

# Fate and Transport Analysis for U Plant Groundwater Plumes in the 200-UP-1 Operable Unit

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



**P.O. Box 1600  
Richland, Washington 99352**

# Fate and Transport Analysis for U Plant Groundwater Plumes in the 200-UP-1 Operable Unit

Document Type: ENV

Program/Project: EP&SP

M. C. Weber  
INTERA, Inc.

Date Published  
December 2017

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



**P.O. Box 1600**  
**Richland, Washington 99352**

**APPROVED**

*By Erin C. Meegan at 8:00 am, Jan 02, 2018*

---

Release Approval

Date

**TRADEMARK DISCLAIMER**

Reference herein to any specific commercial product, process, or service by tradename, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors.

This report has been reproduced from the best available copy.

Printed in the United States of America

# ENVIRONMENTAL CALCULATION COVER PAGE

**Section 1: Completed by the Responsible Manager**

Project: 200-W

Date: 07/31/2017

Calculation Title & Description: Fate and Transport Analysis for U Plant Groundwater Plumes in the 200-UP-1 Operable Unit

RELEASE / ISSUE

DATE:  
Jan 02, 2018

HANFORD  
RELEASE

**Section 2: Completed by Preparer**

Calculation No.: ECF-200UP1-17-0093

Revision No.: 0

**Revision History**

Revision No.	Description	Date	Affected Pages	ADD ROW
0	Initial issue	07/31/2017	All	[+]

**Section 3: Completed by the Responsible Manager**

**Document Control:**

- Is the document intended to be controlled within the Document Management Control System (DMCS)?  Yes  No
- Does document contain scientific and technical information intended for public use?  Yes  No
- Does document contain controlled-use information?  Yes  No

**Section 4: Document Review & Approval**

M Weber/Hydrogeologist		8/31/17
<b>Preparer:</b> Name /Position	Signature	Date
G Ruskauff/Principal Hydrogeologist		8/31/17
<b>Checker:</b> Name /Position	Signature	Date
AM Lavenue/Principal Hydrogeologist		8/31/17
<b>Senior Reviewer:</b> Name /Position	Signature	Date
AH Aly/Risk & Modeling Integr. Mngr		8/31/17
<b>Responsible Manager:</b> Name /Position	Signature	Date

**Section 5: Applicable if calculation is a risk assessment or uses an environmental model**

**PRIOR TO INITIATING MODELING:**

**Required training for modelers completed:**

WE Nichols/Modeling Team Leader		8/31/17
<b>Integration Lead</b> Name /Position	Signature	Date
WE Nichols/Modeling Team Leader		8/31/17
<b>Integration Lead</b> Name /Position	Signature	Date

**CALCULATION APPROVED:**

AH Aly/Risk & Modeling Integr. Mngr		8/31/17
<b>Risk/Modeling Integration Manager:</b> Name /Position	Signature	Date

## **Basis of Qualifications for ECF Roles**

**Preparer: Mary Weber**  
**Hydrogeologist**

MS, Geoscience, University of Iowa, 2015

BS, Geoscience, University of Iowa, 2013

Mary Weber focuses her geoscientific skills on the development and application of groundwater flow and contaminant fate and transport models. She uses models to help guide environmental investigation and remediation efforts and to project future water availability as part of developing and managing groundwater resources. Mary currently provides modeling and other technical support for remedial investigations and feasibility studies being performed on one of the largest environmental restoration projects in the world at the U.S. Department of Energy's Hanford Site.

**Checker: Gregory Ruskauff**  
**Principal Hydrogeologist**

MS, Petroleum Engineering, New Mexico Institute of Mining and Technology, 1985

BS, Petroleum Engineering, New Mexico Institute of Mining and Technology, 1983

Greg Ruskauff's professional experience has focused on the areas of performance assessment of both near-surface and geological radioactive waste repositories, regulatory development, dose assessment for residual contamination of soils and buildings, toxic materials risk assessment, and mixed waste issues. His experience includes performing, planning, and managing site investigations and groundwater modeling on various types of projects. He brings expertise in coordinating teams of technical experts to perform activities necessary for the development of integrated interpretations of complex groundwater systems in order to meet or exceed regulatory-driven requirements. He led the analysis and modeling team for a large federal environmental restoration site, whose primary task was to characterize the complex subsurface environment and evaluate groundwater contamination from historical underground nuclear testing. Under Greg's leadership the activity passed, for the first time, a public peer review required by the regulatory agency advancing the first corrective action unit out of characterization and toward closure. The organizational approach was judged to be so successful that the preparation for the next peer review followed the same pattern. Greg's career has been marked by numerous promotions on important federal projects due to his reliable technical and regulatory leadership skills.

**Senior Reviewer: Marsh Lavenue, PhD  
President and CEO; Principal Hydrogeologist**

PhD, Hydrogeology, Paris School of Mines, 1998

MS, Geophysics, Texas A&M University, 1985

BS, Geology, Texas A&M University, 1984

BS, Geophysics, Texas A&M University, 1983

Marsh joined INTERA in Austin as a Staff Hydrogeologist in 1985 and since that time has served as Albuquerque Group Manager, Director of Marketing and Sales, Vice President of Western Operations and as Senior Vice President of INTERA's Performance Assessment Division. During Marsh's technical career, he specialized in regional hydrologic model development, calibration, and sensitivity/uncertainty analysis. He has been involved in domestic and international projects for private industry and/or state or federal governmental agencies concerning water resource management, fate and transport of contaminants in the subsurface, and the performance assessment of sites considered for long-term geologic storage of radioactive waste. He has authored and coauthored numerous journal articles and technical reports concerning groundwater flow modeling, surface water modeling, integrated surface water-groundwater modeling but is known mostly for his collaboration in the development of the Pilot-Point inverse method, now an industry standard for groundwater model parameter estimation. Marsh has been privileged to lead the INTERA leadership team in its execution of INTERA's mission of Delivering Excellence with Every Solution.

## Contents

<b>1</b>	<b>Purpose.....</b>	<b>1</b>
<b>2</b>	<b>Methodology .....</b>	<b>2</b>
2.1	U Plant Transport Model.....	2
2.2	System Optimization.....	3
2.3	UCL95 Calculations.....	4
<b>3</b>	<b>Assumptions and Inputs.....</b>	<b>5</b>
3.1	Model Domain .....	5
3.2	Transport Parameters .....	8
3.3	Boundary and Initial Conditions .....	8
3.3.1	Initial Plume Concentration .....	8
3.3.2	Continuing Sources.....	11
3.3.3	Boundary Conditions .....	11
3.3.4	Additional Flow Models .....	12
3.4	Simulation Period.....	13
<b>4</b>	<b>Software Applications.....</b>	<b>13</b>
4.1	Approved Software .....	13
4.1.1	Description.....	13
4.1.2	Software Installation and Checkout .....	14
4.1.3	Statement of Valid Software Application .....	14
<b>5</b>	<b>Calculation.....</b>	<b>15</b>
<b>6</b>	<b>Results/Conclusions .....</b>	<b>16</b>
6.1	Flow Scenario 1 .....	16
6.1.1	Technetium-99 .....	17
6.1.2	Uranium .....	22
6.2	Flow Scenario 2 .....	32
6.2.1	Technetium-99 .....	33
6.2.2	Uranium .....	38
6.3	Flow Scenario 3 .....	48
6.3.1	Technetium-99 .....	49
6.3.2	Uranium .....	54
6.4	Flow Scenario 4 .....	64
6.4.1	Technetium-99 .....	65
6.4.2	Uranium .....	70
6.5	Summary .....	79

**7 References.....81**

**Attachments**

A. Software Installation and Checkout..... 83  
 B Stress Periods in the U Plant Local-Scale Transport Model ..... 86  
 C. Well Data Used to Create 2016 Working Initial Conditions..... 89

**Figures**

Figure 1. U Plant Groundwater Extraction System..... 2  
 Figure 2. Well Location for SCE Optimization, and Optimized Pumping Rates ..... 4  
 Figure 3. Horizontal Grid Discretization for the U Plant Local-Scale Submodel..... 7  
 Figure 4. 2015 Uranium Initial Conditions ..... 10  
 Figure 5. 2016 Uranium Working Initial Conditions..... 10  
 Figure 6. Assumed Source Term Location ..... 11  
 Figure 7. UCL95 and Pumping Well Locations, Scenario 1..... 16  
 Figure 8. Mass Extraction of Tc-99, Scenario 1, Compared to Actual Mass Extraction Values ..... 17  
 Figure 9. UCL95 Curves for Tc-99, Scenario 1..... 18  
 Figure 10. Tc-99 at U Plant with No Continuing Source, Modeled Year 2037, Scenario 1 ..... 19  
 Figure 11. Tc-99 at U Plant with No Continuing Source, Modeled Year 2137, Scenario 1 ..... 20  
 Figure 12. Tc-99 at U Plant with a Continuing Source, Modeled Year 2037, Scenario 1 ..... 21  
 Figure 13. Tc-99 at U Plant with a Continuing Source, Modeled Year 2137, Scenario 1 ..... 22  
 Figure 14. Mass Extraction of Uranium, Scenario 1, Compared to Actual Mass Extraction Values ..... 23  
 Figure 15. UCL95 Curves for Uranium, Scenario 1 ..... 24  
 Figure 16. Uranium at U Plant with 2015 Initial Conditions, No Continuing Source, Modeled Year 2037,  
 Scenario 1..... 25  
 Figure 17. Uranium at U Plant with 2015 Initial Conditions, No Continuing Source, Modeled Year 2137,  
 Scenario 1..... 26  
 Figure 18. Uranium at U Plant with 2015 Initial Conditions, with Continuing Source, Modeled Year 2037,  
 Scenario 1..... 27  
 Figure 19. Uranium at U Plant with 2015 Initial Conditions, with Continuing Source, Modeled Year 2137,  
 Scenario 1..... 28  
 Figure 20. Uranium at U Plant with 2016 Initial Conditions, No Continuing Source, Modeled Year 2037,  
 Scenario 1..... 29  
 Figure 21. Uranium at U Plant with 2016 Initial Conditions, No Continuing Source, Modeled Year 2137,  
 Scenario 1..... 30  
 Figure 22. Uranium at U Plant with 2016 Initial Conditions, with Continuing Source, Modeled Year 2037,  
 Scenario 1..... 31

Figure 23. Uranium at U Plant with 2016 Initial Conditions, with Continuing Source, Modeled Year 2137, Scenario 1..... 32

Figure 24. UCL95 and Pumping Well Locations, Scenario 2..... 33

Figure 25. Cumulative Activity Extraction of Tc-99, Scenario 2, Compared to Actual Activity Extraction Values ..... 34

Figure 26. UCL95 Curves for Tc-99, Scenario 2..... 34

Figure 27. Tc-99 at U Plant with No Continuing Source, Modeled Year 2037, Scenario 2..... 35

Figure 28. Tc-99 at U Plant with No Continuing Source, Modeled Year 2137, Scenario 2..... 36

Figure 29. Tc-99 at U Plant with Continuing Source, Modeled Year 2037, Scenario 2..... 37

Figure 30. Tc-99 at U Plant with Continuing Source, Modeled Year 2137, Scenario 2..... 38

Figure 31. Cumulative Activity Extraction of Uranium, Scenario 2, Compared to Actual Activity Extraction Values..... 39

Figure 32. UCL95 Curves for Uranium, Scenario 2..... 40

Figure 33. Uranium at U Plant with 2015 Initial Conditions, No Continuing Source, Modeled Year 2037, Scenario 2..... 41

Figure 34. Uranium at U Plant with 2015 Initial Conditions, No Continuing Source, Modeled Year 2137, Scenario 2..... 42

Figure 35. Uranium at U Plant with 2015 Initial Conditions, with Continuing Source, Modeled Year 2037, Scenario 2..... 43

Figure 36. Uranium at U Plant with 2015 Initial Conditions, with Continuing Source, Modeled Year 2137, Scenario 2..... 44

Figure 37. Uranium at U Plant with 2016 Initial Conditions, No Continuing Source, Modeled Year 2037, Scenario 2..... 45

Figure 38. Uranium at U Plant with 2016 Initial Conditions, No Continuing Source, Modeled Year 2137, Scenario 2..... 46

Figure 39. Uranium at U Plant with 2016 Initial Conditions, with Continuing Source, Modeled Year 2037, Scenario 2..... 47

Figure 40. Uranium at U Plant with 2016 Initial Conditions, with Continuing Source, Modeled Year 2137, Scenario 2..... 48

Figure 41. UCL95 and Pumping Well Locations, Scenario 3..... 49

Figure 42. UCL95 Curves for Tc-99, Scenario 3..... 50

Figure 43. Cumulative Activity Extraction of Tc-99, Scenario 3, Compared to Actual Activity Extraction Values ..... 50

Figure 44. Tc-99 at U Plant with No Continuing Source, Modeled Year 2037, Scenario 3..... 51

Figure 45. Tc-99 at U Plant with No Continuing Source, Modeled Year 2137, Scenario 3..... 52

Figure 46. Tc-99 at U Plant with Continuing Source, Modeled Year 2037, Scenario 3..... 53

Figure 47. Tc-99 at U Plant with Continuing Source, Modeled Year 2137, Scenario 3..... 54

Figure 48. Cumulative Activity Extraction of Uranium, Scenario 3, Compared to Actual Activity Extraction Values..... 55

Figure 49. UCL95 Curves for Uranium, Scenario 3..... 56

Figure 50. Uranium at U Plant with 2015 Initial Conditions, No Continuing Source, Modeled Year 2037, Scenario 3..... 57

Figure 51. Uranium at U Plant with 2015 Initial Conditions, No Continuing Source, Modeled Year 2137, Scenario 3..... 58

Figure 52. Uranium at U Plant with 2015 Initial Conditions, with Continuing Source, Modeled Year 2037, Scenario 3..... 59

Figure 53. Uranium at U Plant with 2015 Initial Conditions, with Continuing Source, Modeled Year 2137, Scenario 3..... 60

Figure 54. Uranium at U Plant with 2016 Initial Conditions, No Continuing Source, Modeled Year 2037, Scenario 3..... 61

Figure 55. Uranium at U Plant with 2016 Initial Conditions, No Continuing Source, Modeled Year 2137, Scenario 3..... 62

Figure 56. Uranium at U Plant with 2016 Initial Conditions, with Continuing Source, Modeled Year 2037, Scenario 3..... 63

Figure 57. Uranium at U Plant with 2016 Initial Conditions, with Continuing Source, Modeled Year 2137, Scenario 3..... 64

Figure 58. UCL95 and Pumping Well Locations, Scenario 4..... 65

Figure 59. UCL95 Curves for Tc-99, Scenario 4..... 66

Figure 60. Cumulative Activity Extraction of Tc-99, Scenario 4, Compared to Actual Activity Extraction Values ..... 66

Figure 61. Tc-99 at U Plant with No Continuing Source, Modeled Year 2037, Scenario 4..... 67

Figure 62. Tc-99 at U Plant with No Continuing Source, Modeled Year 2137, Scenario 4..... 68

Figure 63. Tc-99 at U Plant with Continuing Source, Modeled Year 2037, Scenario 4..... 69

Figure 64. Tc-99 at U Plant with Continuing Source, Modeled Year 2137, Scenario 4..... 70

Figure 65. UCL95 Curves for Uranium, Scenario 4..... 71

Figure 66. Cumulative Activity Extraction of Uranium, Scenario 4, Compared to Actual Activity Extraction Values..... 71

Figure 67. Uranium at U Plant with 2015 Initial Conditions, No Continuing Source, Modeled Year 2037, Scenario 4..... 72

Figure 68. Uranium at U Plant with 2015 Initial Conditions, No Continuing Source, Modeled Year 2137, Scenario 4..... 73

Figure 69. Uranium at U Plant with 2015 Initial Conditions, with Continuing Source, Modeled Year 2037, Scenario 4..... 74

Figure 70. Uranium at U Plant with 2015 Initial Conditions, with Continuing Source, Modeled Year 2137, Scenario 4..... 75

Figure 71. Uranium at U Plant with 2016 Initial Conditions, No Continuing Source, Modeled Year 2037, Scenario 4..... 76

Figure 72. Uranium at U Plant with 2016 Initial Conditions, No Continuing Source, Modeled Year 2137, Scenario 4..... 77

Figure 73. Uranium at U Plant with 2016 Initial Conditions, with Continuing Source, Modeled Year 2037, Scenario 4..... 78

Figure 74. Uranium at U Plant with 2016 Initial Conditions, with Continuing Source, Modeled Year 2137, Scenario 4..... 79

## Tables

Table 1. Contaminant Transport Parameters.....	8
Table 2. Transport Parameters for the Aquifer .....	8
Table 3. U Plant Groundwater Extraction System Pumping Rates.....	12
Table 4. U Plant Transport Modeling Scenarios.....	15

## Terms

2D	two-dimensional
3D	three-dimensional
CHPRC	CH2M Hill Plateau Remediation Company
CPM	Central Plateau Model
ECF	environmental calculation file
HISI	Hanford Information Systems Inventory
OU	operable unit
SCE	shuffled complex evolution
Tc-99	technetium-99
TMR	telescopic mesh refinement
UCL95	95 <sup>th</sup> percentile upper confidence limit on the plume mean concentration
USGS	U.S. Geological Survey

## 1 Purpose

This environmental calculation file (ECF) documents the results of contaminant transport simulations performed using a local-scale groundwater model for the U Plant Groundwater Extraction System within the 200-UP-1 Groundwater Operable Unit (OU) at the Hanford Site. This system began operating in 2015, and consists of 2 extraction wells, 299-W19-113 and 299-W19-114 (Figure 1). These extraction wells are currently operating at flow rates of approximately 55 and 110 gallons per minute (gpm), respectively. The primary contaminants at the site are technetium-99 (Tc-99) and uranium (U). More information regarding groundwater contamination at U Plant and operation of the groundwater extraction system can be found in DOE/RL-2016-09, *Hanford Site Groundwater Monitoring Report for 2015*, and DOE/RL-2016-20, *Calendar Year 2015 Annual Summary Report for the 200-ZP-1 and 200-UP-1 Operable Unit Pump-and-Treat Operations*.

There were three specific objectives of the transport modeling:

1. Assess the performance of the U Plant Groundwater Extraction System to determine if cleanup objectives will be accomplished within the planned time frame (active remediation through the end of 2037, followed by monitored natural attenuation through the end of 2137)
2. Determine the effect that ongoing sources of contamination will have on remedy performance.
3. Determine if system performance can be improved.

This is the second of two ECFs documenting the assessment and optimization of the U Plant Groundwater Extraction System. In ECF-200W-17-0044, *Capture-Zone and Particle-Tracking Analysis for the U Plant Pump and Treat System using a sub model from the 2017 Updated Central Plateau Model*, construction and results of the local-scale groundwater flow model were presented. The code used for the local-scale flow model was MODFLOW 2000, a finite difference groundwater flow model developed by the U.S. Geological Survey (USGS) (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*). Telescopic mesh refinement (TMR) was used to build the local-scale model from the most recent version of the Central Plateau model (CPM) (CP-47531, *Model Package Report: Central Plateau Model, Version 8.4.5*). With this approach, the portion of the CP model grid surrounding the U Plant vicinity was extracted and made into a local-scale model of higher grid resolution. Thus, the local-scale model is embedded within the regional CP model. Water levels simulated by the CP model at the edges of this grid became the specified boundary conditions for the local model. The stress periods for this model were trimmed to begin at the beginning of 2016, instead of 2012. For this ECF, three additional flow simulations were calculated in attempts to optimize the capture of the uranium plume, including a flow model which maximized capture using shuffled complex evolution (SCE) algorithm.

The local-scale flow model formed the basis for the transport simulations, which were performed using MT3DMS, a three-dimensional transport model which simulates advection, dispersion, and chemical reactions (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*). Simulations of plume movement (Tc-99 and U) with and without ongoing sources of contamination are documented in this ECF. Uranium transport simulations use one of two initial conditions: the 2015 plume from ECF-200UP1-0010, *200-UP-1 Leapfrog Models of U Plant Uranium and Technetium-99 Plumes Fall 2015*, or a working version of the uranium plume, constructed as described in Section 3.3.1. The working version of the plume was constructed due to uncertainty in the current plume interpretation as described in ECF-200UP1-0010.

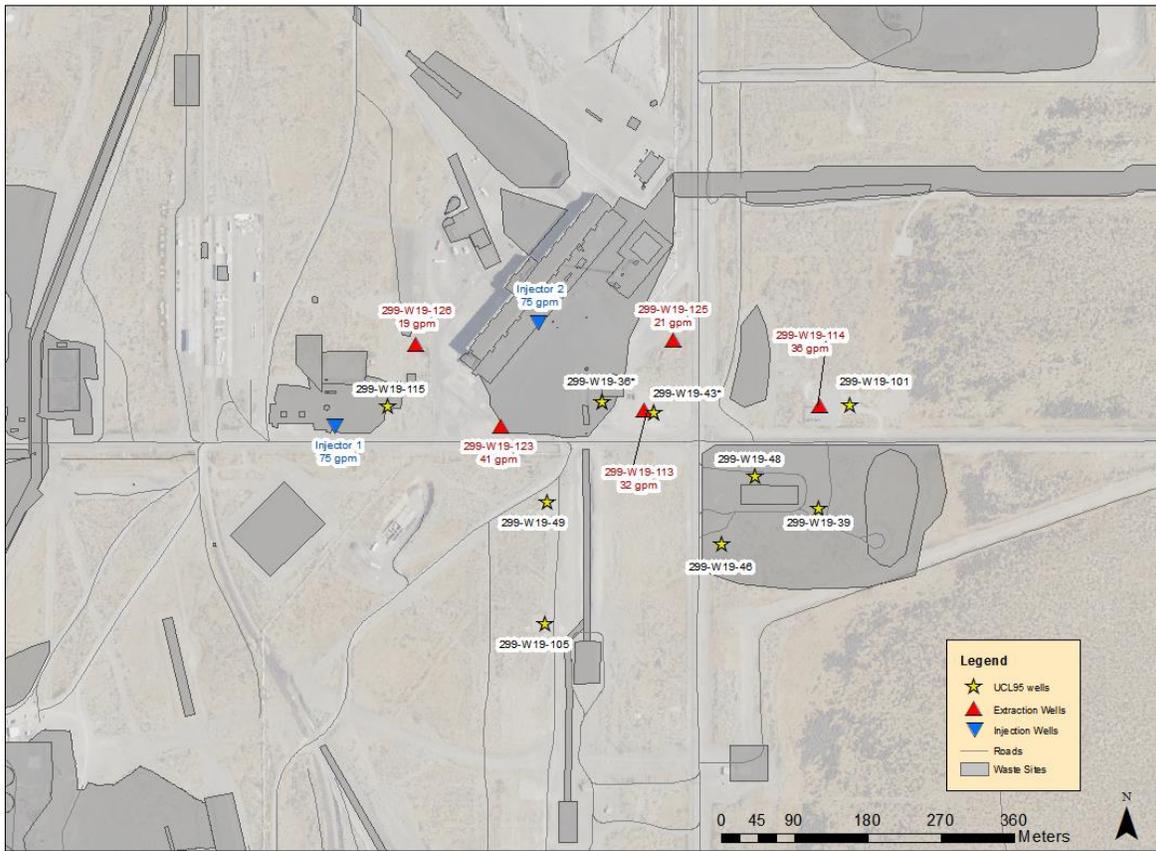


1. Perform the necessary flow modeling prerequisite to using MT3DMS. The flow model is documented in ECF-200W-17-0044. Three additional flow simulations beyond those documented in ECF-200W-17-0044 were performed to optimize uranium capture, as described in Section 2.2.
2. The start date for the transport model was updated to reflect the start date for transport modeling. The flow model in ECF-200W-17-0044 begins modeling in 2012. The transport as modeled in this ECF begins in 2016. Therefore, the constant and initial head values from the flow model were exported at the beginning of 2016, the stress periods were updated to reflect the change in start date, thereby adjusting the start date of the flow model to coincide with the start date of the transport model.
3. Generate the input files for MT3DMS. Input data are described in Chapter 3.
4. Execute the model simulations making use of the Transport Observation Package to gather output concentrations at specific times and locations needed for post-processing of the results (e.g., transport evaluation, calculations of the 95<sup>th</sup> percentile upper confidence limit [UCL95] on mean plume concentrations, etc.).
5. Perform calculations of contaminant mass recovered by the extraction wells.
6. Perform the UCL95 calculations for each scenario (described in Section 2.3).

## 2.2 System Optimization

The substantial change in the interpreted uranium plume initial conditions in 2015 (see Section 3.3.1) shows that the current system (pumping wells -113 and -114 at about 150 gpm total) may no longer satisfy the remedial objectives. Optimization was used to investigate potential system configurations using the same flow rate, but considering additional existing wells for pumping (299-W19-126, -125, and -123). Additionally, the effect of injection was evaluated by adding two injection wells at fixed locations and 75 gpm each (see Figure 2 for well locations and pumping rates optimized as described in the next paragraph).

A mathematical optimization approach was used to determine the optimum pumping rates for the U Plant extraction wells. Mathematical optimization approaches are numerical methods that search for optimal designs based on specified objectives and constraints. These approaches can be coupled to groundwater flow and transport models to evaluate pump and treat designs. Optimization has been demonstrated at several field sites and shown to provide savings (in treatment costs and system infrastructure) over trial-and-error optimization (EPA/542/R-99/011B, *Hydraulic Optimization Demonstration for Groundwater Pump-and-Treat Systems, Volume II: Application of Hydraulic Optimization*). Pump and treat optimization using the flow and transport models developed for U Plant was done with the SCE algorithm, which is part of the PEST suite of software (Doherty [2016], *PEST Model-Independent Parameter Estimation User Manual Part I: PEST, SENSAN, and Global Optimisers: 6<sup>th</sup> Edition*). Broadly, the SCE algorithm is a global optimization approach that generates families of parameter samples that are evolved to the optimum values. The optimization objective for U Plant was to maximize mass recovery as a surrogate for plume concentration reduction subject to pumping rate constraints. Well location is not optimized in this approach; rather a limited number of physically plausible locations is selected based on understanding gained from forward simulations.



299-W19-18 replaced by 299-W19-115 \*Wells are Tc-99 and uranium UCL95 wells

**Figure 2. Well Location for SCE Optimization, and Optimized Pumping Rates**

### 2.3 UCL95 Calculations

Remediation performance was evaluated by calculating the 95<sup>th</sup> percentile upper confidence limit (UCL95) on mean plume concentrations. This is the same method recommended for calculating groundwater plume exposure point concentrations in superfund risk assessment guidance (OSWER 9285.6-10, *Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites*). The advantage of the UCL95 is that it provides a comprehensive evaluation of plume concentrations in a single metric. It is calculated using sample results or simulated concentrations at monitoring wells.

The one-sided UCL95 was calculated using Student’s *t* test assuming a normal distribution (OSWER 9285.6-10):

$$UCL_{95} = \bar{X} + t_{\alpha, n-1} \frac{s}{\sqrt{n}} \tag{1}$$

where

$\bar{X}$  = arithmetic mean of the sample results

- $t_{\alpha,n-1}$  = the  $1-\alpha^{\text{th}}$  quantile of Student's  $t$  distribution with  $n-1$  degrees of freedom; for the 95<sup>th</sup> percentile,  $\alpha = 0.95$  (one-tailed)
- $s$  = standard deviation of the sample results
- $n$  = number of samples.

Well networks for UCL95 calculations in the 200-UP-1 OU are provided in DOE/RL-2015-14, *Performance Monitoring Plan for the 200-UP-1 Groundwater Operable Unit Remedial Action*. These networks are based on the current distribution of contamination. Well networks for the UCL95 calculations at U Plant are shown in the plume result maps in Section 6.

Calculations of UCL95s for transport simulation results were performed as follows:

1. For a given constituent, the wells used for UCL95 calculations were those identified in DOE/RL-2015-14.
2. UCL95s were calculated annually beginning in 2016 (the first year of the transport simulations). The calculations used simulated concentrations at the end of each year. Three years of data were compiled for the calculations. For example, the data used for calculations of the 2018 UCL95 consisted of concentrations at the end of 2016, 2017, and 2018. This ensured that enough data were available for representative calculation results. Note that only 1 year of data could be used for 2016 and 2 years for 2017.
3. When concentrations in a well declined to below one-tenth of the cleanup level, then that well was dropped from the calculation. This is the cutoff specified in DOE/RL-2015-14. However, if concentrations in that well later increased to above one-tenth the cleanup level, it was added back into the calculation. In other words, once a well is part of the UCL95 network, it is always used in the calculation if the concentration is above one-tenth the cleanup level.
4. Calculations were performed until the end of the simulation data set, or until there were fewer than 2 data points above one-tenth the cleanup level available for the calculation. The use of only 2 data points occurred in the simulations performed with no ongoing sources when concentrations were very low and the mean was well below the cleanup level. Thus, the effect of using only a few data points in the calculation was considered minor.

### 3 Assumptions and Inputs

The structure and input data for the U Plant local-scale transport model are described in the following subsections.

#### 3.1 Model Domain

The U Plant local-scale model domain extends 2,700 m east-west and 1,900 m north-south. The lower left corner of the domain has coordinates of 566,550 m east and 133,950 m north (Washington State Plane, South Zone [4602]). The horizontal grid discretization is shown in Figure 3. The area around the 2015 uranium plume extents has a cell size of 5 x 5 m, to characterize the transport with finer discretization. From the 5 x 5 m cells, the row spacings increase to 7 m (for 5 rows and/or columns), then 10 m (5), 15 m (2), 20 m (3), and 25 m, and the column spacings increase to 7 m (5), then 10 m (4), 15 m (2), 20 m (1), and 25. Limiting the cell sizes to no more than 25 m ensured no cell had an aspect ratio of greater than 5, which is desired for transport modeling.

The CP model is vertically discretized into 7 layers. To better represent contaminant plumes in the upper part of the aquifer, two additional layers were added to the U Plant local-scale model (described in ECF-200W-17-0044). Layer elevations and properties are identical to those in the local-scale groundwater flow model (ECF-200W-17-0044).



## 3.2 Transport Parameters

Input data needed for transport modeling consists of values for effective porosity, dispersion, decay, and contaminant distribution coefficients. Contaminant-specific transport parameters used for the U Plant transport modeling are shown in Table 1 and parameters for the aquifer are shown in Table 2. Tc-99 occurs in groundwater as polyatomic anions and was assumed to be non-sorbing. Thus, its distribution coefficient was set to zero. Uranium is known to sorb, and was therefore given a distribution coefficient of 0.4 mL/g. Because their half-lives are much longer than the simulation, both Tc-99 and uranium were modeled as non-decaying constituents. Parameters for the aquifer listed in Table 2 are identical to values used in the CP model.

**Table 1. Contaminant Transport Parameters**

Constituent	Half-Life (years)	Distribution Coefficient (mL/g)
Uranium, soluble salts	N/A	0.4
Technetium-99	210,000	0

Source: DOE/RL-2009-122, *Remedial Investigation/Feasibility Study for the 200-UP-1 Groundwater Operable Unit*.

**Table 2. Transport Parameters for the Aquifer**

Property	Value
Effective Porosity	0.15
Longitudinal Dispersivity	3.5 m
Transverse Horizontal Dispersivity	0.7 m
Transverse Vertical Dispersivity	0.0 m
Molecular Diffusion Constant	0.0 m <sup>2</sup> /day
Bulk density, Hanford, Cold Creek Formations	1.93 g/cm <sup>3</sup>
Bulk density, Ringold Taylor Flat, Ringold Unit E, Ringold Lower Mud, Ringold Unit A	1.90 g/cm <sup>3</sup>

Source: CP-47631, *Model Package Report: Central Plateau Groundwater Model, Version 8.4.5*

## 3.3 Boundary and Initial Conditions

### 3.3.1 Initial Plume Concentration

Evaluating the response of the existing U Plant groundwater plumes to remedial actions requires knowledge of current plume extent and concentrations. Ideally, the existing groundwater plumes at U Plant would be simulated from their inception when vadose-zone sources arrived at the water table to current conditions, producing plumes that are consistent with model hydraulic and transport parameters and source loading mass (Zheng and Bennett [1995], *Applied Contaminant Transport Modeling: Theory and Practice*). However, uncertainty in the amount and time of contaminant release, migration time

through the unsaturated zone, and dynamic groundwater level changes due to operations make such an approach difficult and is beyond the scope of this analysis. A more practical approach is to use the plume maps generated in the annual groundwater report (for example, DOE/RL-2016-09) as initial conditions for fate and transport analysis.

Due to uncertainty in the uranium plume interpretation, this ECF features two interpretations of the uranium plume: the interpretation as described in ECF-200UP1-0010, henceforth referred to as the “2015 initial conditions”, and a working interpretation developed using well data too new to be included in the creation of the raster in DOE/RL-2016-09, henceforth referred to as the “2016 working initial conditions”. Development of the working interpretation of the uranium plume is described in this section. The initial concentration values for uranium from the interpretation in ECF-200UP1-0010 will be referred to in this ECF as the 2015 initial conditions, as that model reflects the plume interpretation based on data from or before 2015. The uranium initial condition values which were built based on newer data will be referred to as the 2016 working initial conditions.

The Tc-99 and 2015 uranium plume initial concentrations for U Plant transport modeling are based on the three-dimensional (3D) plumes documented in ECF-200UP1-0010. The 3D model was created by using depth-discrete measured field data, as well as data from the two-dimensional (2D) uranium plume raster documented in ECF-Hanford-16-0061, *Calculation and Depiction of Groundwater Contamination for the Calendar Year 2015 Hanford Site Groundwater Monitoring Report*, in support of DOE/RL-2016-09. Concentrations from the 3D plumes were translated onto the U Plant local-scale model grid by assigning to each model grid cell the maximum solid model concentration occurring within the volume represented by the model grid cell. The 2015 raster and the well data used in its creation can be seen in Figure 4.

The uranium plume 2016 working initial conditions were built using the raster data from DOE/RL-2016-09 and the well data in Attachment C. Control points were used to constrain the plume boundaries, and they are also listed with the well data. The resulting initial condition plume can be seen in Figure 5. Concentrations from the 3D plumes were translated onto the U Plant local-scale model grid by assigning to each model grid cell the maximum solid model concentration occurring within the volume represented by the model grid cell. In cases where measured well data were present within a cell, the measured well data was given precedence over cell data. The 2016 working initial conditions were created as a 2D plume, and therefore required extrapolation to the lower layers. Individual rates of decreasing concentration for each model cell were calculated using the change in concentration from layer to layer in each cell of the 2015 uranium initial condition. These rates were applied to the 2016 initial condition, and thereby the 2D plume was interpolated into a 3D plume.

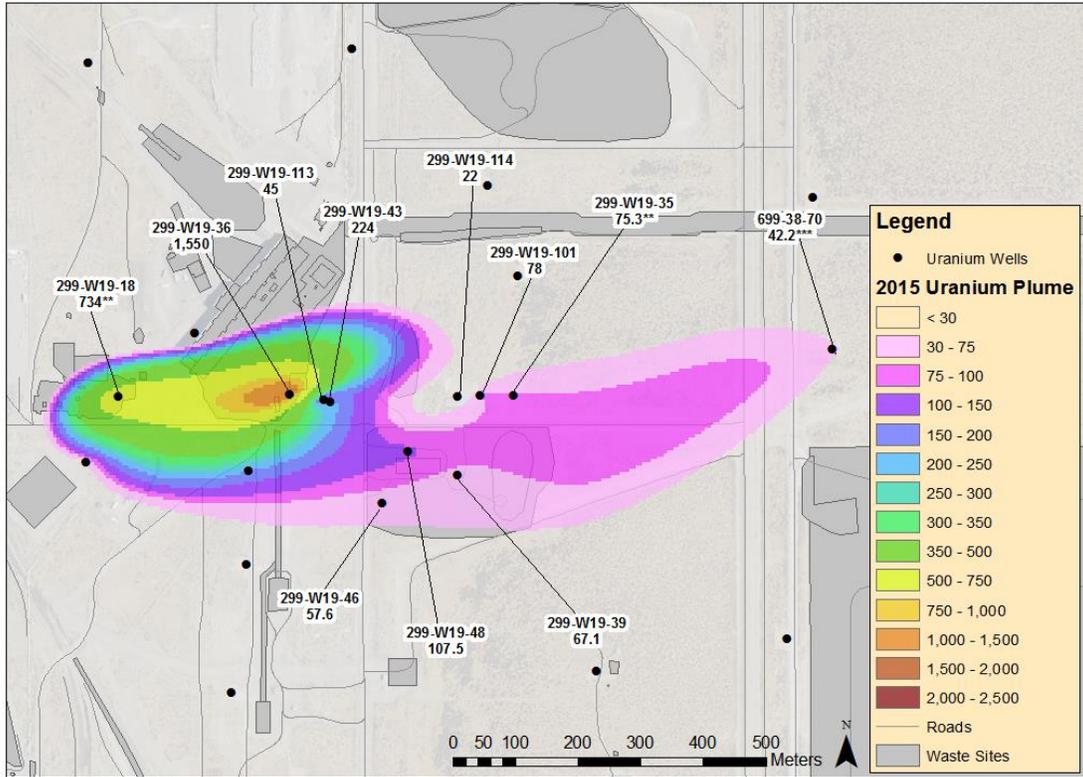


Figure 4. 2015 Uranium Initial Conditions

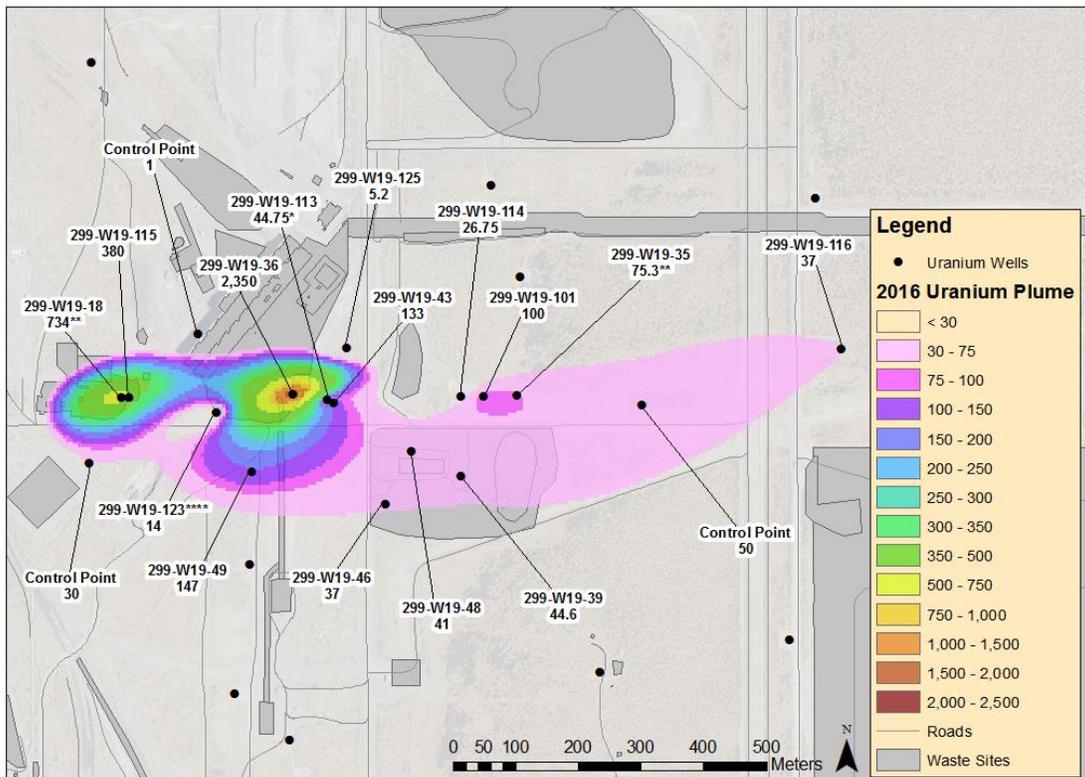


Figure 5. 2016 Uranium Working Initial Conditions

### 3.3.2 Continuing Sources

Some scenarios considered the effect of ongoing sources of contamination to the aquifer. These were added as sources beneath the U1 and U2 Cribs (216-U-1 and 216-U-2) for Tc-99 and uranium. The mass/activity fluxes used for the sources are specified in ECF-200W-17-0030, *Calculation of Source Terms for the 200 West Pump-and-Treat System Optimization Modeling, FY 2017*. These cribs have a small spatial footprint (slightly more than 5 meters by 5 meters for each crib), and loading the entire continuing source mass at those cribs would prevent the model from converging. Therefore, the continuing source mass from these cribs was spread out over 9,500 square meters around the U cribs (Figure 6). The calculations for the source terms are attached in Attachment C of this ECF. The source terms were sized such that resulting groundwater concentrations were similar to the concentrations used to estimate the sources.

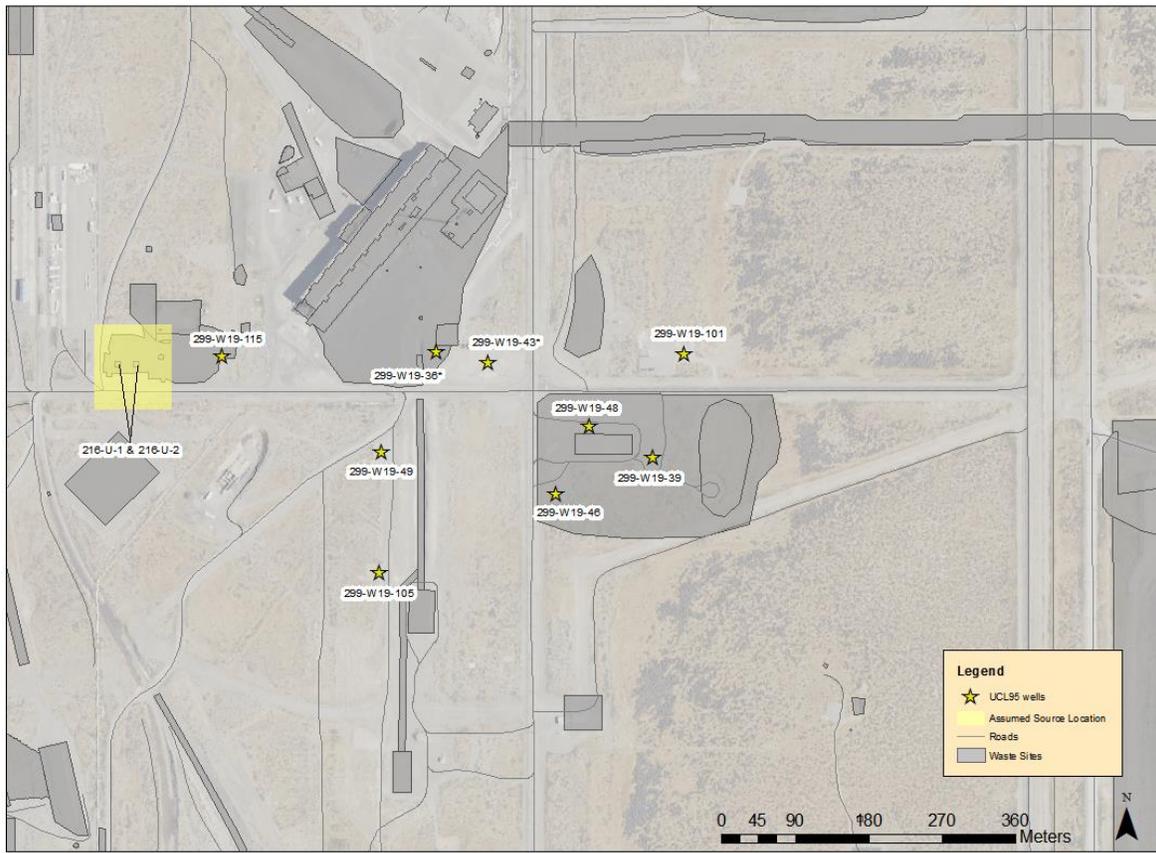


Figure 6. Assumed Source Term Location

### 3.3.3 Boundary Conditions

The U Plant local-scale model grid was sized to entirely contain the U Plant plumes for the duration of the simulations. Thus, the U Plant plumes never reached the boundary of the model. Extraction wells were sinks where contaminant mass was removed from the model domain. When the flow model was trimmed to begin in 2016, the boundary conditions were updated as described in Section 2.1.

### 3.3.4 Additional Flow Models

As mentioned in Section 2.1, three additional flow model simulations were performed with different internal boundary conditions than those documented in ECF-200W-17-0044. For each, the only changes made were to which wells were pumping, and the extraction rates at those wells. All the scenarios modeled are listed in Table 3. Scenario 1 is the base case scenario, with the pumping rates left the same as in the CPM. This scenario was documented in ECR-200W-17-0044. Scenario 2 added in 299-W19-125 as a pumping well. Scenario 3 was performed using the SCE-optimized pumping rates for extraction wells 299-W19-113, -114, -123, -125, and -126, as well as injection in two hypothetical wells. Scenario 4 considered extraction at 299-W19-114, -123, -125, and -126, as well as at two hypothetical wells. Scenario 4 also considered injection at four hypothetical injection wells.

**Table 3. U Plant Groundwater Extraction System Pumping Rates**

Flow Scenario Name and Total Rates	Well Name	Pumping Rate (gpm)
Flow Scenario 1 Total Extraction: 167 gpm	299-W19-113	-57
	299-W19-114	-110
Flow Scenario 2 Total Extraction: 200 gpm	299-W19-113	-50
	299-W19-114	-100
	299-W19-125	-50
Flow Scenario 3 Total Extraction: 150 gpm Total Injection: 150 gpm	299-W19-113	-32
	299-W19-114	-36
	299-W19-123	-41
	299-W19-125	-21
	299-W19-126	-19
	Injector 1	75
	Injector 2	75
Flow Scenario 4 Total Extraction: 365 gpm Total Injection 200 gpm	299-W19-114	-30
	299-W19-123	-90
	299-W19-125	-75
	299-W19-126	-30
	Extractor 1	-90
	Extractor 2	-50
	Injector 1	75
	Injector 2	75
	Injector 3	50
	Injector 4	25

### 3.4 Simulation Period

The U Plant Groundwater Extraction System began operating during 2015, and is currently being modeled to cease pumping in 2037. This will be followed by a period of monitored natural attenuation (MNA) (up to 100 years) to allow concentrations to decline to below the 30 µg/L and 900 pCi/L cleanup levels for uranium and Tc-99<sup>1</sup>. This time is divided into 49 stress periods as listed in Attachment B of this ECF.

## 4 Software Applications

MODFLOW-2000-MST, MT3DMS, Groundwater Vistas<sup>TM2</sup>, and Microsoft Excel<sup>®3</sup> software programs were used for this environmental calculation. MT3DMS is CH2M HILL Plateau Remediation Company (CHPRC) approved software, managed and used in compliance with the requirements of PRC-PRO-IRM-309, *Controlled Software Management*. Groundwater Vistas is support software managed under PRC-PRO-IRM-309 as described in CHPRC-00258, *MODFLOW and Related Codes Software Management Plan*. Microsoft Excel was used as a desktop calculator as defined in PRC-PRO-IRM-309.

### 4.1 Approved Software

Required descriptions for approved calculation software used in this work are provided below.

#### 4.1.1 Description

##### MODFLOW

- Software Title: MODFLOW-2000-MST
- Software Version: CHPRC Build 0008 (mf2k-mst-chprc08dp.exe)
- HISI Identification Number: 2517 (Safety Software, Level C)
- Workstation type and property number: Personal Computer, 00857
- Authorized User: Mary C. Weber
- CHPRC Software Control Documents:
  - CHPRC-00257, *MODFLOW and Related Codes Functional Requirements Document*
  - CHPRC-00258, *MODFLOW and Related Codes Software Management Plan*
  - CHPRC-00259, *MODFLOW and Related Codes Software Test Plan*
  - CHPRC-00260, *MODFLOW and Related Codes Requirements Traceability Matrix*
  - CHPRC-00261, *MODFLOW and Related Codes Acceptance Test Report*

##### MT3DMS

---

<sup>1</sup> These times assume there are no ongoing sources of contamination to the aquifer.

<sup>2</sup> Groundwater Vistas is a trademark of Environmental Simulations, Inc., Reinholds, PA.

<sup>3</sup> Microsoft Excel is a registered product of the Microsoft Corporation in the United States and in other countries.

- Software Title: MT3DMS
- Software Version: CHPRC Build 8 (Windows®<sup>4</sup> executable file mt3d-mst-chprc08dpv.exe)
- Hanford Information Systems Inventory (HISI) Identification Number: 2518 (Safety Software, Level C)
- Workstation type and property number: INTERA Workstation Computer, Property Tag INTERA-00857
- Authorized User: Mary Weber
- CHPRC Software Control Documents:
  - CHPRC-00257, *MODFLOW and Related Codes Functional Requirements Document*
  - CHPRC-00258, *MODFLOW and Related Codes Software Management Plan*
  - CHPRC-00259, *MODFLOW and Related Codes Software Test Plan*
  - CHPRC-00260, *MODFLOW and Related Codes Requirements Traceability Matrix: CHPRC Build 8*
  - CHPRC-00261, *MODFLOW and Related Codes Acceptance Test Report: CHPRC Build 8*

#### 4.1.2 Software Installation and Checkout

The Approved Safety Software package (MODFLOW) was checked out in accordance with procedures specified in CHPRC-00258. Executable files were obtained from the software owner who maintains the configuration-managed copies in MKS Integrity™<sup>5</sup>, installation tests identified in CHPRC-00259 were performed and successful installation confirmed, and Software Installation and Checkout Forms were completed and approved for installations used to perform model runs reported in this calculation. A copy of the Software Installation and Checkout Form is provided in Attachment A of this ECF.

#### 4.1.3 Statement of Valid Software Application

The preparers of this ECF attest that the software identified above, and used for the calculations described in this calculation brief, are appropriate for the application and used within the range of intended uses for which they were tested and accepted by CHPRC.

Because MODFLOW is graded as Level C software, use of this software is required to be logged in the HISI. Accordingly, this environmental calculation has been logged by the software owner in the HISI under Identification Number 2517. Because MT3DMS is graded as Level C software, use of this software is required to be logged in the HISI. Accordingly, this environmental calculation has been logged by the software owner in the HISI under Identification Number 2518 (MT3DMS).

---

<sup>4</sup> Windows is a registered trademark of the Microsoft Corporation in the United States and in other countries.

<sup>5</sup> MKS Integrity is a trademark of PTC, Incorporated.

## 5 Calculation

Simulations were performed for uranium and Tc-99 for all four flow scenarios with and without including ongoing sources of contamination to the aquifer. Table 4 lists the scenarios that were simulated. The results are described in Section 6.

**Table 4. U Plant Transport Modeling Scenarios**

Transport Scenario #	Constituent	Ongoing Sources?
<i>Flow Scenario 1</i>		
1	Technetium-99	No
2	Technetium-99	Yes
3	2015 Uranium	No
4	2015 Uranium	Yes
5	2016 Uranium working interpretation	No
6	2016 Uranium working interpretation	Yes
<i>Flow Scenario 2</i>		
7	Technetium-99	No
8	Technetium-99	Yes
9	2015 Uranium	No
10	2015 Uranium	Yes
11	2016 Uranium working interpretation	No
12	2016 Uranium working interpretation	Yes
<i>Flow Scenario 3</i>		
13	Technetium-99	No
14	Technetium-99	No
15	Technetium-99	Yes
16	2015 Uranium	No
17	2015 Uranium	Yes
18	2016 Uranium working interpretation	No
19	2016 Uranium working interpretation	Yes
<i>Flow Scenario 4</i>		
20	Technetium-99	No
21	Technetium-99	Yes
22	2015 Uranium	No
23	2015 Uranium	Yes
24	2016 Uranium working interpretation	No

**Table 4. U Plant Transport Modeling Scenarios**

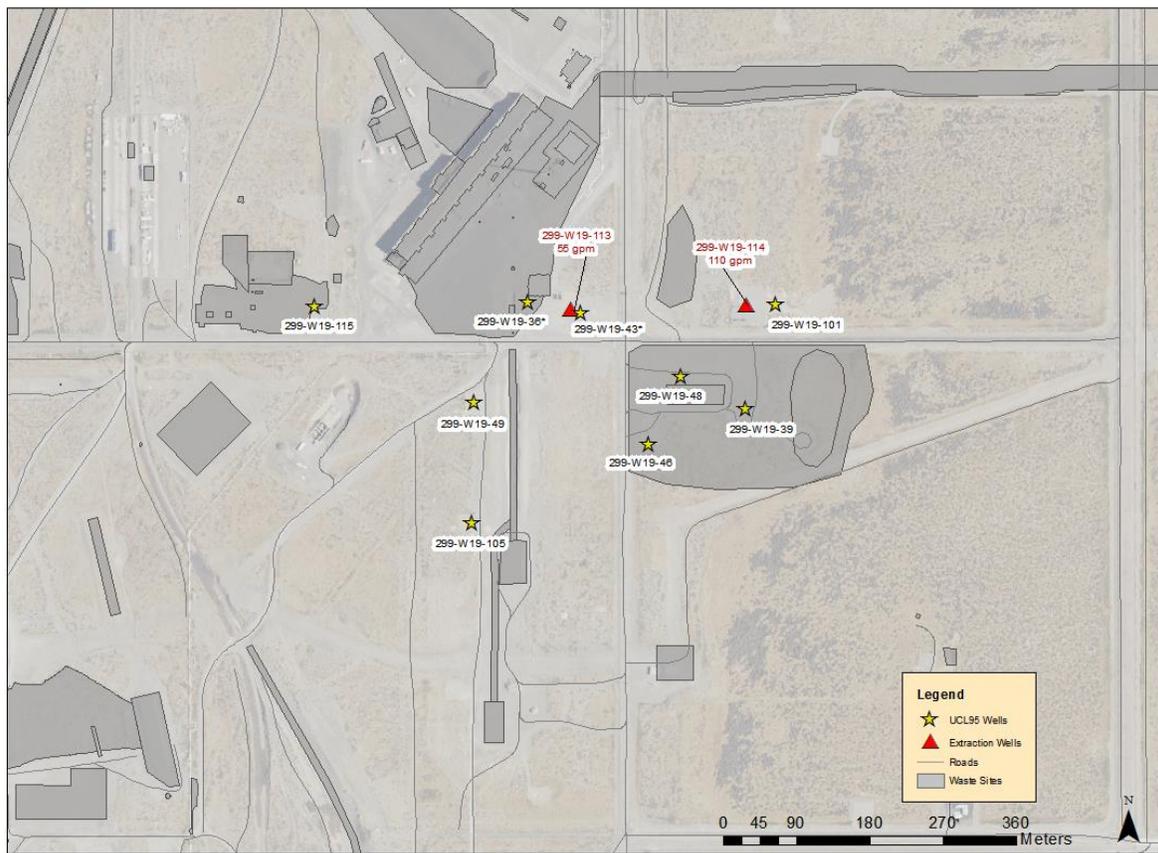
Transport Scenario #	Constituent	Ongoing Sources?
25	2016 Uranium working interpretation	Yes

## 6 Results/Conclusions

In this section, results of the model simulations are presented and evaluated.

### 6.1 Flow Scenario 1

This section contains results from transport models which used the CPM pumping rates as their flow model. In this model, the only wells pumping at U Plant are 299-W19-113 and 299-W19-114, reflecting the current pumping at the site. The failure of this pumping scenario to achieve the cleanup goals for U prompted the construction of the other three transport simulations described in this ECF. The transport results are presented by constituent. Figure 7 is a map of all the pumping wells and their rates.



299-W19-18 replaced by 299-W19-115 \*Wells are Tc-99 and uranium UCL95 wells

**Figure 7. UCL95 and Pumping Well Locations, Scenario 1**

### 6.1.1 Technetium-99

Approximately 1 curie of mass is extracted during pumping, regardless of whether sources are present (Figure 8). Mass recovery of Tc-99 in this scenario is similar to the recorded mass recovery obtained from the pump and treat system reports (DOE/RL-2015-06, *Calendar Year 2014 Annual Summary Report for the 200-ZP-1 and 200-UP-1 Operable Unit Pump and Treat Operations*; DOE/RL-2016-20; DOE/RL-2016-69, *Calendar Year 2016 Annual Summary Report for the 200-ZP-1 and 200-UP-1 Operable Unit Pump-and-Treat Operations*). With or without a continuing source, Tc-99 is cleaned up after five years of pumping (Figure 9). Without a continuing source, Tc-99 remains cleaned up (Figure 10 and Figure 11). With a continuing source, the buildup of mass is enough that a persistent plume is present in 2037 (Figure 12) and increases in size by 2137 (Figure 13). In 2037, the plume direction is to the northeast due to the influence of pumping at ZP-1, but with the cessation of pumping the plume flows due east by 2137.

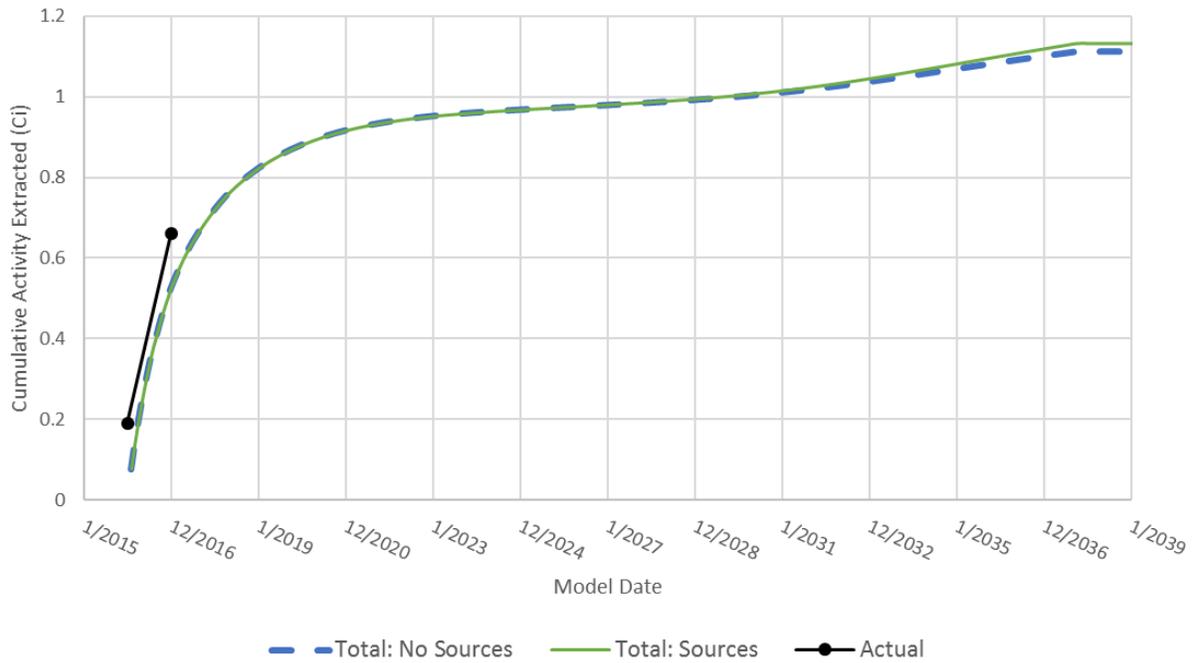


Figure 8. Mass Extraction of Tc-99, Scenario 1, Compared to Actual Mass Extraction Values

U Plant: Simulated UCL95 (Tc-99), Scenario 1

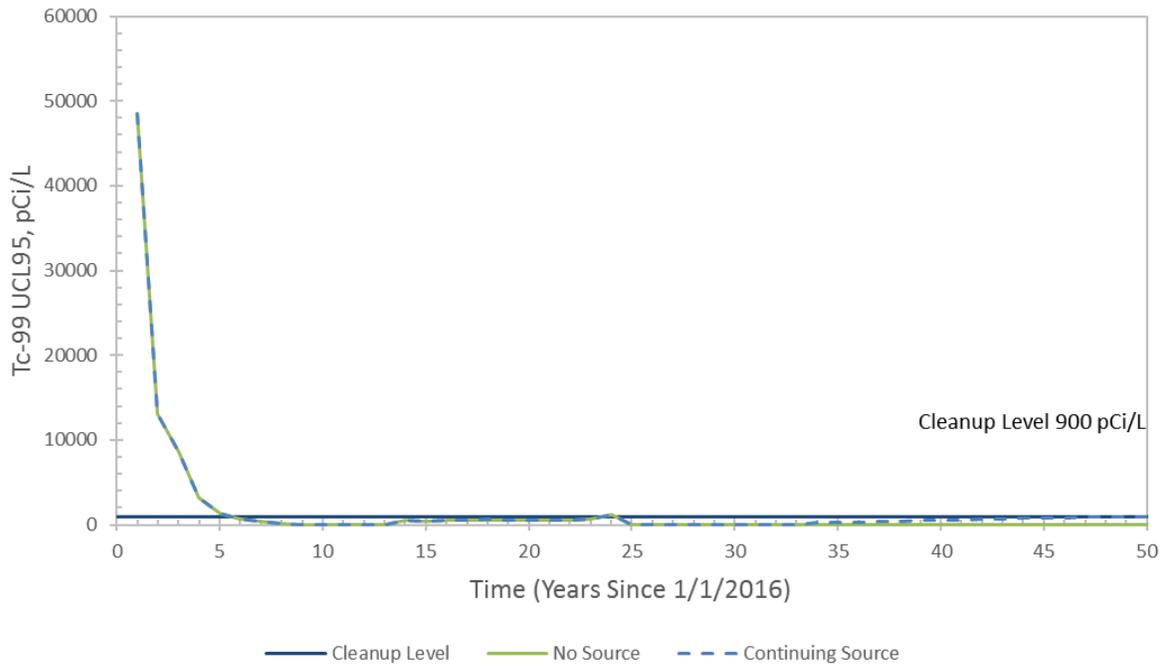
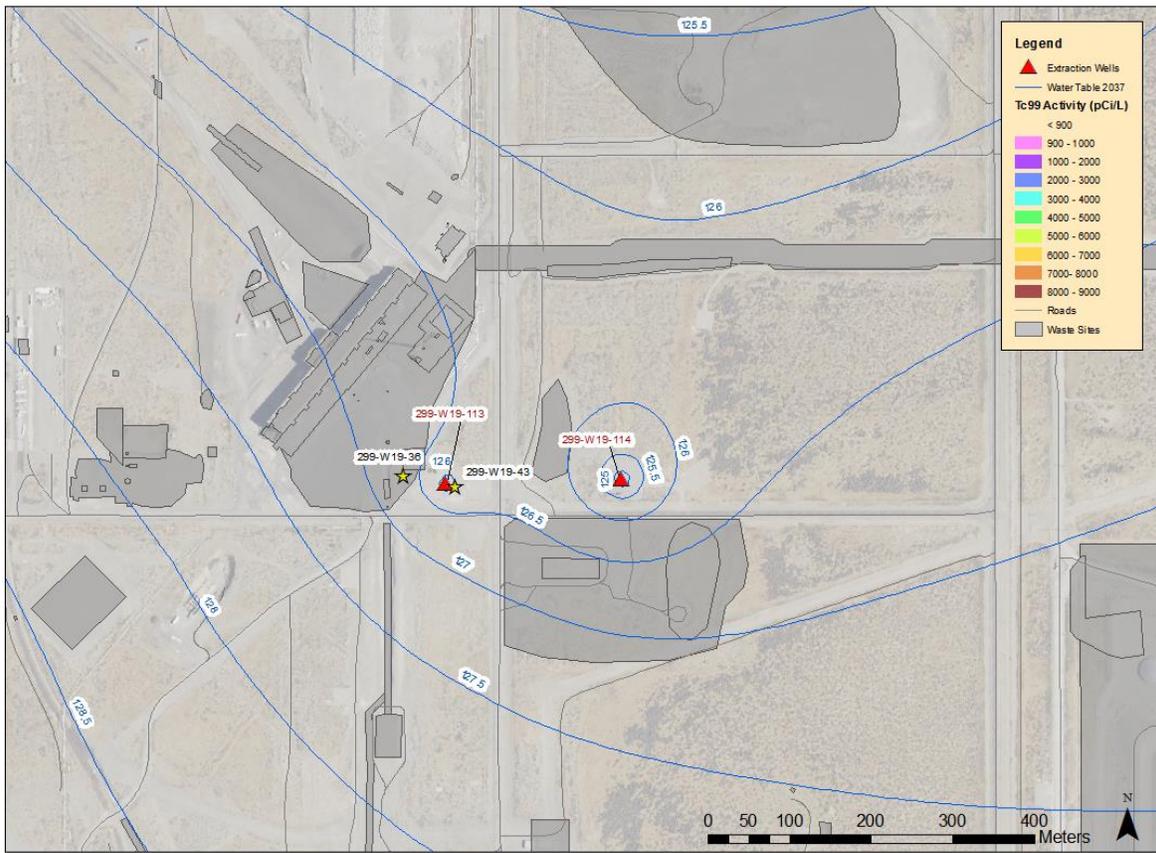
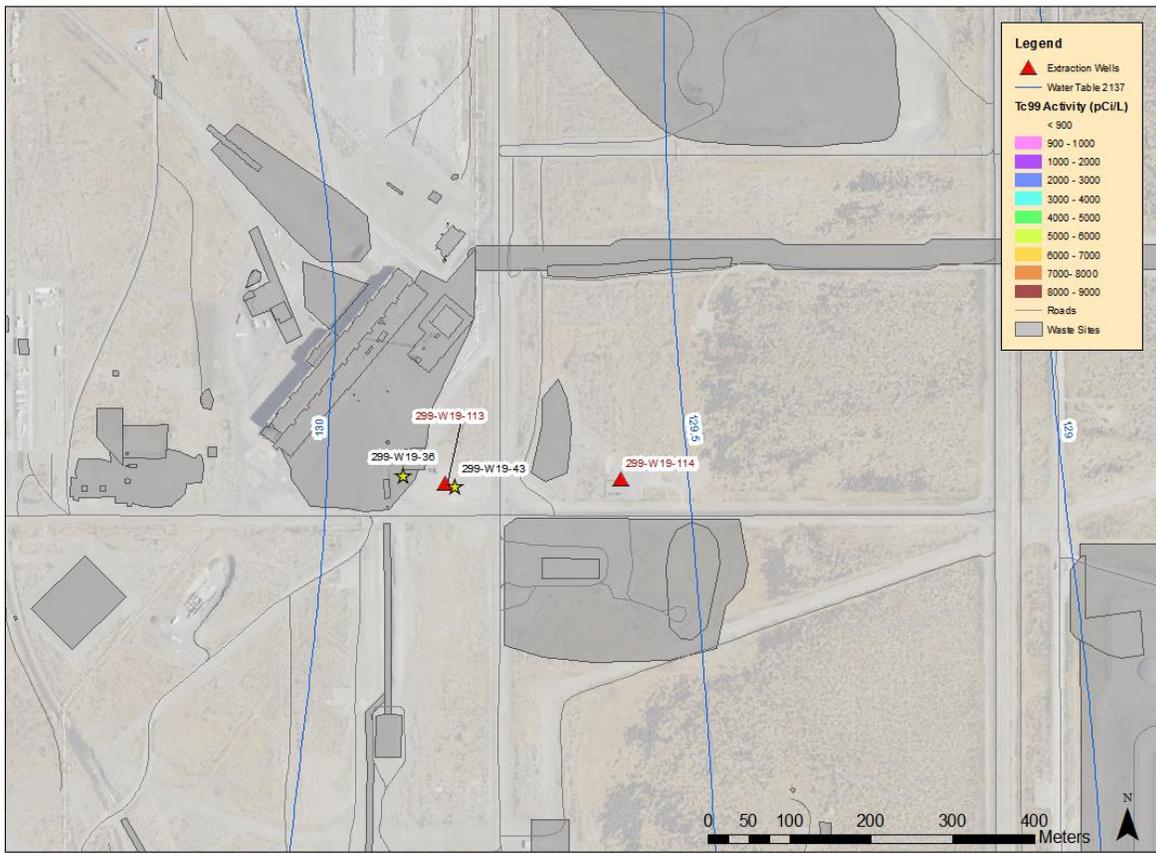


Figure 9. UCL95 Curves for Tc-99, Scenario 1



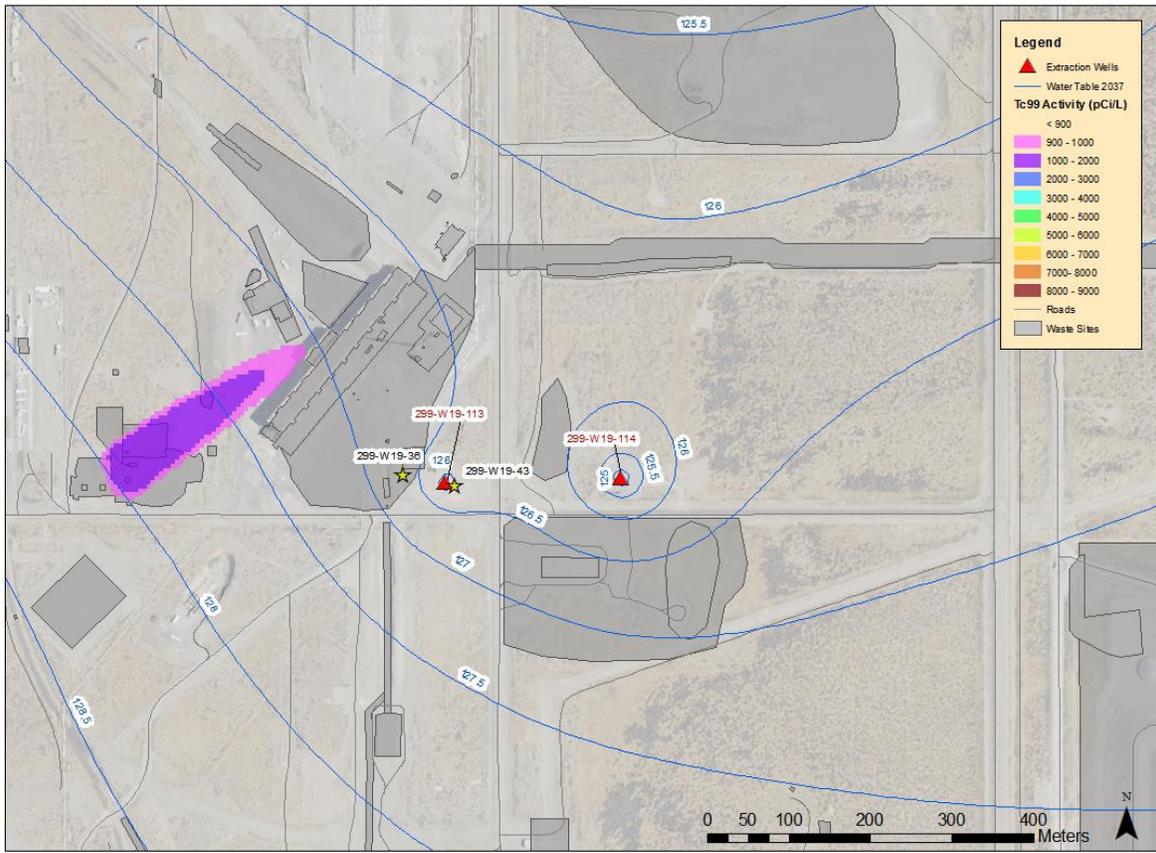
Maximum activity: < 900 pCi/L

Figure 10. Tc-99 at U Plant with No Continuing Source, Modeled Year 2037, Scenario 1



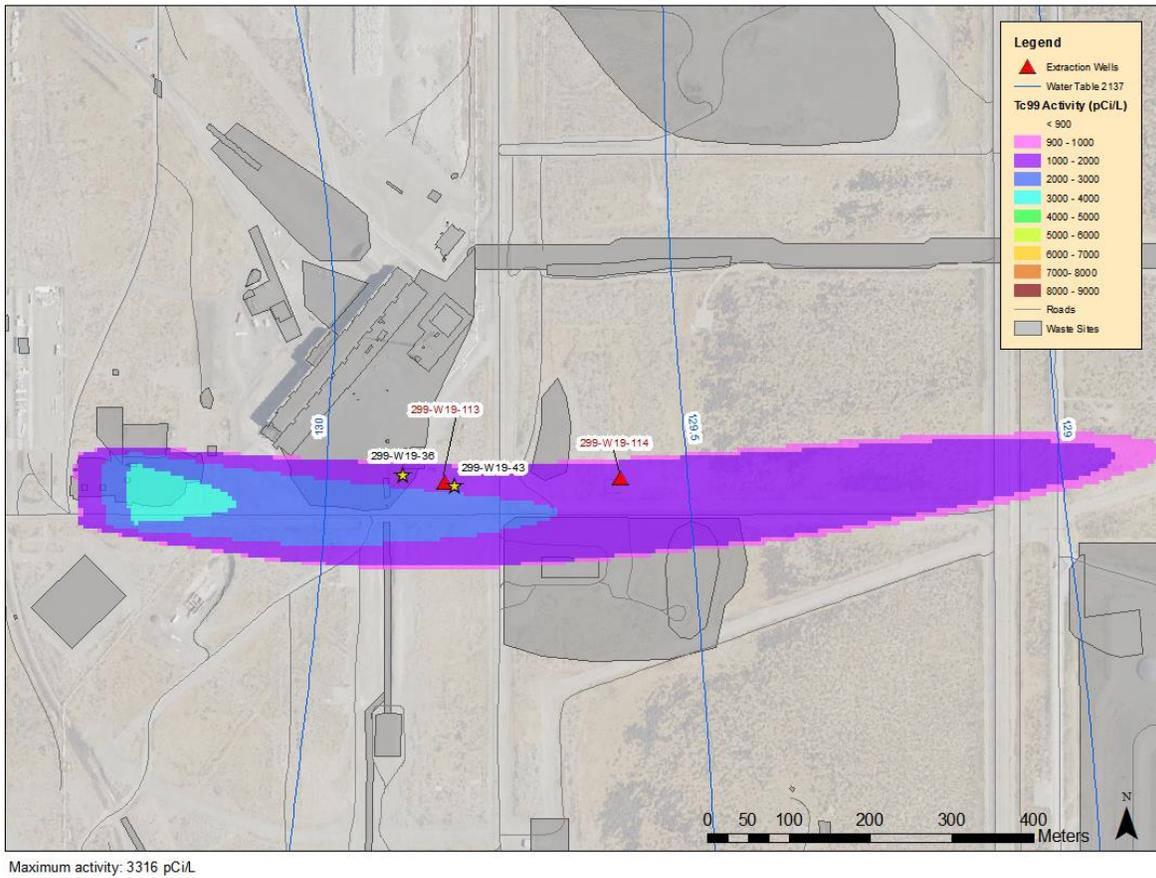
Maximum activity: < 900 pCi/L

Figure 11. Tc-99 at U Plant with No Continuing Source, Modeled Year 2137, Scenario 1



Maximum activity: 1434 pCi/L

Figure 12. Tc-99 at U Plant with a Continuing Source, Modeled Year 2037, Scenario 1



**Figure 13. Tc-99 at U Plant with a Continuing Source, Modeled Year 2137, Scenario 1**

### 6.1.2 Uranium

The impact of the initial conditions can be clearly seen in every figure below. The 2015 initial conditions have an initial mass of approximately 630 kg of uranium, while the 2016 initial conditions have an initial mass of approximately 400 kg of uranium. More mass is recovered when 2015 initial conditions are used (Figure 14), but this does not translate to better cleanup, both in terms of UCL95 (Figure 15) and overall plume size and concentration (Figure 16 through Figure 23). Cleanup is not reached with 2015 initial conditions, with or without sources. With 2016 working initial conditions and no sources, the UCL95 is reached approximately 23 years after the start of pumping, even though a sizable plume is present with concentrations above the maximum contaminant level (MCL) of 30 µg/L (Figure 22 and Figure 23)



Figure 14. Mass Extraction of Uranium, Scenario 1, Compared to Actual Mass Extraction Values

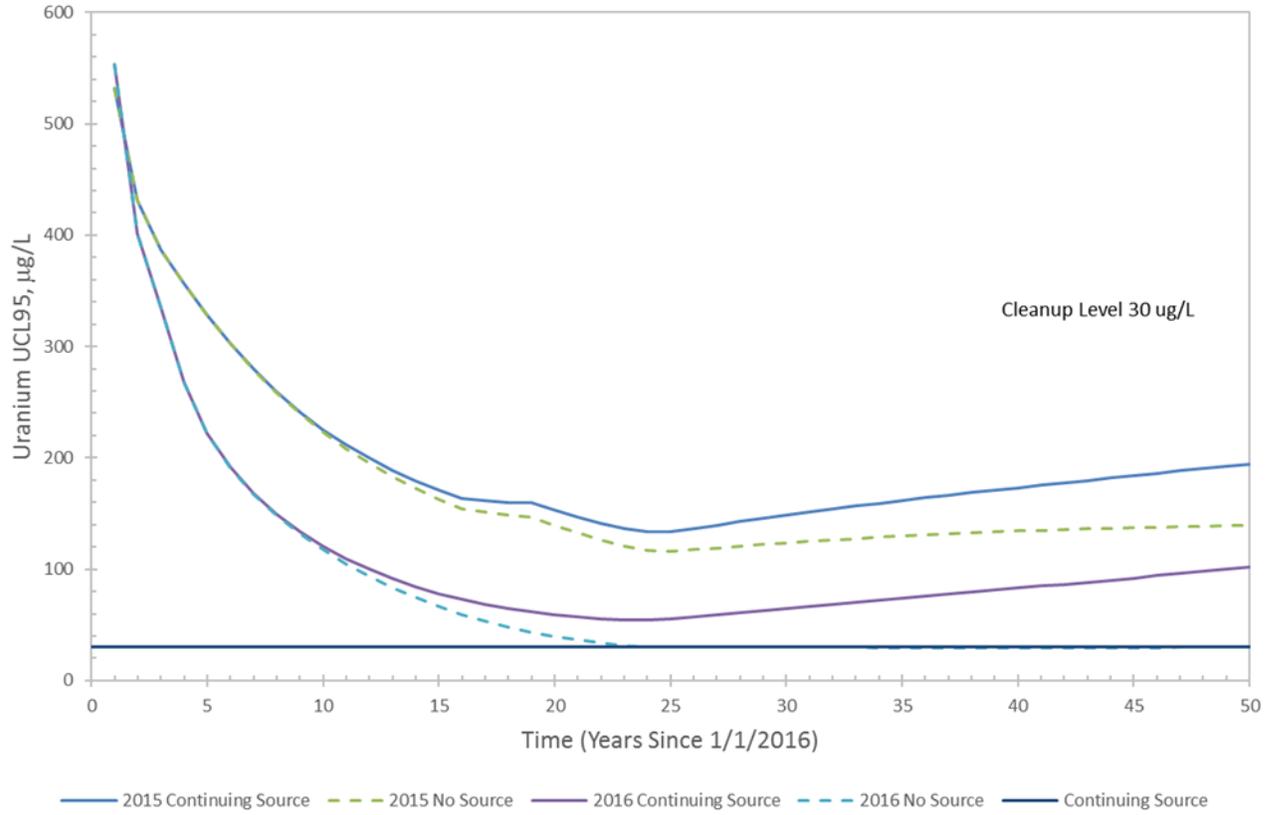
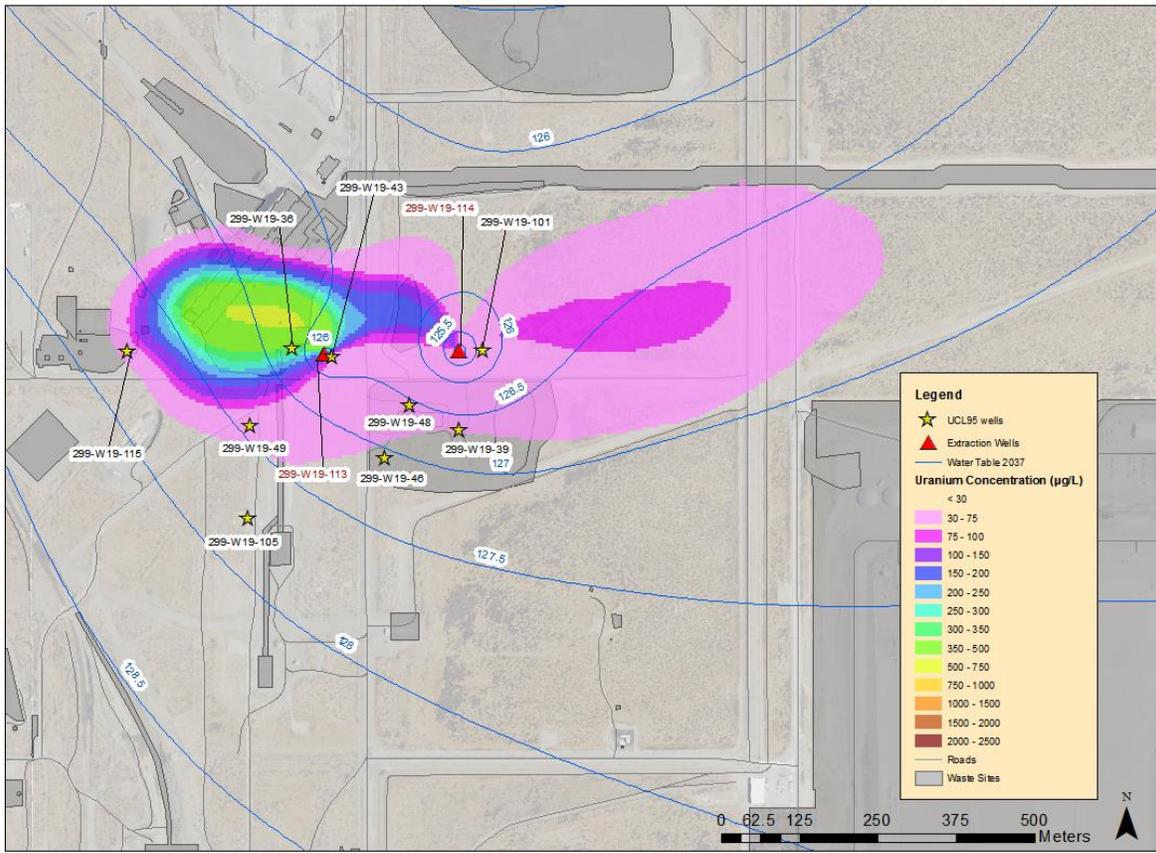
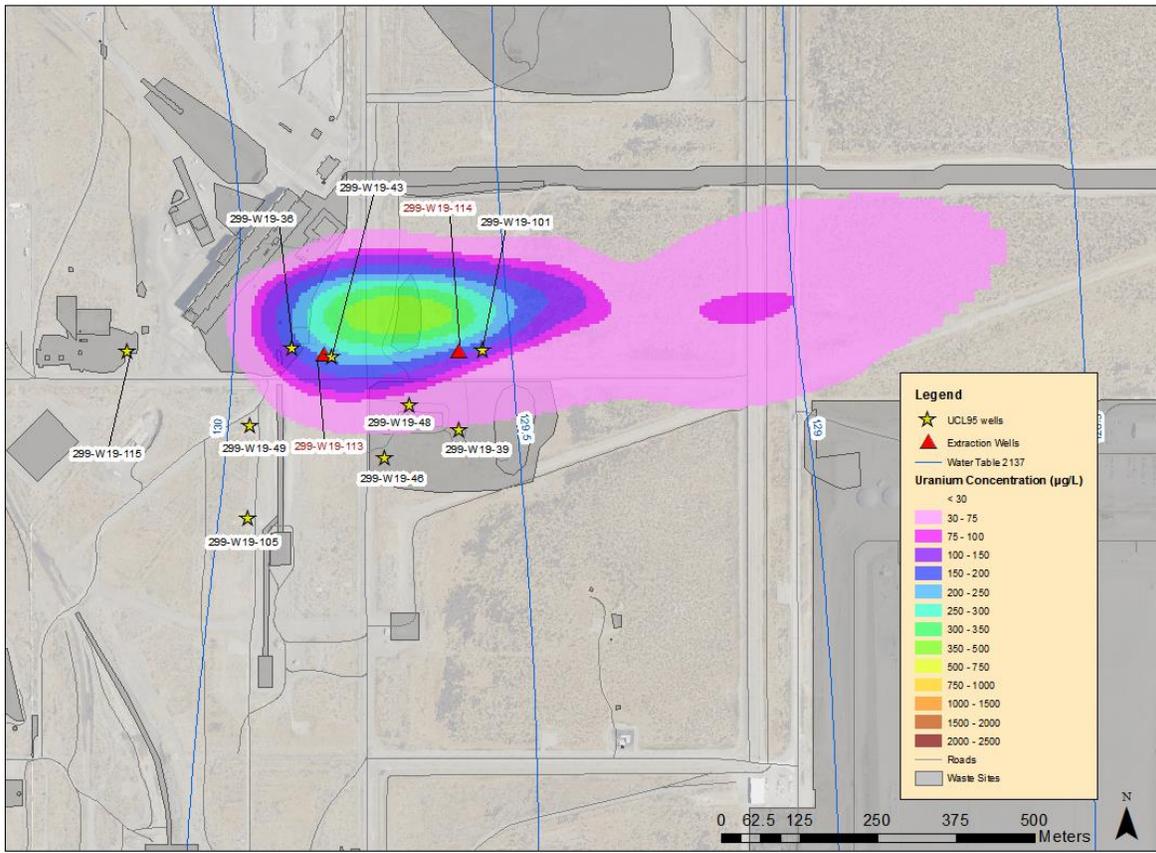


Figure 15. UCL95 Curves for Uranium, Scenario 1



Maximum activity: 523 µg/L      299-W19-18 replaced by 299-W19-115

**Figure 16. Uranium at U Plant with 2015 Initial Conditions, No Continuing Source, Modeled Year 2037, Scenario 1**



Maximum activity: 396 µg/L      299-W19-18 replaced by 299-W19-115

**Figure 17. Uranium at U Plant with 2015 Initial Conditions, No Continuing Source, Modeled Year 2137, Scenario 1**

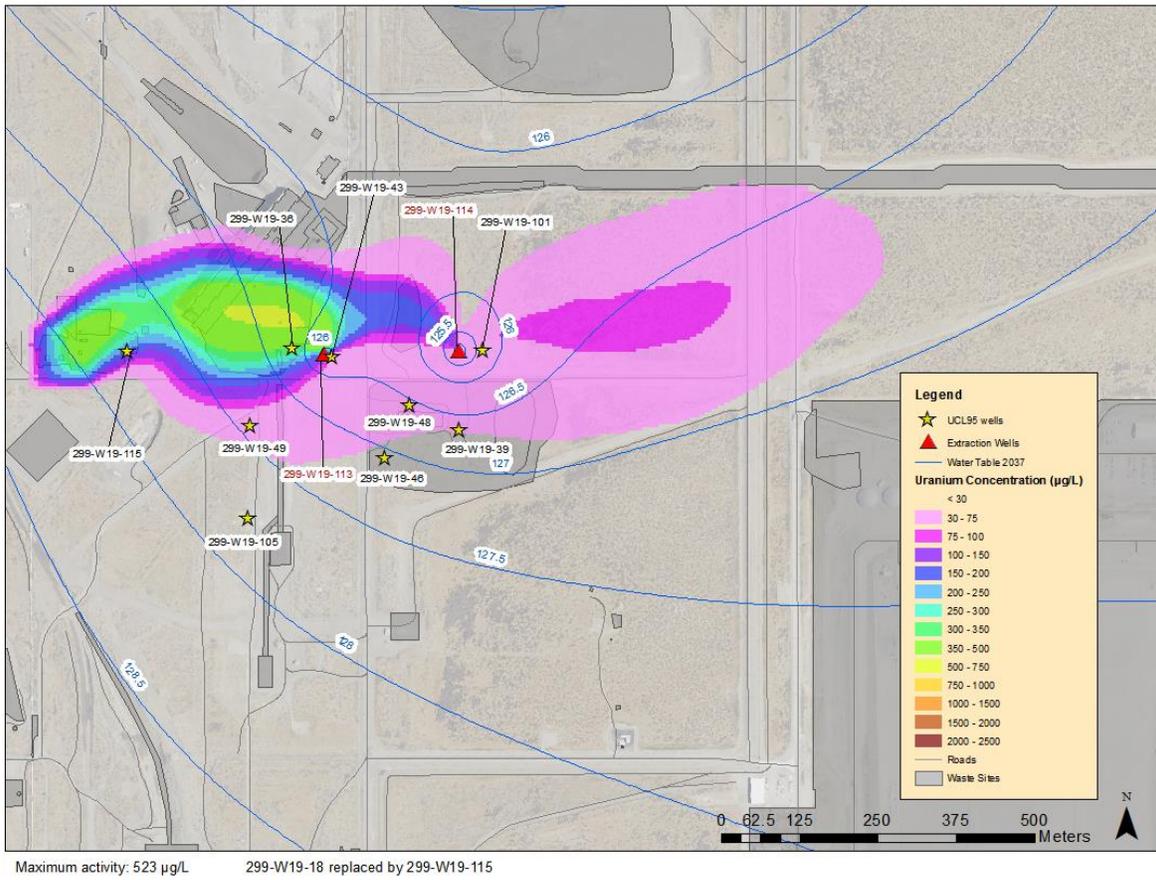
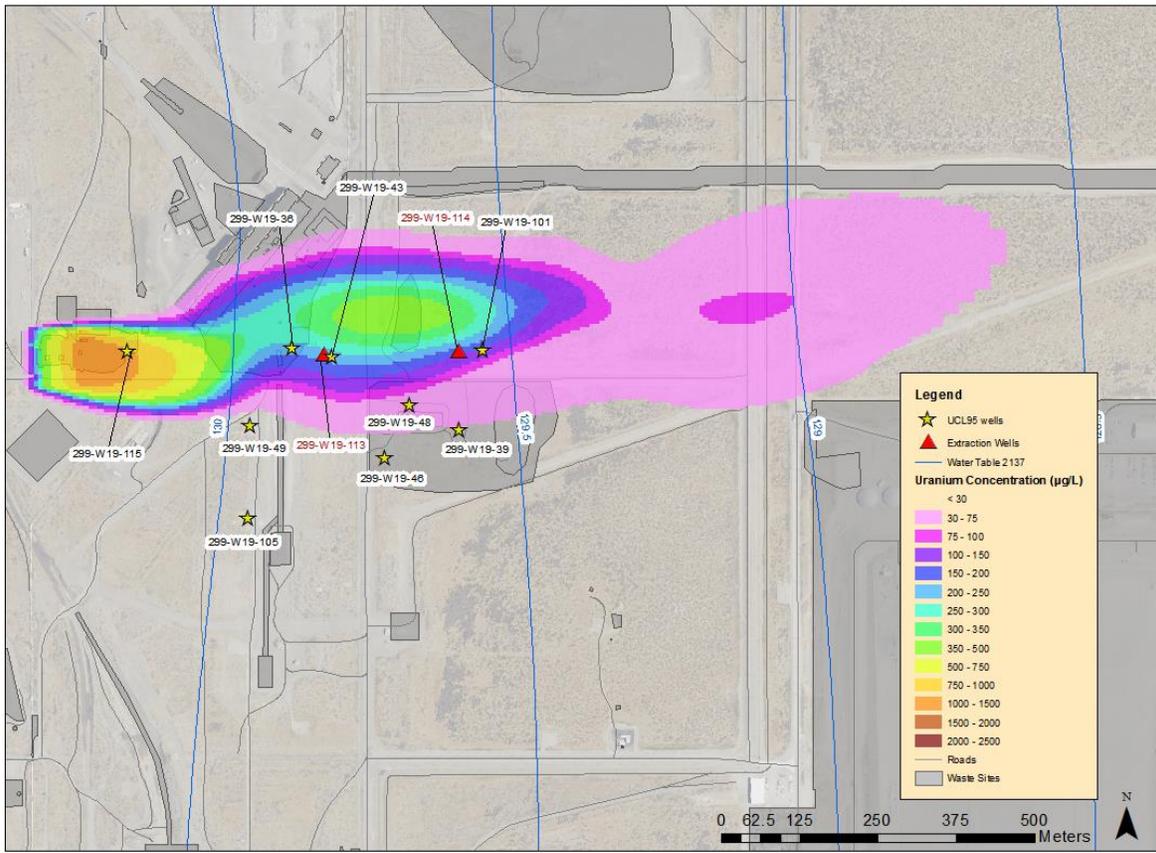
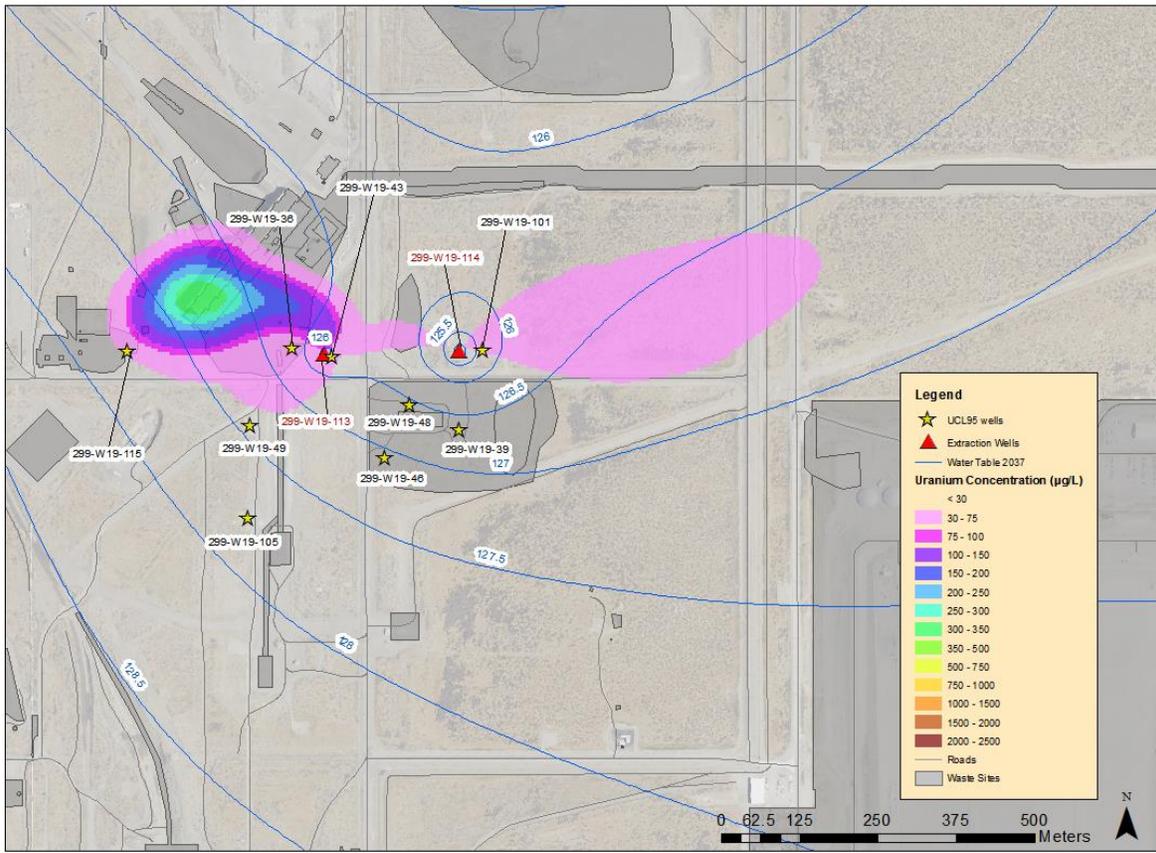


Figure 18. Uranium at U Plant with 2015 Initial Conditions, with Continuing Source, Modeled Year 2037, Scenario 1



Maximum activity: 1215 µg/L      299-W19-18 replaced by 299-W19-115

Figure 19. Uranium at U Plant with 2015 Initial Conditions, with Continuing Source, Modeled Year 2137, Scenario 1



Maximum activity: 348 µg/L      299-W19-18 replaced by 299-W19-115

**Figure 20. Uranium at U Plant with 2016 Initial Conditions, No Continuing Source, Modeled Year 2037, Scenario 1**

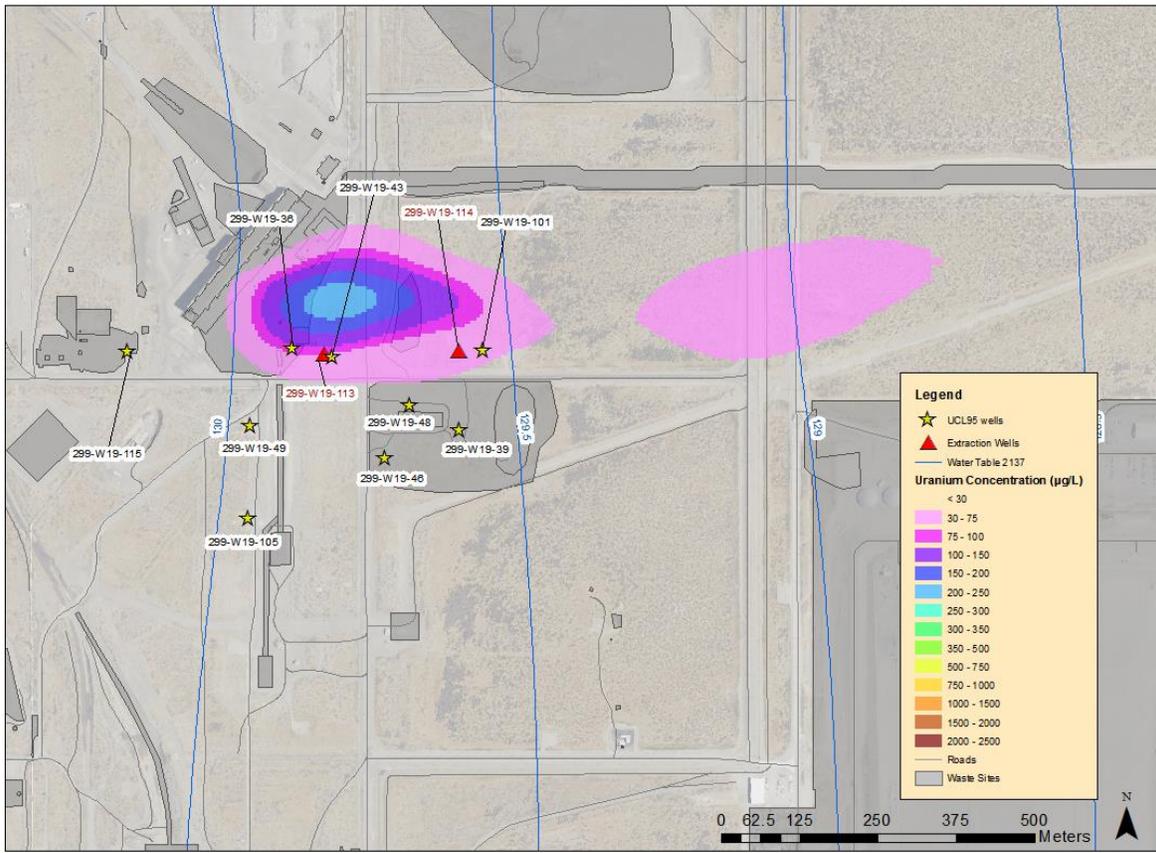
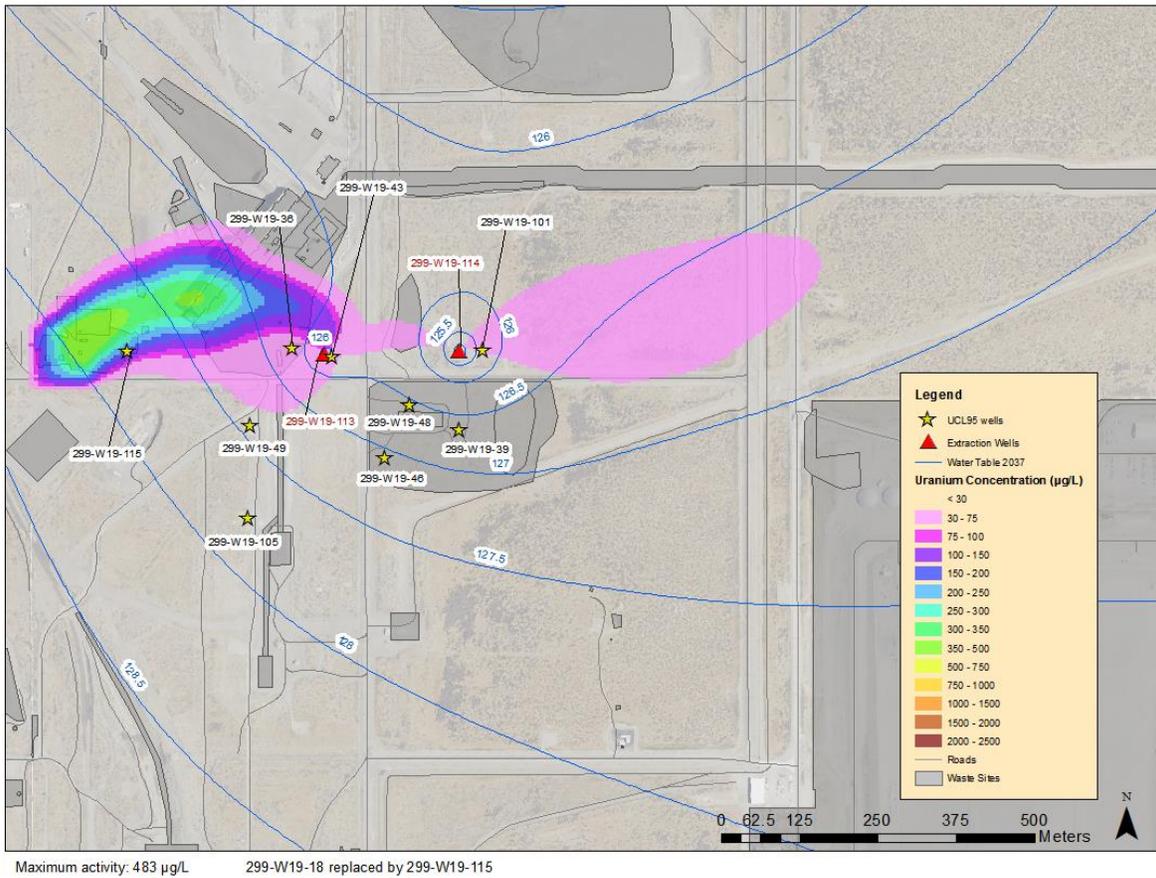
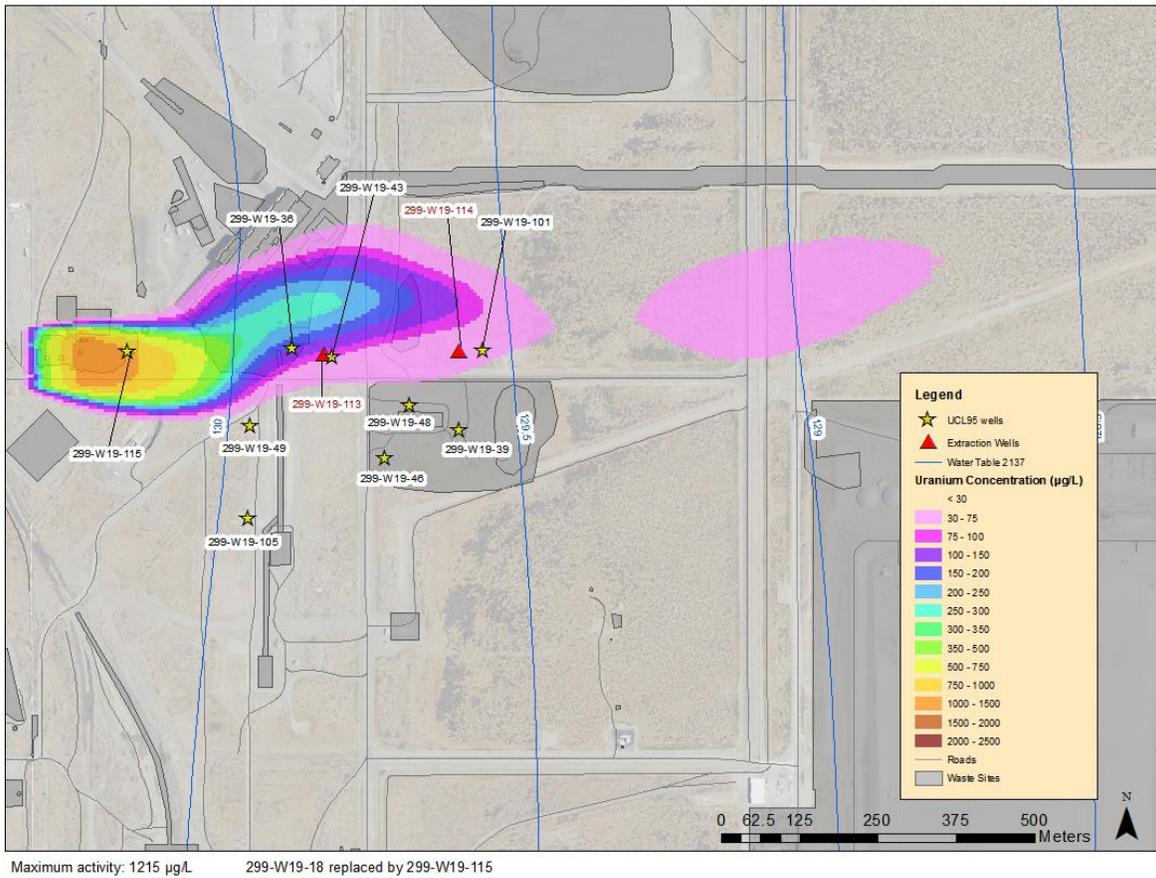


Figure 21. Uranium at U Plant with 2016 Initial Conditions, No Continuing Source, Modeled Year 2137, Scenario 1



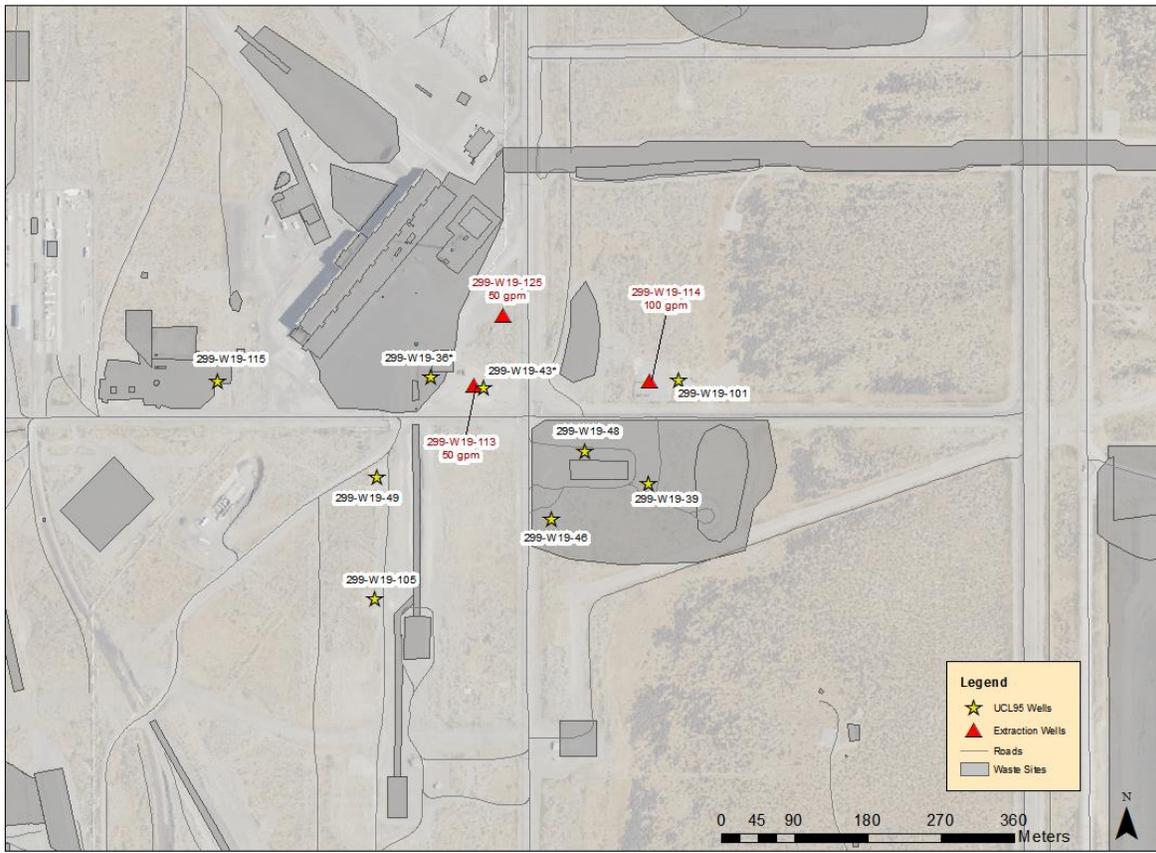
**Figure 22. Uranium at U Plant with 2016 Initial Conditions, with Continuing Source, Modeled Year 2037, Scenario 1**



**Figure 23. Uranium at U Plant with 2016 Initial Conditions, with Continuing Source, Modeled Year 2137, Scenario 1**

## 6.2 Flow Scenario 2

This section contains results from transport models used Scenario 2 as their flow model. In Scenario 2, 299-W19-113 and 299-W19-125 are each pumping at 50 gpm and 299-W19-114 is pumping at 100 gpm, for a total extraction rate of 200 gpm. Figure 24 is a map of all the pumping wells and their rates.



299-W19-18 replaced by 299-W19-115 \*Wells are Tc-99 and uranium UCL95 wells

**Figure 24. UCL95 and Pumping Well Locations, Scenario 2**

### 6.2.1 Technetium-99

When sources are present, slightly over 1.2 curies are extracted by the end of pumping; when they are not present, approximately 1.1 curies are recovered (Figure 25). Mass recovery of Tc-99 in this scenario is similar to the recorded mass recovery obtained from the pump and treat system reports (DOE/RL-2015-06, DOE/RL-2016-20, DOE/RL-2016-69). With or without a continuing source, Tc-99 is cleaned up after slightly over five years of pumping (Figure 26). Without a continuing source, Tc-99 remains cleaned up (Figure 27 and Figure 28). With a continuing source, the buildup of mass is enough that a persistent plume formed exclusively by the continuing source is present in 2037 (Figure 29), and increases in size by 2137 (Figure 30). In 2037, the plume direction is to the northeast due to the influence of pumping at ZP-1, but with the cessation of pumping the plume flows due east by 2137.

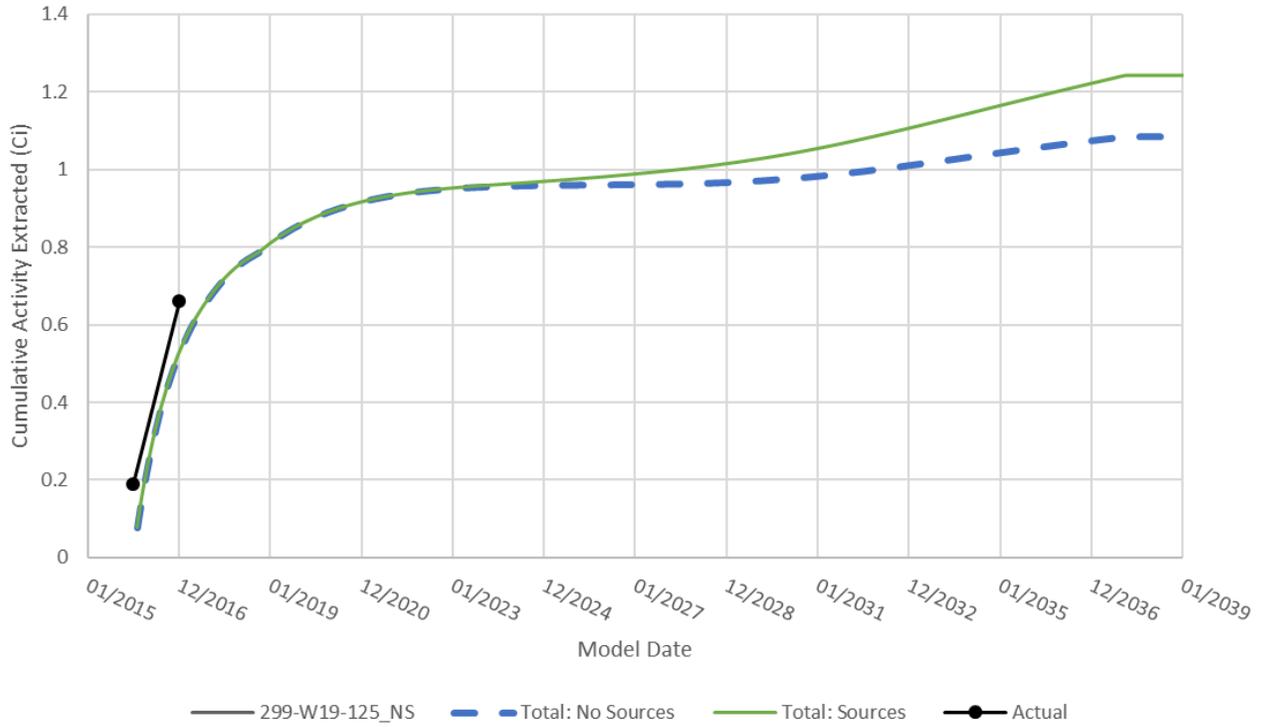


Figure 25. Cumulative Activity Extraction of Tc-99, Scenario 2, Compared to Actual Activity Extraction Values

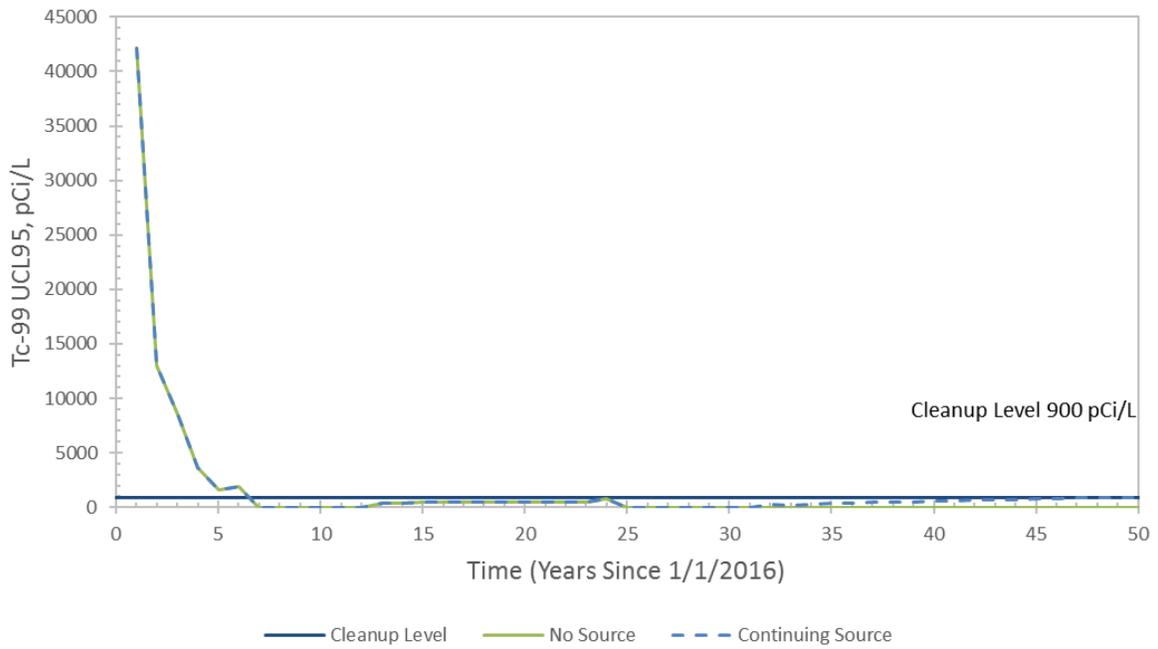
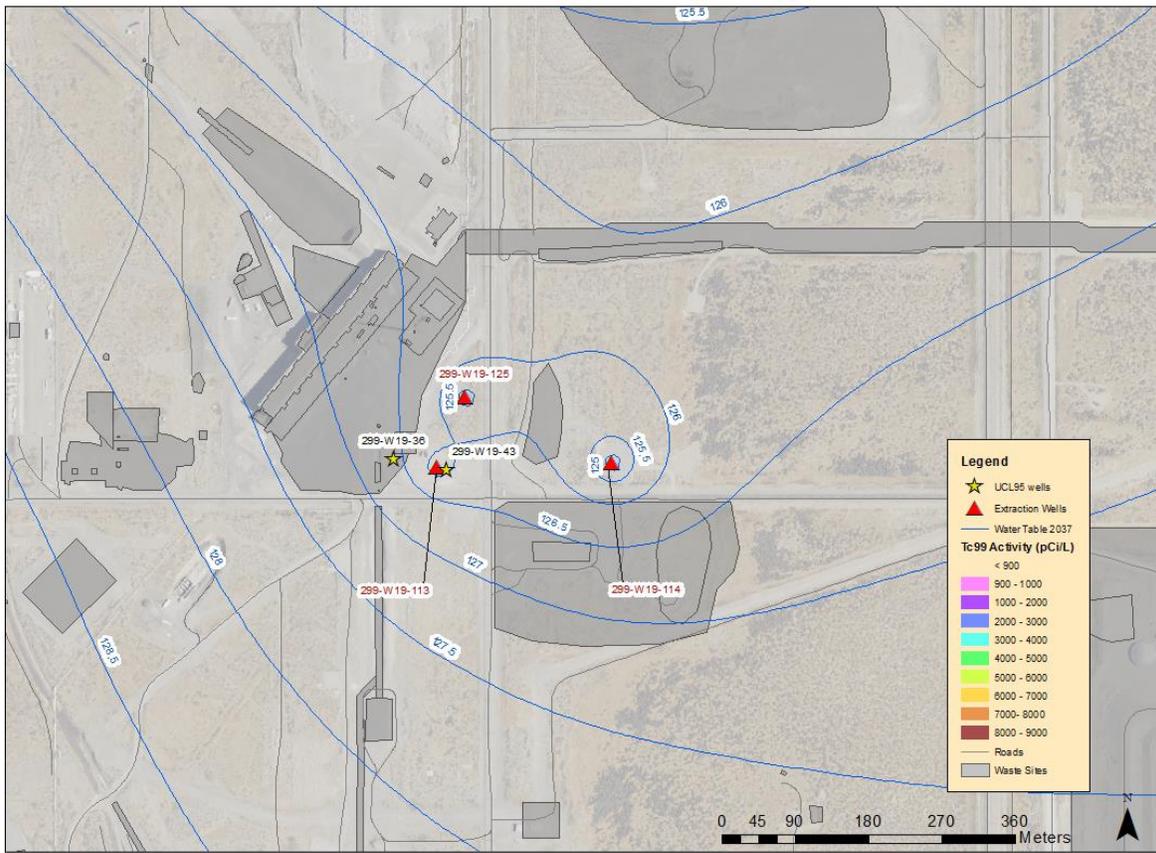
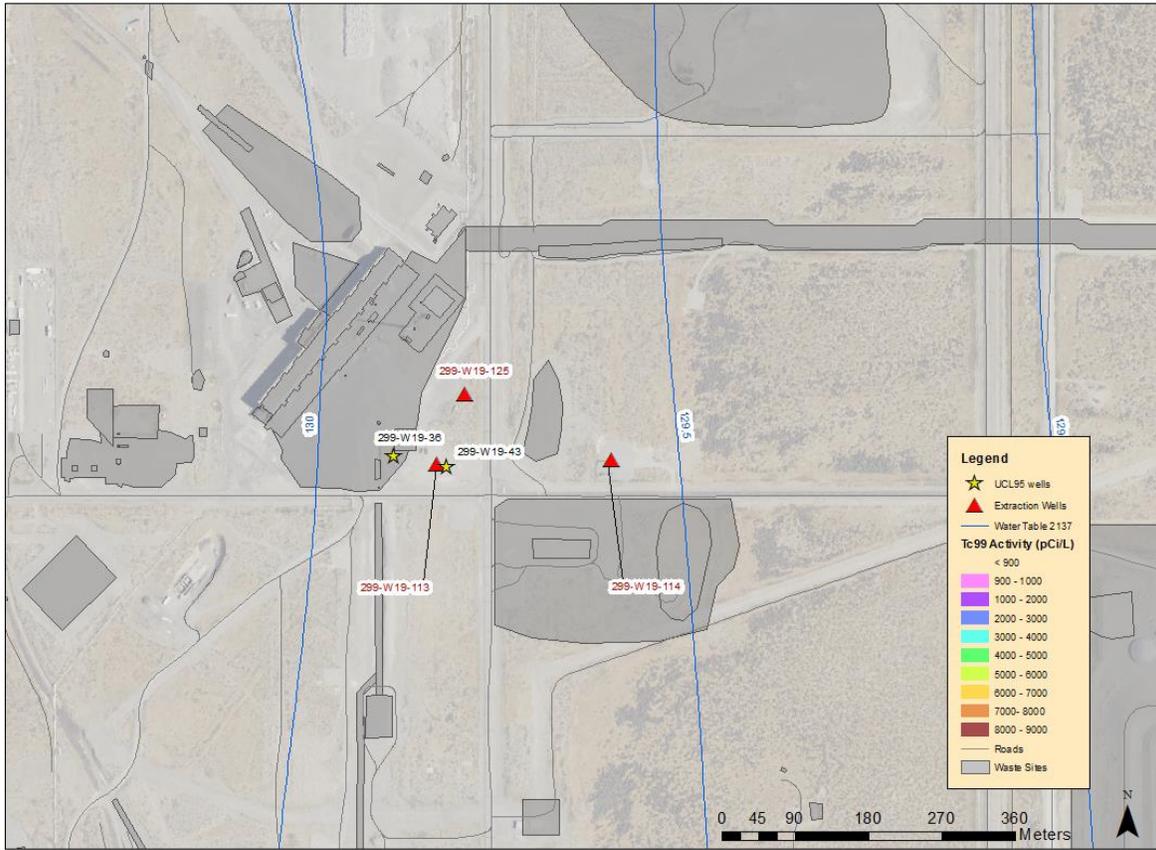


Figure 26. UCL95 Curves for Tc-99, Scenario 2



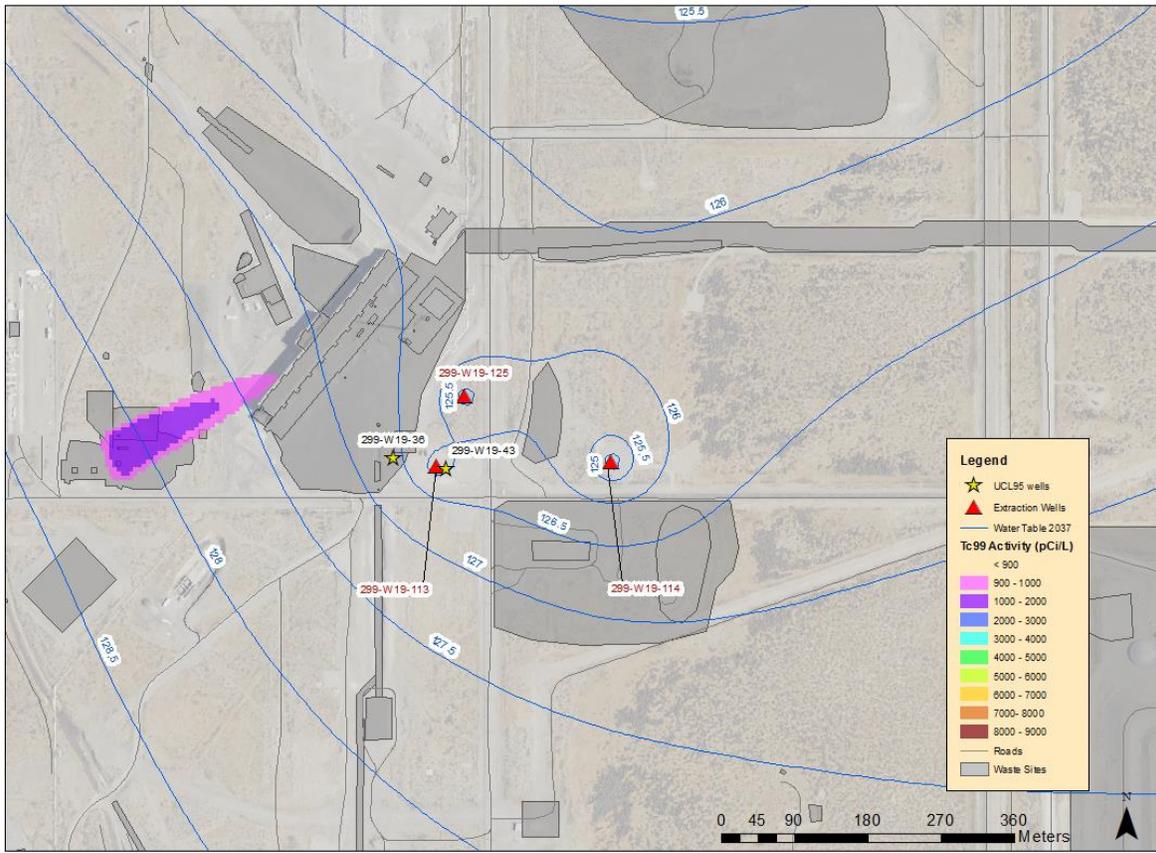
Maximum activity: < 900 pCi/L

**Figure 27. Tc-99 at U Plant with No Continuing Source, Modeled Year 2037, Scenario 2**



Maximum activity: < 900 pCi/L

Figure 28. Tc-99 at U Plant with No Continuing Source, Modeled Year 2137, Scenario 2



Maximum activity: 1228 pCi/L

Figure 29. Tc-99 at U Plant with Continuing Source, Modeled Year 2037, Scenario 2

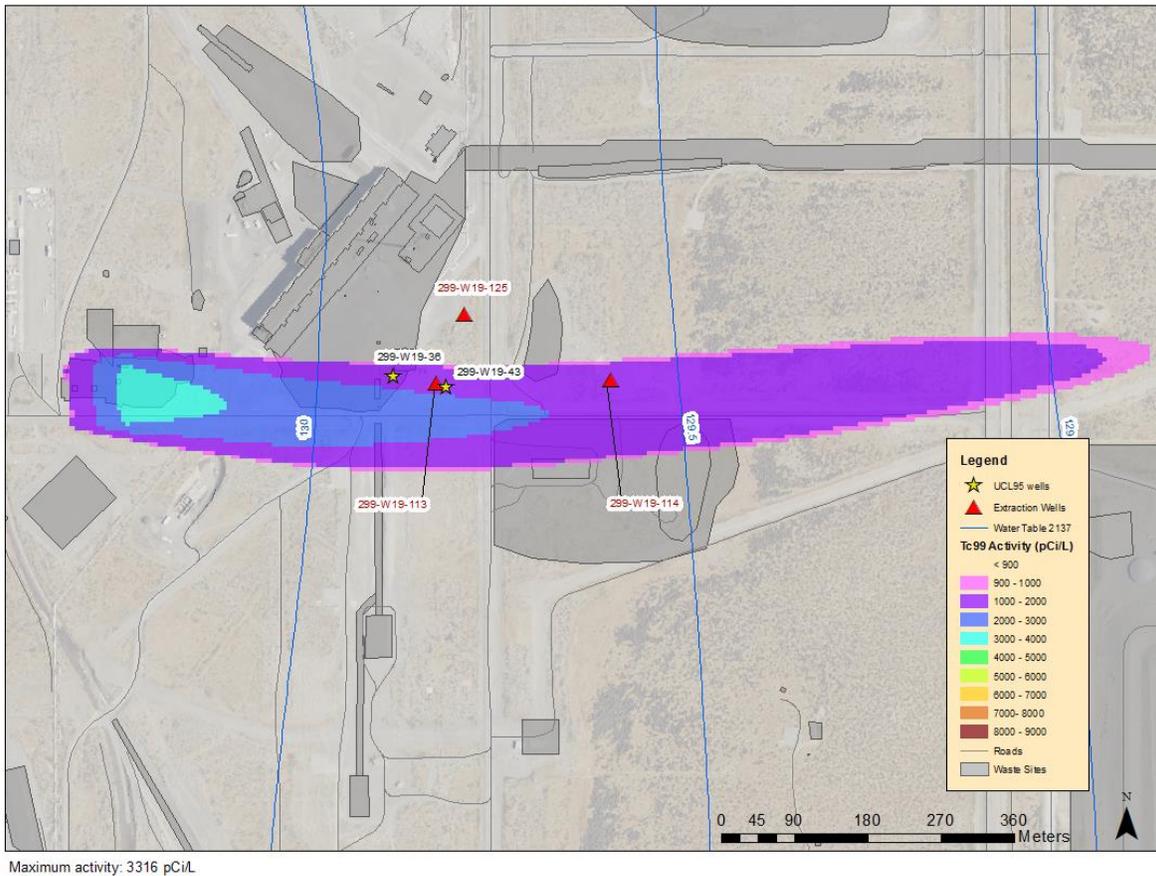
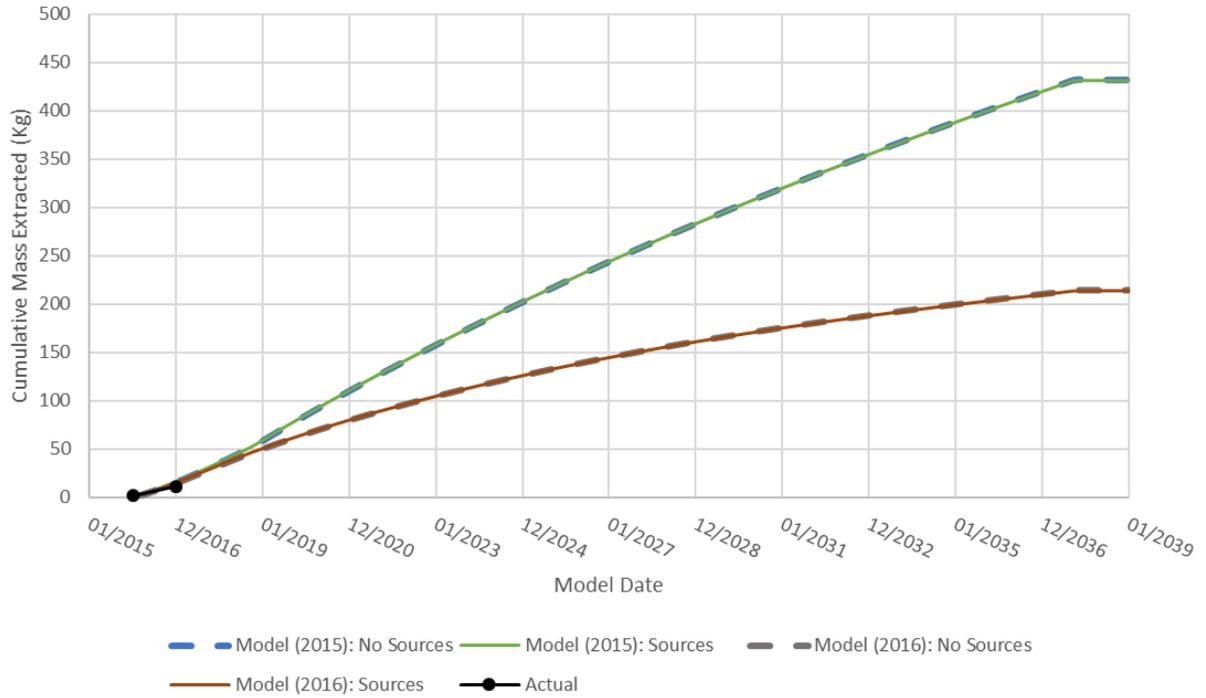


Figure 30. Tc-99 at U Plant with Continuing Source, Modeled Year 2137, Scenario 2

## 6.2.2 Uranium

The impact of the initial conditions can be clearly seen in every figure below. The 2015 initial conditions have an initial mass of approximately 630 kg of uranium, while the 2016 initial conditions have an initial mass of approximately 400 kg of uranium. More Tc-99 is recovered when 2015 initial conditions are used (Figure 31), but this does not translate to better cleanup, both in terms of UCL95 (Figure 32) and overall plume size and concentration (Figure 33 through Figure 40). Cleanup is not reached with 2015 initial conditions, with or without sources. With 2016 working initial conditions and no sources, the UCL95 is reached approximately 23 years after the start of pumping, even though a sizable plume is present with

concentrations above the MCL of 30 µg/L (Figure 37 and Figure 38). Cleanup, in terms of plume size and UCL95, is very similar to Scenario 1.



**Figure 31. Cumulative Activity Extraction of Uranium, Scenario 2, Compared to Actual Activity Extraction Values**

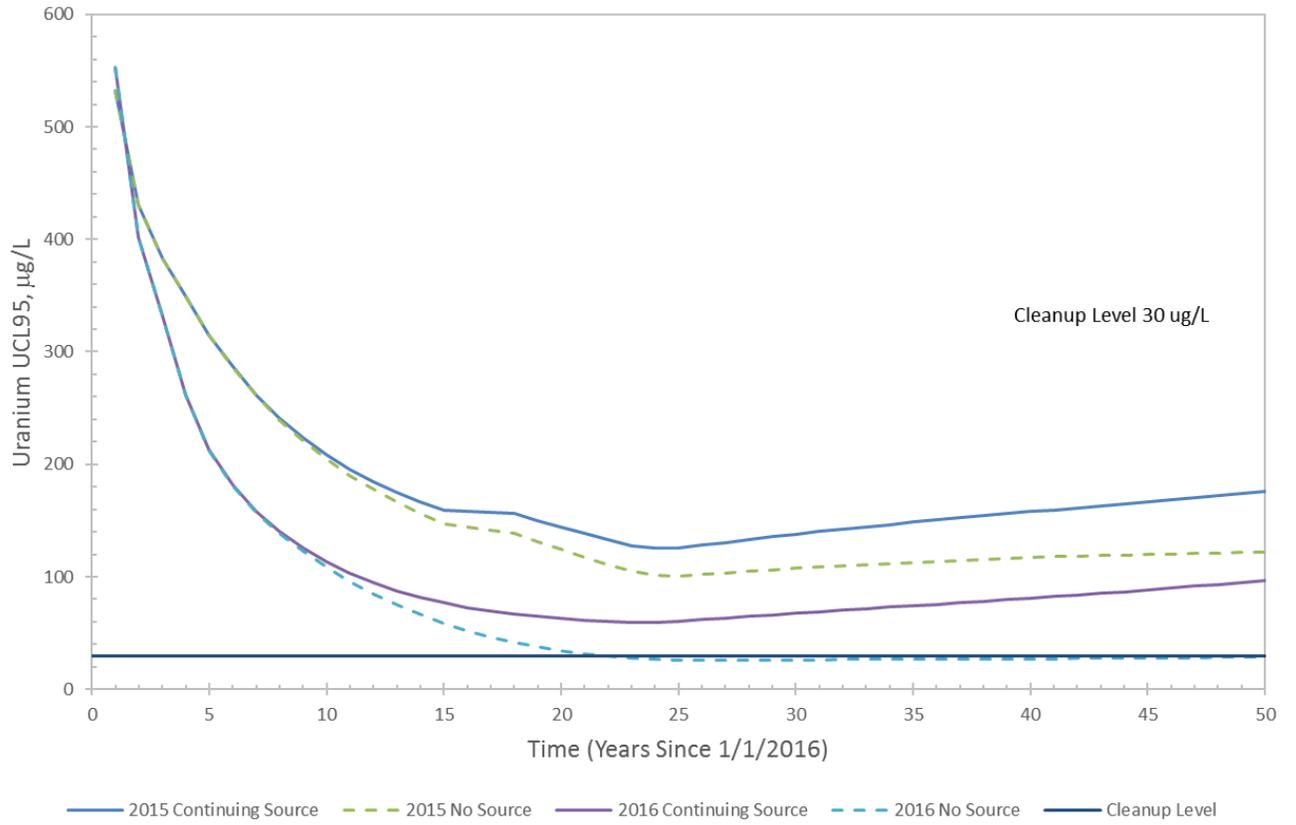
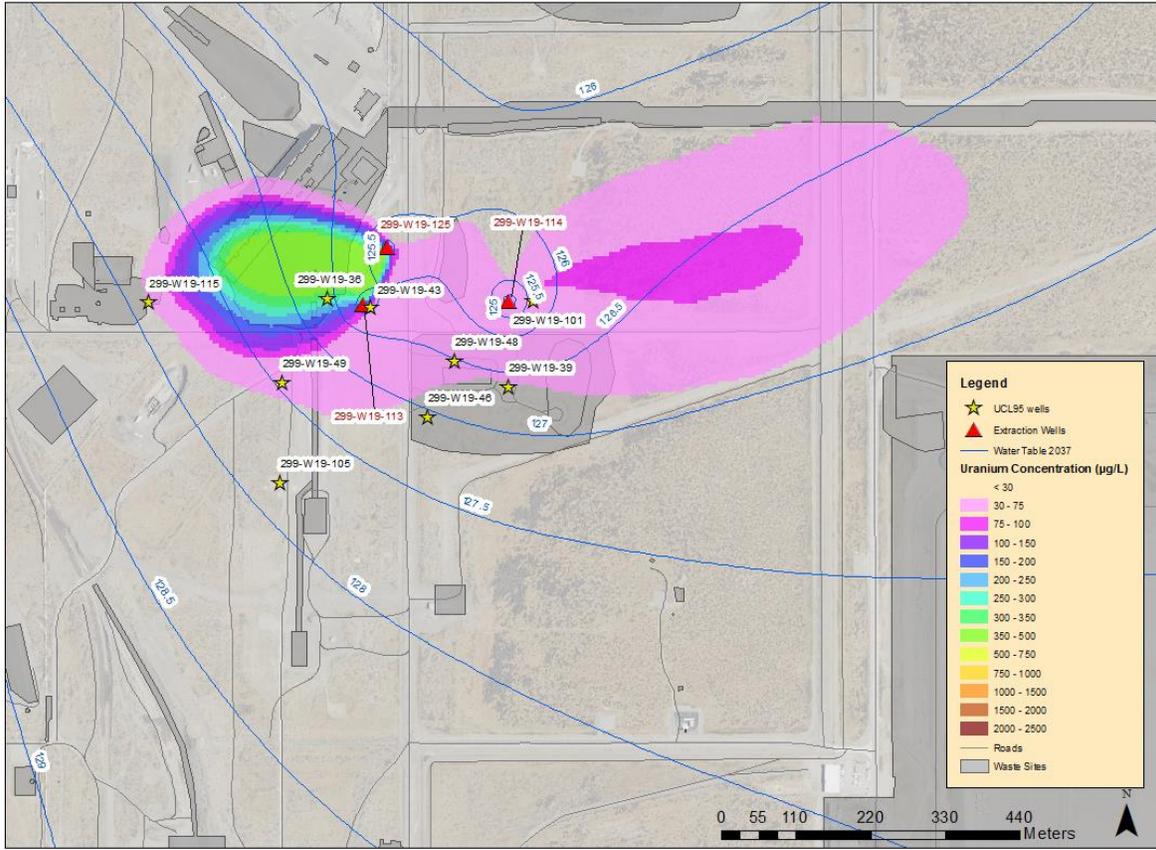
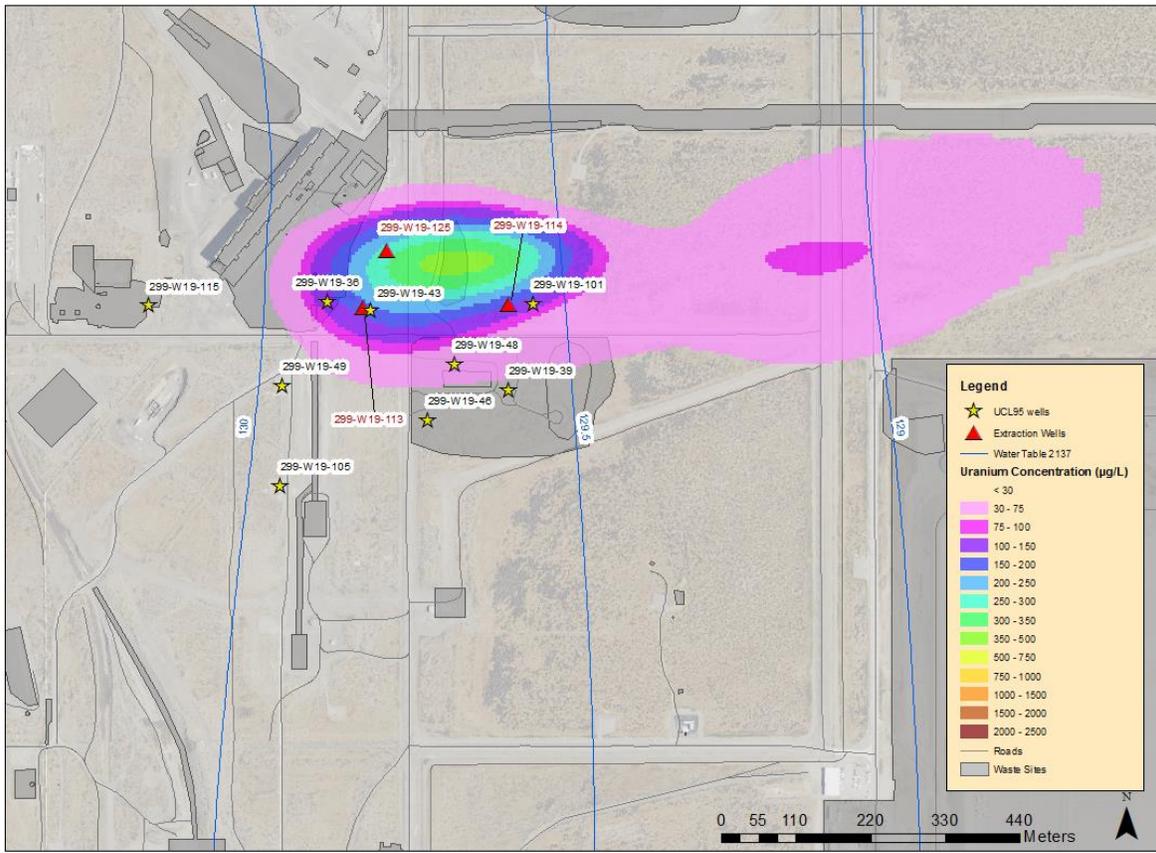


Figure 32. UCL95 Curves for Uranium, Scenario 2

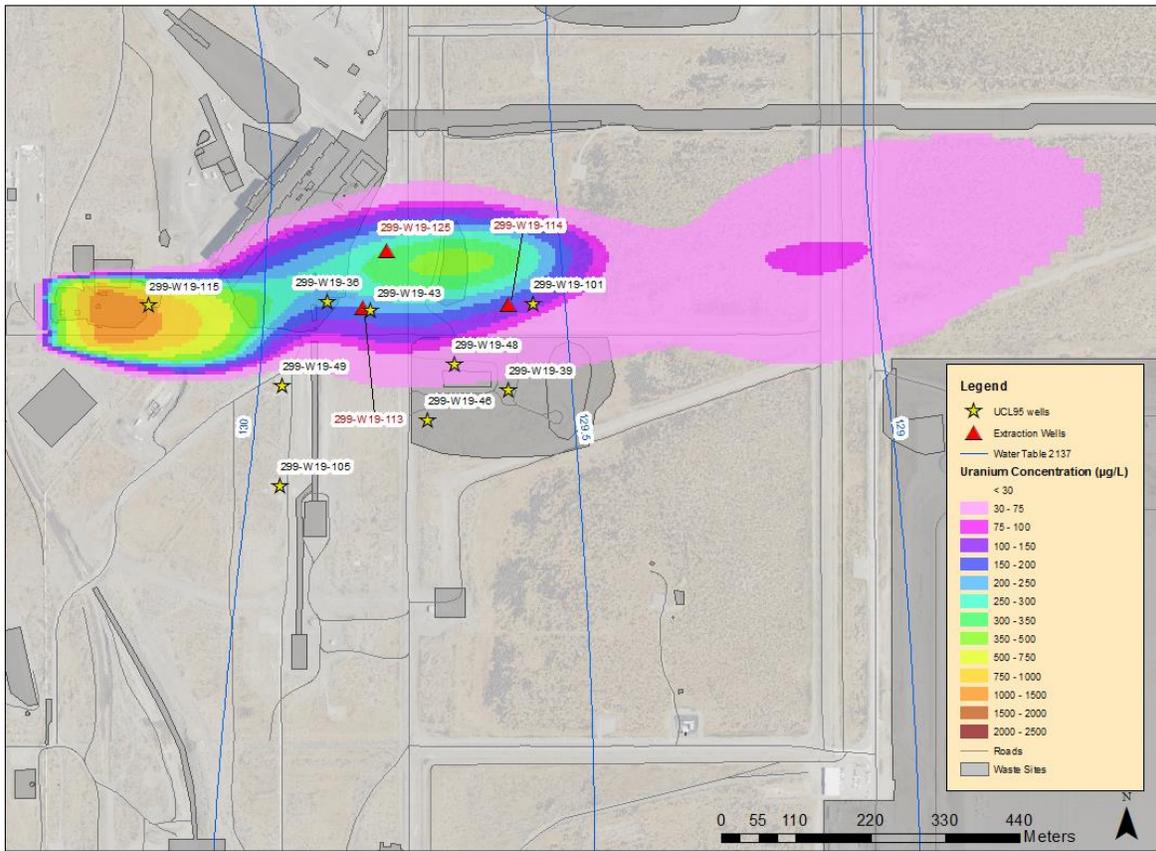




Maximum Concentration: 369 µg/L 299-W19-18 replaced by 299-W19-115

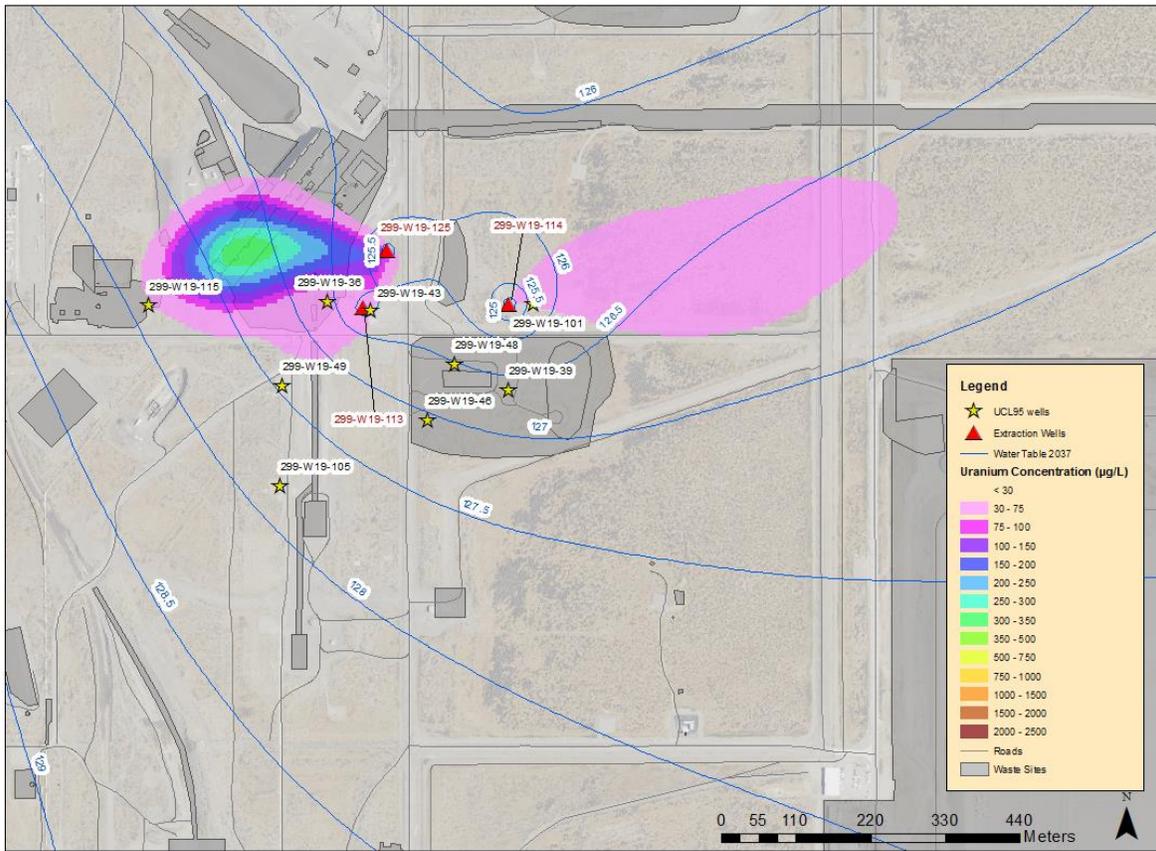
**Figure 34. Uranium at U Plant with 2015 Initial Conditions, No Continuing Source, Modeled Year 2137, Scenario 2**





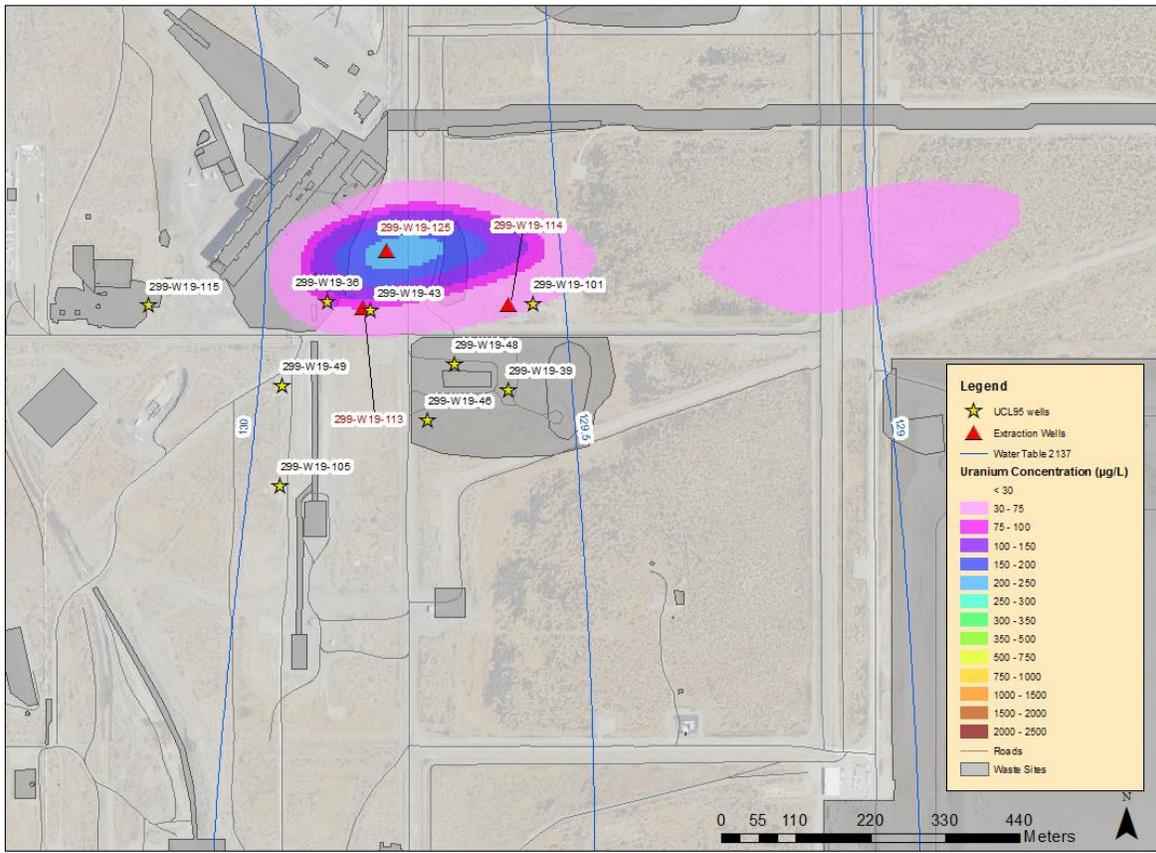
Maximum Concentration: 1215 µg/L 299-W19-18 replaced by 299-W19-115

**Figure 36. Uranium at U Plant with 2015 Initial Conditions, with Continuing Source, Modeled Year 2137, Scenario 2**



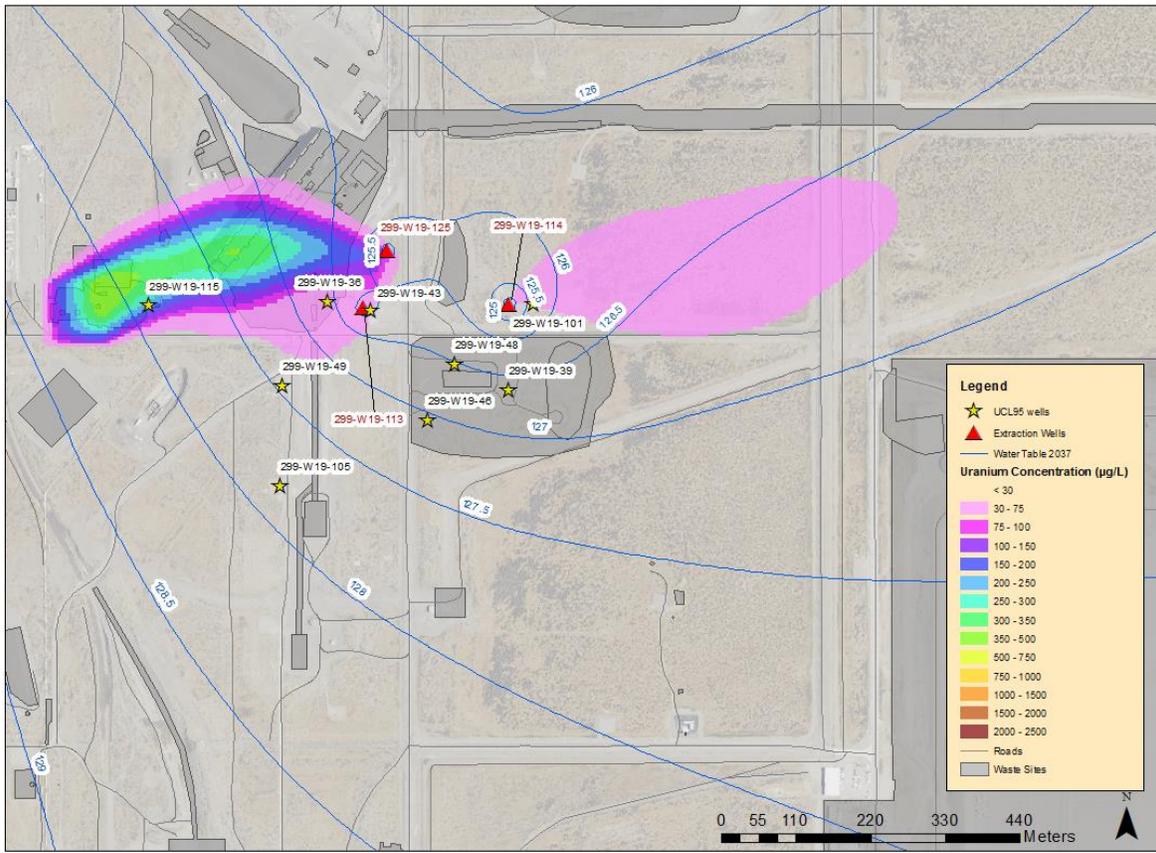
Maximum Concentration: 335 µg/L 299-W19-18 replaced by 299-W19-115

**Figure 37. Uranium at U Plant with 2016 Initial Conditions, No Continuing Source, Modeled Year 2037, Scenario 2**



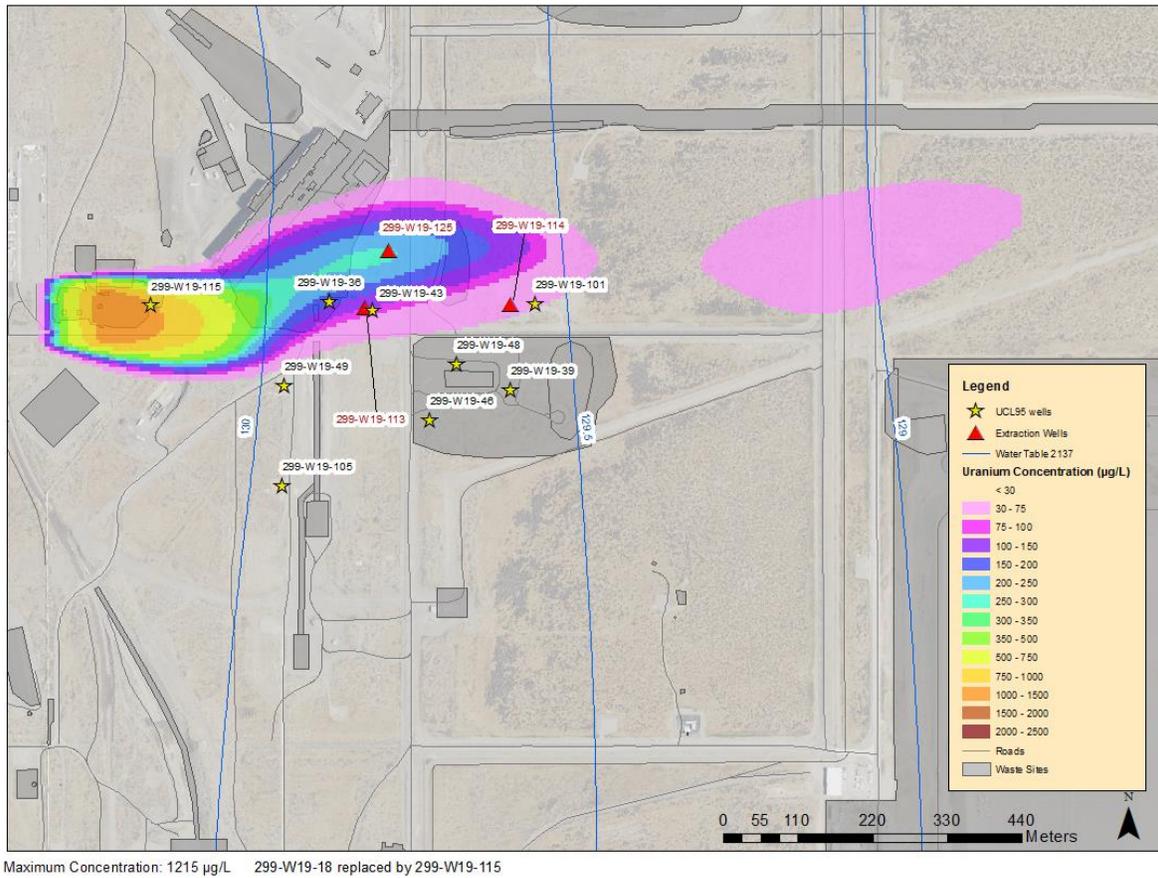
Maximum Concentration: 226 µg/L 299-W19-18 replaced by 299-W19-115

**Figure 38. Uranium at U Plant with 2016 Initial Conditions, No Continuing Source, Modeled Year 2137, Scenario 2**



Maximum Concentration: 423 µg/L 299-W19-18 replaced by 299-W19-115

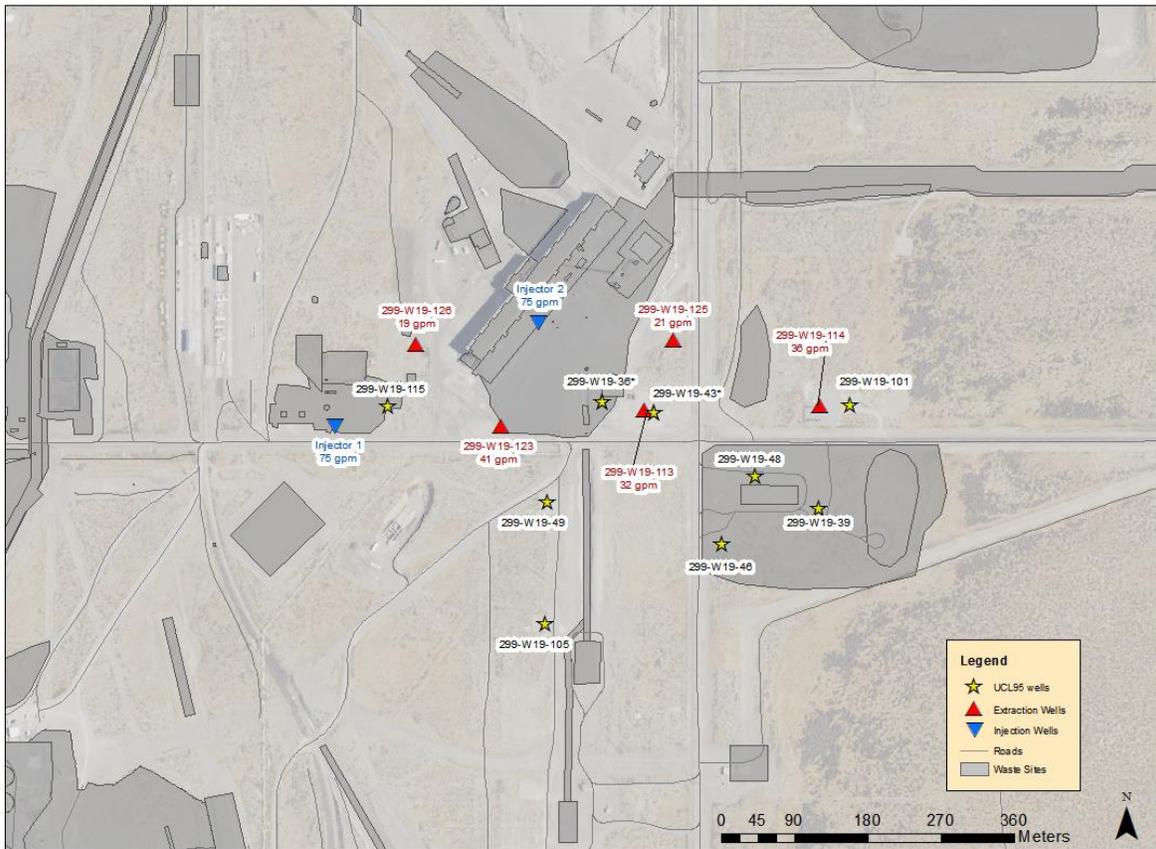
**Figure 39. Uranium at U Plant with 2016 Initial Conditions, with Continuing Source, Modeled Year 2037, Scenario 2**



**Figure 40. Uranium at U Plant with 2016 Initial Conditions, with Continuing Source, Modeled Year 2137, Scenario 2**

### 6.3 Flow Scenario 3

This section contains results from transport models used Scenario 3 as their flow model. In Scenario 3, extraction rates are as follows: 299-W19-113 at 32 gpm, 299-W19-114 at 36 gpm, 299-W19-123 at 41 gpm, 299-W19-125 at 21 gpm, and 299-W19-126 at 19. The total extraction rate is 150 gpm. This scenario also has two injection wells, Injector 1 and 2, with injection rates of 75 gpm, for a total injection rate of 150 gpm. These extraction and injection rates were selected using SCE. Figure 41 is a map of all the pumping wells and their rates.



299-W19-18 replaced by 299-W19-115 \*Wells are Tc-99 and uranium UCL95 wells

Figure 41. UCL95 and Pumping Well Locations, Scenario 3

### 6.3.1 Technetium-99

With or without a continuing source, Tc-99 is cleaned up after approximately six years of pumping (Figure 42). Approximately 1 curie of mass is extracted during pumping, regardless of whether sources are present (Figure 43). Mass recovery of Tc-99 in this scenario is similar to the recorded mass recovery obtained from the pump and treat system reports (DOE/RL-2015-06, DOE/RL-2016-20, DOE/RL-2016-69). Without a continuing source, Tc-99 remains cleaned up (Figure 44 and Figure 45) and even pulls some of the Tc-99 from the S-SX area in 2037. With a continuing source, the buildup of mass is enough that a persistent plume is present in 2037 (Figure 46), and increases in size by 2137 (Figure 47). The plume from the continuing source is much smaller in 2037 than it is in continuing source transport simulations for Scenario 1 and 2, due to the influence of the injection well near the source. The peak concentration in 2037 for this scenario is 1002 pCi/L, while for Scenario 1 it's 1434 (Figure 12) and for Scenario 2 it's 1228 (Figure 29). However, all three plumes behave the same by 2137, with the same maximum concentrations, and very similar flow directions and plume sizes (Figure 13, Figure 30, and Figure 47 for Scenarios 1, 2, and 3, respectively).

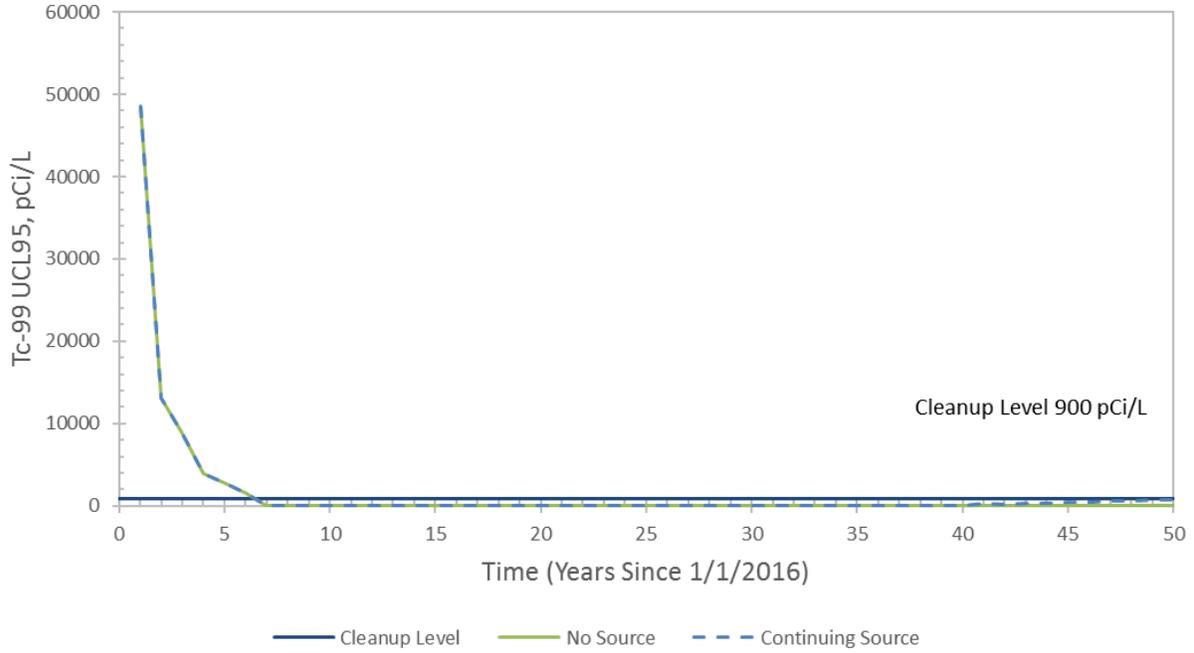


Figure 42. UCL95 Curves for Tc-99, Scenario 3

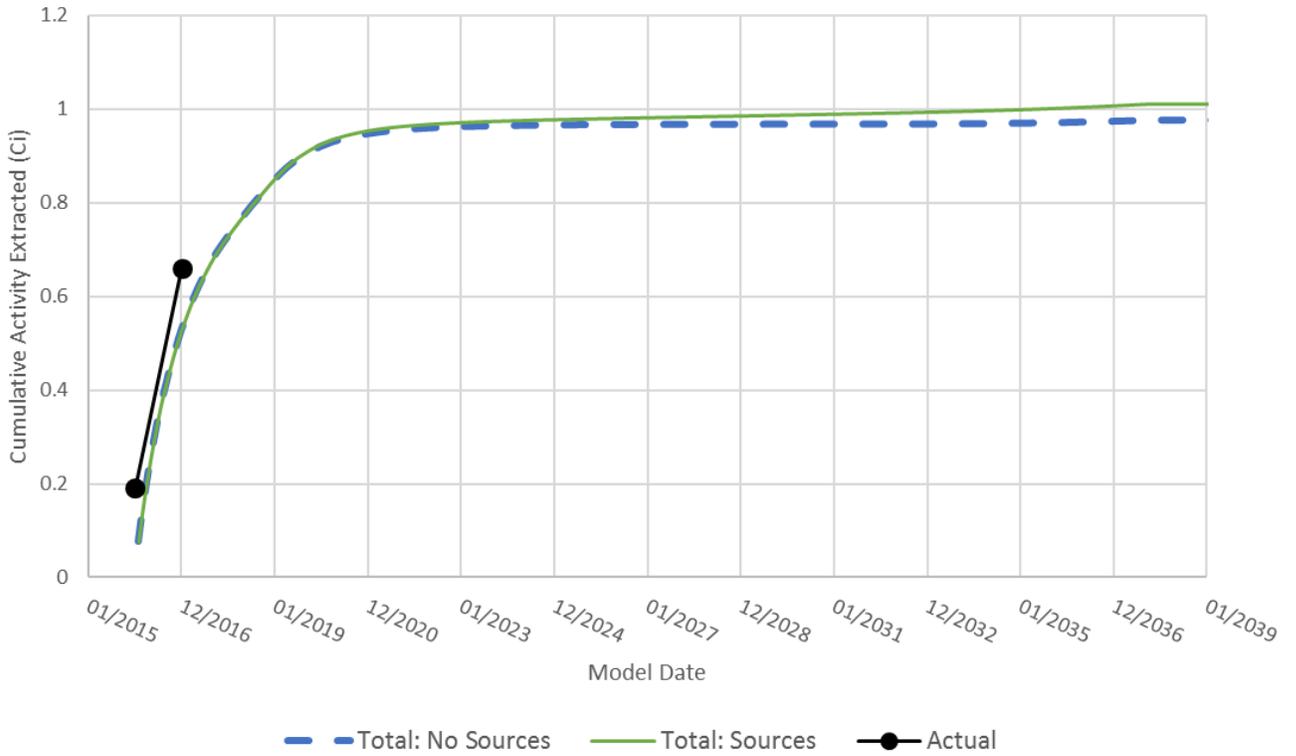
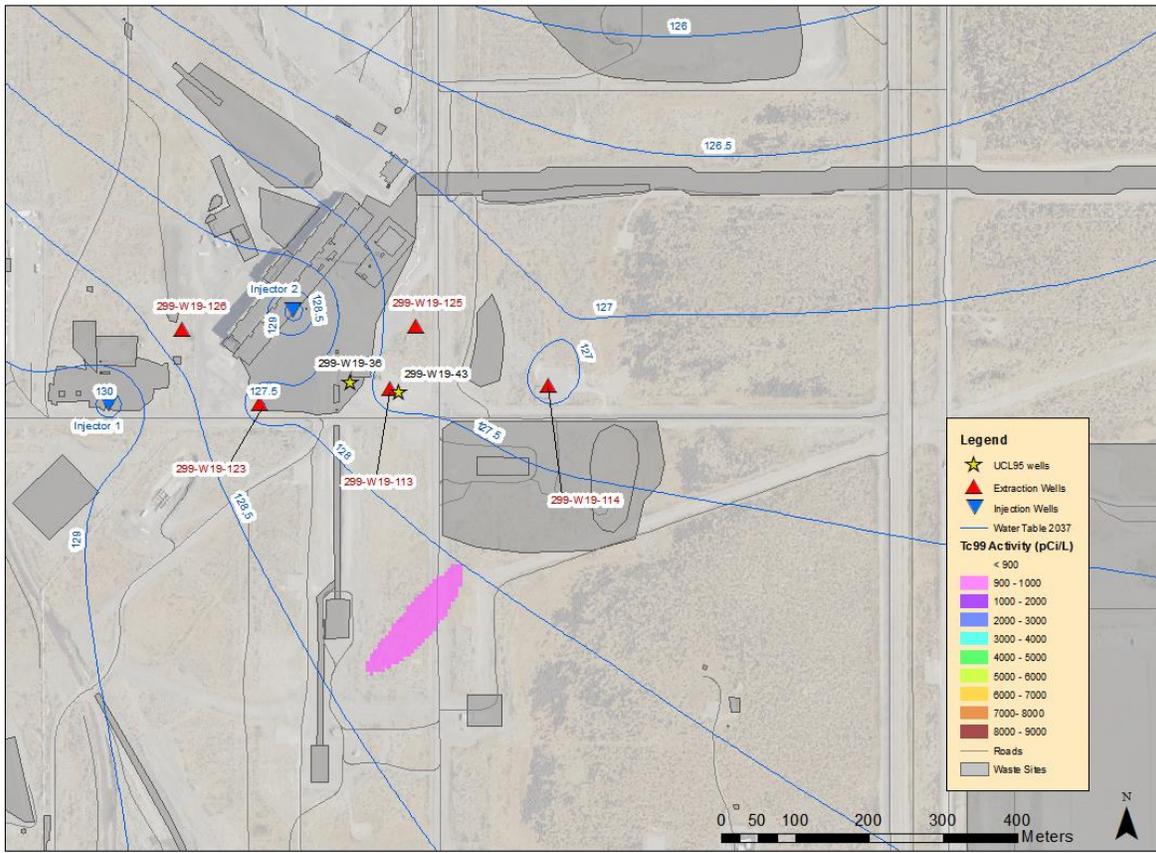
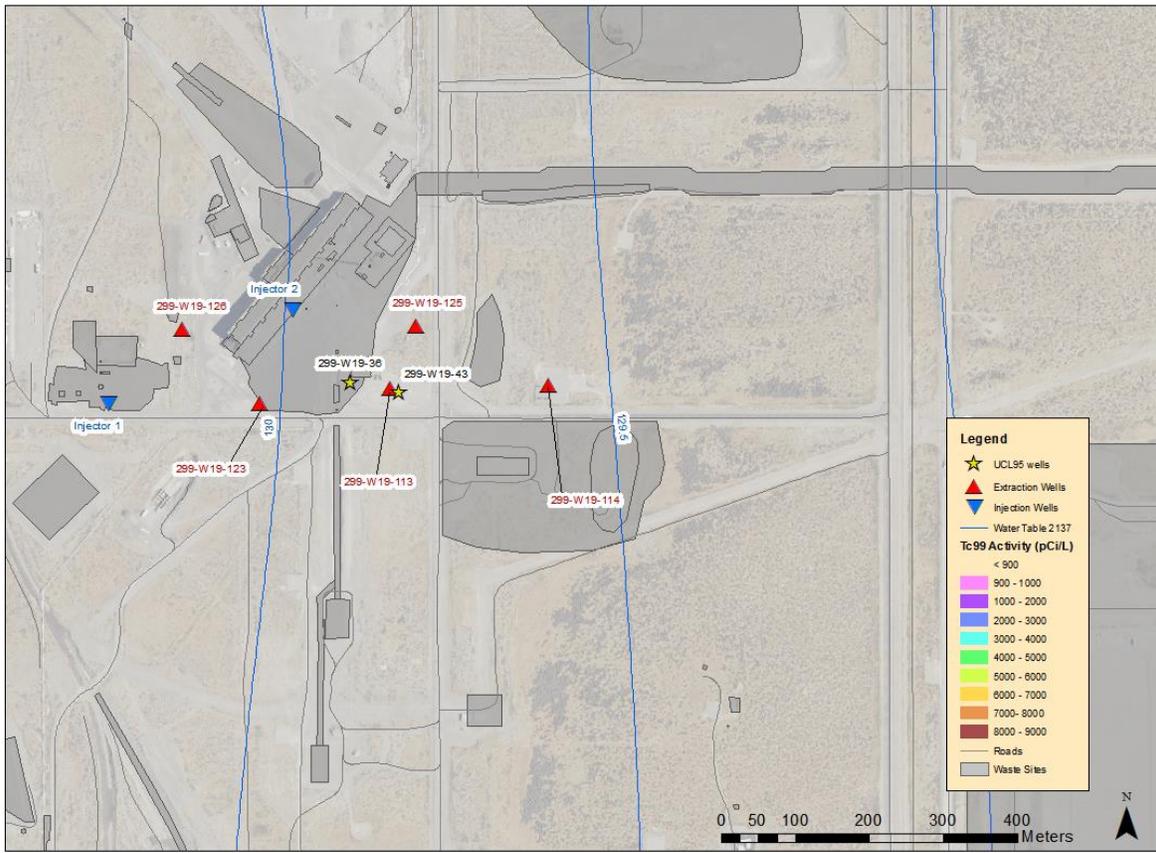


Figure 43. Cumulative Activity Extraction of Tc-99, Scenario 3, Compared to Actual Activity Extraction Values



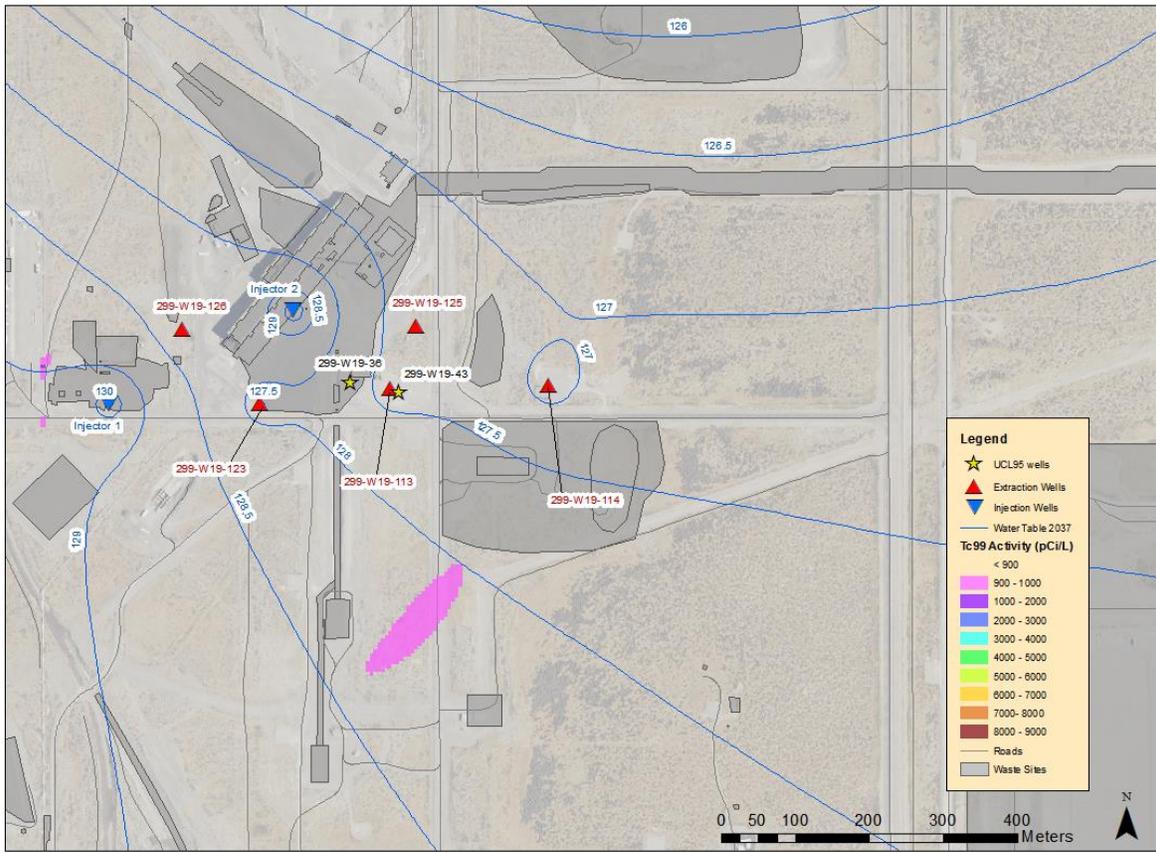
Maximum activity: 993 pCi/L

Figure 44. Tc-99 at U Plant with No Continuing Source, Modeled Year 2037, Scenario 3



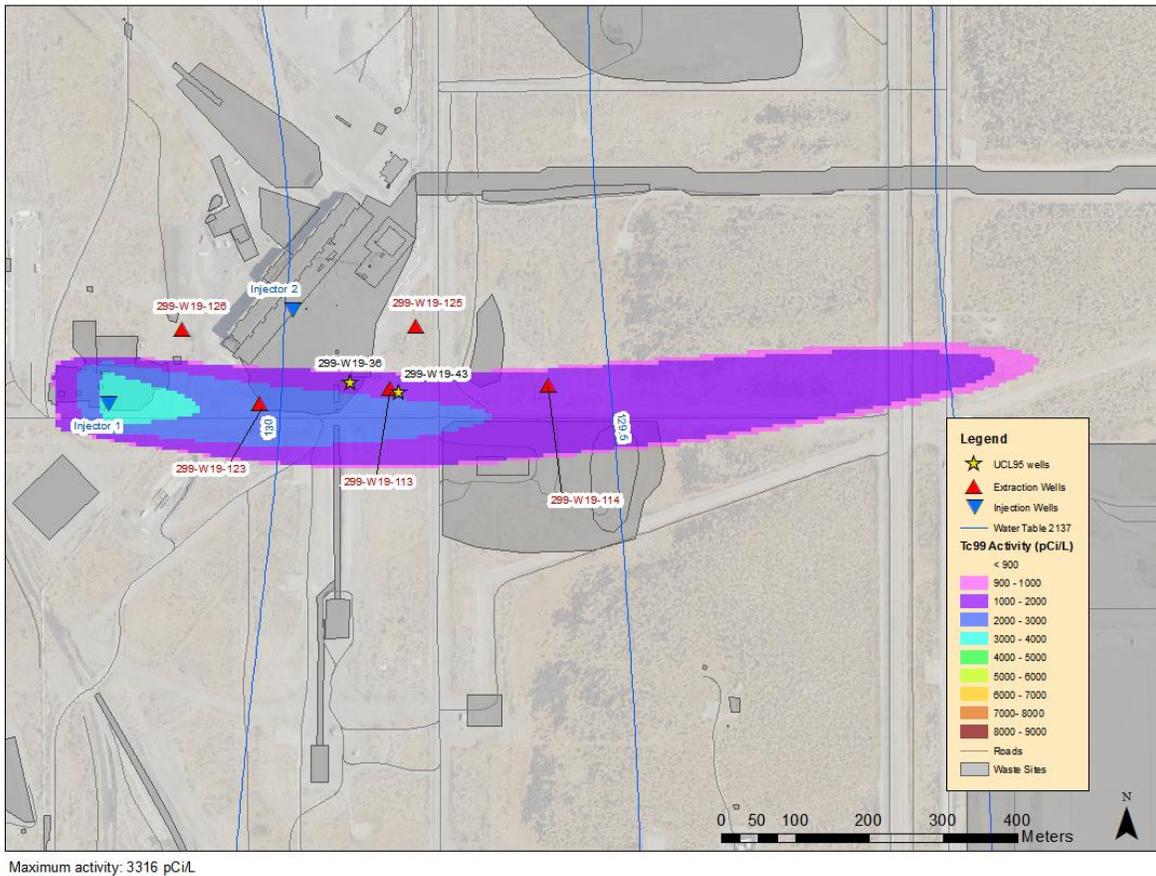
Maximum activity: < 900 pCi/L

Figure 45. Tc-99 at U Plant with No Continuing Source, Modeled Year 2137, Scenario 3



Maximum activity: 1002 pCi/L

Figure 46. Tc-99 at U Plant with Continuing Source, Modeled Year 2037, Scenario 3



**Figure 47. Tc-99 at U Plant with Continuing Source, Modeled Year 2137, Scenario 3**

### 6.3.2 Uranium

The impact of the initial conditions on the uranium plume can be clearly seen in every figure below. The 2015 initial conditions have an initial mass of approximately 630 kg of uranium, while the 2016 initial conditions have an initial mass of approximately 400 kg of uranium. Nearly twice as much mass is recovered when 2015 initial conditions are used instead of the 2016 working initial conditions (Figure 48), but this does not translate to better cleanup, both in terms of UCL95 (Figure 49) and overall plume size and concentration (Figure 50 through Figure 57). The UCL95 indicates that cleanup is not reached with 2015 initial conditions, with or without sources. The peak concentrations in 2037 and 2137 (Figure 50 and Figure 51) are lower than Scenario 1 or Scenario 2 transport runs with 2015 initial conditions and no continuing source, due to the capture or dilution of the core of the plume. The peak concentration when sources are present is also lower in 2037 in this scenario (Figure 52) than the peak concentration in Scenarios 1 or 2. However, by 2137 (Figure 53), the peak concentration when sources are present is similar to that of the other scenarios, though the size of the plume is significantly smaller. With 2016

working initial conditions, the UCL95 indicates cleanup may be reached approximately 20 years after the start of pumping, regardless of whether a continuing source is present (Figure 56 and Figure 57).



Figure 48. Cumulative Activity Extraction of Uranium, Scenario 3, Compared to Actual Activity Extraction Values

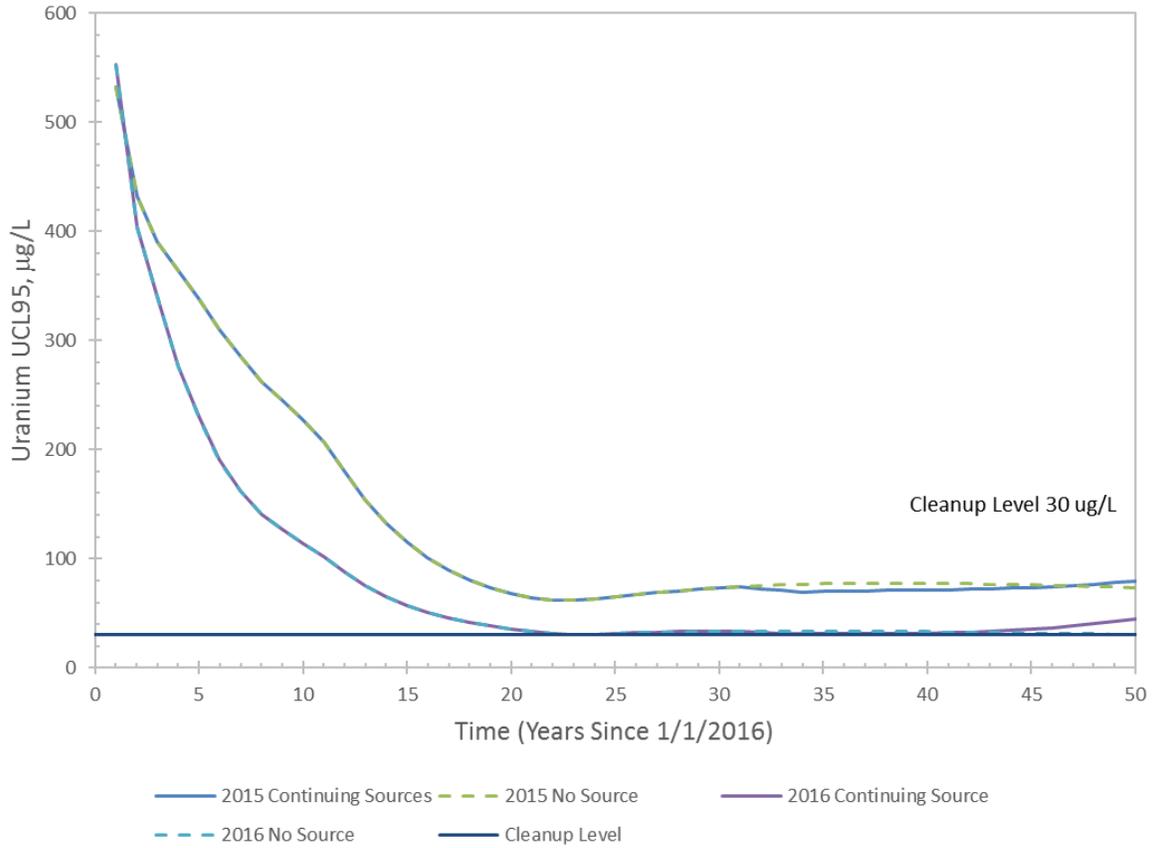
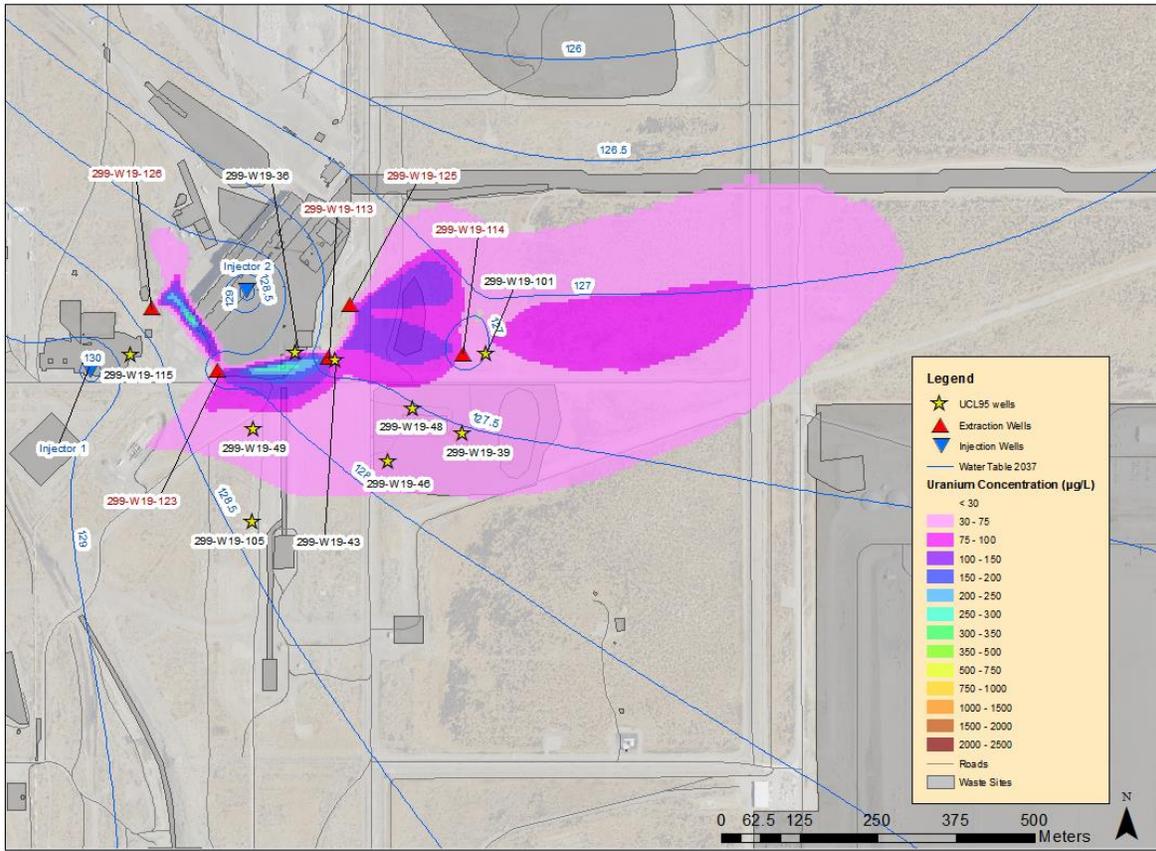
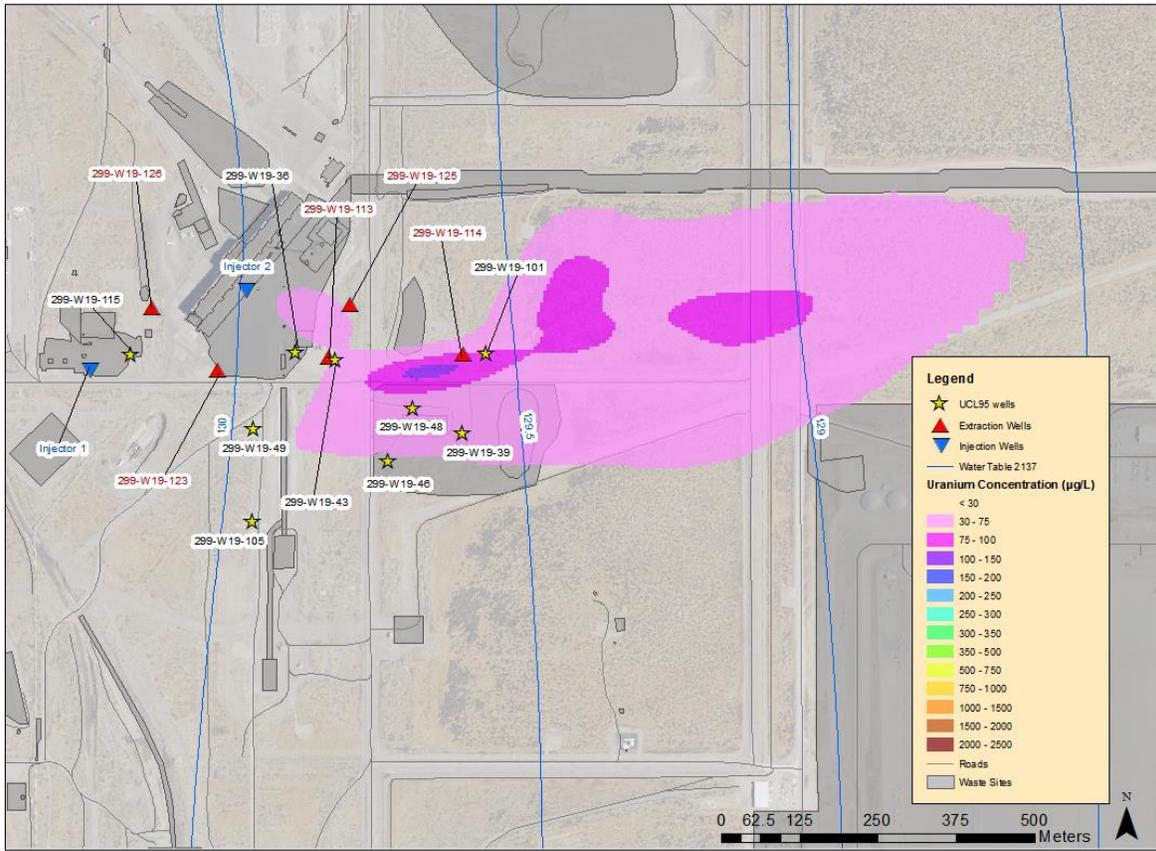


Figure 49. UCL95 Curves for Uranium, Scenario 3



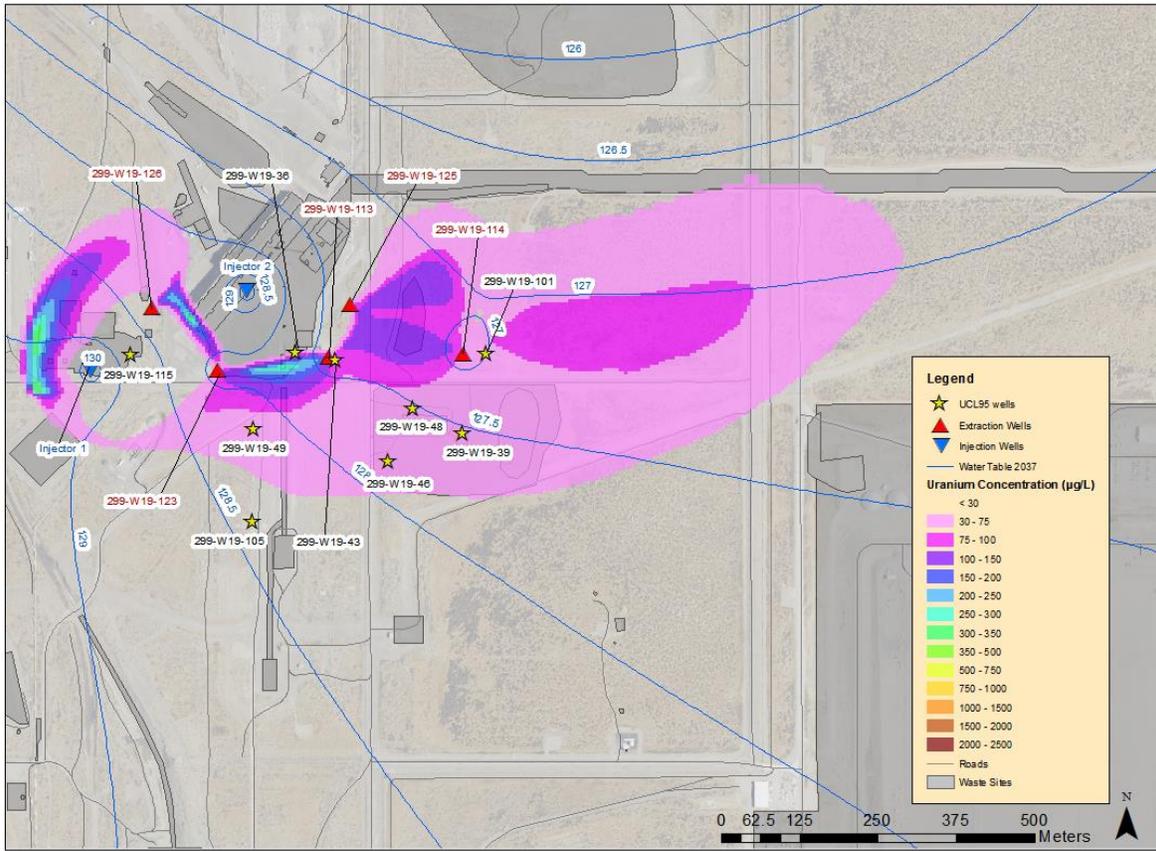
Maximum concentration: 330 µg/L 299-W19-18 replaced by 299-W19-115

**Figure 50. Uranium at U Plant with 2015 Initial Conditions, No Continuing Source, Modeled Year 2037, Scenario 3**



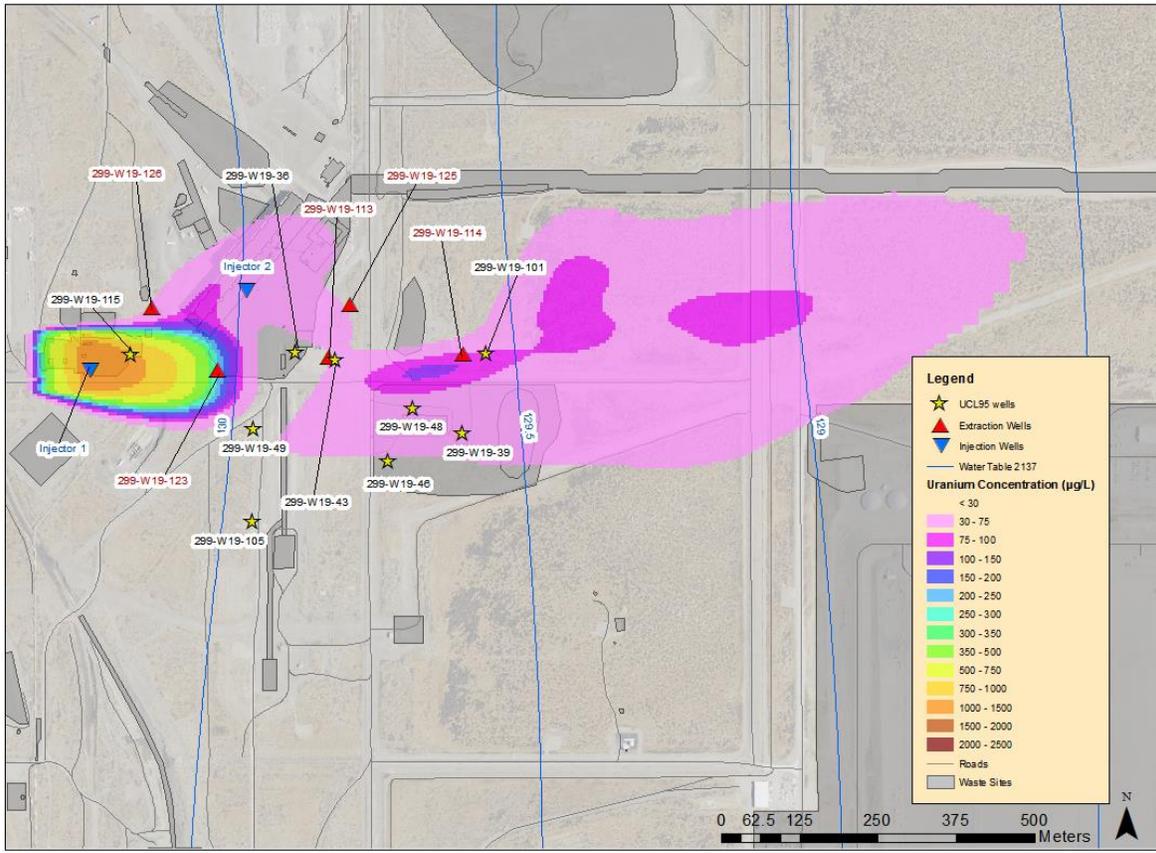
Maximum concentration: 105 µg/L 299-W19-18 replaced by 299-W19-115

**Figure 51. Uranium at U Plant with 2015 Initial Conditions, No Continuing Source, Modeled Year 2137, Scenario 3**



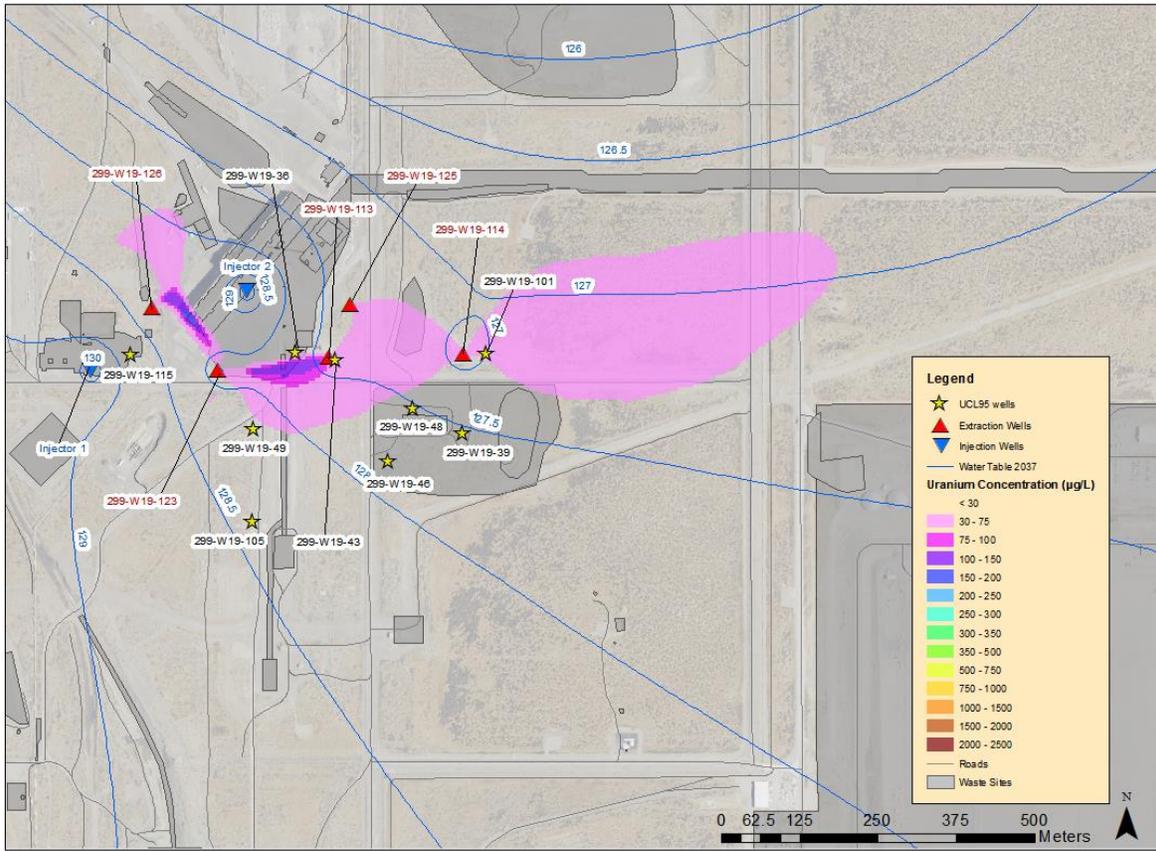
Maximum concentration: 348 µg/L 299-W19-18 replaced by 299-W19-115

**Figure 52. Uranium at U Plant with 2015 Initial Conditions, with Continuing Source, Modeled Year 2037, Scenario 3**



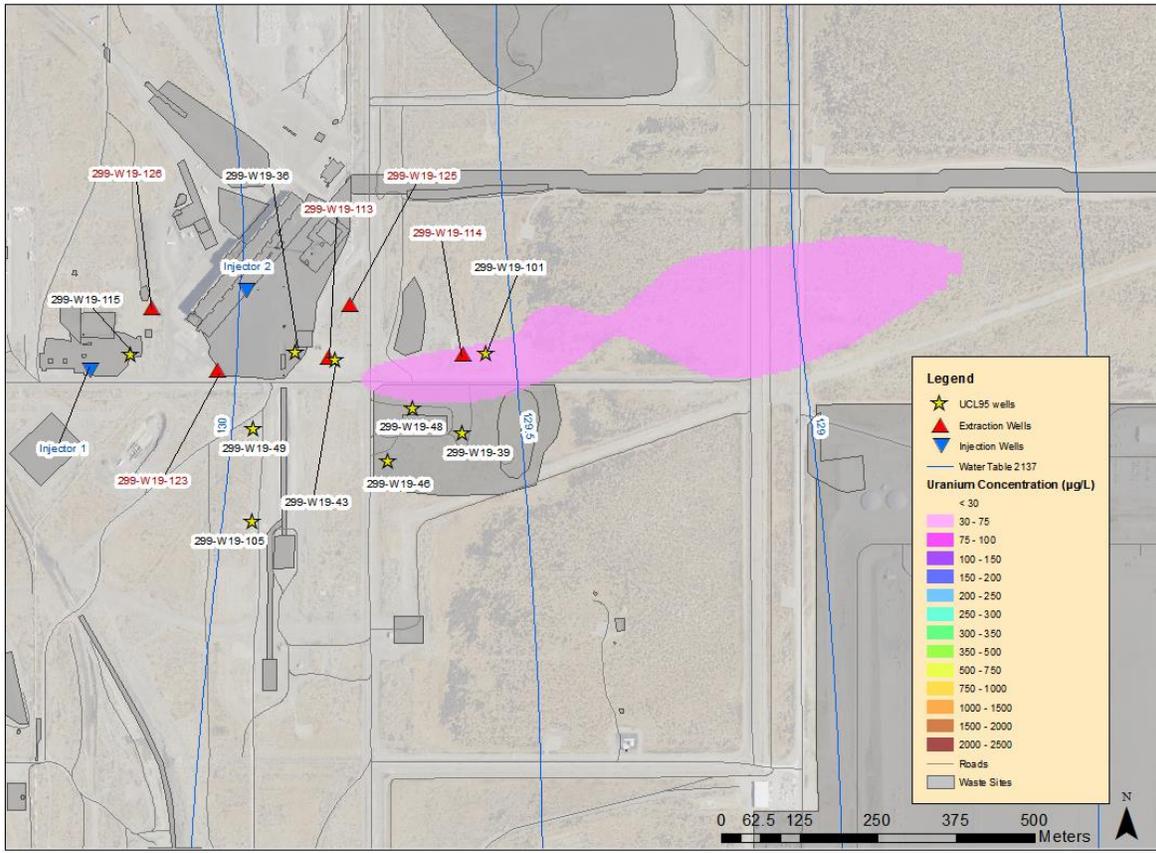
Maximum concentration: 1217 µg/L 299-W19-18 replaced by 299-W19-115

**Figure 53. Uranium at U Plant with 2015 Initial Conditions, with Continuing Source, Modeled Year 2137, Scenario 3**



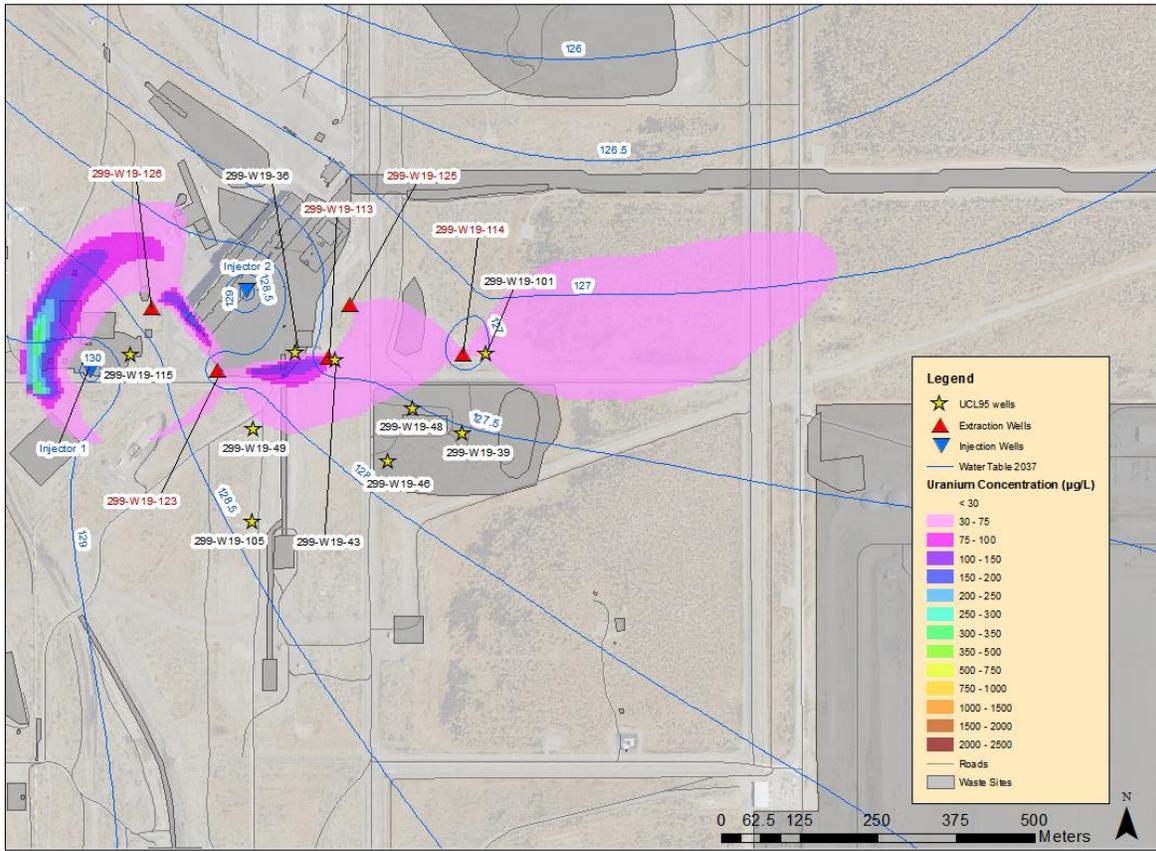
Maximum concentration: 192 µg/L 299-W19-18 replaced by 299-W19-115

**Figure 54. Uranium at U Plant with 2016 Initial Conditions, No Continuing Source, Modeled Year 2037, Scenario 3**



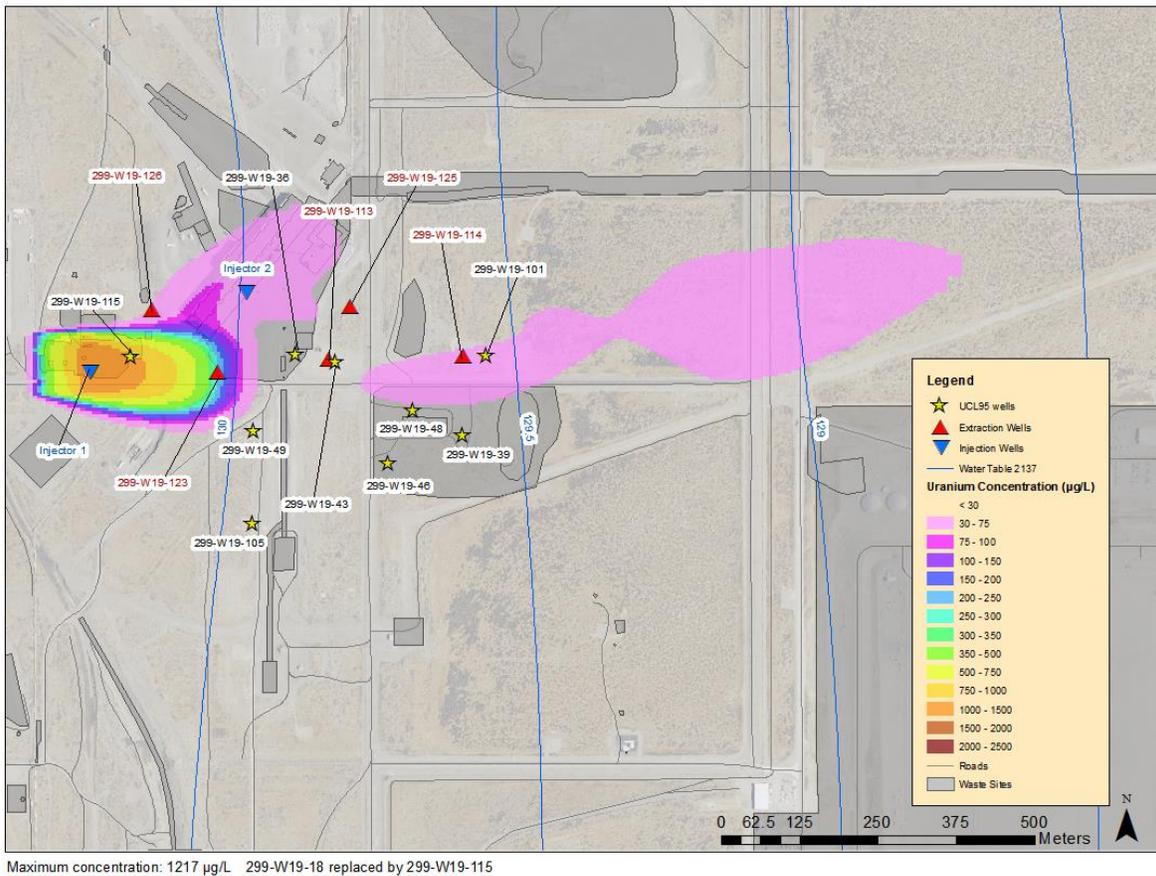
Maximum concentration: 54 µg/L 299-W19-18 replaced by 299-W19-115

**Figure 55. Uranium at U Plant with 2016 Initial Conditions, No Continuing Source, Modeled Year 2137, Scenario 3**



Maximum concentration: 348 µg/L 299-W19-18 replaced by 299-W19-115

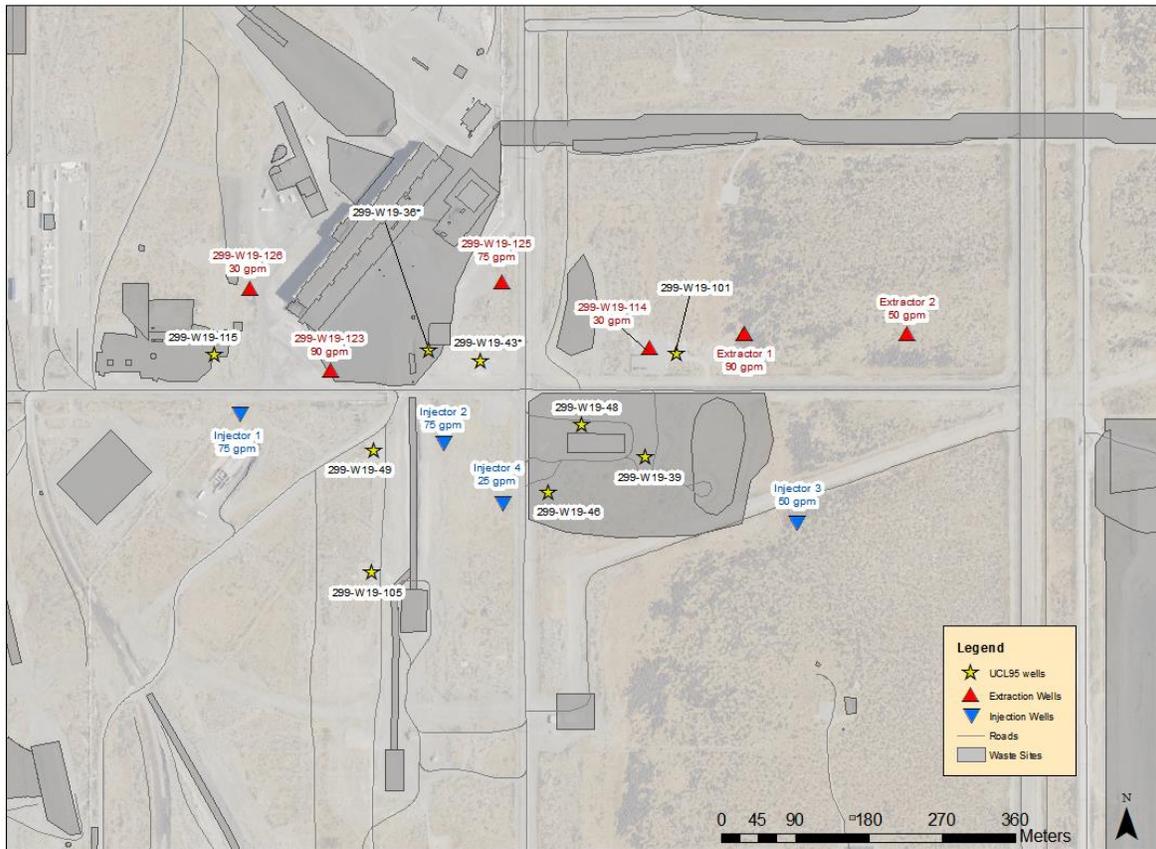
**Figure 56. Uranium at U Plant with 2016 Initial Conditions, with Continuing Source, Modeled Year 2037, Scenario 3**



**Figure 57. Uranium at U Plant with 2016 Initial Conditions, with Continuing Source, Modeled Year 2137, Scenario 3**

### 6.4 Flow Scenario 4

This section contains results from transport models using Scenario 4 as the flow model. In Scenario 4, extraction rates are as follows: 299-W19-114 at 30 gpm, 299-W19-123 at 90 gpm, 299-W19-125 at 75 gpm, and 299-W19-126 at 30 gpm. Two hypothetical extraction wells were added, one pumping at 90 gpm and one pumping at 50gpm. The total extraction rate is 365 gpm. This scenario also has three injection wells, two with injection rates of 75 gpm, and one with an injection rate of 50 gpm, for a total injection rate of 150 gpm. These extraction and injection rates were selected after examining the results of Scenario 3, and selecting well locations which would better capture the uranium plume. Figure 58 is a map of all the pumping wells and their rates.



299-W19-18 replaced by 299-W19-115 \*Wells are Tc-99 and uranium UCL95 wells

**Figure 58. UCL95 and Pumping Well Locations, Scenario 4**

### 6.4.1 Technetium-99

With or without a continuing source, Tc-99 is cleaned up after approximately five years of pumping (Figure 59). Approximately 1 curie is extracted during pumping when sources are present, and approximately 0.9 curies are recovered when sources are not present (Figure 60). Recovery of Tc-99 in this scenario is similar to the recorded recovery obtained from the pump and treat system reports (DOE/RL-2015-06, DOE/RL-2016-20, DOE/RL-2016-69). Without a continuing source, Tc-99 remains cleaned up (Figure 61 and Figure 62) and even pulls some of the Tc-99 from the S-SX area in 2037. With a continuing source, the buildup of mass is enough that a persistent plume is present in 2037 (61), and increases in size by 2137 (Figure 64). The plume from the continuing source is much smaller in 2037 than it is in continuing source transport simulations for Scenario 1 and 2, due to the influence of the injection well near the source, but it is not as small as the 2037 plume for Scenario 3 when sources are assumed. The peak concentration in 2037 when a continuing source is assumed for this scenario is 1171 pCi/L (Figure 63), while for Scenario 1 it's 1434 (Figure 12), for Scenario 2 it's 1228 (Figure 29), and for Scenario 3 it's 1002 pCi/L (Figure 45). However, all four plumes behave the same by 2037, with the same maximum concentrations, and very similar flow directions and plume sizes (Figure 13, Figure 30, Figure 47, and Figure 64 for Scenarios 1, 2, 3, and 4 respectively).

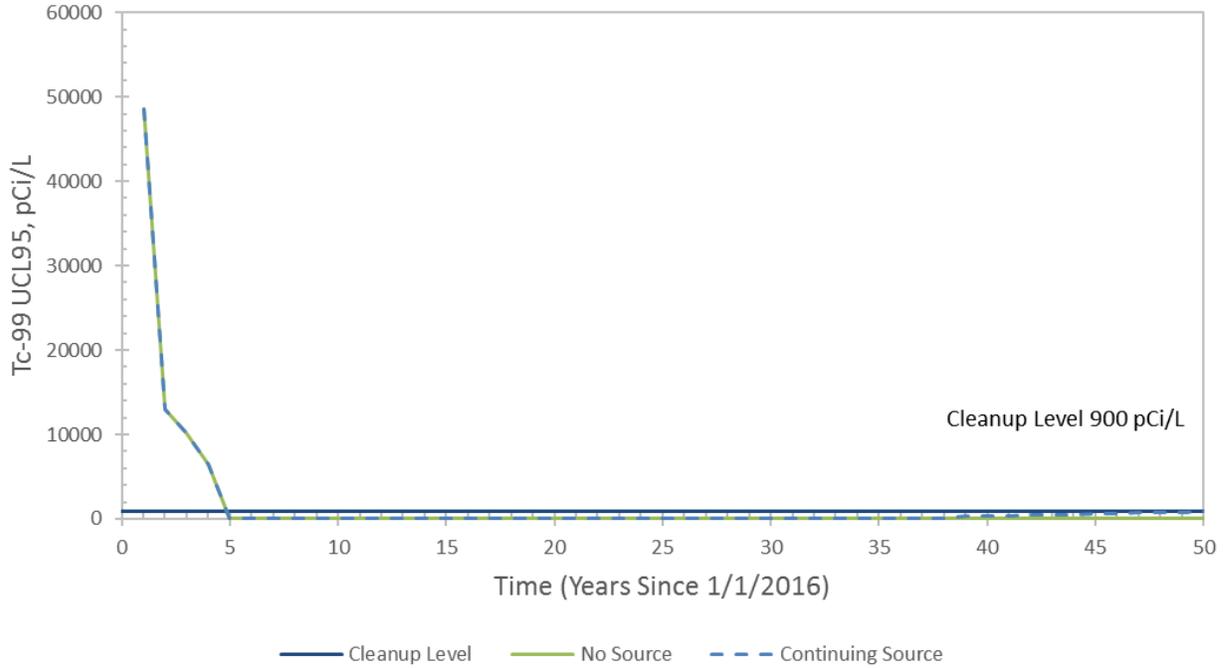


Figure 59. UCL95 Curves for Tc-99, Scenario 4

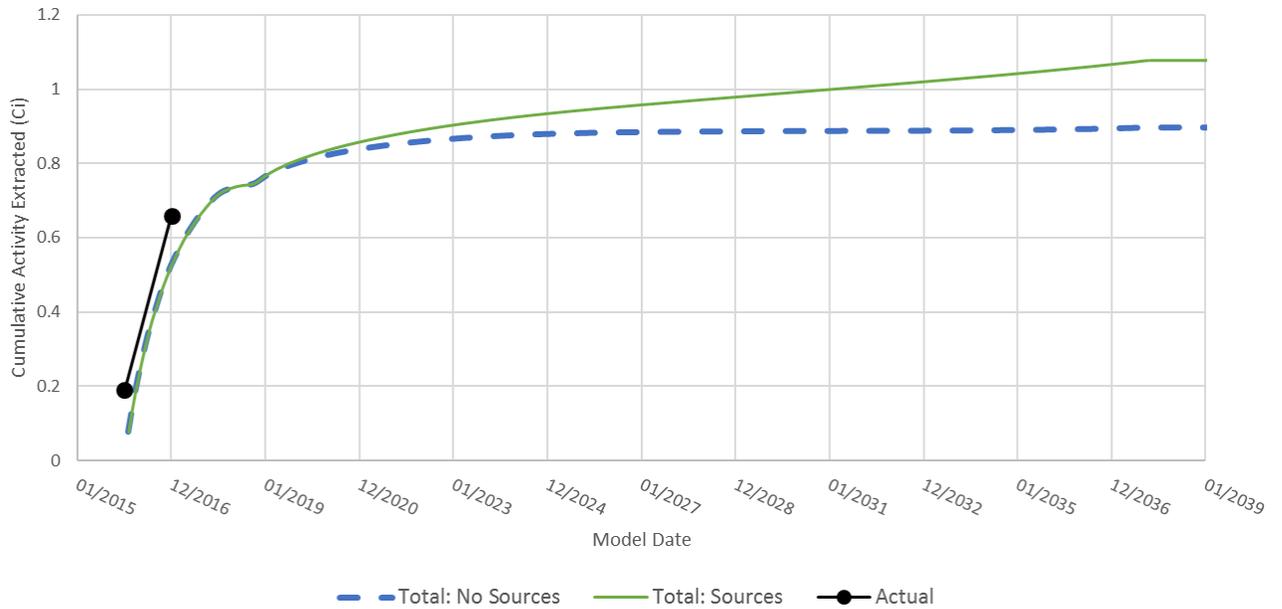


Figure 60. Cumulative Activity Extraction of Tc-99, Scenario 4, Compared to Actual Activity Extraction Values

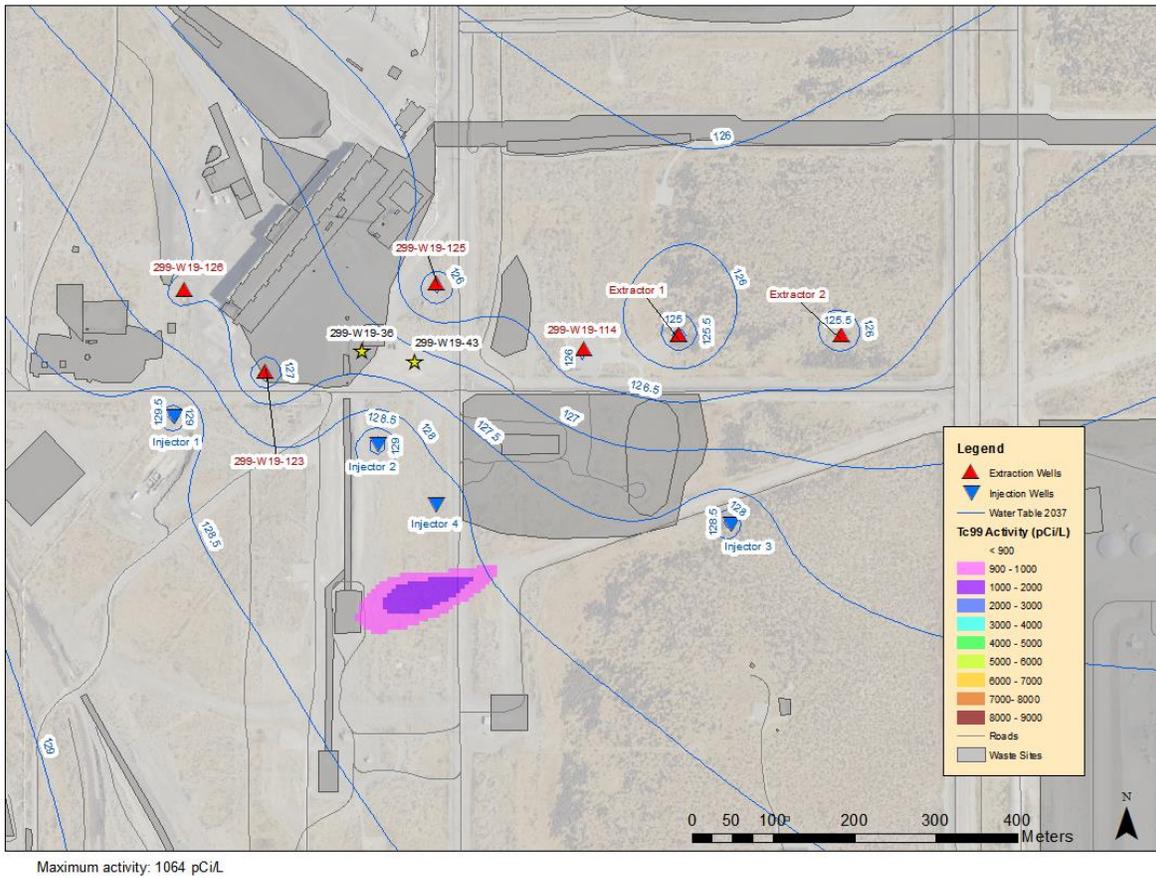


Figure 61. Tc-99 at U Plant with No Continuing Source, Modeled Year 2037, Scenario 4

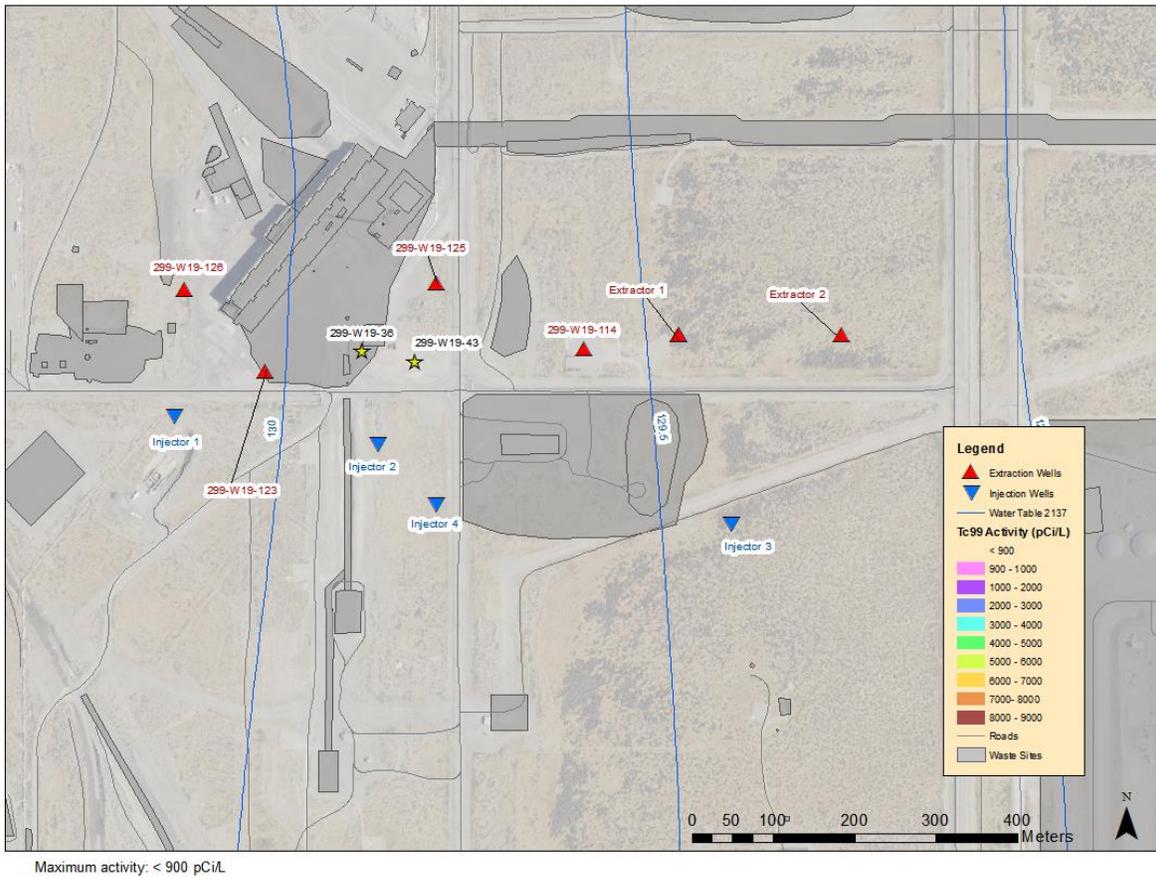


Figure 62. Tc-99 at U Plant with No Continuing Source, Modeled Year 2137, Scenario 4

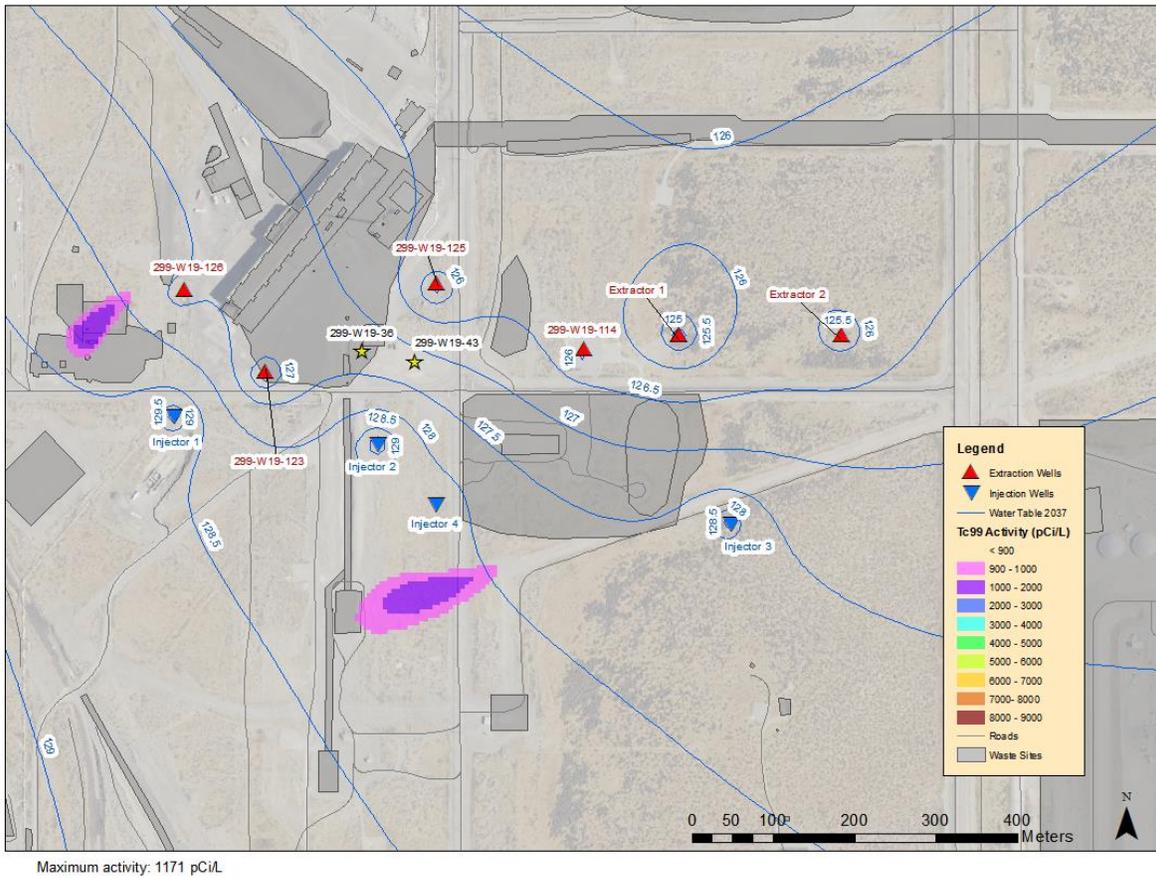


Figure 63. Tc-99 at U Plant with Continuing Source, Modeled Year 2037, Scenario 4

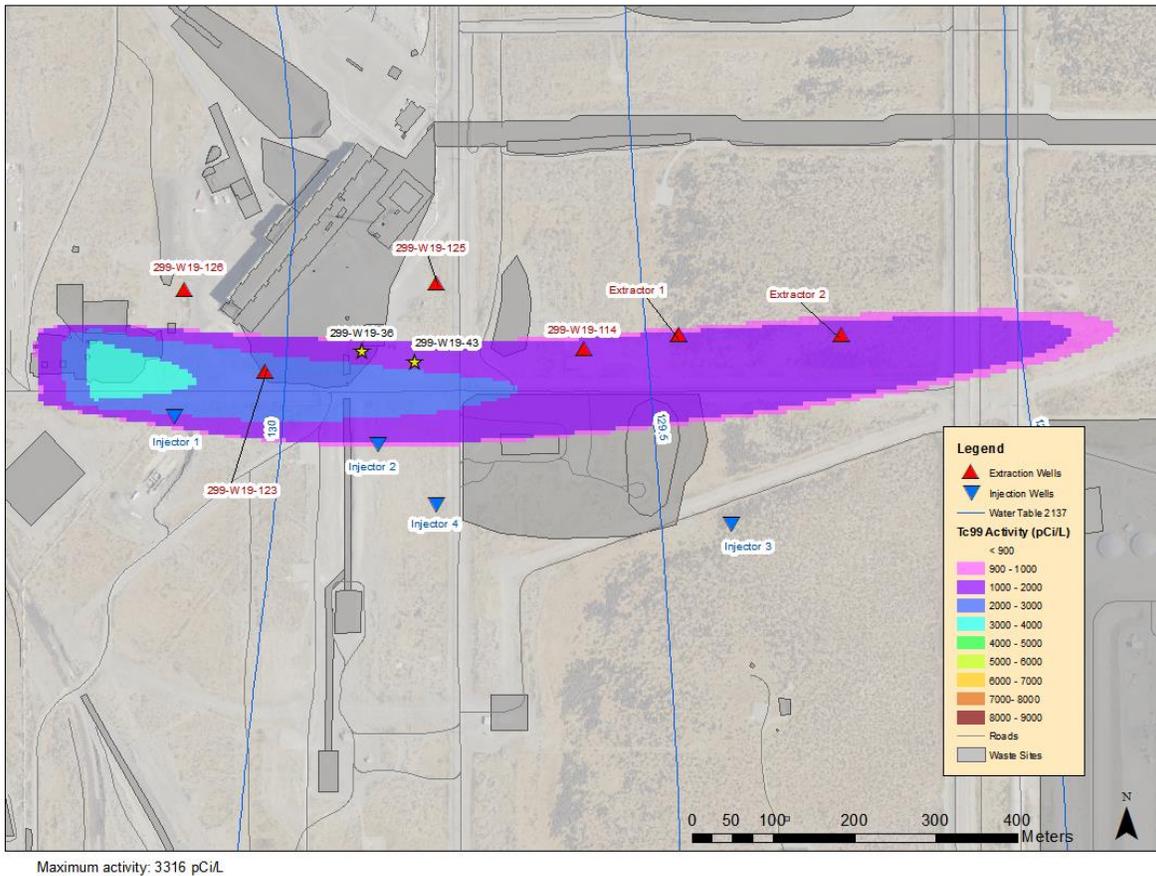


Figure 64. Tc-99 at U Plant with Continuing Source, Modeled Year 2137, Scenario 4

## 6.4.2 Uranium

Scenario 4 is the only scenario where reaching the UCL95 suggests cleanup levels can be achieved for both 2015 and 2016 working initial conditions (Figure 65). This occurs for cases with and without sources, but the cases with continuing sources begin to rise above the UCL95 approximately 30 years after pumping begins. As with all other scenarios, when 2015 initial conditions are used, more mass is extracted than with 2016 working initial conditions (Figure ). In this scenario, the presence of sources can be seen in the cumulative mass extraction. Figure 67 and Figure 68 show the plumes with 2015 initial conditions and no sources at 2037 and 2137, respectively, and show considerably smaller plumes than the 2016 working initial conditions with no sources in 2037 and 2137, as seen in Figure 71 and Figure 72, respectively. Figure 69 and Figure 70 show the plumes with 2015 initial conditions and continuing

sources, and Figure 73 and Figure 74 show the plumes with 2016 working initial conditions and continuing sources.

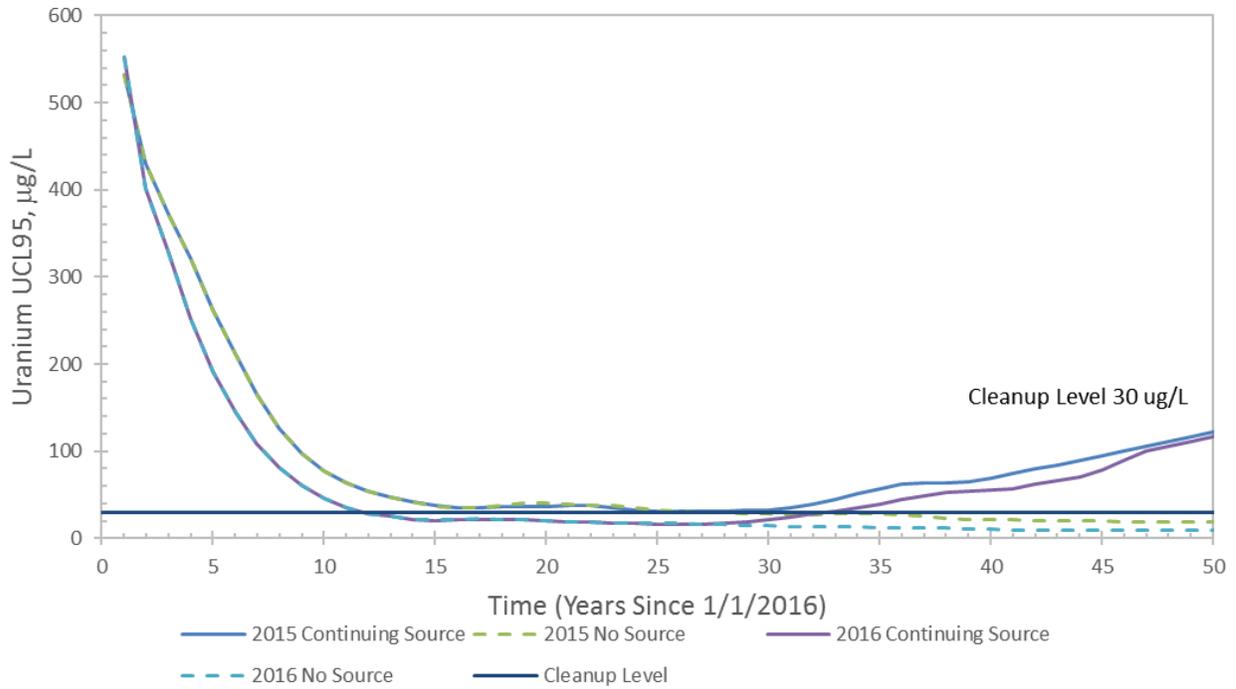
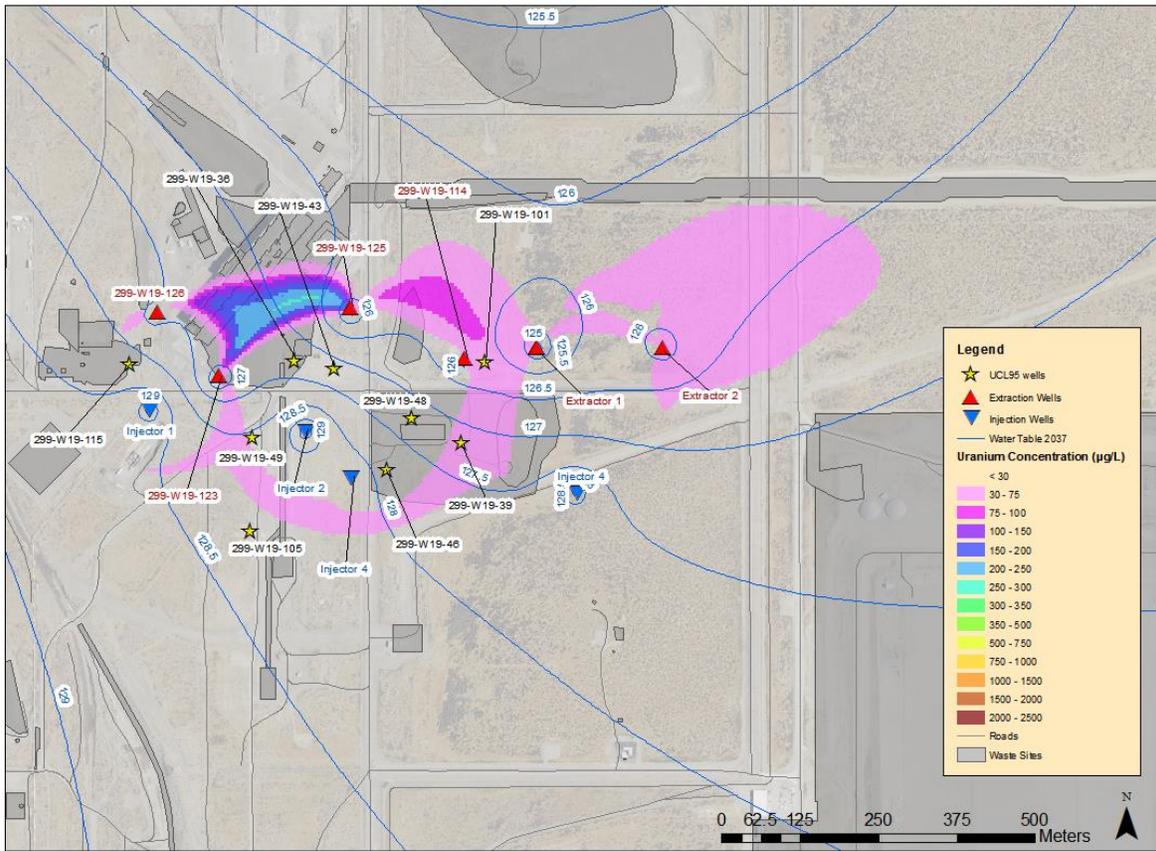


Figure 65. UCL95 Curves for Uranium, Scenario 4



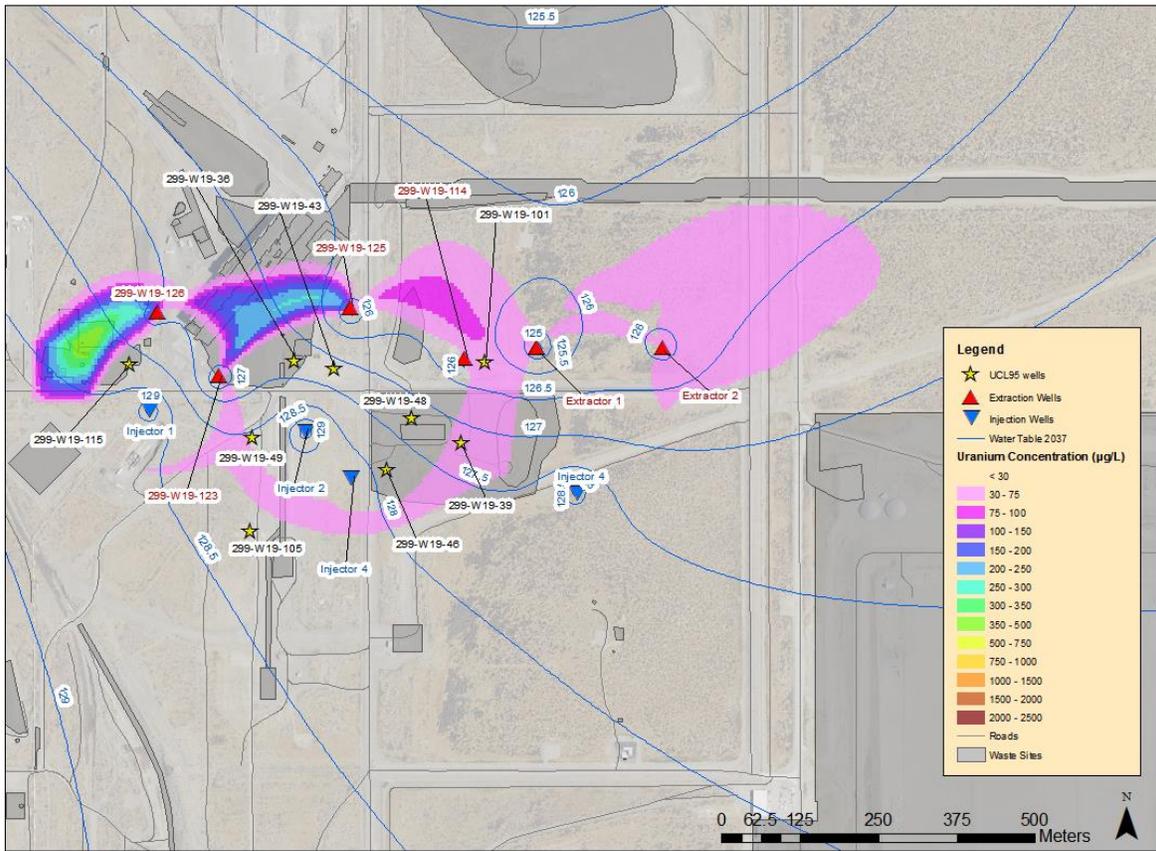
Figure 66. Cumulative Activity Extraction of Uranium, Scenario 4, Compared to Actual Activity Extraction Values



Maximum concentration: 252 µg/L 299-W19-18 replaced by 299-W19-115

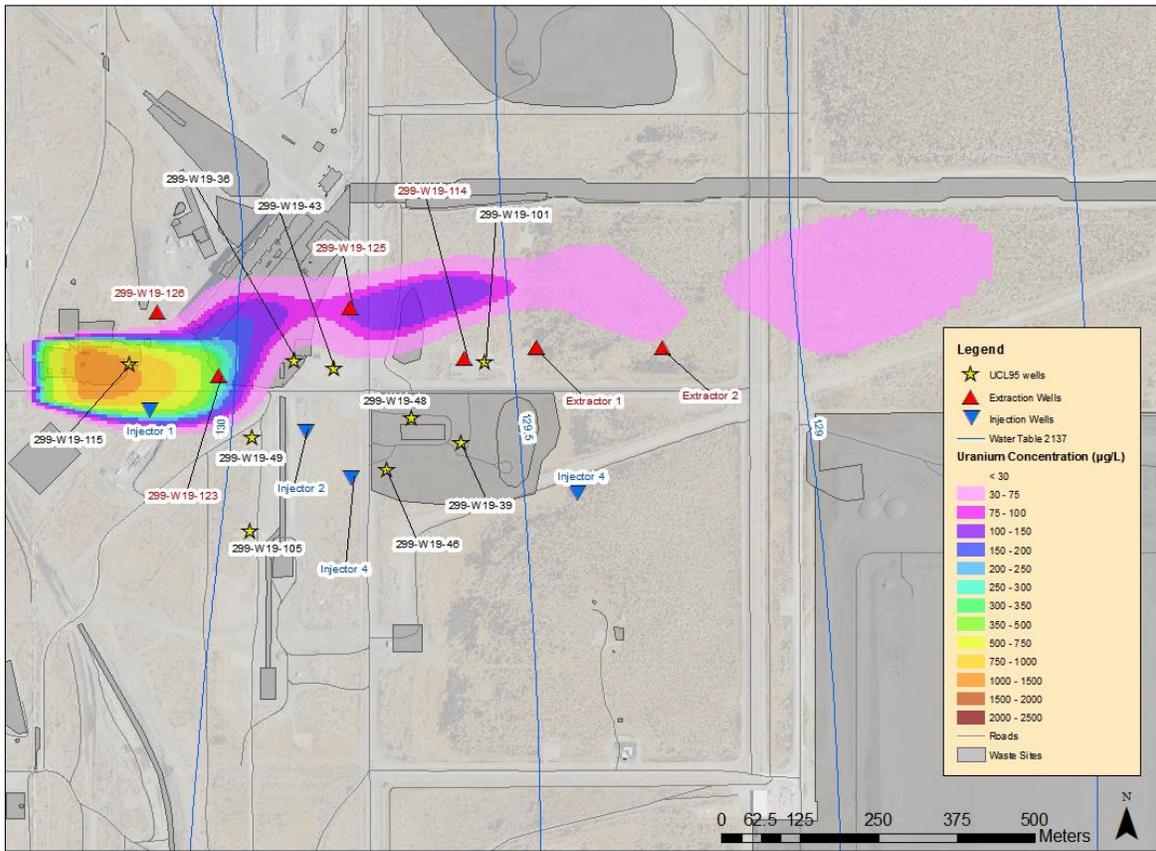
**Figure 67. Uranium at U Plant with 2015 Initial Conditions, No Continuing Source, Modeled Year 2037, Scenario 4**





Maximum concentration: 410 µg/L 299-W19-18 replaced by 299-W19-115

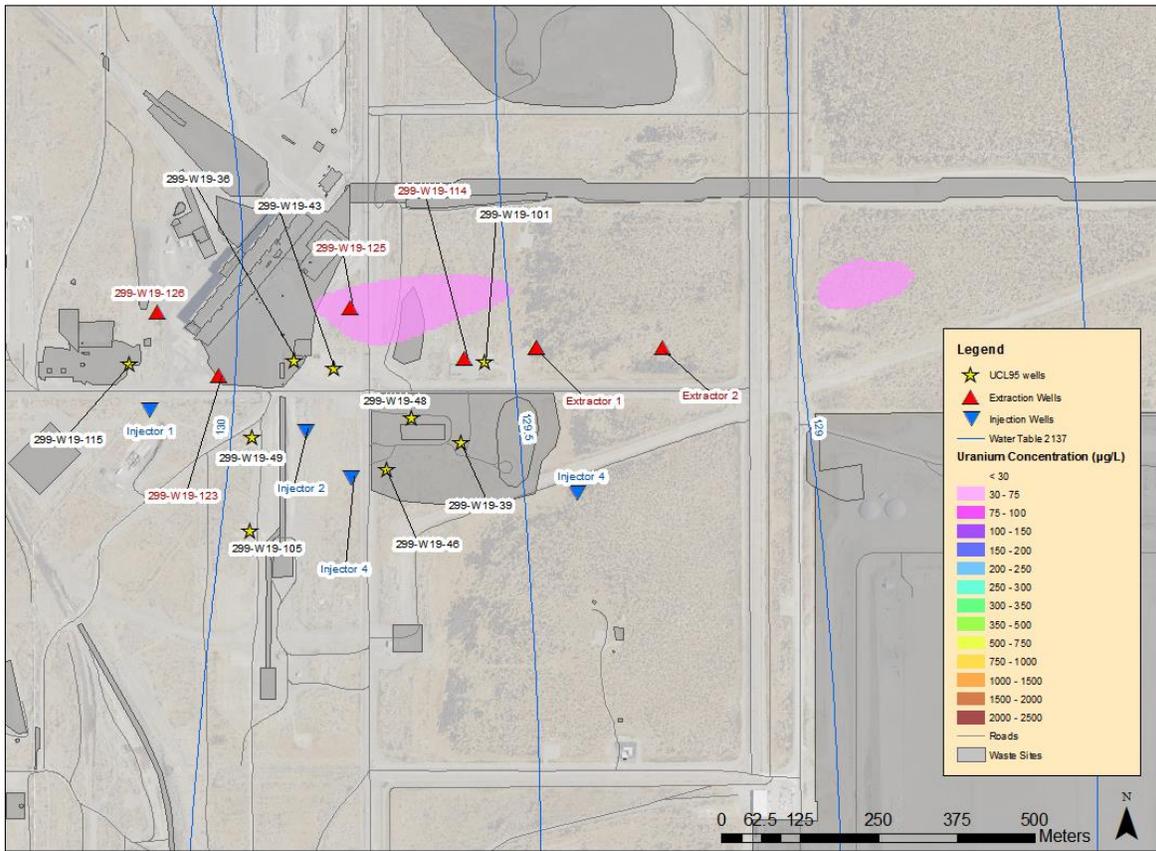
**Figure 69. Uranium at U Plant with 2015 Initial Conditions, with Continuing Source, Modeled Year 2037, Scenario 4**



Maximum concentration: 1215 µg/L. 299-W19-18 replaced by 299-W19-115

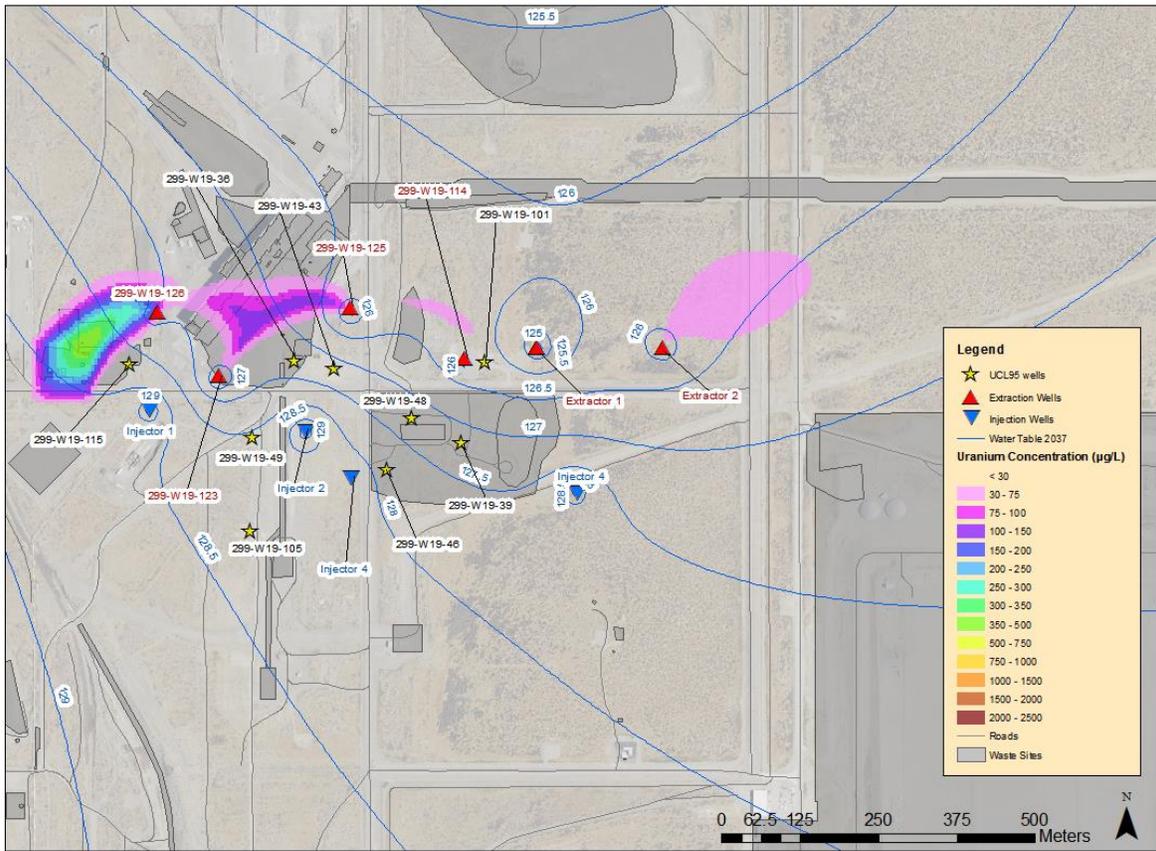
**Figure 70. Uranium at U Plant with 2015 Initial Conditions, with Continuing Source, Modeled Year 2137, Scenario 4**





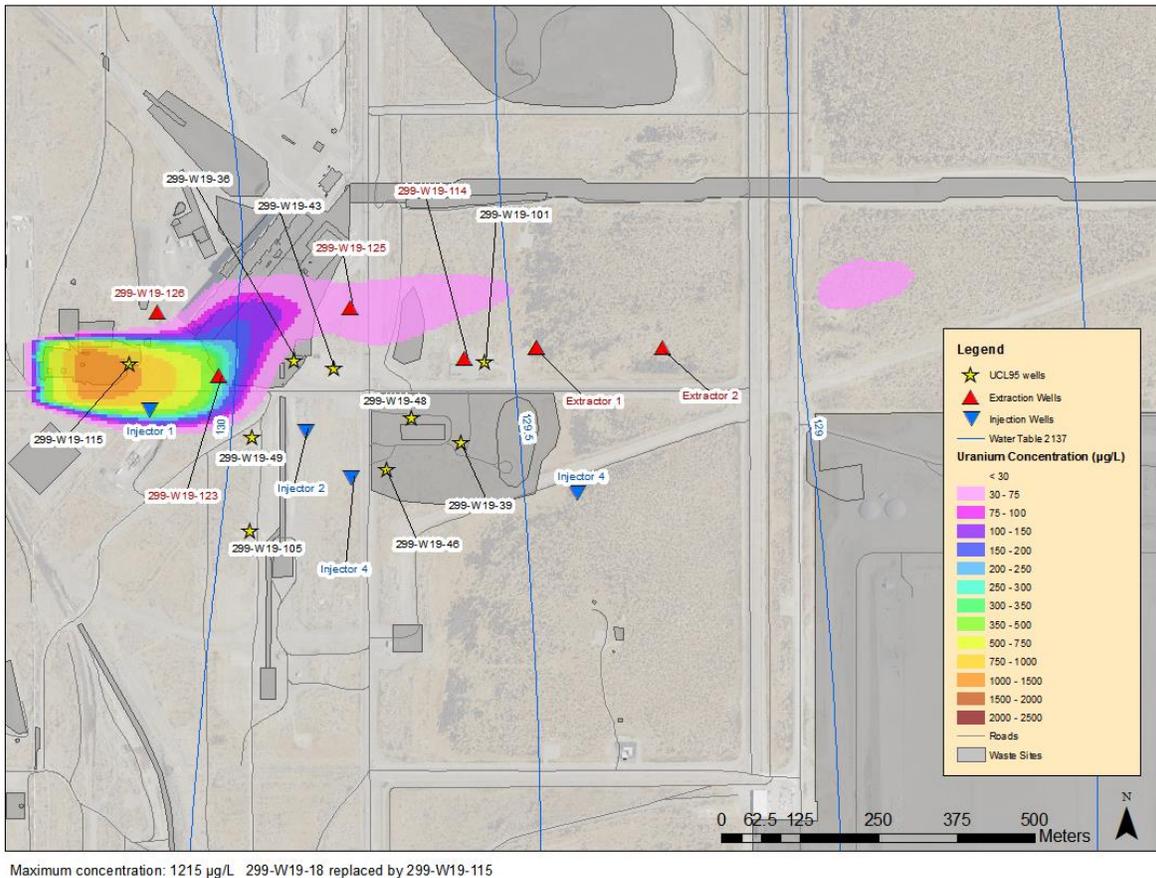
Maximum concentration: 68 µg/L 299-W19-18 replaced by 299-W19-115

**Figure 72. Uranium at U Plant with 2016 Initial Conditions, No Continuing Source, Modeled Year 2137, Scenario 4**



Maximum concentration: 409 µg/L 299-W19-18 replaced by 299-W19-115

**Figure 73. Uranium at U Plant with 2016 Initial Conditions, with Continuing Source, Modeled Year 2037, Scenario 4**



**Figure 74. Uranium at U Plant with 2016 Initial Conditions, with Continuing Source, Modeled Year 2137, Scenario 4**

## 6.5 Summary

The following are the key findings of the transport modeling performed to evaluate the U Plant Groundwater Extraction System:

1. Residual plumes of uranium persist in 2137 in all scenarios considered in this ECF.
2. The model simulations show that the pumping scenarios considered in this ECF do not result in uranium cleanup if 2015 initial uranium concentrations are assumed, with the exception of Scenario 4.
3. If 2016 initial uranium concentrations without continuing sources are assumed, the UCL95 network data suggests cleanup levels could be achieved during or within five years of the active remediation period under all scenarios considered in this ECF.
4. Scenario 4 outperforms all other scenarios modeled in this ECF. This may be due in part to the injection wells: Scenarios 1 and 2 utilized solely extraction wells, and Scenario 3 had fewer extraction wells and an overall lower extraction rate.

5. UCL95 data suggests uranium cleanup can be reached for both 2015 and 2016 initial conditions under Scenario 4; however, the concentration rebounds over time when continuing sources are assumed.
6. UCL95 data suggests cleanup levels can be reached for Tc-99 with the current U Plant Groundwater Extraction System when no continuing source is present. When continuing sources are assumed, cleanup levels can be reached during the active remediation period, but contamination eventually rebounds above cleanup levels.
7. Simulations that include approximations of ongoing sources of contamination indicate that groundwater plumes will reform after the active remedy period unless near-field extraction wells are operated to contain the plumes or the sources are otherwise mitigated. It should be emphasized that simulated future plume conditions caused by ongoing sources are approximations due to the assumptions upon which the source terms are based. While the simulations indicate that substantial plumes would reform after the active remedy phase, the concentrations and extent of those plumes are uncertain.

## 7 References

- CHPRC-00257, 2010, *MODFLOW and Related Codes Functional Requirements Document*, Rev. 1, CH2M HILL Plateau Remediation Company, Richland, Washington.
- CHPRC-00258, 2015, *MODFLOW and Related Codes Software Management Plan*, Rev 4, CH2M HILL Plateau Remediation Company, Richland, Washington.
- CHPRC-00259, 2014, *MODFLOW and Related Codes Software Test Plan*, Rev. 3, CH2M HILL Plateau Remediation Company, Richland, Washington.
- CHPRC-00260, 2015, *MODFLOW and Related Codes Requirements Traceability Matrix: CHPRC Build 8*, Rev. 8, CH2M HILL Plateau Remediation Company, Richland, Washington.
- CHPRC-00261, 2015, *MODFLOW and Related Codes Acceptance Test Report: CHPRC Build 8*, Rev. 8, CH2M HILL Plateau Remediation Company, Richland, Washington.
- CP-47531, 2017, *Model Package Report: Central Plateau Model, Version 8.4.5*, Rev. 4, CH2M Hill Plateau Remediation Company, Richland, Washington.
- DOE/RL-2015-06, 2015, *Calendar Year 2014 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=0080209H>.
- DOE/RL-2015-14, 2015, *Performance Monitoring Plan for the 200-UP-1 Groundwater Operable Unit Remedial Action*, CH2M Hill Plateau Remediation Company, Richland, Washington. Available at: <http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0080202H>.
- DOE/RL-2016-09, 2016, *Hanford Site Groundwater Monitoring Report for 2015*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: <http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0075314H>.
- DOE/RL-2016-20, 2016, *Calendar Year 2015 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=0074339H>.
- DOE/RL-2016-69, 2017, *Calendar Year 2016 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=0068097H>.
- Doherty, J. 2003, "Ground Water Model Calibration Using Pilot Points and Regularization," *Ground Water* 41(2):170-177.
- Doherty, J, 2016, *PEST Model-Independent Parameter Estimation User Manual Part I: PEST, SENSAN, and Global Optimisers:6<sup>th</sup> Edition*, Watermark Numerical Computing, Brisbane, Australia.
- ECF-200W-17-0030, 2017, *Calculation of Source Terms for the 200 West Pump-and-Treat System Optimization Modeling, FY 2017*, Rev. 0, CH2M Hill Plateau Remediation Company, Richland, Washington.

- ECF-200W-17-0044, In Press, *Capture-Zone and Particle-Tracking Analysis for the U Plant Pump and Treat System Using a Sub Model from the 2017 Updated Central Plateau Model*, Rev. 0, CH2M Hill Plateau Remediation Company, Richland, Washington.
- EPA/542/R-99/011B, 1999, *Hydraulic Optimization Demonstration for Groundwater Pump-and-Treat Systems, Volume II: Application of Hydraulic Optimization*, Office of Research and Development, Office of Solid Waste and Emergency Response, U.S. Environmental Protection Agency, Washington, D.C.
- EPA, Ecology, and DOE, 2012, *Record of Decision for Interim Remedial Action, Hanford 200 Area Superfund Site, 200-UP-1 Operable Unit*, U.S. Environmental Protection Agency, Washington State Department of Ecology, and U.S. Department of Energy, Olympia, Washington. Available at: <http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0091413>.
- 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.
- OSWER 9285.6-10, 2002, *Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites*, Office of Emergency and Remedial Response, U.S. Environmental Protection Agency, Washington, D.C.
- PRC-PRO-IRM-309, 2017, *Controlled Software Management*, Rev. 5 Chg. 2, CH2M HILL Plateau Remediation Company, Richland, Washington.
- Zheng, C., and G. D. Bennett, 1995, *Applied Contaminant Transport Modeling: Theory and Practice*, Van Nostrand Reinhold, New York, New York.
- Zheng, C., and P. 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*, SERDP-99-1, Engineer Research and Development Center, U.S. Army Corps of Engineers, Washington, D.C.

## **Attachment A**

### **Software Installation and Checkout**

<b>CHPRC SOFTWARE INSTALLATION AND CHECKOUT FORM</b>																													
<p><b>Software Owner Instructions:</b> Complete Fields 1-13, then run test cases in Field 14. Compare test case results listed in Field 15 to corresponding Test Report outputs. If results are the same, sign and date Field 19. If not, resolve differences and repeat above steps.</p> <p><b>Software Subject Matter Expert Instructions:</b> Assign test personnel. Approve the installation of the code by signing and dating Field 21, then maintain form as part of the software support documentation.</p>																													
<p><b>GENERAL INFORMATION:</b></p> <p>1. Software Name: <u>MODFLOW and Related Codes</u> <span style="float: right;">Software Version No.: <u>Bld 8</u></span></p>																													
<p><b>EXECUTABLE INFORMATION:</b></p> <p>2. Executable Name (include path): Following executable files in directory: _____</p> <table style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="text-align: left; border-bottom: 1px dashed black;">MD5 Signature (unique ID)</th> <th style="text-align: left; border-bottom: 1px dashed black;">Executable File Name</th> <th style="text-align: left; border-bottom: 1px dashed black;"></th> </tr> </thead> <tbody> <tr> <td>919F74196F5FB5BF0364FC373011B507</td> <td>mf2k-chprc08dpl.exe</td> <td>MODFLOW-2000 double precision</td> </tr> <tr> <td>EAF037703ADD2C62CDD9CBC47468D2F6</td> <td>mf2k-chprc08spl.exe</td> <td>MODFLOW-2000 single precision</td> </tr> <tr> <td>4E7F29DD5496D2CBA7144ADACB13DAAD</td> <td>mf2k-mst-chprc08dpv.exe</td> <td>MODFLOW-2000-MST single prec</td> </tr> <tr> <td>CEB80288C616E0552E4CE5A2D4719387</td> <td>mf2k-mst-chprc08spv.exe</td> <td>MODFLOW-2000-MST double prec</td> </tr> <tr> <td>ECA9828530B68D2D7C34078C019D5D0C</td> <td>mt3d-chprc08dpl.exe</td> <td>MT3DMS double precision</td> </tr> <tr> <td>0920CC235862665D9400A3FC80F682DD</td> <td>mt3d-chprc08spl.exe</td> <td>MT3DMS single precision</td> </tr> <tr> <td>5C61432D2C898E83DDFE242C52A755AB</td> <td>mt3d-mst-chprc08dpv.exe</td> <td>MT3DMS-MST double precision</td> </tr> <tr> <td>68F89DAF2E6913D2578DE53CBD34FBA0</td> <td>mt3d-mst-chprc08spv.exe</td> <td>MT3DMS-MST single precision</td> </tr> </tbody> </table> <p>3. Executable Size (bytes): MD5 signatures listed above uniquely identify executable files</p>			MD5 Signature (unique ID)	Executable File Name		919F74196F5FB5BF0364FC373011B507	mf2k-chprc08dpl.exe	MODFLOW-2000 double precision	EAF037703ADD2C62CDD9CBC47468D2F6	mf2k-chprc08spl.exe	MODFLOW-2000 single precision	4E7F29DD5496D2CBA7144ADACB13DAAD	mf2k-mst-chprc08dpv.exe	MODFLOW-2000-MST single prec	CEB80288C616E0552E4CE5A2D4719387	mf2k-mst-chprc08spv.exe	MODFLOW-2000-MST double prec	ECA9828530B68D2D7C34078C019D5D0C	mt3d-chprc08dpl.exe	MT3DMS double precision	0920CC235862665D9400A3FC80F682DD	mt3d-chprc08spl.exe	MT3DMS single precision	5C61432D2C898E83DDFE242C52A755AB	mt3d-mst-chprc08dpv.exe	MT3DMS-MST double precision	68F89DAF2E6913D2578DE53CBD34FBA0	mt3d-mst-chprc08spv.exe	MT3DMS-MST single precision
MD5 Signature (unique ID)	Executable File Name																												
919F74196F5FB5BF0364FC373011B507	mf2k-chprc08dpl.exe	MODFLOW-2000 double precision																											
EAF037703ADD2C62CDD9CBC47468D2F6	mf2k-chprc08spl.exe	MODFLOW-2000 single precision																											
4E7F29DD5496D2CBA7144ADACB13DAAD	mf2k-mst-chprc08dpv.exe	MODFLOW-2000-MST single prec																											
CEB80288C616E0552E4CE5A2D4719387	mf2k-mst-chprc08spv.exe	MODFLOW-2000-MST double prec																											
ECA9828530B68D2D7C34078C019D5D0C	mt3d-chprc08dpl.exe	MT3DMS double precision																											
0920CC235862665D9400A3FC80F682DD	mt3d-chprc08spl.exe	MT3DMS single precision																											
5C61432D2C898E83DDFE242C52A755AB	mt3d-mst-chprc08dpv.exe	MT3DMS-MST double precision																											
68F89DAF2E6913D2578DE53CBD34FBA0	mt3d-mst-chprc08spv.exe	MT3DMS-MST single precision																											
<p><b>COMPILATION INFORMATION:</b></p> <p>4. Hardware System (i.e., property number or ID): Vendor Provided (SSP&amp;A)</p> <p>5. Operating System (include version number): Vendor Provided (SSP&amp;A)</p>																													
<p><b>INSTALLATION AND CHECKOUT INFORMATION:</b></p> <p>6. Hardware System (i.e., property number or ID): PSC-Xenon; Intera Property Number 00857</p> <p>7. Operating System (include version number): Windows 10</p> <p>8. Open Problem Report? <input checked="" type="radio"/> No <input type="radio"/> Yes PR/CR No.</p>																													
<p><b>TEST CASE INFORMATION:</b></p> <p>9. Directory/Path:</p> <p>10. Procedure(s): CHPRC-00259 Rev 3, MODFLOW and Related Codes Software Test Plan</p> <p>11. Libraries: N/A (static linking)</p> <p>12. Input Files: MF-ITC-1 and MT-ITC-1 inputs</p> <p>13. Output Files: MF-ITC-1 and MT-ITC-1 outputs</p>																													

<b>CHPRC SOFTWARE INSTALLATION AND CHECKOUT FORM (continued)</b>		
1. Software Name: <u>MODFLOW and Related Codes</u>		Software Version No.: <u>Bld 8</u>
14. Test Cases: MF-ITC-1 (both standard and MST versions of MODFLOW)- run for single & double precision MT-ITC-1 - run for single and double precision		
15. Test Case Results: FC: no differences encountered <i>x8 - PASS.</i>		
16. Test Performed By: <u>Mary Weber</u>		
17. Test Results: <input checked="" type="radio"/> Satisfactory, Accepted for Use <input type="radio"/> Unsatisfactory		
18. Disposition (include HISI update): <i>INSTALLATION ADDED TO APPROVED USER LISTS FOR HISI #2517 (MODFLOW) AND #2518 (MT3DMS) - JAW</i>		
Prepared By: _____		
19. <i>[Signature]</i> Software Owner (Signature)	<u>WE Nichols</u> Print	<u>13 FEB 2017</u> Date
20. Test Personnel:		
<i>[Signature]</i> Sign	<u>M Weber</u> Print	<u>13 FEB 2017</u> Date
_____ Sign	_____ Print	_____ Date
_____ Sign	_____ Print	_____ Date
Approved By:		
21. _____ Software SME (Signature)	<u>N/R (CHPRC-00258 Rev 3)</u> Print	_____ Date

## **Attachment B**

### **Stress Periods in the U Plant Local-Scale Transport Model**

Table B-1 lists the stress periods in the U Plant local-scale model, the length of each period, start and end dates, and the total elapsed time. These are the same as in the CP model extended to year 2137.

**Table B-1. Stress Periods in the U Plant Local-Scale Model**

<b>Stress Period Number</b>	<b>Length (days)</b>	<b>Length (years)</b>	<b>Start Date</b>	<b>End Date (Inclusive)</b>	<b>Elapsed Days</b>	<b>Elapsed Years</b>
1	31	0.08	1/1/2016	1/31/2016	31	0.08
2	29	0.08	2/1/2016	2/29/2016	60	0.16
3	31	0.08	3/1/2016	3/31/2016	91	0.25
4	30	0.08	4/1/2016	4/30/2016	121	0.33
5	31	0.08	5/1/2016	5/31/2016	152	0.42
6	30	0.08	6/1/2016	6/30/2016	182	0.50
7	31	0.08	7/1/2016	7/31/2016	213	0.58
8	31	0.08	8/1/2016	8/31/2016	244	0.67
9	30	0.08	9/1/2016	9/30/2016	274	0.75
10	31	0.08	10/1/2016	10/31/2016	305	0.84
11	30	0.08	11/1/2016	11/30/2016	335	0.92
12	31	0.08	12/1/2016	12/31/2016	366	1.00
13	365	1	1/1/2017	12/31/2017	731	2.00
14	365	1	1/1/2018	12/31/2018	1,096	3.00
15	365	1	1/1/2019	12/31/2019	1,461	4.00
16	366	1	1/1/2020	12/31/2020	1,827	5.01
17	365	1	1/1/2021	12/31/2021	2,192	6.01
18	365	1	1/1/2022	12/31/2022	2,557	7.01
19	365	1	1/1/2023	12/31/2023	2,922	8.01
20	366	1	1/1/2024	12/31/2024	3,288	9.01
21	365	1	1/1/2025	12/31/2025	3,653	10.01
22	365	1	1/1/2026	12/31/2026	4,018	11.01
23	365	1	1/1/2027	12/31/2027	4,383	12.01
24	366	1	1/1/2028	12/31/2028	4,749	13.01
25	365	1	1/1/2029	12/31/2029	5,114	14.01
26	365	1	1/1/2030	12/31/2030	5,479	15.01
27	365	1	1/1/2031	12/31/2031	5,844	16.01

**Table B-1. Stress Periods in the U Plant Local-Scale Model**

<b>Stress Period Number</b>	<b>Length (days)</b>	<b>Length (years)</b>	<b>Start Date</b>	<b>End Date (Inclusive)</b>	<b>Elapsed Days</b>	<b>Elapsed Years</b>
28	366	1	1/1/2032	12/31/2032	6,210	17.01
29	365	1	1/1/2033	12/31/2033	6,575	18.01
30	365	1	1/1/2034	12/31/2034	6,940	19.01
31	365	1	1/1/2035	12/31/2035	7,305	20.01
32	366	1	1/1/2036	12/31/2036	7,671	21.02
33	365	1	1/1/2037	12/31/2037	8,036	22.02
34	365	1	1/1/2038	12/31/2038	8,401	23.02
35	365	1	1/1/2039	12/31/2039	8,766	24.02
36	366	1	1/1/2040	12/31/2040	9,132	25.02
37	365	1	1/1/2041	12/31/2041	9,497	26.02
38	365	1	1/1/2042	12/31/2042	9,862	27.02
39	1826	5	1/1/2043	12/31/2047	11,688	32.02
40	1827	5	1/1/2048	12/31/2052	13,515	37.03
41	1826	5	1/1/2053	12/31/2057	15,341	42.03
42	3652	10	1/1/2058	12/31/2067	18,993	52.04
43	3653	10	1/1/2068	12/31/2077	22,646	62.04
44	3652	10	1/1/2078	12/31/2087	26,298	72.05
45	3653	10	1/1/2088	12/31/2097	29,951	82.06
46	3651	10	1/1/2098	12/31/2107	33,602	92.06
47	3653	10	1/1/2108	12/31/2117	37,255	102.07
48	3652	10	1/1/2118	12/31/2127	40,907	112.07
49	3653	10	1/1/2128	12/31/2137	44,560	122.08

**Attachment C**

**Well Data Used to Create 2016 Working Initial Conditions**

Table C-1 lists the well data used to create the 2016 working initial conditions.

**Table C-1. Well Data Used to Create 2016 Working Initial Conditions**

<b>Well Name</b>	<b>X-Coordinates</b>	<b>Y-Coordinates</b>	<b>Date</b>	<b>Concentration (mg/L)</b>
299-E11-1	571003.1	134505.27	2015	1.2
299-E13-11	573386.512	134207.559	2016	2.95
299-E13-14	573087.497	134474.132	2016	1.45
299-E13-19	573277.657	134061.013	2016	3.67
299-E13-5	573607.493	134319.579	2016	2.9
299-E17-1	574977.079	135386.153	2016	6.63
299-E17-12	574905.372	135125.906	2016	7.55
299-E17-13	574948.031	135172.575	2016	7.8
299-E17-14	575140.608	135333.739	2016	23.58
299-E17-16	575145.774	135210.78	2016	16.35
299-E17-18	575112.433	135123.586	2016	8.65
299-E17-19	575017.183	135414.871	2016	16.3
299-E17-23	574694.483	134842.439	2016	4.68
299-E17-25	574515.185	134845.567	2016	2.5
299-E17-3	575160.625	135390.495	2016	14
299-E18-1	573296.567	135200.161	2016	3.65
299-E20-1	570503	135199.81	2015	1.2
299-E20-2	570897.94	134895.76	2015	1.2
299-E23-1	574043.396	136016.551	2016	8.28
299-E24-16	575017.622	135464.364	2016	17.5
299-E24-18	574647.088	135469.764	2016	9.7
299-E24-23	575205.22	135517.81	2015	35.35
299-E25-36	575403.611	135566.372	2015	42.37
299-W10-1	566663.096	136734.565	2016	1.1
299-W10-14	566017.194	136608.895	2016	0.9
299-W10-26	566843.396	136400.594	2016	1.36
299-W10-27	566843.969	136441.778	2016	1.5
299-W10-28	566701.55	136709.93	2016	2.59
299-W10-29	566082.98	136828.74	2016	0.84

**Table C-1. Well Data Used to Create 2016 Working Initial Conditions**

<b>Well Name</b>	<b>X-Coordinates</b>	<b>Y-Coordinates</b>	<b>Date</b>	<b>Concentration (mg/L)</b>
299-W10-30	566082.78	136739.33	2016	0.89
299-W10-31	566266.44	136968.34	2016	3.92
299-W10-33	566772.75	136610.19	2016	1.32
299-W10-35	566024.73	136995.48	2015	1.2
299-W10-36	566019.19	137451.97	2015	1.2
299-W11-13	567099.363	136424.033	2016	1.1
299-W11-18	567181.916	137161.484	2016	1.6
299-W11-33Q	567184.869	136844.366	2016	0.72
299-W11-42	566920.435	136745.665	2016	0.91
299-W11-43	567269.74	136971.04	2016	2.99
299-W11-45	566992.84	136775.64	2016	0.89
299-W11-47	566933.82	136680.7	2016	0.92
299-W11-48	566881.97	136846.18	2016	1.2
299-W11-49	567361.5	135924.72	2016	0.84
299-W11-50	566966.27	136756.64	2016	1.27
299-W11-87	568141.08	136608.7	2016	1.54
299-W11-88	567874.67	137113.09	2016	1.03
299-W11-90	567306.79	136519.66	2016	1.77
299-W11-92	566692.86	136351.78	2016	0.84
299-W11-96	567774.83	136772.24	2016	1.57
299-W11-97	568317.57	135875.91	2016	1.75
299-W12-2	568312.67	136610.25	2016	1.17
299-W12-3	568321.53	136998.09	2016	1.6
299-W12-4	568327.41	136363.65	2016	1.23
299-W13-1	568148.74	136048.6	2015	0.9
299-W13-2	568832.59	135819.18	2016	2
299-W14-14	566898.386	136181.048	2016	1.02
299-W14-15	566899.685	136230.654	2016	1.15
299-W14-16	567001.334	136318.482	2016	1.34
299-W14-17	567006.773	136218.349	2016	0.96
299-W14-18	566897.47	136344.15	2016	2.05

**Table C-1. Well Data Used to Create 2016 Working Initial Conditions**

<b>Well Name</b>	<b>X-Coordinates</b>	<b>Y-Coordinates</b>	<b>Date</b>	<b>Concentration (mg/L)</b>
299-W14-19	566898.6	136135.06	2016	0.98
299-W14-21	567721.52	135890.01	2015	0.97
299-W14-22	568324.69	136117.29	2016	1.33
299-W14-72	567328.44	135941.28	2015	0.73
299-W14-73	567358.99	136204.58	2016	0.89
299-W14-74	567781.48	136381.29	2016	1.3
299-W15-11	566412.296	136000.716	2015	0.86
299-W15-152	566309.4	135550	2016	2.35
299-W15-17	566306.891	135718.958	2016	0.85
299-W15-224	566307.89	135926.08	2016	0.83
299-W15-225	566657.35	136108.93	2016	0.9
299-W15-226	566033.3	136450.23	2015	1.2
299-W15-227	566034.04	135966.56	2015	1.2
299-W15-228	565745.36	135711.48	2015	1.2
299-W15-229	566049.31	135678.81	2015	1.2
299-W15-29	565921.17	135506.003	2015	1.2
299-W15-30	566304.617	135748.936	2016	1.09
299-W15-33	566433.297	135966.703	2015	0.91
299-W15-37	566716.468	135248.316	2016	1.56
299-W15-42	566581.825	135627.018	2015	1.61
299-W15-44	566685.02	136066.47	2016	0.85
299-W15-46	566752.23	135586.67	2015	0.69
299-W15-49	566307.2	135972.91	2015	0.83
299-W15-50	566793.47	135790.72	2015	0.8
299-W15-7	566675.883	135920.204	2015	1.06
299-W15-763	566809.207	136028.763	2016	0.99
299-W15-765	566697.02	136373.06	2016	1.12
299-W15-83	566304.52	135826.24	2016	0.97
299-W15-94	566307.58	135640.34	2016	0.95
299-W17-1	565310.68	135038.74	2016	0.73
299-W17-2	566951.64	135806.21	2016	0.78

**Table C-1. Well Data Used to Create 2016 Working Initial Conditions**

<b>Well Name</b>	<b>X-Coordinates</b>	<b>Y-Coordinates</b>	<b>Date</b>	<b>Concentration (mg/L)</b>
299-W17-3	566925.89	135325.02	2016	0.86
299-W18-1	566421.515	135465.21	2015	2.74
299-W18-15	566380.033	134733.478	2015	22.5
299-W18-16	566605.05	135425.69	2015	2.85
299-W18-21	566097.7	134978.692	2016	14.75
299-W18-22	566088.632	134990.157	2016	1.03
299-W18-36	565908.606	135419.398	2015	1.2
299-W18-38	565892.132	135232.922	2015	1.2
299-W18-39	565885.563	135141.112	2015	1.2
299-W18-41	566045.06	135048.54	2015	1.2
299-W19-101	567939.14	135014.07	2016	100
299-W19-105	567565.15	134745.44	2016	23.6
299-W19-107	567997.87	135205.66	2016	1.4
299-W19-111	567313.04	135547.02	2016	0.7
299-W19-113	567689.62	135008.2	2016	44.75
299-W19-114	567901.89	135013.21	2016	26.75
299-W19-115	567371.99	135011.96	2016	380
299-W19-116	568510.19	135090.16	2016	37
299-W19-12	566897.131	135059.446	2016	1.29
299-W19-18	567360.647	135012.357	2014	734
299-W19-35	567992.099	135015.156	2014	75.3
299-W19-36	567634.738	135017.052	2016	2350
299-W19-39	567901.739	134886.74	2016	44.6
299-W19-4	567949.931	135350.792	2015	0.88
299-W19-43	567699.15	135004.02	2016	133
299-W19-46	567782.67	134842.46	2016	37
299-W19-47	566895.31	135161.86	2014	1.76
299-W19-48	567822.93	134925.99	2016	41
299-W19-49	567568.04	134894.38	2016	147
299-W19-6	567133.33	134693.76	2014	0.69
299-W21-2	568124.39	134573.79	2015	3.09

**Table C-1. Well Data Used to Create 2016 Working Initial Conditions**

<b>Well Name</b>	<b>X-Coordinates</b>	<b>Y-Coordinates</b>	<b>Date</b>	<b>Concentration (mg/L)</b>
299-W21-3	568570.76	133980.24	2016	4.6
299-W22-10	567012.978	134215.144	2016	1.65
299-W22-113	566904.52	134192.75	2015	1.88
299-W22-114	567726.31	134048.07	2016	4.4
299-W22-115	566939.39	134292.43	2016	2.3
299-W22-116	566900.5	134139.92	2016	4.38
299-W22-45	566945.16	134292.51	2015	4.68
299-W22-47	566908.74	134076.28	2014	4.2
299-W22-49	566904.383	134201.625	2014	4.24
299-W22-72	567237.37	134207.08	2016	0.97
299-W22-79	567629.54	134464.846	2016	1.2
299-W22-83	567009.082	134092.546	2016	1.6
299-W22-86	567186.74	134041.31	2016	2.01
299-W22-87	567541.75	134539.88	2016	0.9
299-W22-88	568046.48	134390.53	2016	3.82
299-W22-90	566961.39	134483.24	2016	2.65
299-W22-91	566911.76	134134.53	2016	2.73
299-W22-92	567167.84	134029.77	2016	4.1
299-W22-93	566949.07	134485.98	2016	3.84
299-W22-95	567170.54	134549.11	2016	1.2
299-W22-96	567351.93	134145.58	2016	1.89
299-W23-19	566759.115	134166.653	2016	6.32
299-W23-21	566707.737	134293.994	2016	6.15
299-W23-4	566628.216	134391.881	2016	35.5
299-W26-13	566424.387	133293.598	2016	1.56
299-W26-14	566682.69	133539.21	2016	0.96
299-W5-1	568329.73	137321.21	2016	1.6
299-W5-2	568175.4	137621.12	2015	1.7
299-W6-13	567313.33	137630.55	2015	1.2
299-W6-14	566939.64	137388.93	2015	1.2
299-W6-15	567781.69	137076.41	2016	1.47

**Table C-1. Well Data Used to Create 2016 Working Initial Conditions**

<b>Well Name</b>	<b>X-Coordinates</b>	<b>Y-Coordinates</b>	<b>Date</b>	<b>Concentration (mg/L)</b>
299-W6-3	567118.18	137299.13	2015	0.95
299-W6-6	567318.74	137638.72	2015	1.07
299-W7-14	566022.21	137639.37	2015	1.2
299-W7-3	566292.031	137638.641	2016	1
299-W9-2	565742.21	136872.84	2016	0.98
699-19-88	563131.105	129413.881	2014	0.6
699-29-66	570053.53	132336.94	2016	3.95
699-30-57	572394.41	132770.78	2016	3.88
699-30-66	569990.98	132739.19	2016	1.55
699-31-68	569598	133080.6	2016	2.97
699-32-62	571009.564	133215.925	2016	2.05
699-32-70B	568461.999	133242.245	2016	1.13
699-32-76	566683.94	133137.73	2016	0.84
699-33-56	572922.693	133627.235	2016	4.2
699-33-74	567472.65	133552.16	2015	1.66
699-33-75	566907.78	133662.48	2015	3.85
699-34-61	571395.863	133809.862	2016	1.83
699-34-72	567859.97	133785.33	2016	6
699-35-66A	569857.861	134099.244	2016	2.16
699-35-78A	566063.586	134271.27	2015	11
699-36-61A	571395.472	134557.106	2016	1.9
699-36-63B	570682.28	134227.58	2016	1.5
699-36-66B	569731.34	134469.01	2016	2.48
699-36-70A	568466.679	134308.839	2016	2.59
699-36-70B	568427.79	134625.98	2016	5.02
699-37-47A	575556.97	134893.26	2016	11.75
699-37-66	569730.32	134797.15	2016	1.79
699-38-64	570189.63	135318.83	2015	1.2
699-38-68A	569180.305	134931.603	2016	3.29
699-38-70B	568469.1	135331.04	2016	1.1
699-38-70C	569084.11	135325.58	2015	2.39

**Table C-1. Well Data Used to Create 2016 Working Initial Conditions**

<b>Well Name</b>	<b>X-Coordinates</b>	<b>Y-Coordinates</b>	<b>Date</b>	<b>Concentration (mg/L)</b>
699-40-62	571164.26	135764.42	2015	2.12
699-40-67	569420.26	135815.7	2015	1.2
699-42-67	569390.25	136199.83	2011	1.2
699-43-67B	569374.78	136560.2	2015	1.2
699-43-69	568967.03	136488.48	2016	1.4
699-44-64	570390.65	136897.43	2014	1.7
699-44-67	569338.04	136894.3	2011	1.2
699-45-67	569257.03	137262.97	2015	1.2
699-45-67B	569264.36	137264.99	2015	1.2
699-45-69A	568729.3	137182.679	2015	1.54
699-45-69C	568947.12	137233.81	2015	1.27
699-46-68	569109.83	137600.88	2015	1.2
699-47-60	571474.38	137968.732	2016	2.46
699-48-71	568387.914	138056.941	2016	1.6
699-48-77C	566468.954	138086.801	2016	0.34
699-48-77D	566433.302	138119.268	2016	1.01
699-49-69	568829.74	137966.54	2015	1.2
699-50-74	567359.52	138646.73	2015	1.4
699-51-63	570664.4	139148.408	2015	2.22
699-55-76	566723.421	140225.816	2016	1.6
CP_2014_15	567483	135114	N/A	1
CP_2016_16	567100	134960	N/A	0
CP_2016_17	567309	134908	N/A	30
CP_2017_1	566904	136285	N/A	2.57
299-W19-123	567511.23	134988.39	N/A	14
299-W19-125	567720.15	135090.95	N/A	5.2
CP_8-2017	568191	135000	N/A	50