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Revision 0

Fate and Transport Analysis for WMA S-SX 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

Approved for Public Release;
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Terms

CHPRC	CH2M Hill Plateau Remediation Company
CL	cleanup level
CP	Central Plateau
ECF	environmental calculation file
EDA	Environmental Dashboard Application
HEIS	Hanford Environmental Information System
HISI	Hanford Information Systems Inventory
MNA	Monitored natural attenuation
OU	operable unit
SCE	shuffled complex evolution
TMR	telescopic mesh refinement
UCL95	95th percentile upper confidence limit on the plume mean concentration
USGS	U.S. Geological Survey
WMA	waste management area

1 Purpose

This environmental calculation file (ECF) documents the results of contaminant transport simulations performed using a local-scale groundwater model for the Waste Management Area (WMA) S-SX groundwater extraction system within the 200-UP-1 Groundwater Operable Unit (OU) at the Hanford Site. This system began operating in 2012 under an interim-action record of decision (EPA et al., 2012, *Record of Decision for Interim Remedial Action, Hanford 200 Area Superfund Site, 200-UP-1 Operable Unit*). It was designed primarily to remediate the technetium-99 plumes downgradient of the 241-S and 241-SX Tank Farms, but it also remediates the collocated chromium and nitrate plumes. The system consists of three extraction wells, one downgradient (east) from the 241-S Tank Farm (299-W22-90) and two downgradient from the 241-SX Tank Farm (299-W22-91 and 299-W22-92) (Figure 1). The wells are currently operating at flow rates ranging from 25 to 35 gpm. More information regarding groundwater contamination at WMA S-SX 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 WMA S-SX groundwater extraction system to determine if cleanup objectives will be accomplished within the planned time frame (15 years of active remediation followed by up to 110 years of monitored natural attenuation [MNA]).
2. Determine the effect that ongoing sources of contamination will have on remedy performance.
3. Perform an optimization analysis to determine if system performance can be improved.

This is the second of two ECFs documenting the assessment and optimization of the WMA S-SX groundwater extraction system. In ECF-200W-17-0045, *Capture Zone and Particle Tracking Analysis for the WMA S-SX 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 (CP) model (CP-47531, *Model Package Report: Central Plateau Model, Version 8.4.5*). With this approach, the portion of the CP model grid surrounding the WMA S-SX 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 local-scale flow model formed the basis for the transport simulations, which were performed using MT3DMS, a three-dimensional transport model simulating 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*). A transport evaluation was performed in which simulated groundwater concentrations near the WMA S-SX groundwater extraction system were compared to monitoring data to determine whether the transport simulations represented plume movement well enough for the intended modeling purpose. This was followed by simulations of future plume movement (chromium, nitrate, and technetium-99) with and without including ongoing sources of contamination.

The remainder of this ECF documents construction of the transport model, the transport evaluation, system optimization, and predictions of future plume movement and remediation system performance.

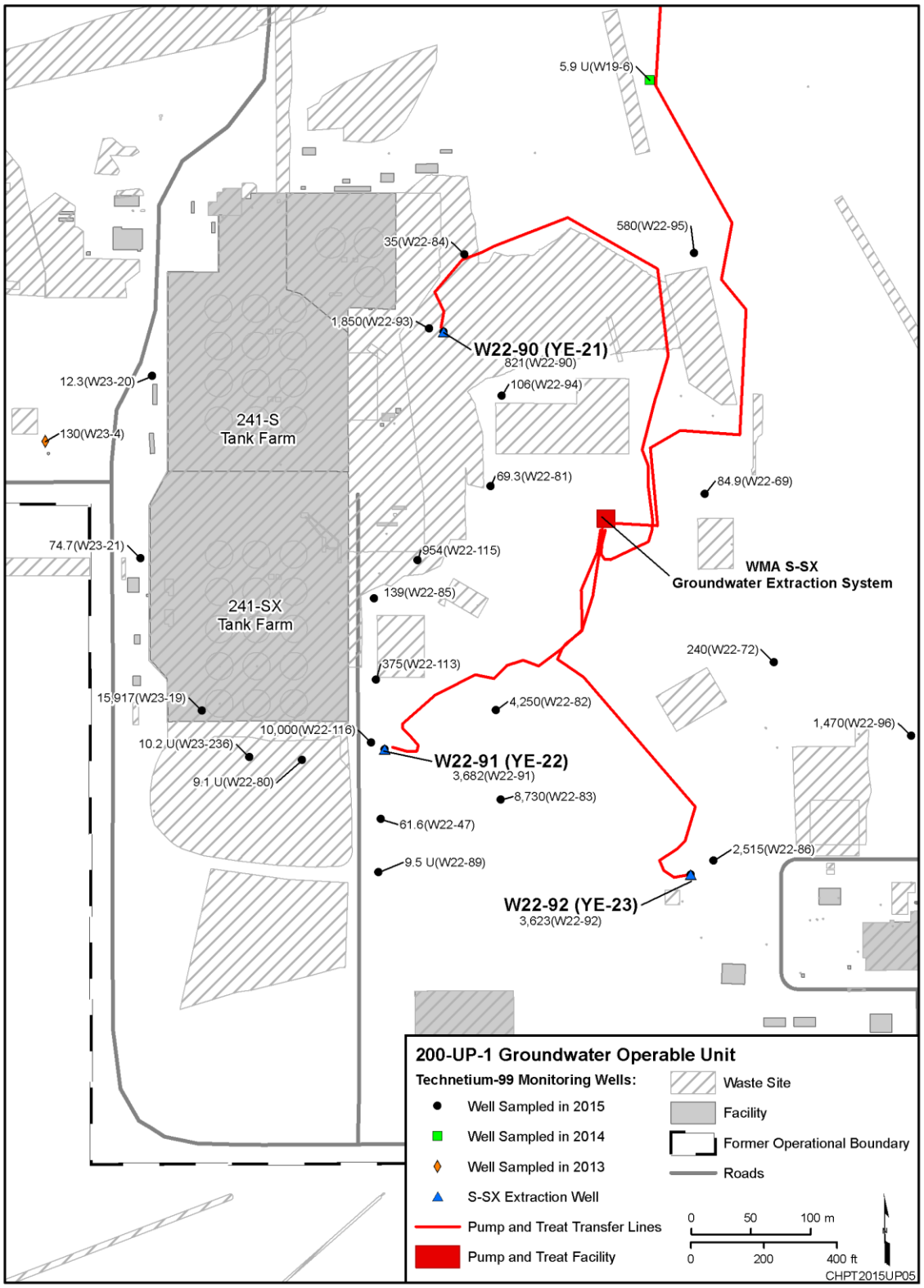

Figure 1. WMA S-SX Tank Farms Groundwater Extraction System

2 Methodology

This section describes the WMA S-SX groundwater extraction system transport model. It also describes how the optimization analysis was conducted and how system performance was measured.

2.1 WMA S-SX Transport Model

Contaminant transport simulations were performed using MT3DMS (Modular Transport, 3-Dimensional, Multi-Species), a three-dimensional transport model simulating advection, dispersion, source/sinks, and chemical reactions (Zheng and Wang, 1999). MT3DMS is designed for use with finite difference flow models, such as MODFLOW 2000 (Harbaugh et al., 2000). The flow model provides the velocity field needed for transport simulations.

The approach to using MT3DMS was as follows:

1. Perform the necessary flow modeling prerequisite to using MT3DMS. The flow model is documented in ECF-200W-17-0045. Additional simulations beyond those documented in ECF-200W-17-0045 were performed to (a) limit pumping from the WMA S-SX extraction wells to 15 years (2012 to 2027), the planned duration of the WMA S-SX groundwater extraction system, and (b) simulate the optimized flow rates at extraction wells 299-W22-91 and 299-W22-92.
2. Generate the input files for MT3DMS. Input data are described in Chapter 3.
3. 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 95th percentile upper confidence limit [UCL95] on mean plume concentrations, etc.).
4. Perform a transport evaluation to assess the adequacy of the simulation results to support the modeling objectives.
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

A mathematical optimization approach was used to determine the optimum pumping rates for the WMA S-SX 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 WMA S-SX was done with the shuffled complex evolution (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:6th 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 WMA S-SX 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; the existing extraction well locations were used.

2.3 UCL95 Calculations

Remediation performance was evaluated by calculating the 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, α = 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. For transport simulations, additional wells needed to be included in the calculation as plumes migrated into regions outside of the network.[1] These additional locations were identified based on transport simulation results through the year 2137. Existing monitoring wells were used where available, but several additional monitoring locations were chosen to fill gaps in the well coverage. These locations are referred to herein as "synthetic" wells. When expanding the network, attempts were made to maintain a reasonably uniform spatial distribution of monitoring locations. Well networks for the UCL95 calculations at WMA S-SX are shown in Section 6.2.5.

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

1. For a given constituent, the wells initially used for UCL95 calculations were those identified in DOE/RL-2015-14.

2. UCL95s were calculated annually beginning in 2012 (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 2014 UCL95 consisted of concentrations at the end of 2012, 2013, and 2014. This ensured that enough data were available for representative calculation results. Note that only 1 year of data could be used for 2012 and 2 years for 2013.

[1] This situation is not addressed in DOE/RL-2015-14; it was expected that this document would be revised over time to include any necessary network revisions.

3. As a plume moved into areas not covered by the UCL95 well network specified in DOE/RL-2015-14, additional wells were added to the calculation data set. This was done when concentrations at a nearby well, or a synthetic well, increased to above the cleanup level. When a new well was added, the convention of using 3 years of data was applied, i.e., if a well increased to above the cleanup level in 2030, concentrations for 2028, 2029, and 2030 were used in the calculation beginning in 2030.

4. 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 as long as the concentration is above one-tenth the cleanup level.

5. Calculations were performed until the end of the simulation data set, or until there were less than two data points above one-tenth the cleanup level available for the calculation. The use of only two 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 WMA S-SX local-scale transport model are described in the following subsections.

3.1 Model Domain

The model grid domain and structure for the WMA S-SX local-scale transport model is identical to the local-scale groundwater flow model (ECF-200W-17-0045). The domain extends 4,100 m east-west and 2,100 m north-south. The lower left corner of the domain has coordinates of 566,150 m east and 133,150 m north (Washington State Plane, South Zone [4602]). The horizontal grid discretization is shown in Figure 2. The highest resolution part of the grid has 5 x 5 m cells around the WMA S-SX Tank Farms and the downgradient groundwater plumes. These cells expand in size to 25 x 25 m toward the northeast portion of the domain in the downgradient migration direction of the plumes, and 50 x 50 m elsewhere. Limiting the cell sizes to no more than 25 m north and east ensured no cell had an aspect ratio of greater than 5, which is desired for modeling.

The CP 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 WMA S-SX local-scale model (described in ECF-200W-17-0045). Layering in the model is shown in Figure 3, which presents an east-west cross section that passes through the 241-SX Tank Farm.

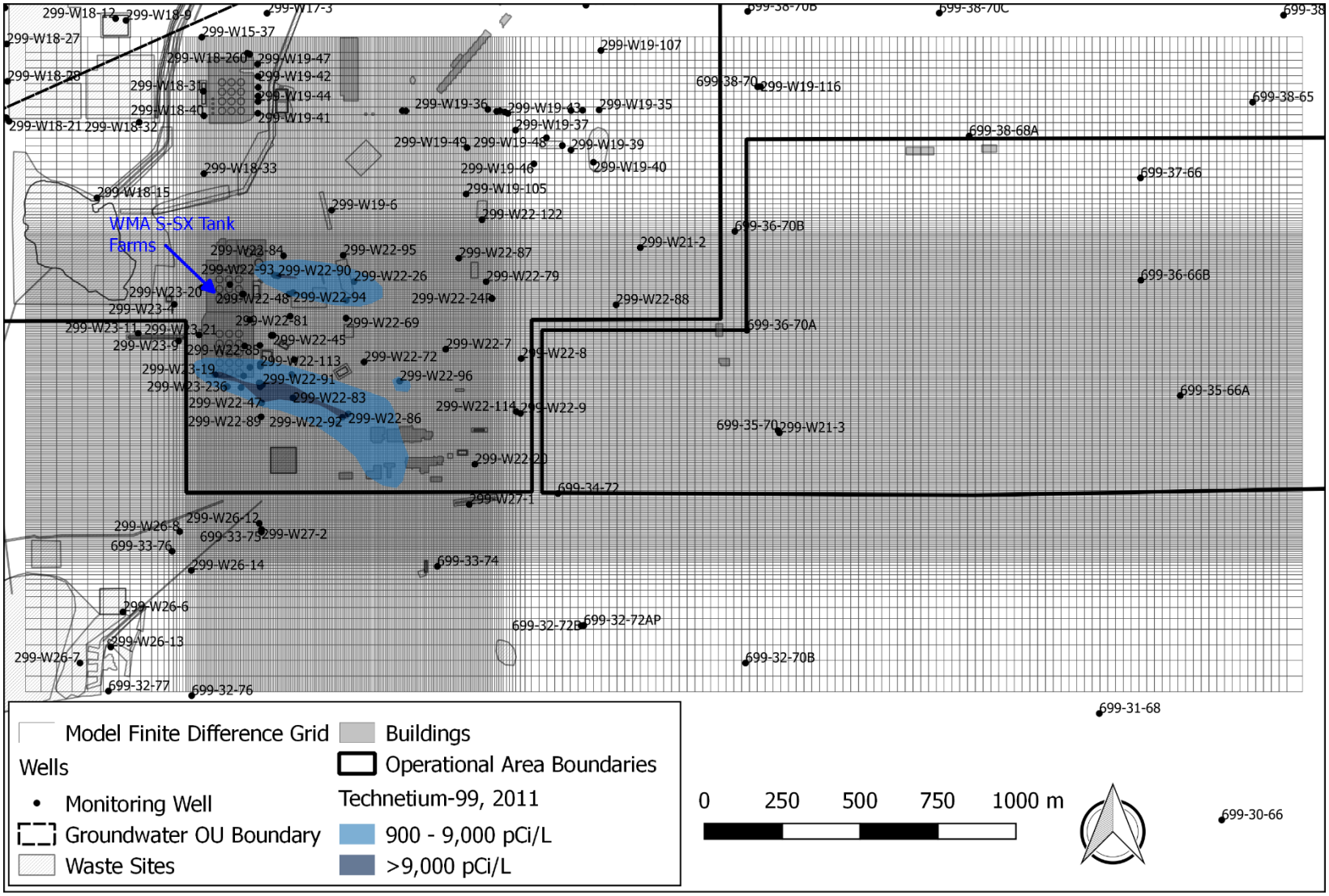

Figure 2. Horizontal Grid Discretization for the WMA S-SX Local-Scale Submodel

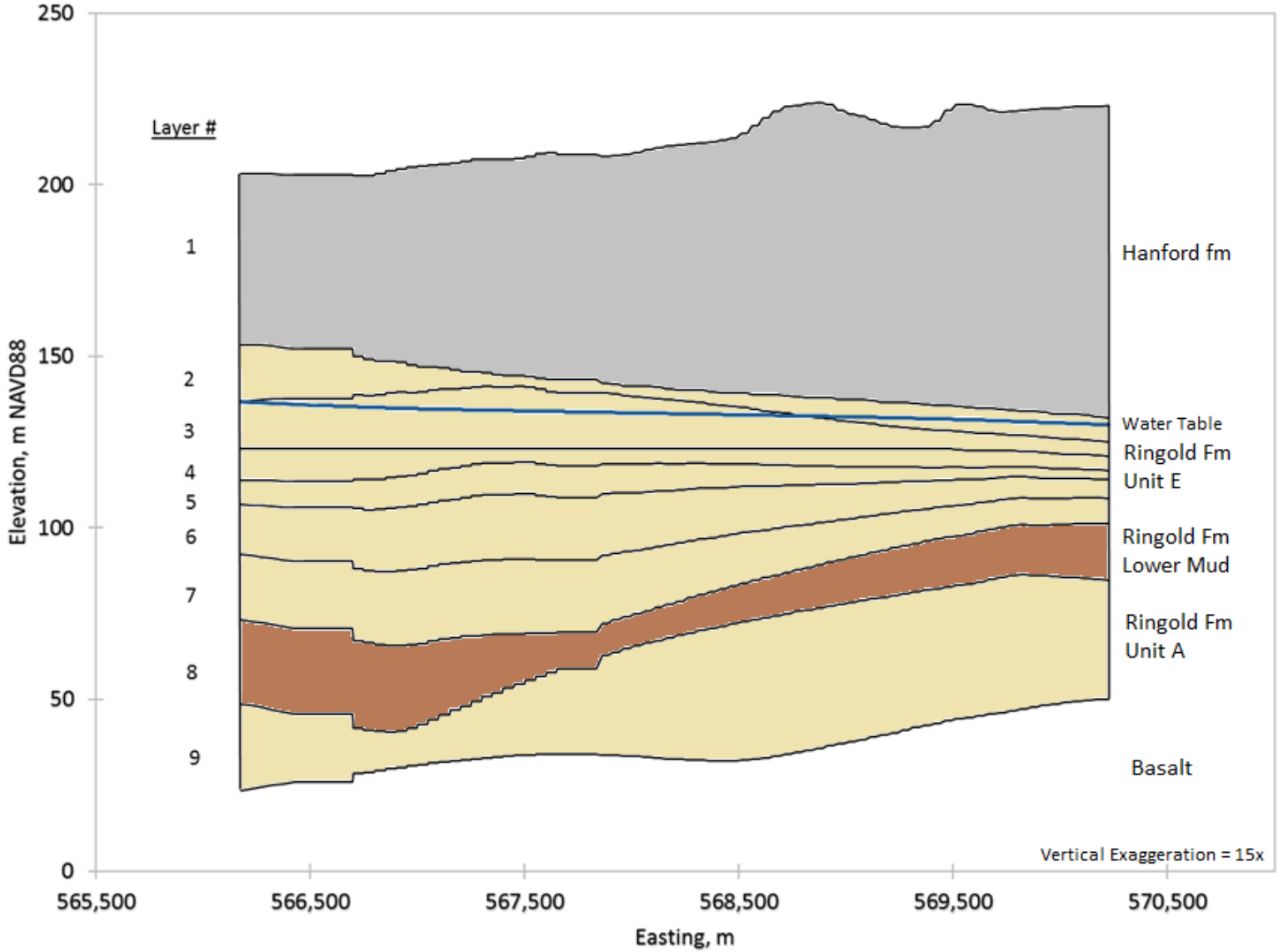

Figure 3. Vertical Discretization of the WMA S-SX Local-Scale Submodel (West to East Cross Section through the 241-SX Tank Farm)

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 WMA S-SX transport modeling are shown in Table 1 and parameters for the aquifer are shown in Table 2. All three constituents (chromium, nitrate, and technetium-99) occur in groundwater as polyatomic anions and were assumed to be non-sorbing. Thus, the distribution coefficients for all three were set to zero. All constituents were simulated as non-decaying. This was justified for technetium-99 because its radiological half-life of 210,000 years is much longer than the duration of the simulations. Parameters for the aquifer listed in Table 3 are identical to values used in the CP model.

Table 1. Contaminant Transport Parameters

Constituent	Half-Life (yrs)	Distribution Coefficient (mL/g)
Chromium/Hexavalent Chromium	N/A	0.0
Nitrate	N/A	0.0
Technetium-99	210,000*	0.0

* Radiological decay was not included in the transport simulations for technetium-99 because the half-life is very long compared to the 125-year duration of the simulations.

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	0.0 m^2/day

Table 3. WMA S-SX Groundwater Extraction System Pumping Rates

Extraction Well	Baseline Pumping Rate, m^3/d (gpm)[1]	Optimized Pumping Rate, m^3/d (gpm)[2]
299-W22-90	130.0 (23.85)	130.0 (23.85)[3]
299-W22-91	210.0 (38.53)	220.5 (40.46)
299-W22-92	210.0 (38.53)	149.7 (27.47)

1. Applicable beginning January 2017. Prior to this, actual pumping rates were used in the model.
2. It was assumed the optimized pumping rates would begin in 2018.
3. Not optimized because well is already pumping at the minimum rate and fully captures the plumes from 241-S Tank Farm.

3.3 Boundary and Initial Conditions

Evaluating the response of the existing WMA S-SX groundwater plumes to remedial actions requires knowledge of current plume extent and concentrations. Ideally, the existing groundwater plumes at WMA S-SX 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.

The initial plume conditions for the WMA S-SX transport modeling are based on the annual groundwater report plumes for 2011. These plumes were extrapolated from the 2-dimensional annual report grids to three-dimensional solid models (ECF-200UP1-16-0071, *Initial Groundwater Plume Development at Year of Remedy Initiation for S-SX Area Technetium-99 [2011], U Plant Area Uranium [2014], U Plant Area Technetium-99 [2014], Nitrate [2014], and Tritium [2014] to Support Fate and Transport Modeling for Remedial Evaluation in the 200-UP-1 Groundwater Operable Unit*; ECF-200W-17-0097; *Initial Concentration Conditions for Cr(VI) and NO3 at WMA S-SX for 2011*). Concentrations in the solid models were then translated onto the WMA S-SX 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.

Although more practical than simulating original plume emplacement, the approach of using the annual report plumes can have substantial uncertainty due to limited sample data and because the interpolation algorithm used to generate the plumes does not consider groundwater flow and transport processes (Zheng and Bennet, 1995). Because technetium-99 is the primary focus of the groundwater extraction system, it was desired that uncertainty in the initial conditions for technetium-99 be reduced. Thus, the 2011 initial conditions for this constituent were adjusted, as explained in the following paragraphs.

Since the WMA S-SX groundwater extraction system began operating in 2012, concentration trends in sample results from the monitoring wells have become apparent (DOE/RL-2016-20), particularly because the constituents simulated do not adsorb to the aquifer matrix and therefore have responded quickly to groundwater extraction. Concentration trends over time at a monitoring well are caused by spatial variations in plume concentrations migrating through the location of the well as the groundwater moves. In effect, a concentration trend at a well provides a record of the historical plume concentrations upgradient of a well. Thus, concentration trends provide information about the spatial distribution of contamination at previous times. This fact was used to adjust the 2011 starting plume for technetium-99 to be consistent with the observed concentration changes at monitoring wells from 2012 through 2016.

The adjustment of the 2011 technetium-99 starting plume was accomplished with a hybrid approach combining transport simulation and parameter estimation using the pilot point method discussed by Doherty (2003), *Ground Water Model Calibration Using Pilot Points and Regularization*. In this method, multiplication factors are defined at key locations (i.e., the pilot points) within the plume and factors are assigned to the remaining plume grid by spatially interpolating the pilot points. As implemented in this analysis, the pilot points were interpolated by ordinary kriging and were used to multiply the 2011 technetium-99 plume concentrations, thus changing the initial concentrations that were input into the transport simulations. The goodness of agreement between the simulated concentrations and sample results at selected wells was used to adjust the multipliers using the PEST software (Doherty, 2016).

Thus, the data and computationally intensive exercise of recreating the WMA S-SX technetium-99 plume from its beginning is avoided, as is the potentially inconsistent non-mass-conservative use of mapped plumes. The 2011 mapped technetium-99 plume was adjusted to account for recent concentration trends, therefore getting the benefit of recent data to inform the model. Areas where no recent sample results were available were populated with pilot points having fixed values of 1.0 to leave the initial mapped concentrations unchanged. As a final step to gauge the reasonableness of the results, the simulated plume for 2015 was compared to the mapped plume from DOE/RL-2016-09 (Section 6.1). For chromium and nitrate, the unadjusted 2011 plumes were used as the starting conditions.

The WMA S-SX local-scale model grid was sized to entirely contain the plumes for the duration of the simulations. Thus, the plumes never reached the boundary of the model. Extraction wells were sinks where contaminant mass was removed from the model domain. Some scenarios considered the effect of ongoing sources of contamination to the aquifer. These were added as sources beneath the 241-S and 241-SX Tank Farms for chromium, nitrate, and technetium-99, and beneath the 216-S-25 Crib (upgradient of the 241-SX Tank Farm) for nitrate. 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*. The source terms were sized such that resulting groundwater concentrations were similar to the concentrations used to estimate the sources.

As described in Section 2.1, two additional flow model simulations were performed with different internal boundary conditions than those documented in ECF-200W-17-0045. In the first, the duration of pumping from the WMA S-SX extraction wells was reduced from 25 to 15 years, the latter being the planned duration of the WMA S-SX groundwater extraction system. Second, a simulation was performed using the optimized pumping rates for extraction wells 299-W22-90 and 299-W22-91 in which the optimized pumping rates begin in year 7 (2018). Table 3 shows the baseline pumping rates and the rates resulting from the optimization analysis described in Section 2.2.

3.4 Simulation Period

The WMA S-SX groundwater extraction system began operating during 2012, and it has been estimated that 15 years of pumping are required to meet the active-remedy cleanup objective of reducing the technetium-99 concentration in groundwater to below 9,000 pCi/L (DOE/RL-2013-07, *200-UP-1 Groundwater Operable Unit Remedial Design/Remedial Action Work Plan*). This will be followed by a period of MNA (up to 110 years) to allow concentrations to decline to below the 900 pCi/L cleanup level[2]. The cleanup timeframe for CP groundwater is 125 years, so the WMA S-SX local-scale model simulations begin on 1/1/2012 and end 126 years later on 12/31/2137. This time is divided into 97 stress periods as listed in Appendix A.

3.5 Transport Evaluation Data

An evaluation was performed to verify that the transport model results were adequate for the intended purpose. This was accomplished by comparing simulated concentrations to monitoring data. The evaluation period was 2012 through 2016. Monitoring data were also needed to adjust the technetium-99 starting concentrations (Section 3.3). Sample results from monitoring and extraction wells were obtained from the Hanford Environmental Information System (HEIS) database using the Environmental Dashboard Application (EDA) accessible at https://ehs.hanford.gov/eda/. Wells used for the transport evaluation are described in Section 6.1.

[2] These times assume there are no ongoing sources of contamination to the aquifer.

4 Software Applications

MODFLOW-2000-MST, MT3DMS, Groundwater Vistas™[3], and Microsoft Excel®[4] software programs were used for this environmental calculation. MODFLOW and MT3DMS are 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 8 (Windows®[5] executable file mf2k-mst-chprc08dp.exe)
- Hanford Information Systems Inventory (HISI) Identification Number: 2517 (Safety Software, Level C)
- Workstation type and property number: INTERA Workstation Computer, Property Tag INTERA-00590
- Authorized User: John P. McDonald
- 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*

MT3DMS

- Software Title: MT3DMS
- Software Version: CHPRC Build 8 (Windows®[6] executable file mt3d-mst-chprc08dpv.exe)
- HISI Identification Number: 2518 (Safety Software, Level C)

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[3] Groundwater Vistas is a trademark of Environmental Simulations, Inc., Reinholds, PA.
[4] Microsoft Excel is a registered product of the Microsoft Corporation in the United States and in other countries.
[5] Windows is a registered trademark of the Microsoft Corporation in the United States and in other countries.
[6] Windows is a registered trademark of the Microsoft Corporation in the United States and in other countries.

- Workstation type and property number: INTERA Workstation Computer, Property Tag INTERA-00590
- Authorized User: John P. McDonald
- 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 and MT3DMS) 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™[7], installation tests identified in CHPRC-00259 Rev. 2 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 Appendix B 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 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 Numbers 2517 (MODFLOW) and 2518 (MT3DMS).

5 Calculation

Transport simulations were performed through the year 2137, which is the end of the 125-year cleanup timeframe for CP groundwater beginning in 2012 when the 200 West Pump and Treat began operating. Simulations were performed for chromium, nitrate, and technetium-99 for both baseline and optimized extraction wells flow rates (shown in Table 3) and with and without including ongoing sources of contamination to the aquifer. Estimates of the source terms are documented in ECF-200W-17-0030. Table 4 lists the scenarios that were simulated. The results are described in Section 6.

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

Table 4. WMA S-SX Transport Modeling Scenarios

Scenario #	Constituent	Pumping Duration (yrs)	Pumping Flow Rates	Ongoing Sources?
Baseline Cases				
1	Chromium	25	Baseline	No
2	Chromium	25	Baseline	Yes
3	Nitrate	25	Baseline	No
4	Nitrate	25	Baseline	Yes
5	Technetium-99	25	Baseline	No
6	Technetium-99	25	Baseline	Yes
Forecast Cases				
7	Chromium	15	Baseline	No
8	Chromium	15	Optimized	No
9	Chromium	15	Baseline	Yes
10	Chromium	15	Optimized	Yes
11	Nitrate	15	Baseline	No
12	Nitrate	15	Optimized	No
13	Nitrate	15	Baseline	Yes
14	Nitrate	15	Optimized	Yes
15	Technetium-99	15	Baseline	No
16	Technetium-99	15	Optimized	No
17	Technetium-99	15	Baseline	Yes
18	Technetium-99	15	Optimized	Yes

6 Results/Conclusions

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

6.1 Baseline Simulations and Transport Evaluation

Model evaluation is the process whereby simulation results are compared to field measured data to determine if the model represents field conditions well enough for its intended purpose. The transport simulations for WMA S-SX were evaluated by comparing simulated concentrations to monitoring data. Wells used for the transport evaluation are shown in Figure 4.

Base case simulations were performed to provide model results for the transport evaluation. These cases are listed in Table 4 and default to a pumping duration of 25 years, same as for the 200 West pump and treat. The period of interest for the transport evaluation was the first five years of pumping, so only results from 2012 through 2016 were used from these cases. Simulations were performed for all

three constituents (chromium, nitrate, and technetium-99) with and without the inclusion of ongoing sources.

Example comparisons of simulated concentrations to sample results are provided for chromium and nitrate in Figure 5 and Figure 6, respectively (graphs of all comparisons performed for the transport evaluation are shown in Appendix C)[8]. Each figure shows comparisons for two wells and simulated concentrations are provided for cases with and without ongoing sources of contamination to the aquifer. Overall, the agreement between simulated concentrations and sample results was good. For chromium in 299-W23-19 (Figure 5) and nitrate in 299-W22-90 (Figure 6), the simulated concentrations match the sample results better in the cases that include the ongoing sources.

Example comparisons of simulated concentrations to sample results for technetium-99 are provided in Figure 7 and Figure 8. These figures show comparisons prior to and after the adjustment of initial conditions for technetium-99 (described in Section 3.3). Figure 7 shows results for cases without the ongoing sources, and the cases including sources are shown in Figure 8. As with chromium and nitrate, overall the comparisons were good. Both figures show the improvement realized after adjusting the technetium-99 initial concentrations.

A source was inferred to occur in the north part of the 241-SX Tank Farm due to the increasing concentrations at 299-W22-45 (now dry) and its replacement well 299-W22-115 (Figure 8) (ECF-200W-17-0030). The inclusion of this source in the model is necessary to provide a reasonable match to the monitoring data (Figure C-14 in Appendix C). This plume is not currently being captured.

To further assess the technetium-99 initial concentrations adjustment, the simulated plume for 2015 is compared to the plume mapped from monitoring data (DOE/RL-2016-09) in Figure 9. The simulated plume downgradient from the 241-S Tank Farm is larger than the mapped plume. This is because there is little actual monitoring directly downgradient of extraction well 299-W22-90 to inform the mapping. The mapped and simulated plumes downgradient from 241-SX are similar in extent. This ability to simulate a reasonable 2015 technetium-99 plume from a transient simulation starting with 2011 conditions indicates that the adjusted starting concentrations are reasonable.

Graphs of all comparisons for all three constituents performed for the transport evaluation are shown in Appendix C.

[8] Some of the charts in this document contain two well names, such as “299-W22-45/299-W22-115.” This indicates that a well has become dry or is nearly dry (first well) and has been replaced (second well), and monitoring data from both wells are used on the chart.

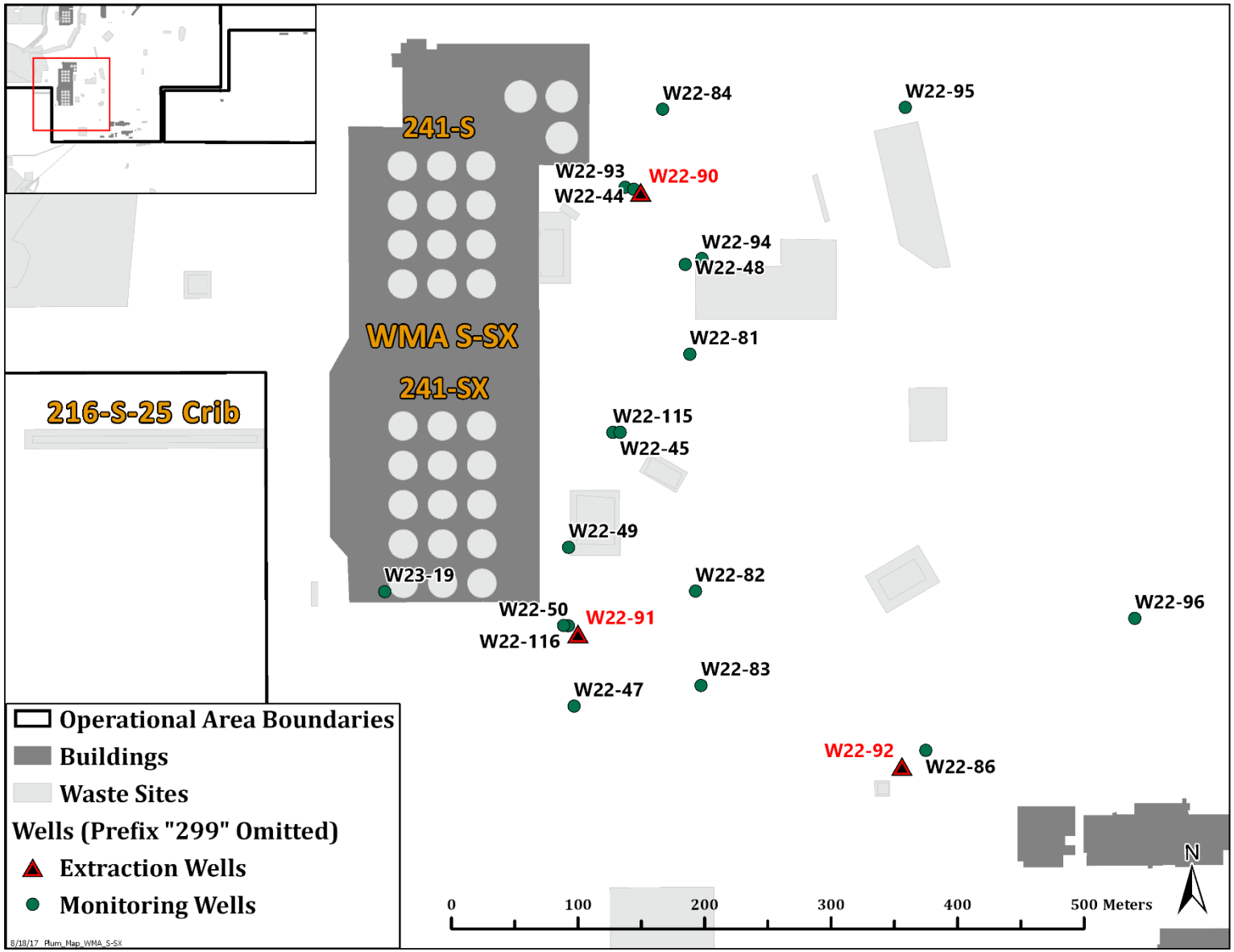


Figure 4. Wells Used for the Transport Evaluation

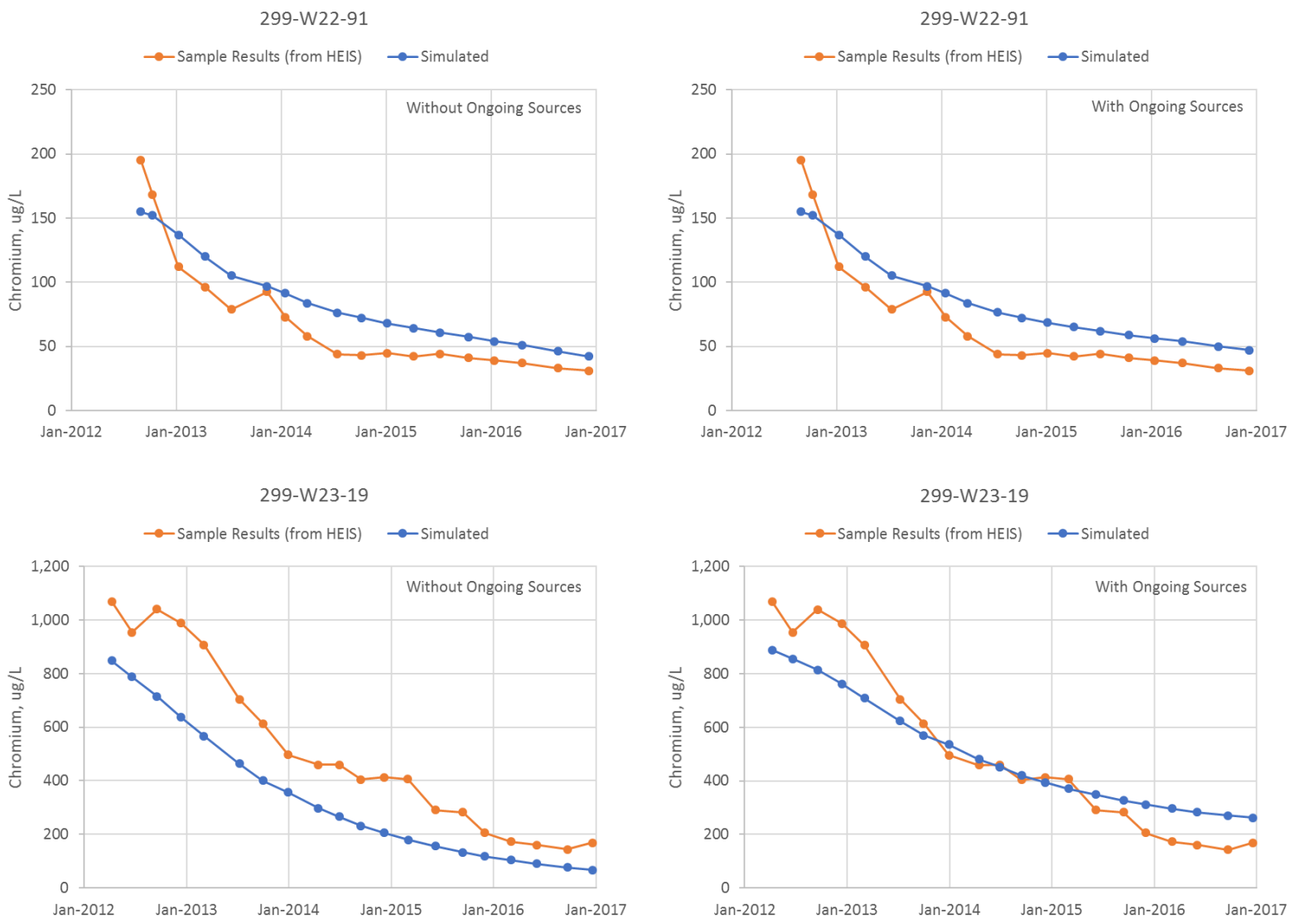


Figure 5. Simulated Chromium Concentrations and Sample Results for Selected Wells in the WMA S-SX Vicinity (Base Case)

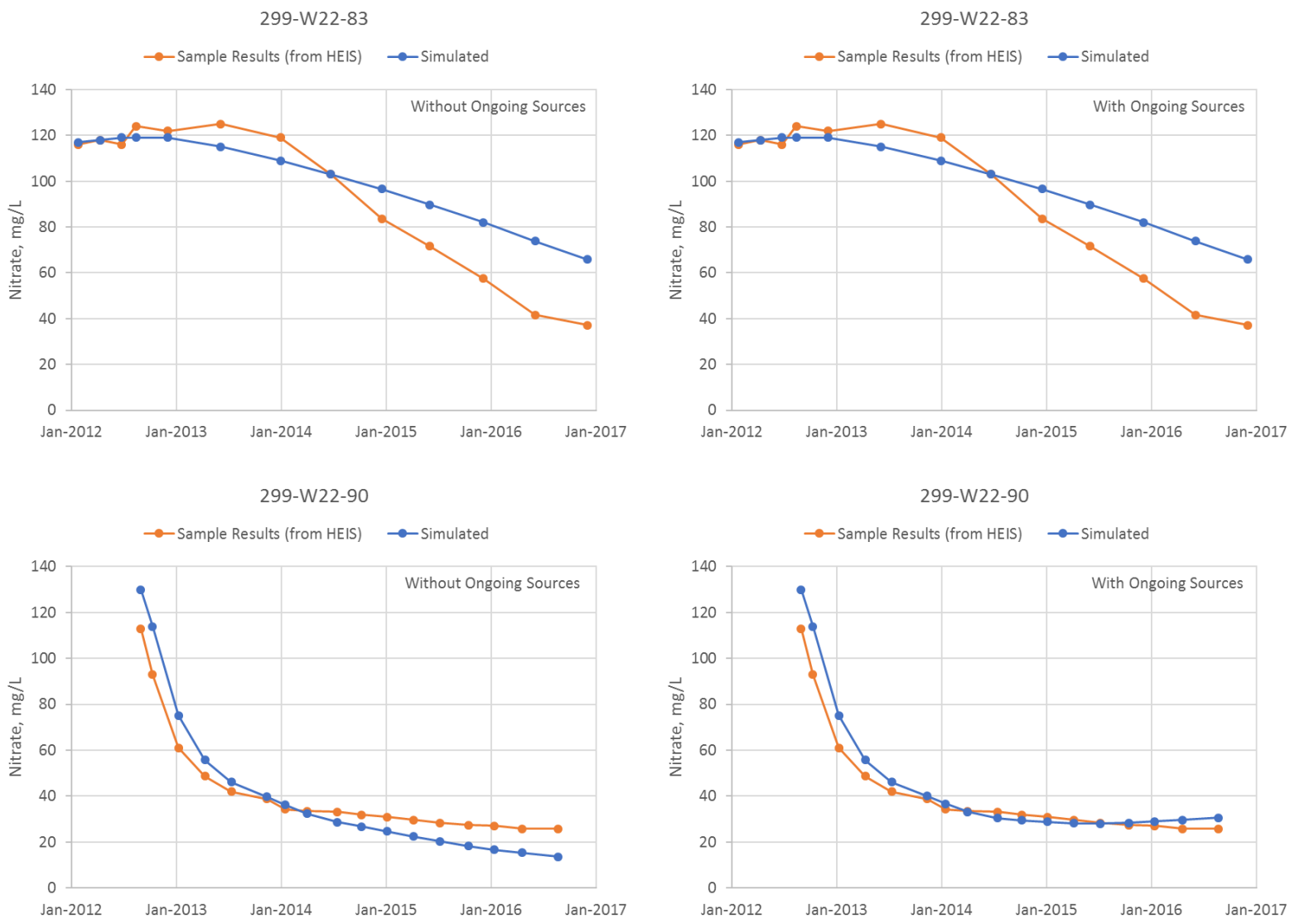


Figure 6. Simulated Nitrate Concentrations and Sample Results for Selected Wells in the WMA S-SX Vicinity (Base Case)

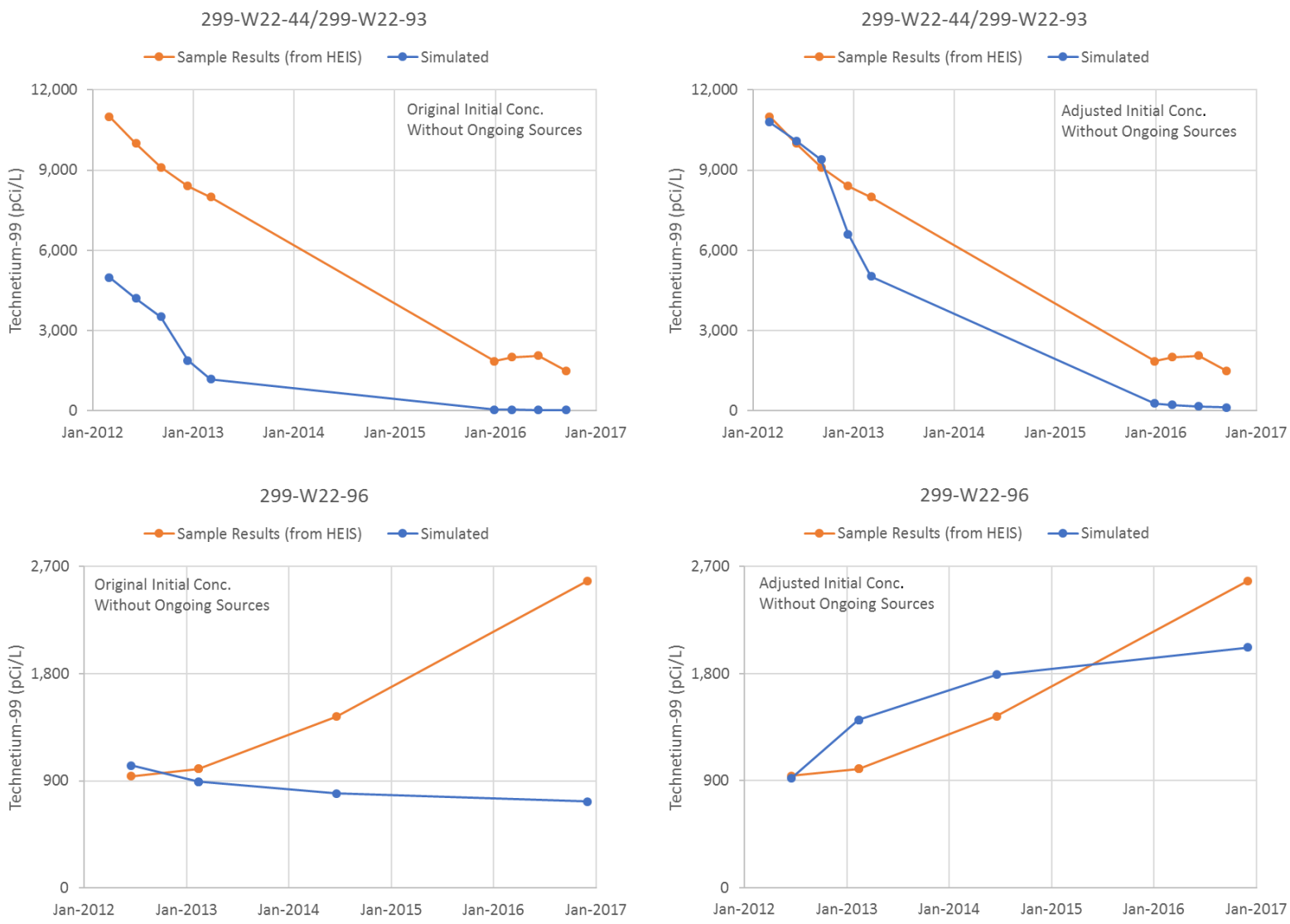


Figure 7. Simulated Technetium-99 Concentrations (Without Ongoing Sources) and Sample Results for Selected Wells in the WMA S-SX Vicinity (Base Case)

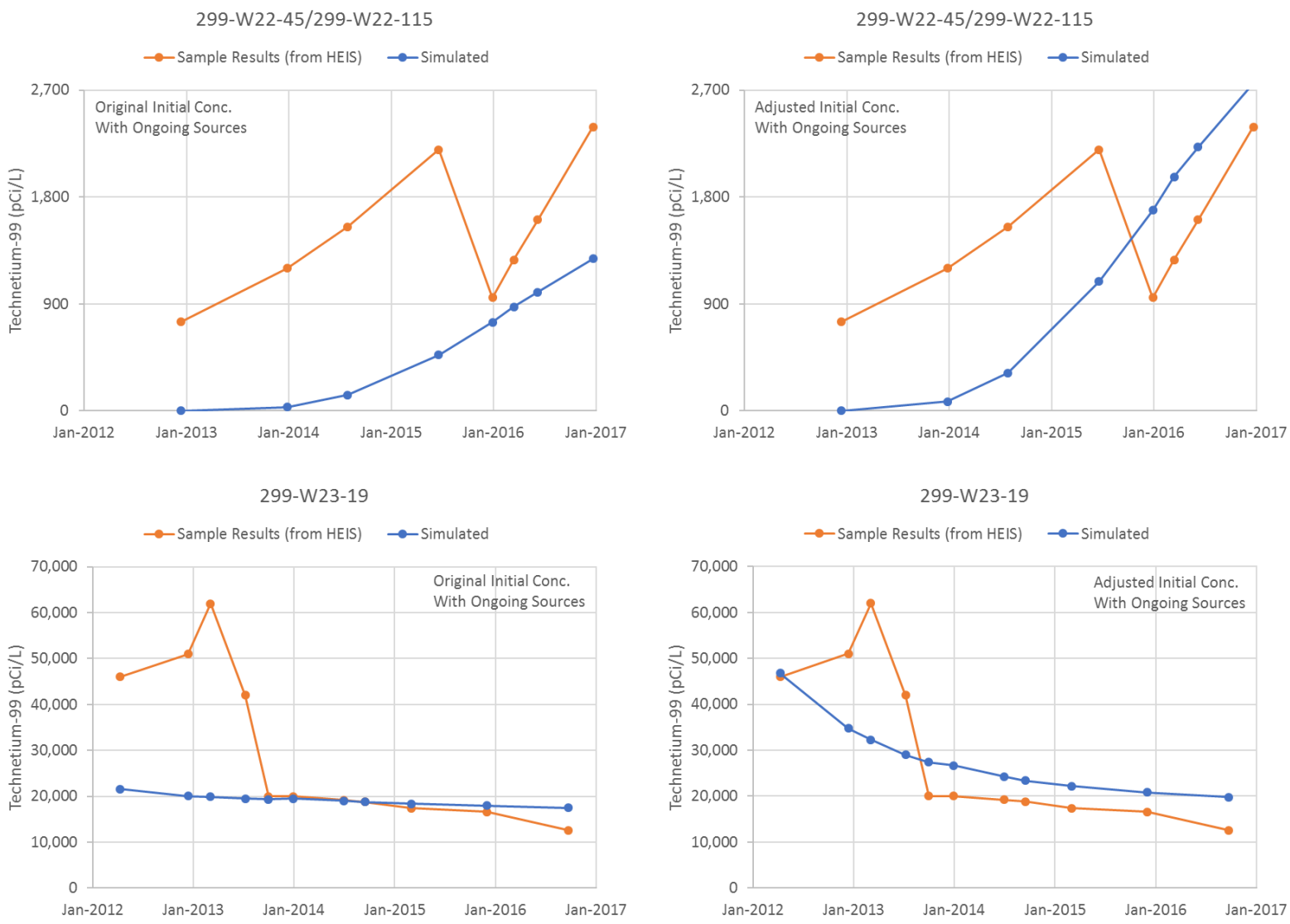


Figure 8. Simulated Technetium-99 Concentrations (With Ongoing Sources) and Sample Results for Selected Wells in the WMA S-SX Vicinity (Base Case)

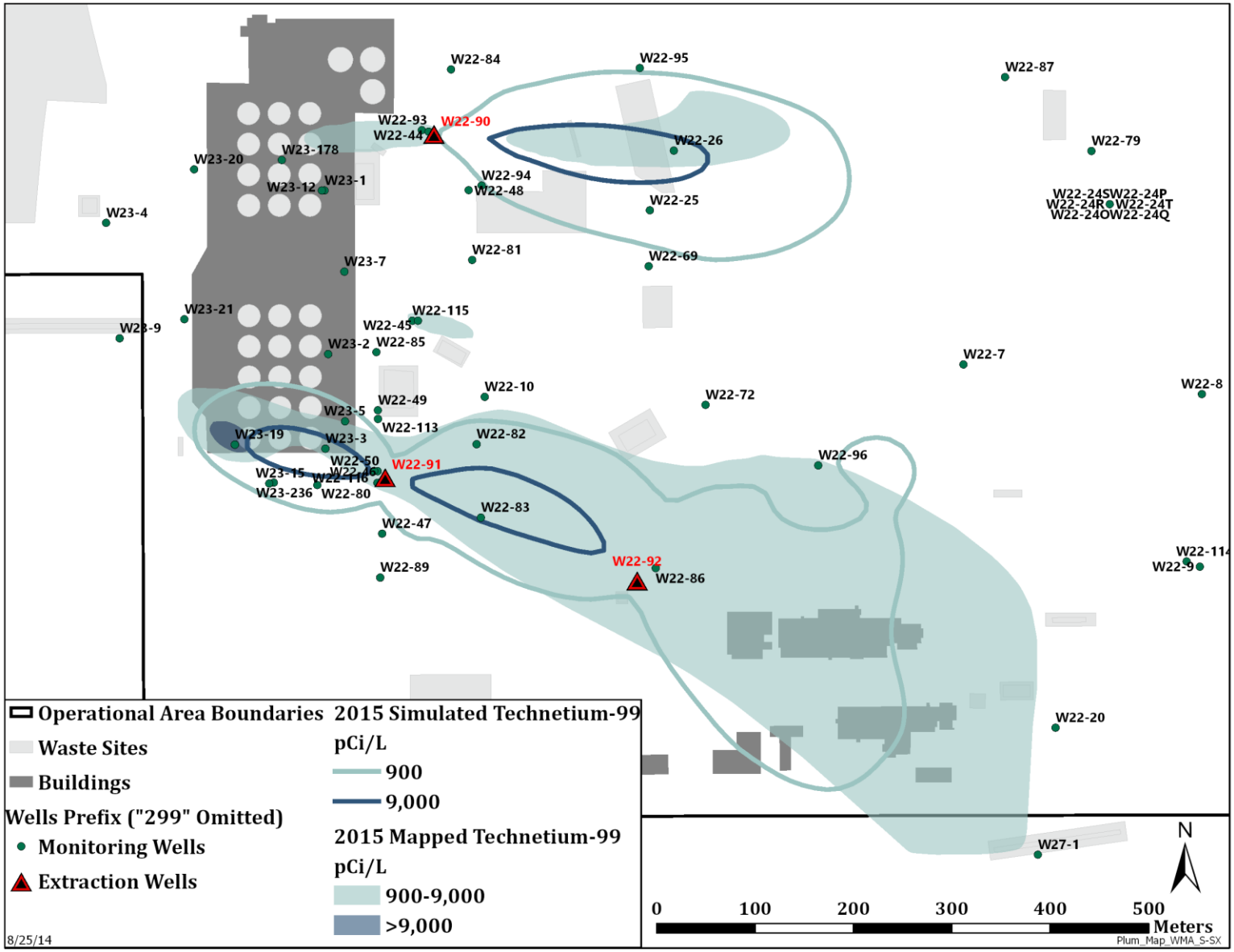


Figure 9. Comparison of the Simulated and Mapped Technetium-99 Plume for 2015

6.2 Forecast Transport Simulations

Results of the forecast transport simulations are provided in the following sections. The results are organized by constituent. In Sections 6.2.1, 6.2.2, and 6.2.3, plume maps are provided showing simulated concentrations over time for chromium, nitrate, and technetium-99, respectively. This is followed by graphs of contaminant mass removed by the groundwater extraction system along with the results of the flow rate optimization analysis in Section 6.2.4. There was very little difference in the results when the optimized extraction well flow rates were used in the simulations, so the results presented in Sections 6.2.1 through 6.2.3 are for baseline extraction well flow rates. Graphs of the calculated UCL95s are provided in Section 6.2.5. Results are provided for cases both with and without the inclusion of the ongoing sources. Dates are given as years since 1/1/2012 (close to when the groundwater extraction system started operating in September 2012) with the calendar year in parentheses.

6.2.1 Chromium

Plume maps of simulated chromium concentrations without ongoing sources for years 1 (2012), 5 (2016), and 15 (2027) (end of pumping) are shown in Figure 10 through Figure 12, respectively. These figures show that at the end of the planned 15-year pumping duration (Figure 12), much of the chromium plume has been captured by the extraction wells. The small portion of the plume downgradient from the 241-SX Tank Farm not captured disperses to below the cleanup level by year 22 (2033).

The situation is different when the ongoing sources are added to the simulations. These results are shown in Figure 13, Figure 14, Figure 15, and Figure 16 for years 1 (2012), 5 (2016), 15 (2027), and 126 (2137), respectively. At year 15 (Figure 15), plumes from the sources are contained by the near-field extraction wells. However, after pumping is terminated, substantial chromium plumes reform over the next 110 years (Figure 16).

The result in Figure 16 for year 126 (2137) approximates future plume conditions due to the approximations and assumptions upon which the source terms are based (ECF-200W-17-0030). While the simulation indicates that substantial chromium plumes would reform, the concentrations and extent of those plumes are uncertain.

6.2.2 Nitrate

Plume maps of simulated nitrate concentrations without ongoing sources for years 1 (2012), 5 (2016), and 15 (2027) (end of pumping) are shown in Figure 17 through Figure 19, respectively. These figures show that at the end of the planned 15-year pumping duration (Figure 19), two main sections of the nitrate plumes remain, one downgradient from the 241-S Tank Farm and another downgradient from the 216-S-25 Crib. These plumes disperse to below the cleanup level by year 27 (2038).

When the ongoing sources are added to the simulations, nitrate contamination in the aquifer persists. These results are shown in Figure 20, Figure 21, Figure 22, and Figure 23 for years 1 (2012), 5 (2016), 15 (2027), and 126 (2137), respectively. At year 15 (Figure 22), plumes from the tank farm sources are contained by the near-field extraction wells, but only a portion of the plume from the 216-S-25 Crib is captured. At the end of the simulation, 110 years after pumping was terminated, substantial nitrate plumes remain (Figure 23). The plume from the 241-S Tank Farm (east of well 299-W22-88) is disconnected from the source and has nearly dispersed to below the cleanup level because the source term for 241-S is projected to end after 30 years. The plume from the 241-SX Tank Farm is also disconnected from its source because nitrate releases are projected to end after 75 years. There is no projected end date for the 216-S-25 Crib source, so this source continues for the duration of the simulation and results in the most substantial plume (merges with the plume from 241-SX).

The result in Figure 23 for year 126 (2137) approximates future plume conditions due to the approximations and assumptions upon which the source terms are based (ECF-200W-17-0030). While the simulation indicates that substantial nitrate plumes would reform, the concentrations and extent of those plumes are uncertain.

6.2.3 Technetium-99

Plume maps of simulated technetium-99 concentrations without ongoing sources for years 1 (2012), 5 (2016), and 15 (2027) (end of pumping) are shown in Figure 24 through Figure 26, respectively. These figures show that at the end of the planned 15-year pumping duration (Figure 26), three sections of the technetium-99 plumes remain, one downgradient from the 241-S Tank Farm and two downgradient from the 241-SX Tank Farm. All three sections disperse to below the cleanup level by year 46 (2057), well within the 125-year cleanup timeframe.

When the ongoing sources are added to the simulations, the results are similar to chromium and nitrate in that groundwater plumes reform after pumping is terminated. These results are shown in Figure 27 through Figure 30 for years 1 (2012), 5 (2016), 15 (2027), and 126 (2137), respectively. Three source areas have been identified in the WMA S-SX Tank Farms: one from 241-S, and two from 241-SX forming north and south plumes. Figure 29 shows the simulated plume configurations for year 15 (2027) at the end of the pumping period. The plume from 241-S and the south plume from 241-SX are contained by the extraction wells, but the north plume from 241-SX is not contained. The other three plume sections in Figure 29 are identical to those in the simulations without sources (Figure 26) and disperse to below the cleanup level by year 46 (2057). However, the sources cause new plumes to form as is shown in Figure 30 for year 126 (2137).

The result in Figure 30 for year 126 (2137) approximates future plume conditions due to the approximations and assumptions upon which the source terms are based (ECF-200W-17-0030). While the simulation indicates that substantial technetium-99 plumes would reform, the concentrations and extent of those plumes are uncertain.

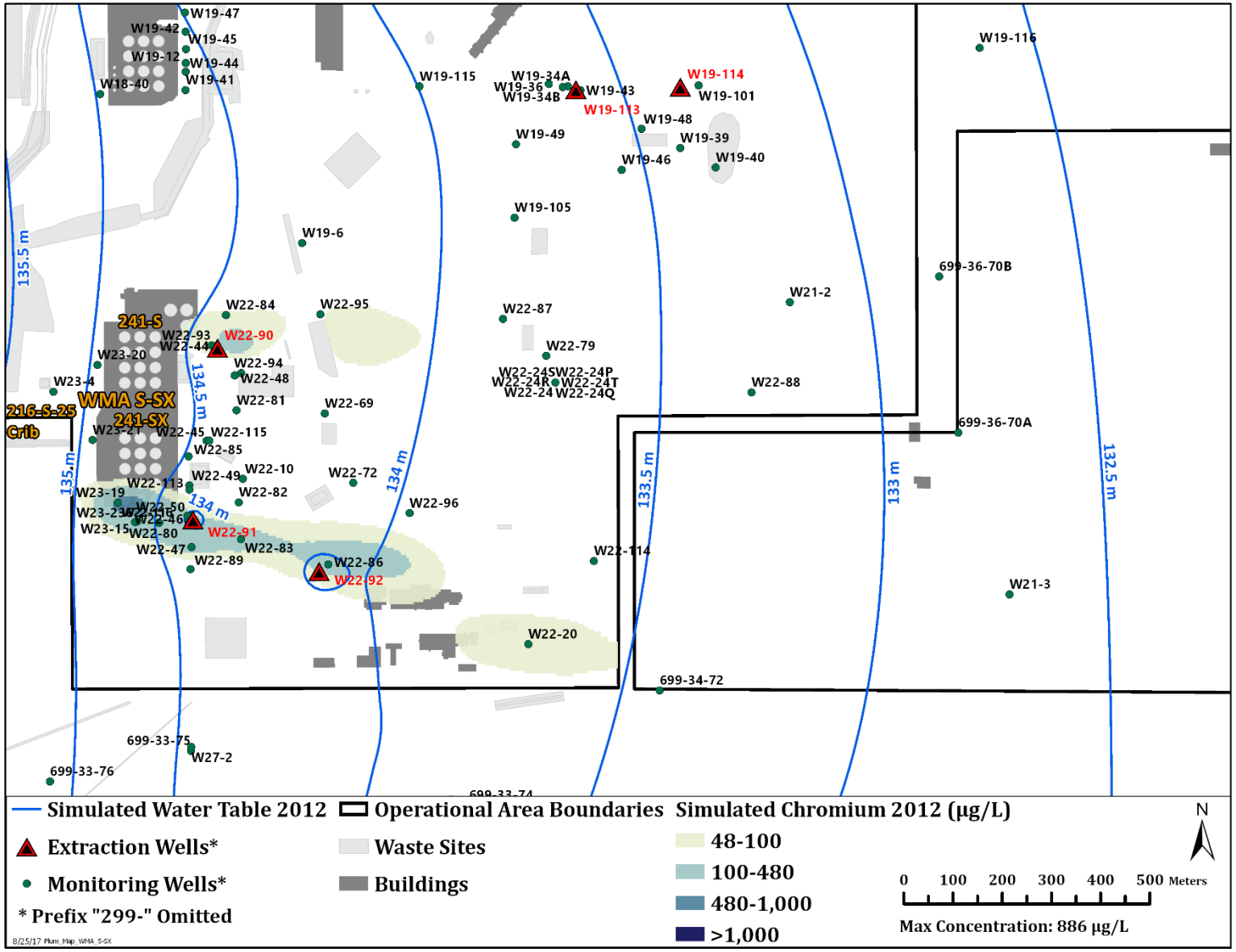


Figure 10. Simulated Chromium Plumes for Year 1 (2012) Without Ongoing Sources

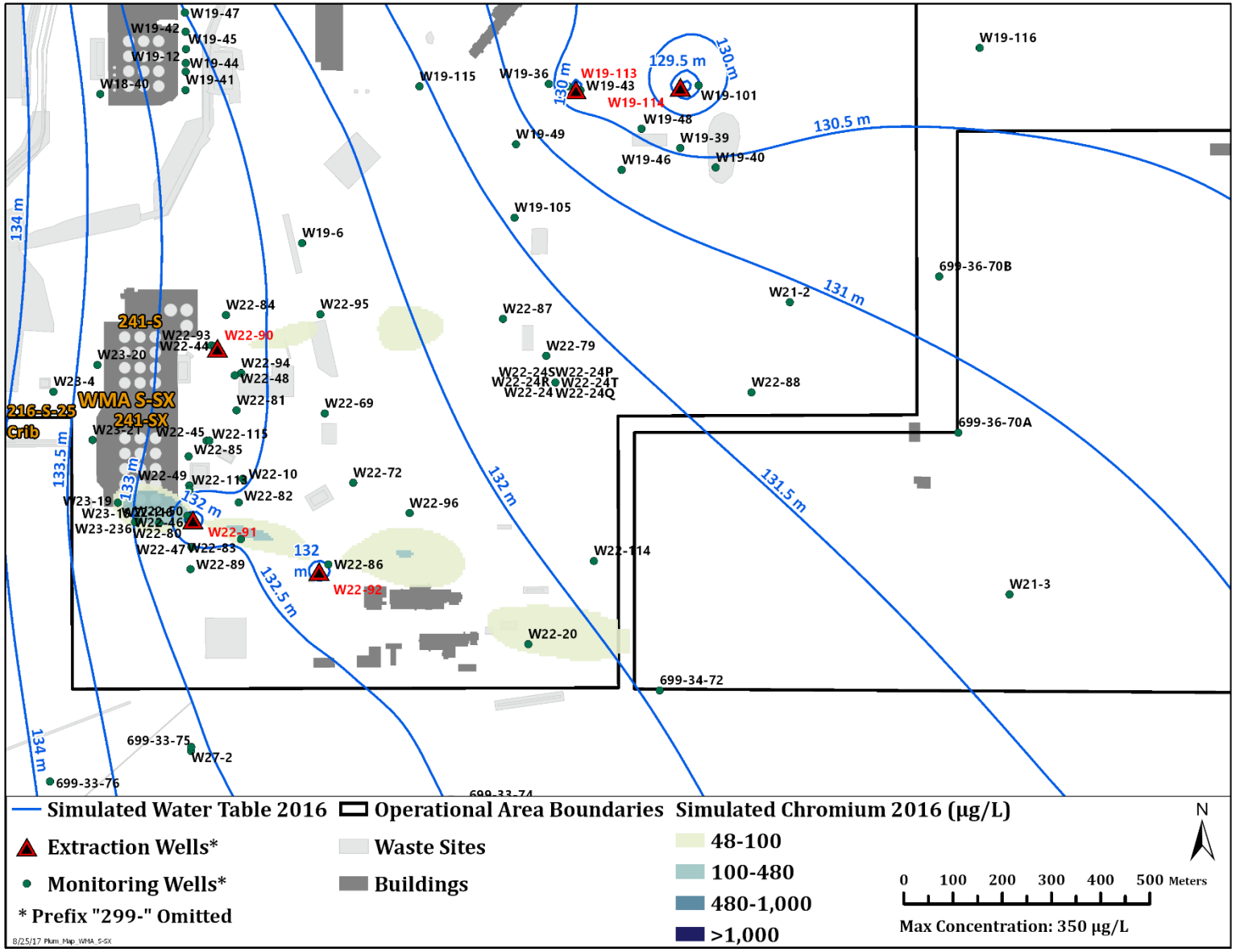


Figure 11. Simulated Chromium Plumes for Year 5 (2016) Without Ongoing Sources

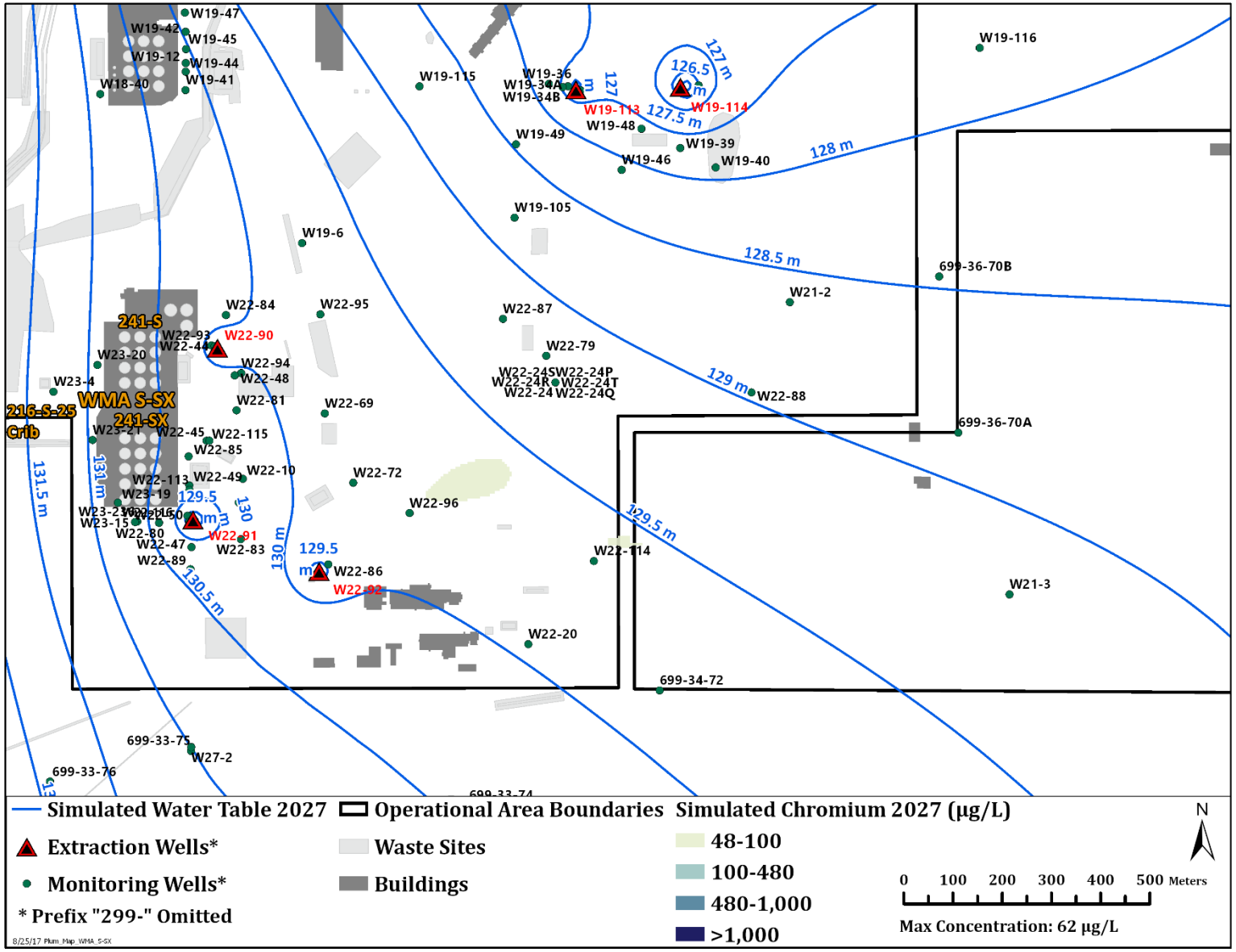


Figure 12. Simulated Chromium Plumes for Year 15 (2027) Without Ongoing Sources

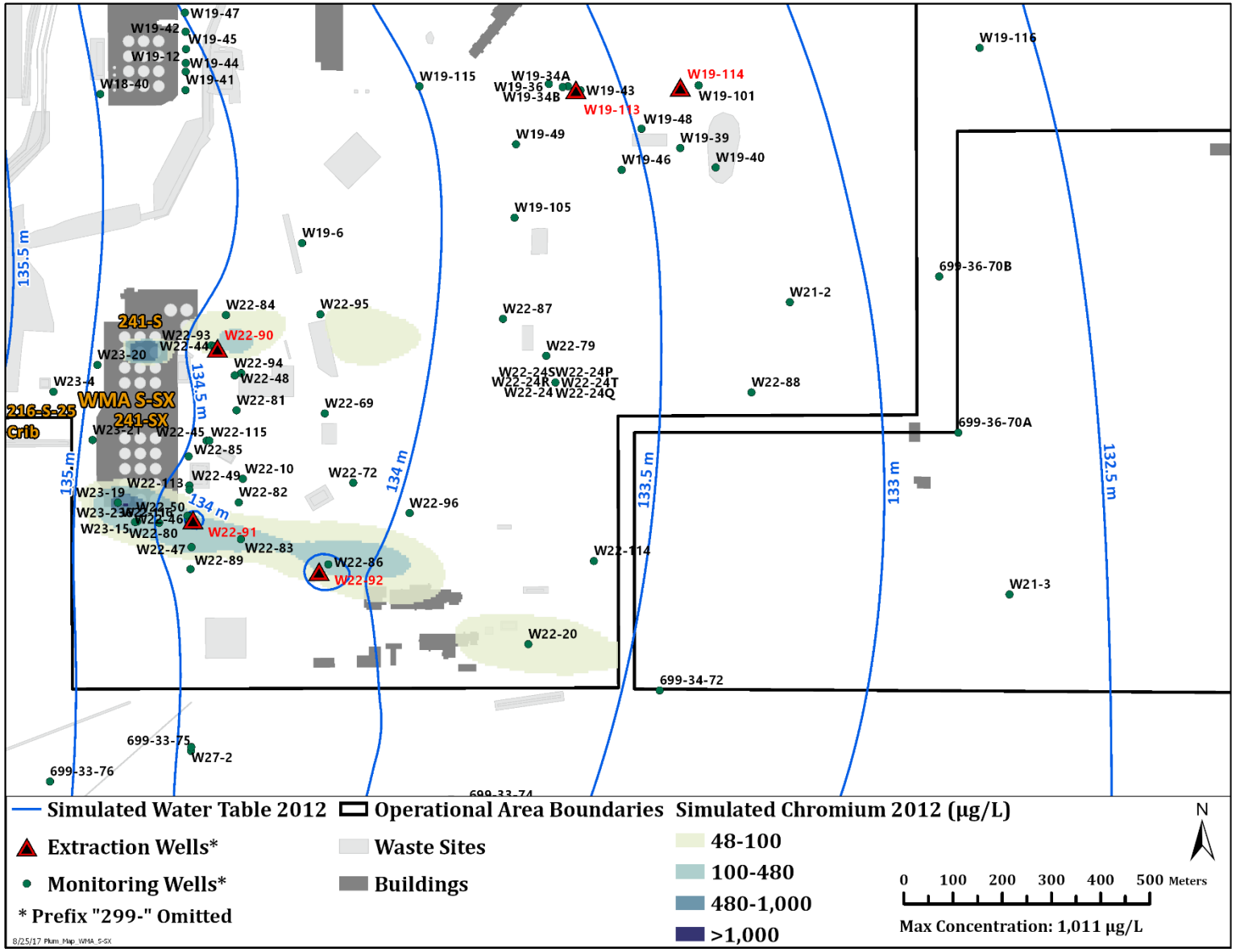


Figure 13. Simulated Chromium Plumes for Year 1 (2012) With Ongoing Sources

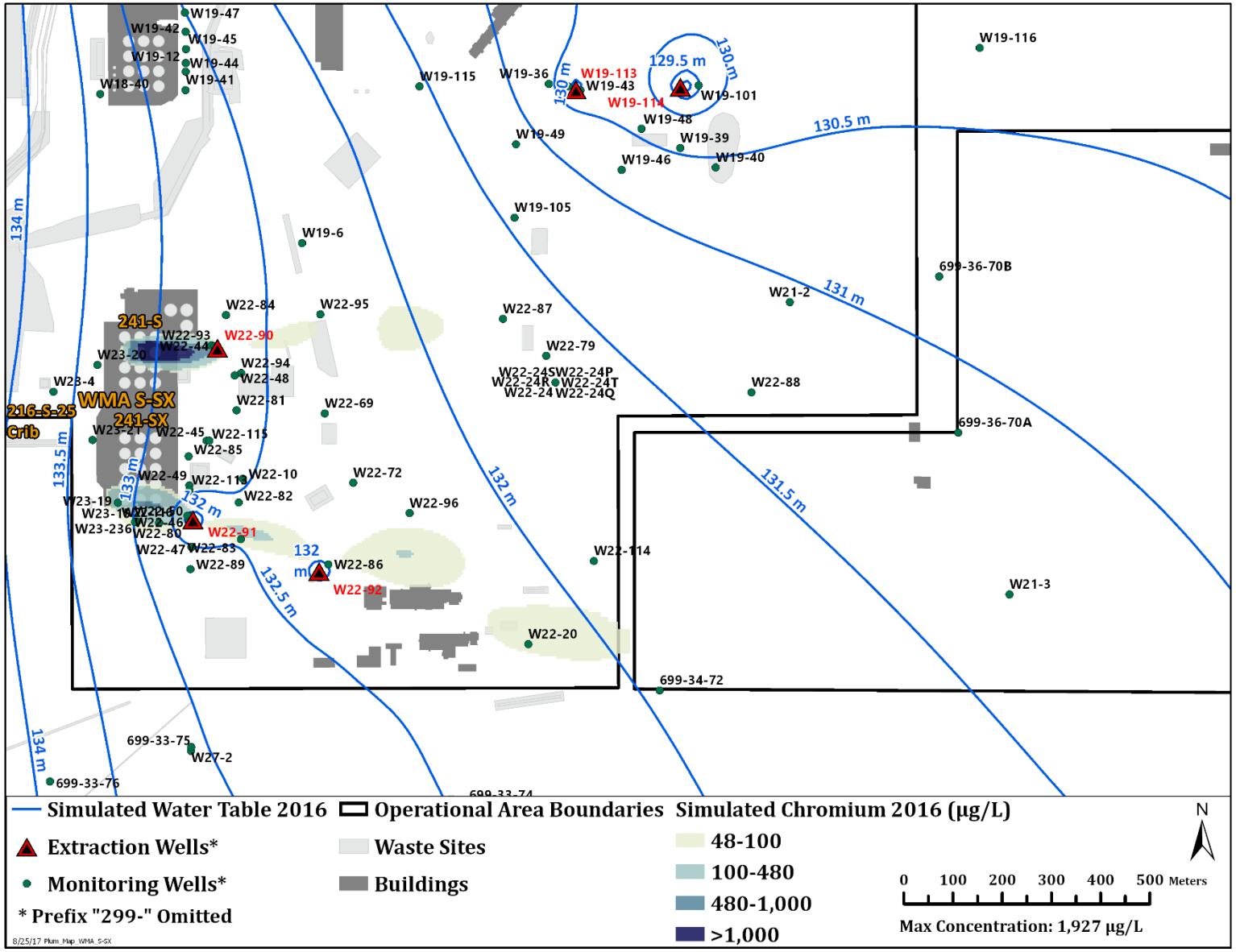


Figure 14. Simulated Chromium Plumes for Year 5 (2016) With Ongoing Sources

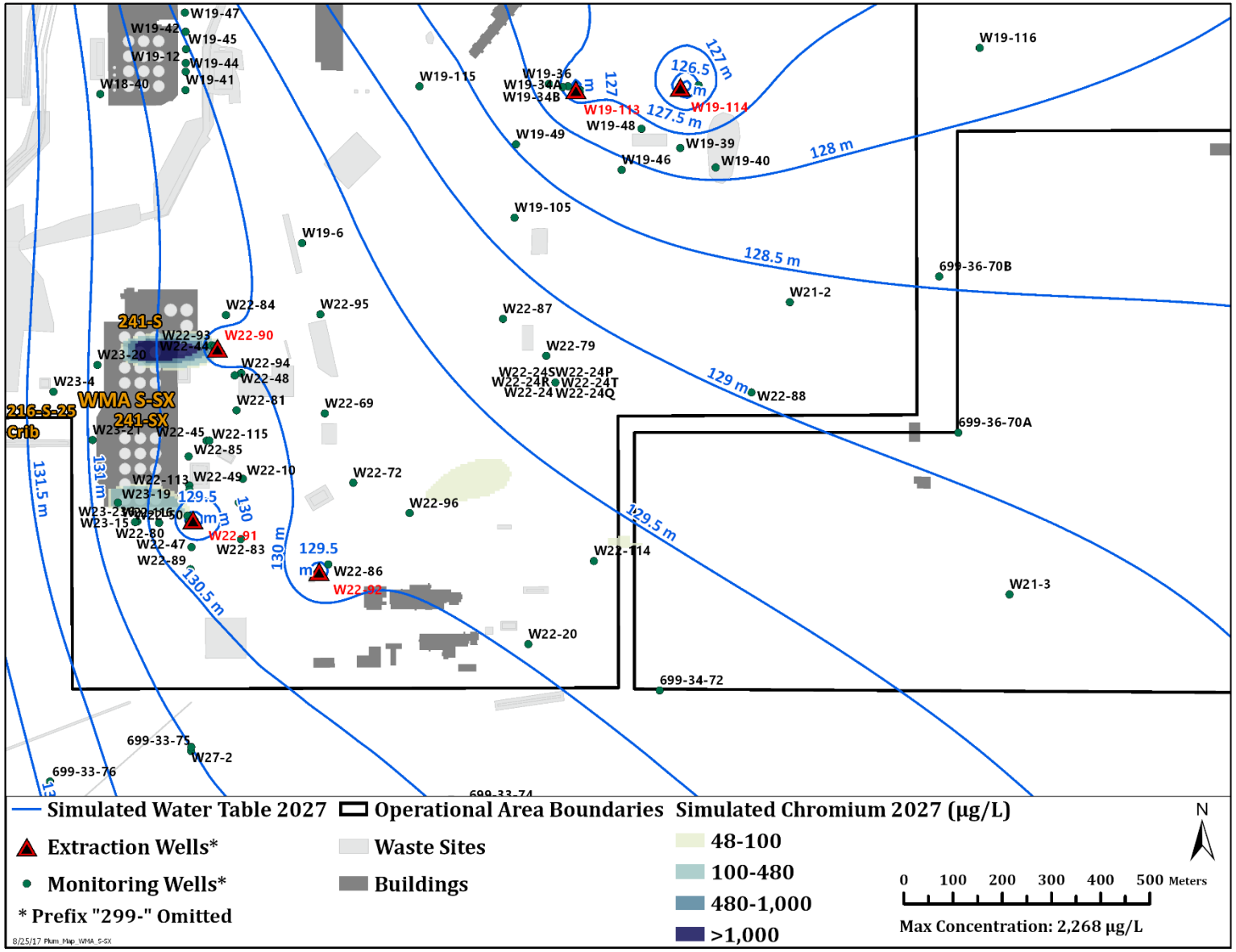


Figure 15. Simulated Chromium Plumes for Year 15 (2027) With Ongoing Sources

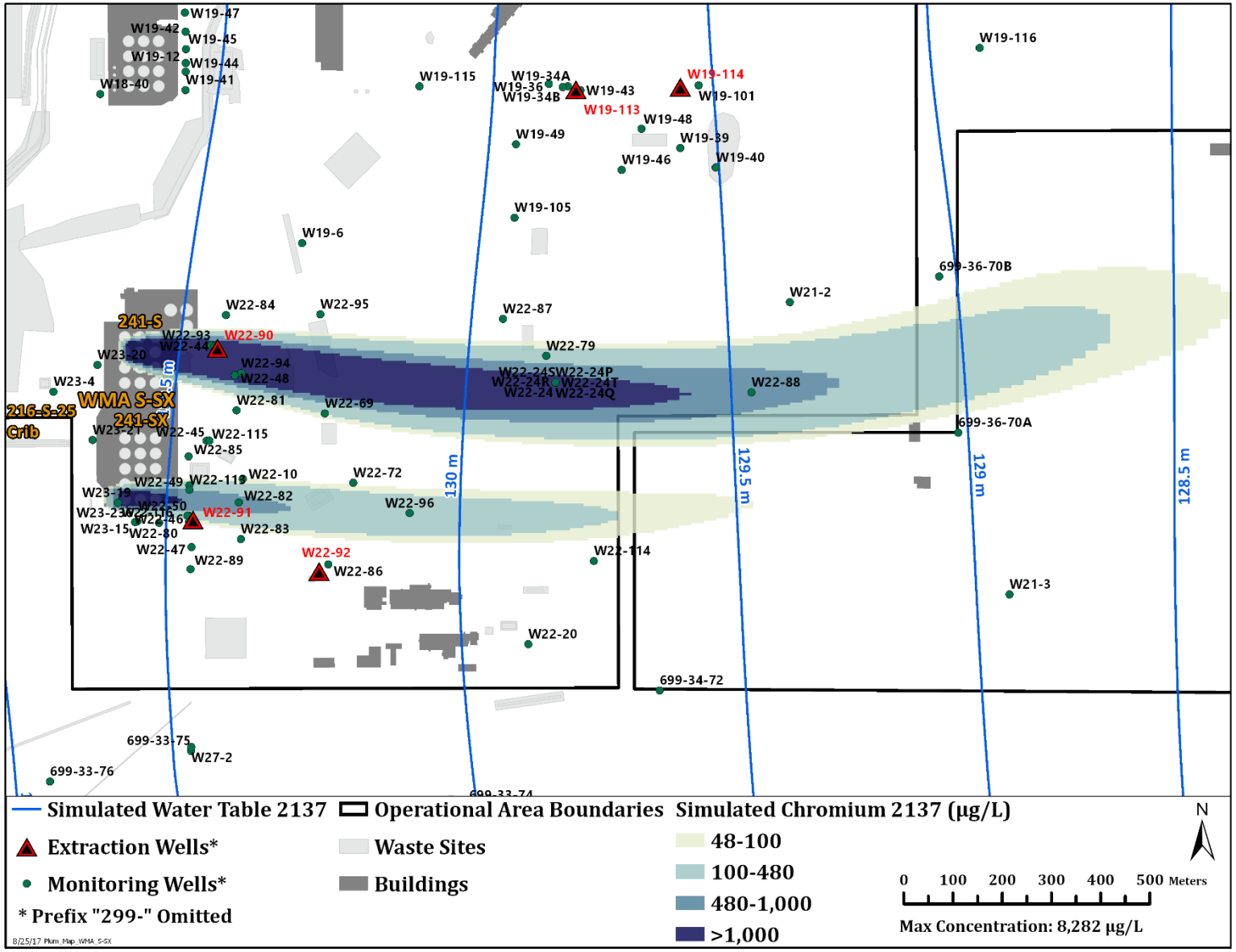


Figure 16. Simulated Chromium Plumes for Year 126 (2137) With Ongoing Sources

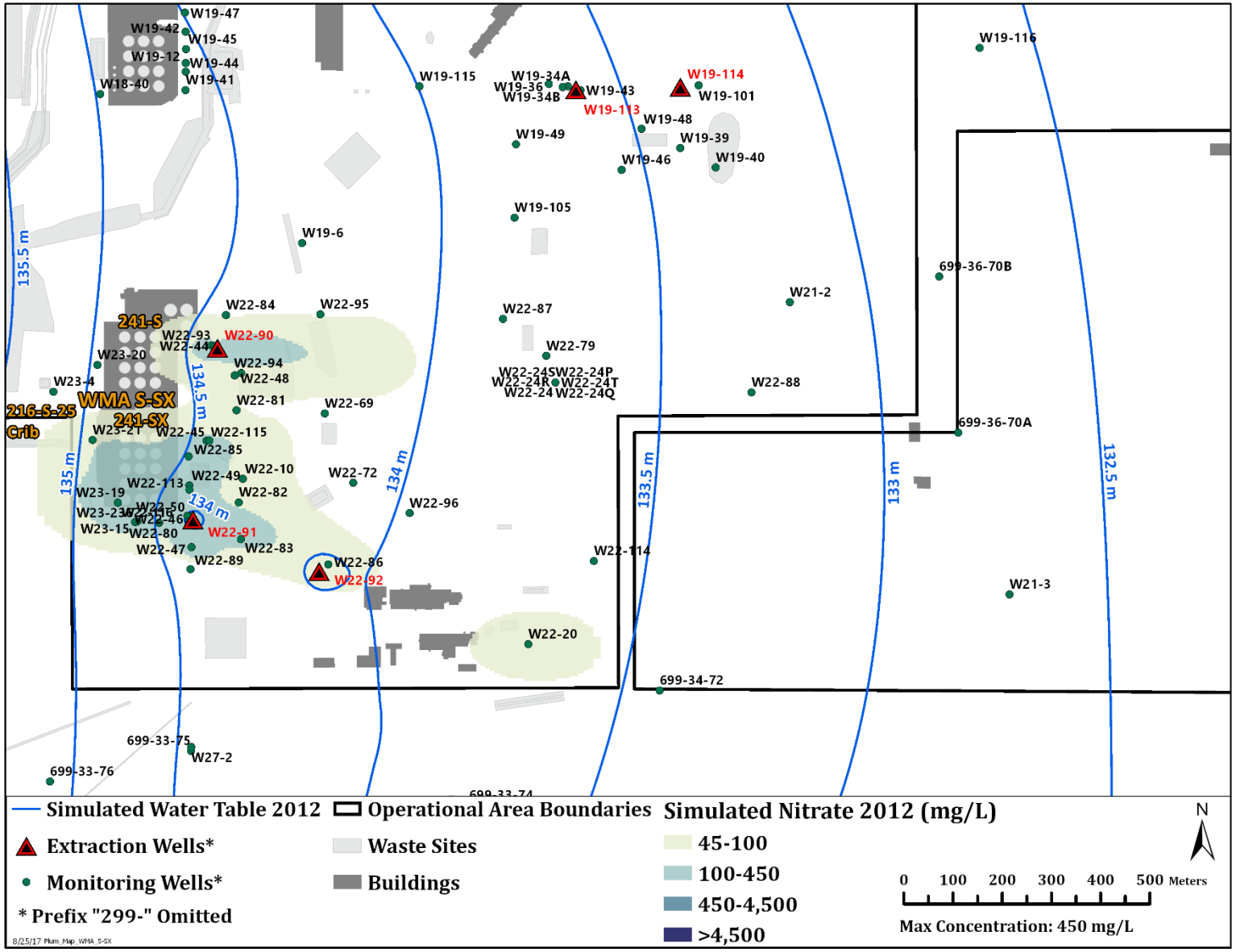


Figure 17. Simulated Nitrate Plumes for Year 1 (2012) Without Ongoing Sources

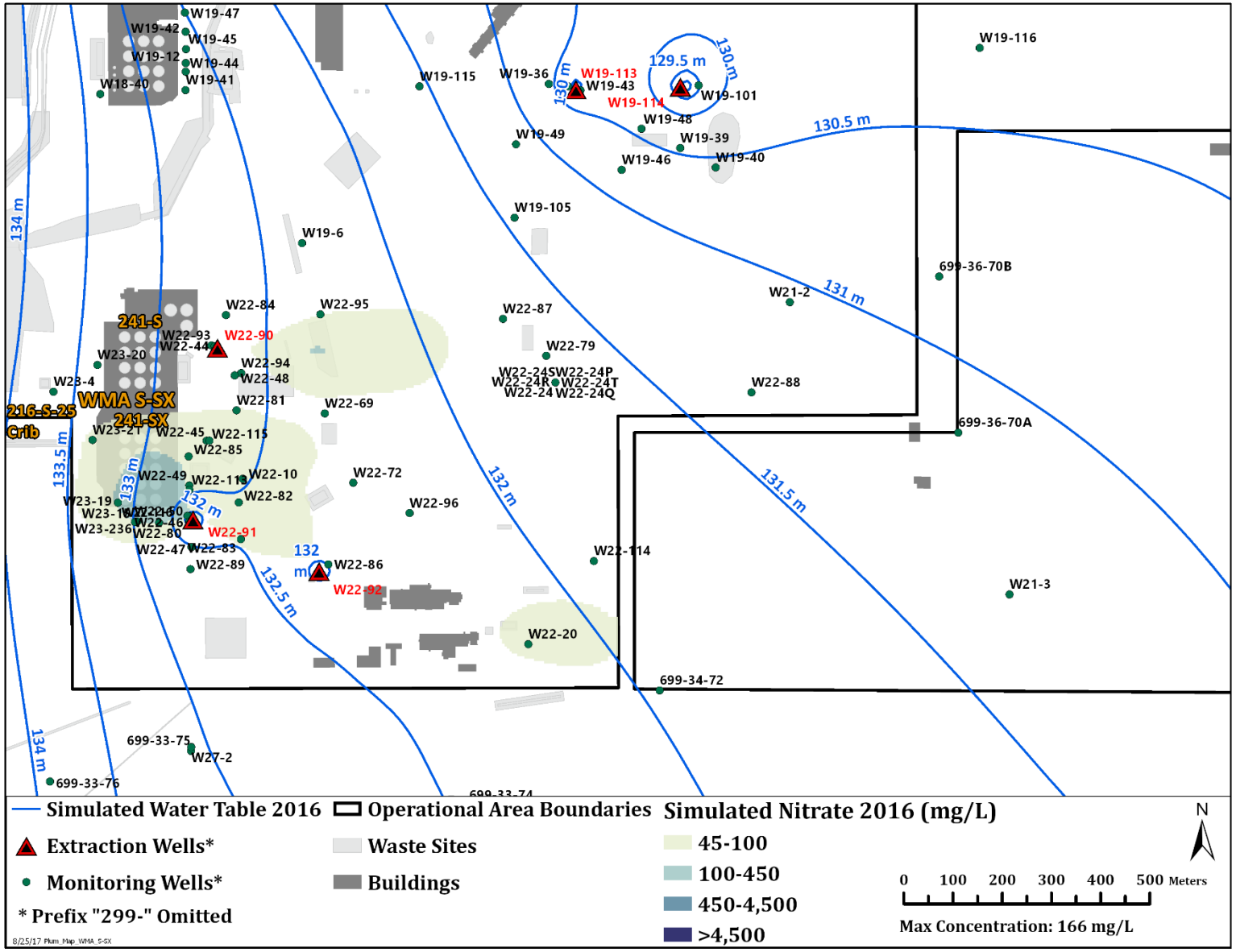


Figure 18. Simulated Nitrate Plumes for Year 5 (2016) Without Ongoing Sources

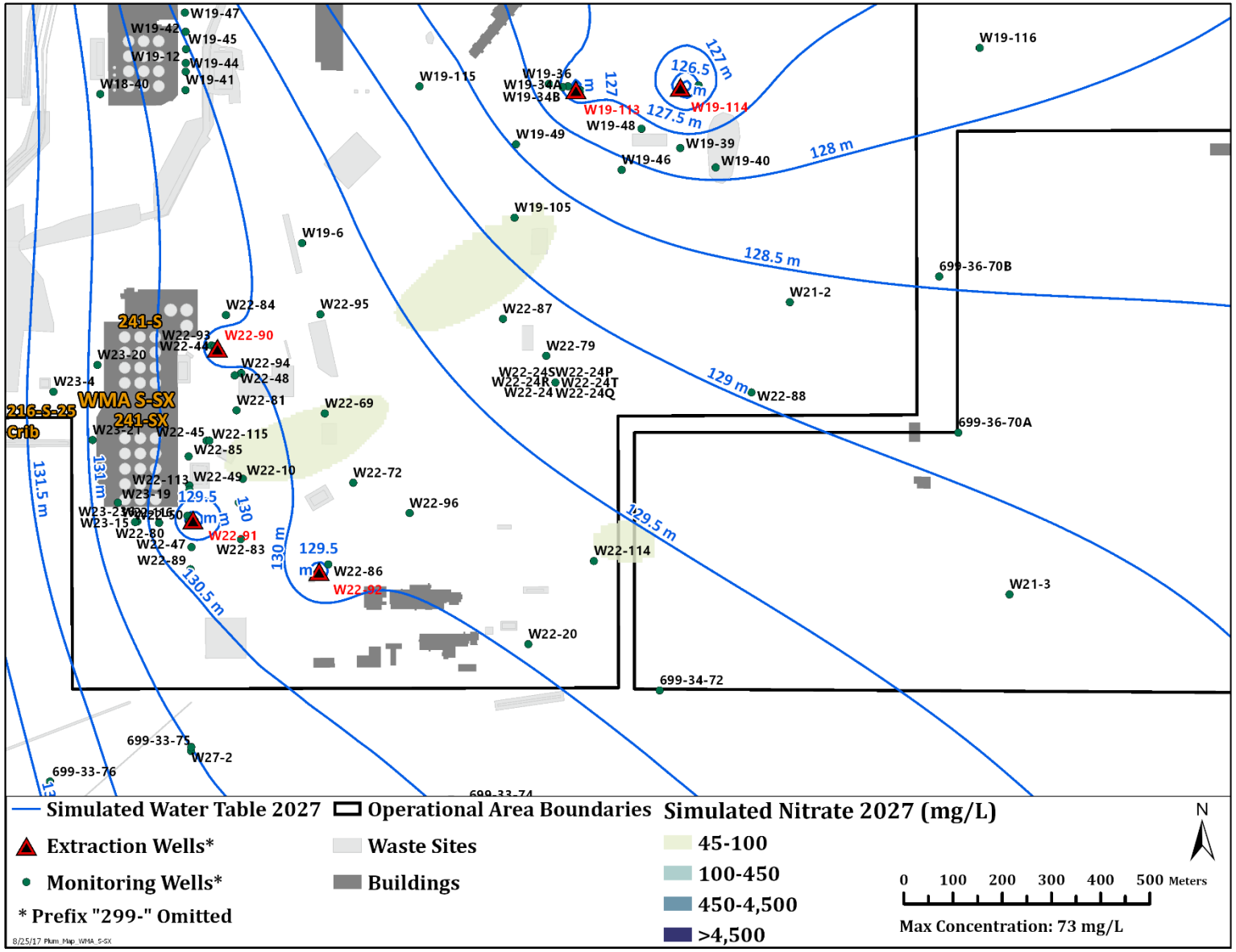


Figure 19. Simulated Nitrate Plumes for Year 15 (2027) Without Ongoing Sources

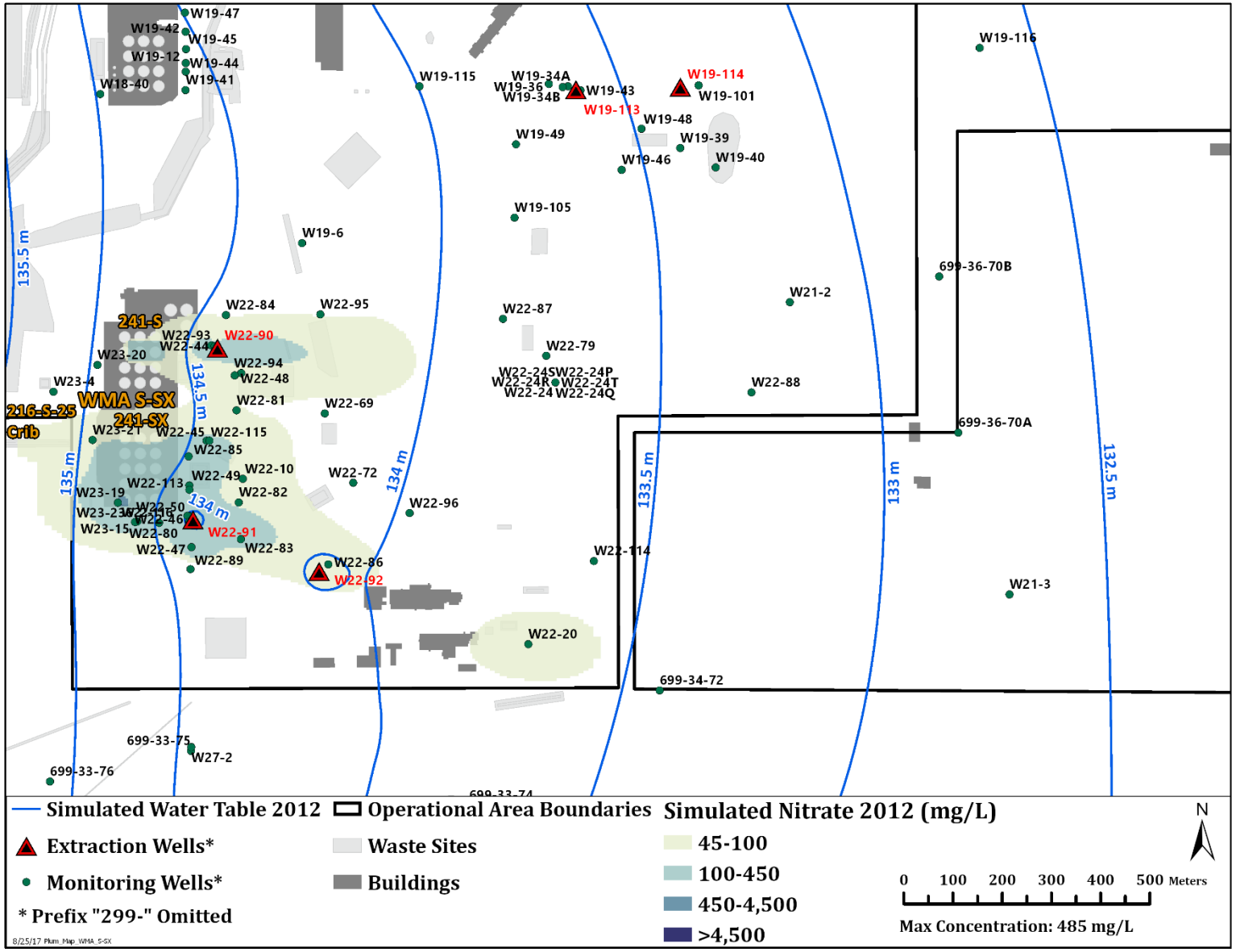


Figure 20. Simulated Nitrate Plumes for Year 1 (2012) With Ongoing Sources

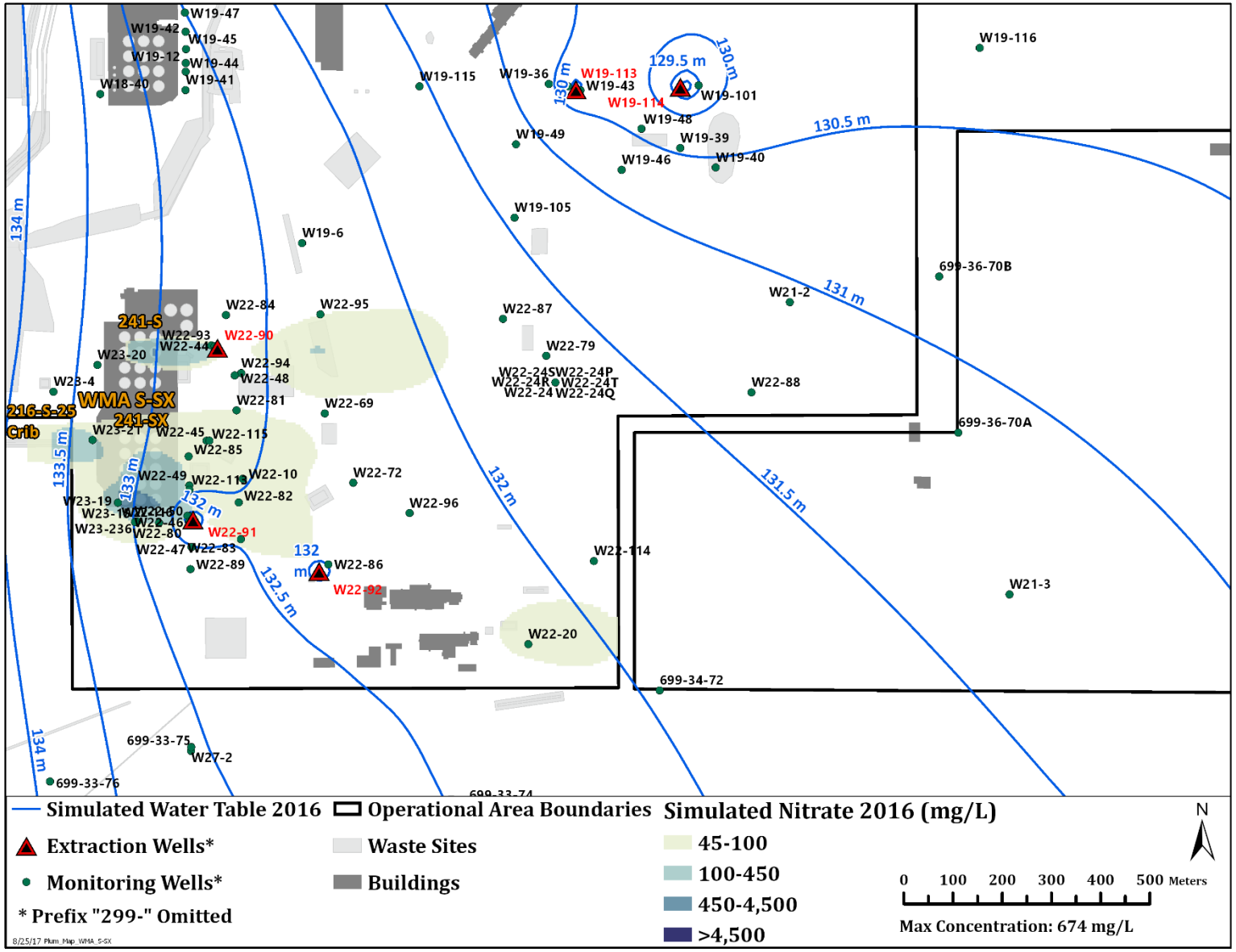


Figure 21. Simulated Nitrate Plumes for Year 5 (2016) With Ongoing Sources

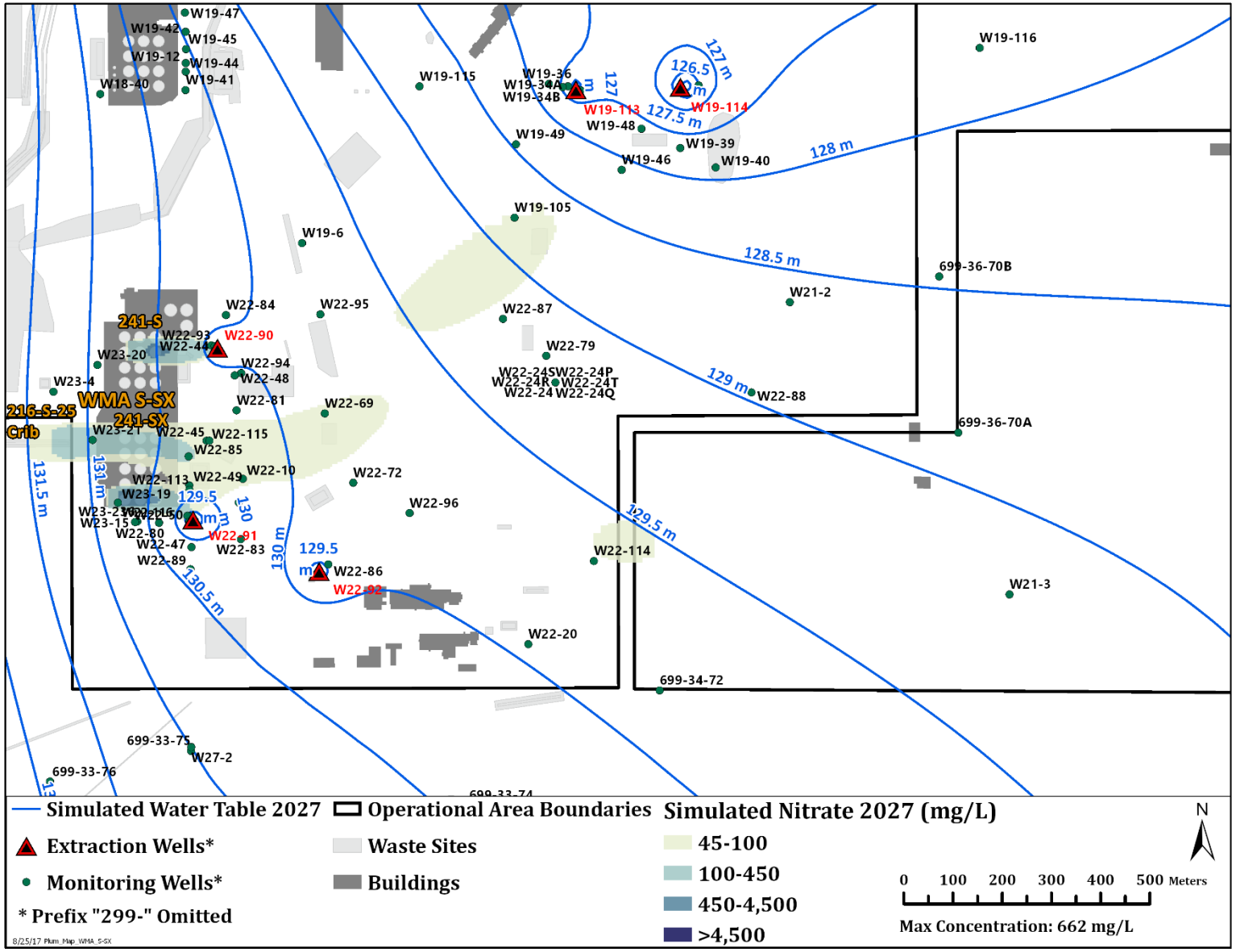


Figure 22. Simulated Nitrate Plumes for Year 15 (2027) With Ongoing Sources

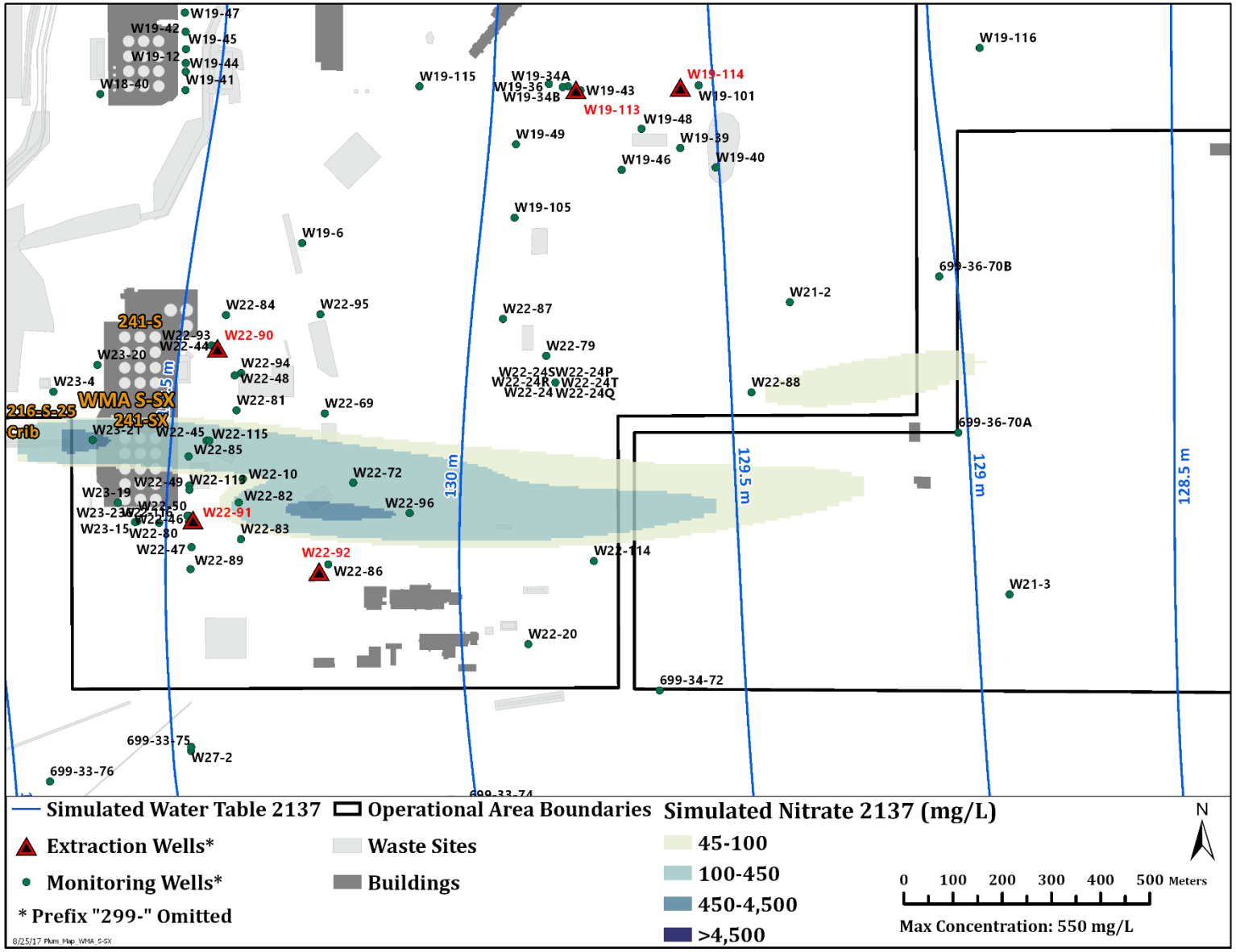


Figure 23. Simulated Nitrate Plumes for Year 126 (2137) With Ongoing Sources

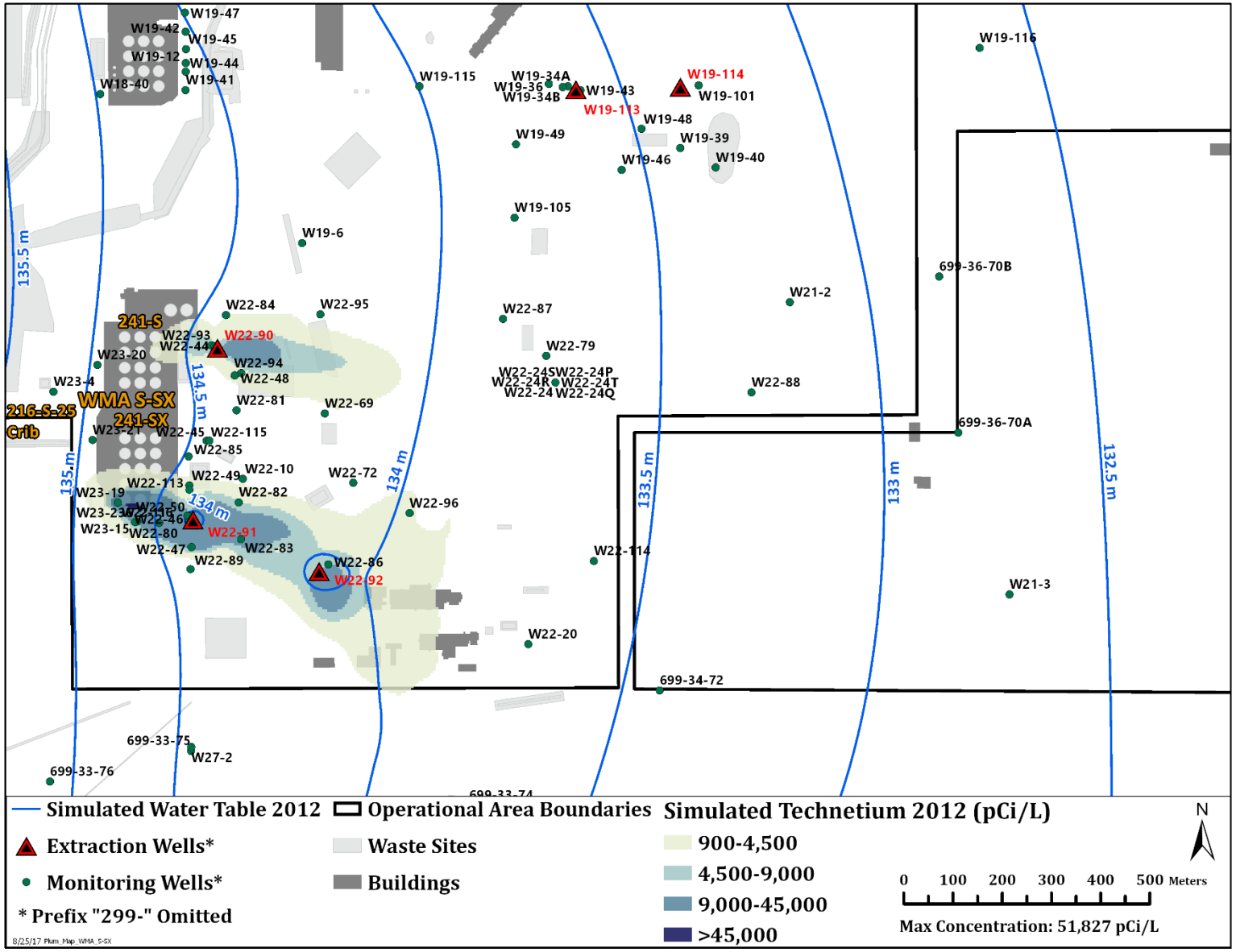


Figure 24. Simulated Technetium-99 Plumes for Year 1 (2012) Without Ongoing Sources

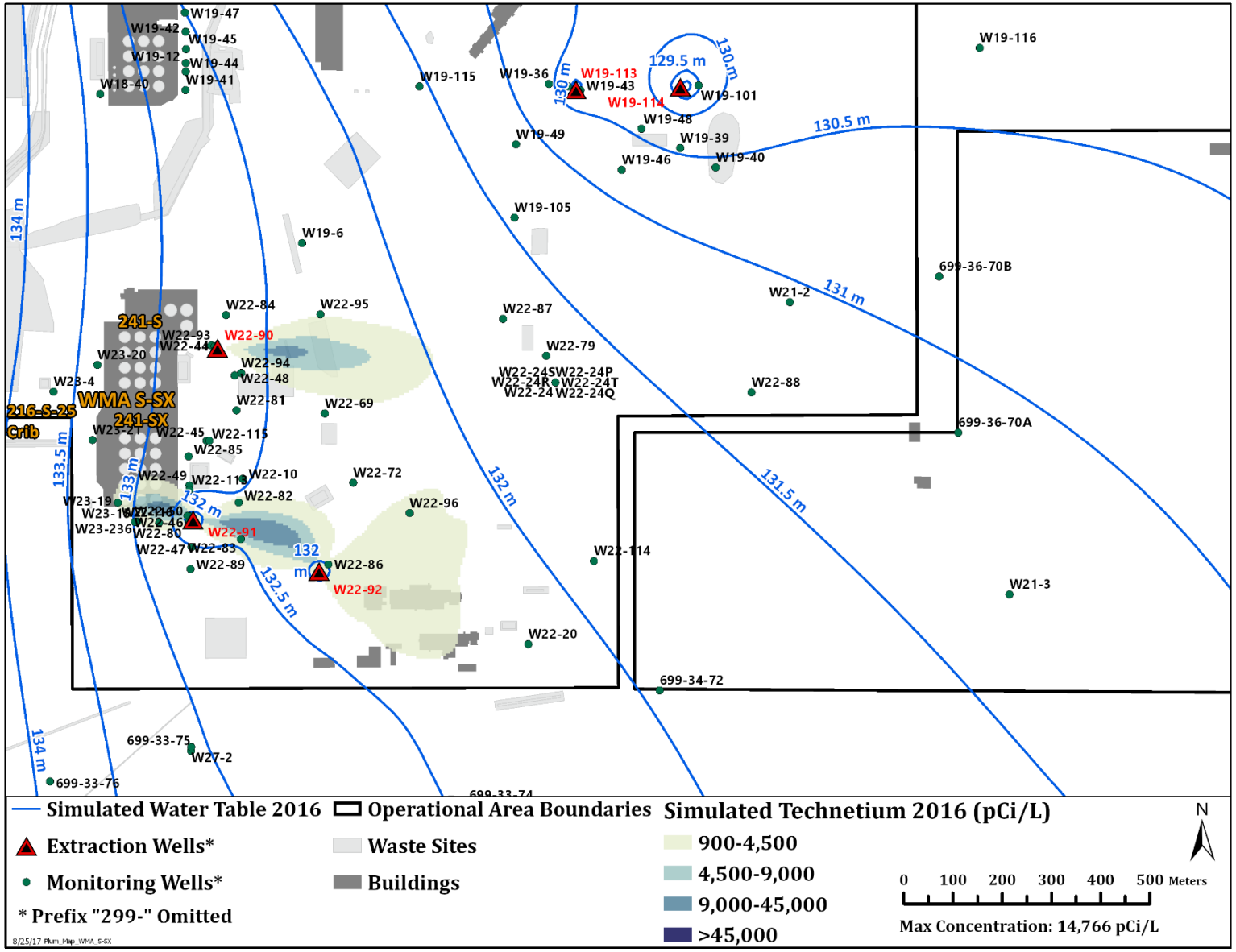


Figure 25. Simulated Technetium-99 Plumes for Year 5 (2016) Without Ongoing Sources

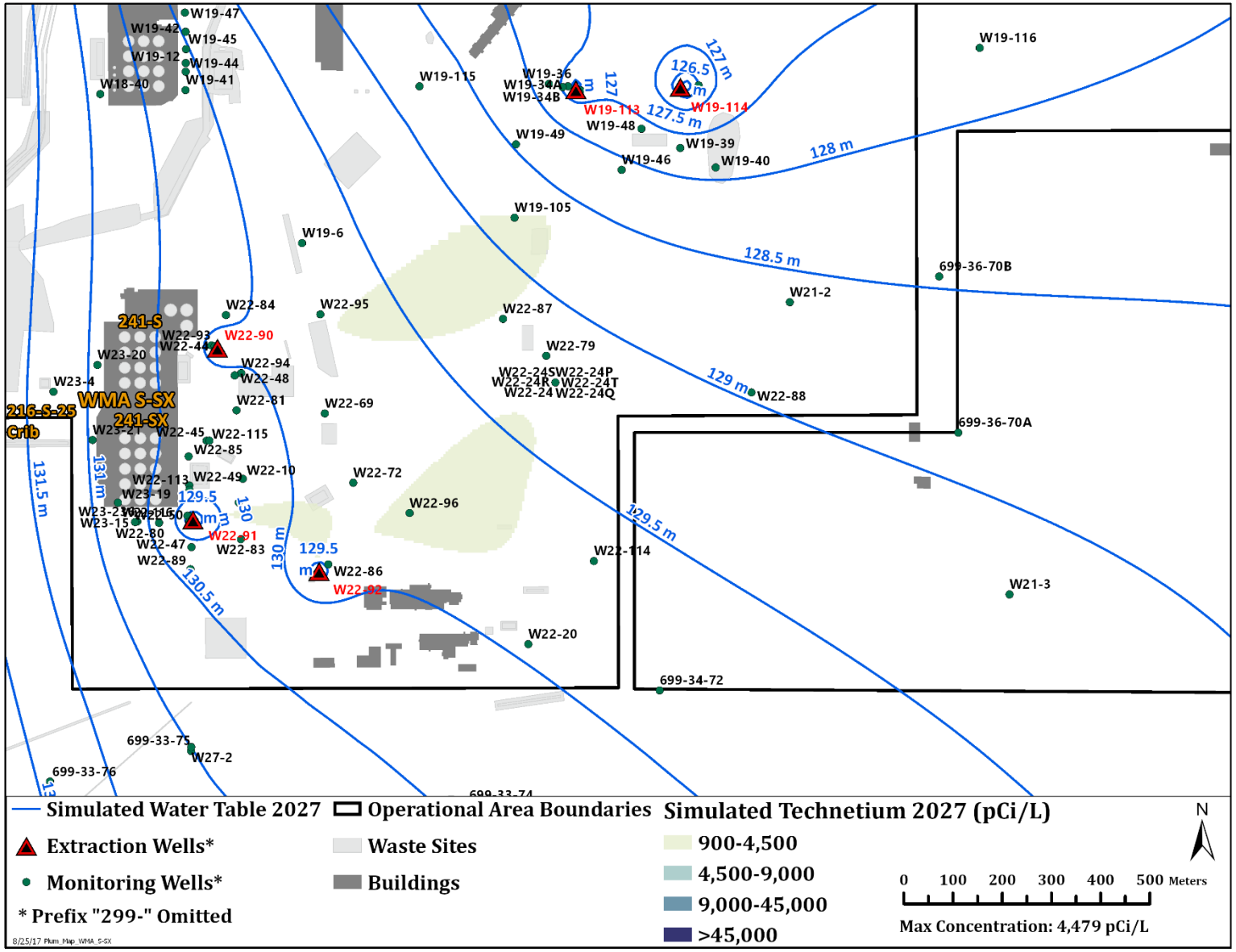


Figure 26. Simulated Technetium-99 Plumes for Year 15 (2027) Without Ongoing Sources

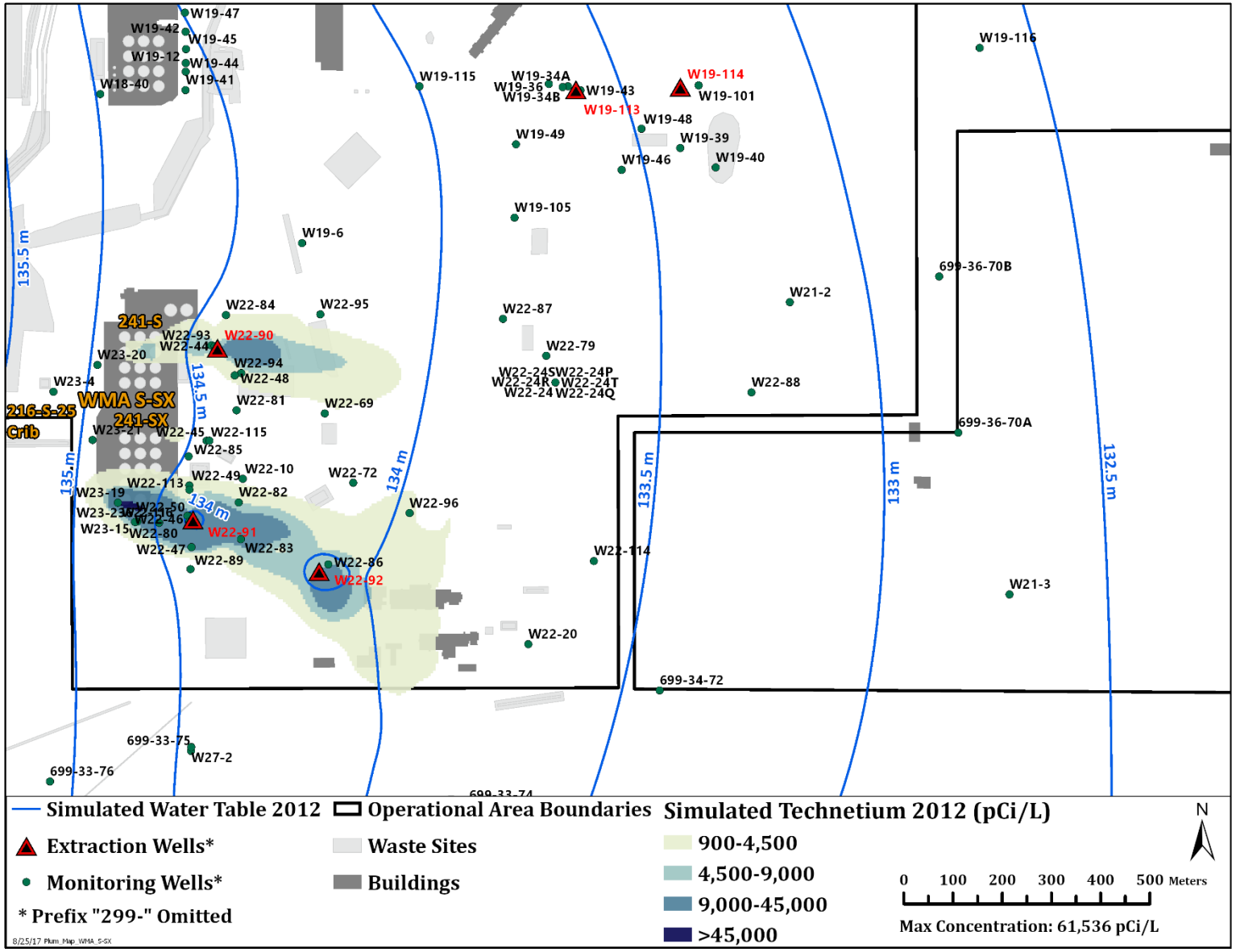


Figure 27. Simulated Technetium-99 Plumes for Year 1 (2012) With Ongoing Sources

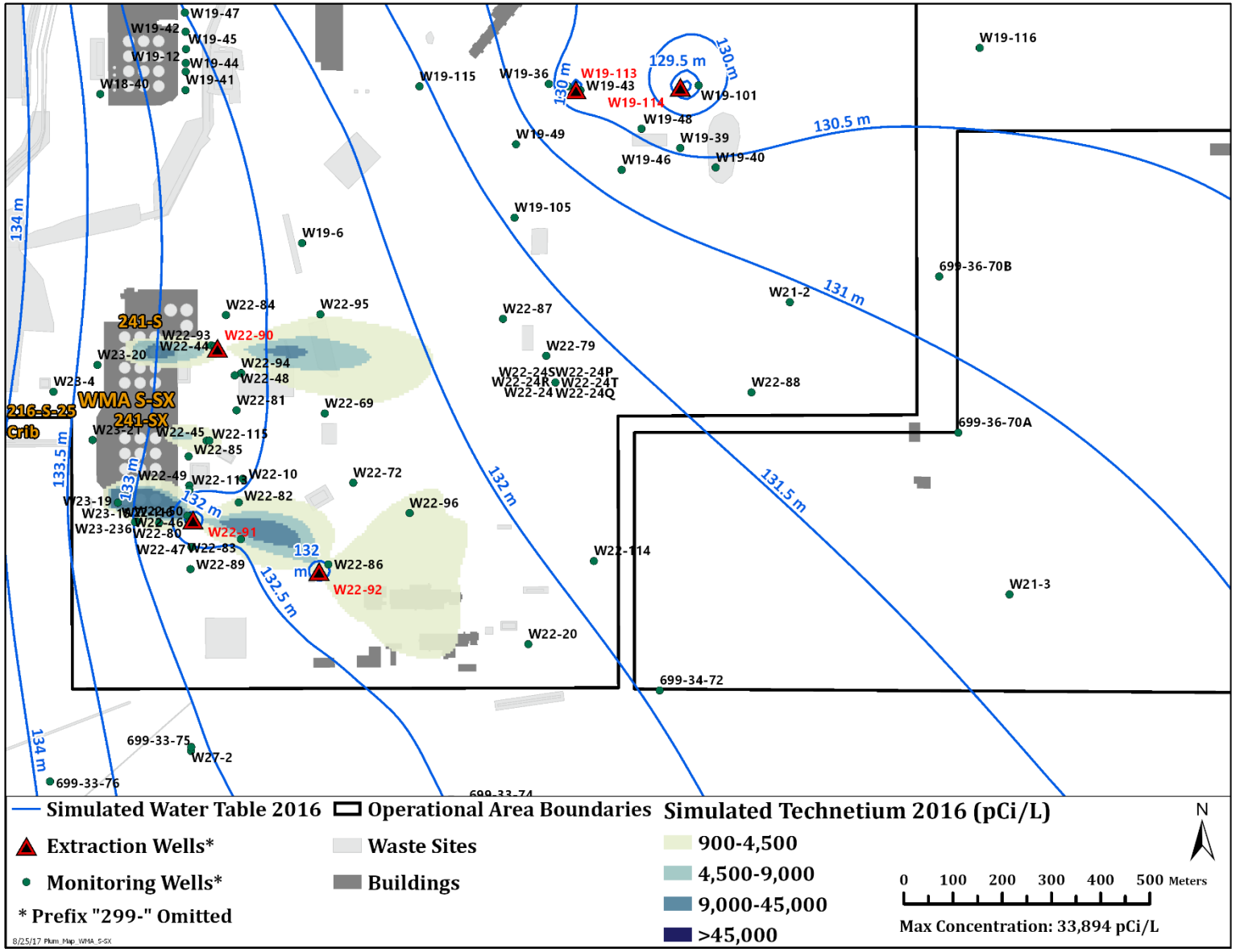


Figure 28. Simulated Technetium-99 Plumes for Year 5 (2016) With Ongoing Sources

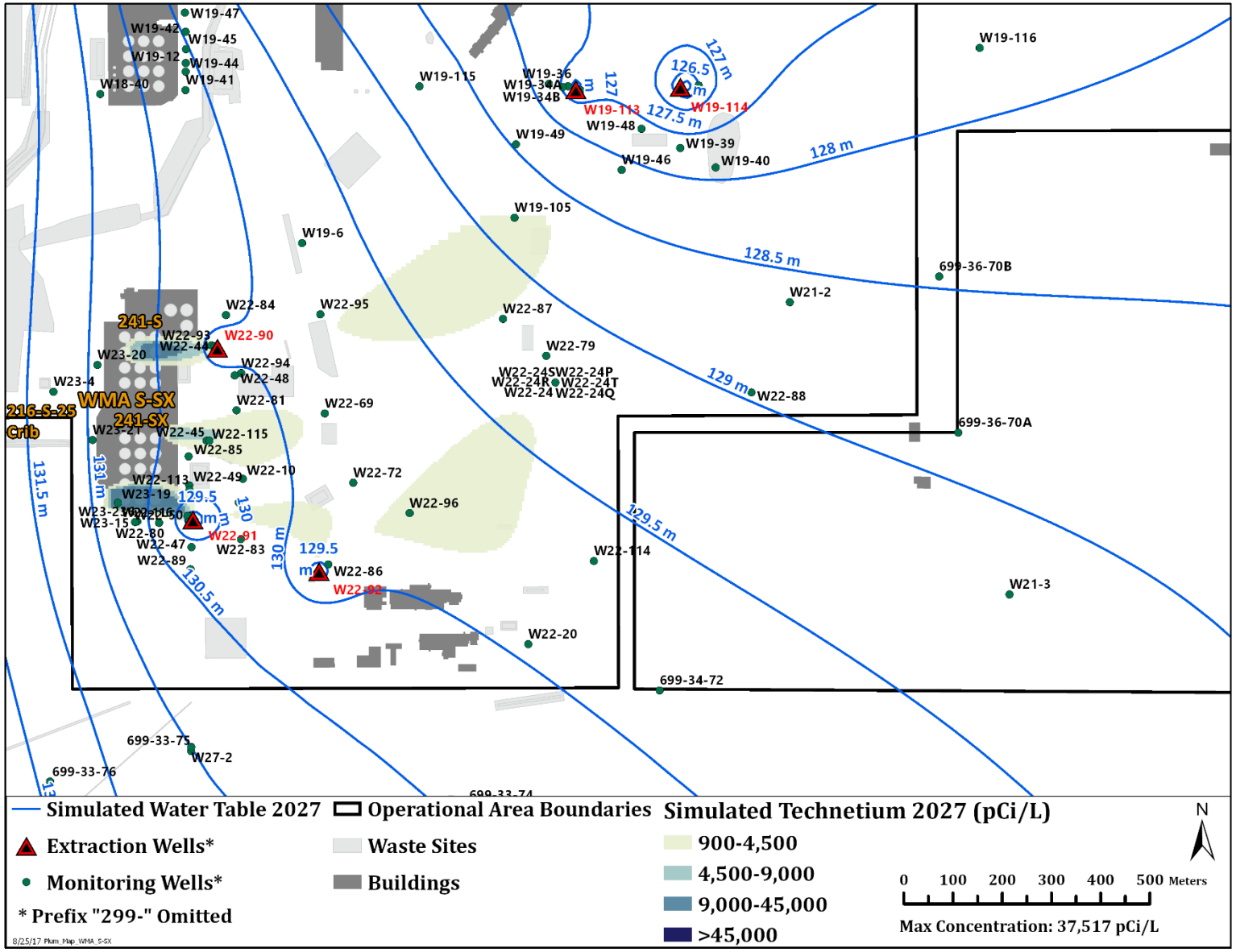


Figure 29. Simulated Technetium-99 Plumes for Year 15 (2027) With Ongoing Sources

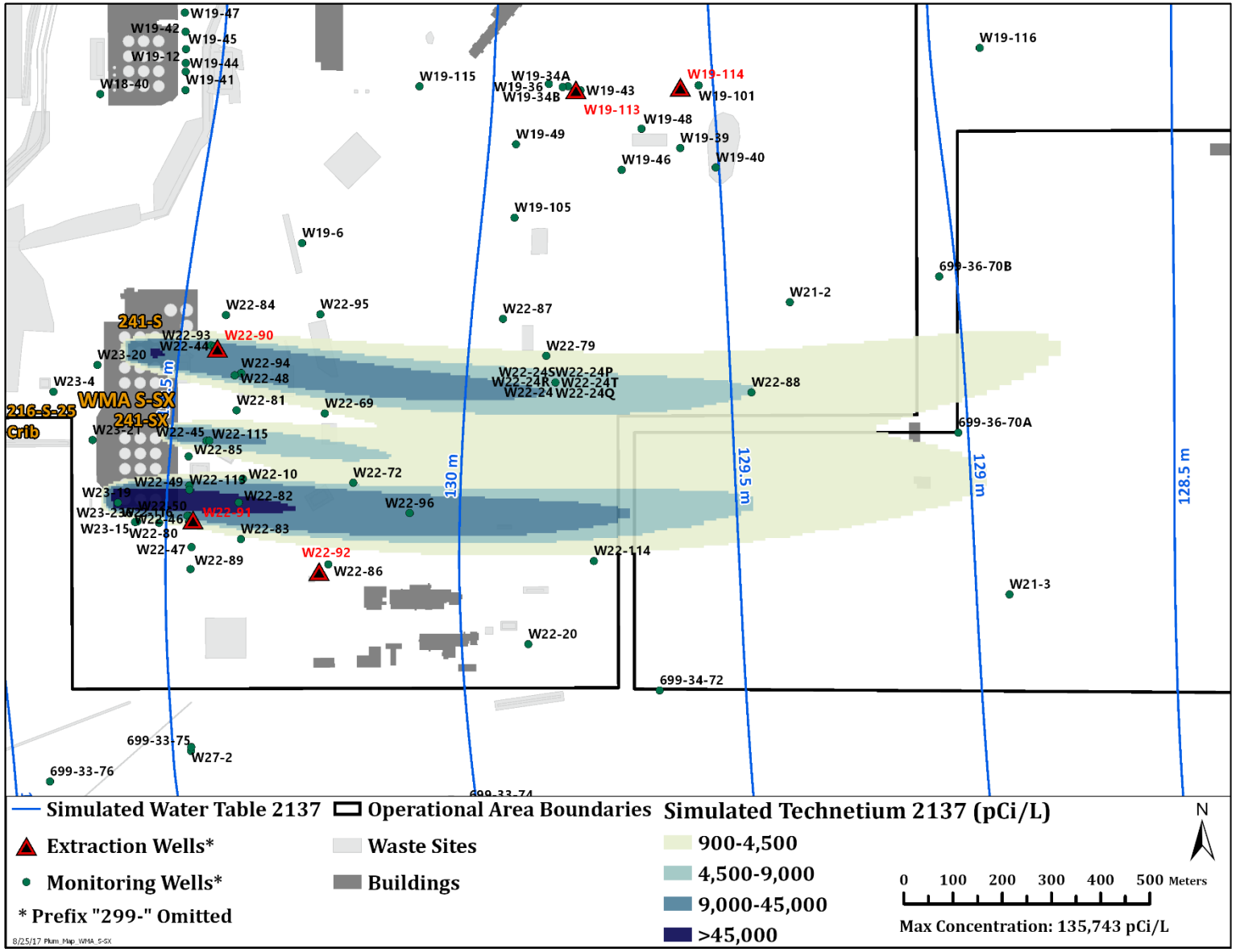


Figure 30. Simulated Technetium-99 Plumes for Year 126 (2137) With Ongoing Sources

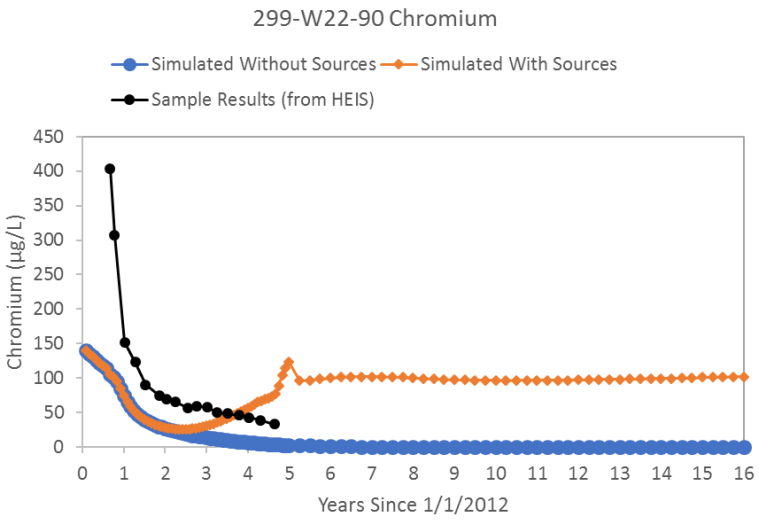
6.2.4 Extraction Well Concentrations, Mass Recovery and System Optimization

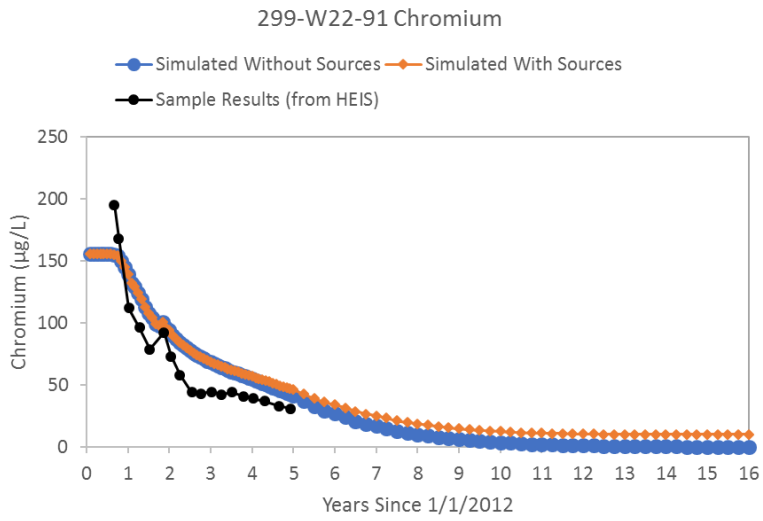
Simulated concentrations at the extraction wells during the 15-year pumping period, along with sample results for 2012 through 2016, are shown in Figure 31, Figure 32, and Figure 33 for chromium, nitrate, and technetium-99, respectively. Each figure shows simulated concentrations with and without sources. Concentrations initially show a rapid decline due to the startup of pumping. This is followed by tailing of concentrations near zero for the scenarios without sources or at a higher concentration in the cases with sources. The concentrations approach zero at 299-W22-92 in both cases because this well is downgradient from extraction well 299-W22-91 which fully contains the plume formed by the 241-SX Tank Farm source. The very good agreement between the simulated concentrations and sample results for technetium-99 (Figure 33) is due to the adjustment of the technetium-99 initial concentrations.

The simulated extraction well concentrations were used to calculate the cumulative mass (or activity for technetium-99) recovered by the extraction wells during the planned 15 years of pumping and are shown in Figure 34, Figure 35, and Figure 36 for chromium, nitrate, and technetium-99, respectively. The figures show simulated mass recovery for 15 years, actual recovery for 2012 through 2016, and the effect of system optimization performed using SCE as described in Section 2.2. Values for actual recovery were obtained from the pump and treat system reports (DOE/RL-2013-14, *Calendar Year 2012 Annual Summary Report for the 200-ZP-1 and 200-UP-1 Operable Unit Pump-and-Treat Operations*; DOE/RL-2014-26, *Calendar Year 2013 Annual Summary Report for the 200-ZP-1 and 200-UP-1 Operable Unit Pump-and-Treat Operations*; 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*).

There is good agreement for all three constituents between simulated and actual mass recovery for the first five years of system operation. The effect of the sources becomes apparent in the simulated mass recovery curves between approximately years 5 (2016) and 7 (2018) where the mass recovered in the cases with sources becomes greater than the cases without sources.

System optimization was performed for technetium-99 for the case without sources. Recovery of technetium-99 with the optimized flow rates is nearly identical to recovery with the baseline flow rates. In the case without sources, an additional 0.01 Ci is recovered over 15 years with the optimized flow rates. However, in the case with sources, 0.01 Ci less is recovered. For chromium and nitrate, the optimized flow rates lead to slightly less total mass recovery. This indicates that the system as currently operating is already well optimized.





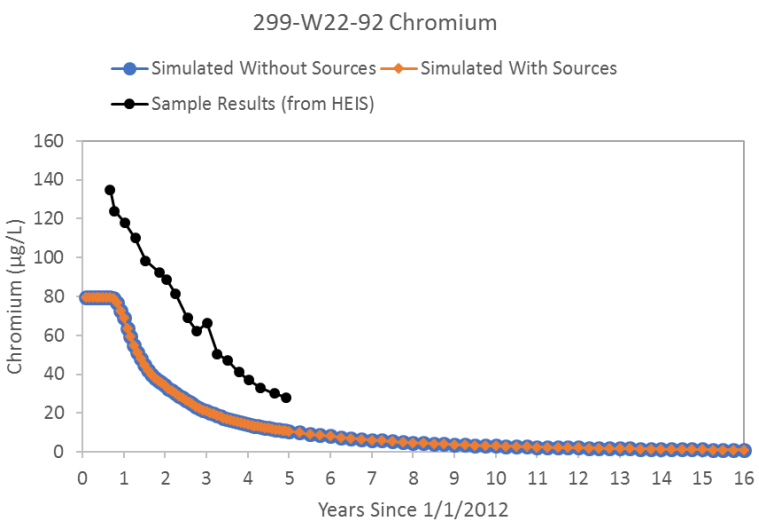


Figure 31. Extraction Well Chromium Concentrations

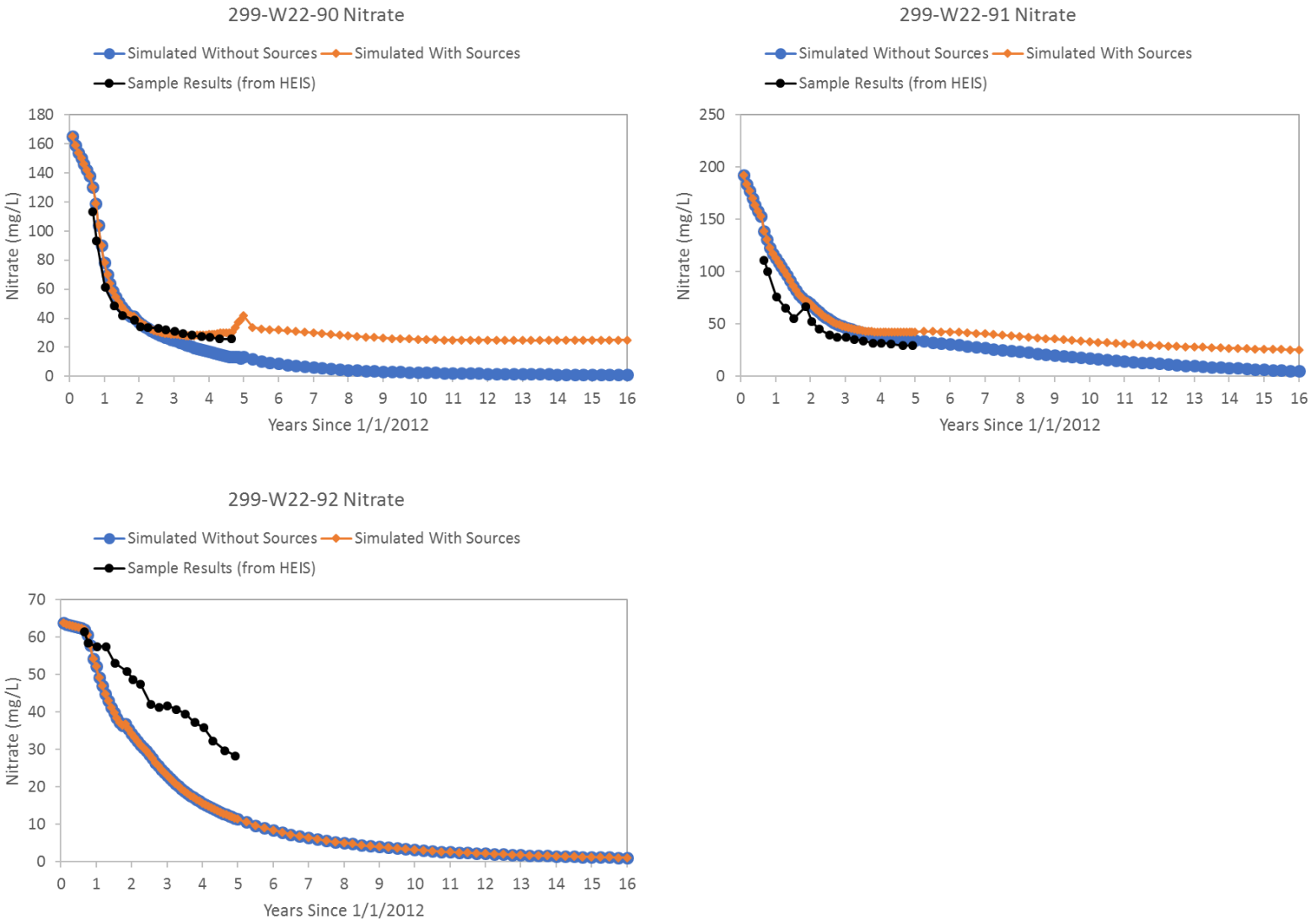


Figure 32. Extraction Well Nitrate Concentrations

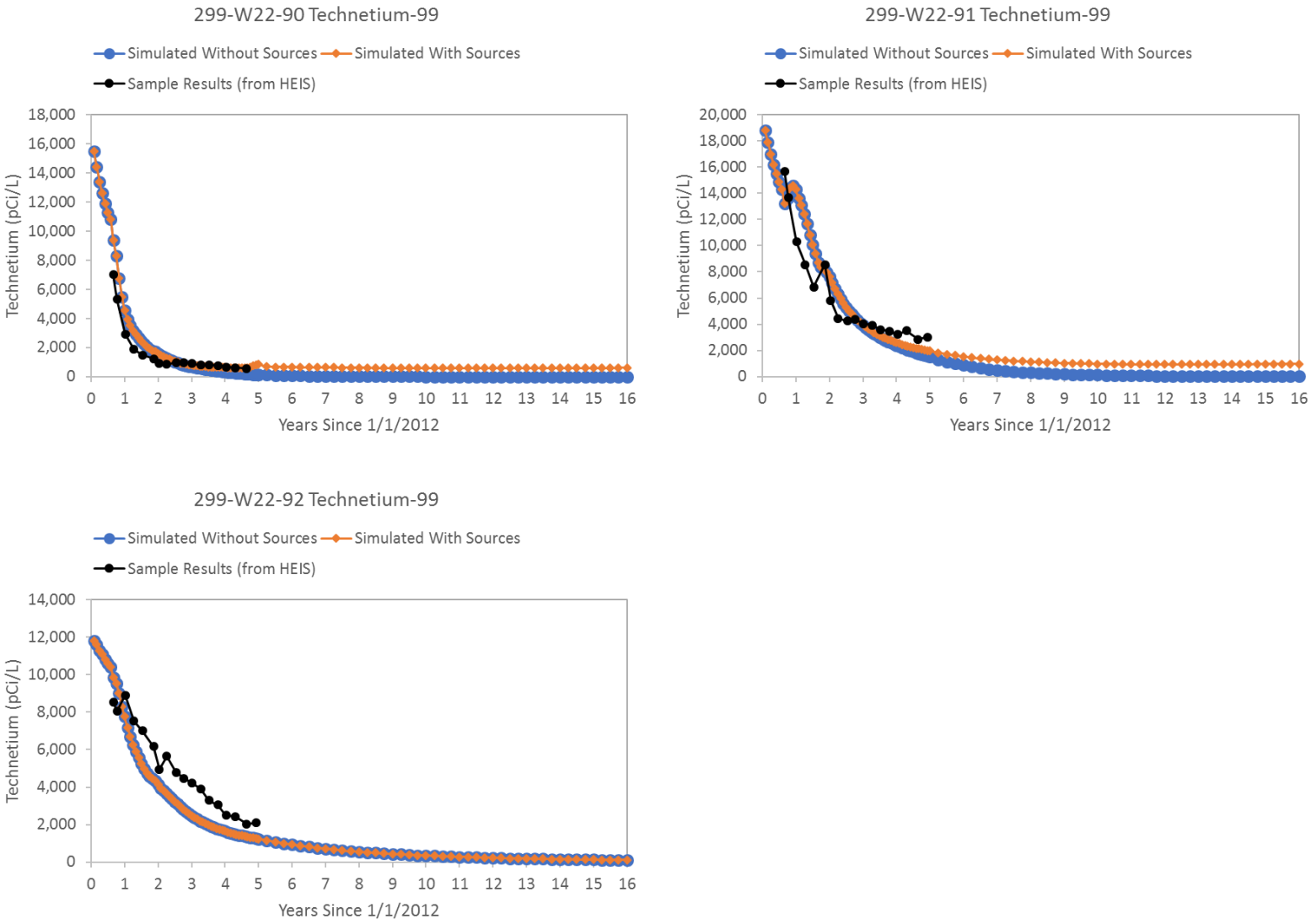


Figure 33. Extraction Well Technetium-99 Concentrations

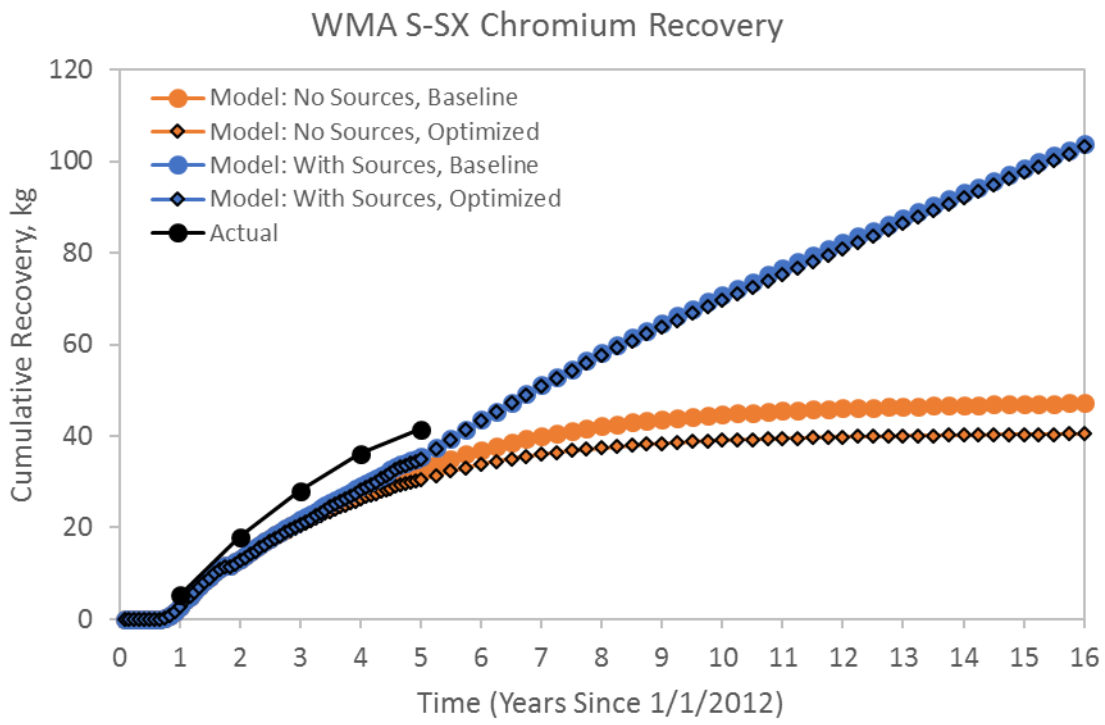


Figure 34. Simulated and Actual Cumulative Mass of Chromium Recovered by the Extraction Wells

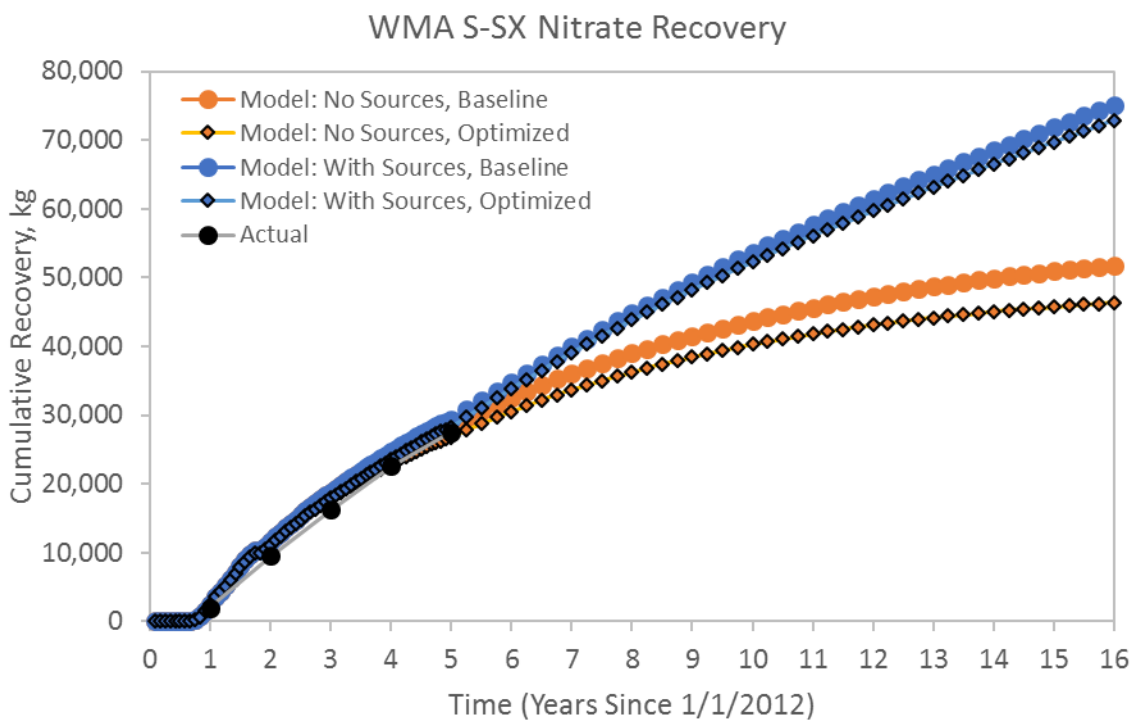


Figure 35. Simulated and Actual Cumulative Mass of Nitrate Recovered by the Extraction Wells

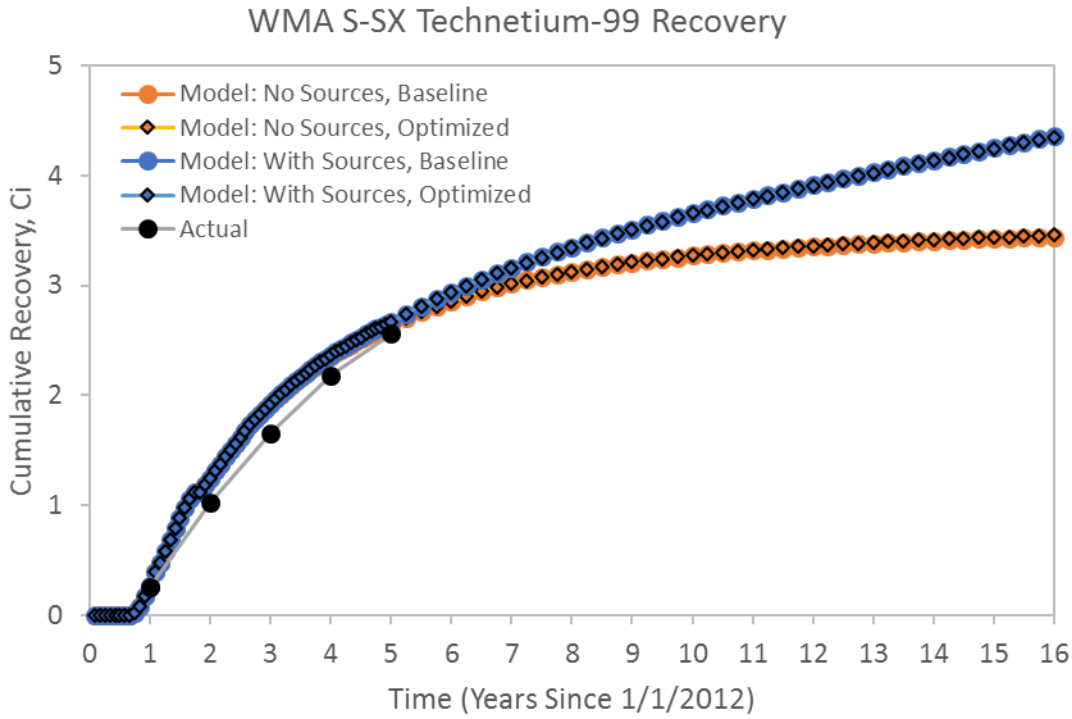


Figure 36. Simulated and Actual Cumulative Activity of Technetium-99 Recovered by the Extraction Wells

6.2.5 Simulated UCL95s

This section presents the UCL95s for the model simulation results. The well network used for the calculations is shown in Figure 37. This network includes wells identified in DOE/RL-2014-15 for UCL95 calculations, as well as additional existing wells and synthetic wells identified to provide coverage in areas where the plumes are predicted to migrate in the future.

The WMA S-SX groundwater extraction system was designed to remediate the technetium-99 plumes already in groundwater (i.e., with the assumption that there are no ongoing sources of contamination to the aquifer) (DOE/RL-2013-07, *200-UP-1 Groundwater Operable Unit Remedial Design/Remedial Action Work Plan*). The UCL95s for the model results with this assumption are shown in Figure 38. The UCL95s for chromium and nitrate are predicted to decline to below their respective cleanup levels (48 µg/L for chromium and 45 mg/L for nitrate) during the 15-year active remedy period (chromium in year 8 [2019] and nitrate in year 13 [2024]). The chromium UCL95 temporarily increases to above the cleanup level between years 13 (2024) and 16 (2027) as the plume sections not captured by the extraction wells reach monitoring wells that were added to the UCL95 calculation. The technetium-99 UCL95 does not decline to below its 900 pCi/L cleanup level during the active remedy phase, but does so later by year 27 (2038) as the plume sections not captured disperse.

Although the UCL95s shown in Figure 38 indicate the WMA S-SX groundwater extraction system is meeting its design objective, it is known that there are ongoing sources of contamination to the aquifer that will affect remedy performance. When the ongoing sources of contamination are included in the model simulations, the UCL95s for all three constituents do not decline below their cleanup levels either during the active remedy phase or afterwards (Figure 39). Initially, the UCL95s decline in response to pumping, but they stabilize in about years 9 (2020) or 10 (2021) as concentrations in wells upgradient of the extraction wells remain elevated due to the sources. The UCL95s increase after the active remedy

phase as the plumes reform (see Figure 16, Figure 23, and Figure 30 for chromium, nitrate, and technetium-99, respectively). The nitrate UCL95 does start to decline after year 76 (2087) because the nitrate source at 241-S ends after 30 years and the source at 241-SX ends after 75 years.

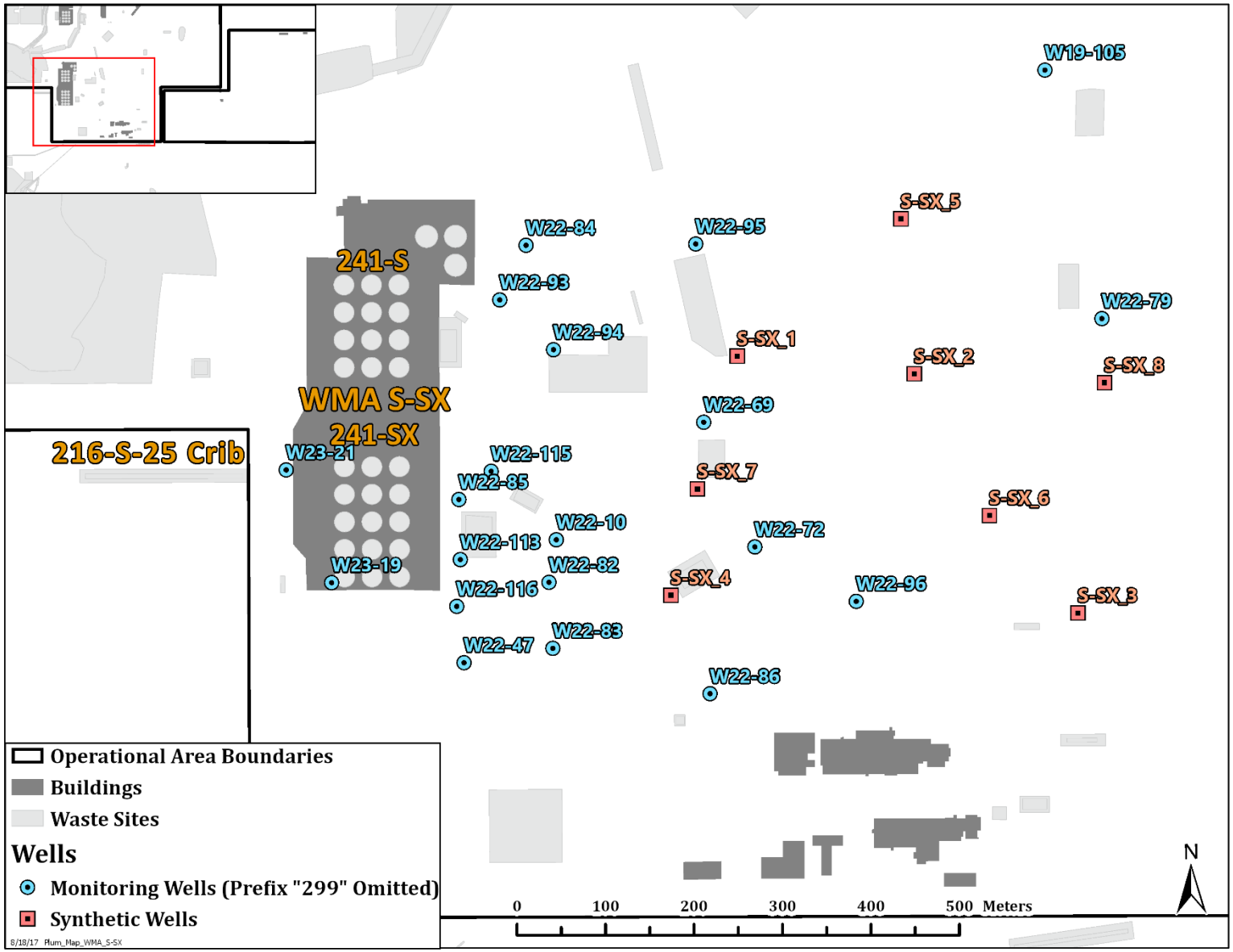


Figure 37. Well Network for UCL95 Calculations

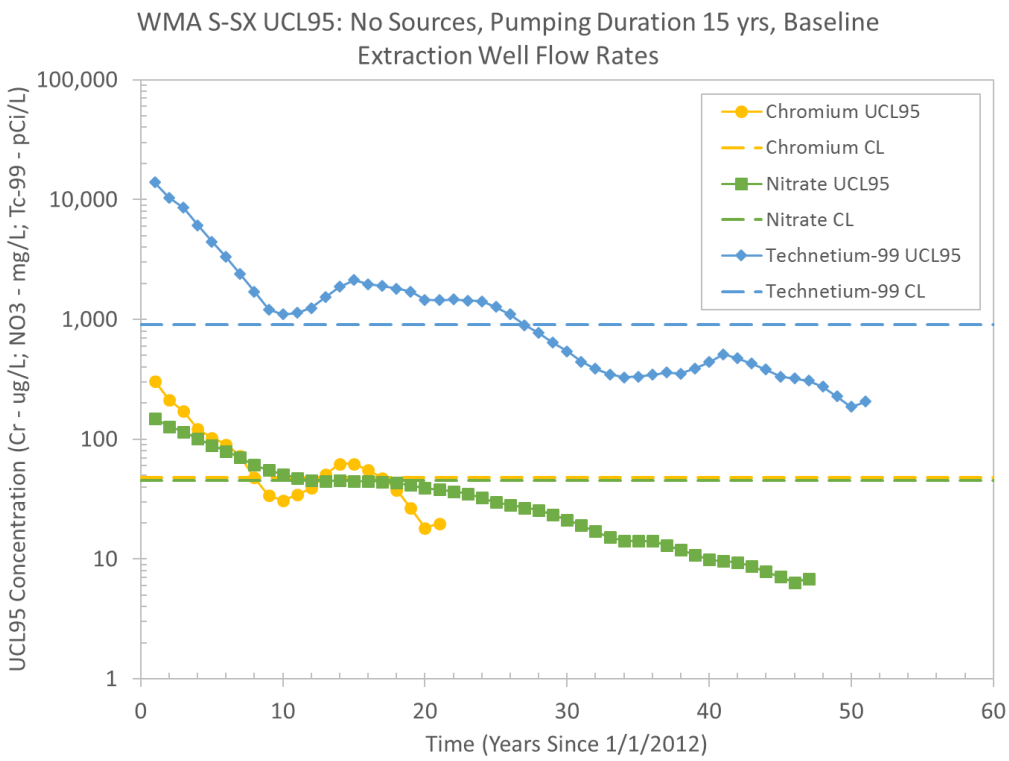


Figure 38. Simulated UCL95s for Cases without Ongoing Sources

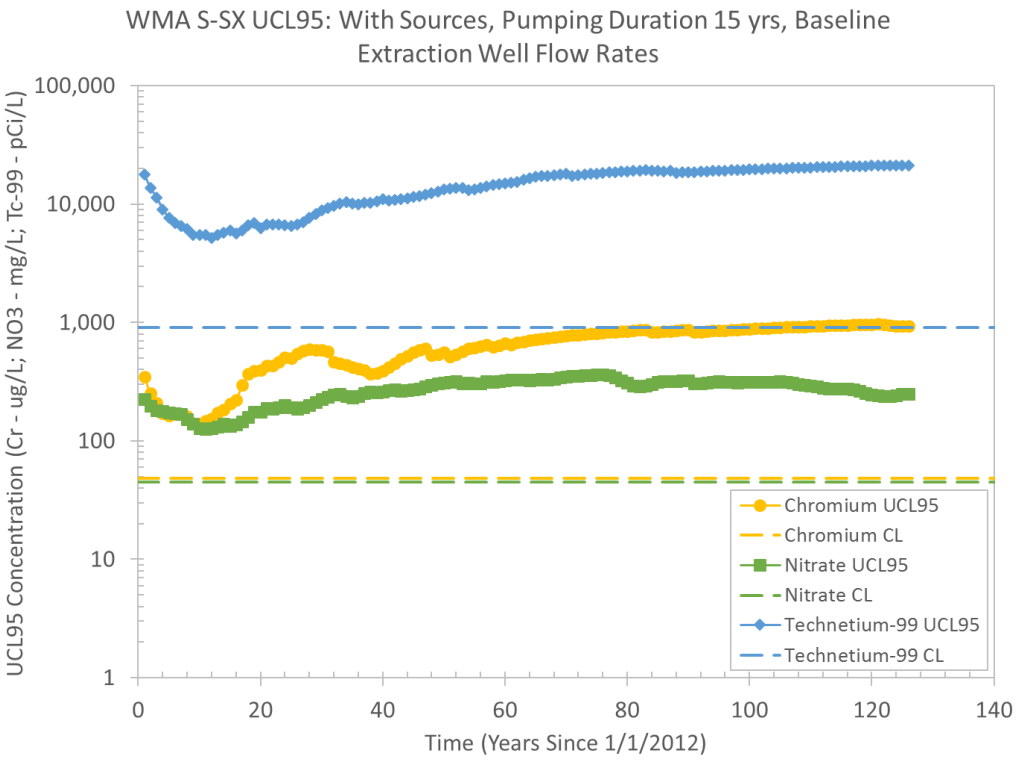


Figure 39. Simulated UCL95s for Cases with Ongoing Sources

6.3 Conclusions

The following are the key findings of the transport modeling performed to evaluate the WMA S-SX groundwater extraction system:

1. The model simulations show that the WMA S-SX groundwater extraction system is operating as designed. The system was designed to remediate the technetium-99 plumes already in groundwater, and the simulations without ongoing sources show that technetium-99 disperses to below the cleanup level within the 125-year cleanup timeframe for the CP. In addition, chromium and nitrate also disperse to below the cleanup level within 125 years.

2. Although the system is operating as designed, it is known that there are ongoing sources of contamination to the aquifer. Simulations that include approximations of these sources indicate that groundwater plumes of chromium, nitrate, and technetium-99 will reform after the active remedy period unless near-field extraction wells are operated to contain the plumes or the sources are otherwise mitigated. One of the sources, technetium-99 from the north part of the 241-SX Tank Farm, generates a plume from the start of the simulations because is not currently being captured by an extraction well. 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.

3. The portions of the chromium, nitrate, and technetium-99 plumes currently in groundwater and not captured by the extraction wells during the active remedy phase will disperse naturally to below cleanup levels within the 125-year cleanup timeframe.

4. The results of system optimization indicated that the system is already well optimized. Recovery of technetium-99 with the optimized flow rates is nearly identical to recovery with the baseline flow rates.

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Appendix A

Stress Periods in the WMA S-SX Local Scale Model

Table A-1 lists the stress periods in the WMA S-SX 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 A-1. Stress Periods in the WMA S-SX Local-Scale Model

Stress Period Number	Length (days)	Length (years)	Start Date	End Date (Inclusive)	Elapsed Days	Elapsed Years
1	31	0.08	1/1/2012	1/31/2012	31	0.08
2	29	0.08	2/1/2012	2/29/2012	60	0.16
3	31	0.08	3/1/2012	3/31/2012	91	0.25
4	30	0.08	4/1/2012	4/30/2012	121	0.33
5	31	0.08	5/1/2012	5/31/2012	152	0.42
6	30	0.08	6/1/2012	6/30/2012	182	0.50
7	31	0.08	7/1/2012	7/31/2012	213	0.58
8	31	0.08	8/1/2012	8/31/2012	244	0.67
9	30	0.08	9/1/2012	9/30/2012	274	0.75
10	31	0.08	10/1/2012	10/31/2012	305	0.83
11	30	0.08	11/1/2012	11/30/2012	335	0.91
12	31	0.08	12/1/2012	12/31/2012	366	1.00
13	31	0.08	1/1/2013	1/31/2013	397	1.08
14	28	0.08	2/1/2013	2/28/2013	425	1.16
15	31	0.08	3/1/2013	3/31/2013	456	1.25
16	30	0.08	4/1/2013	4/30/2013	486	1.33
17	31	0.08	5/1/2013	5/31/2013	517	1.42
18	30	0.08	6/1/2013	6/30/2013	547	1.50
19	31	0.08	7/1/2013	7/31/2013	578	1.58
20	31	0.08	8/1/2013	8/31/2013	609	1.67
21	30	0.08	9/1/2013	9/30/2013	639	1.75
22	31	0.08	10/1/2013	10/31/2013	670	1.83
23	30	0.08	11/1/2013	11/30/2013	700	1.91
24	31	0.08	12/1/2013	12/31/2013	731	2.00
25	31	0.08	1/1/2014	1/31/2014	762	2.08
26	28	0.08	2/1/2014	2/28/2014	790	2.16
27	31	0.08	3/1/2014	3/31/2014	821	2.25
28	30	0.08	4/1/2014	4/30/2014	851	2.33
29	31	0.08	5/1/2014	5/31/2014	882	2.42
30	30	0.08	6/1/2014	6/30/2014	912	2.50
31	31	0.08	7/1/2014	7/31/2014	943	2.58
32	31	0.08	8/1/2014	8/31/2014	974	2.67

Table A-1. Stress Periods in the WMA S-SX Local-Scale Model

Stress Period Number	Length (days)	Length (years)	Start Date	End Date (Inclusive)	Elapsed Days	Elapsed Years
33	30	0.08	9/1/2014	9/30/2014	1,004	2.75
34	31	0.08	10/1/2014	10/31/2014	1,035	2.83
35	30	0.08	11/1/2014	11/30/2014	1,065	2.91
36	31	0.08	12/1/2014	12/31/2014	1,096	3.00
37	31	0.08	1/1/2015	1/31/2015	1,127	3.08
38	28	0.08	2/1/2015	2/28/2015	1,155	3.16
39	31	0.08	3/1/2015	3/31/2015	1,186	3.25
40	30	0.08	4/1/2015	4/30/2015	1,216	3.33
41	31	0.08	5/1/2015	5/31/2015	1,247	3.42
42	30	0.08	6/1/2015	6/30/2015	1,277	3.50
43	31	0.08	7/1/2015	7/31/2015	1,308	3.58
44	31	0.08	8/1/2015	8/31/2015	1,339	3.67
45	30	0.08	9/1/2015	9/30/2015	1,369	3.75
46	31	0.08	10/1/2015	10/31/2015	1,400	3.83
47	30	0.08	11/1/2015	11/30/2015	1,430	3.91
48	31	0.08	12/1/2015	12/31/2015	1,461	4.00
49	31	0.08	1/1/2016	1/31/2016	1,492	4.08
50	29	0.08	2/1/2016	2/29/2016	1,521	4.16
51	31	0.08	3/1/2016	3/31/2016	1,552	4.25
52	30	0.08	4/1/2016	4/30/2016	1,582	4.33
53	31	0.08	5/1/2016	5/31/2016	1,613	4.42
54	30	0.08	6/1/2016	6/30/2016	1,643	4.50
55	31	0.08	7/1/2016	7/31/2016	1,674	4.58
56	31	0.08	8/1/2016	8/31/2016	1,705	4.67
57	30	0.08	9/1/2016	9/30/2016	1,735	4.75
58	31	0.08	10/1/2016	10/31/2016	1,766	4.83
59	30	0.08	11/1/2016	11/30/2016	1,796	4.91
60	31	0.08	12/1/2016	12/31/2016	1,827	5
61	365	1	1/1/2017	12/31/2017	2,192	6
62	365	1	1/1/2018	12/31/2018	2,557	7
63	365	1	1/1/2019	12/31/2019	2,922	8
64	366	1	1/1/2020	12/31/2020	3,288	9
65	365	1	1/1/2021	12/31/2021	3,653	10
66	365	1	1/1/2022	12/31/2022	4,018	11
67	365	1	1/1/2023	12/31/2023	4,383	12

Table A-1. Stress Periods in the WMA S-SX Local-Scale Model

Stress Period Number	Length (days)	Length (years)	Start Date	End Date (Inclusive)	Elapsed Days	Elapsed Years
68	366	1	1/1/2024	12/31/2024	4,749	13
69	365	1	1/1/2025	12/31/2025	5,114	14
70	365	1	1/1/2026	12/31/2026	5,479	15
71	365	1	1/1/2027	12/31/2027	5,844	16
72	366	1	1/1/2028	12/31/2028	6,210	17
73	365	1	1/1/2029	12/31/2029	6,575	18
74	365	1	1/1/2030	12/31/2030	6,940	19
75	365	1	1/1/2031	12/31/2031	7,305	20
76	366	1	1/1/2032	12/31/2032	7,671	21
77	365	1	1/1/2033	12/31/2033	8,036	22
78	365	1	1/1/2034	12/31/2034	8,401	23
79	365	1	1/1/2035	12/31/2035	8,766	24
80	366	1	1/1/2036	12/31/2036	9,132	25
81	365	1	1/1/2037	12/31/2037	9,497	26
82	365	1	1/1/2038	12/31/2038	9,862	27
83	365	1	1/1/2039	12/31/2039	10,227	28
84	366	1	1/1/2040	12/31/2040	10,593	29
85	365	1	1/1/2041	12/31/2041	10,958	30
86	365	1	1/1/2042	12/31/2042	11,323	31
87	1826	5	1/1/2043	12/31/2047	13,149	36
88	1827	5	1/1/2048	12/31/2052	14,976	41
89	1826	5	1/1/2053	12/31/2057	16,802	46
90	3652	10	1/1/2058	12/31/2067	20,454	56
91	3653	10	1/1/2068	12/31/2077	24,107	66
92	3652	10	1/1/2078	12/31/2087	27,759	76
93	3653	10	1/1/2088	12/31/2097	31,412	86
94	3651	10	1/1/2098	12/31/2107	35,063	96
95	3653	10	1/1/2108	12/31/2117	38,716	106
96	3652	10	1/1/2118	12/31/2127	42,368	116
97	3653	10	1/1/2128	12/31/2137	46,021	126

Appendix B

Software Installation and Checkout

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: [redacted]\bin-windows

MD5 Signature (unique ID)	Executable File Name	
919E74196F5EB5BF0364FC373011B507	mf2k-chprc08dpl.exe	MODFLOW-2000 double precision
EAF037703ADD2C62CDD9CBC47468D2F6	mf2k-chprc08spl.exe	MODFLOW-2000 single precision
4E7F23DD5496D2CBA7144ADACB13DAAD	mf2k-mst-chprc08dpv.exe	MODFLOW-2000-MST single prec
CEB80288C616E0552E4CE5A2D4719387	mf2k-mst-chprc08spv.exe	MODFLOW-2000-MST double prec
ECA982B530B68D2D7C34078C019D5D0C	mt3d-chprc08dpl.exe	MT3DMS double precision
09ZOCC235862665D9400A3FC80F682DD	mt3d-chprc08spl.exe	MT3DMS single precision
5C61432D2C898B83DDFE242C52A755AB	mt3d-mst-chprc08dpv.exe	MT3DMS-MST double precision
68FB9DAF2E6913D2578DE53CBD34FBA0	mt3d-mst-chprc08spv.exe	MT3DMS-MST single precision

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

COMPILATION INFORMATION:

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

Vendor Provided (SSP&A)

5. Operating System (include version number):

Vendor Provided (SSP&A)

INSTALLATION AND CHECKOUT INFORMATION:

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

DELL Precision Laptop (INTERA 00590)

7. Operating System (include version number):

Windows 7 Professional Service Pack 1

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

TEST CASE INFORMATION:

9. Directory/Path:

[redacted]\test-windows

10. Procedure(s):

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

11. Libraries:

N/A (static linking)

12. Input Files:

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

13. Output Files:

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

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CHPRC SOFTWARE INSTALLATION AND CHECKOUT FORM (continued)

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

14. Test Cases:

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

15. Test Case Results:

All tests return identical results as base cases.

16. Test Performed By: Jahangir Morshed

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

18. Disposition (include HISI update): Added to HISI ENTRIES #2517 (MODFLOW) & #2518 (MT3DMS)

Prepared By:

19.	Software Owner (Signature)	Print	Date
		WE Nichols	15-MAR-2016

20. Test Personnel:

Sign	Print	Date
J. Morshed	Jahangir Morshed	14-Mar-16

Approved By:

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

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Appendix C

Transport Evaluation Graphs

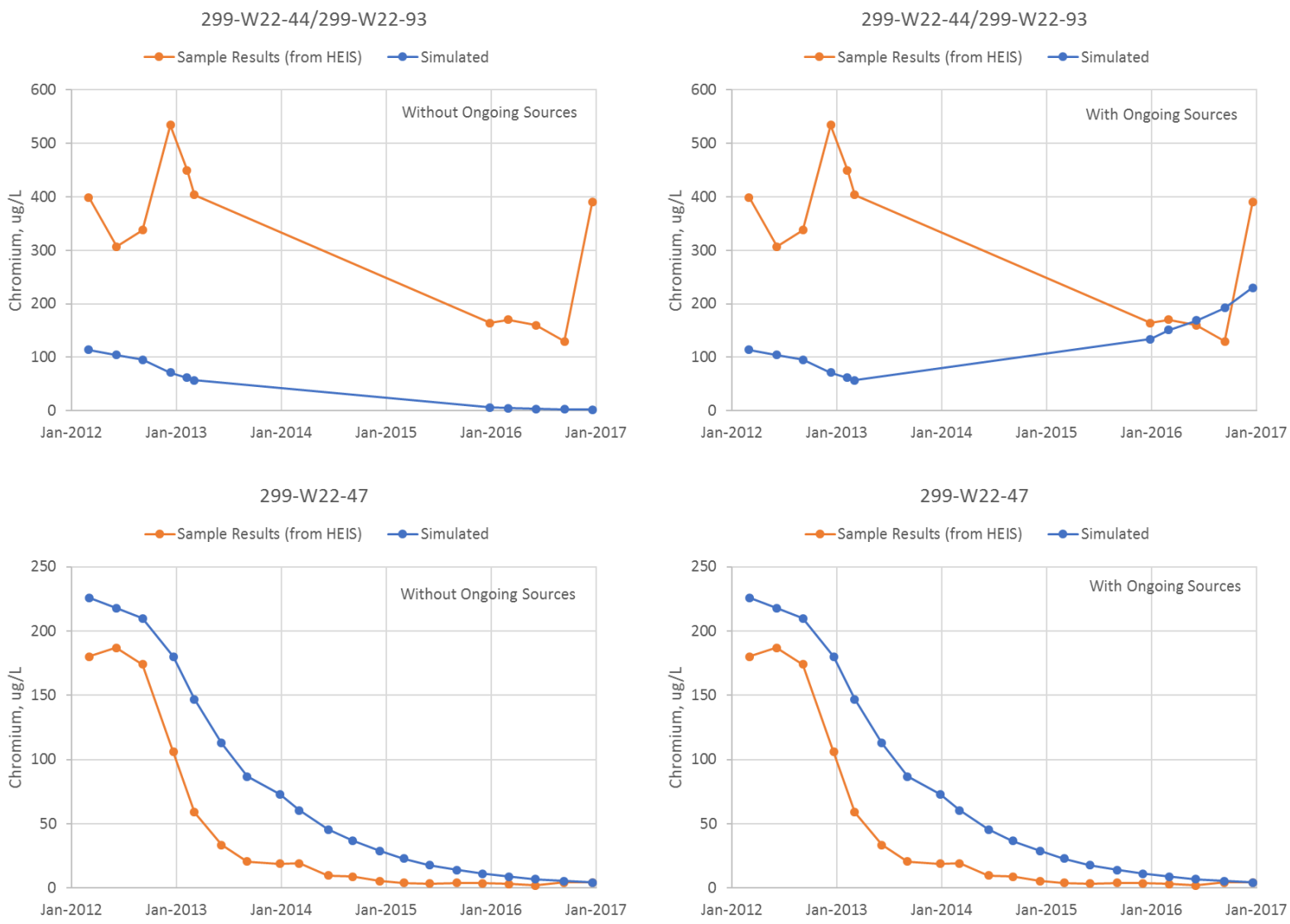

Figure C-1. Simulated Chromium Concentrations and Sample Results for Wells 299-W22-93 and 299-W22-47

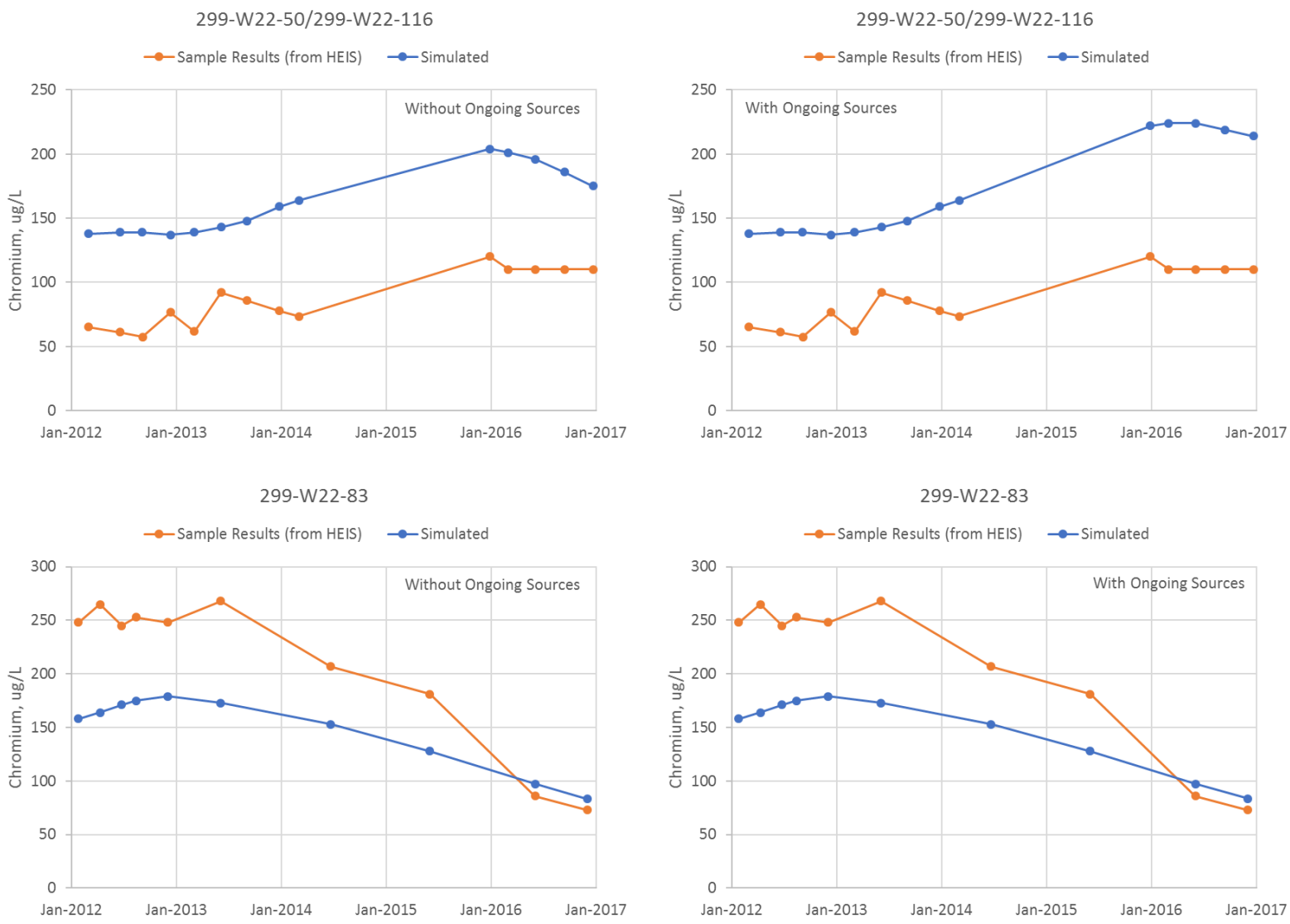

Figure C-2. Simulated Chromium Concentrations and Sample Results for Wells 299-W22-116 and 299-W22-83

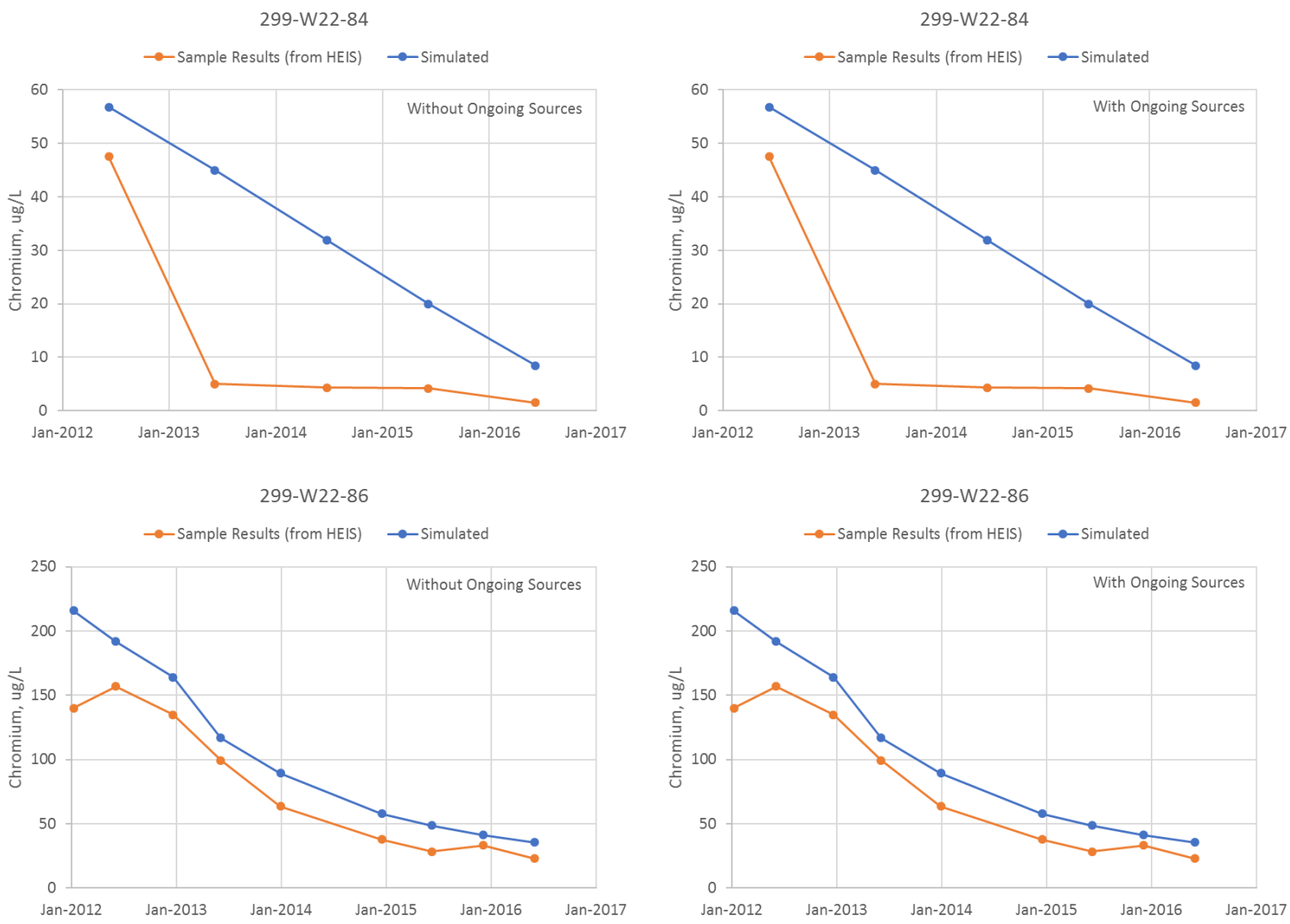

Figure C-3. Simulated Chromium Concentrations and Sample Results for Wells 299-W22-84 and 299-W22-86

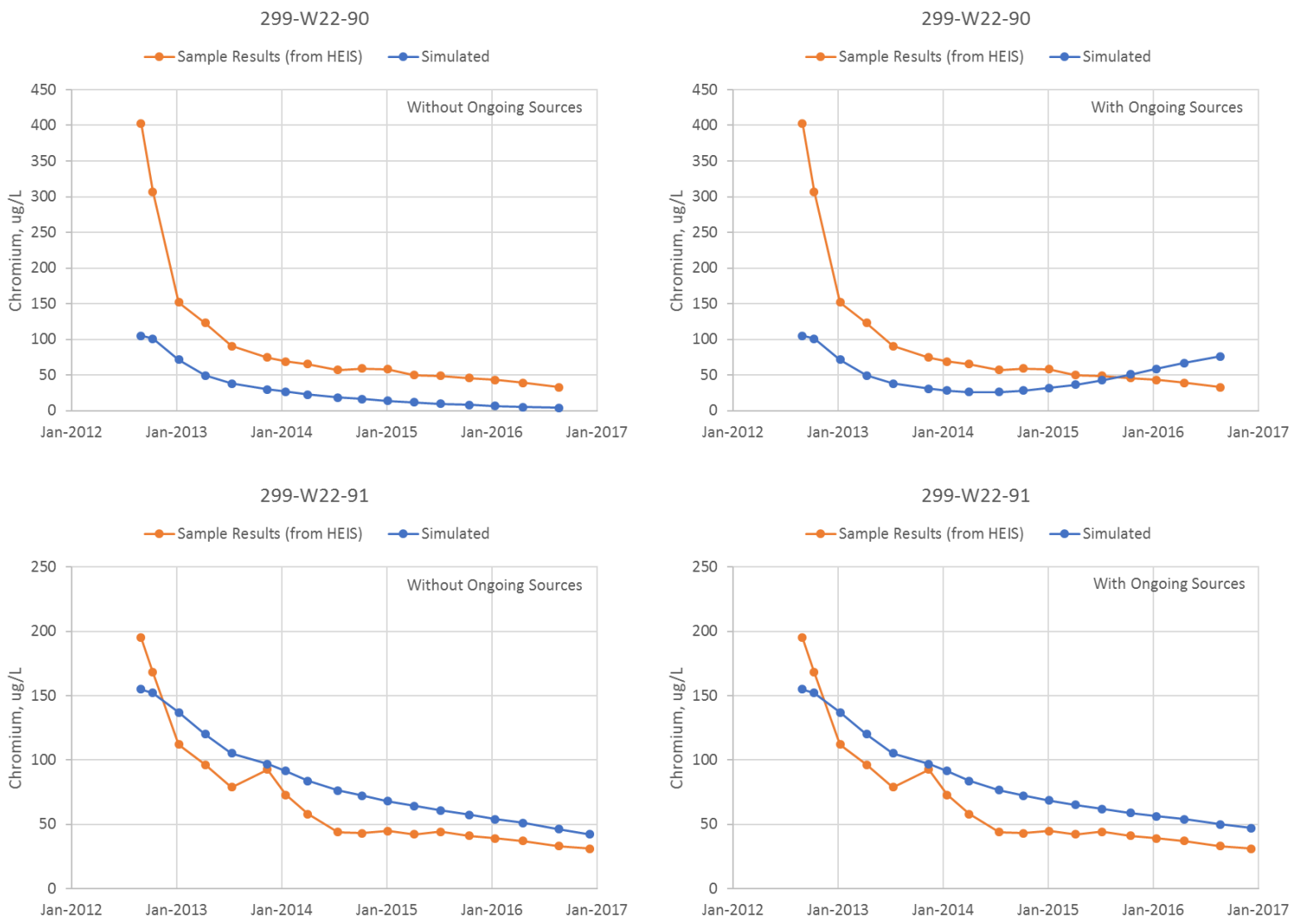

Figure C-4. Simulated Chromium Concentrations and Sample Results for Wells 299-W22-90 and 299-W22-91

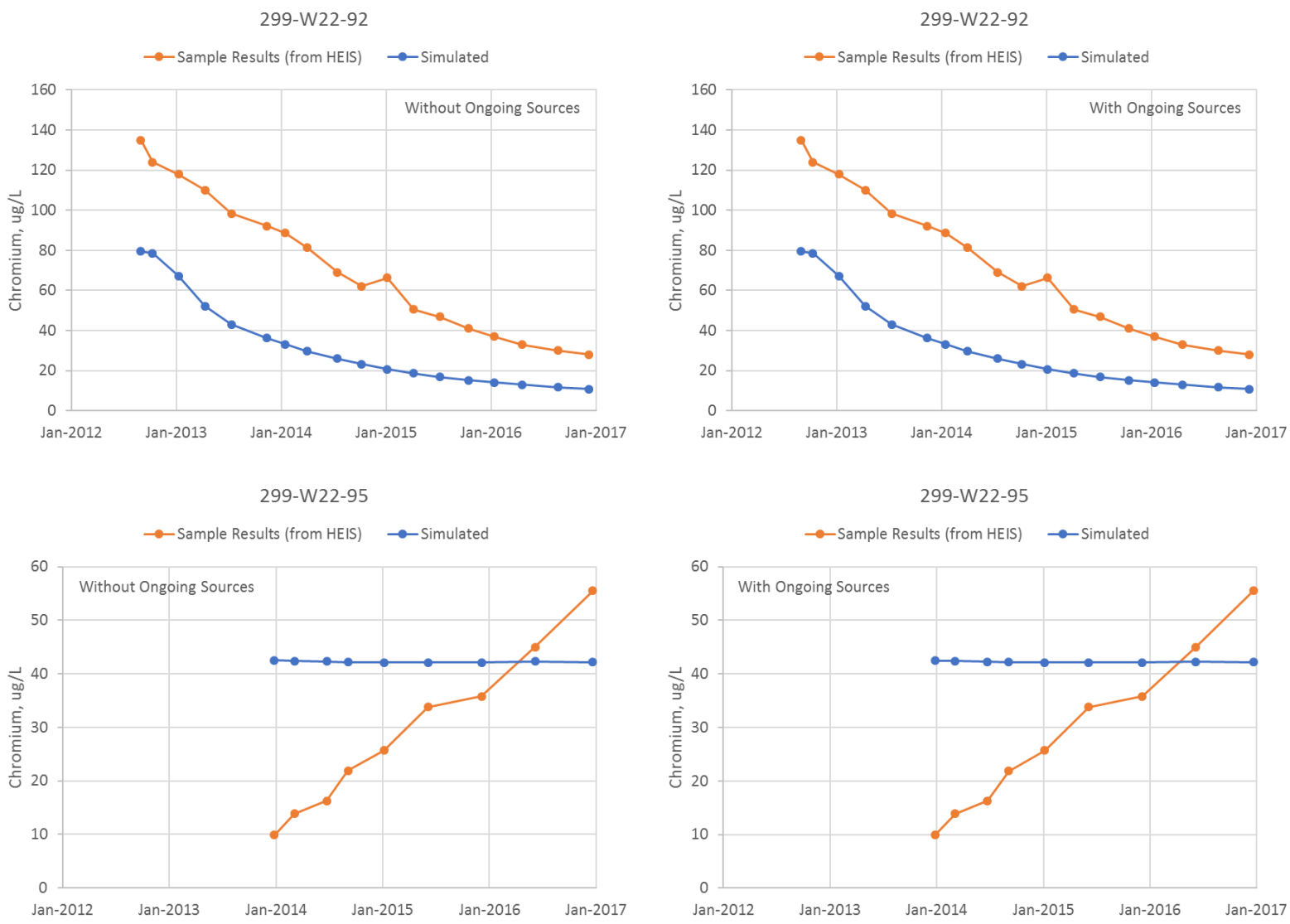

Figure C-5. Simulated Chromium Concentrations and Sample Results for Wells 299-W22-92 and 299-W22-95

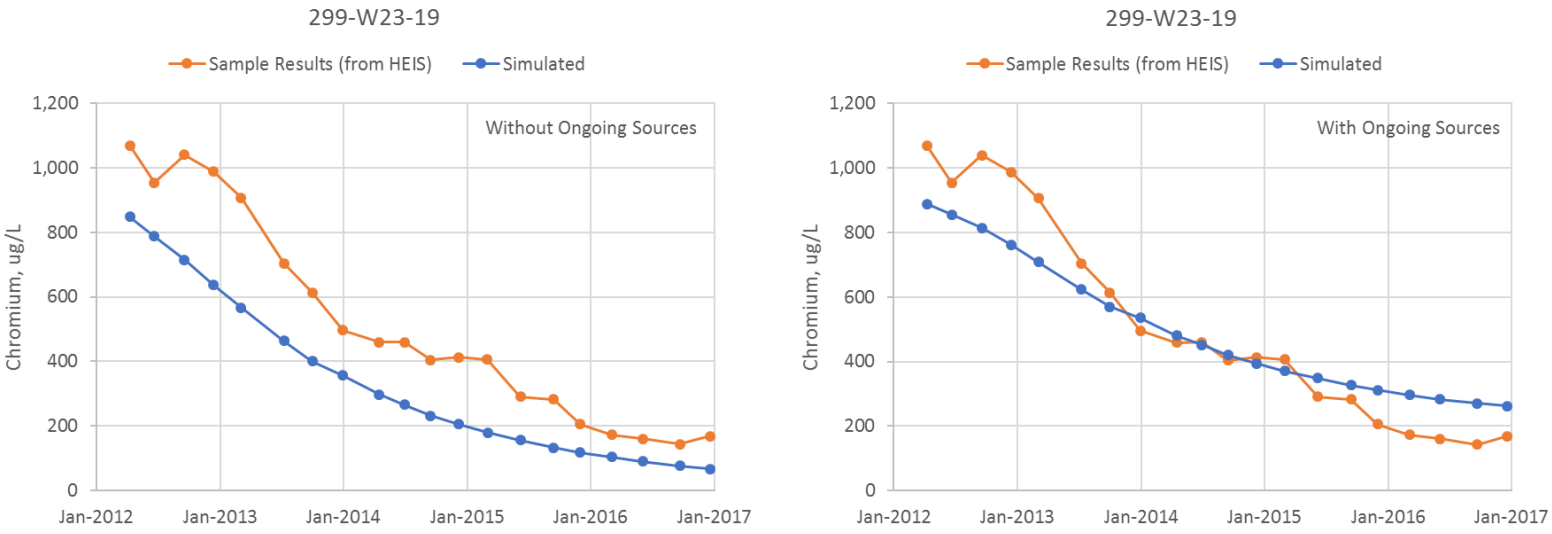

Figure C-6. Simulated Chromium Concentrations and Sample Results for Well 299-W23-19

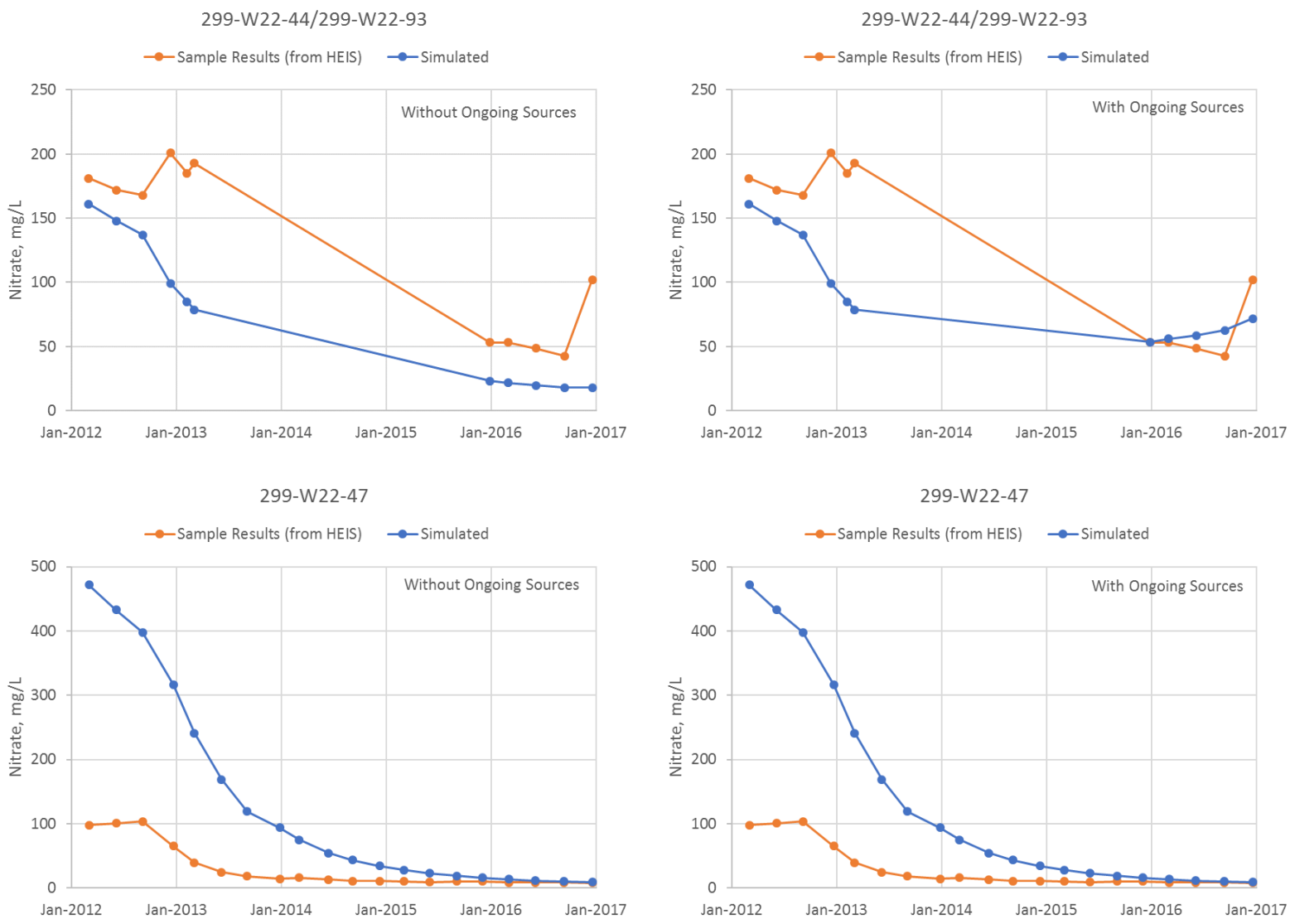

Figure C-7. Simulated Nitrate Concentrations and Sample Results for Wells 299-W22-93 and 299-W22-47

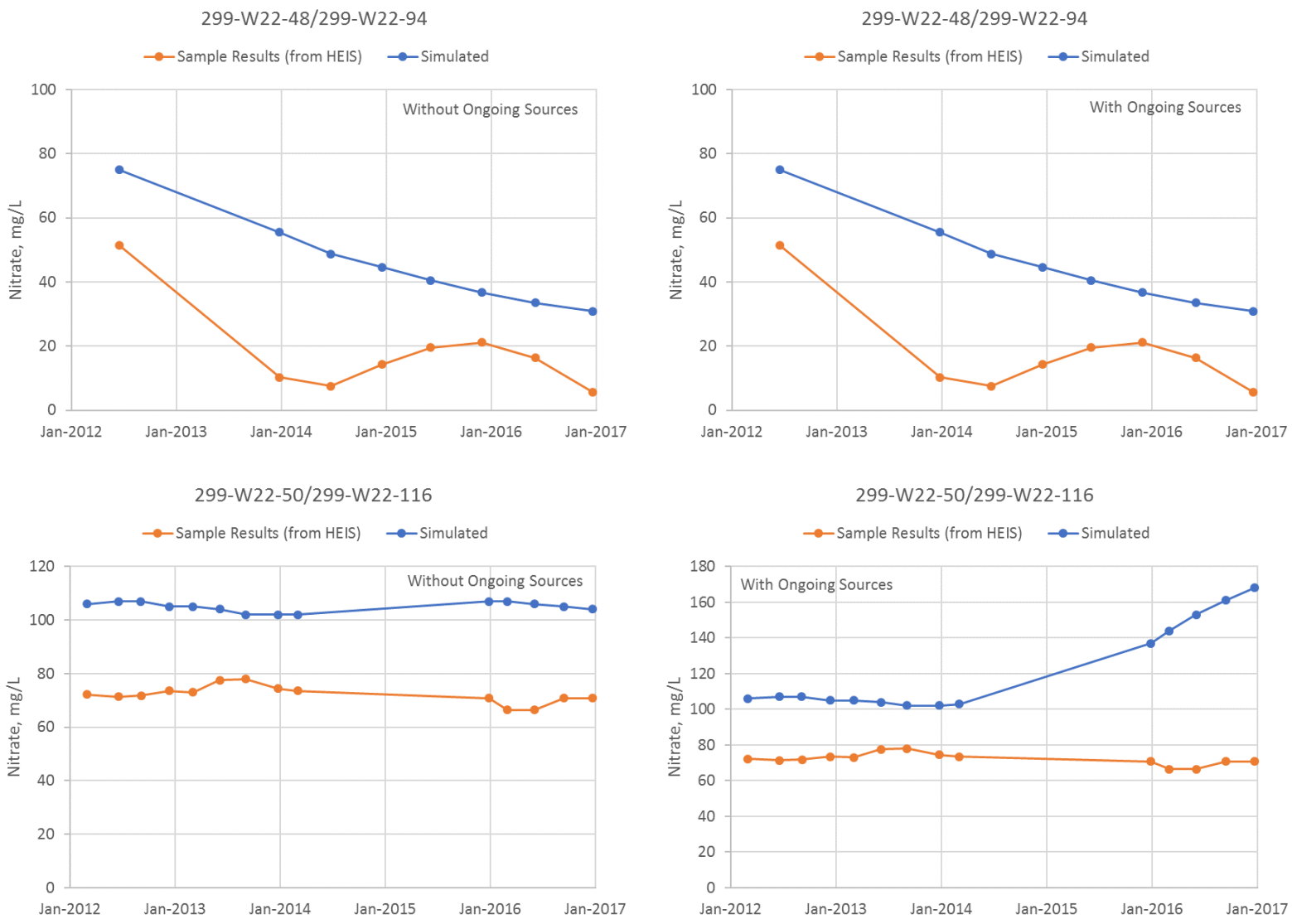

Figure C-8. Simulated Nitrate Concentrations and Sample Results for Wells 299-W22-94 and 299-W22-116

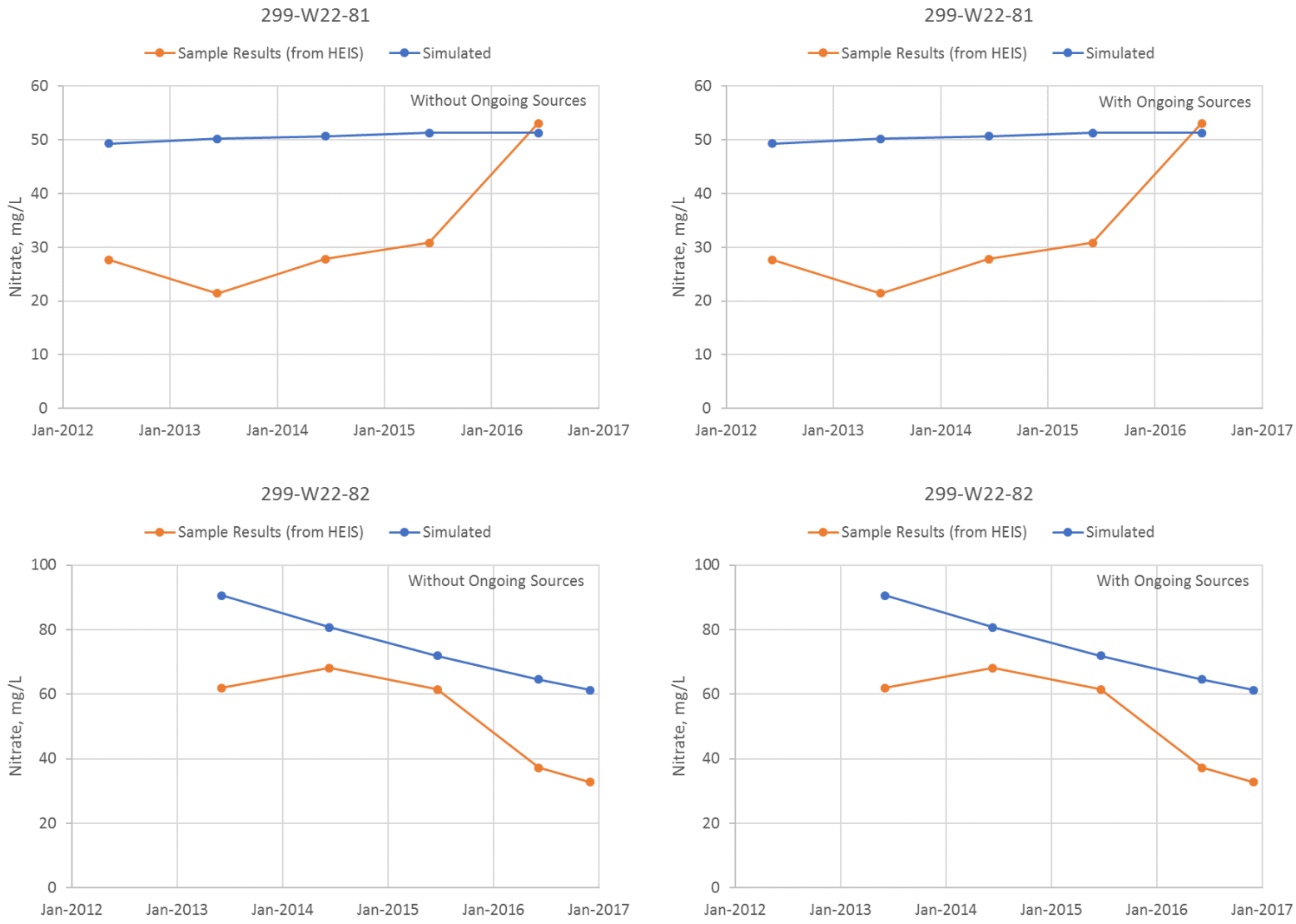

Figure C-9. Simulated Nitrate Concentrations and Sample Results for Wells 299-W22-81 and 299-W22-82

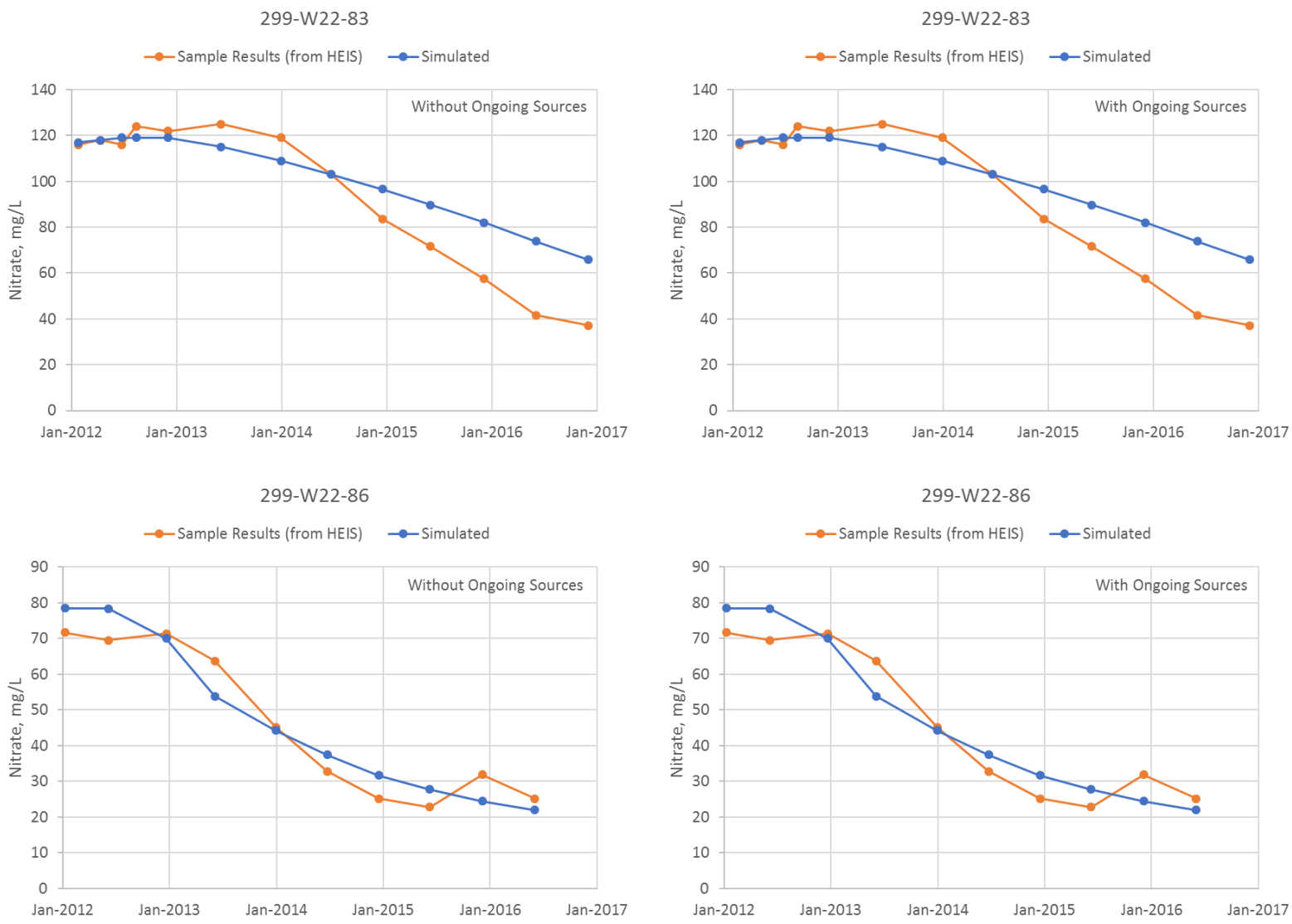

Figure C-10. Simulated Nitrate Concentrations and Sample Results for Wells 299-W22-83 and 299-W22-86

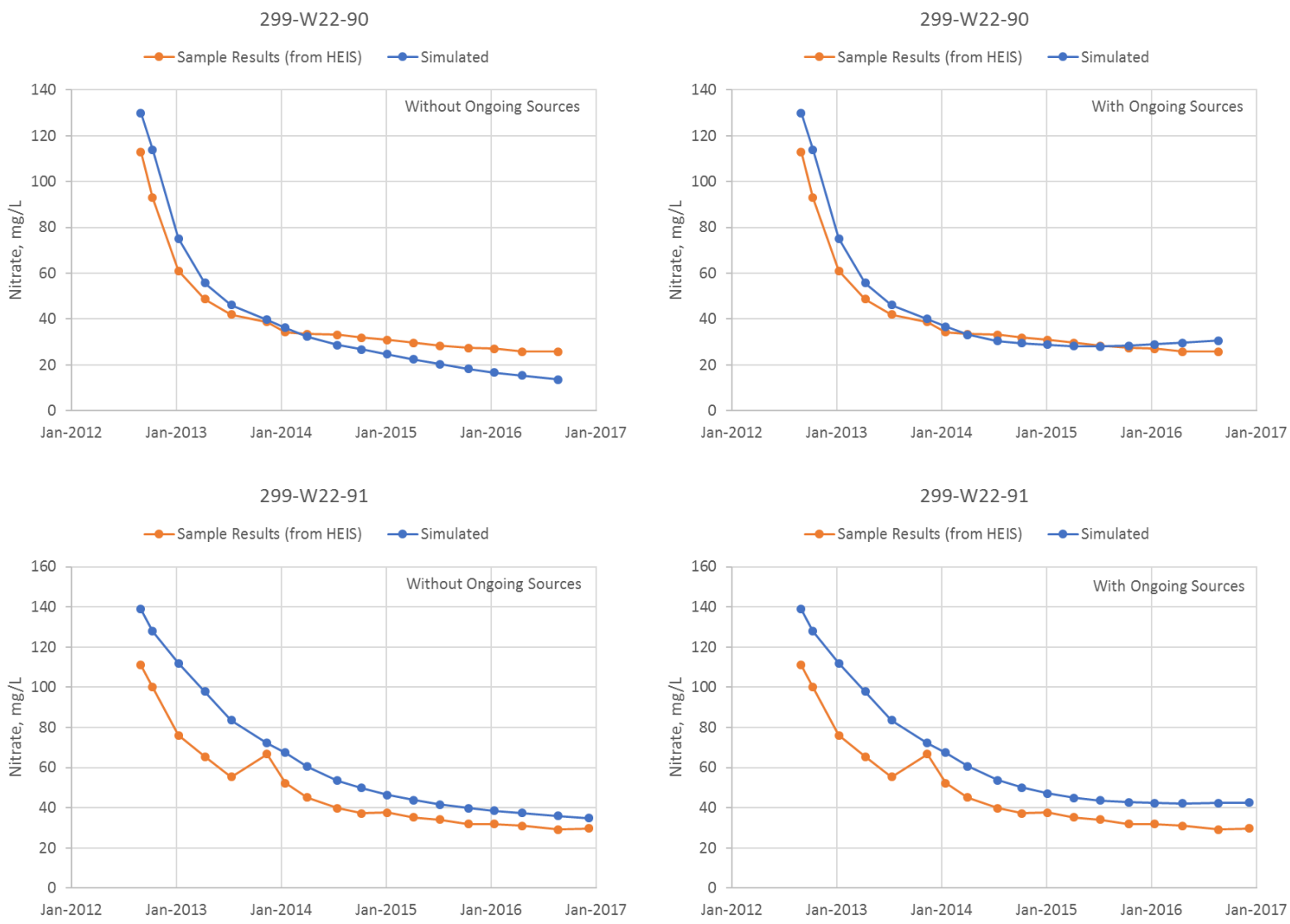

Figure C-11. Simulated Nitrate Concentrations and Sample Results for Wells 299-W22-90 and 299-W22-91

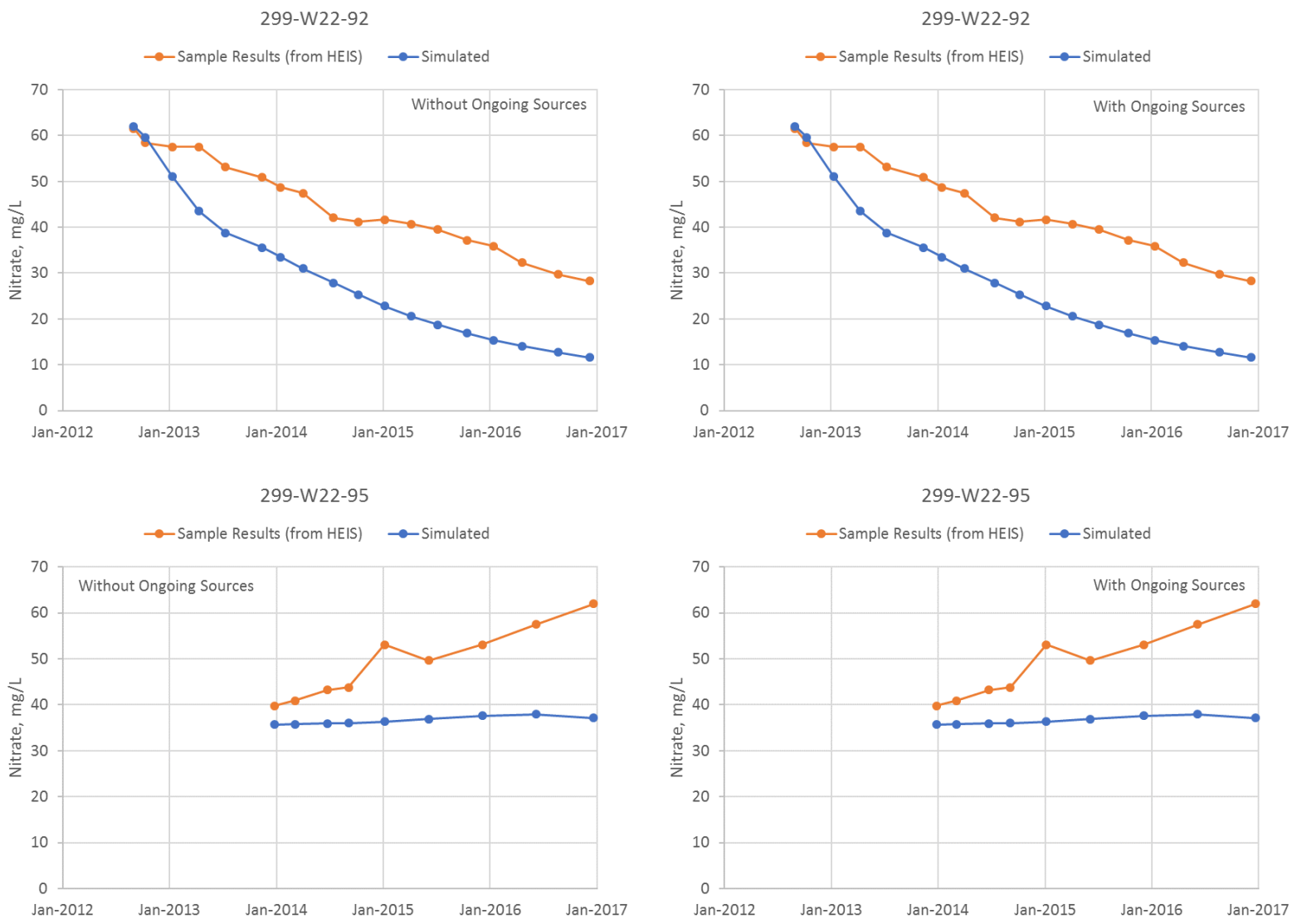

Figure C-12. Simulated Nitrate Concentrations and Sample Results for Wells 299-W22-92 and 299-W22-95

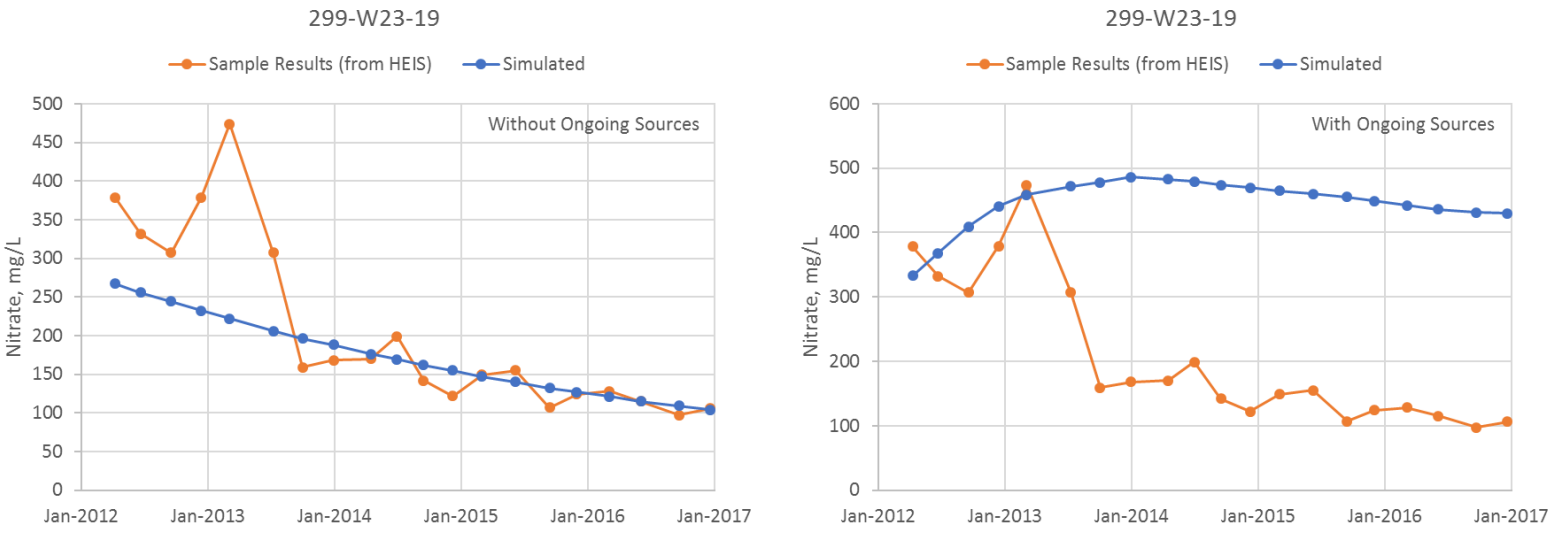

Figure C-13. Simulated Nitrate Concentrations and Sample Results for Well 299-W23-19

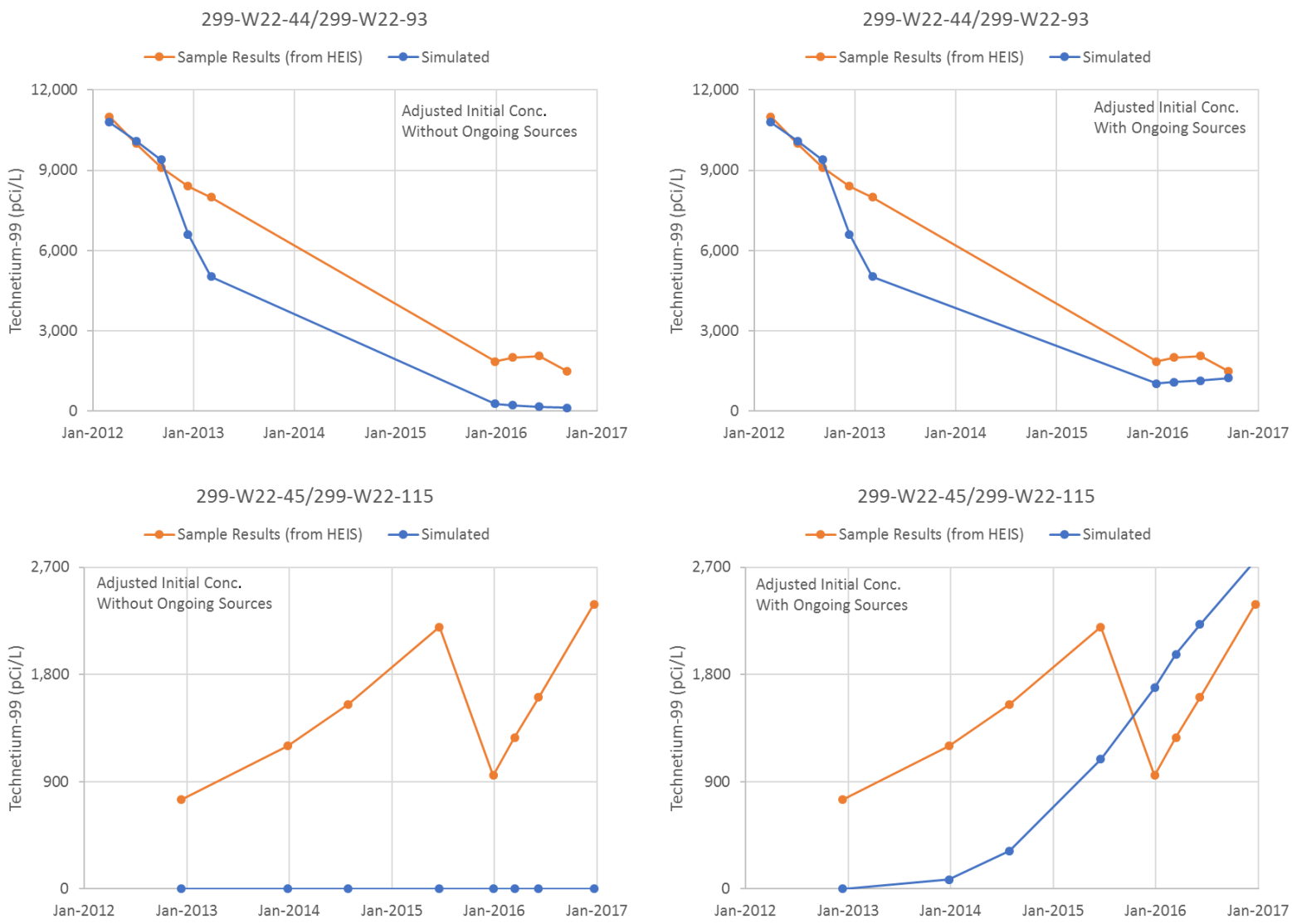

Figure C-14. Simulated Technetium-99 Concentrations and Sample Results for Wells 299-W22-93 and 299-W22-115

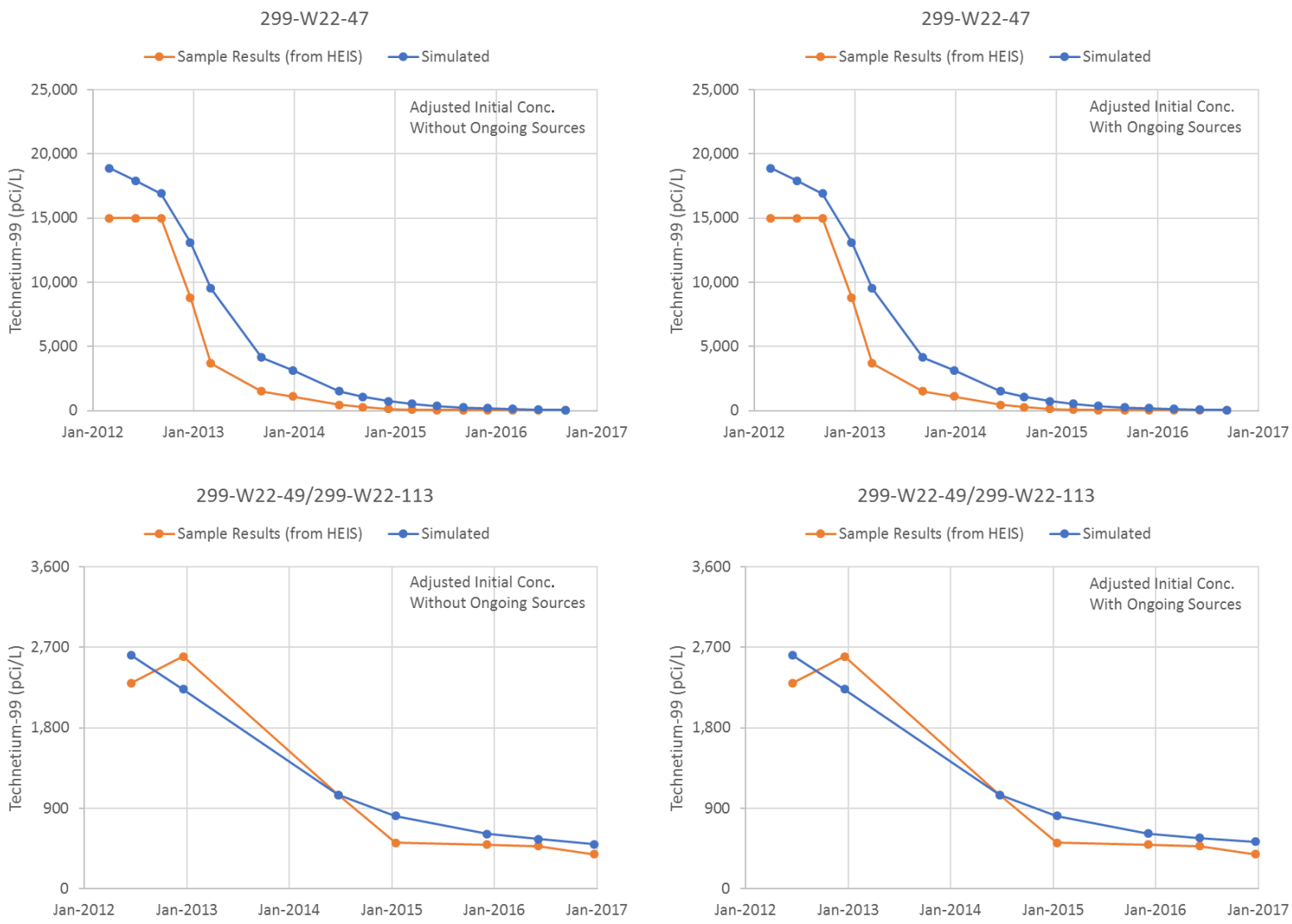

Figure C-15. Simulated Technetium-99 Concentrations and Sample Results for Wells 299-W22-47 and 299-W22-113

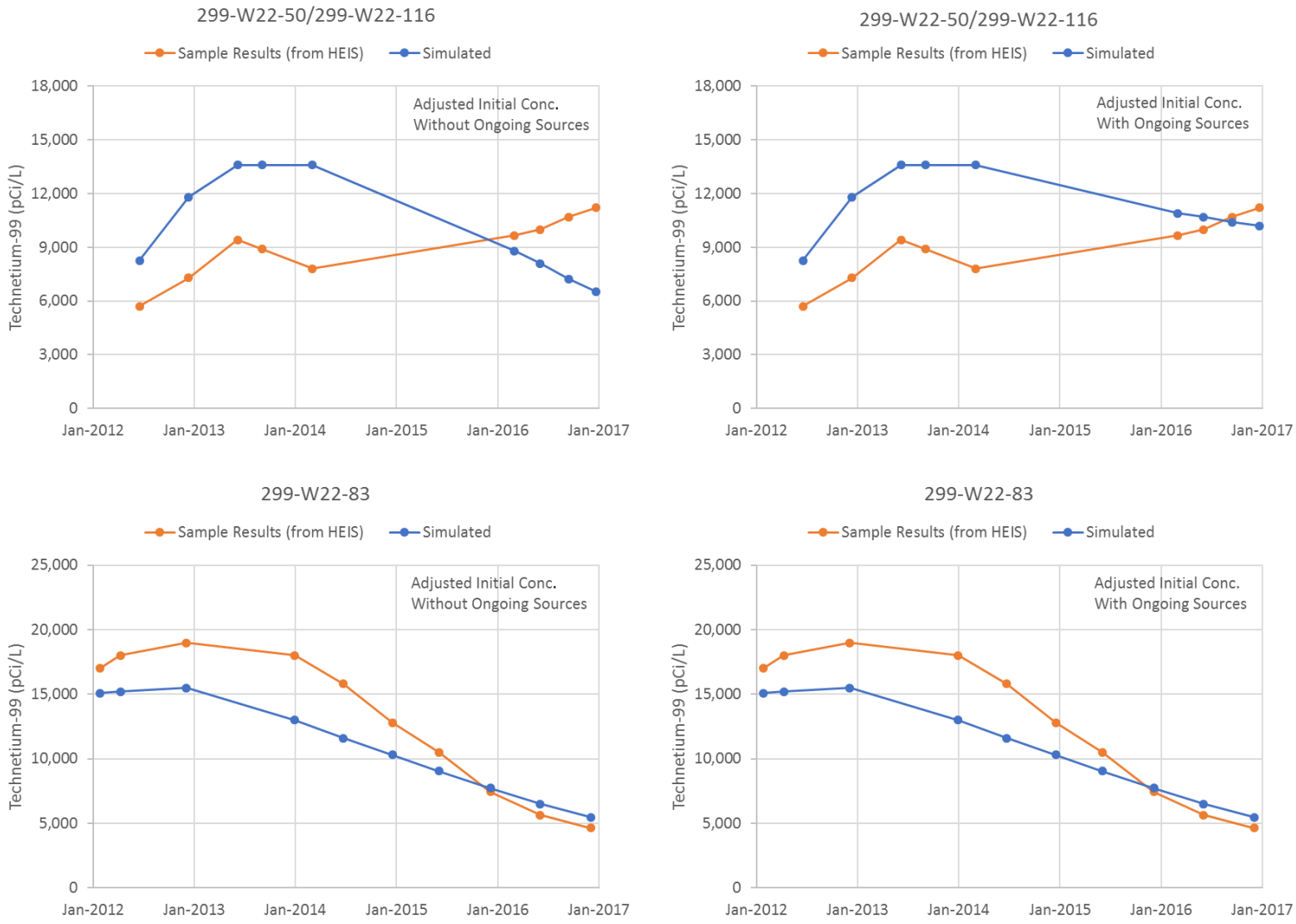

Figure C-16. Simulated Technetium-99 Concentrations and Sample Results for Wells 299-W22-116 and 299-W22-83

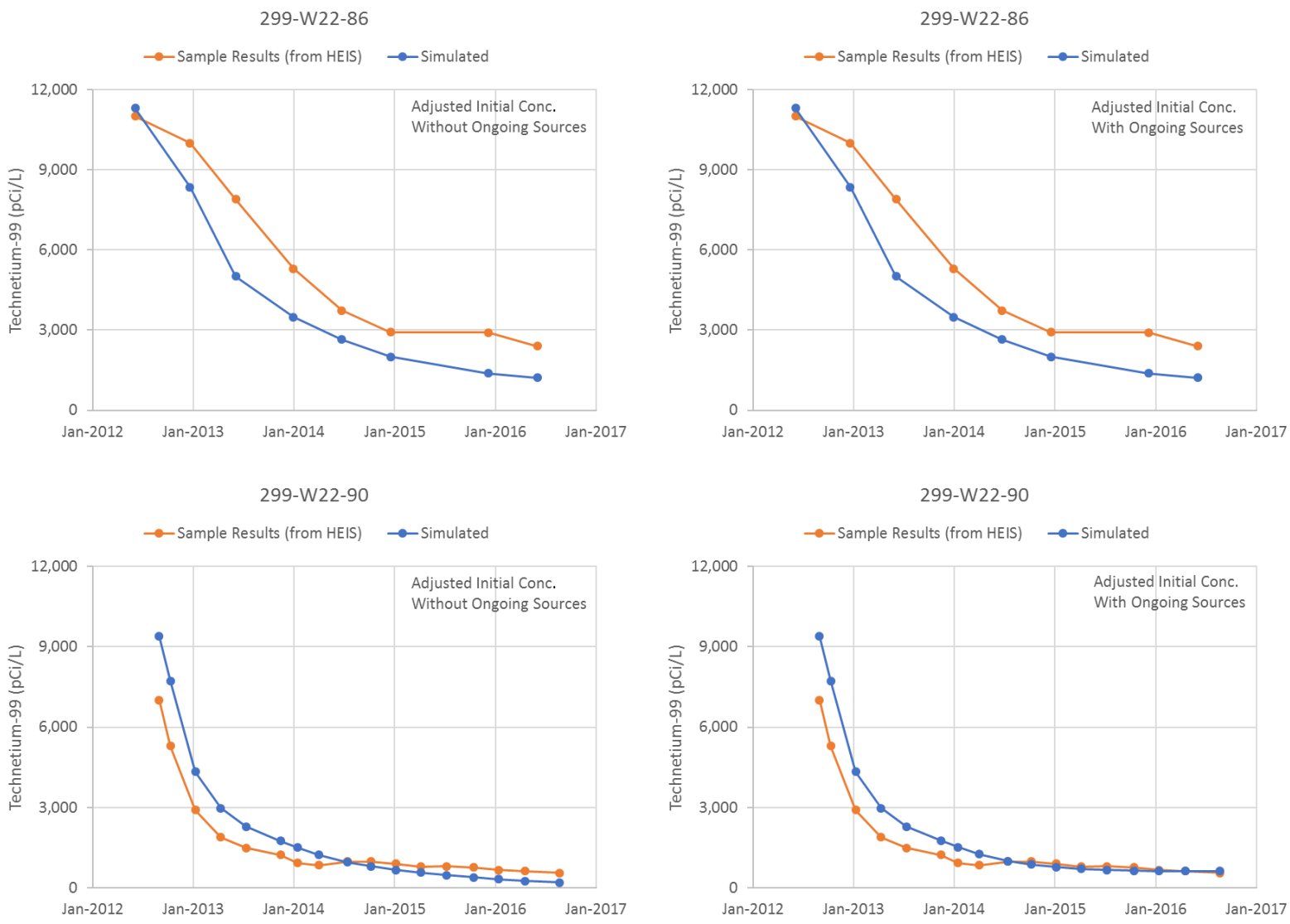

Figure C-17. Simulated Technetium-99 Concentrations and Sample Results for Wells 299-W22-86 and 299-W22-90

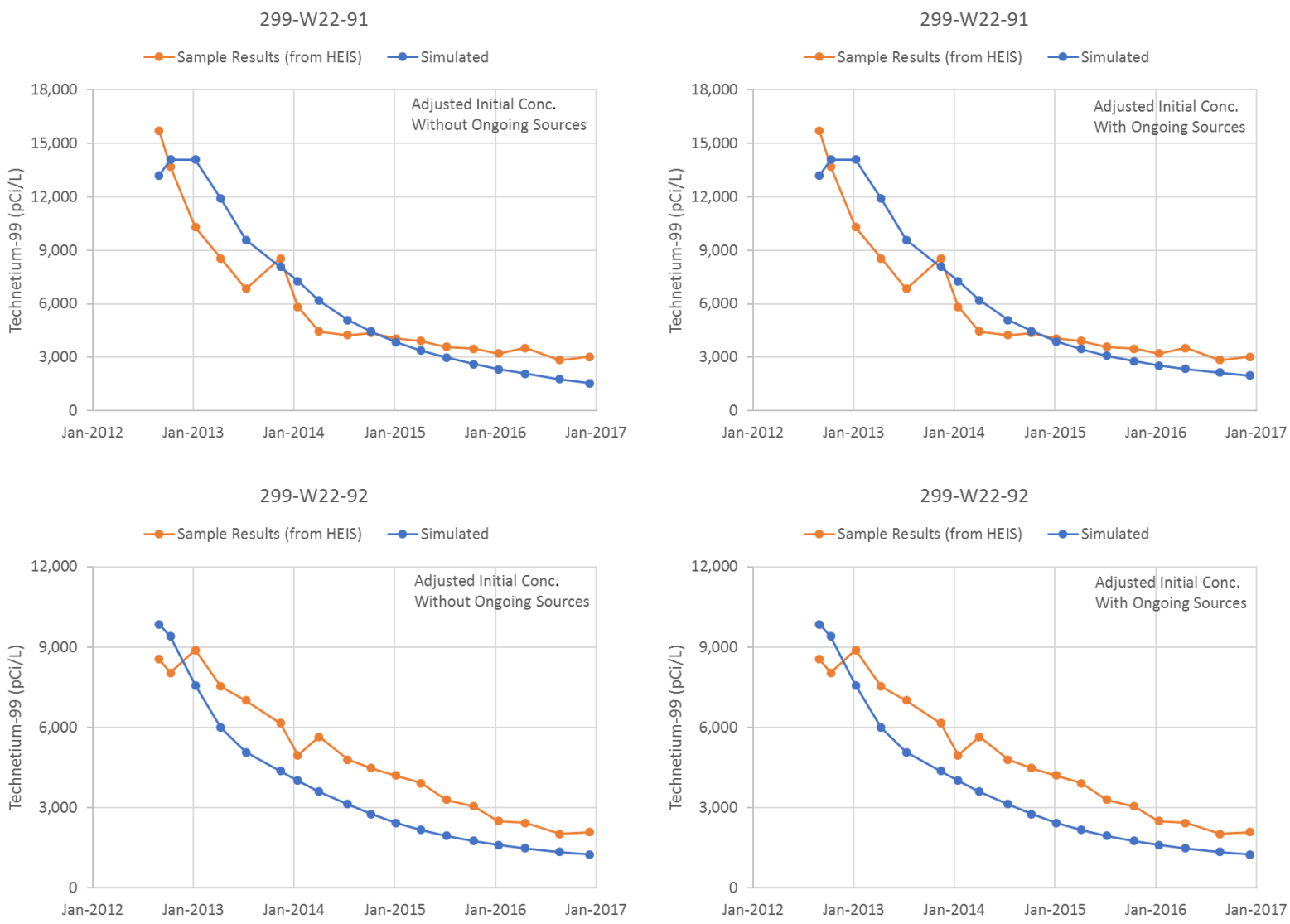

Figure C-18. Simulated Technetium-99 Concentrations and Sample Results for Wells 299-W22-91 and 299-W22-92

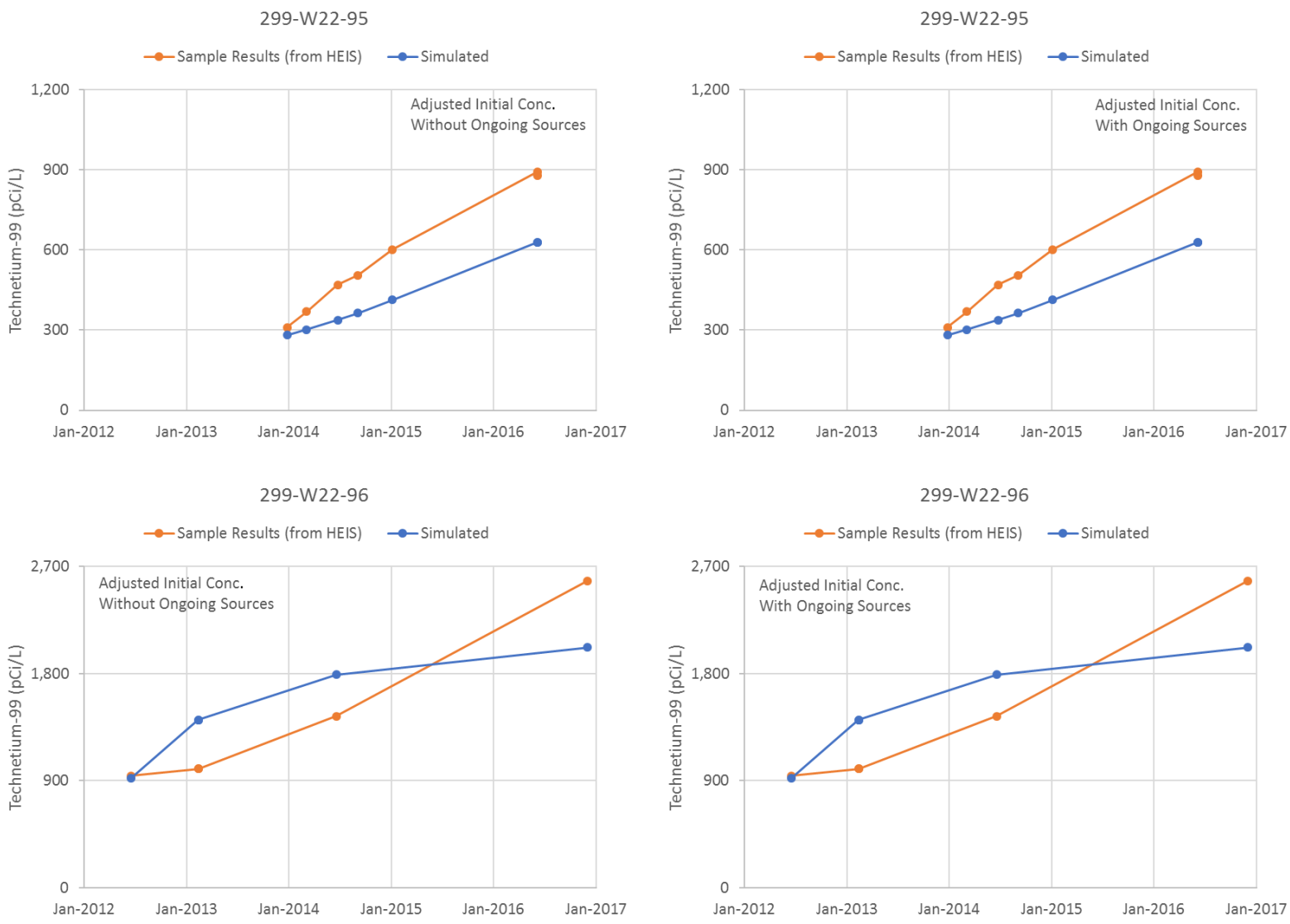

Figure C-19. Simulated Technetium-99 Concentrations and Sample Results for Wells 299-W22-95 and 299-W22-96

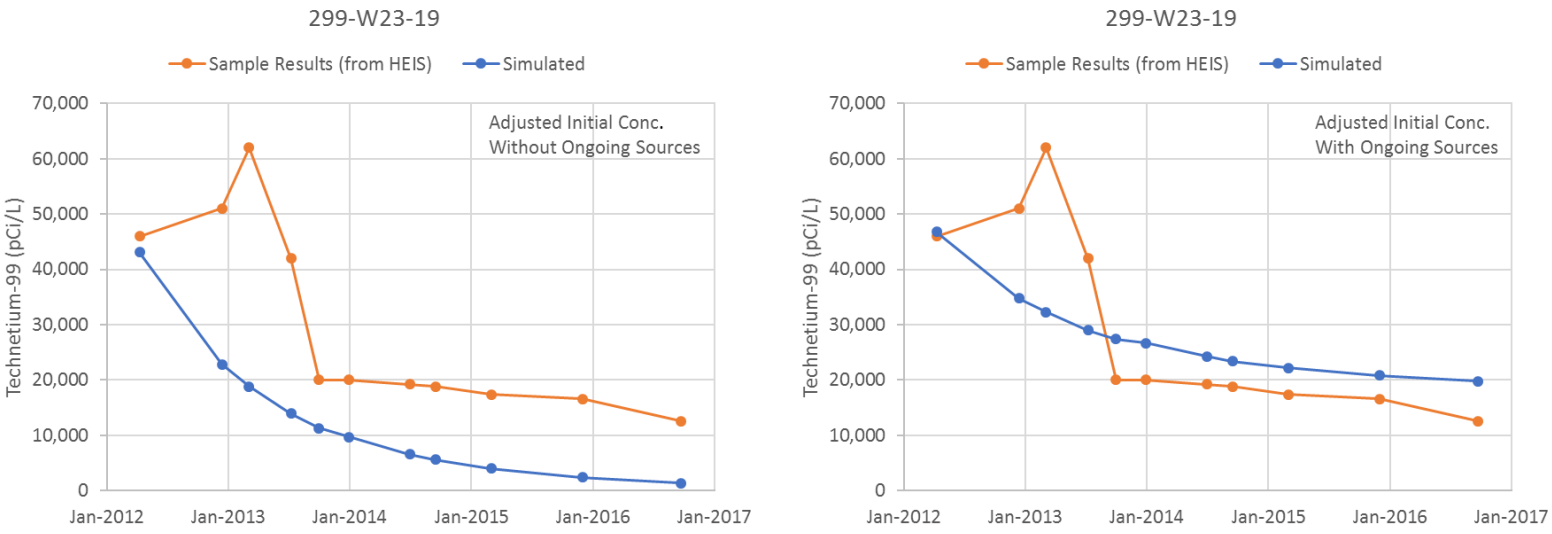

Figure C-20. Simulated Technetium-99 Concentrations and Sample Results for Well 299-W23-19