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Revision 0

200-UP-1 U Plant 2017 Uranium Plume Pump and Treat System Analysis

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

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P.O. Box 1600
Richland, Washington 99352

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INTERA, Inc.

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Terms

2D	two-dimensional
3D	three-dimensional
CHPRC	CH2M Hill Plateau Remediation Company
ECF	environmental calculation file
HISI	Hanford Information Systems Inventory
OU	operable unit
TMR	telescopic mesh refinement
UCL95	95th percentile upper confidence limit on the plume mean concentration
USGS	U.S. Geological Survey

1 Purpose

The purpose of this environmental calculation file (ECF) is to document the results of evaluating the effectiveness of the current U Plant groundwater extraction system, reconfigured current system, and a preliminary redesigned system using the latest (2017) interpretation of the uranium plume within the 200-UP-1 groundwater operable unit (OU) at the Hanford Site. The current system began operating in 2015 with 2 extraction wells (299-W19-113 and 299-W19-114) and another well (299-W19-125) was added in 2017. Figure 1 shows the existing groundwater extraction system along with the latest interpreted uranium plume, monitoring wells and uranium concentration values used for plume mapping. Each of these extraction wells are currently operating at flow rates of approximately 50 gallons per minute (gpm). 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-2016-67, *Hanford Site Groundwater Monitoring Report for 2016*, and 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*. It should be noted that the latest interpretation of the uranium plume which was used as the initial concentrations in the transport simulation has not been published yet but will be documented in the next Hanford Site groundwater monitoring annual report (DOE/RL-2017-66, *Hanford Site Groundwater Monitoring Report for 2017* [in press]).

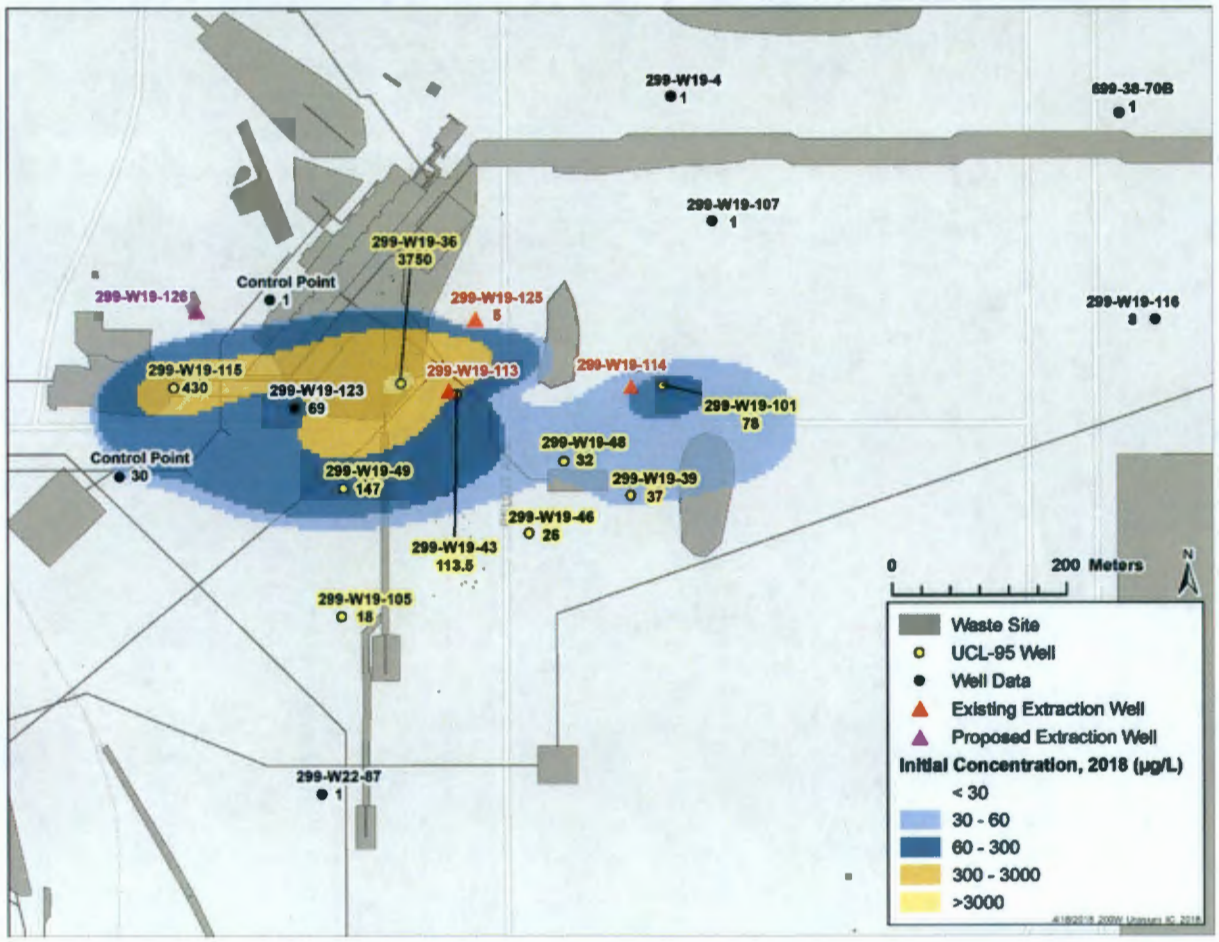

Figure 1. U Plant Groundwater Extraction System

The primary objectives of this fate and transport modeling exercise are:

1. Using the latest interpretation of the uranium plume, assess the performance of the current 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. If cleanup objectives cannot be achieved using the current extraction system, assess whether the cleanup objectives could be achieved for any modified configuration of the current U Plant groundwater extraction system including extending the active remediation period beyond 2037.
3. If cleanup objectives cannot be achieved using any modified configuration of the current system, develop a new optimized pump-and-treat system to achieve cleanup objectives.

A local-scale model, developed by the process of telescopic mesh refinement (TMR) from the most recent version of the Central Plateau Groundwater Model (CP-47631, *Model Package Report: Central Plateau Groundwater Model: Version 8.4.5*) was used for simulating groundwater flow and contaminant transport. The details on the construction, basis, and features of the TMR are documented 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.* Groundwater flow was simulated using 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*).

Contaminant transport of uranium was simulated 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*). The first iteration of the uranium transport simulation using the TMR mentioned above was performed in 2017 and documented in ECF-200UP1-17-0093, *Fate and Transport Analysis for U Plant Groundwater Plumes in the 200-UP-1 Operable Unit*. The flow and transport modeling performed for this ECF is the continuation of analysis performed in ECF-200UP1-17-0093. This ECF documents the capture zone analysis for the extraction/injection wells and the results for the uranium transport models.

2 Methodology

This section describes the changes that were made to the existing flow and transport model described in ECF-200UP1-17-0093.

2.1 Flow Model

The flow model used in ECF-200UP1-17-0093 begins in 2016 and runs until the end of calendar year 2137. In addition, the flow model in ECF-200UP1-17-0093 used two extraction wells (299-W19-113 and 299-W19-114) as the existing U Plant groundwater extraction system. However, a new extraction well (299-W19-125) was added to the current system and started operating in September 2017. The flow model in this ECF simulated the newly added extraction well 299-W19-125 as part of the current U Plant groundwater extraction system. Moreover, this ECF used the latest interpreted uranium plume which represents calendar year 2017 for the predictive transport simulation. Therefore, the flow model was split into two parts: the historic flow model simulated from 2016 through 2017, and the predictive flow model simulated from 2018 through 2137.

2.1.1 System Optimization

The interpreted uranium plume reported in the annual groundwater monitoring reports from the last 3 years (DOE/RL-2016-09, *Hanford Site Groundwater Monitoring Report for 2015;* DOE/RL-2016-67, *Hanford Site Groundwater Monitoring Report for 2016;* and DOE/RL-2017-66) showed substantial changes from one year to another to account for the newly available data in the later years. Optimization was used to investigate potential system reconfigurations using the same flow rate or a total maximum of 200 gpm, and considering current extraction wells, additional existing wells for pumping (e.g., 299-W22-126), and new extraction/injection wells.

2.1.2 Capture Zone Analysis

Capture zones for the U Plant extraction wells were determined by particle tracking using MODPATH. Reverse particle tracking was used with particles released around the extraction wells and tracked backward in time to determine the contributing areas. For each well, 12 particles were released at the time pumping ceased in a particular well and tracked backwards in time to whenever pumping started at a particular well. Starting locations for the particles consisted of a circle of radius 2.5 m centered on each extraction well with the particles evenly distributed about the circle. Vertically, the particles were released near the bottom of layer 3. This ensured the particles did not reach the water table during transport. If that were to happen, particle tracking would be halted because the particle would be at the source where the water entered the model domain.

2.2 UCL95 Calculations

Remediation performance was evaluated by calculating the 95th 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-α^{th} quantile of Student's *t* distribution with *n*-1 degrees of freedom; for the 95th 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 Figure 1.

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 2018 (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 2020 UCL95 consisted of concentrations at the end of 2018, 2019, and 2020. This ensured that enough data were available for representative calculation results. Note that only 1 year of data could be used for 2018 and 2 years for 2019.

3. When concentrations in a well declined to below one-tenth of the cleanup level, 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 two data points above one-tenth the cleanup level available for the calculation.

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 2. The area around the latest interpreted uranium plume (2017) 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 spacing increases to 7 m (for five rows and/or columns), then 10 m (5), 15 m (2), 20 m (3), and 25 m, and the column spacing increases 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 Central Plateau Groundwater Model is vertically discretized into seven 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).

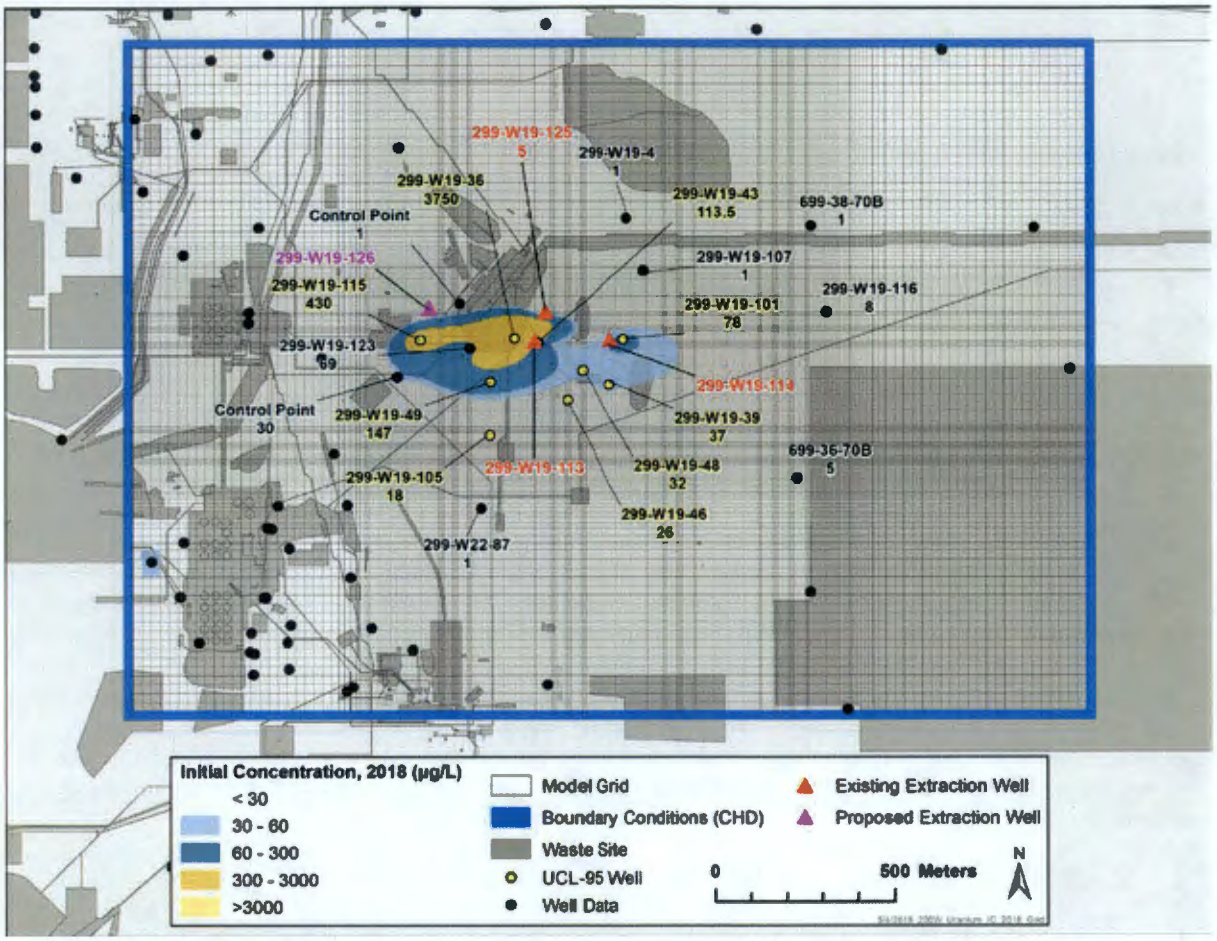

Figure 2. Horizontal Grid Discretization for the U Plant Local-Scale Submodel

3.2 Transport Parameters

Input data needed for transport modeling consists of values for effective porosity, dispersion, decay, and contaminant distribution coefficients. Aquifer transport parameters used for the U Plant transport modeling are tabulated in Table 1. A distribution coefficient (K_d) value of 0.4 mL/g was used for uranium. The transport parameters for the aquifer and uranium are the same as those used for the U Plant transport modeling in ECF-200UP1-17-0093.

Table 1. Aquifer Transport Parameters

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^2/day

Table 1. Aquifer Transport Parameters

Property	Value
Bulk density, Hanford, Cold Creek Formations	1.93 g/cm^3
Bulk density, Ringold Taylor Flat, Ringold Unit E, Ringold Lower Mud, Ringold Unit A	1.90 g/cm^3

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

3.3 Initial Conditions, Sources and Sinks, and Boundary Conditions

Initial conditions, sources and sinks (i.e., continuing sources), and boundary conditions are defined in the subsections that follow.

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, predictive transport simulations documented in ECF-200UP1-17-0093 were performed using two initial concentration plumes: the 2015 plume as described in ECF-200UP1-17-0010, *200-UP-1 Leapfrog Models of U Plant Uranium and Technetium-99 Plumes Fall 2015*, and a working interpreted plume based on 2016 data generated in advance of annual report plume documented in DOE/RL-2016-09 when the modeling was performed (ECF-200UP1-17-0093). Similarly, a working interpreted plume based on 2017 data which is not finalized but will be documented in the next annual groundwater monitoring report (DOE/RL-2017-66) was used as the basis for the initial concentrations in the predictive transport simulations for this ECF.

The first initial concentration plume (i.e., 2015 uranium plume) for U Plant transport modeling in the ECF-200UP1-17-0093 was based on the three-dimensional (3D) plume documented in ECF-200UP1-17-0010. 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 3.

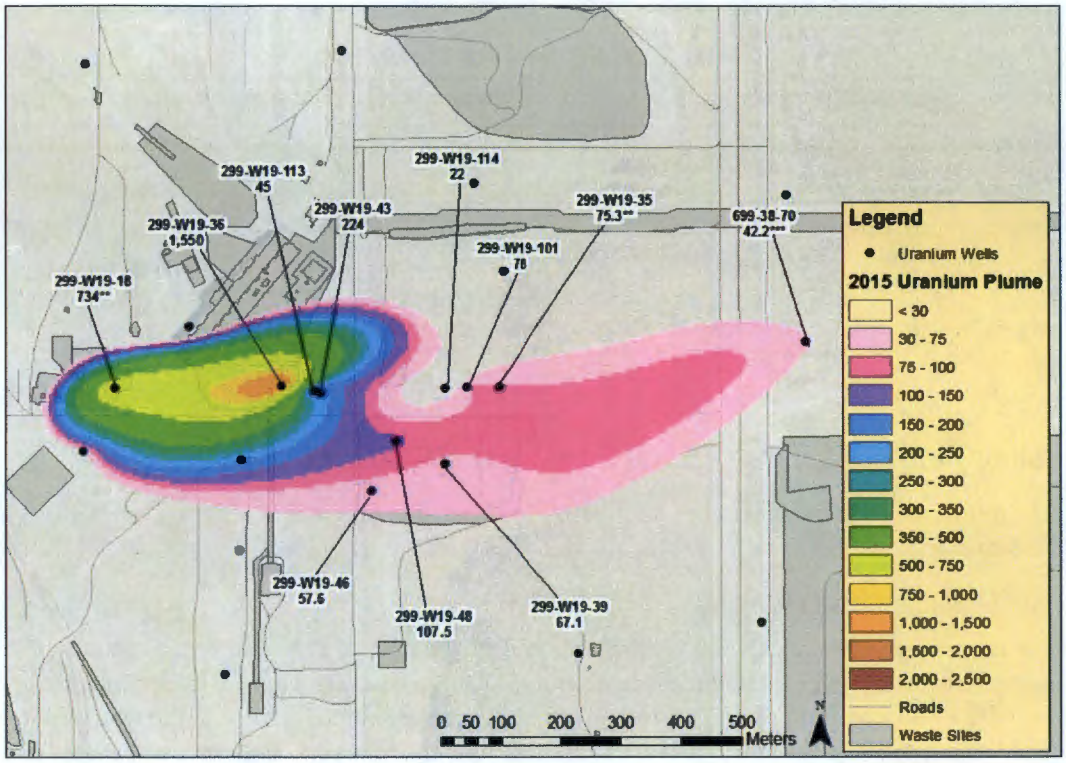

Figure 3. 2015 Uranium Initial Conditions at the Water Table (Used in ECF-200UP1-17-0093)

The second initial concentration plume (i.e., 2016 working initial concentration plume) were built using the raster data from DOE/RL-2016-09 and the well data documented in Appendix C of ECF-200UP1-17-0093. The details of the resulting initial condition plume are documented in ECF-200UP1-17-0093 and is shown in Figure 4. The 2016 working initial conditions were created as a 2D plume, and therefore required extrapolation to the lower layers. Individual percent changes of concentration for each model cell with depth were calculated using the change in concentration from layer to layer in each cell of the 2015 uranium initial condition. These percentage changes were applied to the 2016 initial condition, and thereby the 2D plume was interpolated into a 3D plume. A similar approach was applied to develop initial concentrations for this ECF using the raster based on the most recent well data (DOE/RL-2017-66). The 2017 raster and the well data used in its creation can be seen in Figure 5. The total initial uranium mass used for the analysis in ECF-200UP1-17-0093 was approximately 630 kg in the 2015 initial condition and 400 kg in the 2016 initial condition; the total initial uranium mass used in this ECF is approximately 390 kg.

3.3.2 Continuing Sources

Continuing sources for uranium beneath the U1 and U2 Cribs (216-U-1 and 216-U-2) were identified and mass fluxes releasing to the aquifer were estimated in ECF-200W-17-0030, *Calculation of Source Terms for the 200 West Pump-and-Treat System Optimization Modeling, FY 2017*. The estimated uranium mass flux releases were applied to the groundwater fate and transport model as documented in ECF-200UP1-17-0093.

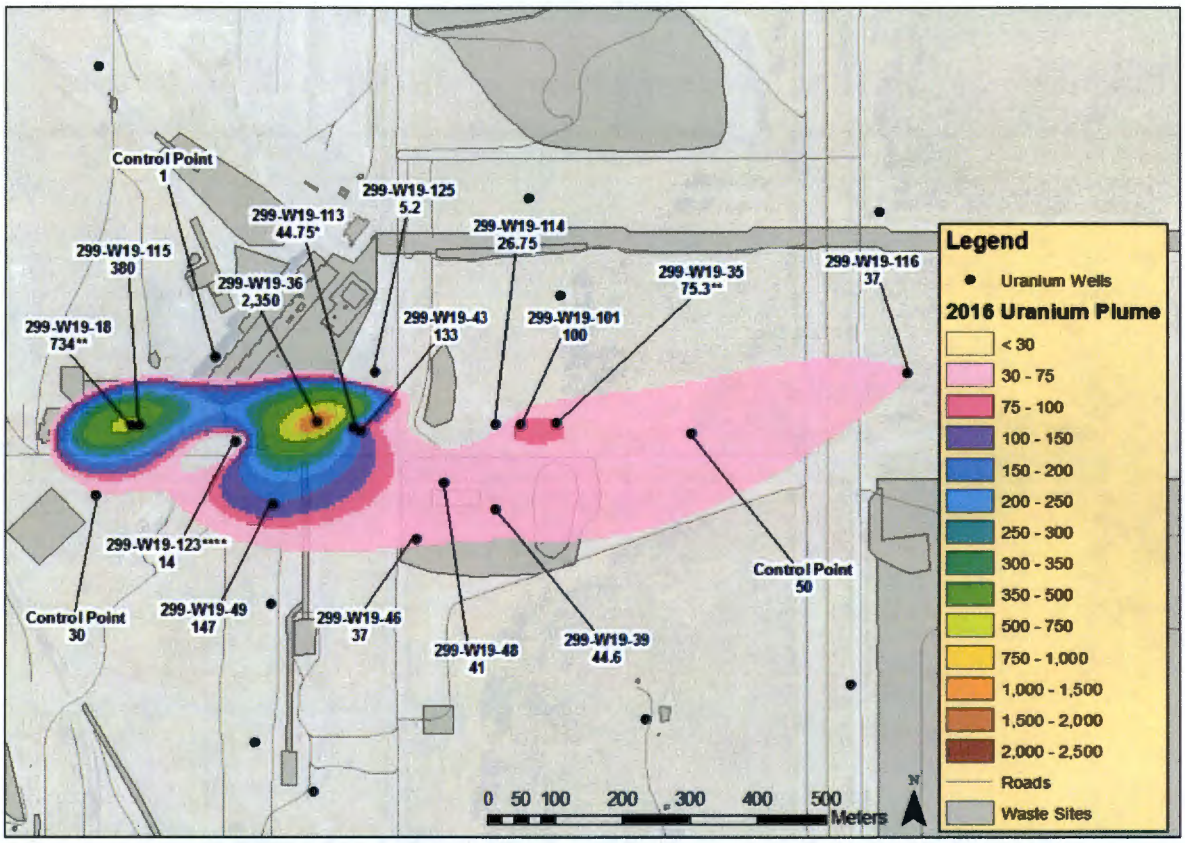

Figure 4. 2016 Working Initial Conditions at Water Table (Used in ECF-200UP1-17-0093)

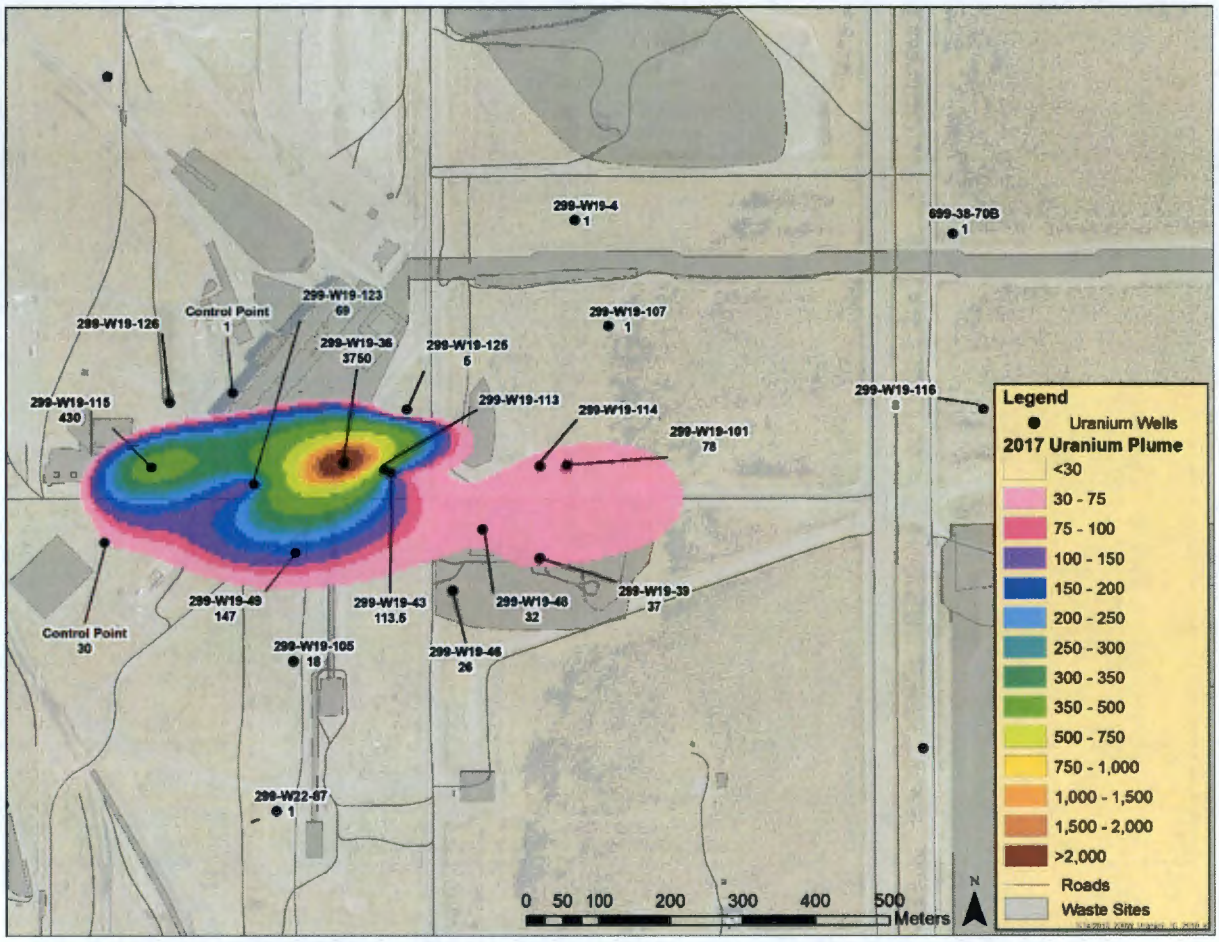

Figure 5. Fall 2017 Initial Conditions at Water Table (Prepared for and Used in this Analysis)

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 predictive flow model was trimmed to begin in 2018, the internal boundary conditions were updated as described in Section 2.1.

3.3.4 Additional Flow Models

As mentioned in Section 2.1.1, additional flow simulations based on two approaches (four flow model simulations for each approach and the base case), were performed with different internal boundary conditions than those documented in ECF-200UP1-17-0093 to assess the performance of new pump-and-treat system configuration. For each flow simulation, the only changes made regarded which wells were pumping, the extraction rates at those wells, and the pumping period. The first approach utilized all the existing extraction wells to assess whether cleanup standards could be achieved by reconfiguring the existing system. All the scenarios modeled as part of first approach are listed in Table 2. The base case scenario simulates three extraction wells currently operating at 50 gpm each within vicinity of U Plant. The other pumping wells within the model domain were kept as same as flow model documented in ECF-200UP1-17-0093. The remaining four scenarios of the first approach used different configurations of existing extraction wells with varying total pumping rates and pumping durations. The second approach

used a combination of existing and new extraction wells and new injection wells to achieve cleanup standards if the first approach were to be unsuccessful. All the scenarios modeled as part of the second approach are listed in Table 3. These four scenarios used four extraction/injection wells in combination with some existing wells with a total extraction rate of 200 gpm and a total injection rate of 200 gpm for any given scenario. The location of the new extraction/injection wells considered for the second approach analysis are tabulated in Table 4. The location of the new extraction/injection wells with respect to the current interpretation of the uranium plume and the existing extraction system for optimization iteration 1 and 2 are shown in Figure 6 and Figure 7, respectively. Similarly, Figure 8 shows the locations of the extraction/injection wells for optimization iteration 3 and 4.

Table 2. U Plant Groundwater Extraction System Pumping Rates for the First Approach

Flow Scenario Name and Total Rates	Well Name	Pumping Rate (gpm)	Pumping Period
Base Case Total Extraction: 150 gpm	299-W19-113	-50	20 years (2018 to 2037)
	299-W19-114	-50	
	299-W19-125	-50	
Base Case Phased 1 Total Extraction: 150 gpm	299-W19-113	-50	5 years (2018 to 2022)
	299-W19-114	-100	
	299-W19-125	-50	
	299-W19-113	-75	15 years (2023 to 2037)
	299-W19-114	0	
	299-W19-125	-75	
Base Case Phased 2 Same as Base Case Phased 1 except pumping continues through 2057 (40 years of pumping)			
Base Case Phased 3 Total Extraction: 150 gpm for 1st 10 years Total extraction: 200 gpm for next 10 years	299-W19-113	-50	10 years (2018-2027)
	299-W19-114	-50	
	299-W19-125	-50	
	299-W19-113	-100	10 years (2028-2037)
	299-W19-114	0	
	299-W19-125	-100	
Base Case Phased 4 Same as Base Case Phased 3 except pumping continues through 2057 (40 years of pumping)			

Table 3. U Plant Groundwater Extraction/Injection System Pumping Rates for the Second Approach

Flow Scenario Name and Total Rates	Well Name	Pumping Rate (gpm)	Pumping Period
Optimization Iteration 1 Existing system runs with 150 gpm until end of 2020. New system starts operating from 2021 with total 200 gpm extraction and total 200 gpm injection	299-W19-114	-50	20 years (2018 to 2037)
	EX2	-50	
	EX3	-50	
	EX4	-50	
	IN1	50	
	IN2	50	
	IN3	50	

Table 3. U Plant Groundwater Extraction/Injection System Pumping Rates for the Second Approach

Flow Scenario Name and Total Rates	Well Name	Pumping Rate (gpm)	Pumping Period
	IN4	50	
Optimization Iteration 2 Existing system runs with 150 gpm until end of 2020. New system starts operating from 2021 with total 200 gpm extraction and total 200 gpm injection	299-W19-114	-50	20 years (2018 to 2037)
	299-W19-125	-50	
	299-W19-126	-50	
	EX3	-50	
	IN5	50	
	IN6	50	
	IN7	50	
	IN8	50	
Optimization Iteration 3 Existing system runs with 150 gpm until end of 2020. New system starts operating from 2021 with total 200 gpm extraction and total 200 gpm injection	299-W19-114	-50	15 years (2018-2032)
	EX2	-50	
	EX3	-50	
	EX4	-50	
	IN1	50	
	IN2	50	
	IN3	50	
	IN4	50	
	299-W19-114	0	
	299-W19-125	-50	5 years (2033-2037)
	EX2	-50	
	EX3	-100	
	EX4	0	
	IN1	50	
	IN2	50	
	IN3	50	
	IN4	50	
Optimization Iteration 4 Existing system runs with 150 gpm until end of 2020. New system starts operating from 2021 with total 200 gpm extraction and total 200 gpm injection	299-W19-114	-50	15 years (2018-2032)
	EX2	-50	
	EX3	-50	
	EX4	-50	
	IN1	50	
	IN2	50	
	IN3	50	
	IN4	50	
	299-W19-114	0	5 years (2033-2037)
	299-W19-125	-100	
	EX2	-50	
	EX3	-50	
	EX4	0	
	IN1	50	
	IN2	50	

Table 3. U Plant Groundwater Extraction/Injection System Pumping Rates for the Second Approach

Flow Scenario Name and Total Rates	Well Name	Pumping Rate (gpm)	Pumping Period
	IN3	50	
	IN4	50	

Table 4. Locations of the Proposed New Extraction/Injection Wells within U Plant Groundwater Pump-and-Treat System

Well Name	Easting (m)	Northing (m)
EX2	567,725	135,050
EX3	567,570	135,070
EX4	567,420	135,050
IN1	567,800	134,850
IN2	567,600	134,900
IN3	567,420	134,930
IN4	567,280	134,940
IN5	567,850	134,830
IN6	567,650	134,870
IN7	567,470	134,890

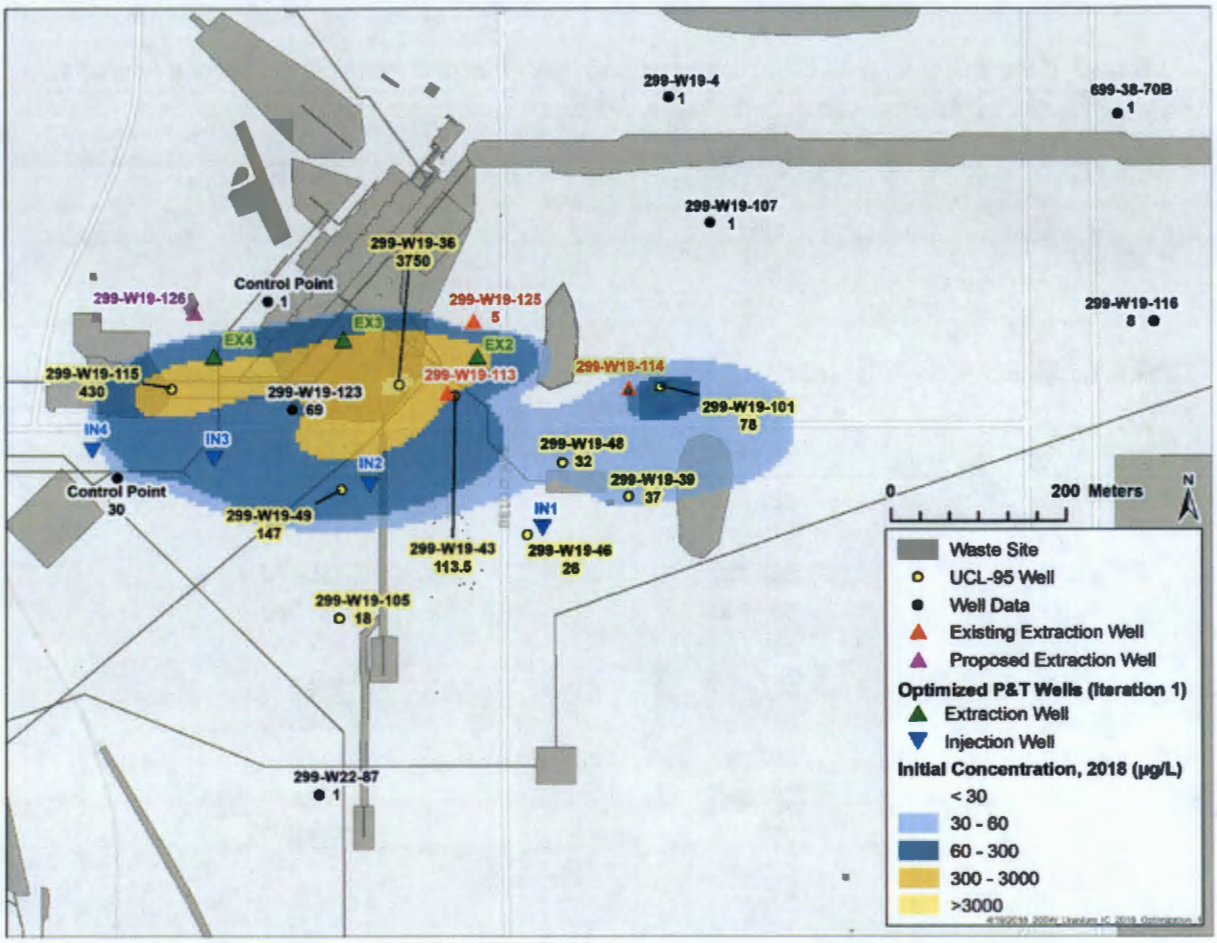

Figure 6. U Plant Groundwater Extraction/Injection System for Optimization Iteration 1

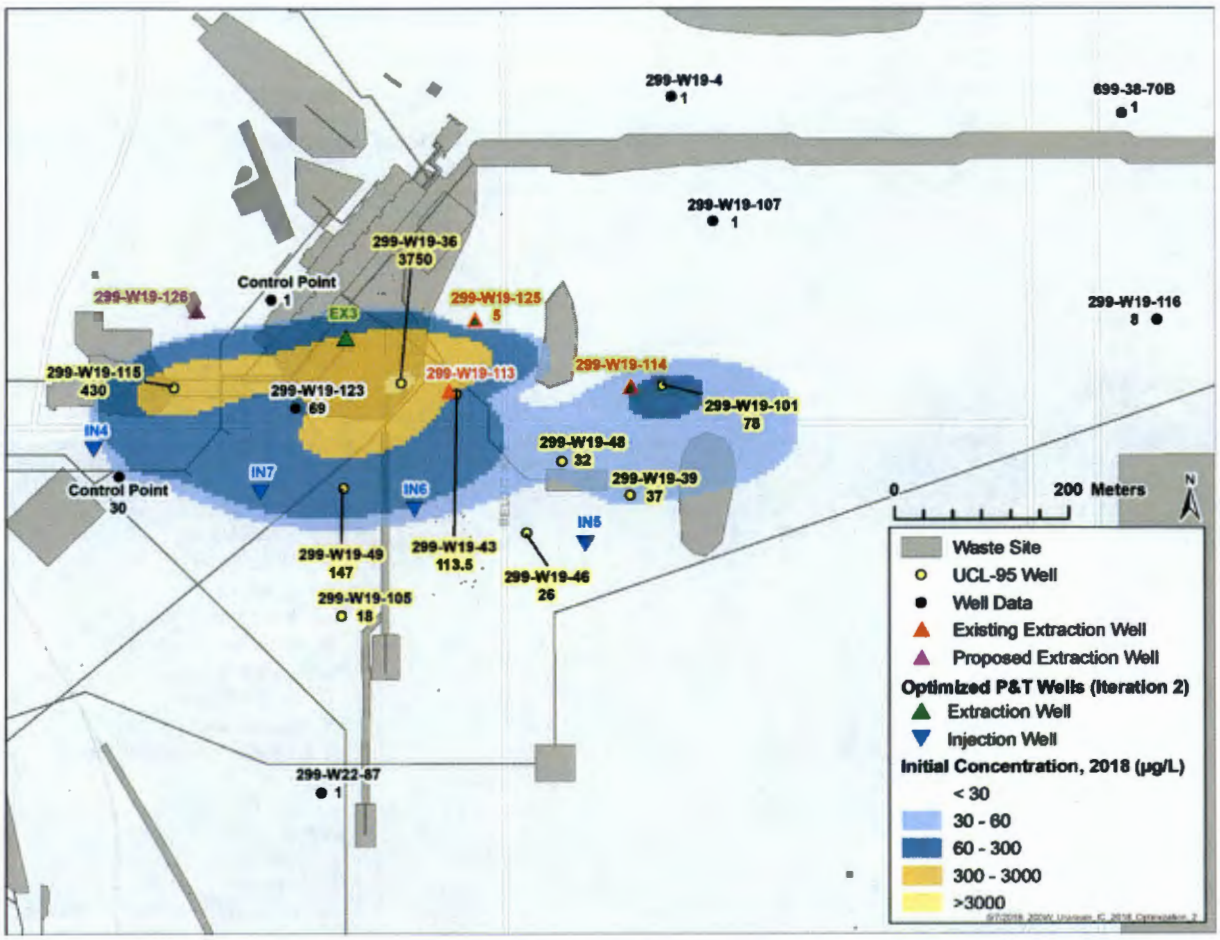

Figure 7. U Plant Groundwater Extraction/Injection System for Optimization Iteration 2

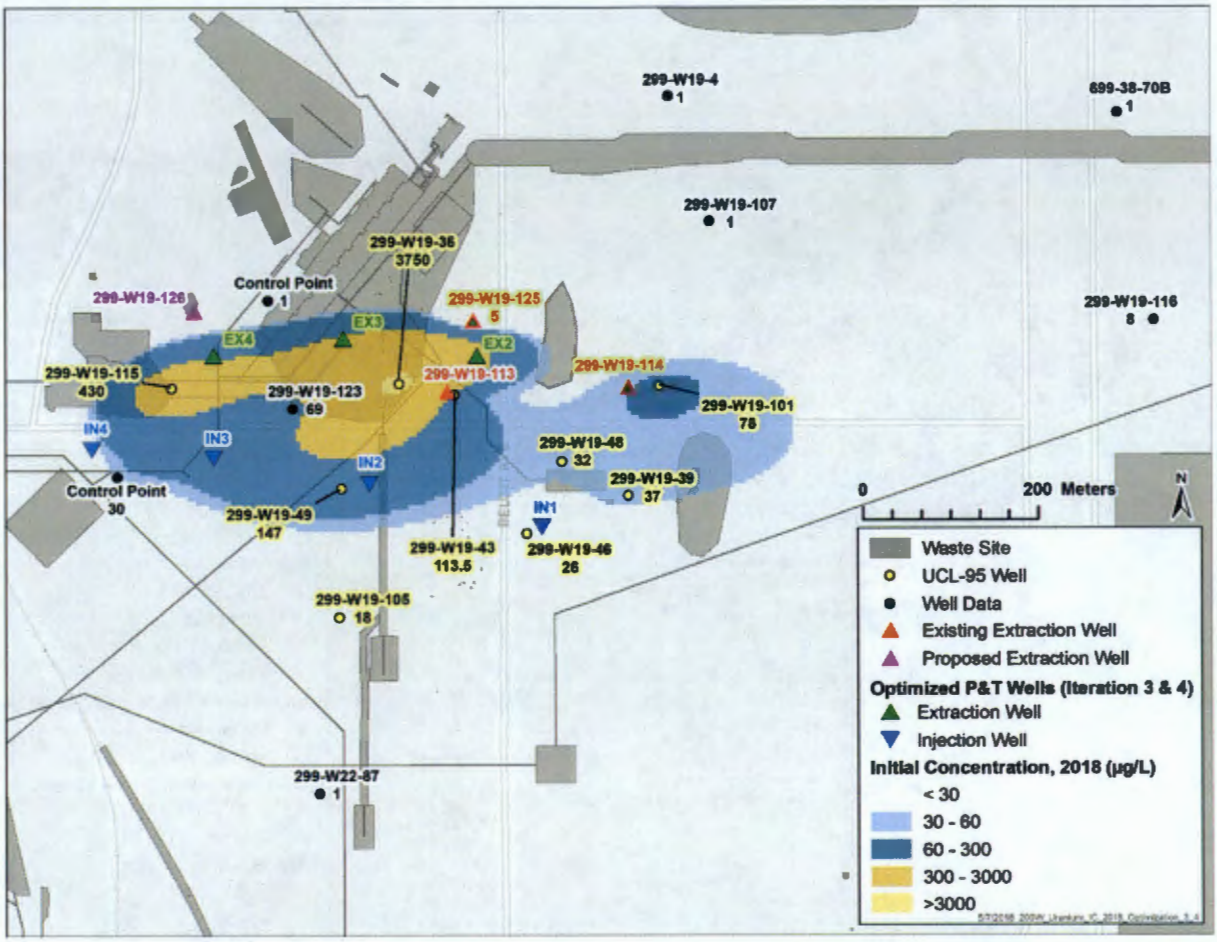

Figure 8. U Plant Groundwater Extraction/Injection System for Optimization Iterations 3 and 4

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 (up to 100 years) to allow concentrations to decline to below the cleanup standard (30 µg/L) for uranium. The simulation period and time discretization used for flow and transport modeling in this ECF were kept as same as ECF-200W-17-0093. The only exception is that the model was split into two models (historic and predictive) so that the predictive simulations could begin in 2018 by using the latest interpreted uranium plume as the initial conditions.

4 Software Applications

CHPRC Build 6 versions of MODFLOW-2000-MST, MT3DMS-MST, and MODPATH as well as Groundwater Vistas™[1] software programs were used for this environmental calculation. These are CH2M HILL Plateau Remediation Company (CHPRC) approved software, managed and used in compliance with the requirements of the CHPRC procedure that implements the controlled software

[1] Groundwater Vistas is a trademark of Environmental Simulations, Inc., Reinholds, Pennsylvania.

management requirements of DOE O 414.1D, Admin Chg 1, *Quality Assurance*. The following supporting information is provided.

4.1 Approved Software

For approved software used in this calculation, the required description is provided.

4.1.1 Description

MODFLOW

- Software Title: MODFLOW-2000-MST
- Software Version: CHPRC Build 8 (executable file "mf2k-mst-chprc08dpl.x")
- Hanford Information System Inventory (HISI) Identification Number: 2517 (Safety Software, Level C)
- Workstation type and property number (from which software is run): MODFLOW was executed on the INTERA Richland OLIVE Linux[2] Clusters that is owned and managed by INTERA, Inc., a subcontractor to CHPRC. The computer property tag for the front-end node is #469 at INTERA's office in Richland, Washington. This node is a Dell[3] PowerEdge[4] R510 with two six-core Intel[5] Xeon[6] X5660 processors @ 2.80GHz and 48 GB of RAM. As given by the command "uname –a", the operating system details are:
    - Linux olive 4.4.0-38-generic #57~14.04.1-Ubuntu SMP Tue Sep 6 17:20:43 UTC 2016 x86_64 x86_64 x86_64 GNU/Linux
- 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*
- Approved User: H. Rashid

MT3DMS-MST

- Software Title: MT3DMS-MST
- Software Version: CHPRC Build 8 (executable file "mt3d-mst-chprc08dpl.x")
- HISI Identification Number: 2517 (Safety Software, Level C)
- Workstation type and property number (from which software is run): MT3DMS was executed on the INTERA Richland OLIVE Linux[2] Clusters that is owned and managed by INTERA, Inc., a subcontractor to CHPRC. The computer property tag for the front-end node is #469 at INTERA's

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[2] Linux® is the registered trademark of Linus Torvalds in the U.S. and other countries.

[3] Dell is a trademark of Dell Inc. in the U.S. and other countries.

[4] PowerEdge is a trademark of Dell Inc. in the U.S. and other countries.

[5] Intel is a registered trademark of Intel Corporation or its subsidiaries in the U.S. and/or other countries.

[6] Xeon is a registered trademark of Intel Corporation or its subsidiaries in the U.S. and/or other countries.

office in Richland, Washington. This node is a Dell[3] PowerEdge[4] R510 with two six-core Intel[5] Xeon[6] X5660 processors @ 2.80GHz and 48 GB of RAM. As given by the command "uname –a", the operating system details are:

  - Linux olive 4.4.0-38-generic #57~14.04.1-Ubuntu SMP Tue Sep 6 17:20:43 UTC 2016 x86_64 x86_64 x86_64 GNU/Linux

- 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*
- Approved User: H. Rashid

4.1.2 Software Installation and Checkout

The approved safety software packages (MODFLOW, MT3DMS) and the controlled version of the support software (MODPATH) were 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™[7], 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 for this controlled use software is provided in Appendix A of this ECF.

4.1.3 Statement of Valid Software Application

The preparers of this calculation brief 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 and MT3DMS are graded as Level C software, use of these software programs is required to be logged in the HISI. Accordingly, this environmental calculation has been logged by the software owner in the HISI under Identification Numbers 2517 and 2518, respectively.

5 Calculation

Flow simulation for time period 2016 to 2017 (historic flow model) was performed using U Plant groundwater extraction system rates provided by the pump-and-treat operations group, and simulated hydraulic heads at the end of 2017 were extracted from the model to be used as the initial head for all the predictive flow models tabulated in Table 2 and Table 3. Predictive transport simulations for each of these flow simulations were performed without considering continuing sources except for the base case for which transport simulations were performed both with the source and no source conditions. In addition, reverse particle tracking analyses for all the flow simulations were performed to delineate capture zones.

6 Results/Conclusions

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

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[7] MKS Integrity is a trademark of PTC, Incorporated.

6.1 Capture Zone Analysis

Capture zone analyses using reverse particle tracking were performed for all the flow simulations described in Table 2 and Table 3. As described in section 2.1.2, particles are placed around the extraction wells and released at the end of pumping period to track the origin of the particles when pumping started through the reverse particle tracking method. The capture zone results for the base case and reconfigured base cases are shown in Figure 9 through Figure 13. The capture zone analysis for the optimization iterations are shown in Figure 14 through Figure 17.

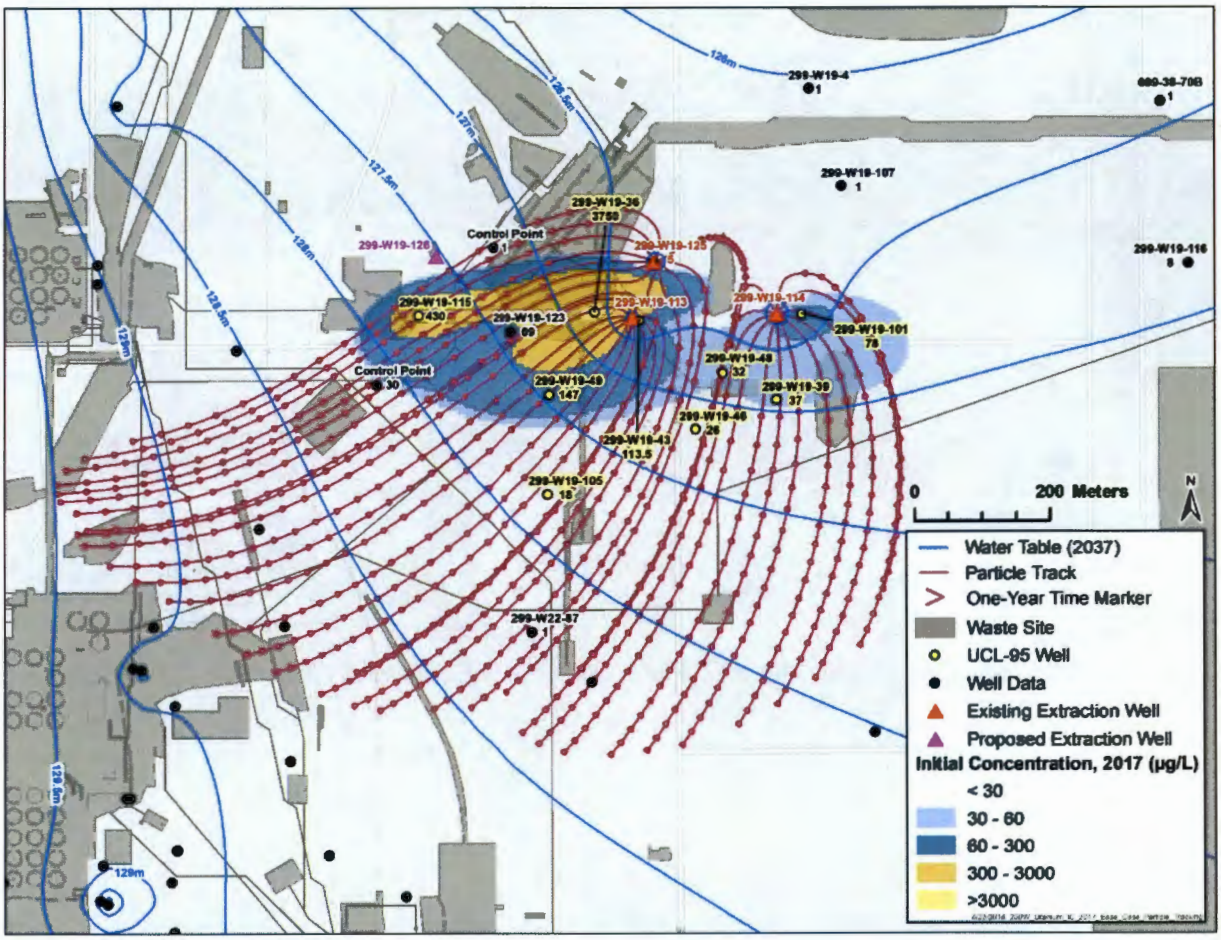

Figure 9. Simulated Capture Zones for the U Plant Groundwater Extraction System (Base Case)

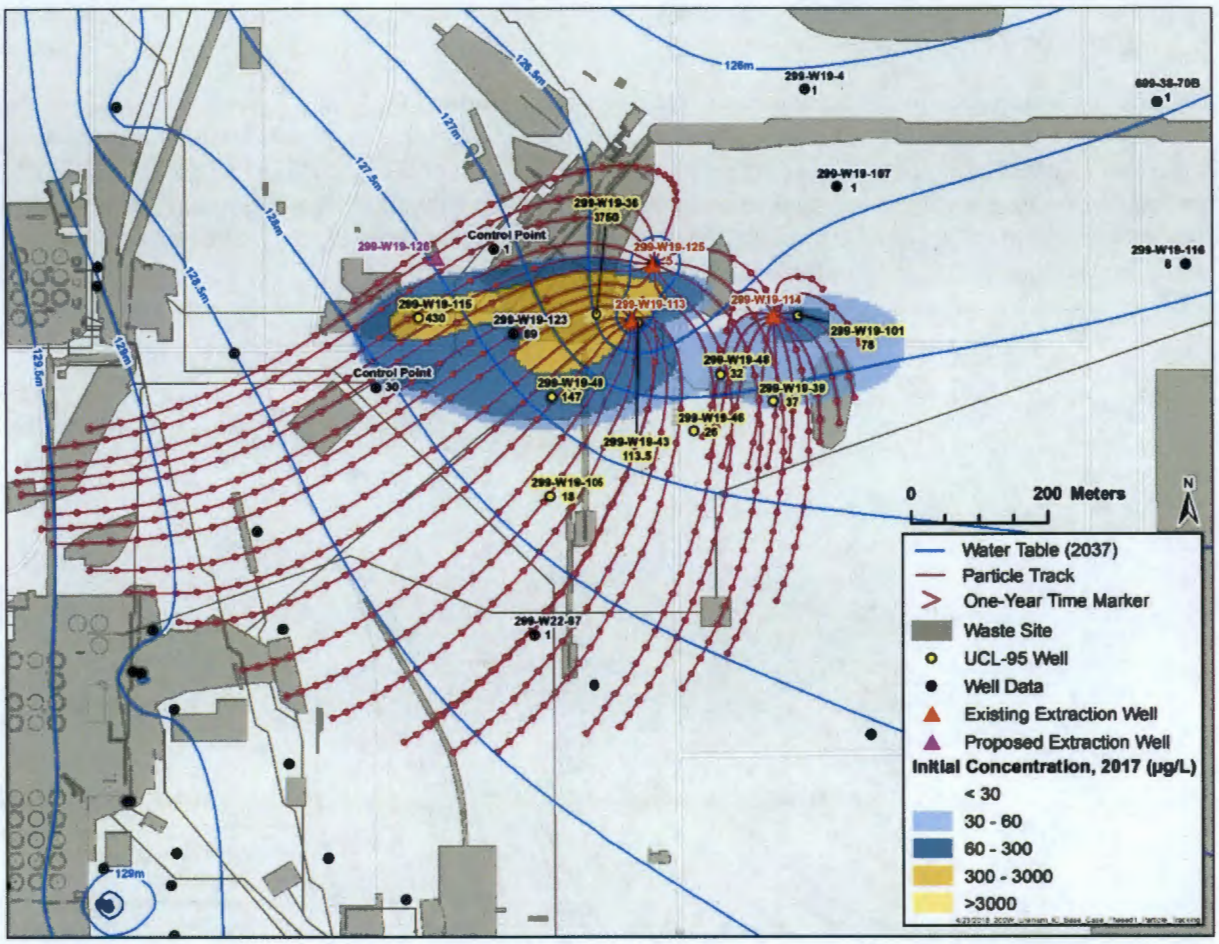

Figure 10. Simulated Capture Zones for the U Plant Groundwater Extraction System (Base Case Phased 1)

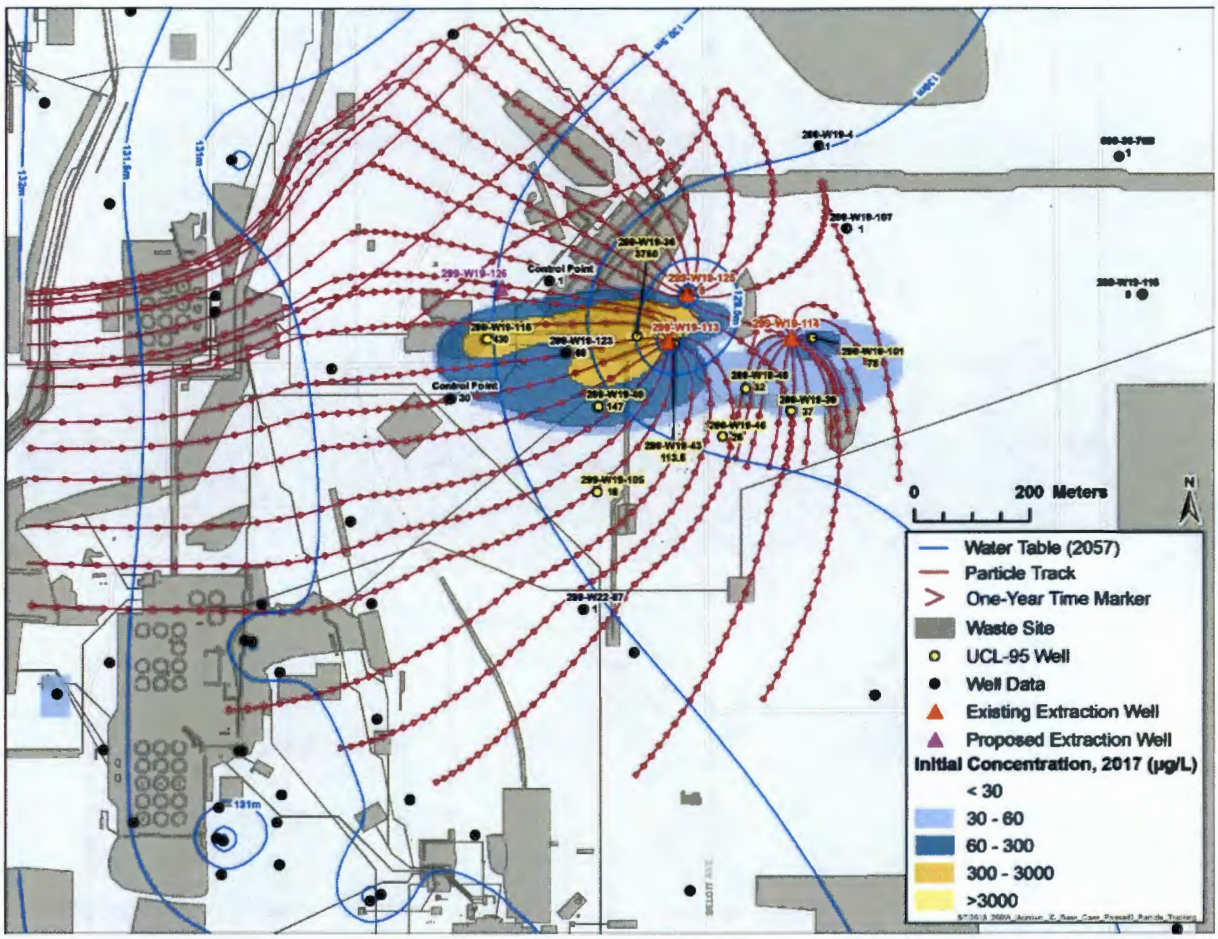

Figure 11. Simulated Capture Zones for the U Plant Groundwater Extraction System (Base Case Phased 2)

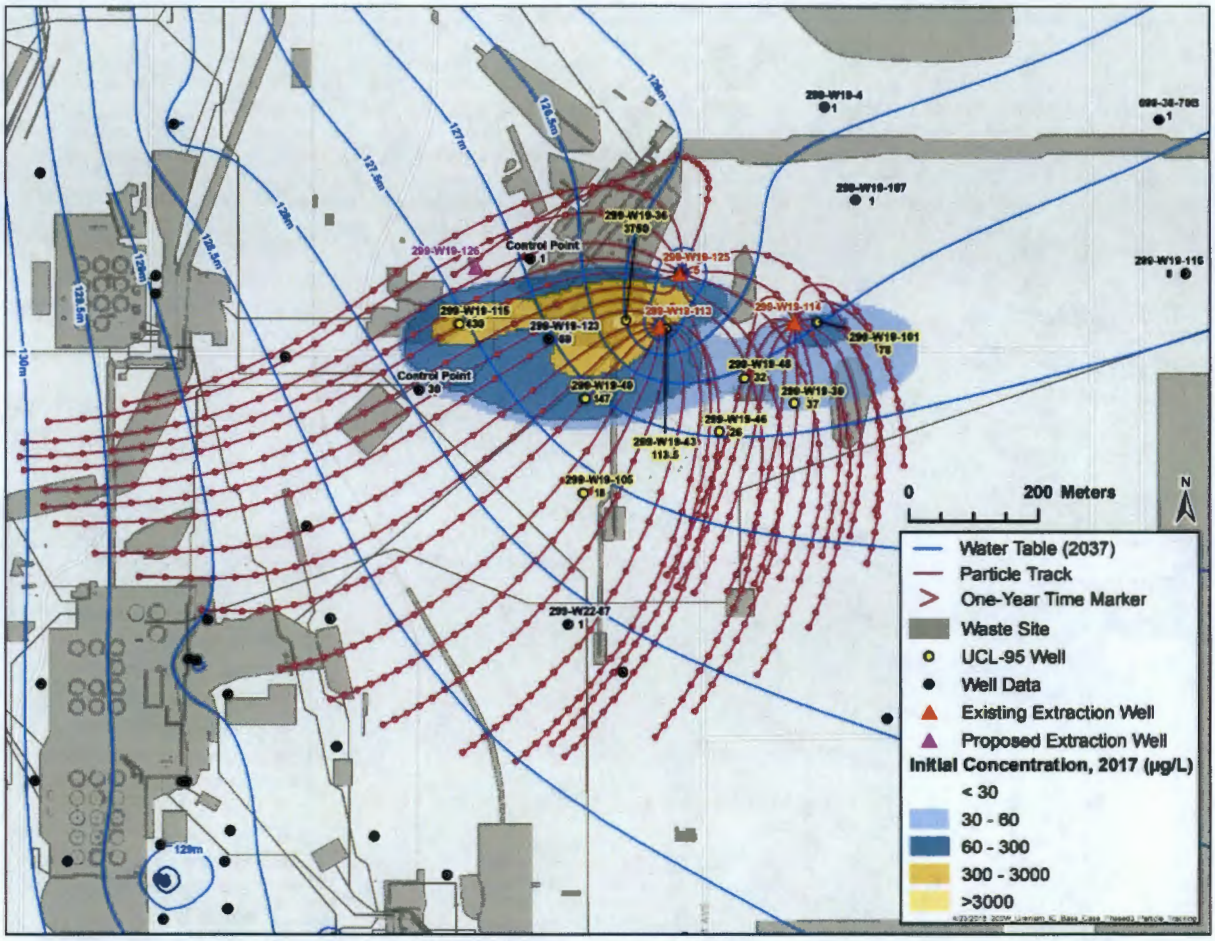

Figure 12. Simulated Capture Zones for the U Plant Groundwater Extraction System (Base Case Phased 3)

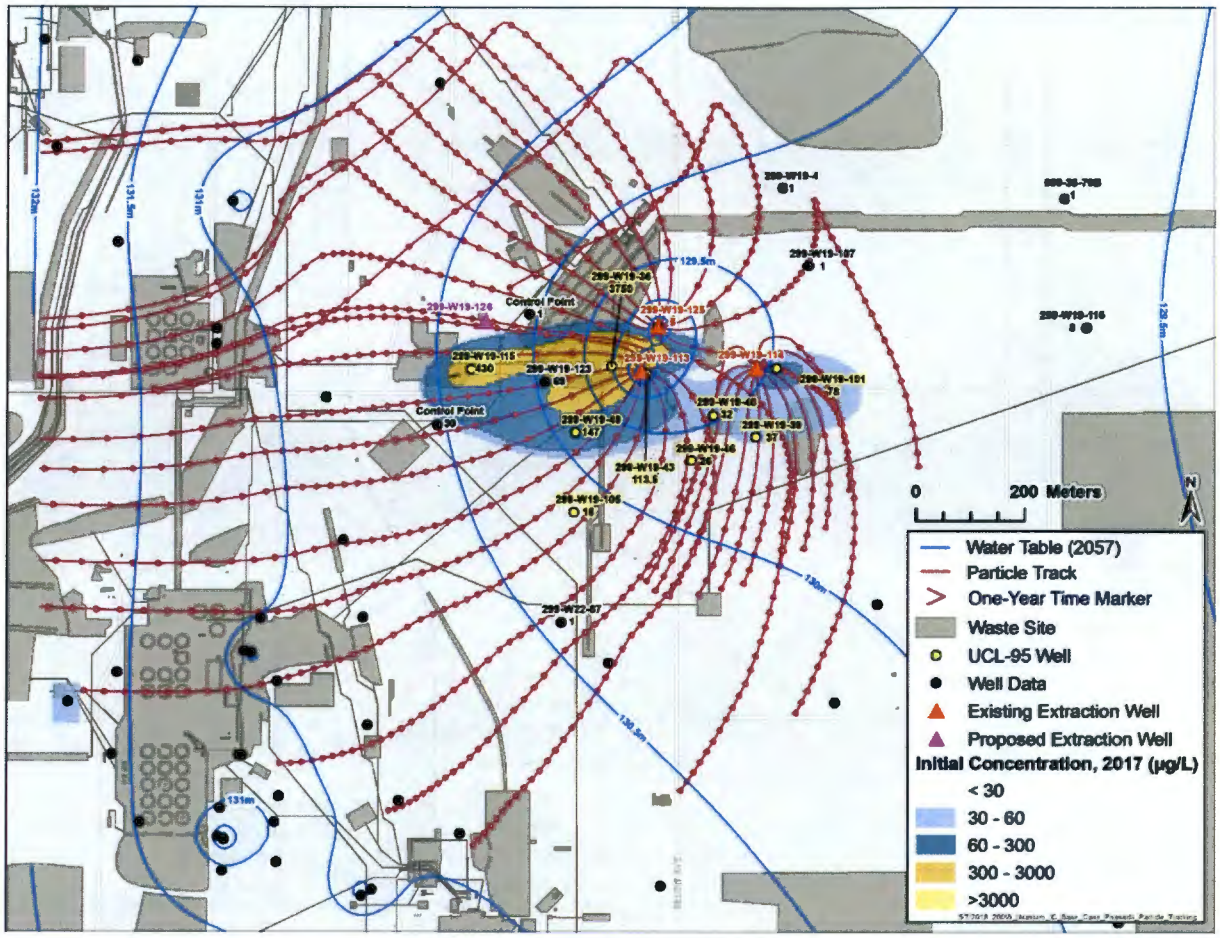

Figure 13. Simulated Capture Zones for the U Plant Groundwater Extraction System (Base Case Phased 4)

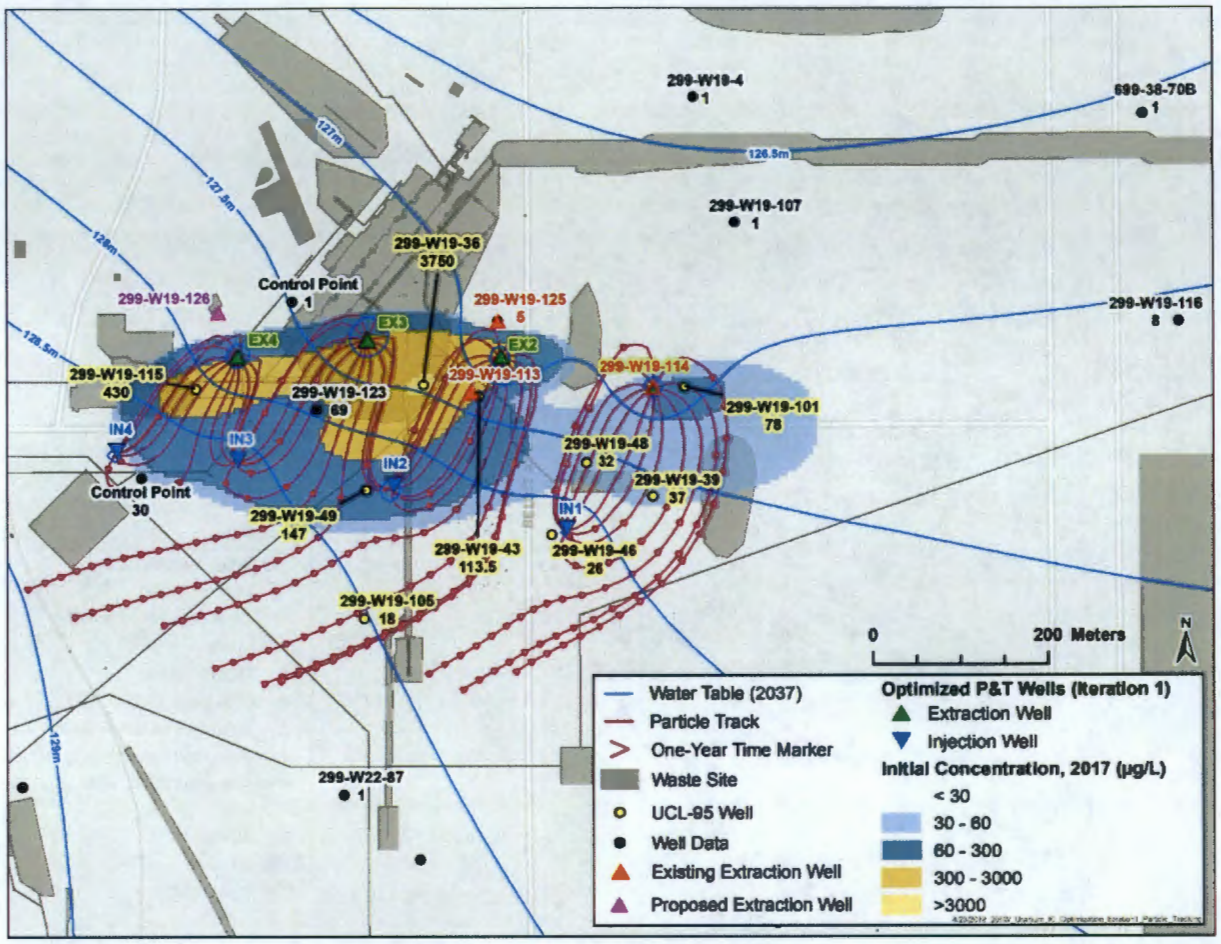

Figure 14. Simulated Capture Zones for the U Plant Groundwater Extraction System (Optimization Iteration 1)

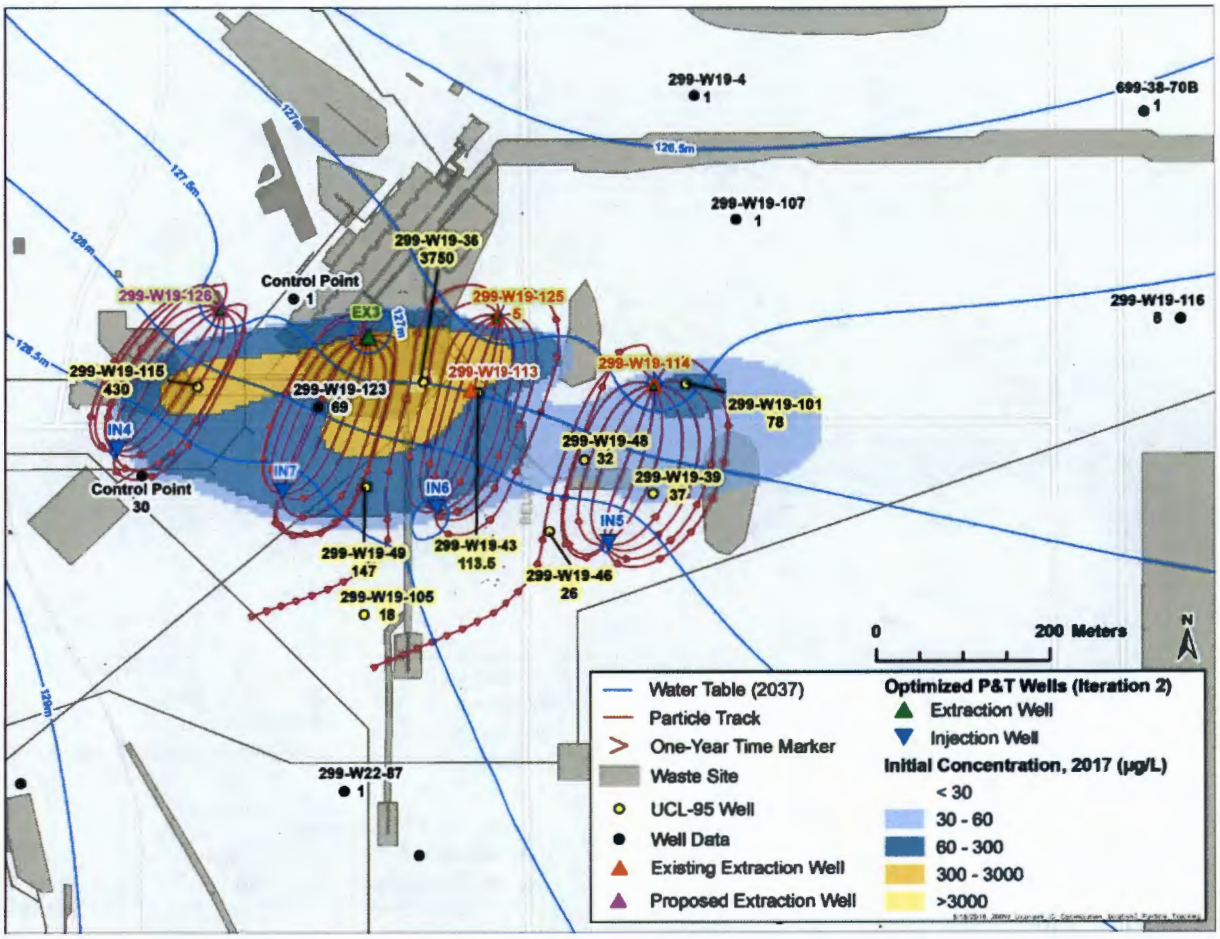

Figure 15. Simulated Capture Zones for the U Plant Groundwater Extraction System (Optimization Iteration 2)

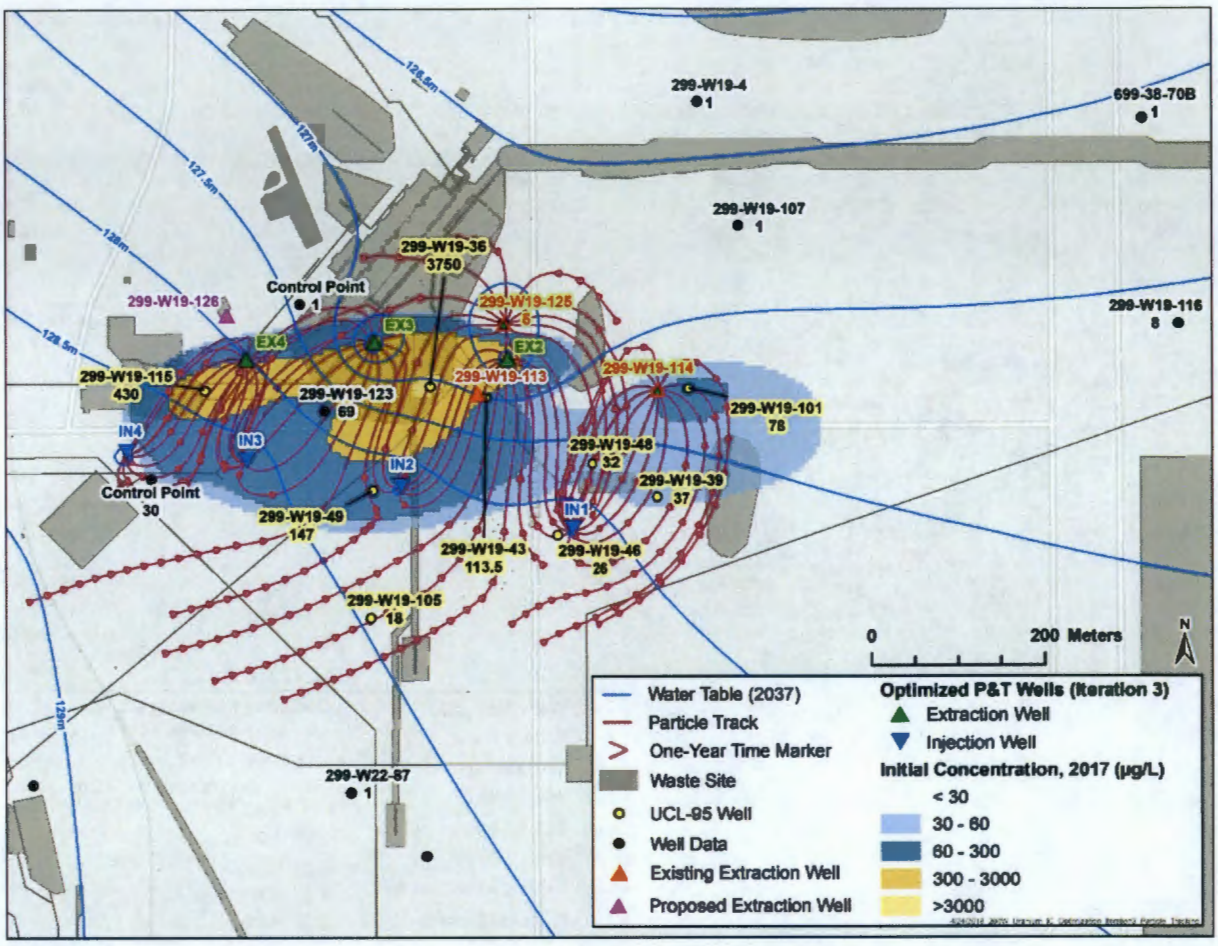

Figure 16. Simulated Capture Zones for the U Plant Groundwater Extraction System (Optimization Iteration 3)

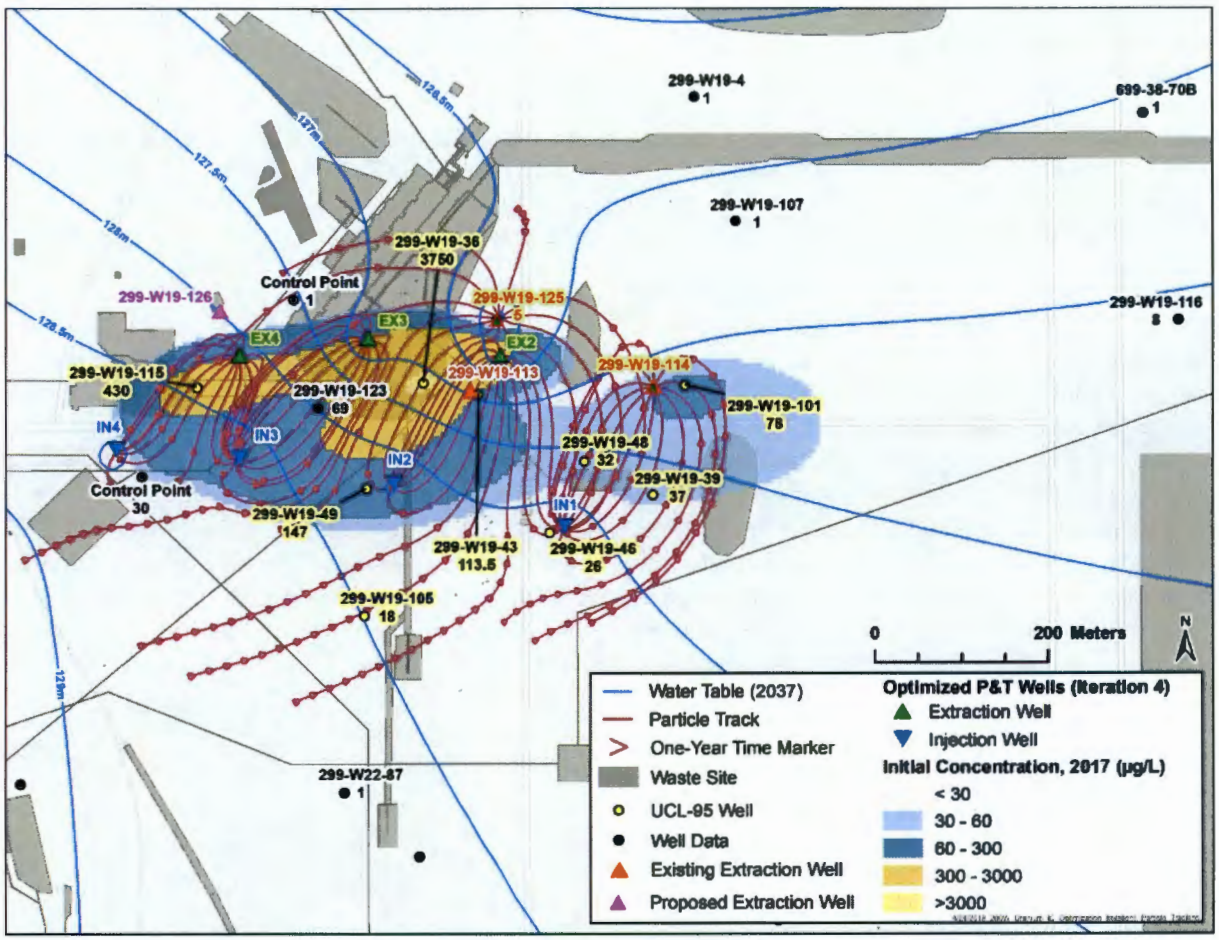

Figure 17. Simulated Capture Zones for the U Plant Groundwater Extraction System (Optimization Iteration 4)

6.2 Transport Analysis

The predictive transport simulation results are analyzed by using the following metrics:

1. The extent of the plume footprint or migration of the plume over time
2. The maximum concentration in the aquifer over time
3. Cumulative mass extracted by the extraction wells
4. UCL95 concentration over time

6.2.1 Transport Simulation Results for First Approach

Transport simulations for the base case flow condition were performed both using continuing source and without the continuing source. Based on the previous study, as documented in ECF-200UP1-17-0093, it was expected that the continuing source would not have any impact on the current U Plant groundwater extraction system performance as the plume related to the continuing source would remain far away from the pump-and-treat vicinity. Given the wide range of uncertainty on the mass releases from the vadose zone to the underlying aquifer, all other transport simulations were performed without the continuing sources. The simulated uranium plume at the water table for the base case scenario without the continuing

source at the end of 2037 and at the end of 2137 are shown in Figure 18 and Figure 19, respectively. Similar plumes for the base case with the continuing source are shown in Figure 20 and Figure 21, respectively.

Four additional flow simulations (Table 2) were performed by modifying the current configuration of the U Plant groundwater extraction system to assess whether the cleanup standard could be achieved by the existing pump-and-treat system. Simulated uranium plumes for these four scenarios without the continuing source at the end of 2037 and at the end of 2137 are shown in Figure 22 through Figure 29.

Figure 30 shows simulated maximum concentrations in the aquifer over the 120-year simulation period. Figure 31 shows UCL95 concentrations for the UCL95 wells network over the 120-year simulation period. From the simulated plume figures, plots of simulated maximum concentration in the aquifer, and plots of simulated UCL95 concentrations, it is evident that the cleanup standard would not be achieved by any of the pump-and-treat scenarios from the first approach. Figure 32 shows the cumulative mass removed from the aquifer by the extraction wells during pump-and-treat operations for all the scenarios of first approach. For the 20-year pumping scenarios, the total uranium mass extraction for base case, base case phased 1, and base case phased 3 are 189 kg, 199 kg, and 216 kg, respectively. On the other hand, as expected, the total uranium mass extraction for the 40-year pumping scenarios of base case phased 2 and base case phased 4 are 270 kg and 297 kg, respectively. That means, approximately 93 kg of uranium mass remains in the aquifer after a 40 year of pumping with the existing extraction wells.

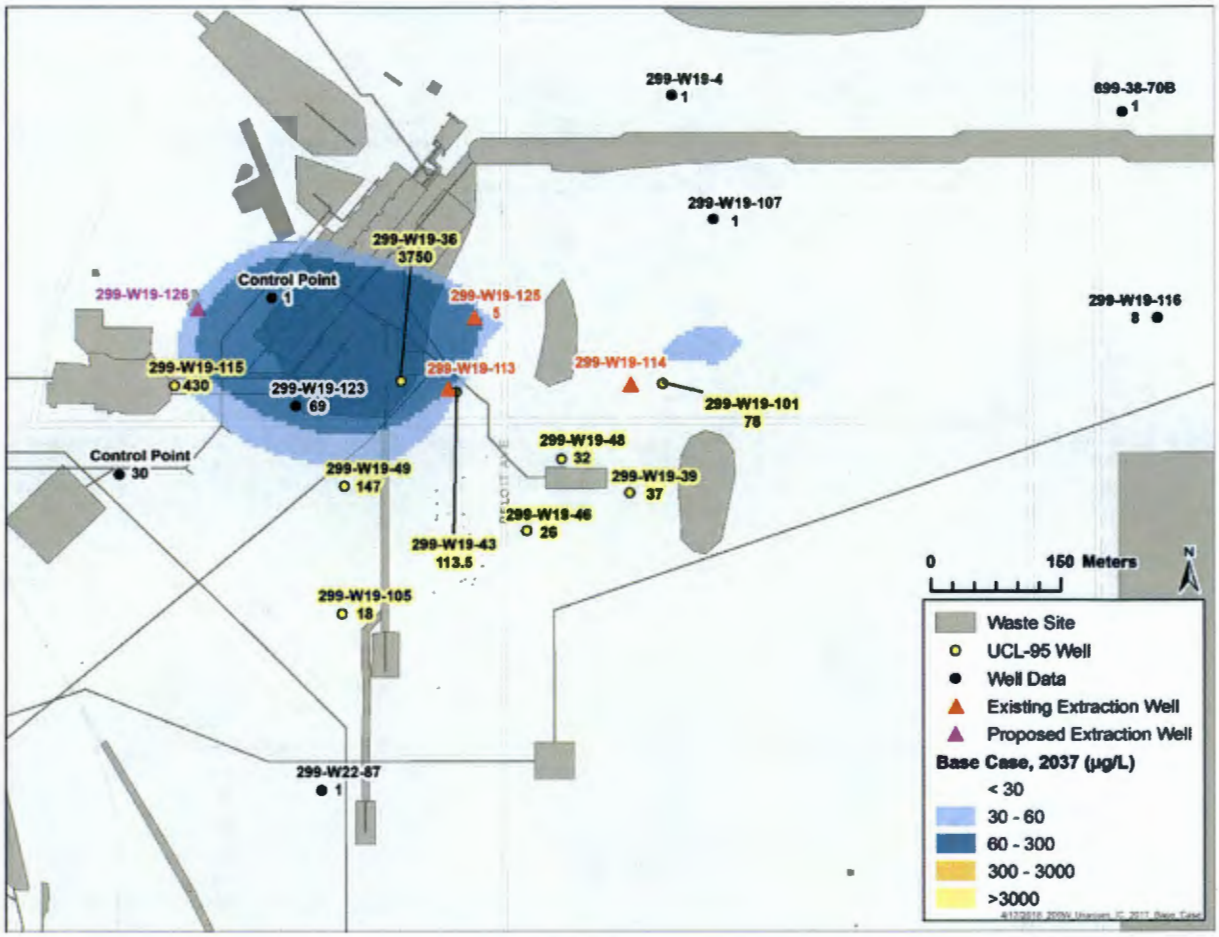

Figure 18. Simulated Uranium Concentration at the End of 2037 at Water Table (Base Case without Continuing Source)

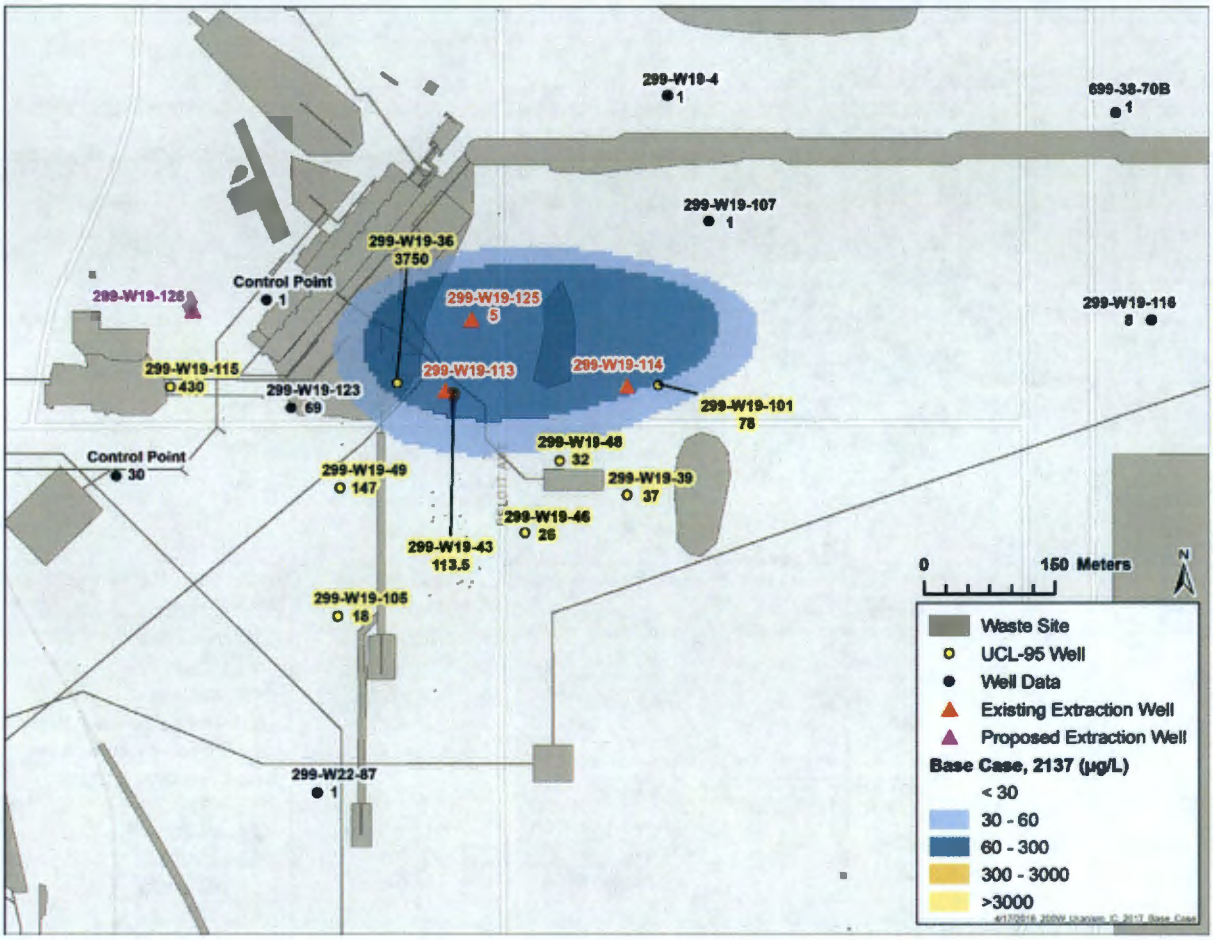

Figure 19. Simulated Uranium Concentration at the End of 2137 at Water Table (Base Case without Continuing Source)

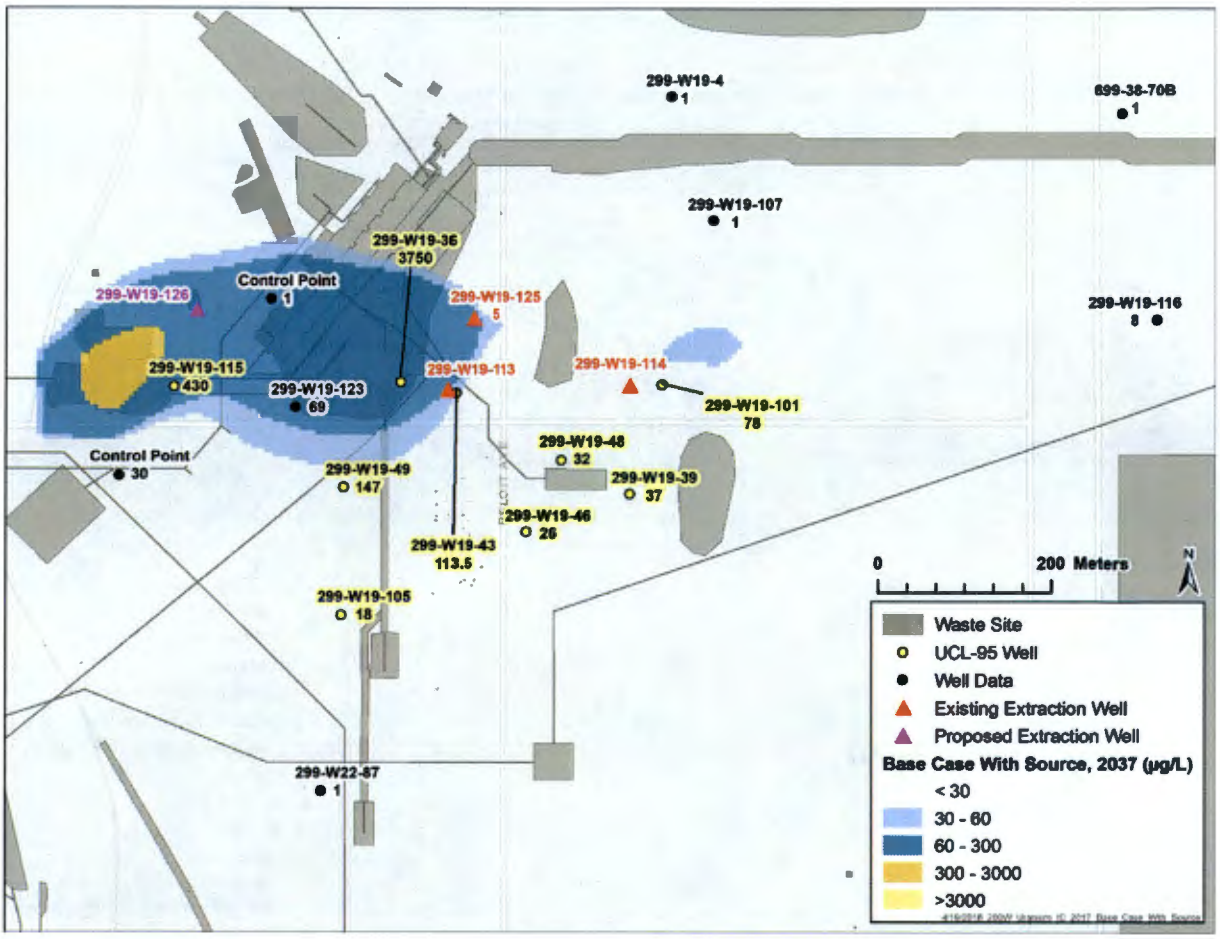

Figure 20. Simulated Uranium Concentration at the End of 2037 at Water Table (Base Case with Continuing Source)

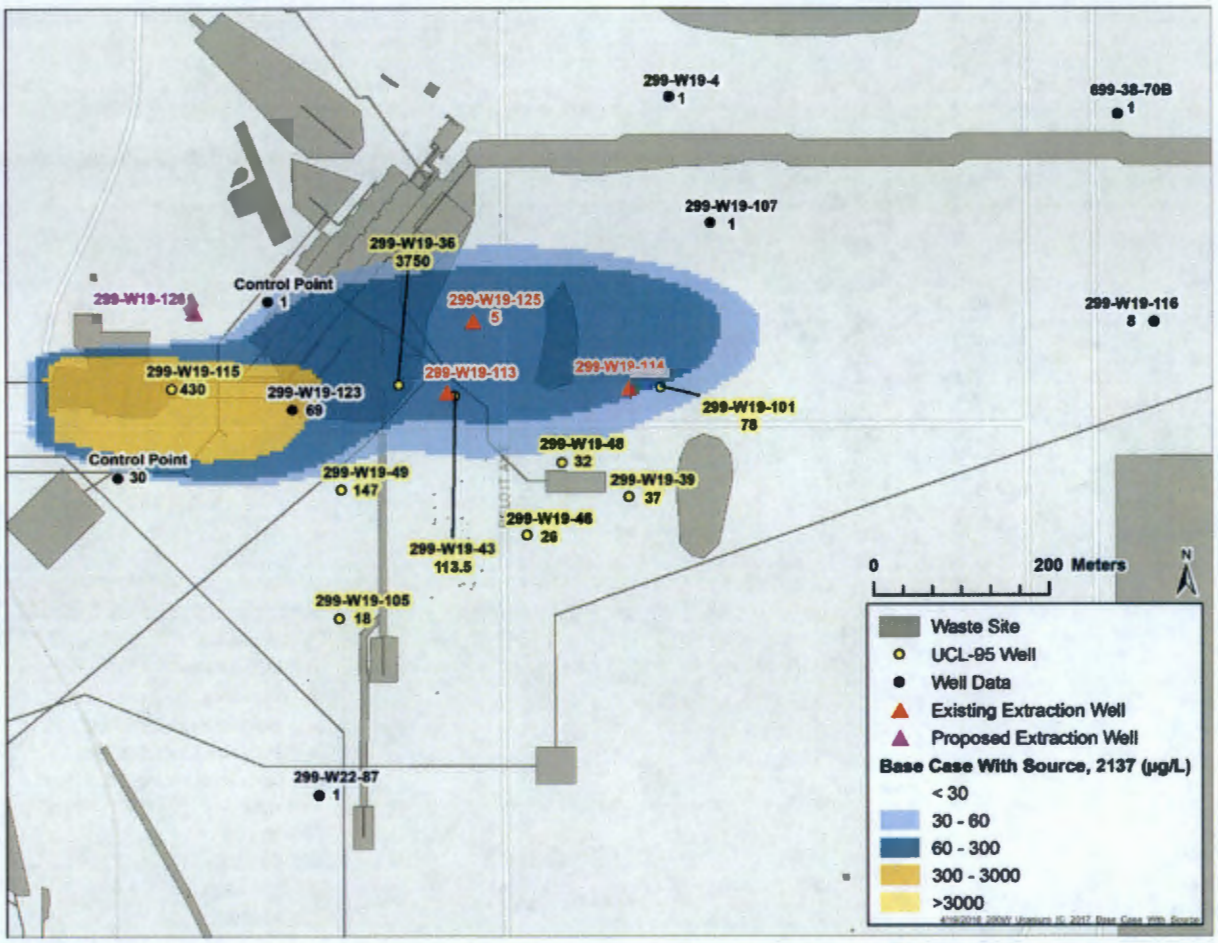

Figure 21. Simulated Uranium Concentration at the End of 2137 at Water Table (Base Case with Continuing Source)

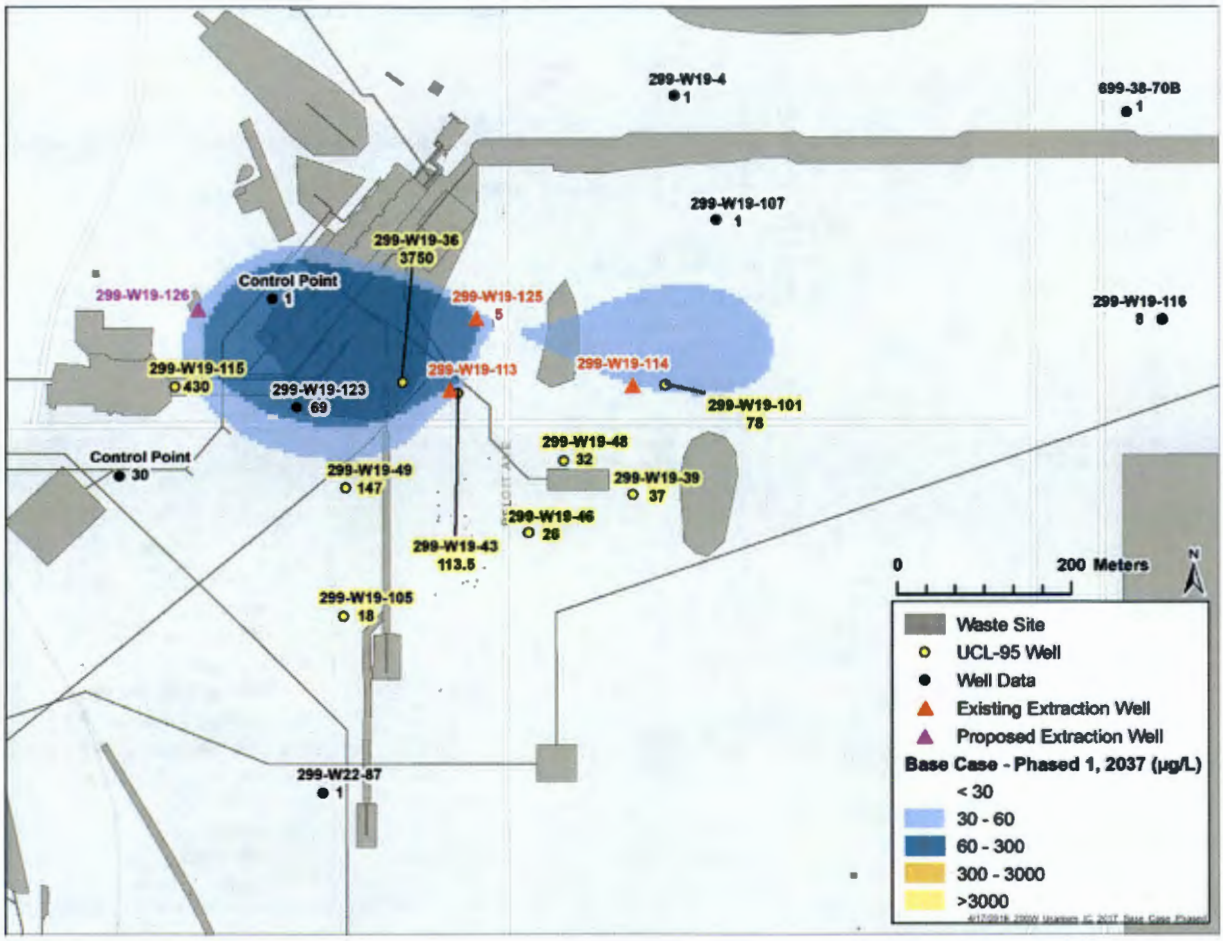

Figure 22. Simulated Uranium Concentration at the End of 2037 at Water Table (Base Case Phased 1 without Continuing Source)

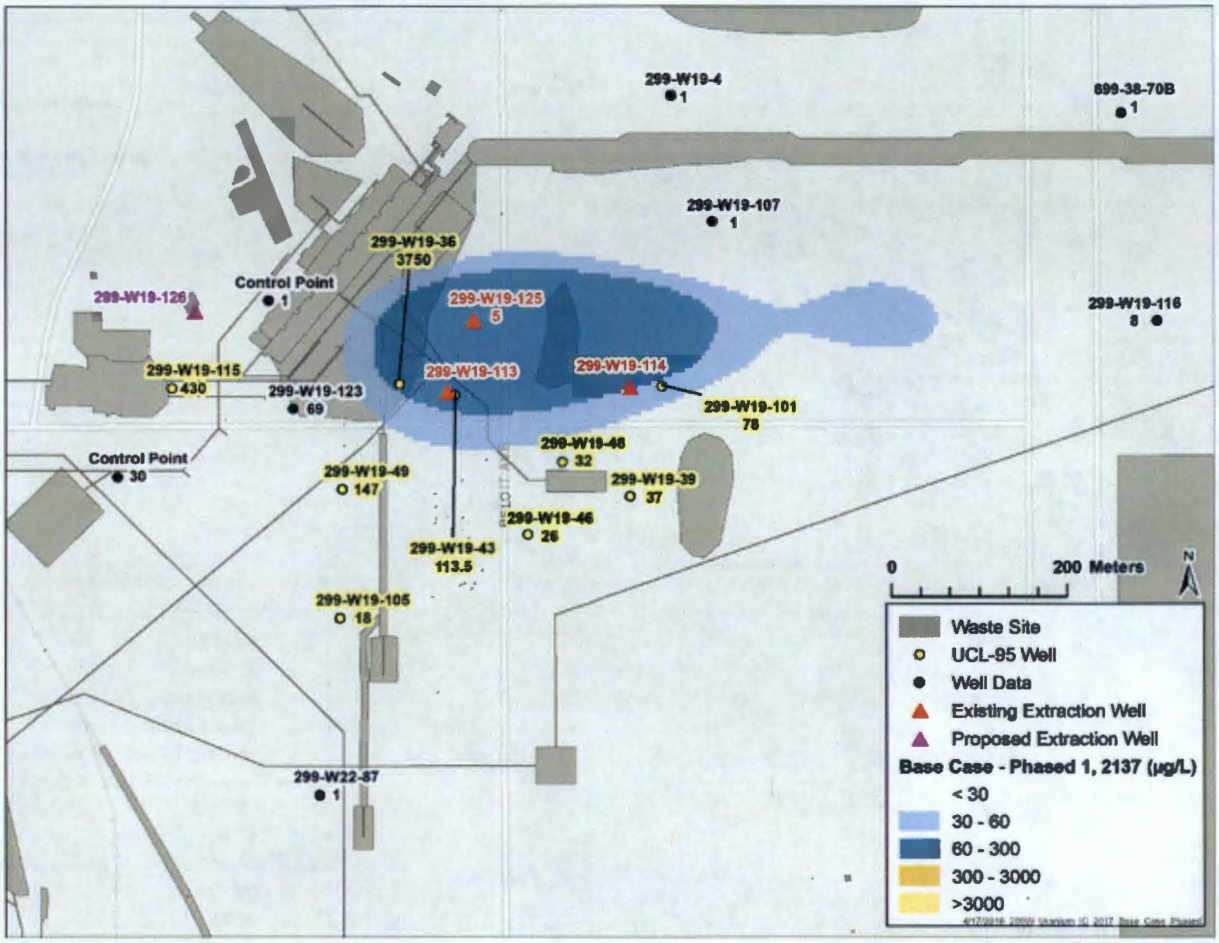

Figure 23. Simulated Uranium Concentration at the End of 2137 at Water Table (Base Case Phased 1 without Continuing Source)

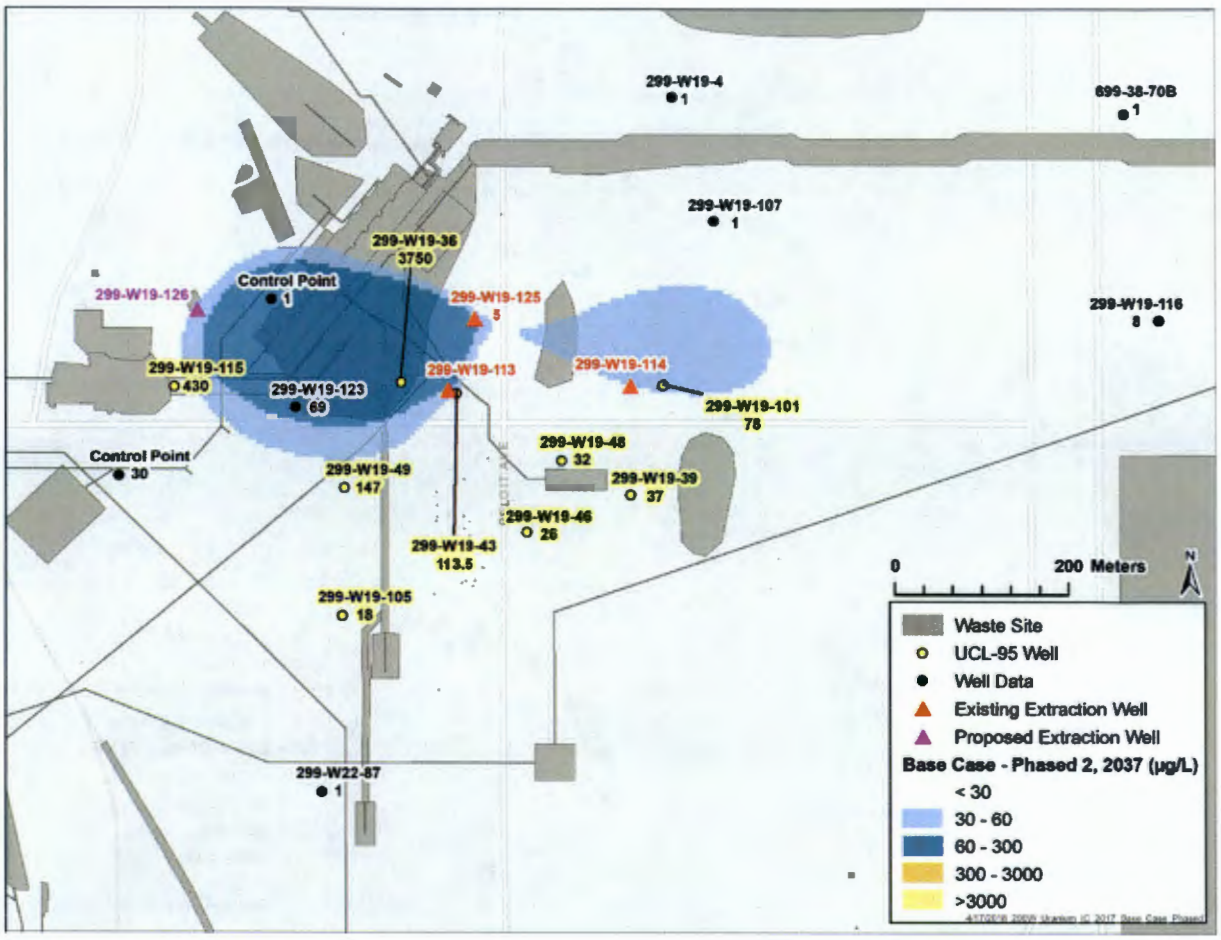

Figure 24. Simulated Uranium Concentration at the End of 2037 at Water Table (Base Case Phased 2 without Continuing Source)

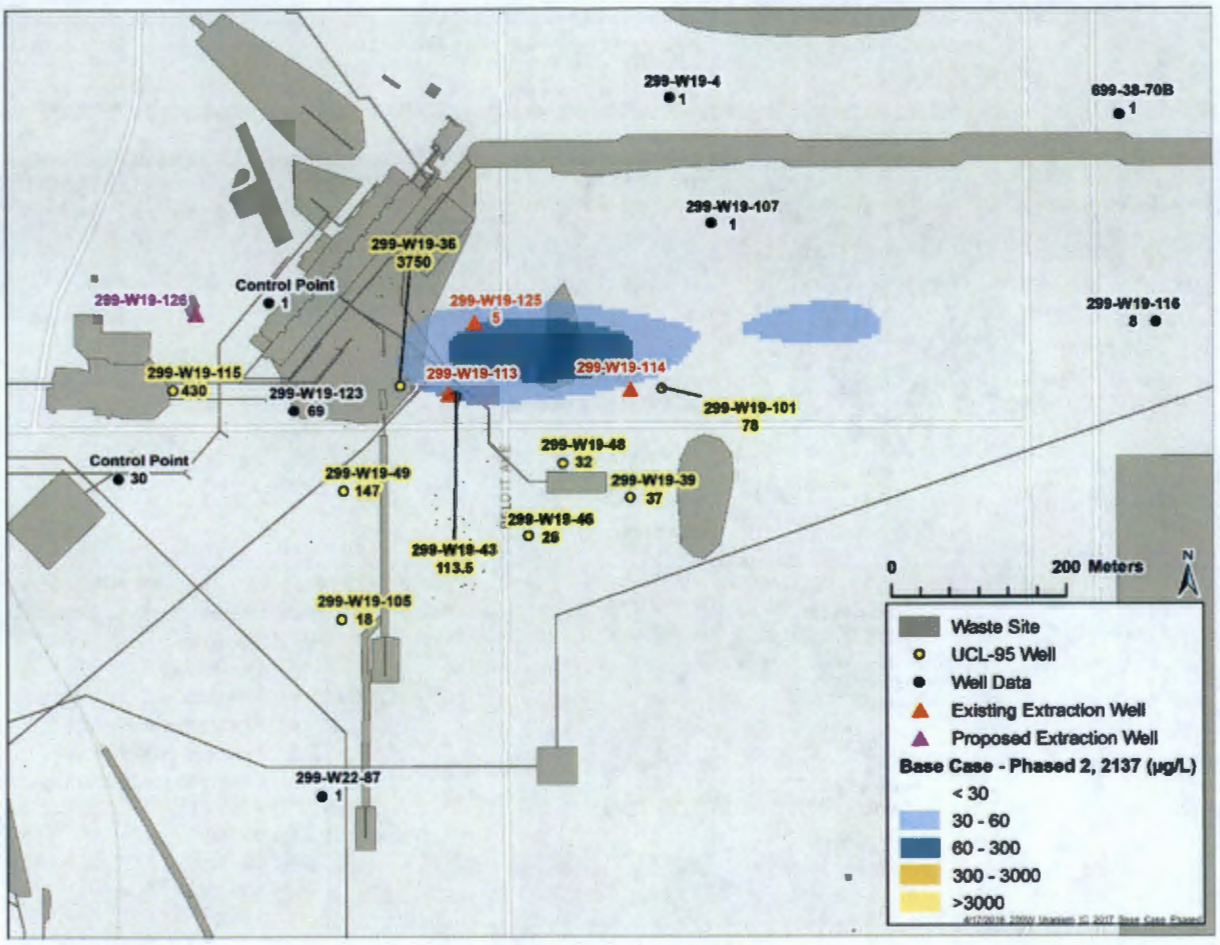

Figure 25. Simulated Uranium Concentration at the End of 2137 at Water Table (Base Case Phased 2 without Continuing Source)

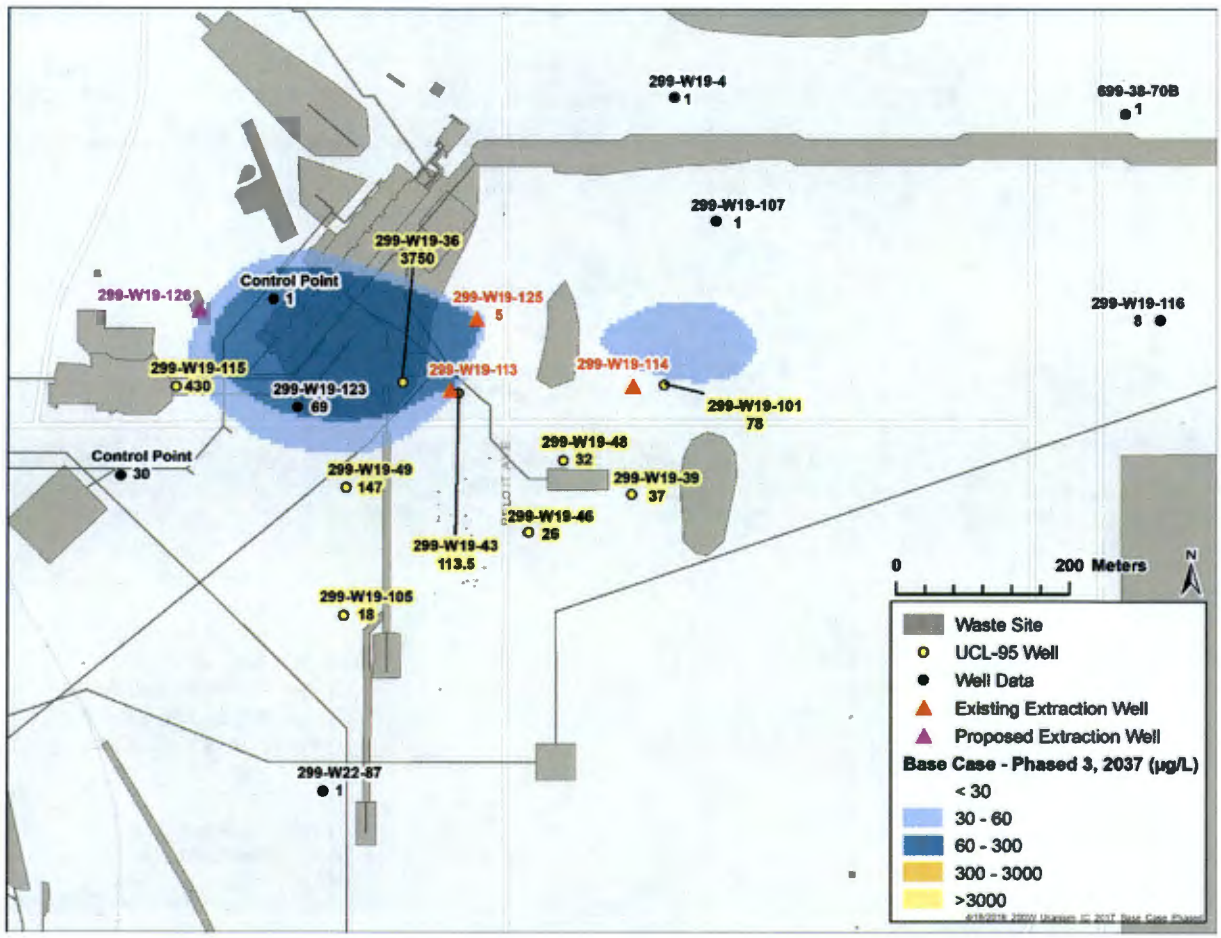

Figure 26. Simulated Uranium Concentration at the End of 2037 at Water Table (Base Case Phased 3 without Continuing Source)

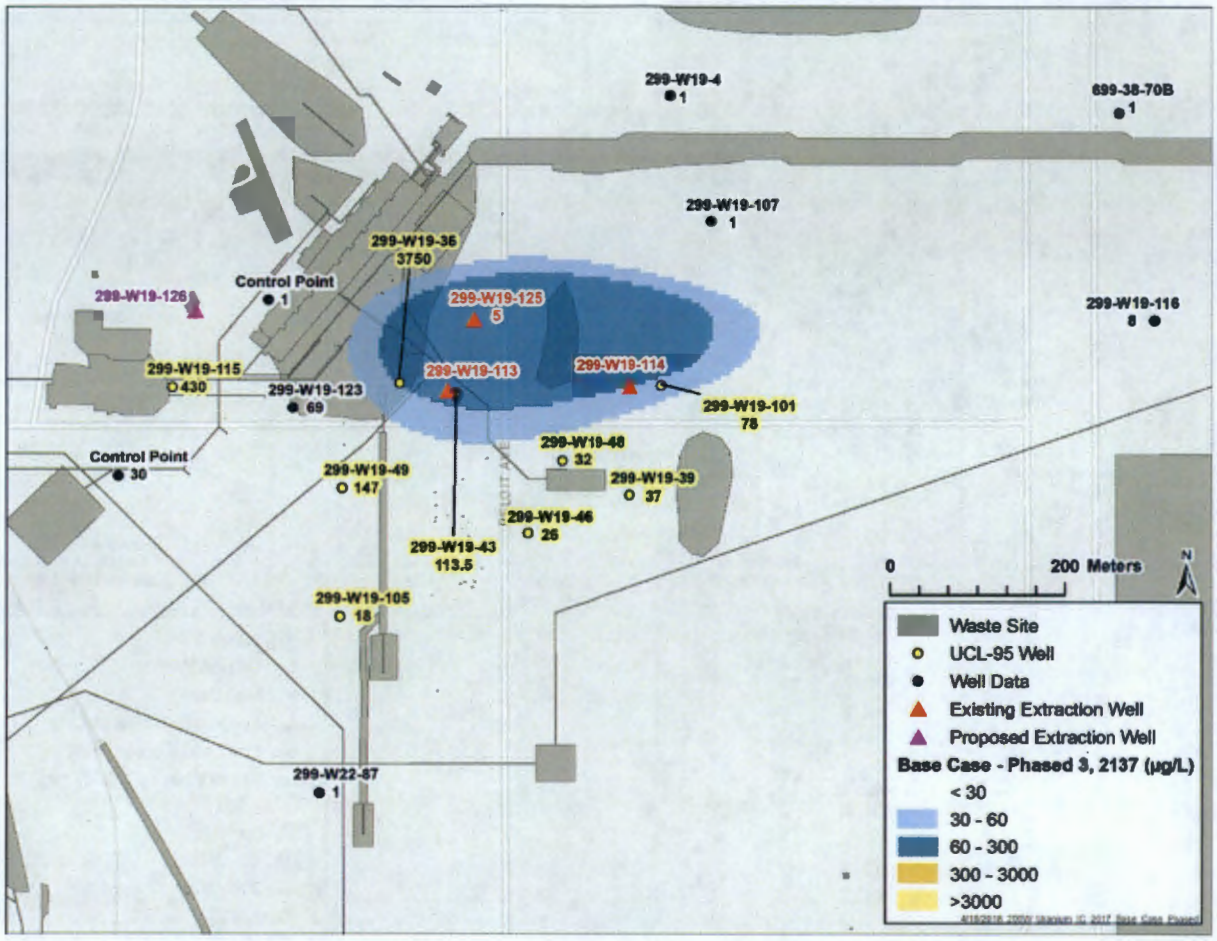

Figure 27. Simulated Uranium Concentration at the End of 2137 at Water Table (Base Case Phased 3 without Continuing Source)

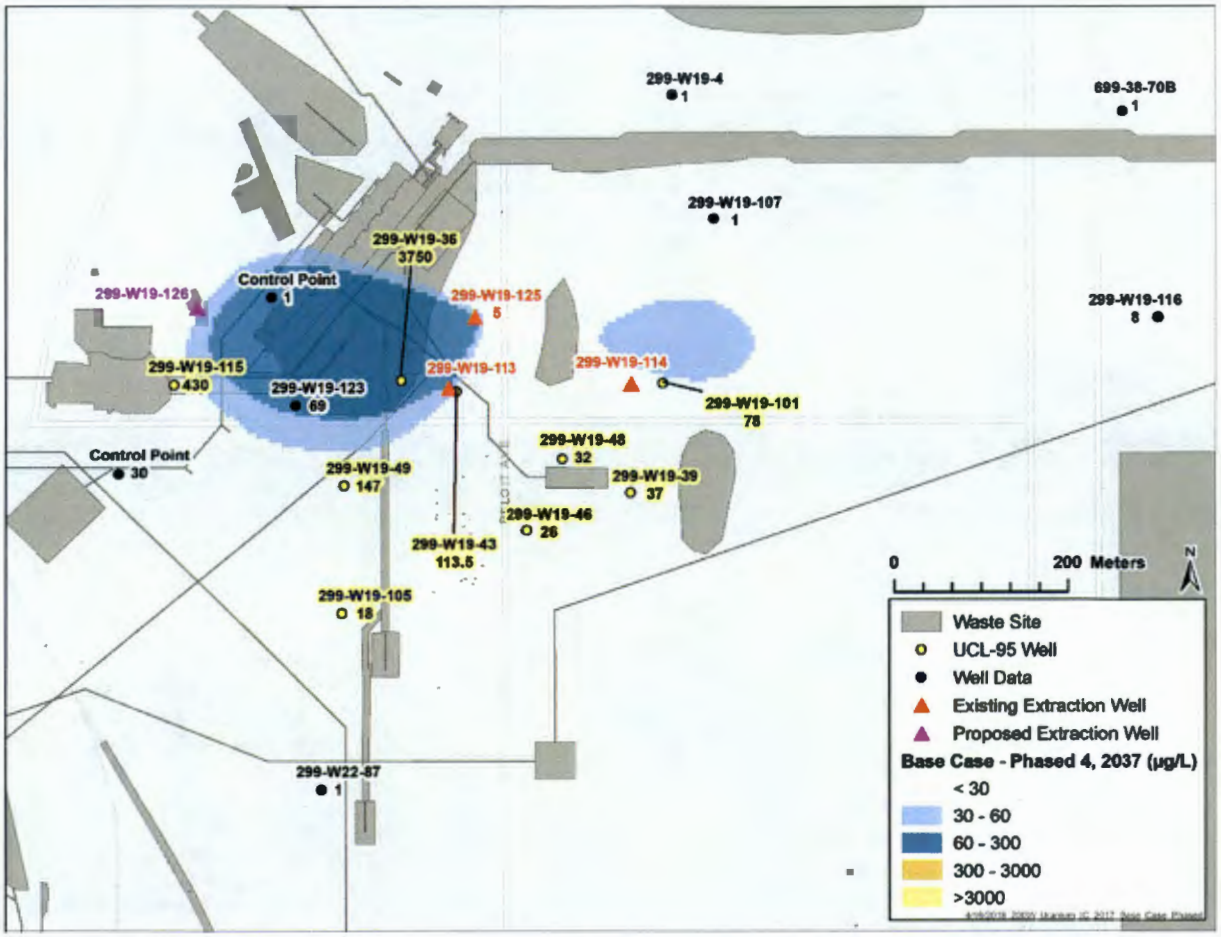

Figure 28. Simulated Uranium Concentration at the End of 2037 at Water Table (Base Case Phased 4 without Continuing Source)

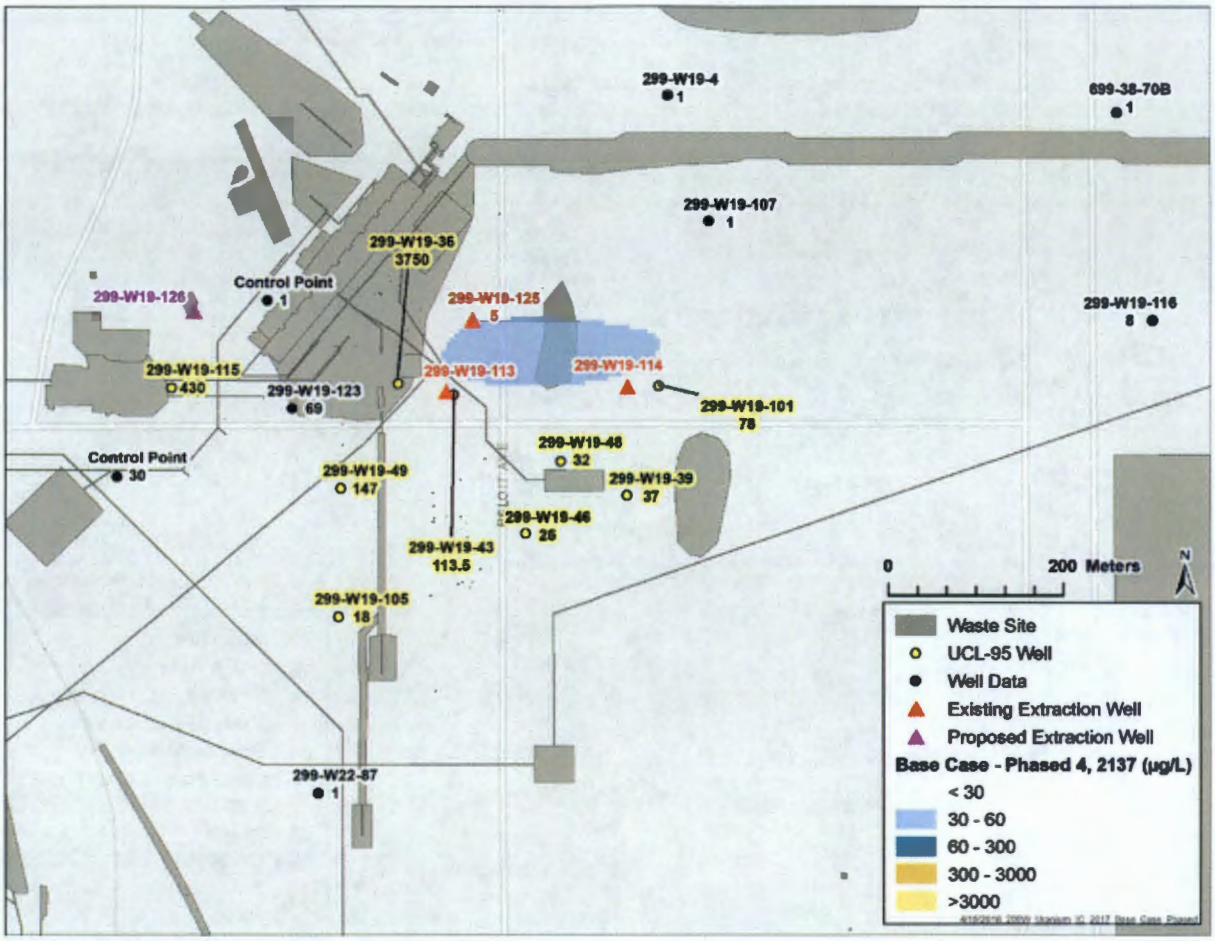

Figure 29. Simulated Uranium Concentration at the End of 2137 at Water Table (Base Case Phased 4 without Continuing Source)

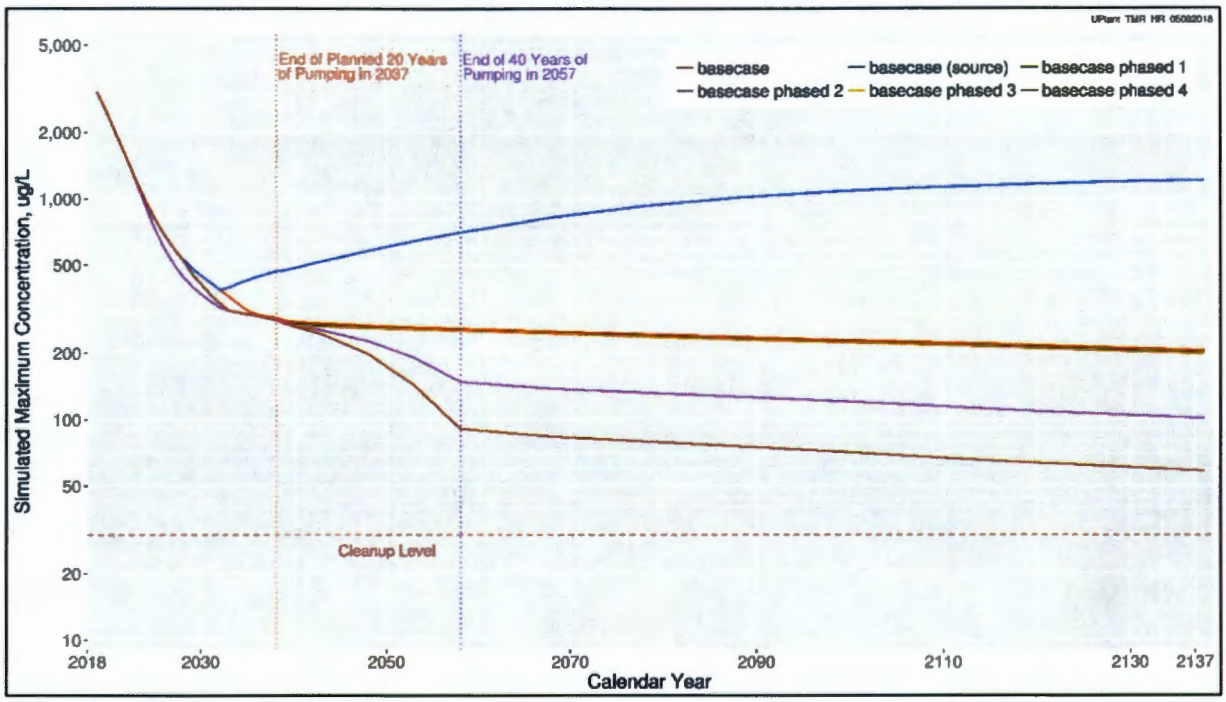

Figure 30. Comparison of Maximum Simulated Uranium Concentrations in the Aquifer for the First Approach

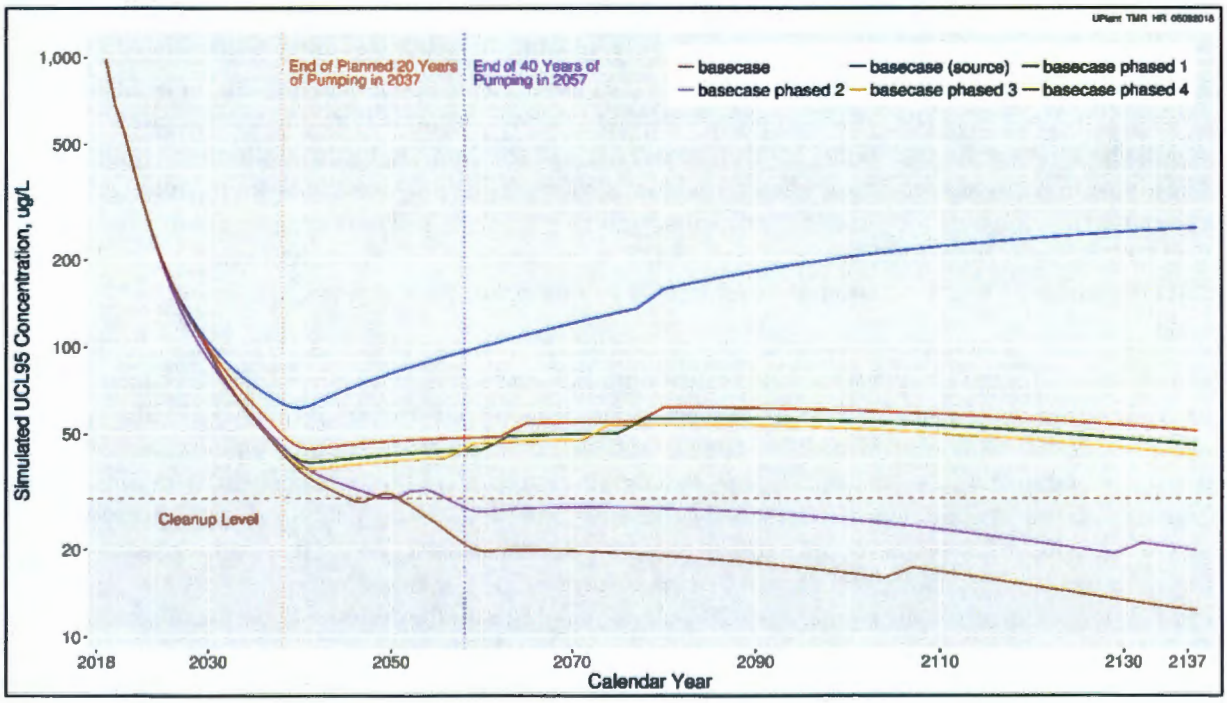

Figure 31. Comparison of UCL95 Concentrations for the First Approach

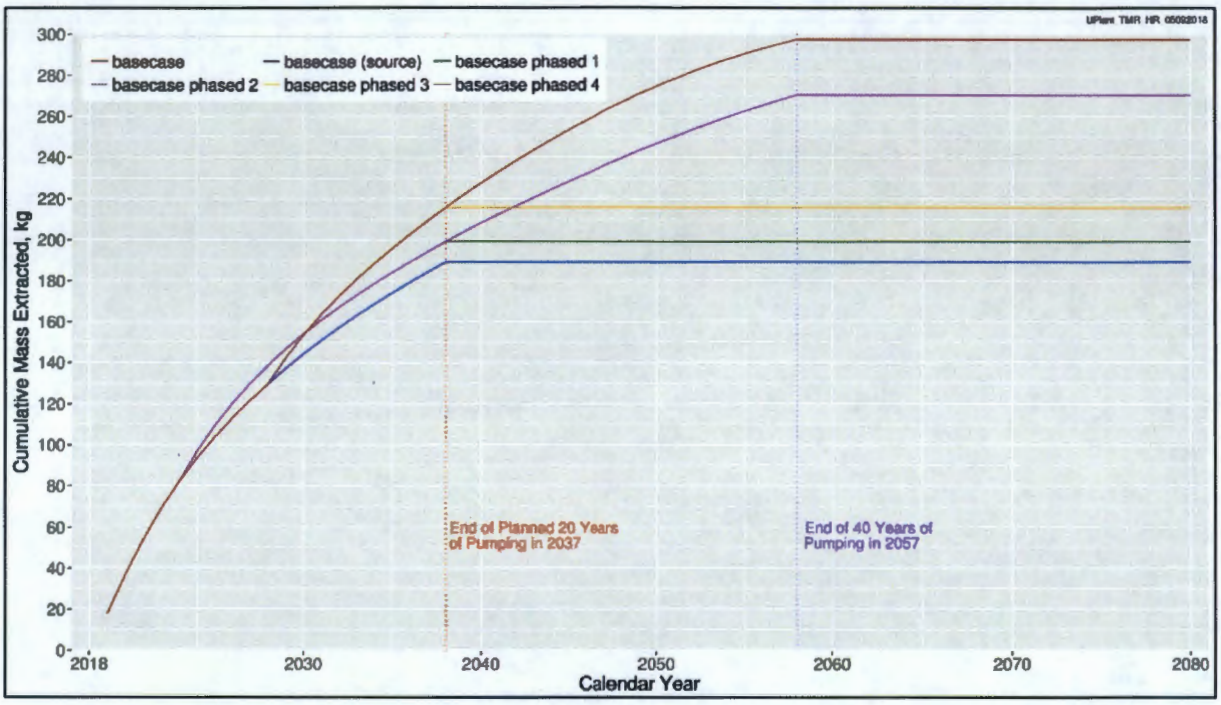

Figure 32. Comparison of Cumulative Mass Extraction for the First Approach

6.2.2 Transport Simulation Results for the Second Approach

Predictive transport simulations for four optimization iterations (second approach), as described in Table 3, were performed to evaluate the performance of the optimized pump-and-treat system for achieving the cleanup standards. Simulated uranium plumes for these four optimization iterations without the continuing source at the end of 2037 and at the end of 2137 are shown in Figure 33 through Figure 40. The plume footprint decreased significantly within 20 years of pumping for all the optimization iterations except iteration 2 where only one new extraction well along with existing extraction wells and dual-use well 299-W19-126 were used as extraction wells. The remainder of the plumes continued to shrink with natural attenuation where iteration 3 and iteration 4 produced the smallest plume area.

Figure 41 shows simulated maximum concentrations in the aquifer and Figure 42 shows UCL95 concentrations for the UCL95 wells network over the 120-year simulation period. UCL95 concentrations for all the optimization iterations declines to below the cleanup standard (30 μg/L) by 2033. The maximum concentrations in the aquifer approaches the cleanup standard (30 μg/L) for iteration 3 and iteration 4 and remains 2-4 times the higher than the cleanup standard for iteration 1 and iteration 2. Figure 43 shows cumulative mass extraction at the extraction wells during pump-and-treat operations for all the scenarios of the second approach. The total uranium mass extraction for four optimization iterations are 284 kg, 280 kg, 290 kg, and 288 kg, respectively. That means, approximately 100 kg of uranium mass remains in the aquifer for a 20 year of pumping with the optimized pump-and-treat system. However, the uranium plume will naturally attenuate and the maximum concentration in the aquifer is expected to nearly achieve the cleanup standard (30 μg/L) within 100 years after the end of pumping.

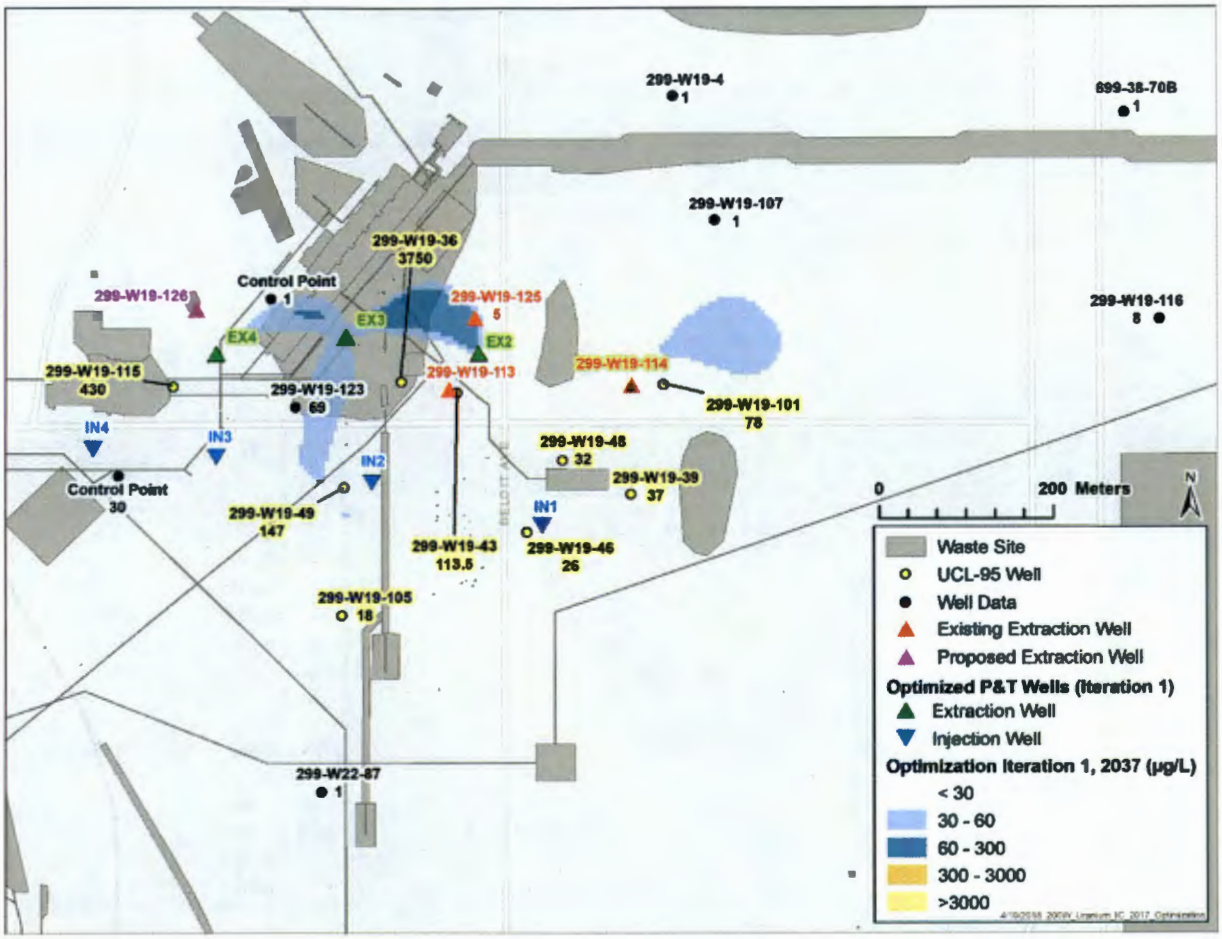

Figure 33. Simulated Uranium Concentration at the End of 2037 at Water Table (Optimization Iteration 1 without Continuing Source)

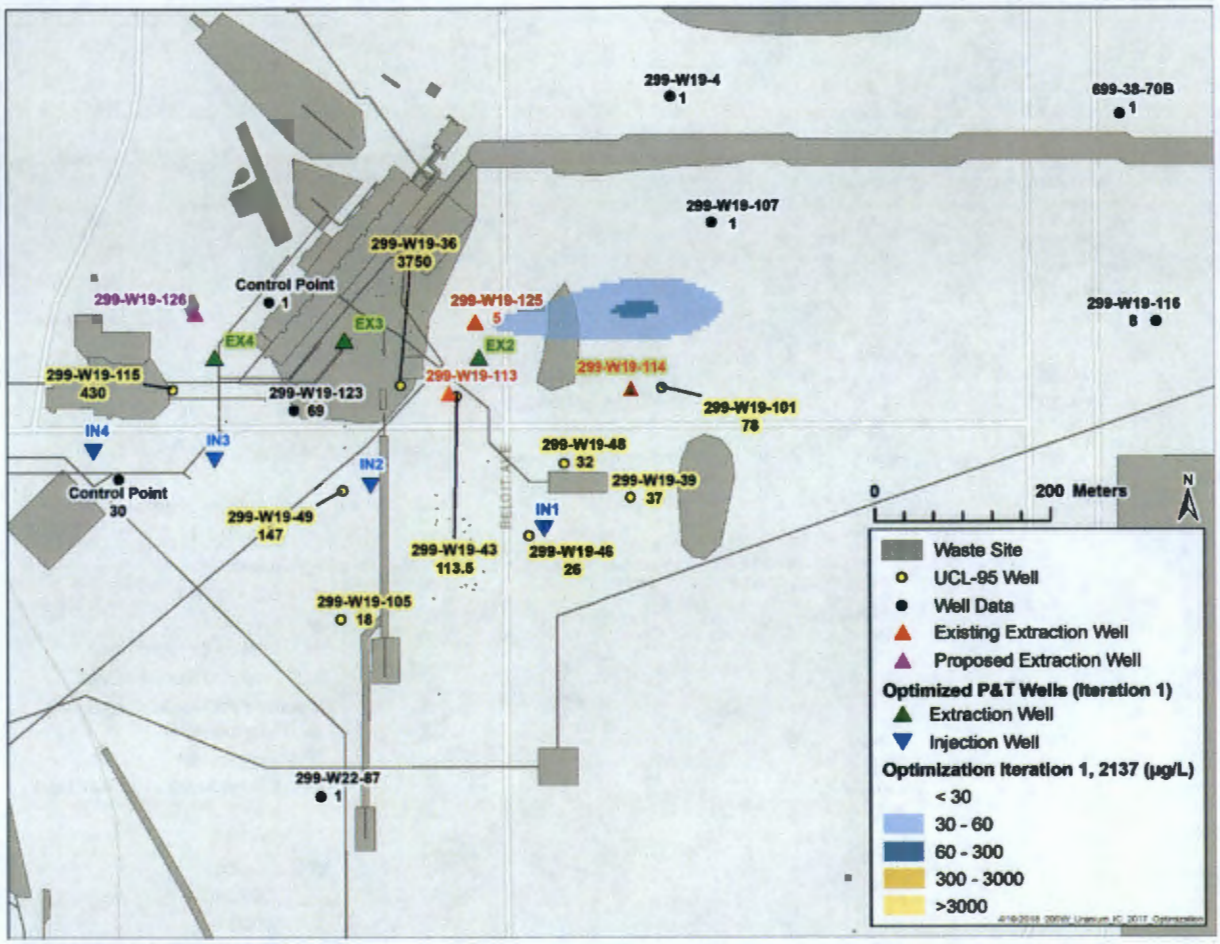

Figure 34. Simulated Uranium Concentration at the End of 2137 at Water Table (Optimization Iteration 1 without Continuing Source)

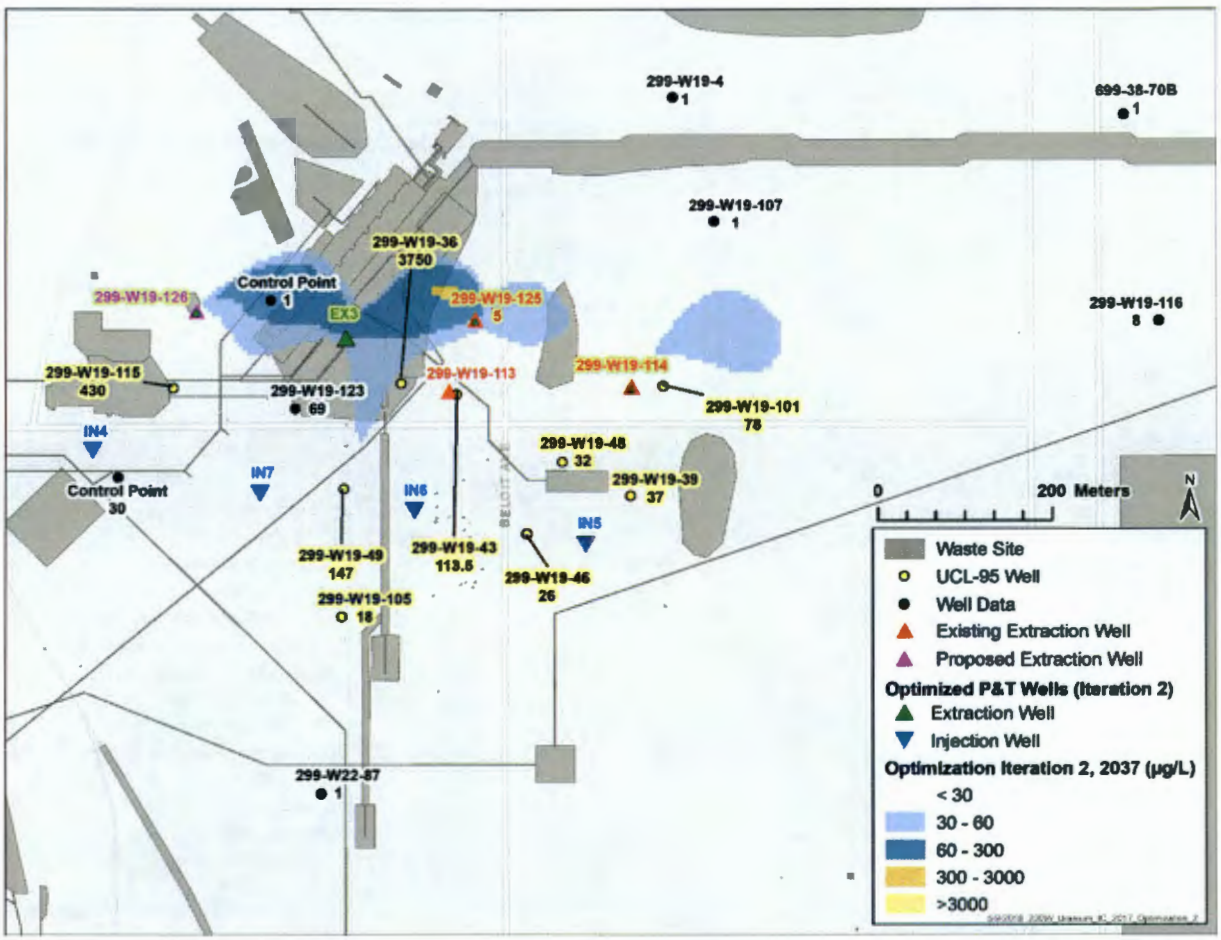

Figure 35. Simulated Uranium Concentration at the End of 2037 at Water Table (Optimization Iteration 2 without Continuing Source)

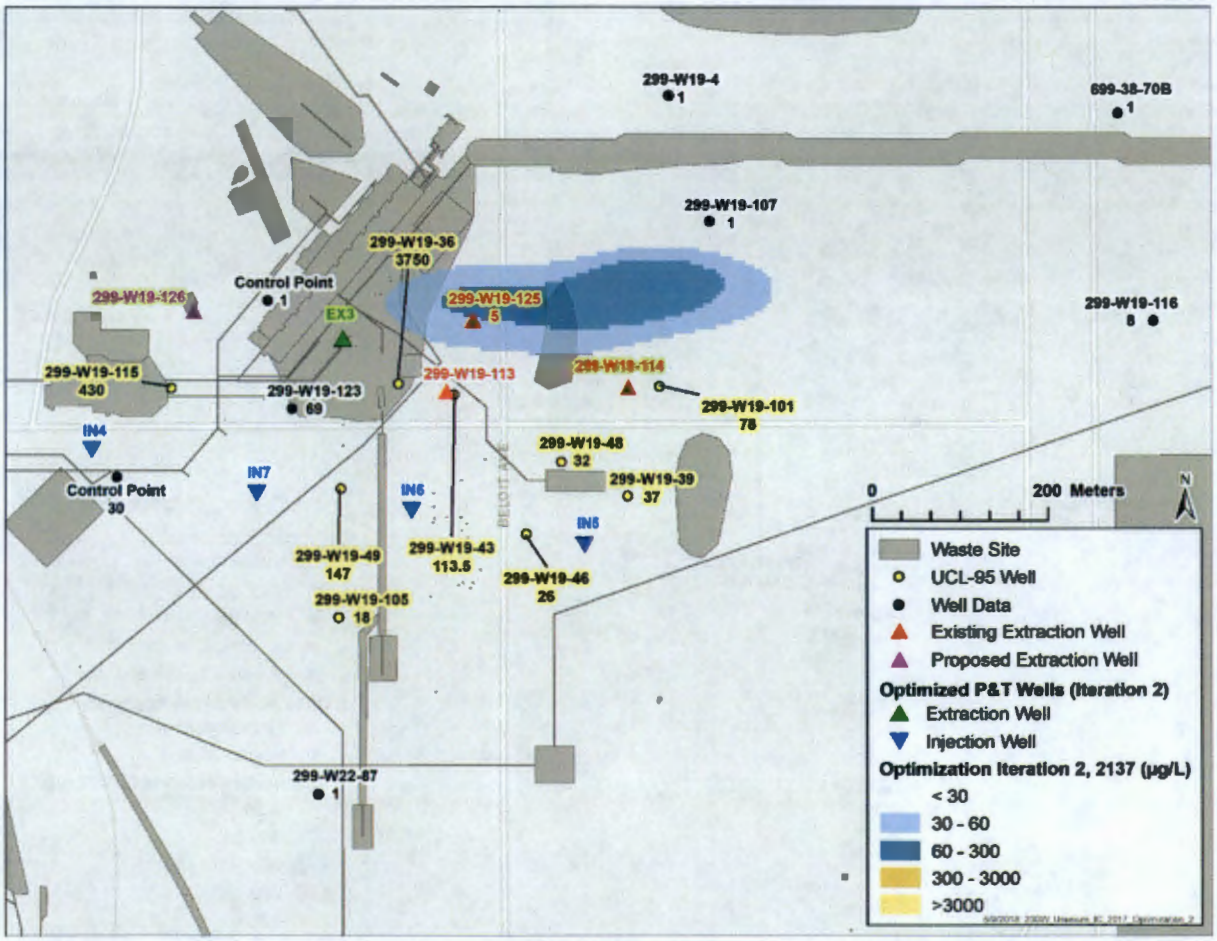

Figure 36. Simulated Uranium Concentration at the End of 2137 at Water Table (Optimization Iteration 2 without Continuing Source)

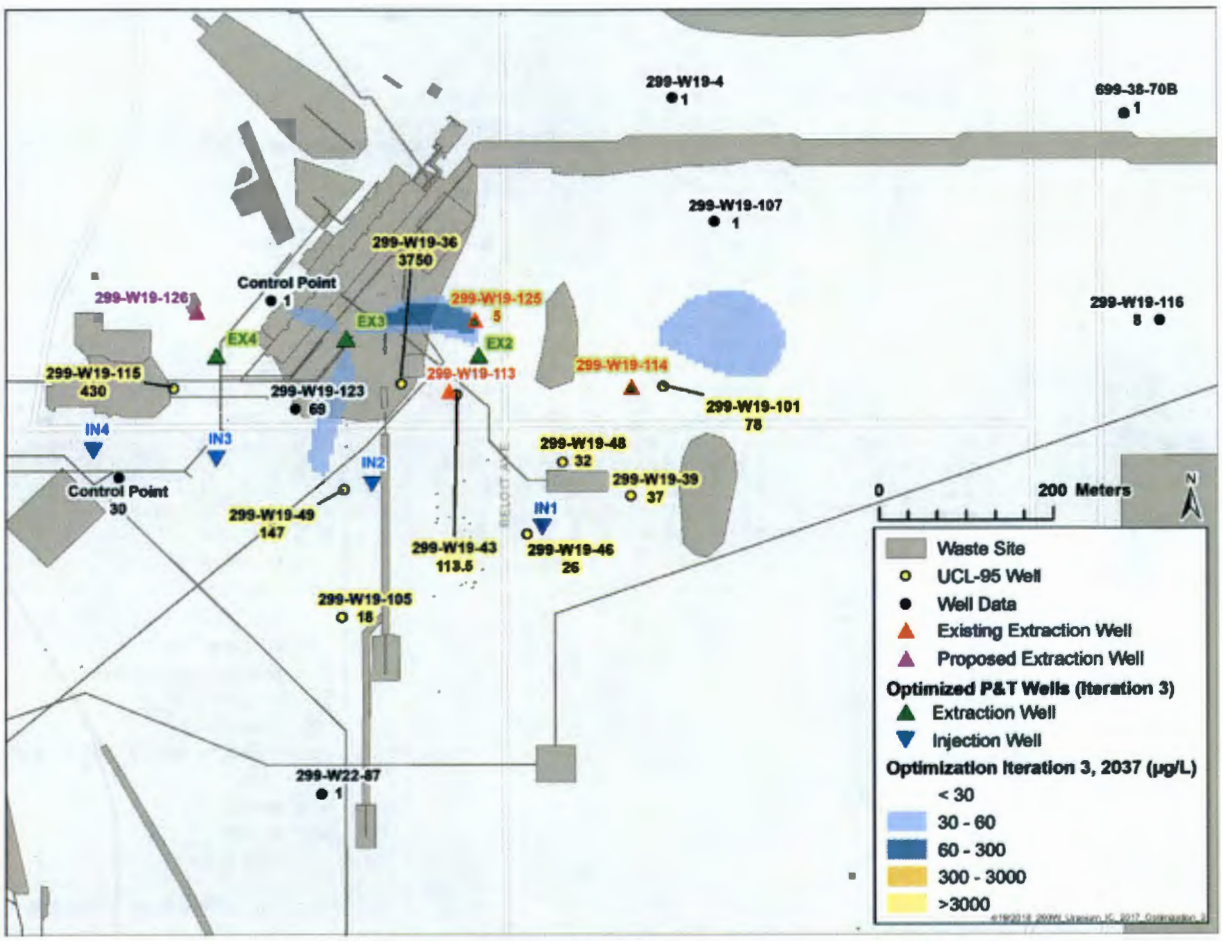

Figure 37. Simulated Uranium Concentration at the End of 2037 at Water Table (Optimization Iteration 3 without Continuing Source)

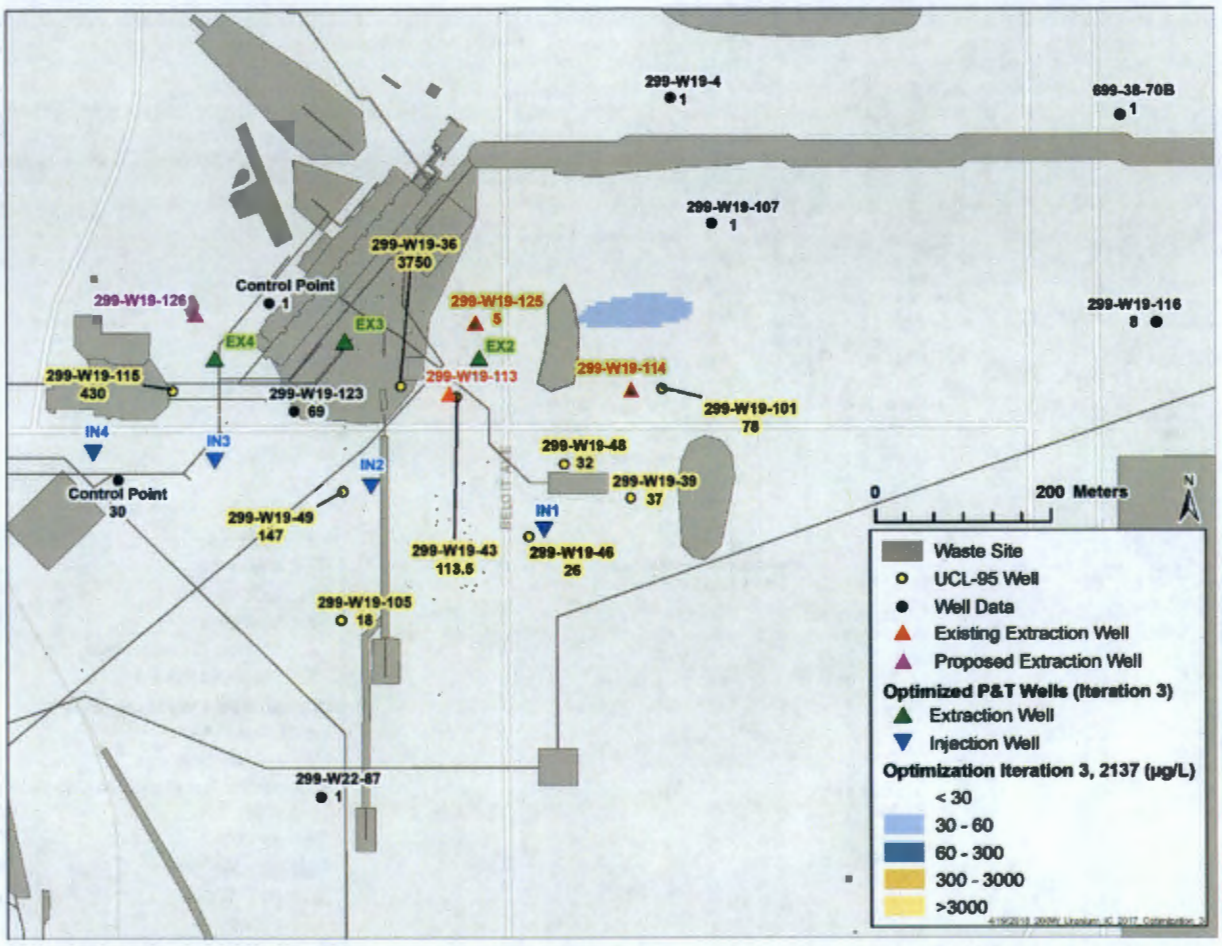

Figure 38. Simulated Uranium Concentration at the End of 2137 at Water Table (Optimization Iteration 3 without Continuing Source)

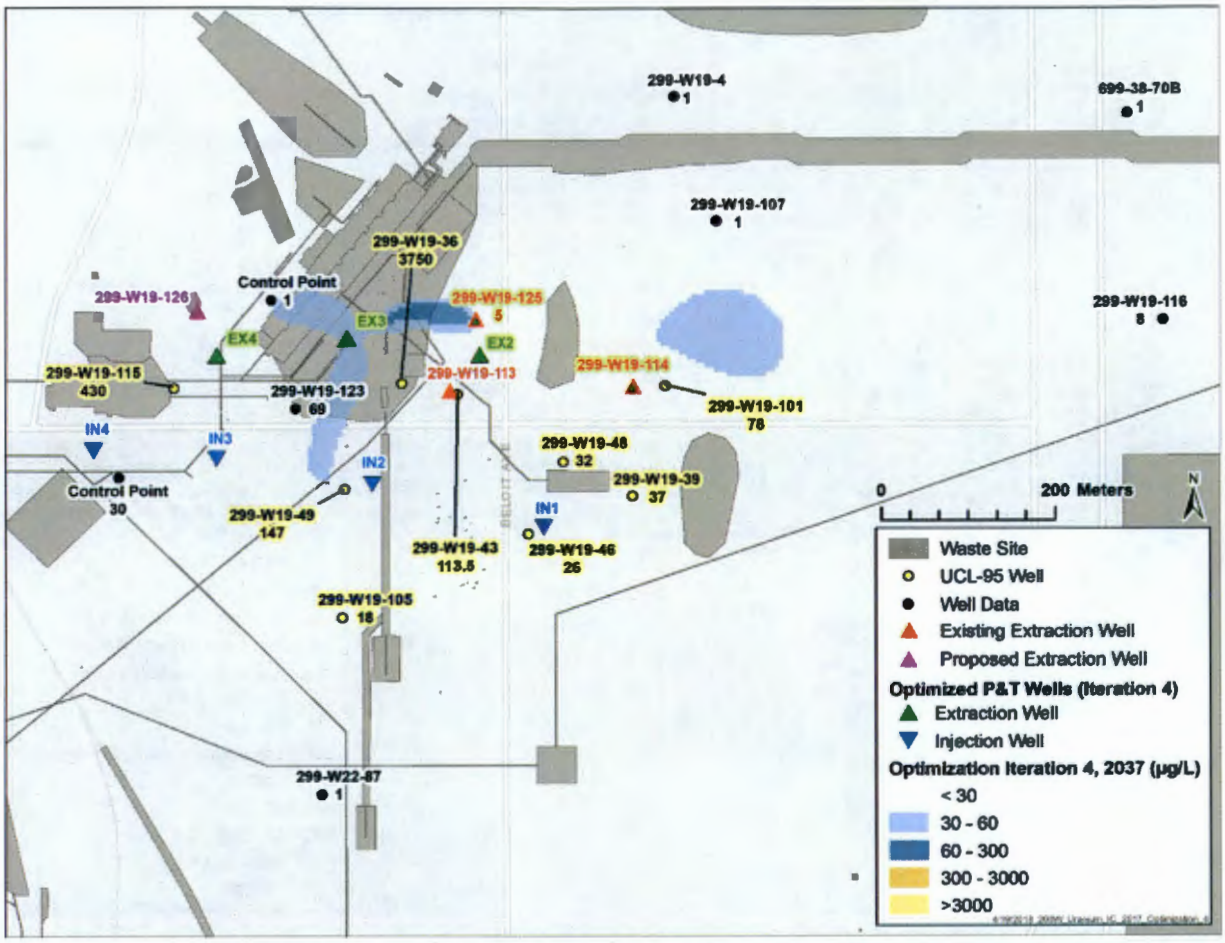

Figure 39. Simulated Uranium Concentration at the End of 2037 at Water Table (Optimization Iteration 4 without Continuing Source)

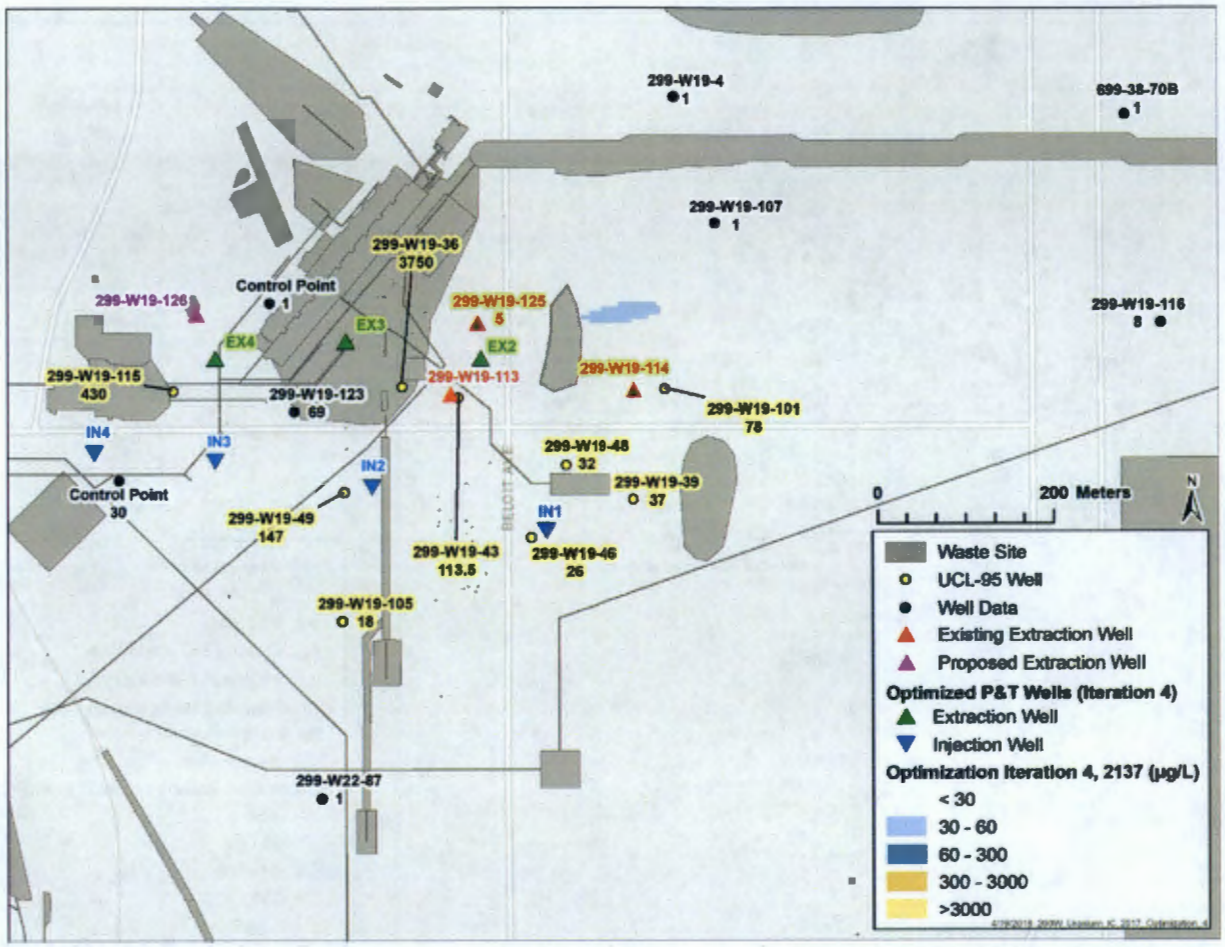

Figure 40. Simulated Uranium Concentration at the End of 2137 at Water Table (Optimization Iteration 4 without Continuing Source)

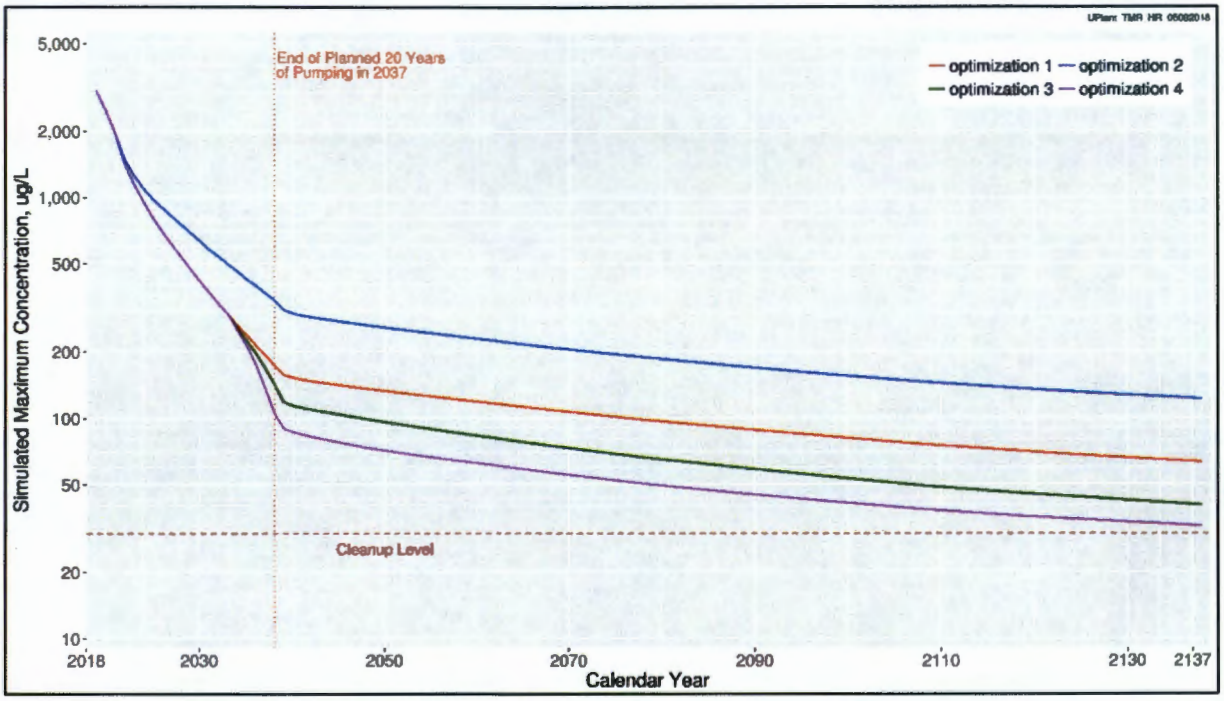

Figure 41. Comparison of Maximum Simulated Uranium Concentrations in the Aquifer for the Second Approach

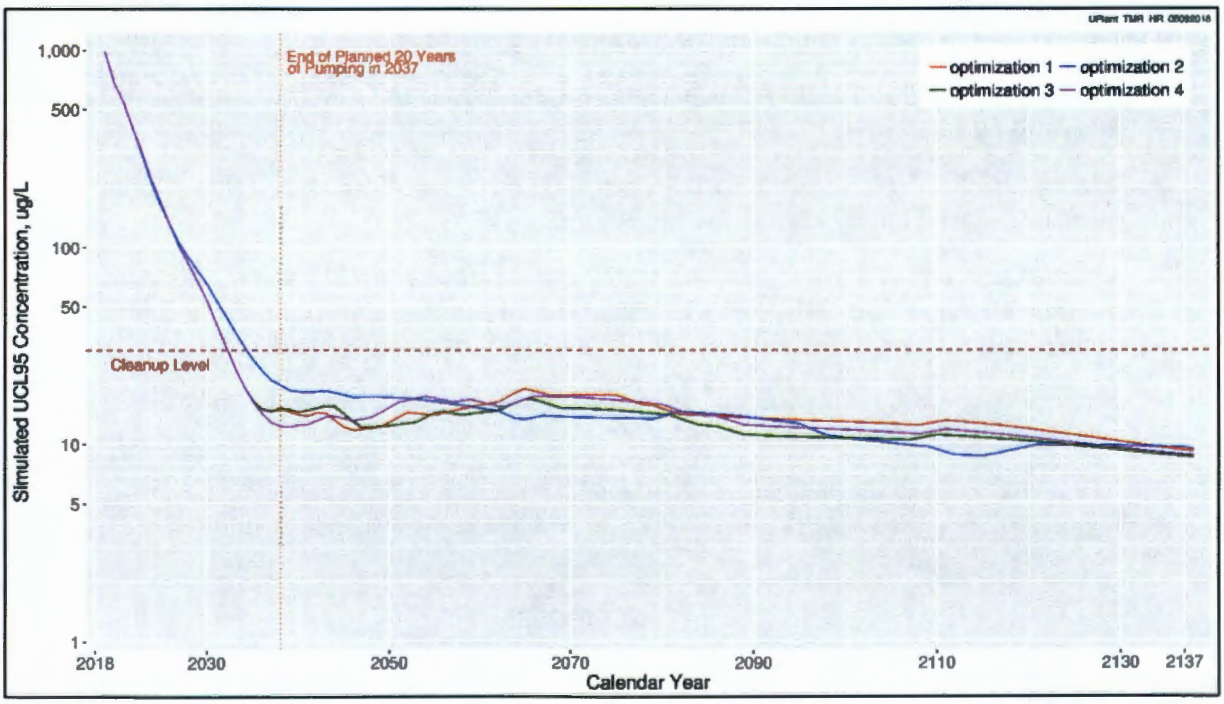

Figure 42. Comparison of UCL95 Concentrations for the Second Approach

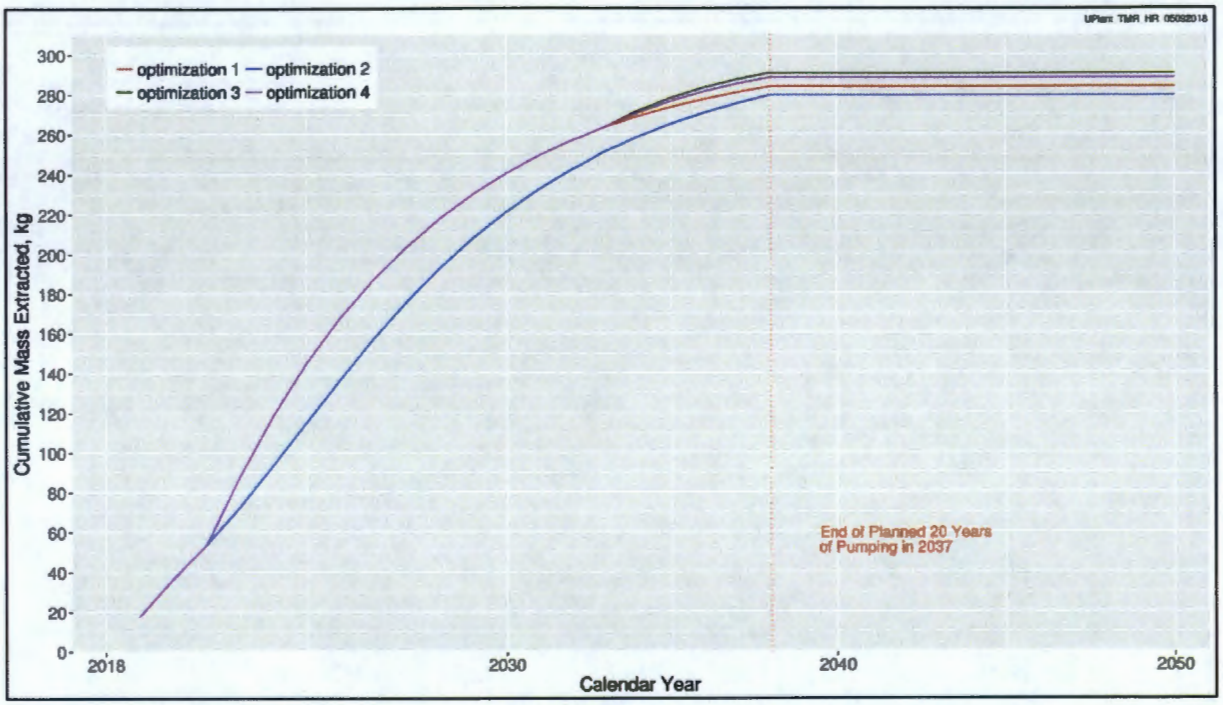

Figure 43. Comparison of Cumulative Mass Extraction for the Second Approach

6.3 Summary

The following are the key findings of the transport modeling performed using existing extraction system (first approach) and preliminary optimized system (second approach):

- The existing pump and treat system, pumping to year 2037 at 150 gpm, will not achieve cleanup standards by year 2137.
- The existing P&T system would need to operate for more than 40 years to achieve cleanup standards, even if the flow is increased to 200 gpm.
- Optimized preliminary redesigned P&T systems, pumping to year 2037 at 200 gpm, nearly achieves cleanup standards by year 2137 using phased pumping (contingent on the initial conditions).
- Three new extraction wells and four new injection wells would be needed by end of 2020 to implement the preliminary redesigned system in 2021.
- The performance of the preliminary redesigned systems is highly dependent on the initial concentrations plume which change every year with the newly available monitoring well data.

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, 2016, *MODFLOW and Related Codes Requirements Traceability Matrix: CHPRC Build 8*, Rev. 8, CH2M HILL Plateau Remediation Company, Richland, Washington.

CHPRC-00261, 2016, *MODFLOW and Related Codes Acceptance Test Report: CHPRC Build 8*, Rev. 8, CH2M HILL Plateau Remediation Company, Richland, Washington.

CP-47631, 2017, *Model Package Report: Central Plateau Model, Version 8.4.5*, Rev. 4, CH2M Hill Plateau Remediation Company, Richland, Washington. Available at: https://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0066449H.

DOE O 414.1D, Admin Chg 1, 2011, *Quality Assurance*, U.S. Department of Energy, Washington, D.C. Available at: https://www.directives.doe.gov/directives/0414.1-BOrder-d/view.

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

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: https://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*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: https://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: https://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0075314H.

DOE/RL-2016-67, 2017, *Hanford Site Groundwater Monitoring Report for 2016*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: https://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0068229H.

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: https://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0068097H.

DOE/RL-2017-66, in press, *Hanford Site Groundwater Monitoring Report for 2017*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

ECF-HANFORD-16-0061, 2016, *Calculation and Depiction of Groundwater Contamination for the Calendar Year 2015 Hanford Site Groundwater Monitoring Report*) , Rev. 0, CH2M Hill Plateau Remediation Company, Richland, Washington. Available at: https://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0075373H.

ECF-200UP1-17-0010, 2017, *200-UP-1 Leapfrog Models of U Plant Uranium and Technetium-99 Plumes Fall 2015*, Rev. 0, CH2M Hill Plateau Remediation Company, Richland, Washington. Available at: https://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0066443H.

ECF-200UP1-17-0093, 2018, *Fate and Transport Analysis for U Plant Groundwater Plumes in the 200-UP-1 Operable Unit*, Rev. 0, CH2M Hill Plateau Remediation Company, Richland, Washington. Available at: https://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0066441H.

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, 2018, *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. Available at: https://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0066439H.

Harbaugh, A. W., E. R. Banta, M. C. Hill, and M. G. McDonald, 2000, *MODFLOW-2000, The U.S. Geological Survey Modular Ground-Water Model – User Guide to Modularization Concepts and the Ground-Water Flow Process*, Open-File Report 00-92, U.S. Geological Survey, Reston, Virginia. Available at: https://water.usgs.gov/nrp/gwsoftware/modflow2000/ofr00-92.pdf.

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.

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. Available at: https://el.erdc.dren.mil/elpubs/pdf/crserdp99-1.pdf.

Appendix A

Software Installation and Checkout Form

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CHPRC SOFTWARE INSTALLATION AND CHECKOUT FORM

Software Owner Instructions:

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

Software Subject Matter Expert Instructions:

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

GENERAL INFORMATION:

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

EXECUTABLE INFORMATION:

2. Executable Name (include path):

Following executable files in directory: /bin

MD5 Signature (unique ID)	Executable File Name	Code
2fade33e27978063a9a70ff8605e4c0c	mf2k-chprc08dpl.x	MODFLOW-2000 double precision
8b0b28c5e102e63df95de542d83d013b	mf2k-chprc08spl.x	MODFLOW-2000 single precision
80d670658425653bf5bcbb97ad2a2730	mf2k-mst-chprc08dpl.x	MODFLOW-2000-MST double precis.
d879defafdc5ad25be51a484d73ea65d	mf2k-mst-chprc08spl.x	MODFLOW-2000-MST single precis.
682f0b1e9fcd6ac0b885f52a7ddfe821	mfusg-chprc08dpl.x	MODFLOW-USG double precision
a8a861f6d453647b100d63f064ca6af2	mfusg-chprc08spl.x	MODFLOW-USG single precision
1be4b7d3fc81881ff0b97ff7e67bd3ff	mt3d-chprc08dpl.x	MT3DMS double precision
37ae3dcb3e56cd27e3e889a90d0ae7c1	mt3d-chprc08spl.x	MT3DMS single precision
1e468c4409ac913843ce783aabed819c	mt3d-mst-chprc08dpl.x	MT3DMS-MST double precision
2d0a8a4c480318763b6aaaa0f880348a	mt3d-mst-chprc08spl.x	MT3DMS-MST single precision

3. Executable Size (bytes): MD5 signatures above uniquely identify each executable file

COMPILATION INFORMATION:

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

INTERA Austin Linux(R) Cluster

5. Operating System (include version number):

Linux head.cluster 2.6.32-358.11.1.el6.centos.plus.x86_64 #1 SMP Wed Jun 12 19:12:17 UTC 2013 x86 64 x86 64 x86 64 GNU/Linux

INSTALLATION AND CHECKOUT INFORMATION:

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

INTERA "OLIVE" Linux Cluster

7. Operating System (include version number):

Linux olive 4.4.0-38-generic #57~14.04.1-Ubuntu SMP Tue Sep 6 17:20:43 UTC 2016 x86_64 x86 64 x86 64 GNU/Linux

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

TEST CASE INFORMATION:

9. Directory/Path:

/Build-8

10. Procedure(s):

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

11. Libraries:

N/A (static linking)

CHPRC SOFTWARE INSTALLATION AND CHECKOUT FORM (continued)

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

12. Input Files:

Per CHPRC-00259 Rev. 3

13. Output Files:

Found in test subdirectories

14. Test Cases:

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

15. Test Case Results:

All pass.

16. Test Performed By: WE Nichols

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

18. Disposition (include HISI update):

Approved; installation added to HISI entries for MODFLOW and MT3DMS.

Prepared By:

19. WILLIAM NICHOLS (Affiliate) Owner (Sig — WE Nichols — Print — Date

20. Test Personnel:

Sign	Print	Date
	WE Nichols	

Approved By:

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

A-6005-149 (REV 0)