization evaluation for remedy Alternative 3, as detailed in SGW-50390. In that simulation, an optimization algorithm was used in an effort to identify groundwater extraction and injection rates that increase the mass of carbon tetrachloride that is recovered by the 200-ZP-1 remedy. The extraction and injection rates used for the FY 2010 and FY 2011 model updates are graphically depicted in Figure B-14, along with the simulated tritium plumes for year 2030. This figure illustrates that the 200-ZP-1 extraction and injection rates used in the FY 2011 analysis place greater emphasis on extraction to the southeast of the SALDS facility (as opposed to extraction that is uniform as in the FY 2010 analysis). This different emphasis in pumping appears to contribute to a more southerly migration of the SALDS tritium plume in later years. It should be noted, however, that the 200-ZP-1 extraction and injection rates used in both the FY 2010 and FY 2011 model updates are, at this time, conjecture based upon current knowledge of the individual well and total system capacity of the 200-ZP-1 remedy. As such, actual rates are expected to differ from those presented in either the FY 2010 or FY 2011 model updates.

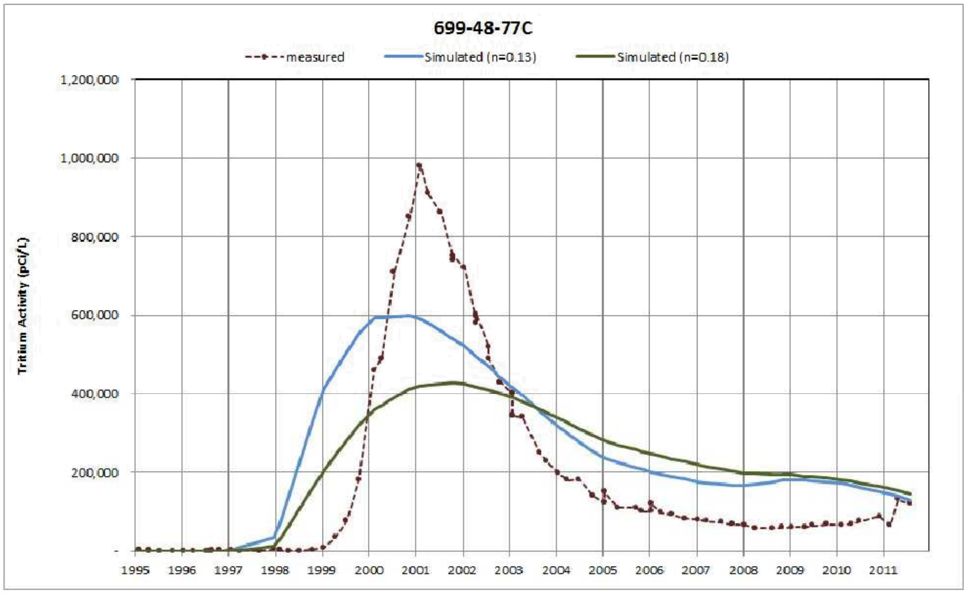


Figure B-5. Simulated and Modeled Tritium Activities for Well 699-48-77C

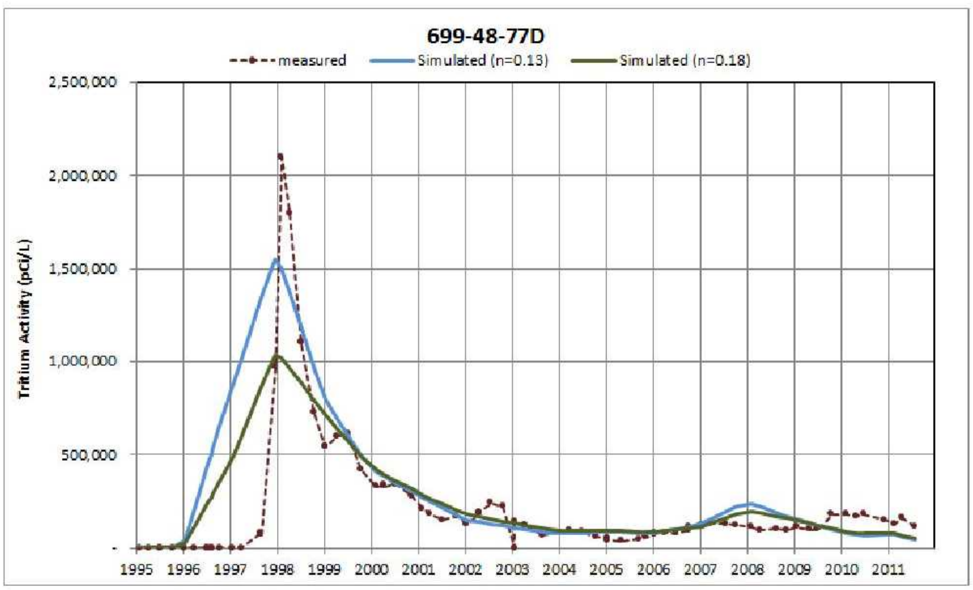


Figure B-6. Simulated and Modeled Tritium Activities for Well 699-48-77D

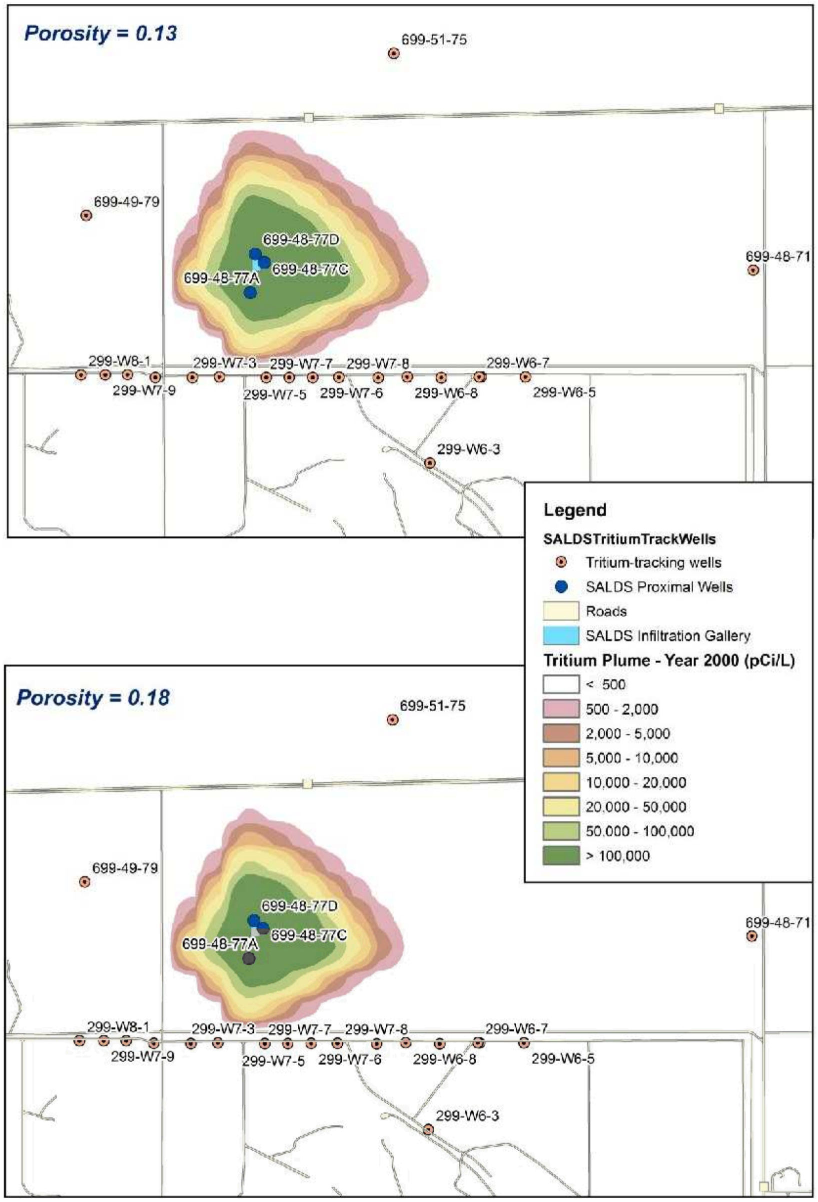


Figure B-7. Simulated Tritium Distribution as a Result of State Approved Land Disposal Site Operation in Year 2000

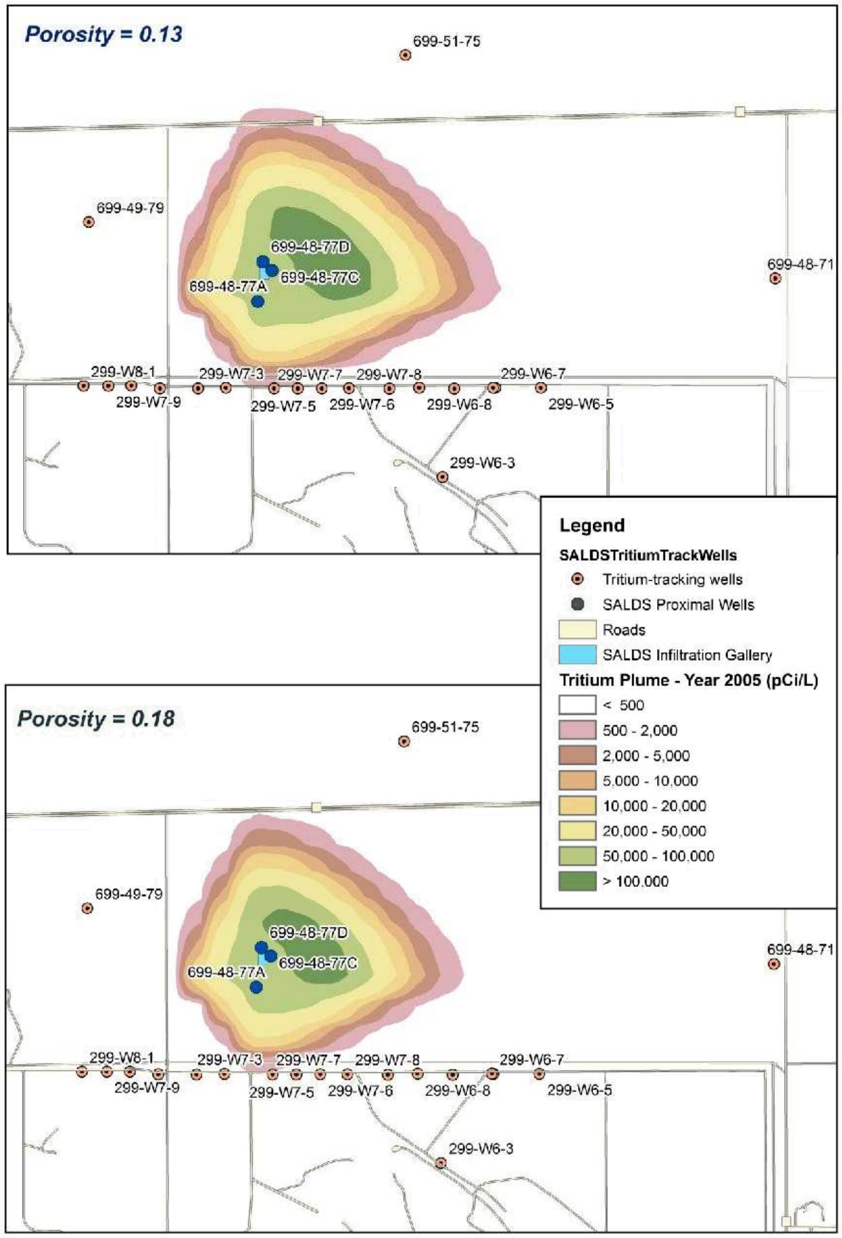


Figure B-8. Simulated Tritium Distribution as a Result of State Approved Land Disposal Site Operation in Year 2005

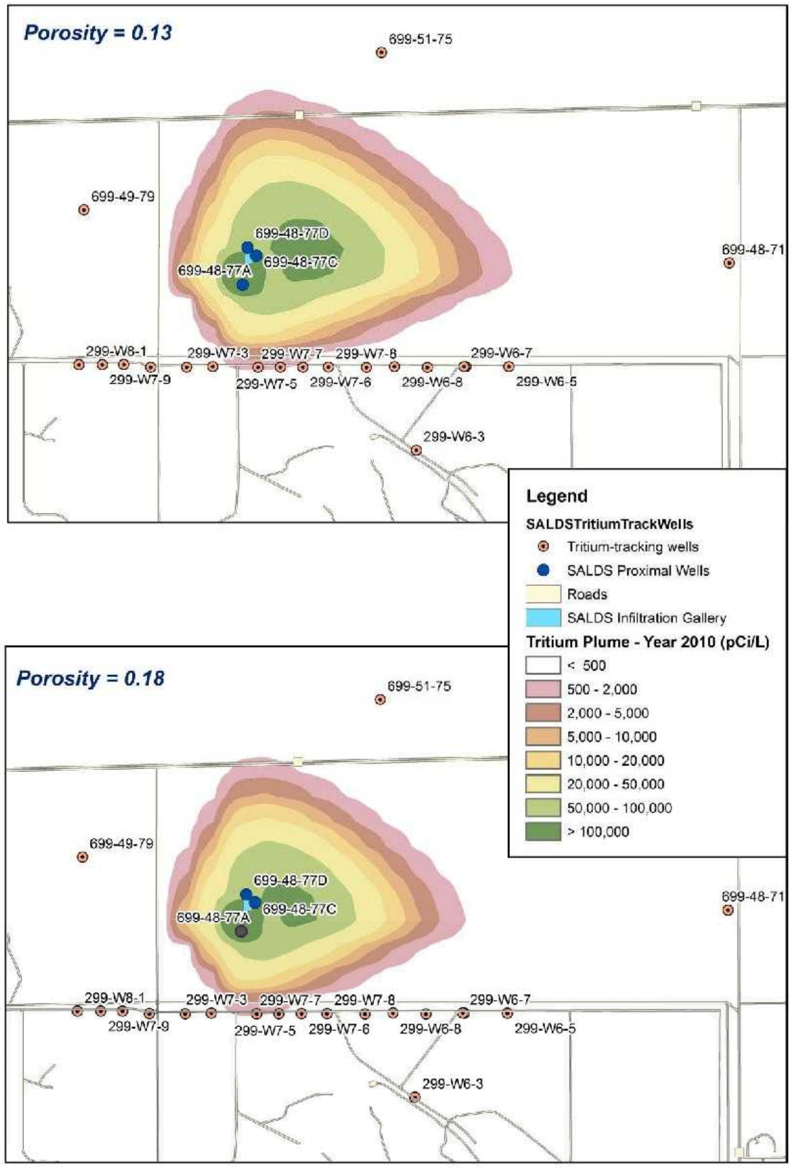


Figure B-9. Simulated Tritium Distribution as a Result of State Approved Land Disposal Site Operation in Year 2010

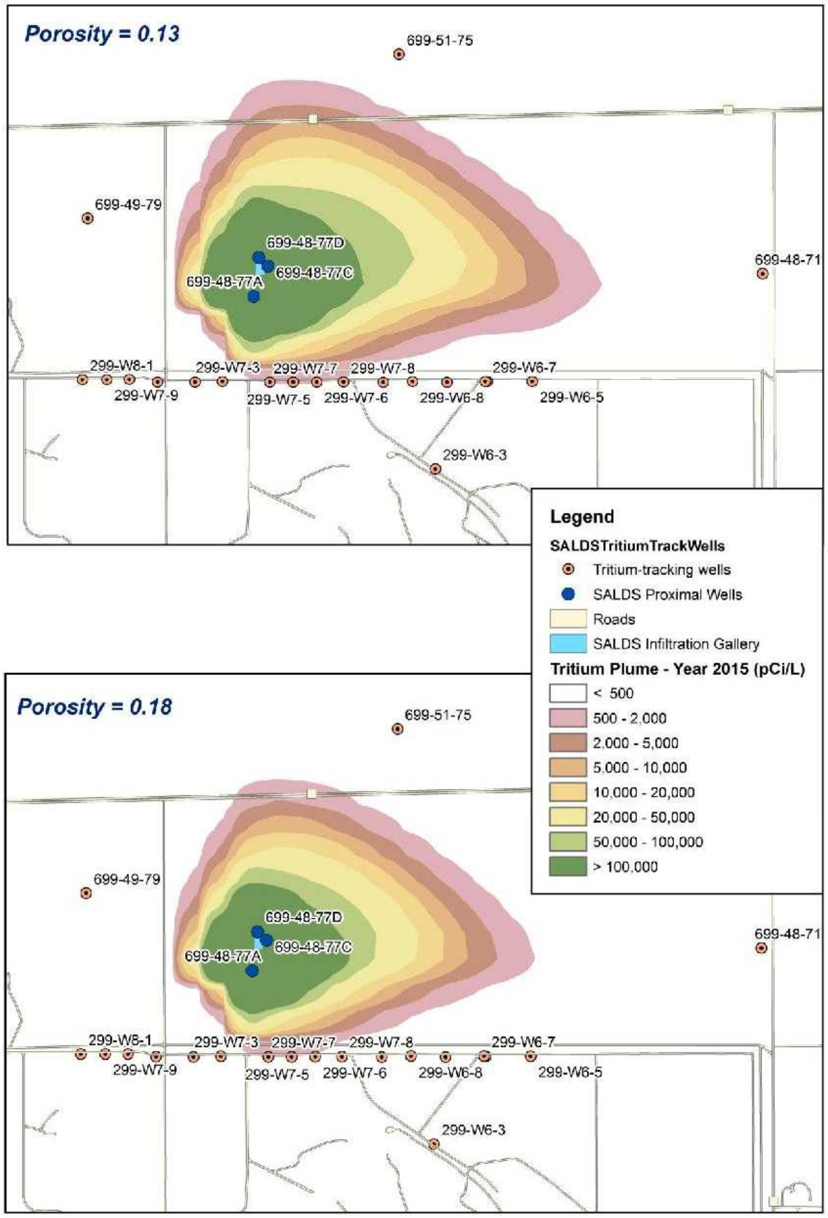


Figure B-10. Simulated Tritium Distribution as a Result of State Approved Land Disposal Site Operation in Year 2015

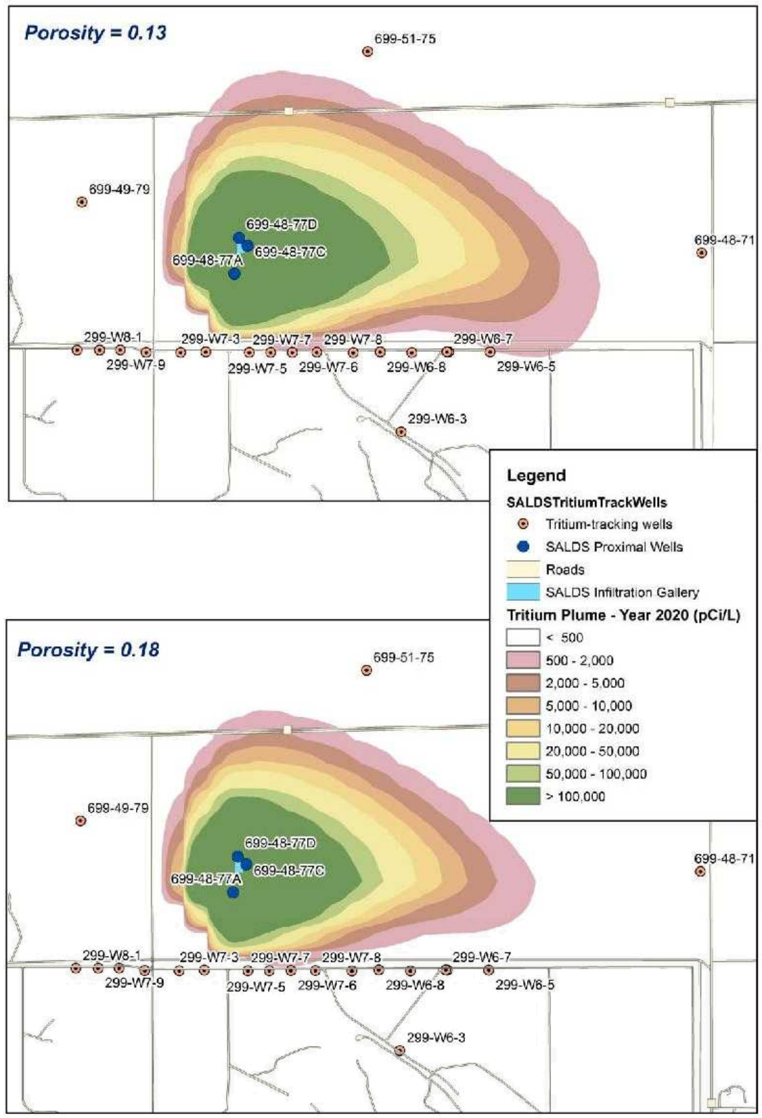


Figure B-11. Simulated Tritium Distribution as a Result of State Approved Land Disposal Site Operation in Year 2020

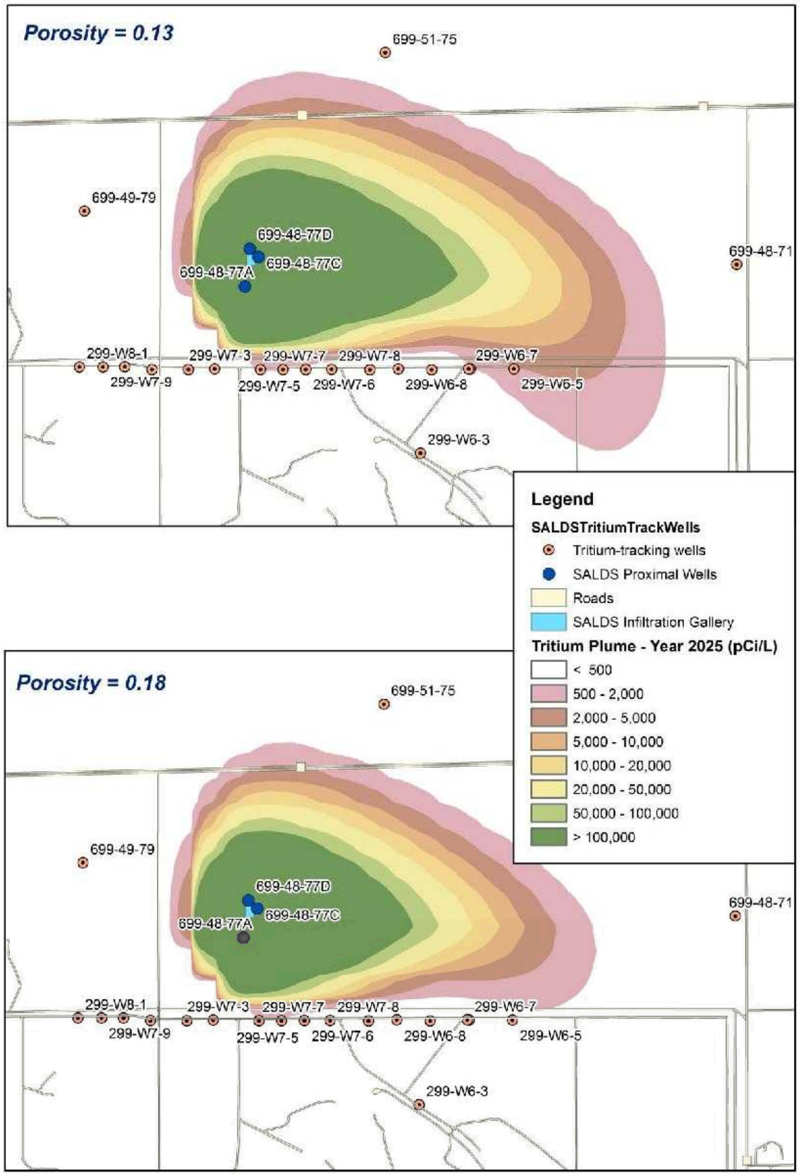


Figure B-12. Simulated Tritium Distribution as a Result of State Approved Land Disposal Site Operation in Year 2025

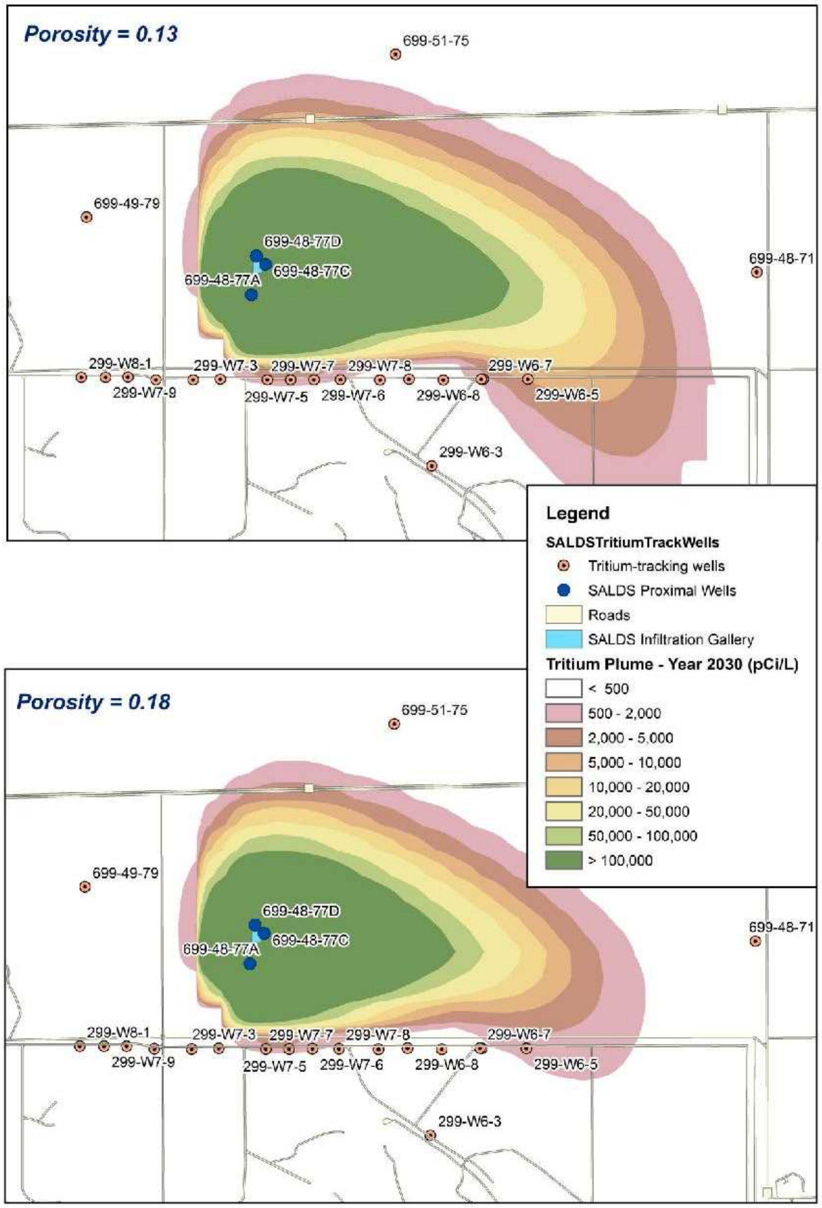


Figure B-13. Simulated Tritium Distribution as a Result of State Approved Land Disposal Site Operation in Year 2030

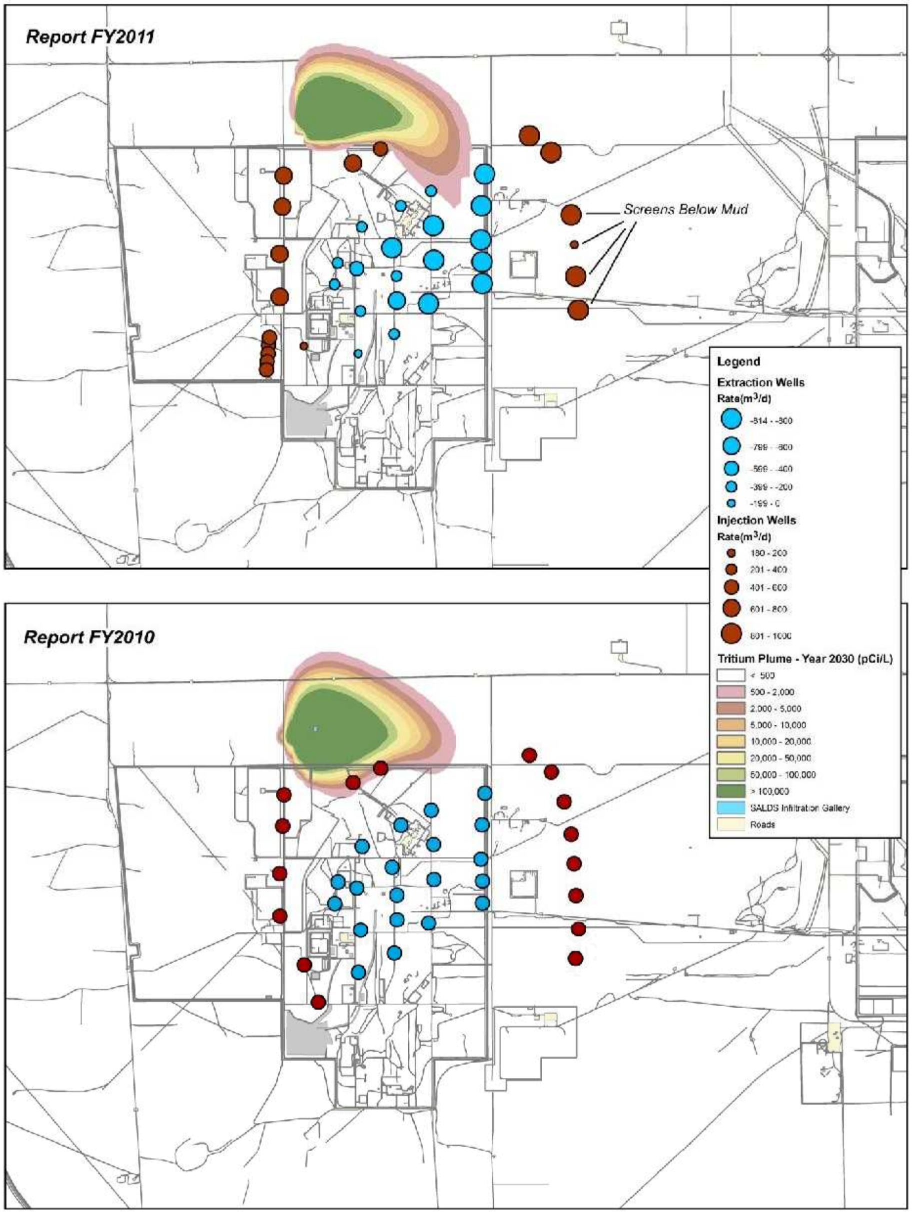


Figure B-14. Comparison of the FY 2010 and FY 2011 Model Update Results for Year 2030

B6 References

BHI-00469, 1996, *Hanford Sitewide Groundwater Remediation Strategy – Groundwater Contaminant Predictions*, Rev. 1, Bechtel Hanford, Inc., Richland, Washington. Available at: http://www5.hanford.gov/arpir/?content=findpage&AKey=D197301490.

CP-47631, 2011, *Model Package Report: Central Plateau Groundwater Model Version 3.3*, Rev. 0, CH2M HILL Plateau Remediation Company, Richland, Washington.

DOE/RL-2007-28, 2008, *Feasibility Study Report for the 200-ZP-1 Groundwater Operable Unit*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington. http://www5.hanford.gov/arpir/?content=findpage&AKey=0808050315, http://www5.hanford.gov/arpir/?content=findpage&AKey=00098828.

DOE/RL-2008-56, 2009, *200-West Area Pre-Conceptual Design for Final Extraction/Injection Well Network and Modeling Analyses*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-2009-38, 2009, *Description of Modeling Analyses in Support of the 200-ZP-1 Remedial Design/Remedial Action Work Plan*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://www5.hanford.gov/arpir/?content=findpage&AKey=0095363.

ECF-HANFORD-10-0371, 2010, *Central Plateau Version 3 MODFLOW Model*, Rev. 0, CH2M HILL Plateau Remediation Company, Richland, Washington. Available at: http://www5.hanford.gov/arpir/?content=findpage&AKey=0084305.

Gupta, S.K., C.R. Cole, C.T. Kincaid, and A.M. Monti, 1987, *Coupled Fluid, Energy, and Solute Transport (CFEST) Model: Formulation and User's Manual*, Report BMI/ONWI 660, Battelle Memorial Institute, Columbus, Ohio.

Harbaugh, A.W. and M.G. McDonald, 1996, *User's Documentation for MODFLOW-96, an Update to the U.S. Geological Survey Modular Finite-Difference Ground-Water Flow Model*, Open-File Report 96-485, U.S. Geological Survey, Reston, Virginia. Available at: http://water.usgs.gov/software/MODFLOW/code/doc/ofr96485.pdf.

Harbaugh, A.W., E.R. Banta, M.C. Hill, and M.G. McDonald, 2000, *MODFLOW-2000, the U.S. Geological Survey Modular Ground-Water Model – User Guide to Modularization Concepts and the Ground-Water Flow Process*, Open-File Report 00-92, U.S. Geological Survey, Reston, Virginia. Available at: http://pubs.er.usgs.gov/usgspubs/ofr/ofr200092.

Karanovic, M., M. Tonkin, and D. Wilson, 2009, "KT3D_H2O: A Program for Kriging Water Level Data Using Hydrologic Drift Terms," *Ground Water* 47(4):580-586.

McDonald, Michael G. and Arlen W. Harbaugh, 1988, "A Modular Three-Dimensional Finite-Difference Ground-Water Flow Model," *Techniques of Water-Resources Investigations*, Book 6, Chapter A1, U.S. Geological Survey, Reston, Virginia. Available at: http://pubs.usgs.gov/twri/twri6a1/.

NUREG/CR-6805, 2003, *A Comprehensive Strategy of Hydrogeologic Modeling and Uncertainty Analysis for Nuclear Facilities and Sites*, Office of Nuclear Regulatory Research, U.S. Nuclear Regulatory Commission, Washington, D.C. Available at: http://www.nrc.gov/reading-rm/doc-collections/nuregs/contract/cr6805/cr6805.pdf.

PNNL-11665, 1997, *Tritium Monitoring in Groundwater and Evaluation of Model Predictions for the Hanford Site 200 Area Effluent Treatment Facility*, Pacific Northwest National Laboratory, Richland, Washington. Available at: http://www.osti.gov/energycitations/servlets/purl/554804-aEgmwz/webviewable/554804.pdf.

PNNL-13121, 2000, *Groundwater Monitoring and Tritium-Tracking Plan for the 200 Area State-Approved Land Disposal Site*, Pacific Northwest National Laboratory, Richland, Washington. Available at: http://www.pnl.gov/main/publications/external/technical_reports/PNNL-13121.pdf.

PNNL-14753, 2006, *Groundwater Data Package for Hanford Assessments*, Rev. 1, Pacific Northwest National Laboratory, Richland, Washington. Available at: http://www.pnl.gov/main/publications/external/technical_reports/PNNL-14753Rev1.pdf.

PNNL-14898, 2004, *Results of Groundwater Modeling for Tritium Tracking at the Hanford Site 200 Area State-Approved Land Disposal Site – 2004*, Rev. 0, Pacific Northwest National Laboratory, Richland, Washington. Available at: http://www.pnl.gov/main/publications/external/technical_reports/PNNL-14898.pdf.

Pollock, D.W., 1994, *User's Guide for MODPATH/MODPATH-PLOT, Version 3: A Particle Tracking Post-Processing Package for MODFLOW, the U.S. Geological Survey Finite-Difference Ground-Water Flow Model*, Open-File Report 94-464, U.S. Geological Survey, Reston, Virginia. Available at: http://www.geo.wvu.edu/~donovan/ftp/modpath.pdf.

Press, W.H., S.A. Teukolsky, W.T. Vetterling, and B.P. Flannery, 1996, *Numerical Recipes in Fortran 90*, Vol. 2, 2nd Edition, Cambridge University Press, Cambridge, New York. Available at: http://apps.nrbook.com/fortran/index.html.

Prickett, T.A., T.G. Naymik, and C.G. Lonnquist, 1981, *A "Random-Walk" Solute Transport Model for Selected Groundwater Quality Evaluations*, Illinois State Water Survey Bulletin 65, Champaign, Illinois. Available at: http://www.isws.illinois.edu/pubdoc/B/ISWSB-65.pdf.

SGW-42305, 2009, *Collection and Mapping of Water Levels to Assist in the Evaluation of Groundwater Pump-and-Treat Remedy Performance*, Rev. 0, CH2M HILL Plateau Remediation Company, Richland, Washington. Available at: http://www5.hanford.gov/arpir/index.cfm?content=findpage&AKey=1001210169.

SGW-42604, 2009, *Results of Tritium Tracking and Groundwater Monitoring at the Hanford Site 200 Area State-Approved Land Disposal Site Fiscal Year 2009*, Rev. 0, CH2M HILL Plateau Remediation Company, Richland, Washington.

SGW-47651, 2010, *Final 200-ZP-1 Pump-and-Treat Remedy: Results of FY 2010 Groundwater Flow and Contaminant Transport Simulations*, Rev. 0, CH2M HILL Plateau Remediation Company, Richland, Washington.

SGW-47923, 2010, *Results of Tritium Tracking and Groundwater Monitoring at the Hanford Site 200 Area State-Approved Land Disposal Site, Fiscal Year 2010*, Rev. 0, CH2M HILL Plateau Remediation Company, Richland, Washington. Available at: http://www5.hanford.gov/arpir/?content=findpage&AKey=1011190085.

SGW-50390, 2011, *FY 2011 Simulation-Optimization of the 200-ZP-1 Remedy Using the Central Plateau Model*, Rev. 0, CH2M HILL Plateau Remediation Company, Richland, Washington. Theis, C. V., 1935, "The Relation Between the Lowering of the Piezometric Surface and the Rate and Duration of Discharge of a Well Using Ground-Water Storage," *American Geophysical Union Transactions*, 16(2):519-524.

WHC-MR-0276, 1991, *Groundwater Mounding and Plume Migration Analyses for Candidate Soil Column Disposal Sites, Hanford Site, Washington*, Westinghouse Hanford Company, Richland, Washington. Available at: http://www5.hanford.gov/pdw/fsd/AR/FSD0001/FSD0057/E0016415/0016415%20-%20%5B1007140240%5D.PDF.

Zheng, Chunmiao, 2009, "Recent Developments and Future Directions for MT3DMS and Related Transport Codes," *Ground Water* 47(5):620-625. Available at: http://hydro.geo.ua.edu/mt3d/MT3DMS_dev_2009.pdf.

Zheng, Chunmiao, 2010, *MT3DMS v5.3: A Modular Three-Dimensional Multi-Species Transport Model for Simulation of Advection, Dispersion, and Chemical Reactions of Contaminants in Groundwater Systems – Supplemental User's Guide*, Department of Geological Sciences, University of Alabama, Tuscaloosa, Alabama. Available at: http://hydro.geo.ua.edu/mt3d/mt3dms_v5_supplemental.pdf.

Zheng, Chunmiao and Gordon D. Bennett, 2002, *Applied Contaminant Transport Modeling*, Second Edition, John Wiley & Sons, New York, New York.

Zheng, Chunmiao and Patrick P. Wang, 1999, *MT3DMS: A Modular Three-Dimensional Multi-Species Transport Model for Simulation of Advection, Dispersion, and Chemical Reactions of Contaminants in Groundwater Systems; Documentation and User's Guide*, Contract Report SERDP-99-1, U.S. Army Engineer Research and Development Center, U.S. Army Corps of Engineers, Vicksburg, Mississippi. Available at: http://hydro.geo.ua.edu/mt3d/mt3dmanual.pdf.

Zheng, Chunmiao, Jim Weaver, and Matt Tonkin, 2010, *MT3DMS, A Modular Three-Dimensional Multispecies Transport Model – User Guide to the Hydrocarbon Spill Source (HSS) Package*, prepared for the U.S. Environmental Protection Agency. Available at: http://hydro.geo.ua.edu/mt3d/HSS_Package_2010.pdf.

Appendix C

Software

Contents

Terms

CHPRC	CH2M HILL Plateau Remediation Company
HSU	hydrostratigraphic unit
MNW	multi-node well
WEL	well package

Software

This appendix describes the software used for the update to the numerical groundwater flow and transport model of the tritium plume.

C1 Approved Software

Software was used to perform the model update calculations that are managed under the following 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 Acceptance Test Report*
- CHPRC-00261, *MODFLOW and Related Codes Requirements Traceability Matrix*

CHPRC-00258 distinguishes between safety software and support software based on whether the software managed calculates reportable results or provides run support, visualization, or other similar functions. The following sections provide brief descriptions of the software.

C1.1 MODFLOW (Controlled Calculation Software)

- **Software title:** MODFLOW-2000 (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*); solves transient groundwater flow equations using the finite-difference discretization technique
- **Software version:** Version 1.19.01, modified by S.S. Papadopulos and Associates, Inc., for minimum saturated thickness and using the Orthomin solver; approved as CH2M HILL Plateau Remediation Company (CHPRC) Build 0004 using executable "mf2k-mst-0004dp" (compiled to default double precision for real variables)
- **Hanford Information Systems Inventory identification number:** 2517 (safety software, graded Level C)
- **Workstation type and property number (from which software is run):** S.S. Papadopulos and Associates, Inc., PC #FE404

C1.2 MT3DMS (Controlled Calculation Software)

- **Software title:** MT3DMS (Zheng and Wang, 1999, *MT3DMS, A Modular Three-Dimensional Multi-Species Transport Model for Simulation of Advection, Dispersion, and Chemical Reactions of Contaminants in Groundwater Systems; Documentation and User's Guide*; Zheng, 2010, *MT3DMS v5.3: A Modular Three-Dimensional Multi-Species Transport Model for Simulation of Advection, Dispersion, and Chemical Reactions of Contaminants in Groundwater Systems – Supplemental User's Guide*)
- **Software version:** Version 5.3, modified by S.S. Papadopulos and Associates, Inc., for minimum saturated thickness; approved as CHPRC Build 0004 using executable "mt3d-mst-0004dp" (compiled to default double precision for real variables)

- **Hanford Information Systems Inventory identification number:** 2518 (safety software, graded Level C)
- **Workstation type and property number (from which software is run):** S.S. Papadopulos and Associates, Inc., PC #FE404

C1.3 MODPATH

- **Software title:** MODPATH (OFR 94-464, *User's Guide for MODPATH/MODPATH-PLOT, Version 3: A Particle Tracking Post-Processing Package for MODFLOW, the U.S. Geological Survey Finite-Difference Ground-Water Flow Model*). A particle-tracking post-processor developed for use with the MODFLOW codes; was used to evaluate the approximate directions and rates of groundwater flow
- **Software version:** Version 5.0 modified by S.S. Papadopulos and Associates, Inc., for minimum saturated thickness; approved as CHPRC Build 0004 using executable "modpath-mst-0004sp.exe"
- **Workstation type and property number (from which software is run):** S.S. Papadopulos and Associates, Inc., PC #FE404

C1.4 KT3D_H2O

- The KT3D-H20 software is listed in the Hanford Information Systems Inventory under entries #2832 and #2833 (identical entries). This software was not classified as safety software. It was graded "N/A" based on negative responses to all software grading checklist questions. Consequently, there are no controlled use requirements pertaining to this software.
- The KT3D-H20 software was used consistent with its intended use as identified in Karanovic et al., 2009, *KT3D_H20: A Program for Kriging Water Level Data Using Hydrologic Drift Terms* and in SGW-42305, 2009, *Collection and Mapping of Water Levels to Assist in the Evaluation of Groundwater P&T Remedy Performance* and is a valid use of this software for the problem addressed in this calculation.

C1.5 Support Software

Support software was used that has been identified in CHPRC-00258, Rev. 1, or is scheduled by the software owner to be included as support software in the next revision to that document. Software with a trademark designation is commercial software. Software listed without a trademark has been developed internally.

- **ALLOCATEQWELL:** Constructs a MODFLOW well package (WEL) or a multi-node well (MNW) package file.
- **READ-LST-BUDGET:** Tabulates volumetric budget terms for the MODFLOW simulation.
- **READ-MT3D-OUT-BUDGET:** Tabulates mass budget terms for the MT3DMS simulation.
- **HEADTARG_D:** Retrieves and interpolates simulated heads allowing for dry model cells. It is used for model calibration. Performs linear interpolation between model nodes to the coordinates of the monitoring location, and includes options to "hunt" down through dry layers for the water table.
- **CONCTARG:** Retrieves and interpolates simulated concentration. Performs linear interpolation between model nodes to the coordinates of the monitoring location.

- **Groundwater Vistas™:** (*Guide to Using Groundwater Vistas* [Rumbaugh and Rumbaugh, 2007].) Translated well pumping data from spreadsheet HistoricWells.csv to WEL file. It also provided graphical tools used for model quality assurance.
- **ArcGIS™:** (*The ESRI Guide to GIS Analysis, Volume 1: Geographic Patterns and Relationships* [Mitchell, 1999].) Provided visualization tool for assessing validity of interpolated hydrostratigraphic unit (HSU) surfaces and HSU extents. Used to locate visual placement of control points to constrain the HSU surfaces as explained in Section 5.1.

C2 Software Installation and Checkout

Safety software (CHPRC Build 0004 of MODFLOW-2000-SSPA) is checked out in accordance with procedures specified in CHPRC-00258, Rev. 2. Executables are obtained from the CHPRC software owner who maintains the configuration managed copies in MKS Integrity™, installation tests identified in CHPRC-00259, Rev. 1, performed and successful installation confirmed, and Software Installation and Checkout Forms are required and must be approved for installations used to perform model runs. Approved users are registered in HISI for safety software.

The software identified above was used consistent with intended use for CHPRC as identified in CHPRC-00257, Rev. 1, and is a valid use of this software for the problem addressed in this application. The software was used within its limitations as identified in CHPRC-00257, Rev. 1.

C3 References

CHPRC-00257, 2010, *MODFLOW and Related Codes Functional Requirements Document*, Rev. 1, CH2M HILL Plateau Remediation Company, Richland, Washington.

CHPRC-00258, 2010, *MODFLOW and Related Codes Software Management Plan*, Rev. 2, CH2M HILL Plateau Remediation Company, Richland, Washington.

CHPRC-00259, 2010, *MODFLOW and Related Codes Software Test Plan*, Rev. 1, CH2M HILL Plateau Remediation Company, Richland, Washington.

CHPRC-00260, 2010, *MODFLOW and Related Codes Acceptance Test Report*, Rev. 2, CH2M HILL Plateau Remediation Company, Richland, Washington.

CHPRC-00261, 2010, *MODFLOW and Related Codes Requirements Traceability Matrix*, Rev. 2, CH2M HILL Plateau Remediation Company, Richland, Washington.

ECF-HANFORD-10-0371, 2010, *Central Plateau Version 3 MODFLOW Model*, Rev. 0, CH2M HILL Plateau Remediation Company, Richland, Washington. Available at: http://www2.hanford.gov/arpir/?content=findpage&AKey=0084305.

Karanovic, M., M. Tonkin, and D. Wilson, 2009, "KT3D_H2O: A Program for Kriging Water Level Data Using Hydrologic Drift Terms," *Ground Water* 47(4):580-586.

™ Groundwater Vistas is a trademark of Scientific Software Group, Sandy, Utah.

™ ArcGIS is a registered trademark of ESRI, Redlands, California.

™ MKS Integrity, a PTC product, is a trademark of MKS, Inc., Waterloo, Ontario, Canada.

Mitchell, A., 1999, *The ESRI Guide to GIS Analysis Volume 1: Geographic Patterns and Relationships*, ESRI Press, Redlands, California.

OFR 00-92, 2000, *MODFLOW-2000, The U.S. Geological Survey Modular Ground-Water Model – User Guide to Modularization Concepts and the Ground-Water Flow Process*, Open-File Report 00-92, U.S. Geological Survey, Reston, Virginia. Available at: http://water.usgs.gov/nrp/gwsoftware/modflow2000/ofr00-92.pdf.

OFR 94-464, 1994, *User's Guide for MODPATH/MODPATH-PLOT, Version 3: A Particle Tracking Post-Processing Package for MODFLOW, the U.S. Geological Survey Finite-Difference Ground-Water Flow Model*, Open File Report 94-464, U.S. Geological Survey, Reston, Virginia. Available at: http://www.geo.wvu.edu/~donovan/ftp/modpath.pdf.

Rumbaugh, J.O. and D.B. Rumbaugh, 2007, *Groundwater Vistas Version 5*, Environmental Simulations, Inc.

SGW-42305, 2009, *Collection and Mapping of Water Levels to Assist in the Evaluation of Groundwater Pump-and-Treat Remedy Performance*, Rev 0, CH2M HILL Plateau Remediation Company, Richland, Washington.

Zheng, Chunmiao, 2010, *MT3DMS v5.3: A Modular Three-Dimensional Multi-Species Transport Model for Simulation of Advection, Dispersion, and Chemical Reactions of Contaminants in Groundwater Systems – Supplemental User's Guide*, Technical Report to the U.S. Army Engineer Research and Development Center, Department of Geological Sciences, University of Alabama, Tuscaloosa, Alabama. Available at: http://hydro.geo.ua.edu/mt3d/mt3dms_v5_supplemental.pdf.

Zheng, Chunmiao and P. Patrick Wang, 1999, *MT3DMS, A Modular Three-Dimensional Multi-Species Transport Model for Simulation of Advection, Dispersion, and Chemical Reactions of Contaminants in Groundwater Systems; Documentation and User's Guide*, Report SERDP-99-1, U.S. Army Engineer Research and Development Center, Vicksburg, Mississippi. Available at: http://hydro.geo.ua.edu/mt3d/mt3dmanual.pdf.