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Revision 0

GROUNDWATER FLOW AND MIGRATION CALCULATIONS TO ASSESS MONITORING NETWORKS IN THE 200 EAST AREA DANGEROUS WASTE MANAGEMENT UNITS

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

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

CH2MHILL
Plateau Remediation Company

P.O. Box 1600
Richland, Washington 99352

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ENVIRONMENTAL CALCULATION COVER PAGE

SECTION 1 - Completed by the Responsible Manager

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Date: 7/1/2018	DATE: Dec 18, 2018 HANFORD RELEASE
Calculation Title and Description: Groundwater Flow and Migration Calculations to Assess Monitoring Networks in the 200 East Area Dangerous Waste Management Units	

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ENVIRONMENTAL CALCULATION COVER PAGE (Continued)

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ENVIRONMENTAL CALCULATION COVER PAGE (Continued)

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Terms

ASCII	American Standard Code for Information Interchange
API	American Petroleum Institute
CHPRC	CH2M HILL Plateau Remediation Company
CPGWM	Central Plateau Groundwater Model
CY	calendar year
DWMU	dangerous waste management unit
ECF	environmental calculation file
HSU	hydrostratigraphic unit
LLBG	Low-Level Burial Grounds
OU	operable unit
P&T	pump and treat
SME	subject matter expert
SST	single-shell tank
TRIM	Tikhonov Regularized Inverse Method
WMA	waste management area

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1 Purpose

This environmental calculation file (ECF) describes calculations made to evaluate whether the interim status groundwater monitoring networks in the 200 East Area of the Hanford Site Central Plateau are adequate for detecting significant increases in groundwater contamination that would result from one or more releases from various dangerous waste management units (DWMUs) at the site.

The calculations were made to contribute to a series of engineering reports pertaining to the DWMUs listed below and depicted in Figure 1-1:

- 216-A-29 Ditch
- 216-A-36B Crib
- 216-A-37-1 Crib
- 216-B-3 Pond
- 216-B-63 Trench
- Integrated Disposal Facility
- Low-Level Burial Grounds (LLBG) Waste Management Area (WMA)-1
- Single-Shell Tank (SST) WMA A-AX
- SST WMA B-BX-BY
- SST WMA C

These DWMUs collectively are referred to herein as the 200 East Facilities. This ECF provides the conceptual basis for the calculations that were performed, details the specific methods and codes used to undertake the calculations, and presents results of calculations that are applicable to the 200 East Area generally and to each specific 200 East Facility.

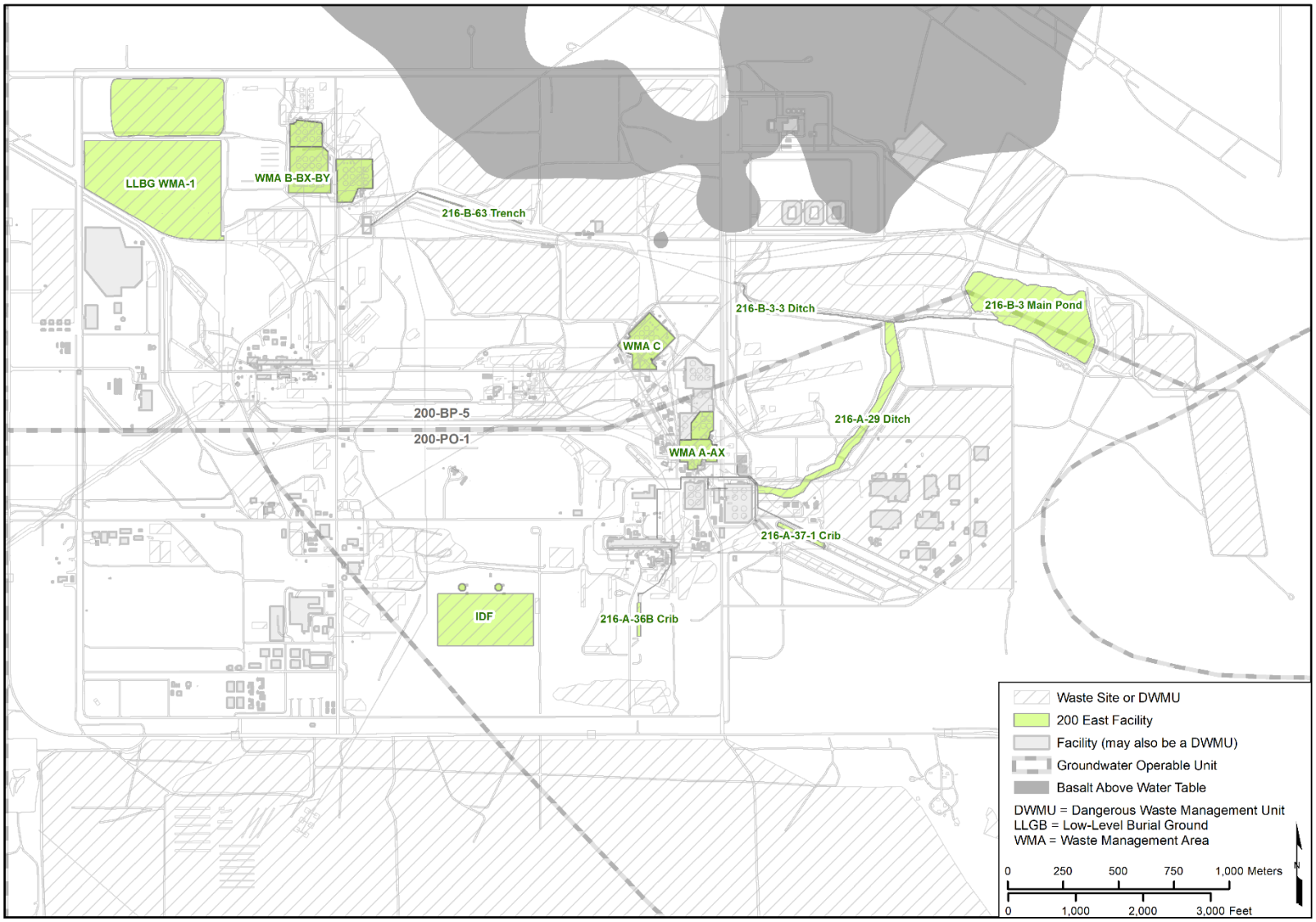

Figure 1-1. 200 East Facilities Evaluated in this ECF

2 Background

Interim status groundwater monitoring networks have been established for each of the 200 East Facilities. The interim status groundwater monitoring network for each 200 East Facility generally comprises at least one upgradient well and a larger number of downgradient wells. The wells typically are screened at the top of the unconfined aquifer in order to detect significant increases in groundwater contamination that would result from a release that reaches the water table from within the regulated unit. The interim status monitoring networks for the 200 East Facilities are shown in Figure 2-1. More detailed figures for each facility-specific monitoring network are provided in the corresponding facility-specific appendix.

2.1 Groundwater Remediation in the 200 East Area

A groundwater pump and treat (P&T) system is in place and operating within the main unconfined aquifer in the 200 East Area to address groundwater contamination at the 200-BP-5 Groundwater Operable Unit (OU). In 2016, this groundwater P&T system consisted of a single well (299-E33-268), but since that time modifications to the system have occurred, including operation of different extraction wells. These modifications are expected to affect hydraulic gradients and corresponding groundwater flow directions and rates in the vicinity of the extraction operations. The effects of groundwater extraction at the single P&T well operating in 2016 have been incorporated into the groundwater elevation analysis described herein. The operation of the P&T system in 2016 was anticipated to only influence hydraulic gradients and corresponding groundwater flow directions and rates near WMA B-BX-BY.

In addition to the single P&T well operating in the main unconfined aquifer in 2016, three extraction wells (299-E33-344, 299-E33-350, and 299-E33-351) operate within a perched water zone in the vicinity of WMA B-BX-BY. The bottom of the perched sand unit within which those extraction wells are screened is about 4.6 m (15 ft) above the unconfined aquifer at its lowest point. However, extraction rates are not expected or designed to greatly alter flow directions within the unconfined aquifer. Estimates of the transmissivity within the perched zone based upon testing of three wells that are intermittently pumped range between about 0.51 and 4.01 m^2/d (Table 5-4 in 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*). During “on” cycles these wells pump between about 8 and 19 L/min (2 and 5 gal/min); however, their longer term average rates are on the order of 0.57 to 1.14 L/min (0.15 to 0.30 gal/min) (Table 5-3 in DOE/RL-2016-69). Recent estimates of the lateral extent of the perched zone range between about 19,173 m^2 (PNNL-22499, *Perched-Water Evaluation for the Deep Vadose Zone Beneath the B, BX, and BY Tank Farms Area of the Hanford Site*) and 35,300 m^2 (DOE/RL-2016-69), which can be conceived as a square of side length between 138.5 and 188 m. In contrast, estimates of the transmissivity of the regional water table aquifer, which resides locally within the Cold Creek paleochannel, are many orders of magnitude higher. For example, the 200-BP-5 treatability test report (DOE/RL-2015-75, *Aquifer Treatability Test Report for the 200-BP-5 Groundwater Operable Unit*) presents well-specific capacities of 1,666 to 2,884 L/min/m (440 to 762 gal/min/ft) and transmissivities estimated from controlled constant rate pumping tests in multiple wells averaging about 40,000 m^2/d, four to five orders of magnitude greater than reported for the perched zone.

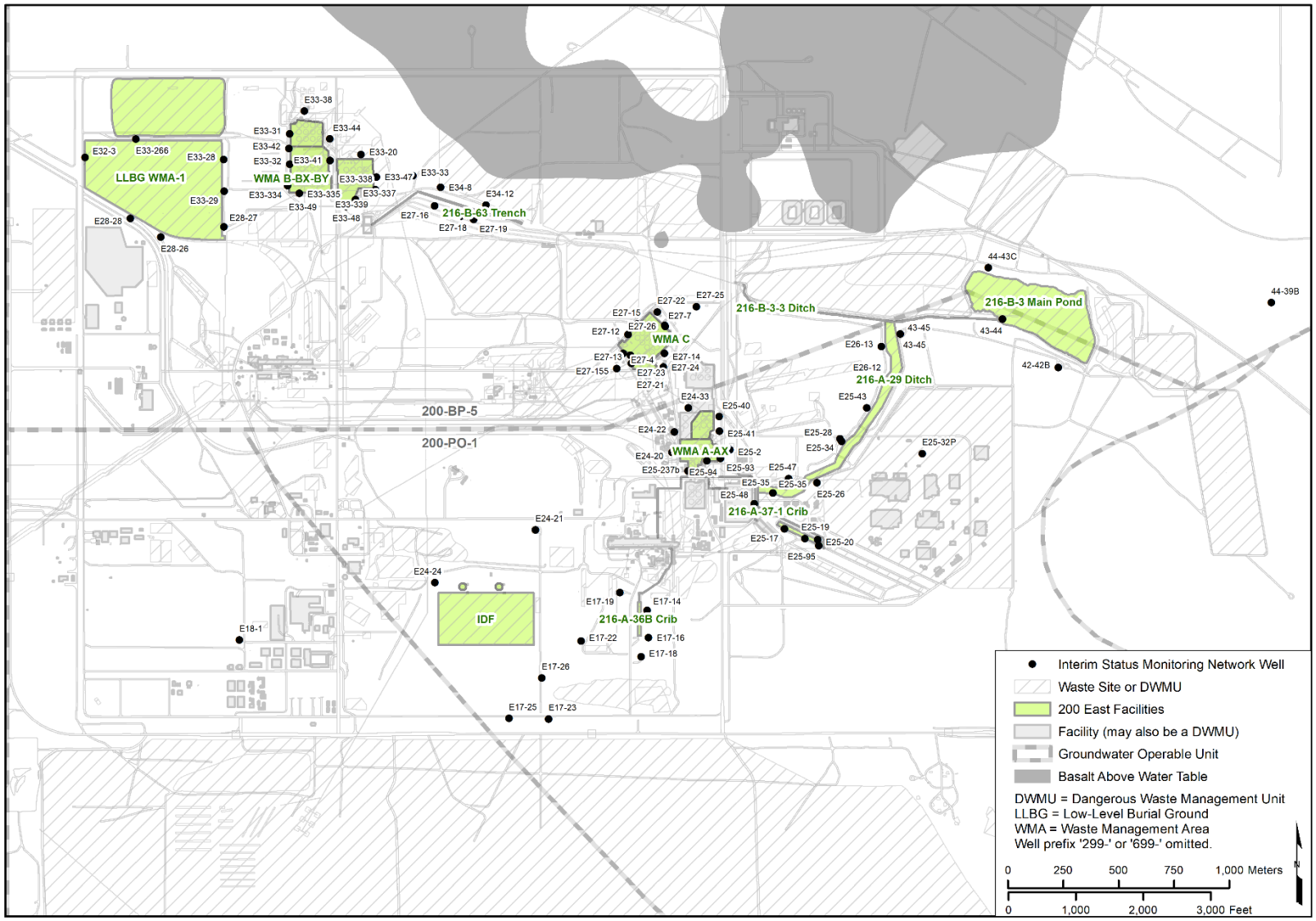

Figure 2-1. Interim Status Monitoring Networks Associated with 200 East Facilities

2.2 Water-Level Mapping in the 200 East Area

To support the assessment of the groundwater monitoring networks associated with each facility, the evaluation performed in this ECF required the production of a piecewise, continuous (i.e., gridded) depiction of groundwater elevations throughout the 200 East Area. Historically, groundwater elevations in the 200 East Area varied greatly in response to discharges of water from site operations to many large wastewater receiving features such as 216-B-3 Pond. Most of those discharges ceased by the mid-1990s, after which groundwater elevations in the 200 East Area have fallen steadily in areas where discharges formerly occurred. In recent years, changes in groundwater elevations and in corresponding hydraulic gradients and flow directions have been less evident from year to year, as groundwater elevations asymptotically approach a quasi-steady-state condition.

The unconfined aquifer beneath the 200 East Area occurs in a buried paleochannel consisting of highly permeable sediments of the Hanford formation and Cold Creek unit. As a result, the water table exhibits a low-magnitude hydraulic gradient (i.e., a flat water table). In 2004, the hydraulic gradient magnitude in the 200 East Area vicinity was estimated using regional water-level measurement data to be 1.8×10^{-5} m/m (1.8×10^{-5} ft/ft) (SGW-54165, *Evaluation of the Unconfined Aquifer Hydraulic Gradient Beneath the 200 East Area, Hanford Site*). At LLBG WMA-1, for example, this equates to a water table elevation change of 1.6 cm (0.63 in.) across the site. However, water-level measurements at LLBG WMA-1 typically exhibited a range of 6 cm (2.4 in.). As a result, estimates of hydraulic gradients for the water table are subject to a low signal-to-noise ratio (i.e., noise in the data can obscure small differences in the true water table making the determination of hydraulic gradients difficult).

To improve the accuracy of depth-to-groundwater measurements and corresponding water table maps in the 200 East Area, a network of wells was established for which steps were taken to reduce water-level measurement error. This was first done at LLBG WMA-1 and then later at the Integrated Disposal Facility/Plutonium Uranium Extraction Plant Cribs area, LLBG WMA-2, and the Liquid Effluent Retention Facility. Previous work indicated that borehole deviation was the most important source of error in the 200 East Area water-level measurements. To remedy this, gyroscope surveys were performed in the wells to correct for verticality error and the tops of all the well casings were resurveyed for elevation using a highly accurate leveling technique.

The initial results at the facilities were mixed (SGW-54165) with some areas indicating uncertain flow directions. Based on this, it was reasoned that larger study areas were needed to allow for water-level elevation differences between wells to be more easily discerned. The well networks were expanded so that eventually a single low-gradient well network was established encompassing much of the 200 East Area. The collection of monthly water-level measurements from this network began during May 2013. The 200 East Area low-gradient network initially consisted of 56 wells and was expanded to 62 wells in 2015.

Groundwater elevations throughout the 200 East Area have been evaluated several times recently from an area-wide perspective. Examples of these evaluations are included in the following:

- ECF-Hanford-16-0013, *Hydraulic Gradients and Velocity Calculations for RCRA Sites in 2015*
- ECF-200E-12-0086, *Calculations in Support of the Low Hydraulic Gradient Evaluation Study for the 200 East Area Unconfined Aquifer*
- ECF-200E-15-0037, *Preparation of 200 East Area Water Table Maps for Calendar Years 2013 and 2014*

- ECF-200E-16-0093, *Preparation of 200 East Area Water Table Maps for Calendar Year 2015*
- SGW-54165, *Evaluation of the Unconfined Aquifer Hydraulic Gradient Beneath the 200 East Area, Hanford Site*
- SGW-58828, *Water Table Maps for the Hanford Site 200 East Area, 2013 and 2014*
- SGW-60338, *Historical Changes in Water Table Elevation and Groundwater Flow Direction at Hanford: 1944 to 2014*

Those studies did not, however, produce groundwater elevation depictions and resulting piecewise, continuous groundwater elevation grids throughout the 200 East Facilities suitable to meet the objectives of this ECF in supporting the assessment of the groundwater monitoring network associated with each facility.

To meet the objectives of this ECF, the method used to obtain groundwater elevation maps is a regularized inverse interpolation technique that is referred to here as the Tikhonov Regularized Inverse Method (TRIM). TRIM, summarized briefly here and detailed in Chapter 3, is founded upon a formal mathematical method that seeks a tradeoff between the complexity of the method or parameterization used to interpret measured data versus the "fit" to those data that the chosen method or parameterization attains. As described by Menke, 2018, *Geophysical Data Analysis: Discrete Inverse Theory, Fourth Edition*, and others, the calibration process is a tradeoff between method or parameter complexity and data fit – the more complex the method, or its parameterization, the more closely the outputs from that method or parameterization can be expected to fit the data. However, a better fit does not guarantee a better estimator or predictor. Particularly in cases where there is a low signal-to-noise ratio in the data, "over-fitting" can occur during which parameters respond to the noise rather than signal (Doherty, 2015, *Calibration and Uncertainty Analysis for Complex Environmental Models, PEST: Complete Theory and What it Means for Modelling the Real World*). Without suitable constraints that recognize the presence of a low signal-to-noise ratio, overfitting can attain a very good data fit by inferring high parameter or method complexity – manifested as a high parameter variance, such as exaggerated heterogeneity in a homogeneous system. In contrast, under-fitting can occur when method or parameterization used is too simple – either in that it does not reasonably approximate the underlying physics or reflect the dominant physical characteristics of the system and as a result has insufficient capability (degrees-of-freedom) to sufficiently reproduce the data. In either case of over- or under-fitting, the results often do not comport well with subject matter expert (SME) knowledge of the system or with independent sources of information.

For the purposes of this ECF, TRIM is used to obtain a piecewise, continuous grid of groundwater elevations using a simplified groundwater flow simulator as the underlying mechanism to interpolate between measured water levels. This is accomplished by developing a single-layer (i.e., two-dimensional) steady-state simulation approximating dominant groundwater flow characteristics over an area encompassing the 200 East Facilities, and then using Tikhonov regularization (Tikhonov and Arsenin, 1977, *Solutions of Ill-Posed Problems*, detailed in Chapter 3) to constrain parameter complexity in the simulation to prevent over-fitting to the measured water-level data. The advantage of using a simplified groundwater flow simulation as the underlying mechanism to interpolate between the measured water levels is that the resulting groundwater elevation grids conserve mass and are suitable for tracking particles to evaluate the likely paths of groundwater and any contaminants that may reach the water table beneath the 200 East Facilities.

3 Calculation Methods

This chapter describes the calculation methods used to support this ECF. Simulations were conducted to evaluate the interim status groundwater monitoring networks at each of the 200 East Facilities. The objective of the simulations was to evaluate the efficacy of the networks to detect significant increases in groundwater contamination that might occur from a contaminant release that reaches the underlying water table.

3.1 Water-Level Mapping Using the Tikhonov Regularized Inverse Method

Using the data and methods described in the following sections, regularized inverse mapping was performed to produce continuous gridded depictions of groundwater elevations encompassing the 200 East Facilities to represent groundwater elevations throughout the 200 East Area.

3.1.1 Data Used

For each well, the annual average values of the measured groundwater elevations obtained from the four most recent comprehensive monitoring data sets (obtained for 2013, 2014, 2015, and 2016) were evaluated for assessing the monitoring networks. The annual average water levels used for low-gradient network wells were described in SGW-58828 for years 2013 and 2014; in ECF-200E-16-0093 for 2015; and in ECF-200E-17-0121, *Preparation of 200 East Area Water Table Maps for Calendar Year 2016*, for 2016. Water-level measurements for two wells that are not in the low-gradient network were also used in the analysis. For these two wells, the water-level measurements from March of the corresponding year were used. The evaluation of the monitoring well network for each 200 East Facility is based upon evaluation of all four of these annually averaged data sets, collectively. Piecewise, continuous grids of groundwater elevations that both conserve flow throughout the area of interest and are consistent with measured groundwater levels where available were prepared for each of the years considered in the calculations (i.e., 2013 through 2016). Maps of groundwater levels in the 200 East Area rely primarily on the wells of the low-gradient network, supplemented with other wells when necessary.

3.1.2 Method Description

The method used to obtain the groundwater elevation grids (TRIM) is a formal mathematical technique that is used to tradeoff the complexity of a method or parameterization that is being used to analyze measured data. When used with a deterministic model, the Tikhonov regularization is used to constrain the parameters of the model while attempting to attain a satisfactory “fit” to the measured data that also comports with independent or SME knowledge and information.

TRIM implements a common application of Tikhonov regularization, by supplementing the measurement dataset, in this case, annually averaged water-level measurements from the years 2013 through 2016, with other information derived from SME knowledge. This information is cast formally as “prior information” representing a preferred system condition. The addition of this information results in a mathematical technique often referred to as penalized-least-squares regression, because a penalty is incurred when the parameters deviate too far from the preferred system condition specified by the SME. The size of the penalty that is incurred during the regression is controlled using a global weighting parameter (Tikhonov and Arsenin, 1977), referred to as the global regularization weight parameter that is commonly denoted by μ (Doherty, 2015). The size of this penalty is “traded” against the degree to which the simulation matches or “fits” the measurement data: to attain a better fit to the measurement data, a larger penalty is usually incurred by deviating further from the preferred system condition.

This method of specifying the preferred system condition can take many forms, although it is most commonly specified as either a preferred-value (e.g., it is desired that the best fit to the data be attained

while attaining parameter values that are close to a preferred value of X) or a preferred-difference condition (e.g., it is desired that the best fit be obtained to the data while obtaining parameter values that deviate minimally from each other). In the context of groundwater data analysis, particularly for clastic sedimentary aquifer materials such as those encountered in the unconfined aquifer of the 200 East Area, the preferred system condition that is specified is typically homogeneity, i.e., that the regression should seek as good a fit as can be obtained while keeping parameters as homogeneous as possible. This approach, also often referred to as "smoothness" regularization, is used to prevent the regression from inferring parameter values that are considered by SMEs to be unlikely given their system knowledge.

The tradeoff between the complexity of the simulator or its parameterization versus the fit obtained to the measurement data can be plotted graphically. Doing so often results in a shape similar to an upper-case letter L (i.e., concave upward to the right) and for this reason it is referred to as an L-curve (Hansen, 2000, *The L-curve and its use in the numerical treatment of inverse problems*). L-curves are used to evaluate the relationship between two related or competing terms in many different analyses, providing a graphical means to identify an acceptable solution that does not either over-fit or under-fit the data. In the context of Tikhonov regularization, the L-curve plot depicts the tradeoff between a sum-of-squared-weighted-residuals (or "least-squares") measurement objective function, usually depicted on the X-axis, and a regularization objective function that is calculated as the sum-of-squared deviations from the preferred system condition. The manner in which this plot changes with different values of the global regularization weight parameter, μ, traces the tradeoff between these two objective functions.

An example L-curve is depicted in Figure 3-1 (after Hansen, 2000). The figure illustrates that as the value of the global regularization weight parameter increases, greater emphasis is placed on honoring the preferred system condition which keeps the regularization objective function low but results in a larger measurement objective function (effectively penalizing the fit achieved to the measured data). Conversely, as the value of the global regularization weight parameter decreases, less emphasis is placed on honoring the preferred system condition that results in a larger regularization objective function but enables the regression process the flexibility to deviate from the preferred condition and attain a better fit to the measurement data.

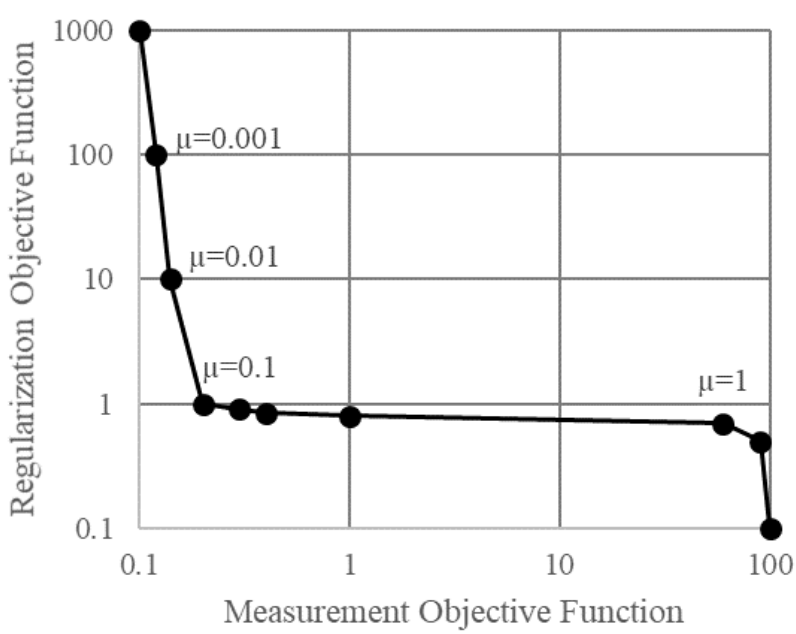

Figure 3-1. L-Curve Example

3.1.3 Implementation using MODFLOW-USG and PEST

Two linked calculation tools are needed to obtain the necessary piecewise grids from 2013 through 2016:

1. A method for calculating groundwater elevations throughout the area
2. A method for implementing the Tikhonov regularization technique to evaluate the tradeoff between complexity and data fit

3.1.3.1 Groundwater Elevations

Throughout the 200 East Area the predominant factors that affect area-wide groundwater flow patterns are (1) the high-hydraulic conductivity sediments that comprise the Hanford formation and the Cold Creek unit, (2) the location of lower hydraulic conductivity sediments and basalts that are lateral to or located within the high-conductivity sediments, and (3) lateral sources and sinks (inflows and outflows) of water particularly along the northwest and southeast extents of the 200 East Area. For purposes of this ECF, these predominant factors are represented by developing and parameterizing a simplified single-layer (two-dimensional) steady-state simulation of groundwater flow using the unstructured grid release of the MODFLOW program, MODFLOW-USG.

The MODFLOW-USG simulation code is a control-volume finite difference formulation of the commonly used finite-difference U.S. Geological Survey MODFLOW groundwater flow simulator. A disadvantage of the regular rectangular grids that result from the use of regular finite-difference methods when calculating groundwater levels is that when small cells are used to represent an area of interest, a very large number of cells is created throughout the domain. When used together with Tikhonov regularization, this can produce a number of relationships between parameters that can render the problem mathematically intractable. An advantage of the unstructured grid formulation implemented in MODFLOW-USG is that it can support irregular and non-rectangular grids. In particular, MODFLOW-USG can support a Voronoi grid, which is well suited to the purpose of this exercise because (a) a much smaller number of cells is needed to discretize the area encompassing the 200 East Facilities, and (b) a correspondingly smaller number of regularization (prior information) equations is needed to specify relations between the parameter value in each cell and that of its nearest neighbors.

The simplified two-dimensional simulator of groundwater flow conditions was constructed as follows:

1. A single-layer grid was constructed using a Voronoi mesh. The Voronoi mesh was designed using the software program AlgoMesh® (HydroAlgorithmics, 2016, *AlgoMesh User Guide*) that enables the user to adjust the number of cells, their geometry, aspect ratios, and density in focused areas of the domain. AlgoMesh writes a file that defines the Voronoi mesh in a format that can be read by the Groundwater Vistas program, from which the MODFLOW-USG specific input files are generated and through which initial parameters and boundary conditions were developed.
2. Lateral boundary conditions were specified using (a) specified-flux boundaries to represent the flow between 200 East Area and 200 West Area, Gable Gap to the north, the basalt to the north, and the Treated Effluent Disposal Facility to the east; and (b) a specified-head boundary to represent the region to the southeast where groundwater flows eastward toward the Columbia River.
3. Based on SME knowledge of the system, the hydraulic conductivity of the sediments within which the water table resides was discretized into three hydrostratigraphic unit (HSU) zones, representing the Hanford formation, Cold Creek unit, and Ringold Formation member of Wooded Island – unit E. Delineation of HSUs at the elevation of the water table was prepared by intersecting the Central

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Plateau Groundwater Model (CPGWM) water table grid with a three-dimensional geological model (ECF-HANFORD-13-0029, *Development of the Hanford South Geologic Framework Model, Hanford Site, Washington*). Within each of these delineated HSU zones, the hydraulic conductivity was defined as homogeneous for purposes of defining initial parameter values (this represents the "preferred system condition" at the commencement of the Tikhonov regularization that followed).

The boundary conditions and initial parameter values were defined in text files in a format that can be read by the MODFLOW-USG program. The resulting simplified groundwater flow simulator is two-dimensional (i.e., a single layer) and is composed of 1,811 active cells with the resolution of the mesh refined in areas of particular interest such as groups of monitoring wells. The resulting grid, boundaries, and hydraulic conductivity zones are shown in Figure 3-2.

3.1.3.2 Tikhonov Regularization

The method of Tikhonov regularization is implemented in several commonly used software packages and programming environments. One of these is the parameter estimation and uncertainty analysis program PEST (Doherty, 2015), which implements Tikhonov regularization as a form of constrained parameter estimation or calibration procedure. PEST is used widely at the Hanford Site to assist with the calibration of groundwater models and other models, using a suite of utilities for linking it to groundwater models and other programs, and for this reason was selected for use for purposes of this ECF. When incorporating Tikhonov regularization in a calibration using the PEST software, the sum-of-squared-weighted-residuals measurement objective function that PEST seeks to minimize during traditional parameter estimation is augmented with a second term that describes in a similar manner the degree of deviation from the preferred system condition, by calculating a sum-of-squared-weighted differences between the preferred condition and the actual condition that is represented by the value of the parameters (Tonkin and Doherty, 2005, "A Hybrid Regularized Inversion Methodology for Highly Parameterized Environmental Models"; Doherty, 2015; Doherty, 2016, *PEST Model-Independent Parameter Estimation User Manual Part I: PEST, SENSAN, and Global Optimisers*). This sum-of-squared-weighted deviations from the preferred conditions constitutes the regularization objective function that is depicted on the L-curve figure shown in Figure 3-1.

The PEST software can implement Tikhonov regularization in two specific modes of operation. When operating in the first of these modes, denoted as regularization mode, the PEST program calculates updates to the values of the parameters that provide an improved fit to the measured values and also determines a global regularization weight parameter that enables the measurement component of this composite objective function to meet a target value ascribed by the user as representing an "acceptable" fit (Doherty, 2015). When operating in the second of these modes, denoted as Pareto Mode, the PEST program calculates updates to the values of the parameters by conducting a form of line-search that describes a Pareto-front exploring the relationship between the regularization objective function, the global regularization weight parameter, and measurement objective function in a manner that can be used to plot an L-Curve such as that depicted in Figure 3-1. Both modes of operation were used for purposes of this ECF, as detailed in Chapter 6.

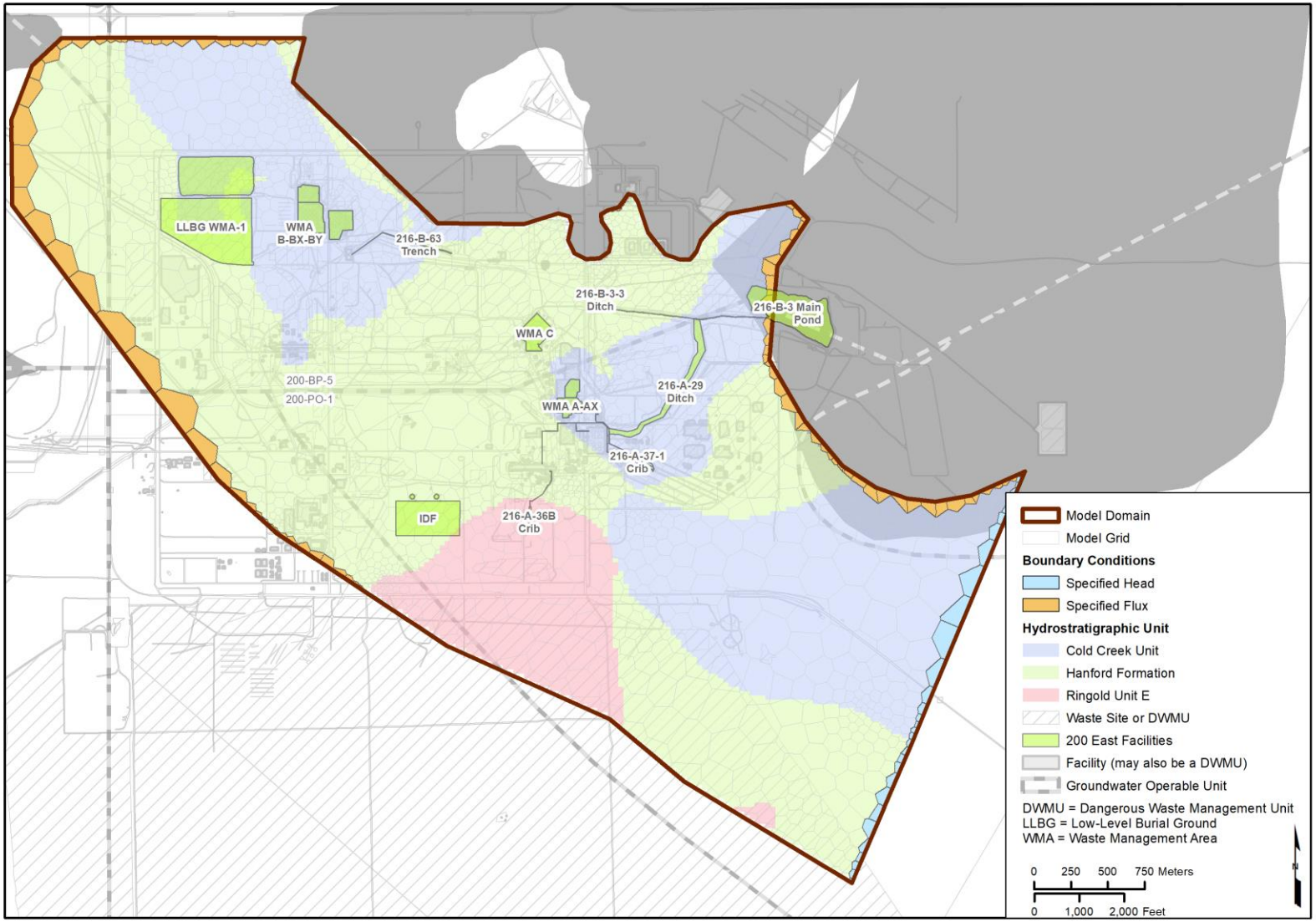

Figure 3-2. Two-Dimensional Simulator Boundary Conditions and HSU Zones

3.1.3.3 Limitations

The simplified two-dimensional groundwater flow simulator that underlies TRIM, developed using the MODFLOW-USG code for purposes of this ECF, was implemented specifically for the purpose of providing a mechanism to interpret groundwater level data and obtain contours depicting directions of groundwater flow and potential migration pathways based upon those measured data. The groundwater elevation contours are obtained by trading-off the complexity of the parameterization of the groundwater simulator versus the fit that is obtained to the measured groundwater elevation data, effectively using the groundwater simulator as an alternative to distance-weighted interpolation (such as kriging) to interpolate between the measured groundwater level data. Because the resulting piecewise-continuous groundwater elevation grids depict hydraulic gradients that comport with independent SME knowledge of subsurface conditions, they are suitable for particle-tracking analyses to depict approximate rates and directions of groundwater flow and potential contaminant migration in the vicinity of the 200 East Facilities.

The simplified two-dimensional groundwater flow simulator that underlies TRIM is not a substitute for existing three-dimensional groundwater flow and contaminant transport models at the Hanford Site, such as the CPGWM and the Plateau to River model. There are many simplifications in the underlying groundwater flow simulator developed for purposes of this ECF: these include use of a single layer representing only water table conditions; the regularization objective sought in TRIM of homogeneity without specific regard for the values or physical meaning of the resulting parameters; and the simplified representation of the lateral boundaries of the area of interest. Because of these and other simplifications and limitations, the MODFLOW-USG simulator underlying TRIM should not be used for mass-conserved simulations of contaminant transport either together with or as an alternative to the existing three-dimensional groundwater flow and contaminant transport models (i.e., the CPGWM and Plateau to River model).

3.2 Particle Tracking

The groundwater elevation maps produced using TRIM depict general patterns of hydraulic gradients and groundwater flow and therefore the likely directions of contaminant migration if a contaminant release from a facility reaches the water table. Particle tracking provides a method of visualizing these directions and potential paths of contaminant migration enabling a more detailed assessment of monitoring well locations. After the grids of groundwater elevations were created using TRIM, they were used as the base for particle tracking. Particle tracking was performed using mod-PATH3DU and considering advective-only or advective and dispersive transport mechanisms (Muffels et al., 2018, *User's Guide for mod-PATH3DU: A Groundwater Path and Travel-Time Simulator*). The parameters used to calculate particle pathlines assume migration of a conservative (i.e., nonreactive) dissolved contaminant under representative conditions.

Calculated particle pathlines provide a way to visualize how a hypothetical release to the water table from the facility would move and spread under conditions represented in each of the four mapped years (2013, 2014, 2015, and 2016). Particle-tracking calculations specific to each facility and assuming advective-dispersive transport, produced both particle pathlines and particle counts.

3.2.1 Regional-Scale Advection-Only Particle Tracking

Advection-only particle tracking based upon water-level mapping was performed on a regional scale to provide general patterns of groundwater flow near each facility under conditions represented by each of the four mapped events (calendar years [CYs] 2013, 2014, 2015, and 2016). No detailed post-processing of the advection-only particle traces was undertaken because their intent is qualitative only.

3.2.2 Regional-Scale Advective-Dispersive Particle Tracking

Regional-scale particle tracking considering both advection and dispersion was performed to examine how a potential release that might reach the underlying water table from a facility would realistically move and spread downgradient under conditions represented by each of the four mapped events (CYs 2013, 2014, 2015, and 2016). Similar to the regional-scale advection-only particle tracking, no detailed post-processing of the particle traces was undertaken because their intent is to illustrate general patterns of migration for a hypothetical release that reaches the underlying water table from the 200 East Facilities. However, detailed post-processing of local-scale advective-dispersive particle traces was undertaken to support the facility-specific assessments of monitoring network efficacy as described below.

3.2.3 Local-Scale Advective-Dispersive Particle Pathlines

Advective-dispersive particle-tracking calculations were also performed on a local or facility-specific scale. At the facility-specific scale, a higher volume of particles was released at the release locations to produce many pathlines, each of which depicts the potential path of a particle of dissolved contaminant released at the water table beneath a facility. Because of this, the calculated particle pathlines provide a way to visualize how a hypothetical release to the water table from the facility would move and spread under conditions represented in each of the four mapped years (2013, 2014, 2015, and 2016). The particle pathlines simulate the one-time release of a large number of particles representing an instantaneous release to the water table. Because vadose zone travel time is ignored the particle release year represents only the year that hypothetical contamination reaches the water table.

In addition to the presentation of particle pathlines, the particle paths were post-processed following the series of steps described in Chapter 6 to provide additional depictions and calculations including particle counts at well locations and maps of particle density (particle count maps) as described below.

3.2.4 Particle Counts

Calculated particle counts can be used as a surrogate for contaminant concentration to evaluate the relative efficacy of the interim status groundwater monitoring wells and the need for and suitability of any proposed new monitoring wells. Relative particle counts at well locations were calculated by counting the number of particles that pass through the vicinity of an existing or potential new monitoring well location and recording the time of each particle's arrival. A radius of 20 m (66 ft) around each well location was used to count particles as they arrived. The calculations produce two outputs that are used to help evaluate the groundwater monitoring network:

- A tabulation of particle density (counts) arriving at each interim status groundwater monitoring well and each potential new monitoring well. This count is the total number of particles that pass through the vicinity of the well (within 20 m [66 ft] radius surrounding the well), regardless of time.
- A time-series plot of the likely arrival, peak, and decline in the (relative) concentration at each location resulting from an instantaneous release at the associated facility. This plot is prepared by summing the particles within a small number of arrival time bins in the manner used to construct a histogram.

Particle counts were also used to create particle count maps that depict areas of relatively higher and lower potential impact from a release that reaches the water table from a given facility. Contour maps of particle counts were generated by counting the number of particles that pass through a pre-defined uniform calculational grid. The grids used at each facility to develop the relative particle density maps are defined by 10 by 10 m (33 by 33 ft) cells that are oriented parallel to the predominant groundwater flow

direction under each facility. The calculational grids for each facility are presented in the facility-specific appendices.

3.3 Evaluation of Vertical Migration Potential

Dissolved constituents that are released within the vadose zone (i.e., above the water table) and migrate downward, ultimately make their first impact to groundwater at the top of the aquifer (i.e., at the water table. Although the initial impact is at the water table, over time any dissolved constituents that mix with actively moving groundwater have the potential to move vertically within the aquifer). When attempting to monitor for and detect potential releases that have affected the water table, the possibility that constituents may migrate beneath the bottom of the screen interval of monitoring wells is of great concern.

An analysis of the vertical migration of dissolved constituents is presented in Appendix A. The likely vertical migration due to recharge accrual at a specific site can be estimated using a variety of methods, including analytical and numerical models. The analysis in Appendix A concluded that an analytical calculation, the American Petroleum Institute (API) plume diving calculation (Nichols and Roth, 2006,"*Downward Solute Plume Migration: Assessment, Significance, and Implications for Characterization and Monitoring of "Diving Plumes"*) could be used to estimate the likely rate of vertical migration of dissolved constituents downward under the influence of recharge at the water table. The API plume diving calculation estimates the anticipated slope at which the dissolved constituents will migrate, the slope of the dive:

$$Slope\ of\ Dive\ (S) = \frac{Accretion\ Rate\ (I)}{Seepage\ Velocity\ (V)} = \frac{Vertical\ velocity\ (v_v)}{Horizontal\ velocity\ (v_h)} = \frac{Recharge\ Rate\ (i)}{Darcy\ Flux\ (q)} \qquad \text{Eq. (1)}$$

The calculations performed involved dividing the recharge rate (e.g., in units of m/yr) by the Darcy Flux (in consistent units of m/yr, also known as the specific discharge). The Darcy Flux is calculated by multiplying the hydraulic conductivity by the hydraulic gradient.

The calculated slope can be used to estimate the distance beneath the water table at which dissolved concentrations will be found at a specified distance from the point of release. Equation 1 can be reorganized to estimate the potential for dissolved constituents to migrate beneath a specific well screen that is located a known distance (x) from the point of release in Equation 2 (Nichols and Roth, 2006):

$$i \geq \frac{qd}{x} \qquad \text{(Eq. 2)}$$

where the quantity *d* corresponds to the depth from the water table to the bottom of the monitoring well screen.

Thus, at each well the slope of the plume dive can be multiplied by the distance from the particle starting location to the well location to estimate the depth to which the dissolved constituents may be anticipated to have migrated by the time they reach the monitoring well location. This estimated depth of the plume can be compared to the depth from the water table to the bottom of the monitoring well screen. If the depth of the plume is below the bottom of the monitoring well screen, then the dissolved constituents may be anticipated to pass beneath the well screen. If it falls within the interval between the top of the water table and the bottom of the well screen, then the well depth is appropriate for detection of releases at the facility. For DWMUs in the 200 East Area, the API plume diving calculator was used to evaluate the depths of monitoring well screens in relation to the likely average rate of vertical migration of dissolved constituents moving downgradient from their location of release to the water table.

4 Assumptions and Inputs

This chapter outlines those assumptions and inputs that underlie the calculations presented in this ECF.

4.1 Assumptions

Assumptions used for the groundwater flow analysis, groundwater elevation mapping, and particle tracking are discussed in the following sections.

4.1.1 Tikhonov Regularized Inverse Method of Water-Level Analysis

Water-level contour maps were constructed using a method that combines the use of a simplified simulator of groundwater flow together with the use of Tikhonov regularization implemented in both calibration and Pareto-front analysis modes. The resulting groundwater elevation contour maps provide plausible interpretations of groundwater levels and hydraulic gradients between measured locations that match measured water levels and monitoring wells to a degree consistent with the tradeoff between that fit and parameter complexity and that achieve flow conservation through the use of the underlying groundwater flow simulator as the interpolation mechanism between measurement locations.
The accuracy of the contours, however, is influenced by several factors, including the following:

- The accuracy of the measured or recorded water levels
- The number, distribution, and location of monitoring wells
- The relationship between the vertical open interval(s) of the monitoring wells and those of the extraction and injection wells

These potential sources of error mean that the maps only approximate actual conditions. The water-level and particle pathline maps are considered reasonable approximations that provide inference in the interpretation of likely directions and rates of groundwater movement. The maps also help identify areas downgradient of the 200 East Facilities that likely would be impacted by a potential release that reached the underlying water table. Considering multiple groundwater elevation events in the analysis helps to develop a reasonable estimate of potential migration pathways under the different conditions represented by those events.

4.1.2 Particle Tracking

Particle tracking based upon water-level mapping relies upon outputs (i.e., grids of mapped groundwater elevations) computed using TRIM. As a result, the assumptions and limitations that underlie the preparation of those maps are implied in any subsequent particle tracking.

Particle tracking that considers advection-only relies upon the assumption that the values of the hydraulic conductivity and mobile (effective) porosity of the aquifer, which are represented as single best-estimate values in most calculations, are representative of the bulk conservative transport of water and dissolved constituents.

Particle tracking that considers advection and dispersion relies upon the assumption that the values of the dispersion coefficients in the two principal directions (longitudinal and transverse) are representative of physical processes that act to disperse dissolved constituents in groundwater at the scale of the calculations.

4.1.3 Vertical Migration

The geographic locations of the Central Plateau DWMUs and their monitoring well networks indicate that existing or proposed monitoring wells usually are located within the same HSU as the aquifer material beneath the release site (i.e., there are no intervening transitions between the release location and the monitoring wells). In most cases, the monitoring wells also are closer to the release location than to any groundwater pumping wells. Given these conditions, the API plume diving calculator provides reliable estimates of the likely average rate of vertical migration of dissolved constituents moving downgradient from the simulated location of their release to the water table. The use of the API plume diving calculator assumes the vertical migration is attributed solely to displacement from recharge and that there is negligible vertical mixing.

4.2 Input Data

This section summarizes the general input requirements for the calculations described in this ECF.

4.2.1 Water-Level Mapping Input

Appendix B of this ECF provides tables of the annual average measured groundwater levels for CYs 2013, 2014, 2015, and 2016, which are inputs to the water-level mapping.

4.2.1.1 Migration Parameters for Particle Tracking

Only a few parameters are required for the migration calculations performed using the groundwater-level maps and particle-tracking methods. The mobile porosity and hydraulic conductivity values were defined specific to each HSU detailed in CP-47631, *Model Package Report: Central Plateau Groundwater Model, Version 8.4.5*. The values for each HSU are listed in Table 4-1. Dispersivity values are assumed constant throughout entire region and are listed in Table 4-1.

Table 4-1. Aquifer Transport Parameter Values

Property		Value	Comments
Hydraulic conductivity	Hanford formation	15000 m/d (49,213 ft/d)	CP-47631
	Cold Creek unit	18200 m/d (59,711 ft/d)	CP-47631
	Rwie	35.6 m/d (117 ft/d)	CP-47631
Effective porosity	Hanford formation and Cold Creek unit	0.25	CP-47631
	Rwie	0.08	CP-47631
Longitudinal dispersivity		3.5 m (11.5 ft)	Introduced for stability of the transport calculations using recommendation from the MT3DMS manual (Zheng and Wang, 1999)
Transverse dispersivity		0.7 m (2.3 ft)	20% of longitudinal (DOE/RL-2008-56)

Table 4-1. Aquifer Transport Parameter Values

Property	Value	Comments
Vertical dispersivity	0.0 m (0.0 ft)	DOE/RL-2008-56

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

DOE/RL-2008-56, *200 West Area Pre-Conceptual Design for Final Extraction/Injection Well Network: Modeling Analyses*.

Zheng, C., and P. Wang, 1999, *MT3DMS: A Modular Three-Dimensional Multispecies Transport Model for Simulation of Advection, Dispersion, and Chemical Reactions of Contaminants in Groundwater Systems; Documentation and User's Guide*.

MT3DMS = Modular Three-Dimensional Multispecies Transport Model for Simulation of Advection, Dispersion, and Chemical Reactions of Contaminants in Groundwater Systems

Rwie = Ringold Formation member of Wooded Island – unit E

The primary purpose of the assessment presented in this ECF is to estimate directions of potential contaminant migration in order to assess the efficacy of the monitoring well networks. The values assigned to the hydraulic conductivity and mobile (effective) porosity for the calculations for the 200 East Facilities do not affect the assessment of the monitoring network efficacy. The values assigned to those parameters do, however, affect the calculations of (relative) arrival times at existing and proposed monitoring locations.

Appropriate values for dispersivity in transport calculations generally are recognized to be scale dependent. For purposes of the engineering evaluations, the simulations of transport in the saturated zone assume values for dispersivity in all three directions (longitudinal [3.5 m {11.5 ft}], transverse [0.7 m {2.3 ft}], and vertical [0.0 m {0.0 ft}]). These values are on the lower end of values identified as typical of field-scale sites by, among others, Gelhar et al., 1992, "A Critical Review of Data on Field-Scale Dispersion in Aquifers," and Xu and Eckstein, 1995, "Use of Weighted Least-Squares Method in Evaluation of the Relationship Between Dispersivity and Field Scale." The values are considered to be on the lower end primarily for the following reasons:

- First, the dominant mechanisms leading to spreading of contamination at the Central Plateau historically are likely to have been hydraulic transients and subsurface heterogeneity, and to some degree, the latter mechanism is represented in the analysis by virtue of the heterogeneous parameterization.
- Second, although the historical groundwater plumes of the Central Plateau are on the order of hundreds of meters in length and/or width, the distances and scales relevant to specifying dispersion lengths for the engineering evaluations is the typical distance from potential release locations to downgradient monitoring wells, which is substantially less than the scale of the historical plumes.

The range of values listed below for longitudinal dispersion are based upon a typical migration distance from the potential source to the monitoring network of about 200 m (656 ft) and the recommendations of Gelhar et al., 1992, and Xu and Eckstein, 1995, as incorporated in the U.S. Environmental Protection Agency's online calculator, EPA, 2016, "Estimated Longitudinal Dispersivity":

- 0.37 m (1.2 ft) (lower limit: Gelhar et al., 1992)
- 1100 m (3,609 ft) (upper limit: Gelhar et al., 1992)
- 6.21 m (20.4 ft) (Xu and Eckstein, 1995)
- 20 m (66 ft) (1/10th of migration distance, "rule-of-thumb")

The values for longitudinal dispersivity used in the engineering evaluation calculations (3.5 m [11.5 ft]) are at the lower end, as noted above. The assumption of a lower end value for longitudinal dispersivity has two implications for evaluating the efficacy of a monitoring network for detecting a release: first, lower end values result in relatively narrower plumes than would higher end values; and second, the lower values result in relatively higher detectability for monitoring wells that are located directly in the path of a release. Given the objective of identifying a suitable spatial distribution of monitoring wells, emphasis was placed upon producing results that do not overestimate the likely width of groundwater effects resulting from a hypothetical release.

4.2.2 Particle Starting Locations

This ECF describes particle-tracking calculations that depict general patterns of hydraulic gradients, groundwater flow, and likely contaminant migration. The particle release locations for the calculations include the plausible area over which a potential release might occur from each facility. For tank farms, particle starting locations were specified around the perimeter of each SST. For other DWMUs, the particle release locations were specified to have approximately 50 m (164 ft) between release points, either along the facility perimeter or throughout the footprint of a predefined release location.

For the regional-scale analysis, one particle was released and tracked from each particle starting location. For the more detailed analyses pertaining to each facility, 20 particles were released from each particle release location to provide the density of particles in space and time required for those more detailed calculations. The starting locations for simulated releases from each facility are shown in each facility-specific appendix. The particles were tracked randomizing the seed values for the dispersion calculations.

4.2.3 Vertical Migration Input

The slope of the plume dive is computed using the API plume diving calculation as detailed in Section 3.3. The facility-specific migration parameters for each facility that were used in the calculation of slope include hydraulic conductivity, recharge rate, and hydraulic gradient.

The distance from a release location to each monitoring well location and the recharge rate specific to each well location were used to calculate the likely depth of the contamination at each well location using Equation 2 in Section 3.3. For most of the facilities, the distance used in the calculation was the distance from the centroid of the facility to the specific well location. For a few of the sites where the geometry of the facility made the use of the centroid unreasonable, the distance used in the calculation was the maximum distance of a particle's pathline from its starting location at the facility to its intersection with the well. For each well, the depth from the water table to the bottom of the monitoring well screen was obtained from published monitoring or assessment reports.

For each facility, a single representative facility-specific recharge rate was used. The recharge values represent fluxes from surface water discharge due to historical operations at the Hanford Site and are summarized in EMDT-BC-0002, *Vadose Zone Attenuated Recharge, Electronic Modeling Data Transmittal – Boundary Condition (Artificial Recharge)*-0002. The anthropogenic flux is added to the natural recharge component in order to establish the final total recharge flux used in the simulations. Discharges included in EMDT-BC-0002 have been attenuated to account for travel through the vadose zone.

The calculated depth of the contamination was then compared to the depth of the bottom of the monitoring well screen as described in Section 3.3. The values and sources of the above parameters used for each facility are discussed in the facility-specific appendices.

5 Software Applications, Descriptions, Installation and Checkout, and Statements of Validity

Software used to perform the calculations for this ECF was in accordance with PRC-PRO-IRM-309, *Controlled Software Management*.

5.1 Approved Software

The software used for this ECF was approved and complies with PRC-PRO-IRM-309. The software is managed under the following documents consistent with PRC-PRO-IRM-309:

- CHPRC-00257, *MODFLOW and Related Codes Functional Requirements Document*
- CHPRC-00258, *MODFLOW and Related Codes Software Management Plan*
- CHPRC-00259, *MODFLOW and Related Codes Software Test Plan*
- CHPRC-00260, *MODFLOW and Related Codes Requirements Traceability Matrix*
- CHPRC-00261, *MODFLOW and Related Codes Acceptance Test Report*

PRC-PRO-IRM-309 distinguishes between safety software and support software based upon whether the software calculates reportable results or provides run support, visualization, or similar functions. Brief descriptions of the software are provided in Section 5.2.

5.2 Software Description

A controlled calculation software, MODFLOW-USG (Panday et al., 2013, "MODFLOW-USG version 1: An unstructured grid version of MODFLOW for simulating groundwater flow and tightly coupled processes using a control volume finite-difference formulation"), was used for the calculations that support this ECF.

- **Software title**: MODFLOW-USG solves transient groundwater flow equations using the finite-difference discretization technique.
- **Software version**: USG-TRANSPORT VERSION 1.0.0
- **Hanford Information Systems Inventory identification number**: **2517**
- **Workstation type and property number (from which software is run)**: SSP&A, FE563.

5.3 Support Software

The following software programs are classified as support software.

- **PEST**: (Doherty, 2016) Estimates parameter values that minimize the objective function(s) to calibrate models using inverse theory.
- **Groundwater Vistas™:** Rumbaugh and Rumbaugh, 2017, *Groundwater Vistas Version 7*. Provided graphical tools used for model quality assurance and model input/output review.

™ Groundwater Vistas is a trademark of Environmental Simulations, Inc., Reinholds, Pennsylvania.

- **ArcGIS®**: Visualization and post-processing tool for assessing simulated plume distributions, identifying extraction/injection well coordinates, and mapping auxiliary data (Mitchell, 1999, *The ESRI Guide to GIS Analysis, Volume 1: Geographic Patterns & Relationships*).
- **Surfer®:** Data interpolation for visualization, model implementation, and quality assurance.
- **mod-PATH3DU**: Particle-tracking code for calculating the three-dimensional flow pathlines and travel times of solute particles.
- **Python™:** The calculation and visualization of particle counts utilized Python, an interpreted, object-oriented programming language, with scripts executed using the Anaconda® freeware: Python Version 2.7.11 distributed with Anaconda 4.1.1 (64 bit).
- **AlgoMesh®:** A mesh-generating software used for creating unstructured triangular and Voronoi grids for MODFLOW-USG: AlgoMesh Version 1.2.0.37827 (64 bit) (HydroAlgorithmics, 2016).

5.4 Software Installation and Checkout

Safety software is checked out in accordance with procedures specified PRC-PRO-IRM-309. Executables are obtained from the CH2M HILL Plateau Remediation Company (CHPRC) software owner (who maintains the configuration-managed copies in MKS Integrity®). Installation tests identified in CHPRC-00259 are performed on the software and successful installation confirmed. Software installation and checkout forms are required and must be approved for installations used to perform model runs. Approved users are registered in Hanford Information Systems Inventory for safety software.

5.4.1 Statement of Valid Software Application

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

® ArcGIS is a registered trademark of the Environmental Systems Research Institute, Inc., Redlands, California.

® Surfer is a registered trademark of Golden Software, LLC, Golden, Colorado.

™Python is a registered trademark of Python Software Foundation, Beaverton, Oregon (www.python.org).

® Anaconda is a registered trademark of Anaconda, Inc., Austin, Texas (https://store.continuum.io/cshop/anaconda).

® Surfer is a registered trademark of Golden Software, LLC, Golden, Colorado.

® AlgoMesh is registered trademark of HydroAlgorithmics Pty Ltd, Canberra, Australia

® MKS Integrity is a registered trademark of MKS, Inc., Needham, Massachusetts.

6 Calculations

This chapter describes the calculations performed to examine all 200 East Facilities. The following steps were taken to develop the necessary input files, perform the calculations, and post-process the outputs to produce the results presented in this ECF.

6.1 Water-Level Analysis Using the Tikhonov Regularized Inverse Method

The following three steps were taken to produce the groundwater elevation maps presented in this ECF and used in all subsequent particle-tracking calculations:

1. **Data Compilation**: Input data were compiled from the retrieved database sources. Average groundwater elevations were calculated for 2013, 2014, 2015, and 2016 and used to define calibration targets for TRIM.

2. **Tikhonov Regularized Inversion**: Values for the parameters of the simplified two-dimensional groundwater flow simulator were iteratively updated using the Tikhonov regularization method implemented in PEST by obtaining successive improvements in the fit between the calculated and measured annual average groundwater levels for each year from 2013 through 2016, simultaneously. This process occurred in two substeps:

    a. First, an initial calibration was undertaken to produce a groundwater elevation map that approximated the measured groundwater levels but resulted in minimal deviation from the preferred system condition of homogeneity. This provided initial estimates for (a) the (relative) flow rates at each of the specified flux boundaries, (b) the hydraulic head at the specified head boundary for each of the four years, and (c) the (relative) hydraulic conductivity in each of the three HSU zones.

    b. Second, a series of iterations of Tikhonov regularized inversion was executed using PEST in the regularization mode, during which the effect on patterns of groundwater flow and hydraulic gradients of trading off the variance of the simulator parameters against the fit to the measured data was explored. For this second step, the value of the (relative) hydraulic conductivity for all cells located within the Ringold Member of Wooded Island – unit E HSU zone was fixed at a constant value, whereas the value of the (relative) hydraulic conductivity in each cell within the Hanford formation and Cold Creek unit HSU zones was defined as a parameter to be estimated via the regularized inversion, resulting in a total of 1,812 parameters. A preferred difference (i.e., smoothness) Tikhonov regularization scheme was defined within each of these three HSU zones by specifying prior information equations that penalized the (square of the) difference in the value of the hydraulic conductivity between neighboring cells. During the second step of the regularized inversion it was observed that a small number of monitoring wells consistently accounted for a significant proportion of the measurement objective function (i.e., the misfit) across all four years. The measurements associated with these wells were consequently ascribed a low-valued or zero-valued weight in the regression. The full set of calibration targets and their associated weights are listed in Table 6-1. A scatter plot that compares the calculated groundwater elevations with the measured groundwater elevations for all four periods as obtained at the conclusion of the regularized inversion steps (i.e., 2013 through 2016) is depicted in Figure 6-1.

Table 6-1. Calibration Targets and Their Weights

Well Name	Weights				Well Name	Weights			
	2013	2014	2015	2016		2013	2014	2015	2016
299-E17-18	10	10	10	10	299-E27-18	10	10	10	10
299-E17-21	5	5	10	5	299-E27-21	10	10	10	10
299-E17-22	10	10	10	10	299-E27-23	10	10	10	10
299-E17-23	10	10	10	10	299-E27-4	1	NA	NA	NA
299-E17-25	10	10	1	10	299-E27-7	10	10	10	10
299-E18-2	NA	NA	NA	2	299-E27-8	10	10	10	10
299-E23-1	10	10	NA	NA	299-E27-9	10	10	10	10
299-E24-16	2	2	2	2	299-E28-1	10	NA	10	10
299-E24-18	2	2	2	2	299-E28-17	1	NA	1	1
299-E24-21	10	10	10	10	299-E28-18	10	10	10	10
299-E24-22	10	10	NA	10	299-E28-27	10	10	10	10
299-E24-24	10	10	10	10	299-E32-5	10	10	NA	10
299-E24-33	10	10	10	10	299-E32-6	10	10	10	10
299-E25-19	10	10	10	10	299-E32-8	10	NA	10	10
299-E25-25	NA	NA	NA	5	299-E33-14	10	10	10	10
299-E25-34	10	10	10	10	299-E33-28	10	10	10	10
299-E25-35	10	10	10	10	299-E33-339	10	10	10	10
299-E25-36	10	10	10	NA	299-E33-34	10	10	10	10
299-E25-93	10	10	NA	10	299-E33-37	10	10	10	10
299-E26-10	10	10	10	10	299-E33-38	10	10	10	10
299-E26-13	10	10	10	10	299-E34-10	10	10	10	10
299-E26-14	0	0	0	0	299-E34-9	10	10	10	10
299-E26-4	10	10	10	10	699-32-43	2	2	2	2
299-E26-79	10	10	10	10	699-34-41B	2	2	2	2
299-E27-12	10	10	10	10	699-37-43	NA	NA	10	5
299-E27-14	10	10	10	10	699-37-47A	10	10	10	10
299-E27-15	10	10	10	10	699-49-55A	10	10	10	10
299-E27-17	10	10	10	10	699-49-57A	10	10	10	10

NA = not applicable

Figure 6-1. Comparison of Observed Versus Simulated Water Levels After Regularized Inversion Step

3. **Formal Pareto Analysis**: In the third step of the process, the PEST program was executed using Pareto mode incorporating the Tikhonov regularization results obtained in Step 2. The purpose of this step of the analysis was to produce the Pareto-front or L-curve to explore the tradeoff between the measurement objective function (i.e., fit to the water-level data) and the regularization objective function (i.e., the correspondence with the preferred state of parameter smoothness) (Doherty, 2015). The parameter value estimates that were obtained from the previously regularized inversion step were used as initial parameter values for the Pareto analysis. The Pest program was then executed to complete 10 iterations within which the global regularization weight parameter applied to the regularization objective function was raised geometrically from 0.01 (1×10^{-2}) to 0.2 (2×10^{-1}). The outputs from these Pareto calculations were then used to plot the L-curve depicted in Figure 6-2.

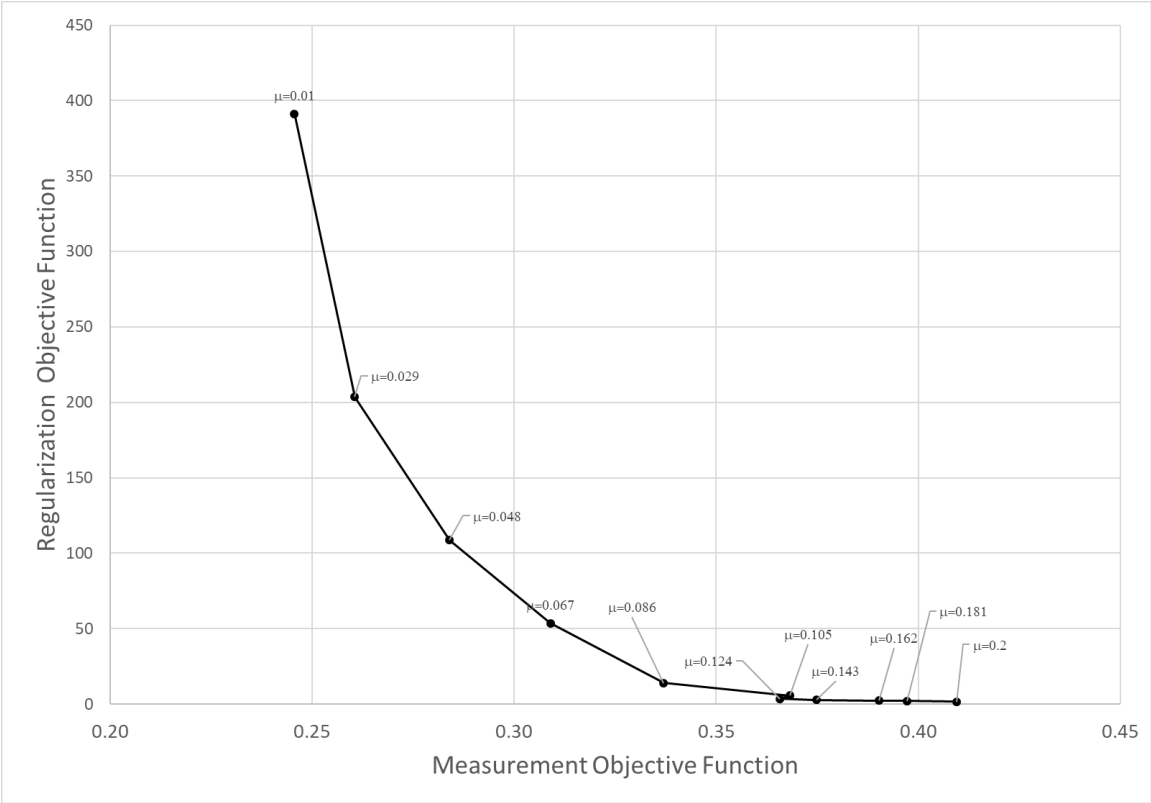

Figure 6-2. Calculated L-Curve

At the conclusion of the Pareto analysis, a combined review was completed by SMEs of both the resulting L-Curve and the individual groundwater elevation contour maps produced using the 10 global regularization weight parameters. From this review, the outputs produced by the Pareto iteration using a global regularization weight parameter of 0.124 were considered to represent a reasonable correspondence between the calculated and measured groundwater elevations, and this global regularization weight parameter was selected for purposes of subsequent assessments. This result was selected based on a weight-of-evidence approach as it (a) provided acceptable correspondence between calculated and measured groundwater elevations given estimated measurement errors, (b) produces groundwater elevation contours and hydraulic gradients that comport with each SME's independent understanding of groundwater elevations and gradients at each of the 200 East Facilities, and (c) results in calculated flow paths that comport with each SME's independent understanding of likely migration patterns downgradient of each of the 200 East Facilities. Using the outputs from the Pareto iteration using a global regularization weight parameter of 0.124, a scatter plot of the calculated versus the measured groundwater elevations is provided as Figure 6-3, and a cumulative plot of the residuals (i.e., difference between the calculated and measured values) is provided as Figure 6-4. Maps of the calculated groundwater levels together with the residuals, for each CY, are presented in Chapter 7.

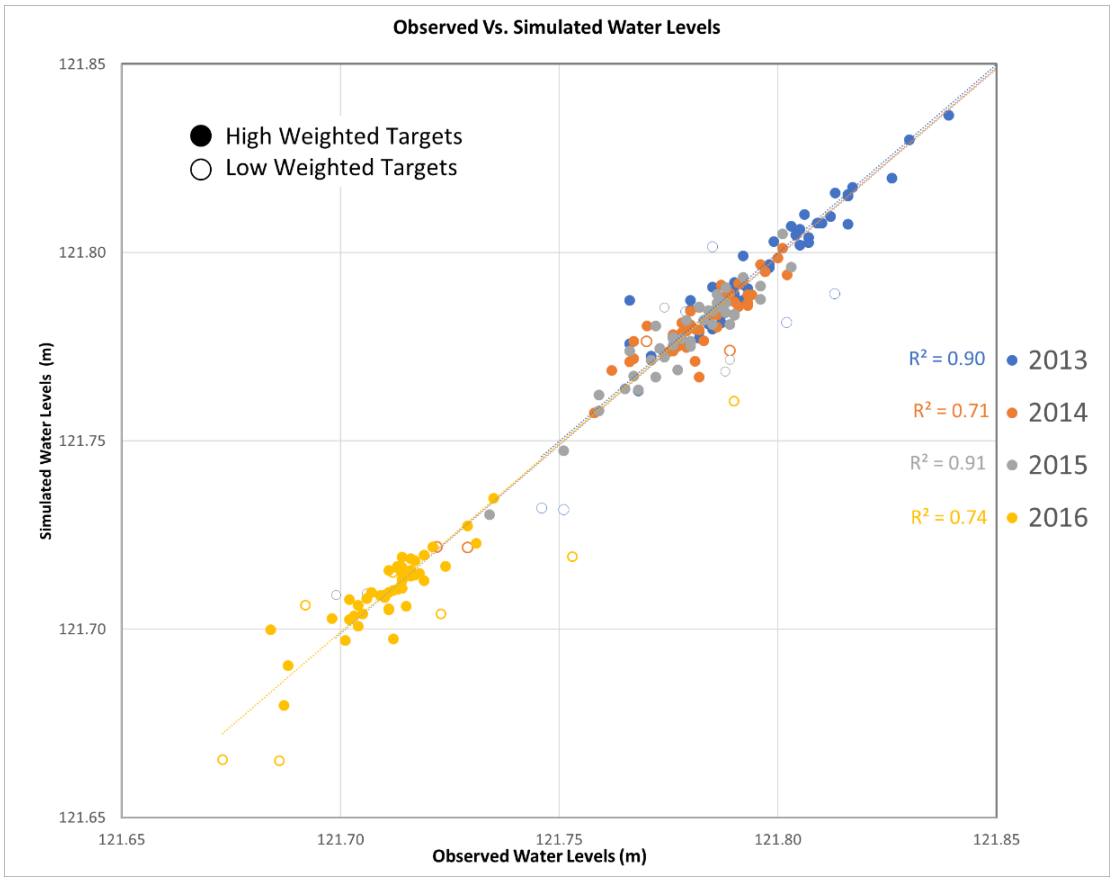

Figure 6-3. Comparison of Observed Versus Simulated Water Levels After Pareto Analysis

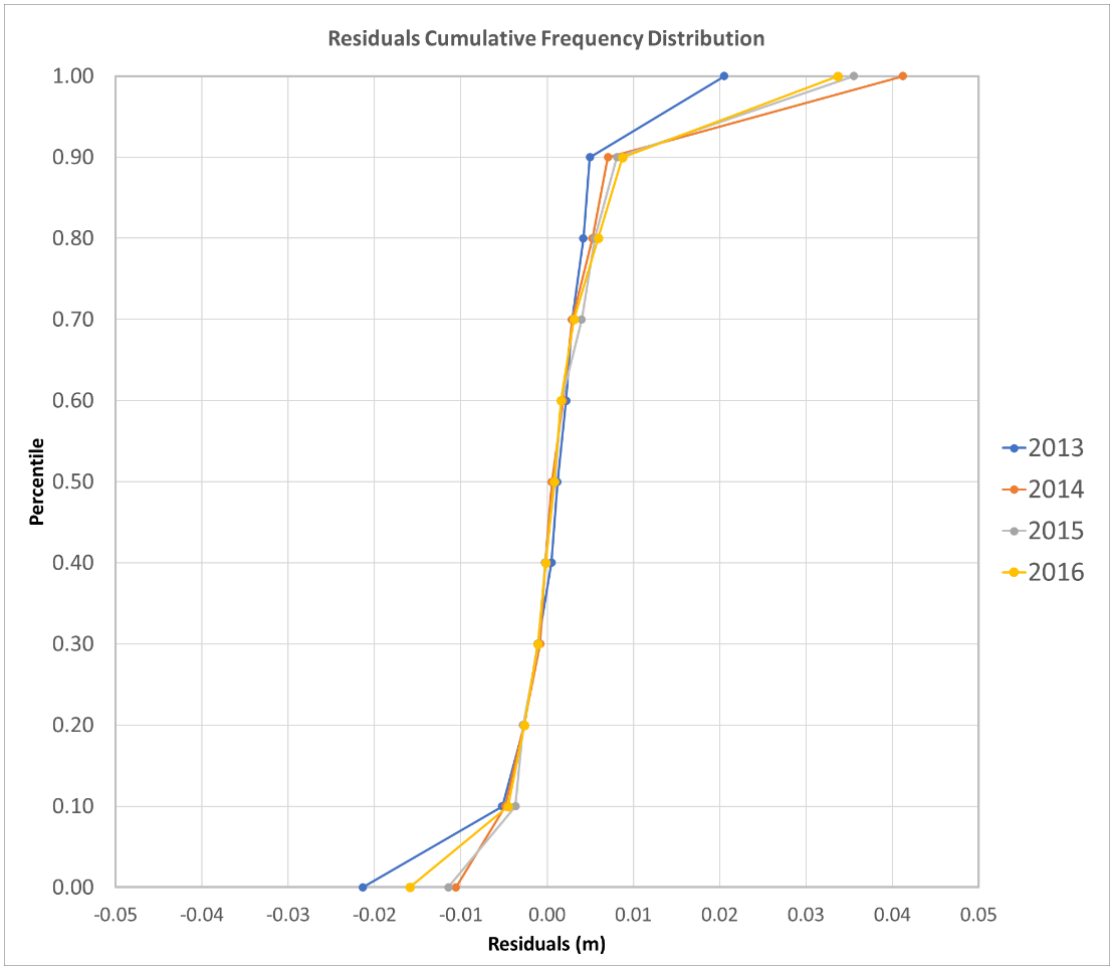

Figure 6-4. Cumulative Frequency Distribution of Residuals (Difference Between the Measured Water Level and Water Level Calculated Using Trim)

6.2 Particle Tracking

At the conclusion of the Pareto front analysis, for each of four CYs (2013 through 2016) the groundwater elevations calculated throughout the domain of the simplified groundwater flow simulator were imported into the Groundwater Vistas Graphical User Interface software, and then exported as a regular grid using the Surfer software grid format for use as input to the particle-tracking calculations. This resulted in four calculation grids for particle tracking: one for each of the years 2013, 2014, 2015, and 2016.

For the particle-tracking calculations presented in this ECF, an input file representing particle starting locations (release points) was prepared in an ArcGIS shapefile format. Particle starting locations were generated using one of the following approaches:

- Tank farms: Release points were located around the perimeter of each SST.
- LLBG WMAs: Release points were located along the centerline of Green Islands trenches.
- Ditches, ponds, and trenches: Release points were located along the centerline or on an equally spaced grid within the facility's footprint.

The ArcGIS shapefile was then used as input to the ModPath3DU program.

For each water-level mapping event (CYs 2013, 2014, 2015, and 2016), the following steps were implemented:

1. A mod-PATH3DU particle-tracking input file that included dispersion parameters was generated. Two sets of calculations were made, one considering advection only, and one considering advection and dispersion. To simulate dispersion with particle tracking, the random-walk particle-tracking option implemented within mod-PATH3DU was used. As described in the software documentation (CHPRC-00261), for consistency, this random-walk module reads and uses the same dispersion inputs as the Hanford Site version of the transport simulator MT3DMS (Modular Three-Dimensional Multispecies Transport Model for Simulation of Advection, Dispersion, and Chemical Reactions of Contaminants in Groundwater Systems).
2. Two American Standard Code for Information Interchange (ASCII) files representing the aquifer sediment's mobile porosity and hydraulic conductivity distributions based on the HSU zones depicted in Figure 3-2 and values from Table 4-1 were generated.
3. A maximum tracking time was set for each facility that allowed the vast majority of the particles released to migrate beyond the locations of the facility's monitoring wells during the calculations.
4. Particles were released and tracked from each particle starting location
   - For regional-scale advection-only calculations one particle was released per release point.
   - For regional-scale calculations using advection and dispersion, 20 particles were released from each starting location, but only 1 particle was displayed to provide an understanding of the general direction and coverage for the facilities.
   - For facility-specific calculations, 20 particles were released from each starting location to provide the high density of particles in space and time required for the detailed facility-specific calculations.
   - ModPath3DU was executed to make the particle-tracking calculations and produce a binary pathline output file containing the pathline for each tracked particle. For purposes of the particle-tracking calculations considering dispersion, particles were tracked from each starting location using a different random seed value for the dispersion calculations.
5. A post-processing program (writep3doutput.exe) was executed to convert the ModPath3DU binary pathline output file into both an ArcGIS shapefile format and an ASCII text file format, both of which list particle locations and travel time.

The resulting particle tracks were superimposed upon figures that showed monitoring well locations to determine whether monitoring locations lie in the migration pathway of the simulated releases from the facilities.

6.3 Particle Counts

Particle counts were calculated to create maps that illustrate the relative particle density downgradient of each facility and to produce time-series plots, or breakthrough curves, to show the relative arrival time of particles at monitoring well locations. The following describes steps to create this output.

For the maps of particle counts:

1. An ArcGIS shapefile grid was defined. The grid was large enough to envelop all pathlines generated in the previous step and was composed of cells that were 10 by 10 m (33 by 33 ft).
2. For each mapped event, the ArcGIS "Join" tool was used to intersect the pathlines with the regular grid and determine the count of unique pathlines intersecting each subgrid cell.
3. This grid of pathline counts was converted to an ASCII grid format and imported in ArcGIS, after which bilinear interpolation was used to develop the particle density (particle count) maps presented in facility-specific Appendices C through L.

Particle counts and breakthrough arrival-time curves for each interim groundwater monitoring well were prepared using the python script *ParticleCountCalc_vLS.py* and *APPDXA_ParticleCountCalc_vLS.py* as follows:

1. The ASCII text file containing particle locations and times was read into memory.
2. The tracking times were binned by subdividing the time into regular divisions, the interval depending upon the maximum tracking time.
3. All pathlines were filtered to determine those that were first to pass within 20 m (66 ft) of each interim status monitoring well. The corresponding tracking time for each particle was recorded.
4. The total number of pathlines that met the above criteria (first to pass within 20 m [66 ft] of a specific well within a specific binned time period) was summed.
5. The results of the above calculations were tabulated and are displayed in plots presented in facility-specific Appendices C through L.
6. The python script *ParticleCountPlots_v6.py* and *APPDXA_ParticleCountPlots_v4.py* were used to plot the breakthrough arrival-time curves, also presented in facility-specific Appendices C through L.

6.4 Vertical Migration Potential

As described in Section 3.3, the API plume diving calculation was used to estimate the anticipated slope at which the dissolved constituents will migrate, by dividing the recharge rate (e.g., in units of m/yr) by the Darcy Flux (in consistent units of m/yr: also known as the specific discharge). The Darcy Flux is calculated by multiplying the hydraulic conductivity by the hydraulic gradient.

The depth to which the dissolved constituents may be anticipated to have migrated by the time they reach the monitoring well location was then estimated by multiplying the calculated slope of the plume dive by the distance from the centroid of the facility to the well location (in some cases where the geometry of the facility precluded the use of the centroid, the maximum distance from the particle starting location to the well location was used). The estimated depth of the plume was compared to the depth from the water table to the bottom of the monitoring well screen. If the depth of the plume was found to be below the bottom of the monitoring well screen, then the dissolved constituents may be anticipated to pass beneath the well screen. If it fell within the interval between the top of the water table and the bottom of the well screen, then the well depth is considered appropriate for detection of releases at the facility. Results of the vertical migration calculations for each 200 East Facility are included in the facility-specific appendices (Appendices C through L).

7 Results

This chapter presents outputs from the previously described calculations. Regional-scale results that apply to the entire 200 East Area of the Hanford Site Central Plateau are presented in the following sections. The results presented include the following:

- The water-level mapping results of the Tikhonov hybrid approach for each of the four mapped years (2013, 2014, 2015, and 2016).
- Maps of calculated particle paths for the flow conditions determined for each of the four years (2013, 2014, 2015, and 2016). These are presented first using advection only and then considering advective and dispersive migration.

Results of the calculations performed at a facility-specific scale are included in each facility-specific appendix (Appendices C through L). The facility-specific output includes the following:

- Maps of calculated particle pathlines for the flow conditions determined for each of the four years (2013, 2014, 2015, and 2016) considering advective and dispersive migration.
- Time-series plots, referred to as particle breakthrough curves, of the relative arrival, peak, and decline in particle counts at each interim status groundwater monitoring well location and each proposed monitoring location, where applicable.
- Tabulation of relative particle counts for each interim status groundwater monitoring well location and each proposed monitoring location, where applicable.
- Maps of particle counts downgradient of each facility based on the flow conditions determined for each of the four years.

7.1 200 East Area Groundwater Elevation Maps

Figures 7-1 through 7-4 depict the groundwater elevation contours throughout the 200 East Area that were prepared using the methods and inputs described previously. The figures depict general patterns of groundwater elevations and hydraulic gradients for conditions represented by CYs 2013, 2014, 2015, and 2016.

7.2 200 East Area Regional-Scale Particle Tracking

Figures 7-5 through 7-8 depict the particle pathlines that were calculated using advection only based upon the mapped groundwater elevations throughout the 200 East Area and considering a small number of particles released at each facility. Because those particle pathlines were calculated using advection only, they depict general patterns of groundwater flow and potential contaminant migration in the vicinity of each facility for conditions represented by CYs 2013, 2014, 2015, and 2016.

In contrast, Figures 7-9 through 7-12 depict the particle pathlines that were calculated using both advection and dispersion. Because of this, the figures depict patterns of groundwater flow and migration as well as general patterns of spreading that might accompany the migration of contaminants in the vicinity of each facility for conditions represented by CYs 2013, 2014, 2015, and 2016.

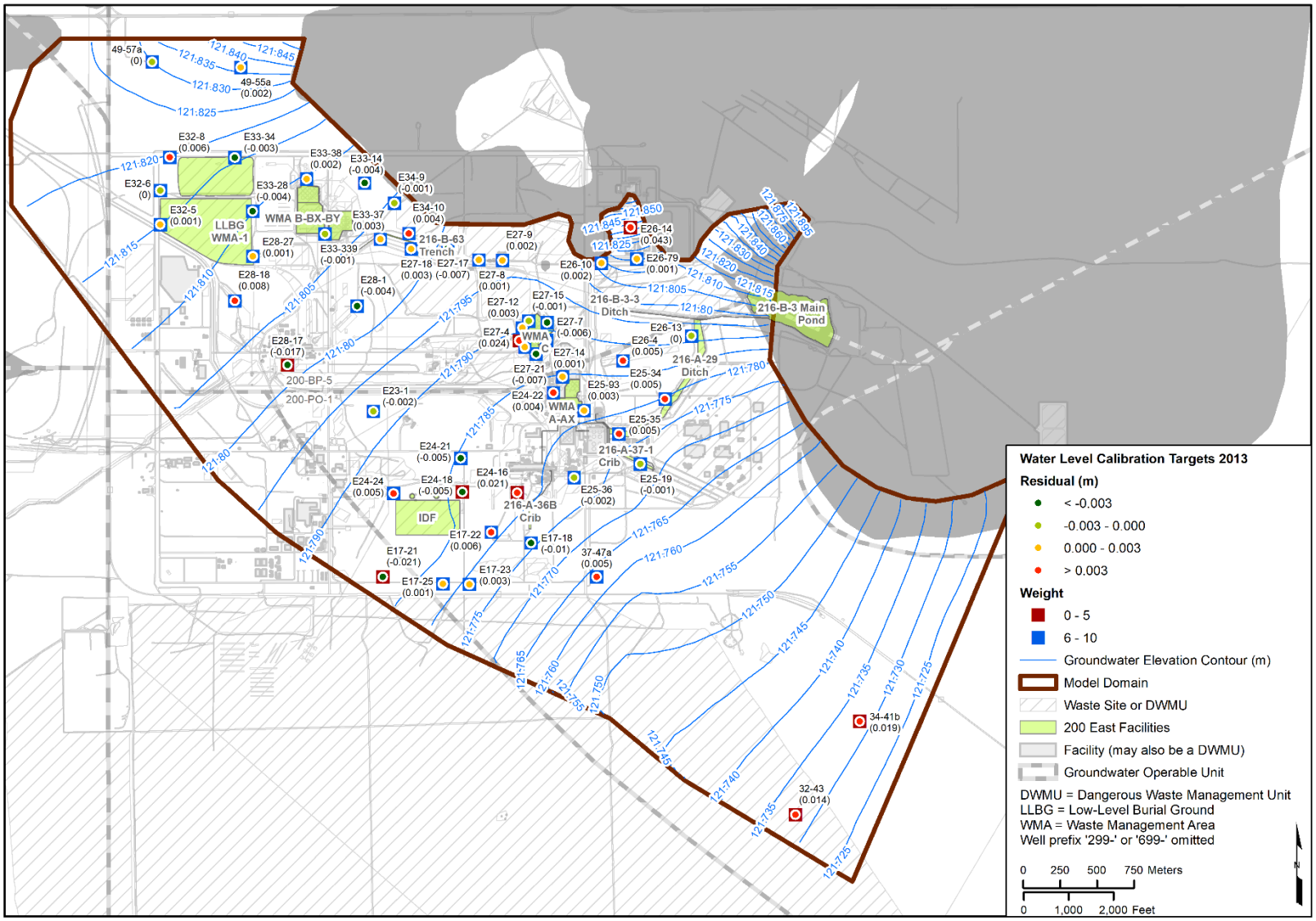

Figure 7-1. Mapped Groundwater Elevations and Calibration Residuals – 2013

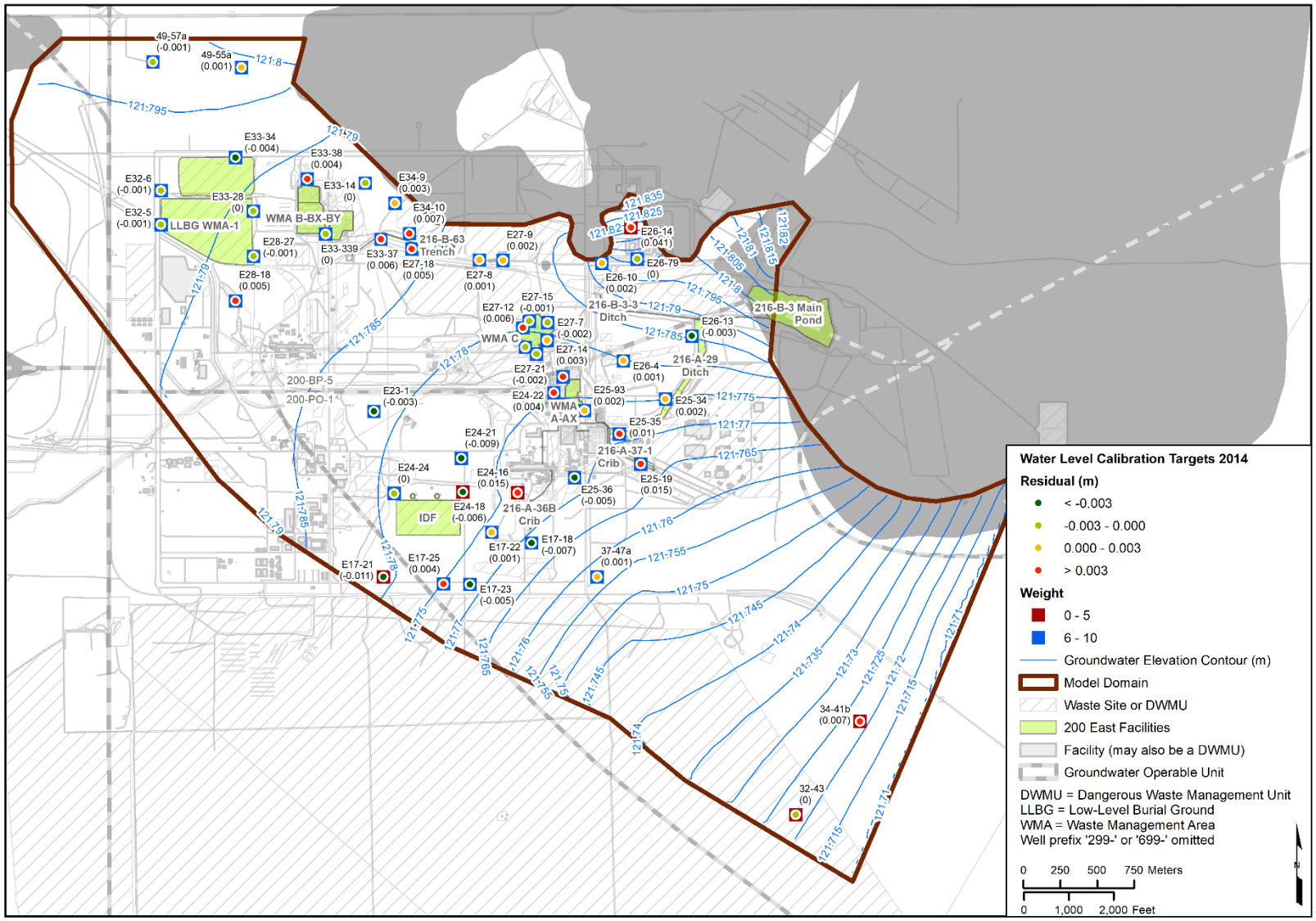

Figure 7-2. Mapped Groundwater Elevations and Calibration Residuals – 2014

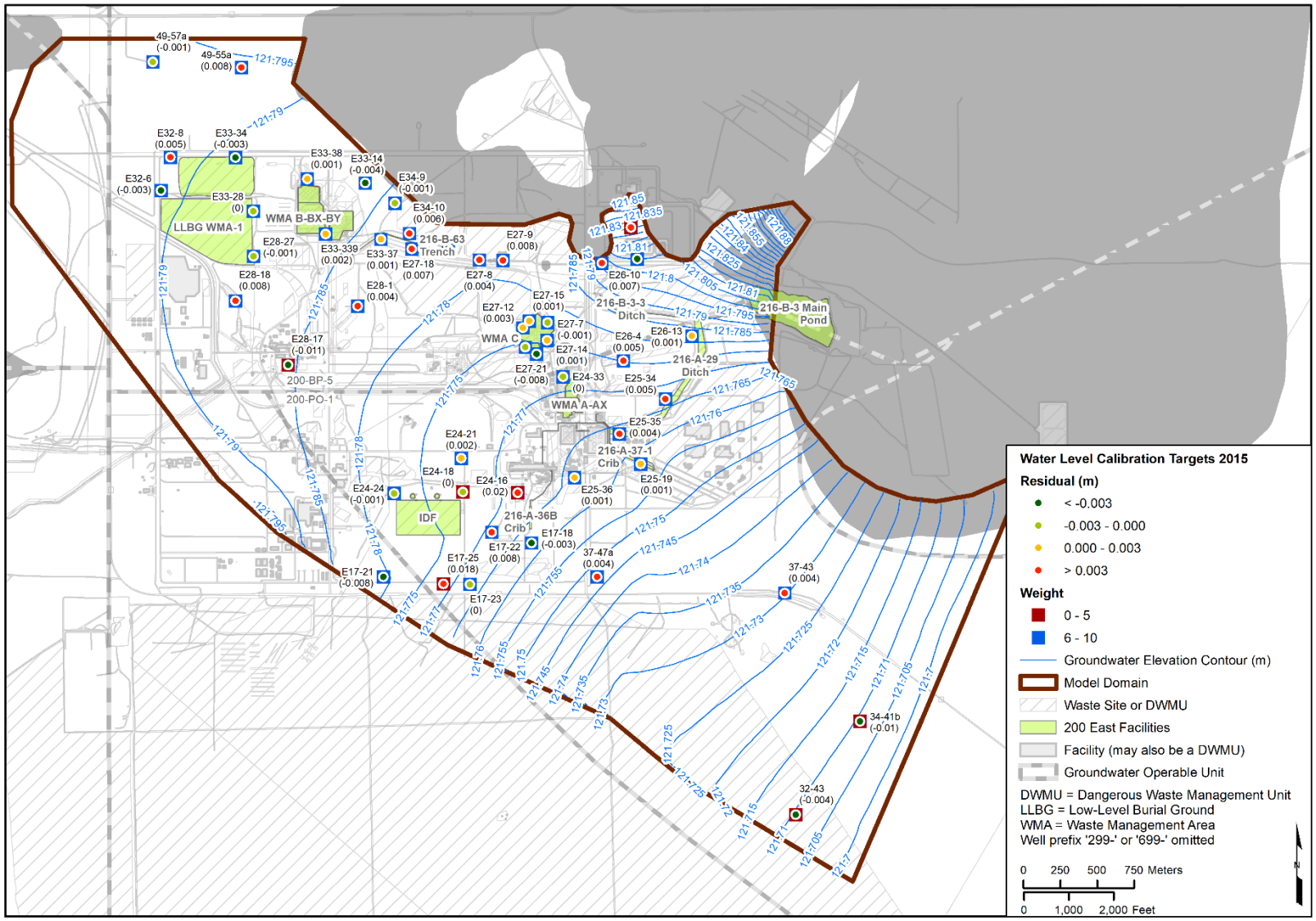

Figure 7-3. Mapped Groundwater Elevations and Calibration Residuals – 2015

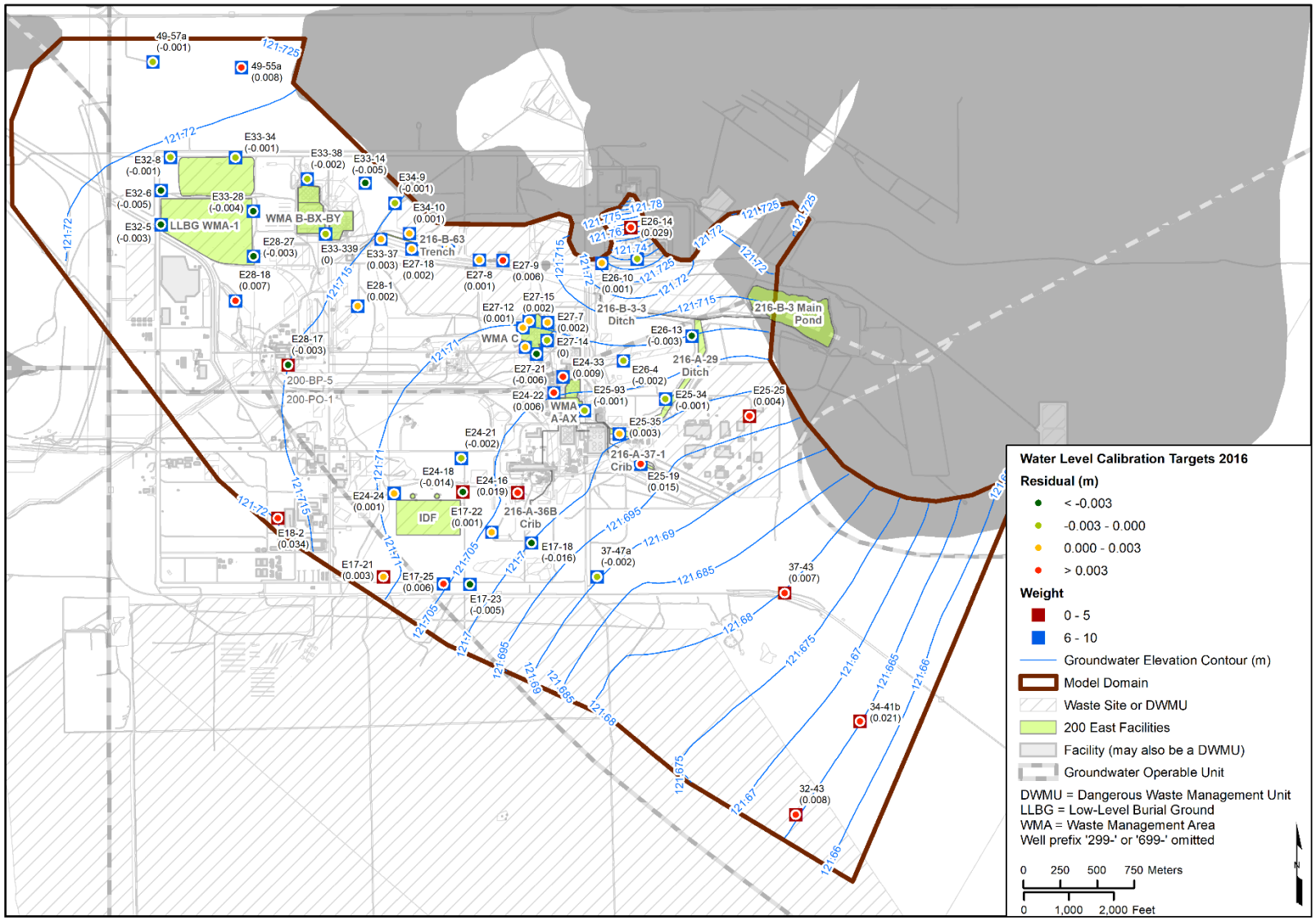

Figure 7-4. Mapped Groundwater Elevations and Calibration Residuals – 2016

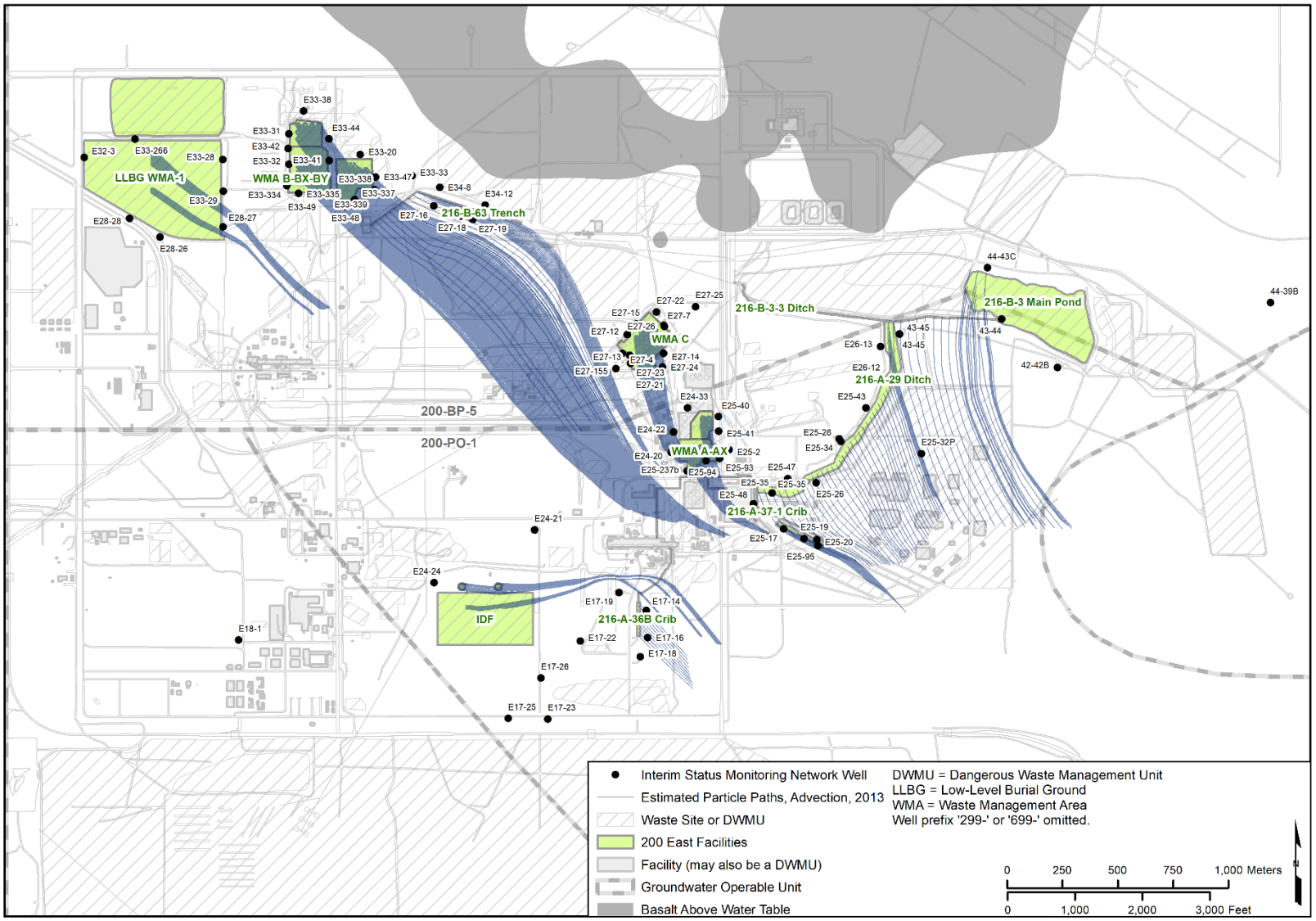

Figure 7-5. Estimated Particle Pathlines, Advection-Only – 200 East Area, 2013

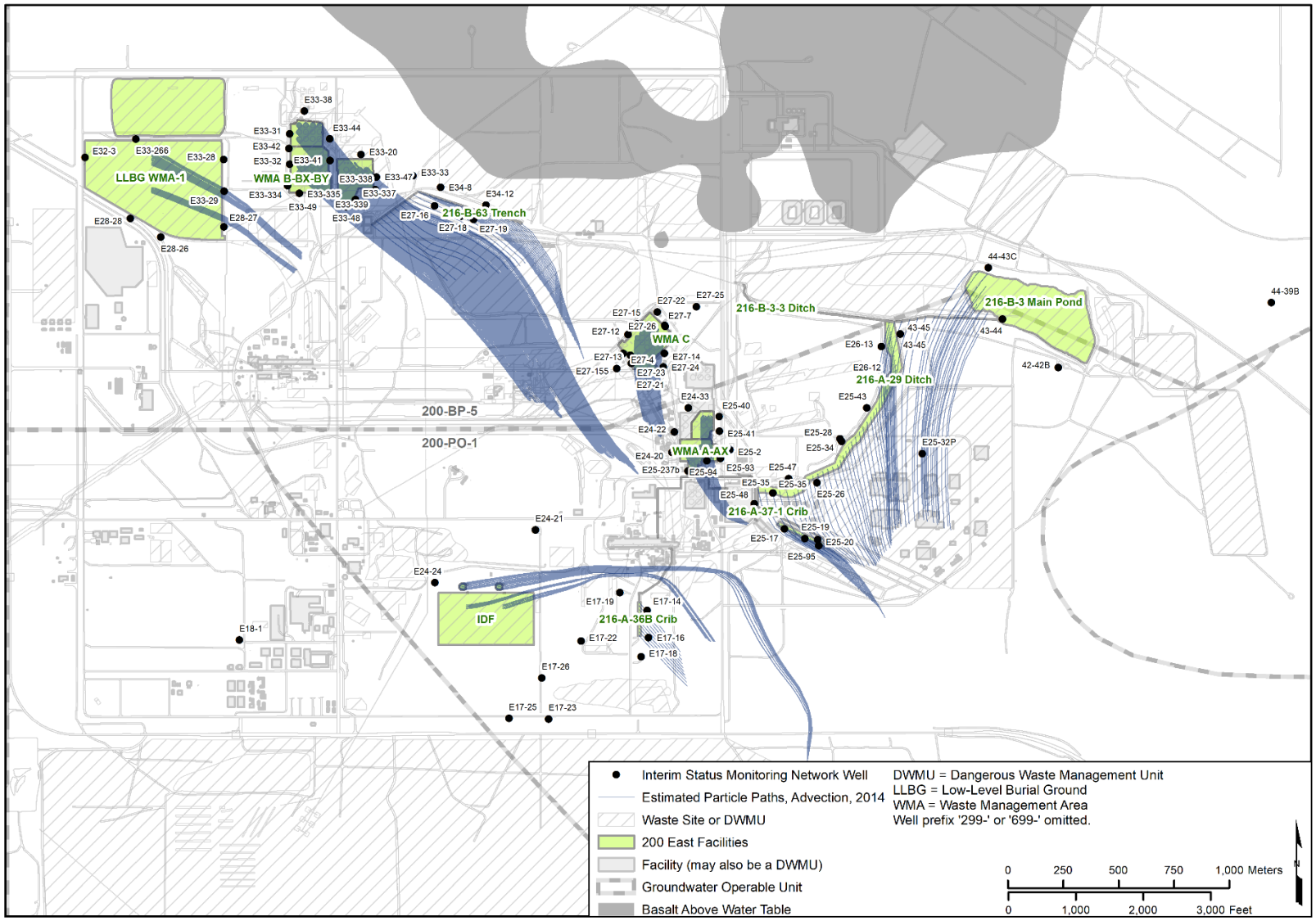

Figure 7-6. Estimated Particle Pathlines, Advection-Only – 200 East Area, 2014

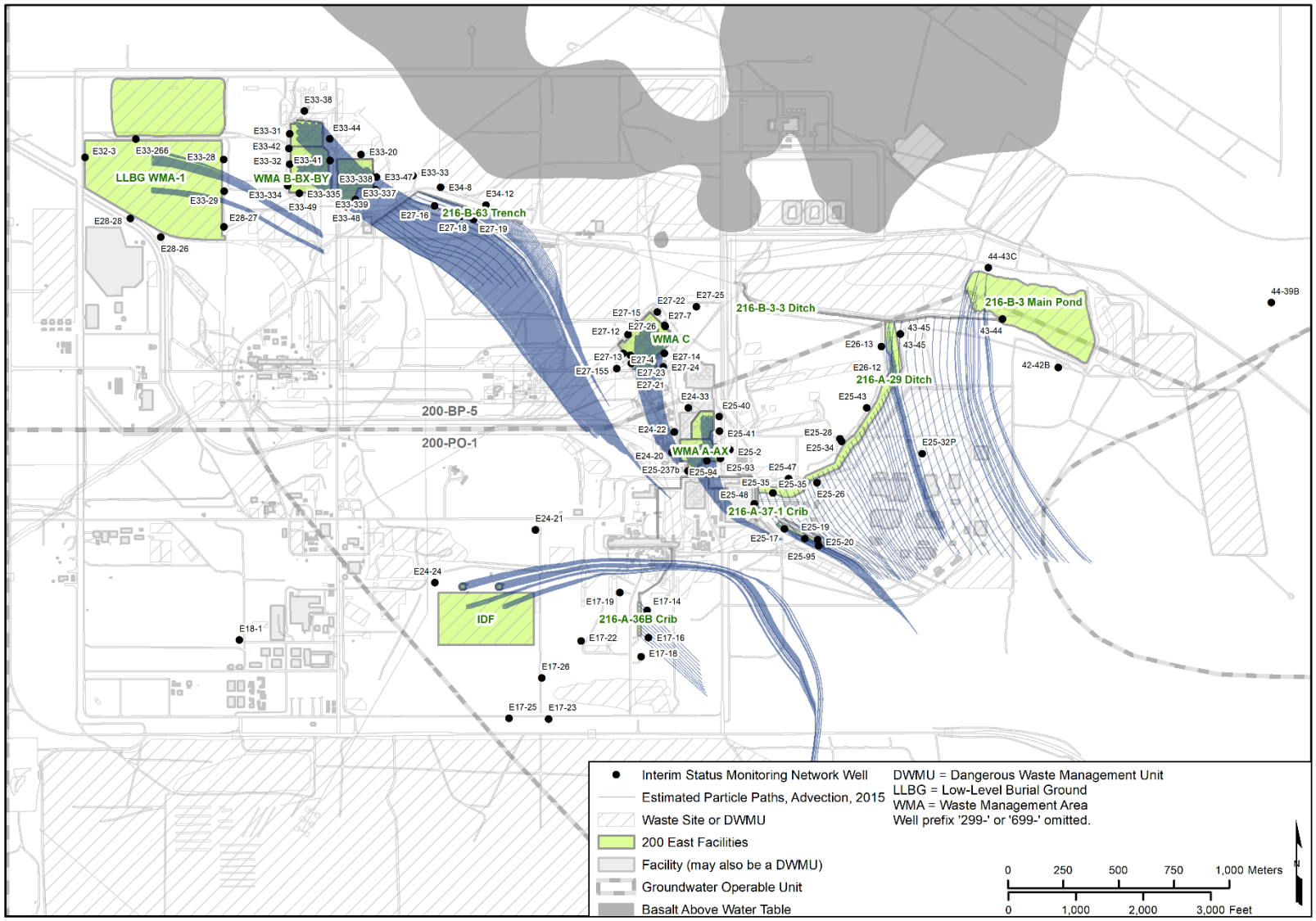

Figure 7-7. Estimated Particle Pathlines, Advection-Only – 200 East Area, 2015

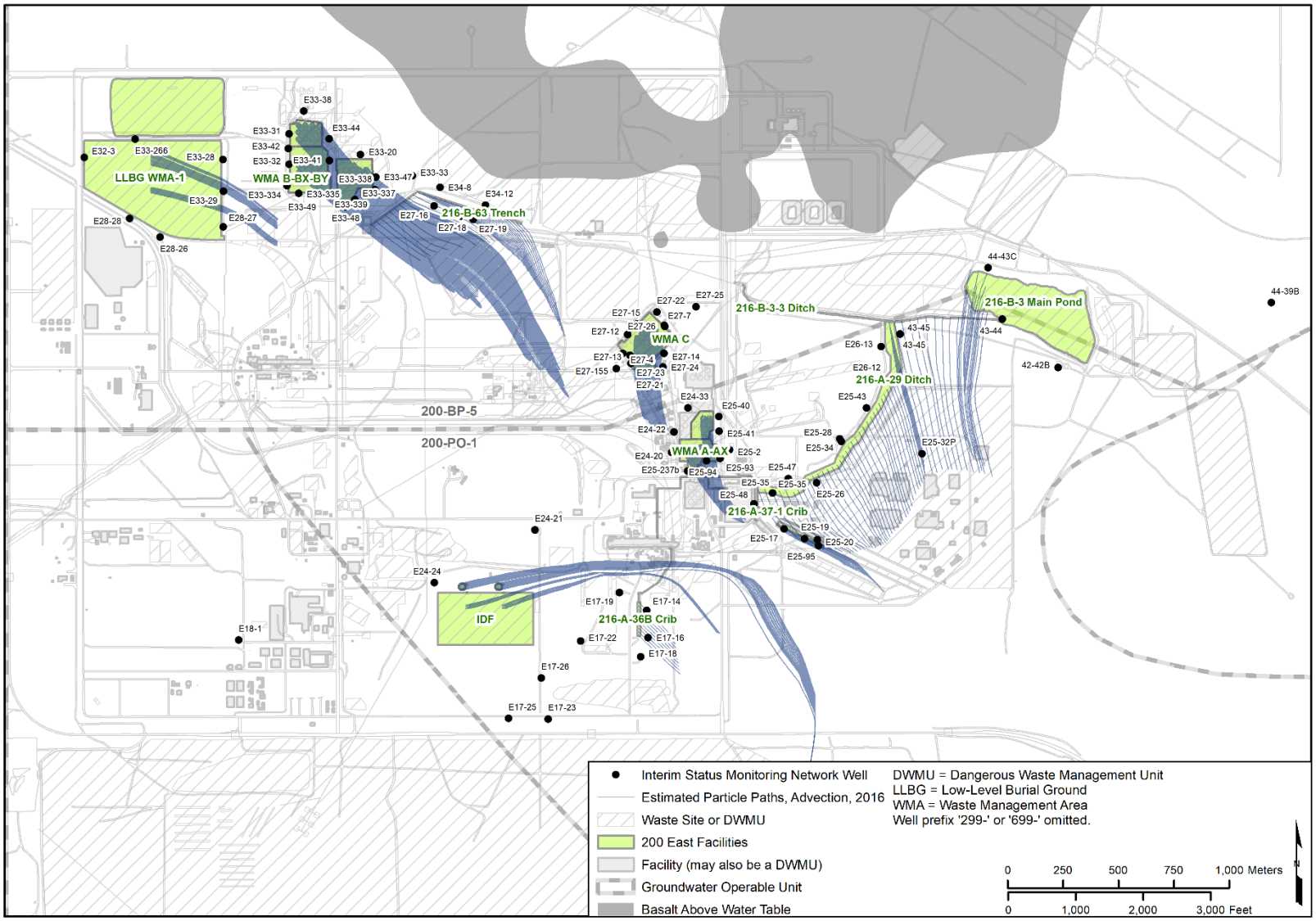

Figure 7-8. Estimated Particle Pathlines, Advection-Only – 200 East Area, 2016

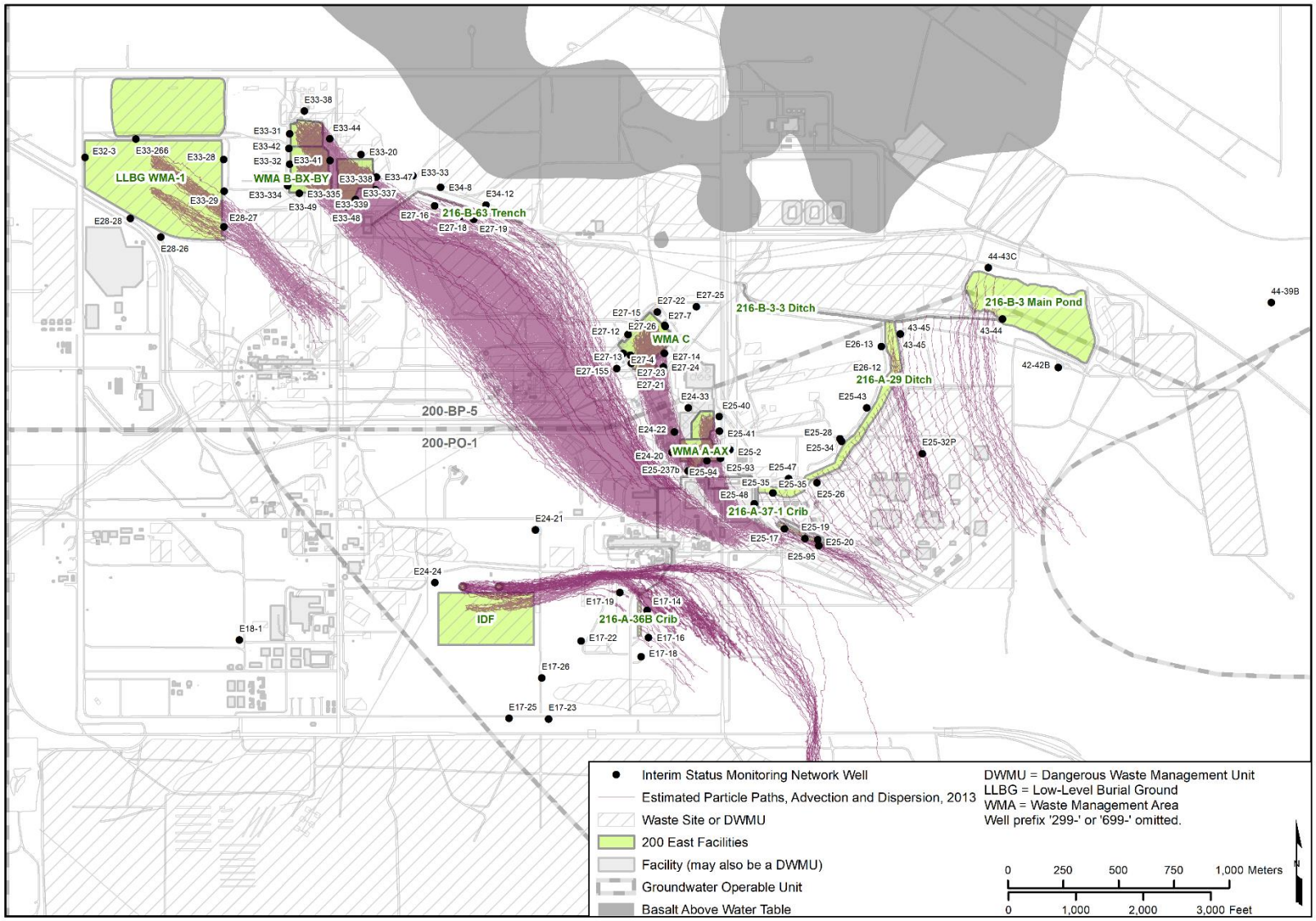

Figure 7-9. Estimated Particle Pathlines, Advection and Dispersion – 200 East Area, 2013

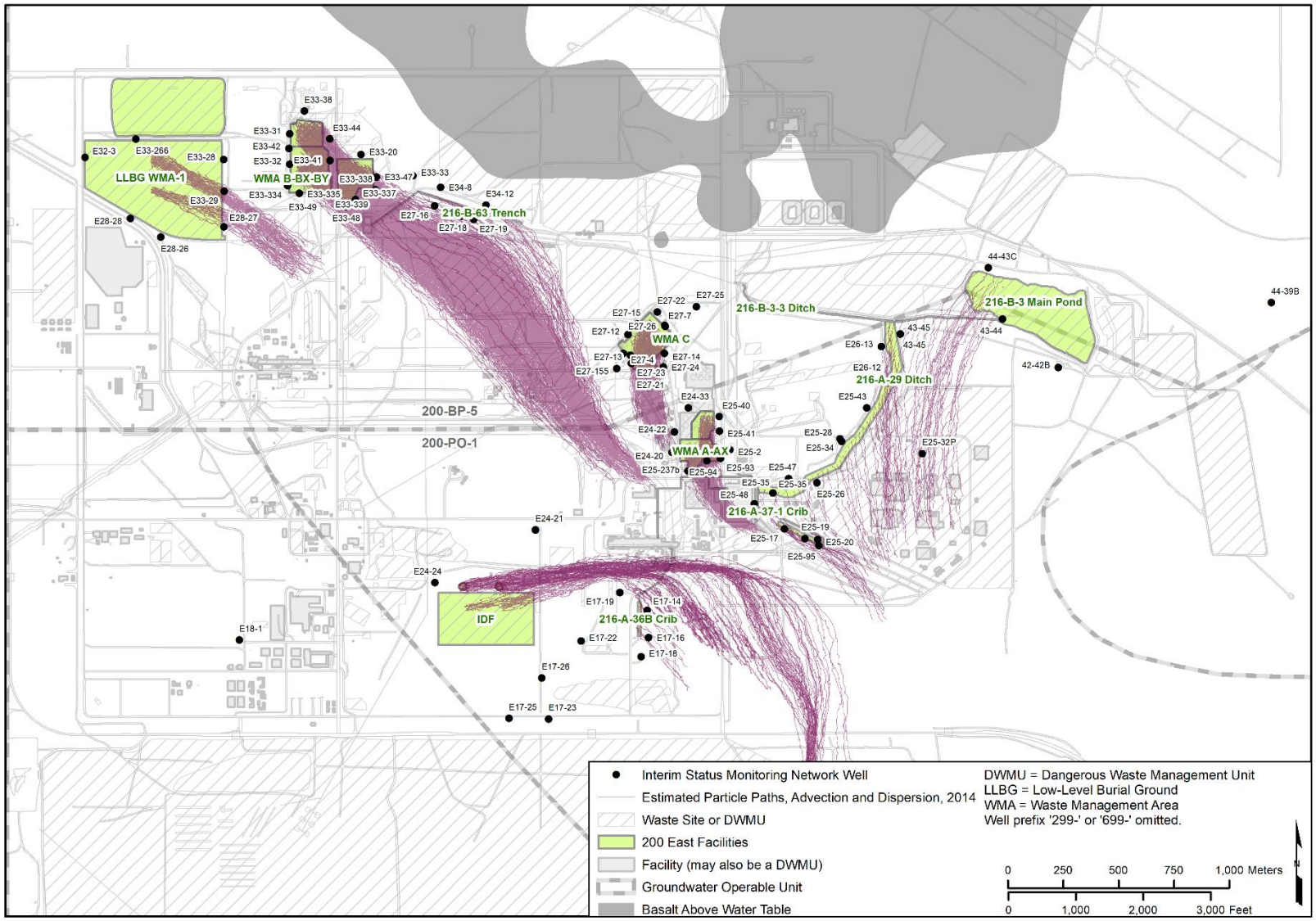

Figure 7-10. Estimated Particle Pathlines, Advection and Dispersion – 200 East Area, 2014

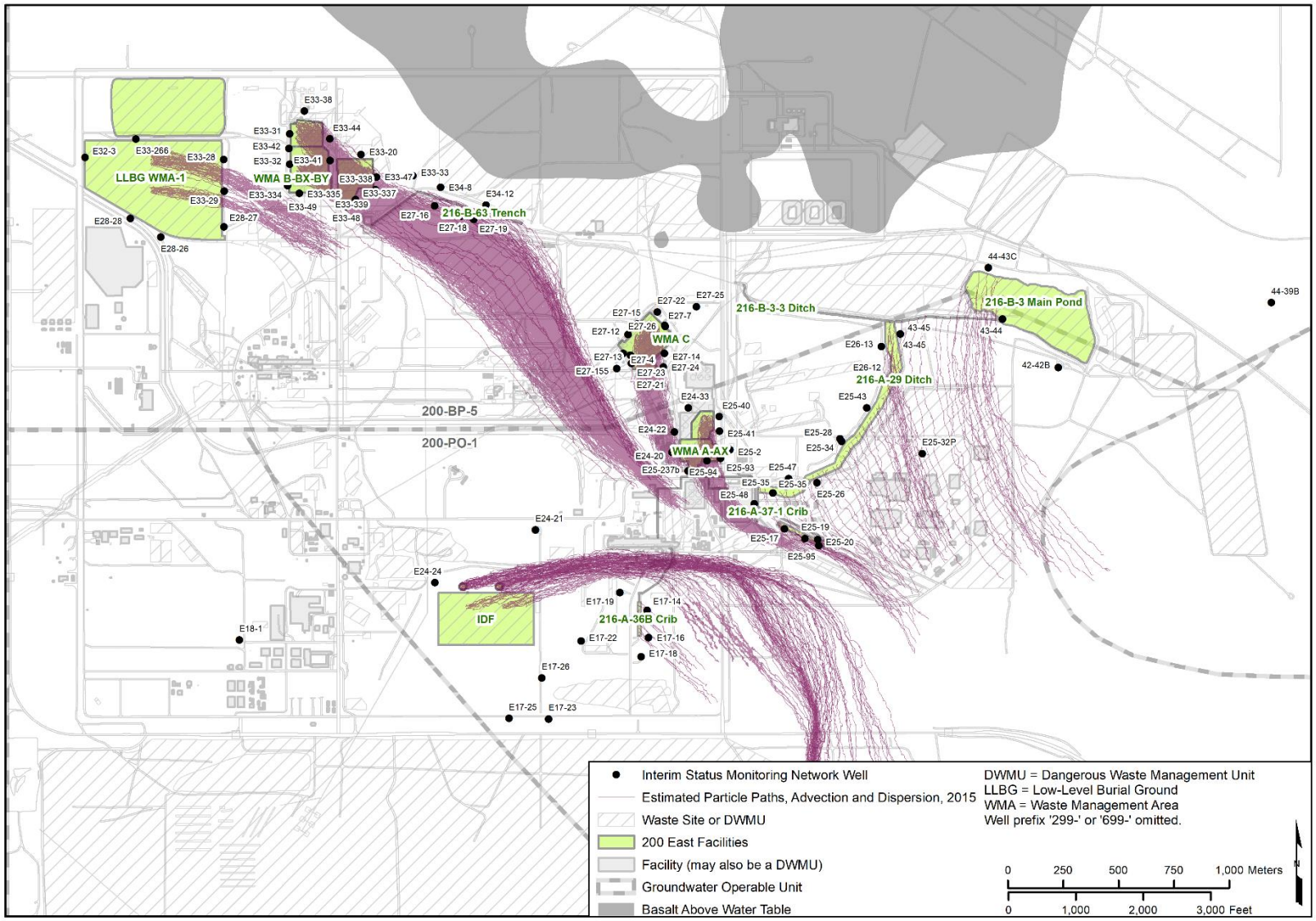

Figure 7-11. Estimated Particle Pathlines, Advection and Dispersion – 200 East Area, 2015

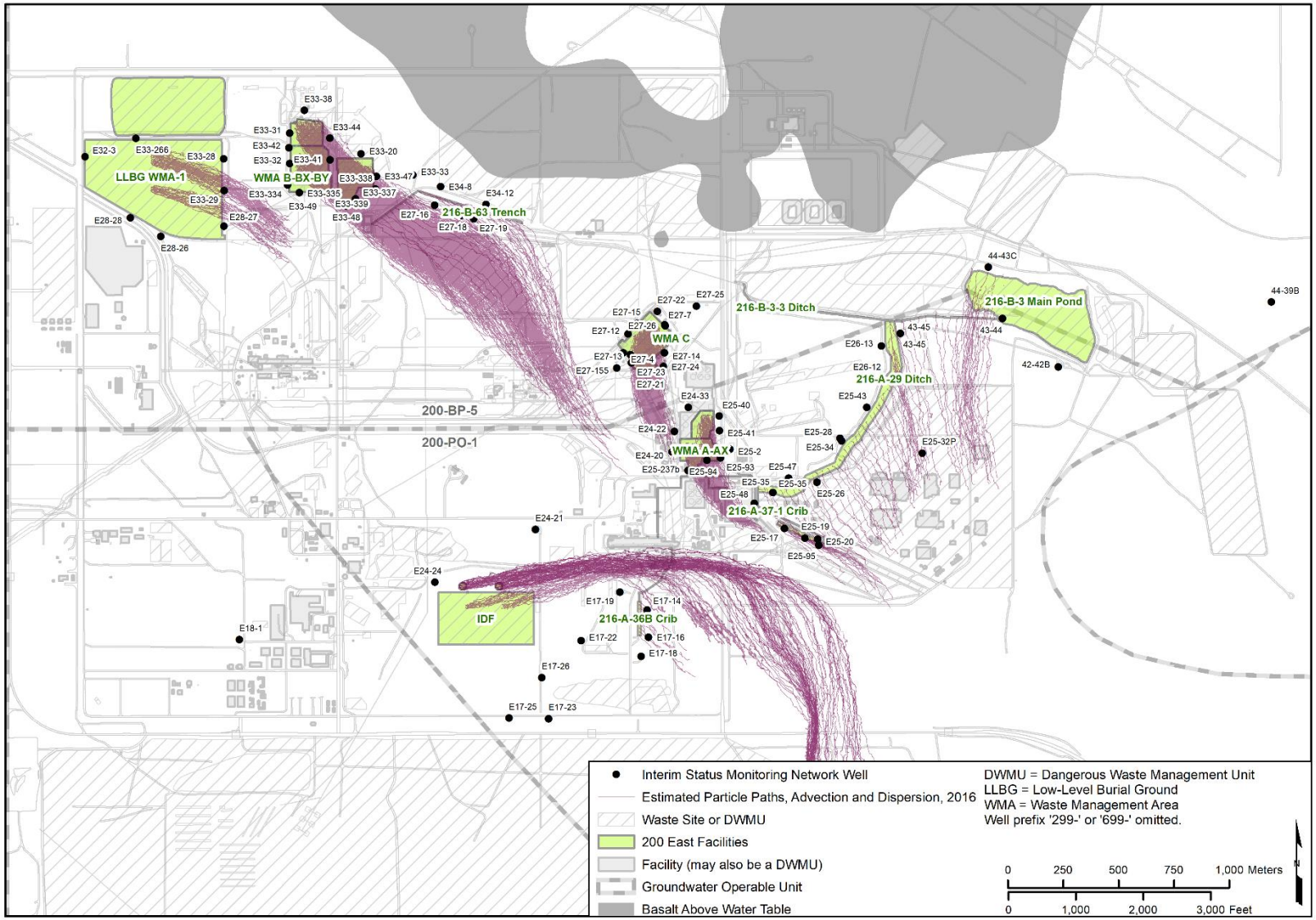

Figure 7-12. Estimated Particle Pathlines, Advection and Dispersion – 200 East Area, 2016

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Appendix A

Evaluation of Vertical Migration Potential

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Terms

API	American Petroleum Institute
CPGWM	Central Plateau Groundwater Model
DWMU	dangerous waste management unit
EPA	U.S. Environmental Protection Agency
HSU	hydrostratigraphic unit
P&T	pump and treat
Rwie	Ringold Formation member of Wooded Island – unit E
WMA	waste management area

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A1 Vertical Migration

Dissolved constituents that are released within the vadose zone (i.e., above the water table) and migrate downward, ultimately make their first impact to groundwater at the top of the aquifer (i.e., at the water table). Although the initial impact is at the water table, over time any dissolved constituents that mix with actively moving groundwater have the potential to move vertically within the aquifer. When attempting to monitor for and detect potential releases that have affected the water table, of great concern is the possibility that constituents may migrate beneath the bottom of the screen interval of monitoring wells.

Vertical movement within an aquifer can arise from several factors, primarily the following:

- Migration within heterogeneous aquifer material
- Drawdown associated with groundwater pumping from nearby wells
- Accrual of recharge resulting in downward displacement

Organic constituents can also be subject to smearing that results from fluctuations in the water table. The focus for this discussion, however, is on constituents dissolved within pore water in the vadose and saturated zones.

The extent to which each of the three foregoing factors can affect the vertical migration of dissolved constituents depends on site-specific conditions. Methods for evaluating the potential for vertical migration associated with each factor are described further below, after which a recommendation for future assessment of vertical migration potential for purposes of dangerous waste management unit (DWMU) monitoring is provided.

A1.1 Migration Within Heterogeneous Media

The potential effect of aquifer heterogeneity on the transport of dissolved constituents can be considered at two scales:

- At the scale of small variations in sedimentary materials (e.g., grain size variation and texture variability) that occurs within the same hydrofacies
- At the scale of lateral or vertical transitions between neighboring hydrofacies that exhibit differences in their physical or transport properties such as grain size, texture, and conductivity

In the first instance, small-scale variations within a hydrofacies can lead to vertical movement in either direction – resulting in movement both deeper or shallower than anticipated for a homogeneous aquifer. Such movement is often represented as nonsystematic or random (i.e., Fickian) by applying the theory and methods of macro-dispersion in calculations. When calculating migration using the particle-tracking code mod-PATH3DU (which represents dispersion in three dimensions), particles subject to dispersion would move upward and downward compared to particles simulated without dispersion. Over sufficiently long travel paths, however, the average path of particles simulated with dispersion will approach that of particles simulated without dispersion.

In the second instance, as groundwater and dissolved constituents move horizontally or vertically between hydrofacies that exhibit substantially different properties (primarily hydraulic conductivity and mobile porosity), dissolved constituents may continue on the same vertical path or may move upward or downward, depending on the differences between the properties of the two hydrofacies. If there is a single horizontal transition (or boundary) at a known location where the properties of the two hydrofacies are approximately known, then the effect of the transition can be approximated using the “plume diving” calculations described in greater detail in Section A1.4.1. If there is more than one horizontal transition,

however, it can become difficult to perform the calculations using analytical techniques. The potential effects of vertical transitions between hydrofacies exhibiting different properties are best represented by applying a groundwater model such as the Central Plateau Groundwater Model (CPGWM).

Given the foregoing, if a monitoring well is screened within the same hydrostratigraphic unit (HSU) as the aquifer material beneath the release site, so that there are no intervening transitions between the release location and the monitoring well, then the potential effects of large-scale heterogeneity on vertical migration may be neglected. In such a case, plume diving calculation methods, such as described by the American Petroleum Institute (API) and presented below, may be used. If this assumption is violated, however, site- or well-specific calculations should be made using a more sophisticated method, such as the following:

- Using the U.S. Environmental Protection Agency (EPA) plume diving calculator, described below, which can represent lateral contrasts in aquifer hydraulic conductivity and recharge
- Using the CPGWM to explicitly represent the different strata

A1.2 Drawdown due to Pumping

Pumping of groundwater at wells screened within an unconfined aquifer induces drawdown of the water table. This drawdown in turn can result in vertical migration of dissolved constituents that are at or close to the water table. The degree of vertical migration, however, depends greatly upon the screened interval of the pumping well and the distance between the dissolved constituents and from the pumping.

If the pumped well is screened throughout the full saturated thickness of the aquifer or is only screened in the upper portion of the aquifer (i.e., across the water table, with the bottom of the screen located above the aquifer base), pumping affects vertical flow via physical displacement of the water table: groundwater flow and constituent migration remain essentially horizontal. If the well screen fully penetrates the aquifer, over time drawdown becomes evenly distributed throughout the entire thickness of the aquifer. Hantush, 1964, “Hydraulics of Wells,” suggests that, for an isotropic aquifer, the drawdown will be the same across the full aquifer thickness beyond a distance of about 1.5 times the initial saturated thickness, B, of the aquifer. Hantush (1964) suggests that for an anisotropic aquifer, the same condition applies beyond a distance of about $1.5 \times B \times \sqrt{(Kh/Kv)}$, where Kh is the horizontal hydraulic conductivity and Kv is the vertical hydraulic conductivity. Although strictly developed for wells within confined aquifers, this rule-of-thumb calculation can reasonably be applied to thick unconfined aquifers. Thus, for a fully-penetrating pumping well, beyond the immediate vicinity of the well, drawdown is approximately evenly distributed throughout the full aquifer thickness and vertical gradients created by pumping dissipate both with distance from the pumping well and with elapsed time since the start of pumping.

A pumping well may be screened in the middle or lower portion of an aquifer (i.e., it is not screened across the water table, but rather the top of the screen is located some distance below the water table). If the top of the screen is located below the water table then this partial penetration can lead the pumping to induce vertical gradients that move groundwater and dissolved constituents further downward than they would move otherwise (Bair and Lahm, 1996, “Variations in Capture-Zone Geometry of a Partially Penetrating Pumping Well in an Unconfined Aquifer”). The magnitude of this effect depends upon the screen interval (i.e., vertical placement and degree of partial penetration of the aquifer), pumping rate, and distance from both the release location and the monitoring well to the pumped well.

Given the foregoing, if the monitoring well is located closer to the release location than to a groundwater extraction well, then the potential effect of groundwater pumping on vertical migration generally may be neglected, particularly if the pumped well screen is open across the water table (i.e., the top of the

pumped well screen is not located at significant depth below the water table). If this assumption is violated, however, site- or well-specific calculations should be made using the appropriate calculation tool, which in the 200 East Area is usually the CPGWM.

A1.3 Accrual of Recharge at the Water Table

Vertical migration due to recharge accrual is often referred to as plume diving (Nichols and Roth, 2006, *Downward Solute Plume Migration: Assessment, significance, and implications for characterization and monitoring of "diving plumes"*), although this term might be applied to all the above-mentioned conditions and factors. Plume diving due to recharge occurs when groundwater recharge has traversed the vadose zone and accrues at the top of an unconfined aquifer. Once within the aquifer, this newly accrued recharge begins to move in the direction of groundwater flow. Because the recharge water enters the aquifer from above, it can push dissolved contaminants downward. The amount that a plume “dives” in response to this accrual of recharge depends on the amount of recharge water entering the system and the relative contribution this additional water makes to flow in the aquifer, which in turn depends upon the properties of the aquifer (principally, the hydraulic conductivity and the ambient horizontal hydraulic gradient).

The likely rate of vertical migration due to recharge accrual at a specific site can be estimated using a variety of methods, including analytical and numerical models. In relatively simple cases, simple analytical models can suffice to approximate the effects of recharge. In many cases, the output from these simple calculations can be compared with numerical simulations to provide confidence that they are representative. In Section A1.4, a series of calculations is presented to illustrate this comparison. In more complex settings, such as those that exhibit lateral transitions between a small number of hydrofacies that exhibit different aquifer properties, the more sophisticated online EPA plume diving calculator (Weaver and Wilson, 2000, *Diving Plumes and Vertical Migration at Petroleum Hydrocarbon Release Sites*) can be used. The calculator can approximate the vertical migration due to recharge within as many as three lateral zones of different aquifer properties. In highly complex settings, where the path from the release point to the monitoring well transitions laterally (or vertically) between several hydrofacies, the EPA calculator may not suffice, and a numerical groundwater model such as the CPGWM can be used to estimate the potential for vertical migration.

Given the foregoing, if the monitoring well is located within the same HSU as the aquifer material beneath the release site, so that there are no intervening transitions between the release location and the monitoring wells, then the potential effects of recharge on vertical migration may be estimated using the analytical techniques described by the API as presented below. If this assumption is violated, however, site- or well-specific calculations should be made using one or more appropriate calculation tools, which may include the EPA plume diving calculator or the CPGWM.

A1.4 Example Calculations

Review of the geographic locations of the Central Plateau DWMUs and the monitoring well networks under development indicates that in the majority of circumstances, the existing or proposed monitoring wells are located within the same HSU as the aquifer material beneath the release site, so that there are no major transitions in the region between the release location and the monitoring wells. Furthermore, in those instances where there is groundwater pumping, primarily throughout the 200 West Area associated with the 200 West pump and treat (P&T) remedies, the pumping wells either fully penetrate the saturated aquifer or are screened across the water table, and the monitoring wells are generally closer to the release location than to the pumped wells so that the effects of vertical gradients induced by pumping should not be significant. Under these conditions, the primary factors that may affect the vertical migration of

dissolved constituents from the water table are small-scale variations within a hydrofacies that can be mimicked through dispersive mechanisms in particle tracking calculations, and accrual of recharge at the water table.

Because the effects of small-scale dispersion can be represented in mod-PATH3DU if required, a series of calculations was performed to examine the effects of recharge at the water table on the likely rate of downward vertical migration of dissolved constituents. The calculations were performed using two approaches. First, analytical calculations were made using the API plume diving calculator, which is based upon the ratio of the groundwater recharge rate to the groundwater discharge rate (also known as the Darcy velocity). Those calculations are the most widely used analytical calculations and have the most widespread applicability. The second method of calculation used the CPGWM, to validate the results obtained using the analytical calculation.

A1.4.1 Analytical Calculation

The analytical calculation presented below assumes that groundwater recharge is fairly evenly distributed at the site; that the subsurface in the region between the release location and the monitoring well is homogeneous; and that the aquifer thickness is large relative to the rate of accumulation of recharge and the likely vertical movement of constituents. The analytical calculation provides an estimate of the rate of vertical migration (i.e., the rate of dive) per unit distance traveled. The calculation can be presented in many ways. Common variants are provided below in Eq. 1 and Eq. 2 (modified after Nichols and Roth, 2006). All variants are collectively referred to hereafter as the API plume diving calculation.

$$Slope\ of\ Dive\ (S) = \frac{Accretion\ Rate\ (I)}{Seepage\ Velocity\ (V)} = \frac{Vertical\ velocity\ (v_v)}{Horizontal\ velocity\ (v_h)} = \frac{Recharge\ Rate\ (i)}{Darcy\ Flux\ (q)} \quad \text{(Eq. 1)}$$

In Eq. 1 the accretion rate is equivalent to the vertical velocity which is equivalent to the recharge rate (e.g., in units of ft/yr or m/d) divided by the aquifer porosity (unitless). The seepage velocity is equivalent to the horizontal velocity, which is equivalent to the Darcy Flux (in consistent units of ft/yr or m/d: also known as the specific discharge), divided by the aquifer porosity. The calculated slope, S, can be used to estimate the distance beneath the water table at which dissolved concentrations will be found at a specified distance from the point of release. Alternatively, Eq. 1 can be reorganized to estimate the potential for dissolved constituents to migrate beneath a specific well screen that is located a known distance (x) from the point of release in Eq. 2 (Nichols and Roth, 2006):

$$i \geq \frac{qd}{x} \quad \text{(Eq. 2)}$$

where the quantity *d* corresponds to the depth from the water table (in consistent units of ft or m) to the bottom of the monitoring well screen.

In this relationship, if the recharge rate, *i* (in ft/yr or m/d), exceeds the value of the right-hand side, then the dissolved constituents may be anticipated to migrate beneath the corresponding well. For aquifers that are bounded below by an aquitard, the foregoing API plume diving calculations tend to overestimate the rate of plume dive. For this reason, the API plume diving calculation can be used as conservative method to ensure that the bottom of well screens for monitoring wells are not placed too high (i.e., too close to the water table), which would enable dissolved constituents to pass beneath the well screen. Furthermore, the calculations can be made quickly and tabulated to evaluate whether existing or proposed wells have vertical screen intervals appropriate for effective monitoring.

For demonstration purposes, to illustrate that for the likely conditions of application in the Hanford Site Central Plateau, the 200 West Area DWMU, Waste Management Area (WMA) T, was used as an

example site. In the vicinity of the WMA T site, the following parameters are estimated based upon published values that are incorporated in the CPGWM:

- Horizontal hydraulic conductivity of Ringold Formation member of Wooded Island – unit E (Rwie) is 5 m/d (16.4 ft/d)
- Horizontal hydraulic gradient is 0.008 m/m (or ft/ft)
- Mobile porosity of the Rwie is 0.15
- Average groundwater recharge is 8.6 mm/yr (2 x 10^{-5} m/d) (6.6 x 10^{-5} ft/d)

Given the above, the API plume diving calculator (Eq. 1) can be used to determine the slope of the dive (to about two significant digits) (Eq. 3 and 4):

$$S = \frac{v_v}{v_H} = \frac{(2 \times 10^{-5}\ m/d)/(0.15)}{(5\ m/d)(0.008)/(0.15)} = 5.0 \times 10^{-4} \qquad \text{(Eq. 3)}$$

or

$$S = \frac{i}{q} = \frac{(2 \times 10^{-5}\ m/d)}{(5\ m/d)(0.008)} = 5.0 \times 10^{-4} \qquad \text{(Eq. 4)}$$

The results of the above calculations can also be summarized as follows: on average, within the same HSU (i.e., within the Rwie), dissolved constituents can be anticipated to migrate vertically downward about 1 m (3.28 ft) for every 2,000 m (6,562 ft) of horizontal migration under the influence only of accrual of recharge at the water table. Using full precision in the calculations results in a ratio of about 1:1690 instead of 1:2000.

A1.4.2 Verification Using the CPGWM

The results obtained using the API plume diving calculations rest upon the simplifying assumptions described previously. To check that the API plume diving calculations are reasonably representative of the site conditions as incorporated in the CPGWM, calculations were conducted using the mod-PATH3DU postprocessor to track particles released throughout the area of the WMA T site. The mod-PATH3DU particle-tracking code uses groundwater heads and flow fields computed by the CPGWM to simulated particle migration considering both advection and dispersion. Because the particle tracking calculations tend to involve the modeling of many hundreds of thousands of particles, for purposes of this verification, the following steps were taken:

1. Particle starting locations were distributed throughout the WMA T site, and the particles were released at the water table to mimic an impact of dissolved constituents from an overlying release. In total, 4,800 particles were released and tracked for the calculation.
2. The paths of all particles were computed over time. The same longitudinal, transverse, and vertical dispersivity parameters were used as for other particle-tracking analyses conducted for evaluating the monitoring well network.
3. At all intermediate steps taken to track migration of the particles, the following were calculated for every tracked particle:
    a. The elevation of both the particle and the water table
    b. The depth below the water table of every particle

c. The horizontal distance of each particle from its initial location.

4. The depths below the water table calculated for each particle were grouped according to horizontal distance from the starting location (for plotting purposes, they were grouped into distance intervals of 100 m [328 ft]).

5. Box-and-whisker plots were constructed of the results of calculating the "depth-below-water-table versus horizontal distance" for the groups of particles.

6. The box-and-whisker plots were graphed along with the results of the API plume diving calculation.

Results of the comparison between particle tracking using mod-PATH3DU and the CPGWM versus the API plume diving calculations are depicted in Figure 1. In this figure, each set of box-and-whiskers summarizes the vertical location of *all* particles within the corresponding 100 m (328 ft) interval travel distance from their release point. The correspondence between the results obtained using the API plume diving calculator and the CPGWM is very good. In reviewing Figure 1, the following points are important to note:

- The figure depicts migration over a distance of 1,000 m (3,281 ft) from the hypothetical release location at WMA T. Although the monitoring wells of the WMA T unit are located within about 200 m (656 ft) of the site, the correspondence between the API plume diving calculator and the CPGWM extends well beyond that distance and is generally good throughout the entire 1,000 m (3,281 ft) distance.

- At a distance of about 550 m (1,804 ft) from the release location, some particles show evidence of greater vertical spread. This distance approximates the location of one of the 200 West P&T system extraction wells, 299-W11-50. At this location, the effect of pumping appears to cause some vertical spread. However, the vertical distances remain small between the top and bottom of the box, which represent the 25th and 75th percentiles of particle depth, respectively, and between the whiskers, which represent the 5th and 95th percentiles of particle depth. The particle depths are also similar to the depths estimated using the API plume diving calculator.

- The results of the API plume diving calculator and the CPGWM are less alike beyond a migration distance of about 550 m (1,804 ft) from the release point. This distance, however, is beyond the distance of monitoring wells relevant to the WMA T unit and beyond the distance of the closest and most influential 200 West P&T system extraction well such that most particles have actually been "captured" by that well and do not migrate beyond this distance. Because particles are removed, calculations beyond the location of the extraction well are based on fewer particles and therefore are subject to relatively more dispersive effects than the calculations upgradient of the extraction well.

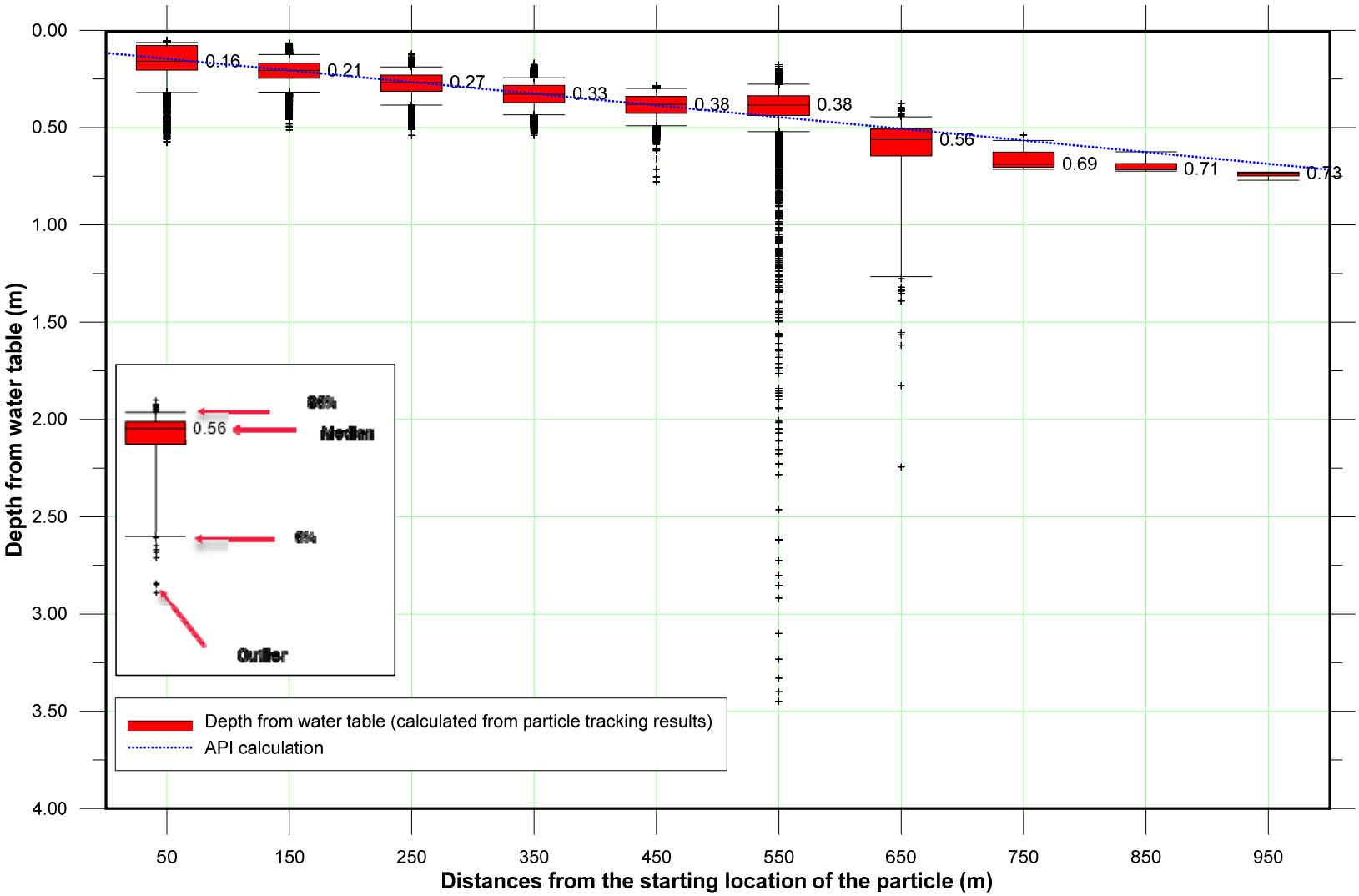

Figure A-1. Comparison of Vertical Migration Results Using the API Plume Calculator and the CPGWM

A1.4.3 Summary of Vertical Evaluation and Applicability to Other DWMUs

The geographic locations of the Central Plateau DWMUs and their monitoring well networks indicate that existing or proposed monitoring wells usually are located within the same HSU as the aquifer material beneath the release site (i.e., there are no intervening transitions between the release location and the monitoring wells). In most cases, the monitoring wells also are closer to the release location than to any groundwater pumping wells. Given these conditions, calculations were performed using the API plume diving calculator to estimate the likely rate of vertical migration of dissolved constituents downward from the water table. In the case of WMA T, as described above, those calculations then were compared to results obtained using particle tracking based on outputs of the CPGWM, to ensure that the results obtained using the API plume diving calculator are representative of the likely conditions to which the API calculator will be applied. The results of this comparison suggest that, for the conditions evaluated, the API plume diving calculator provides reliable estimates of the likely average rate of vertical migration of dissolved constituents moving downgradient from the modeled location of their release to the water table.

For DWMUs in the 200 East Area, the API plume diving calculator can be used to evaluate the depths of monitoring well screens in relation to the likely average rate of vertical migration of dissolved constituents moving downgradient from their location of release to the water table. Given the distance from a release location to the monitoring well, Eq. 2 can be used to calculate the likely depth of the contamination at the well location. This depth can be compared to the depth of the bottom of the monitoring well screen.

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Appendix B

Measured Water Levels Used as Inputs to the Groundwater Level Analysis

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Contents

B1 Measured Water Levels Used as Inputs to the Groundwater Level Analysis B-1

Table

Table B-1. Measured Water Levels B-1

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B1 Measured Water Levels Used as Inputs to the Groundwater Level Analysis

Table B-1 lists annual average measured groundwater levels for calendar years 2013, 2014, 2015, and 2016, which are inputs to the water-level mapping.

Table B-1. Measured Water Levels

Well Name	X Coordinates	Y Coordinates	2013	2014	2015	2016
299-E17-18	575112.4	135123.6	121.766	121.762	121.759	121.684
299-E17-21	574106.8	134893.4	121.766	121.770	121.772	121.714
299-E17-22	574841.1	135195.5	121.787	121.775	121.777	121.705
299-E17-23	574694.5	134842.4	121.782	121.767	121.767	121.698
299-E17-25	574515.2	134845.6	121.783	121.779	121.789	121.711
299-E18-2	573392.2	135291.0	NM	NM	NM	121.753
299-E23-1	574043.4	136016.6	121.790	121.778	NM	NM
299-E24-16	575017.6	135464.4	121.802	121.789	121.788	121.723
299-E24-18	574647.1	135469.8	121.779	121.770	121.772	121.692
299-E24-21	574635.8	135698.2	121.780	121.767	121.774	121.704
299-E24-22	575262.7	136142.8	121.787	121.780	NM	121.711
299-E24-24	574179.8	135459.3	121.792	121.779	121.776	121.710
299-E24-33	575325.4	136251.5	121.787	121.783	121.771	121.715
299-E25-19	575852.3	135659.0	121.771	121.782	121.759	121.712
299-E25-25	576588.9	135984.4	NM	NM	NM	121.701
299-E25-34	576019.0	136100.0	121.785	121.777	121.772	121.702
299-E25-35	575708.3	135864.7	121.782	121.781	121.768	121.704
299-E25-36	575403.6	135566.4	121.776	121.766	121.765	NM
299-E25-93	575471.5	136022.1	121.784	121.776	NM	121.703
299-E26-10	575589.0	137023.5	121.810	121.797	121.803	121.729
299-E26-13	576199.3	136528.6	121.792	121.782	121.783	121.707
299-E26-14	575786.5	137264.5	121.880	121.859	121.861	121.790
299-E26-4	575734.0	136360.9	121.792	121.781	121.780	121.706
299-E26-79	575827.9	137051.5	121.816	121.801	121.801	121.735
299-E27-12	575054.1	136583.5	121.793	121.786	121.780	121.711
299-E27-14	575217.3	136498.2	121.790	121.782	121.776	121.709

Table B-1. Measured Water Levels

Well Name	X Coordinates	Y Coordinates	2013	2014	2015	2016
299-E27-15	575095.3	136630.4	121.790	121.780	121.778	121.712
299-E27-17	574547.3	137122.0	121.792	121.780	121.779	121.714
299-E27-18	574299.6	137119.3	121.805	121.791	121.790	121.716
299-E27-21	575145.0	136407.2	121.780	121.776	121.766	121.702
299-E27-23	575069.5	136452.2	121.790	121.778	121.773	121.710
299-E27-4	575032.0	136497.9	121.813	NM	NM	NM
299-E27-7	575220.6	136619.4	121.785	121.779	121.776	121.713
299-E27-8	574759.1	137044.2	121.798	121.785	121.785	121.714
299-E27-9	574917.7	137040.9	121.798	121.786	121.789	121.719
299-E28-1	573933.4	136732.6	121.799	NM	121.788	121.717
299-E28-17	573461.2	136331.7	121.785	NM	121.774	121.712
299-E28-18	573104.1	136767.8	121.816	121.794	121.796	121.724
299-E28-27	573226.8	137070.1	121.809	121.788	121.786	121.713
299-E32-5	572599.7	137285.1	121.816	121.791	NM	121.716
299-E32-6	572600.4	137515.1	121.817	121.792	121.788	121.714
299-E32-8	572663.4	137741.5	121.826	NM	121.796	121.719
299-E33-14	573985.6	137567.2	121.803	121.788	121.782	121.711
299-E33-28	573226.4	137375.0	121.806	121.789	121.787	121.713
299-E33-339	573716.9	137221.5	121.805	121.788	121.787	121.716
299-E33-34	573104.5	137740.4	121.813	121.787	121.786	121.717
299-E33-37	574091.5	137185.4	121.807	121.793	121.785	121.718
299-E33-38	573591.2	137594.5	121.812	121.793	121.788	121.714
299-E34-10	574284.4	137224.6	121.807	121.793	121.790	121.715
299-E34-9	574186.0	137429.8	121.804	121.790	121.784	121.714
699-32-43	576902.1	133278.6	121.746	121.722	121.706	121.673
699-34-41b	577338.3	133911.7	121.751	121.729	121.699	121.686
699-37-43	576828.5	134782.5	NM	NM	121.734	121.687
699-37-47a	575557.0	134893.3	121.768	121.758	121.751	121.688
699-49-55a	573146.3	138351.8	121.839	121.800	121.802	121.731

Table B-1. Measured Water Levels

Well Name	X Coordinates	Y Coordinates	2013	2014	2015	2016
699-49-57a	572544.3	138389.2	121.830	121.796	121.792	121.721

NM = not measured

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Appendix C

Facility-Specific Results for the 216-A-29 Ditch

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Terms

API	American Petroleum Institute
CPGWM	Central Plateau Groundwater Model
CY	calendar year
ECF	environmental calculation file
TRIM	Tikhonov Regularized Inverse Method
PUREX	Plutonium Uranium Extraction

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C1 Purpose and Background

The primary purpose of the calculations presented here is to estimate directions of potential migration to assess the efficacy of the geographical distribution of wells in the proposed monitoring well network for the subject facility. The calculations described within the main text of this environmental calculation file (ECF) were performed for each of the 200 East Facilities. This appendix presents results developed from the calculations that are specific to the 216-A-29 Ditch.

Located in the eastern part of the 200 East Area, the 216-A-29 Ditch is a surface impoundment placed in service in November 1955 to convey liquid effluent from the Plutonium Uranium Extraction (PUREX) Plant chemical sewer to B Pond (Section 3.8 in DOE/RL-2016-66, *Hanford Site RCRA Groundwater Monitoring Report for 2016*). The 216-A-29 Ditch received continuous discharge of corrosive waste and potentially hazardous spilled chemical materials from PUREX. The most significant chemical discharges included acidic and caustic effluents from backwashing during the regeneration of demineralizer columns. The 216-A-29 Ditch was removed from service in 1991, partly backfilled with material from the ditch sides, and the portion of the ditch inside the 200 East Area security fence brought to grade with clean material (Section 3.8 in DOE/RL-2016-66).

The interim status groundwater monitoring program was described in DOE/RL-2008-58, *Interim Status Groundwater Monitoring Plan for the 216-A-29 Ditch*, Rev. 0, and included monitoring for parameters used as indicators of groundwater contamination from the 216-A-29 Ditch, commonly referred to as an indicator evaluation program. In 2015, the 2010 indicator parameter monitoring plan, DOE/RL-2008-58, Rev. 0, was in the process of being revised (DOE/RL-2008-58, Draft Rev. 1) when specific conductance in three downgradient wells (299-E25-32P, 299-E25-35, and 299-E25-48) exceeded the critical mean value. In January 2016, the 216-A-29 Ditch was placed into a groundwater assessment program under DOE/RL-2016-23, *216-A-29 Ditch Interim Status Groundwater Quality Assessment Monitoring Plan*, Rev. 0, because of the exceedances. Initial semiannual assessment sampling was completed in April 2016 for the wells with exceedances under the assessment monitoring plan. The plan was later revised (DOE/RL-2016-23, Rev. 1) to expand the assessment sampling to include all network wells on a quarterly sampling frequency beginning in October 2016 and to revise the well network. In September 2017, DOE/RL-2016-23, Rev. 2, was issued to update the well network after drilling of three new wells that were added to the network.

The 216-A-29 Ditch interim status monitoring network (Figure C-1) consists of four upgradient wells (299-E25-34, 299-E25-43, 299-E25-47, and 299-E26-13) and four downgradient wells (299-E25-35, 299-E25-238, 299-E25-239, and 299-E26-80). All of the network wells are screened across the water table (or the top of the open interval is within 5 m [16 ft] of the water table), and the bottom of the open interval is no more than 7 m (23 ft) below the water table (DOE/RL-2016-23, Rev. 2).

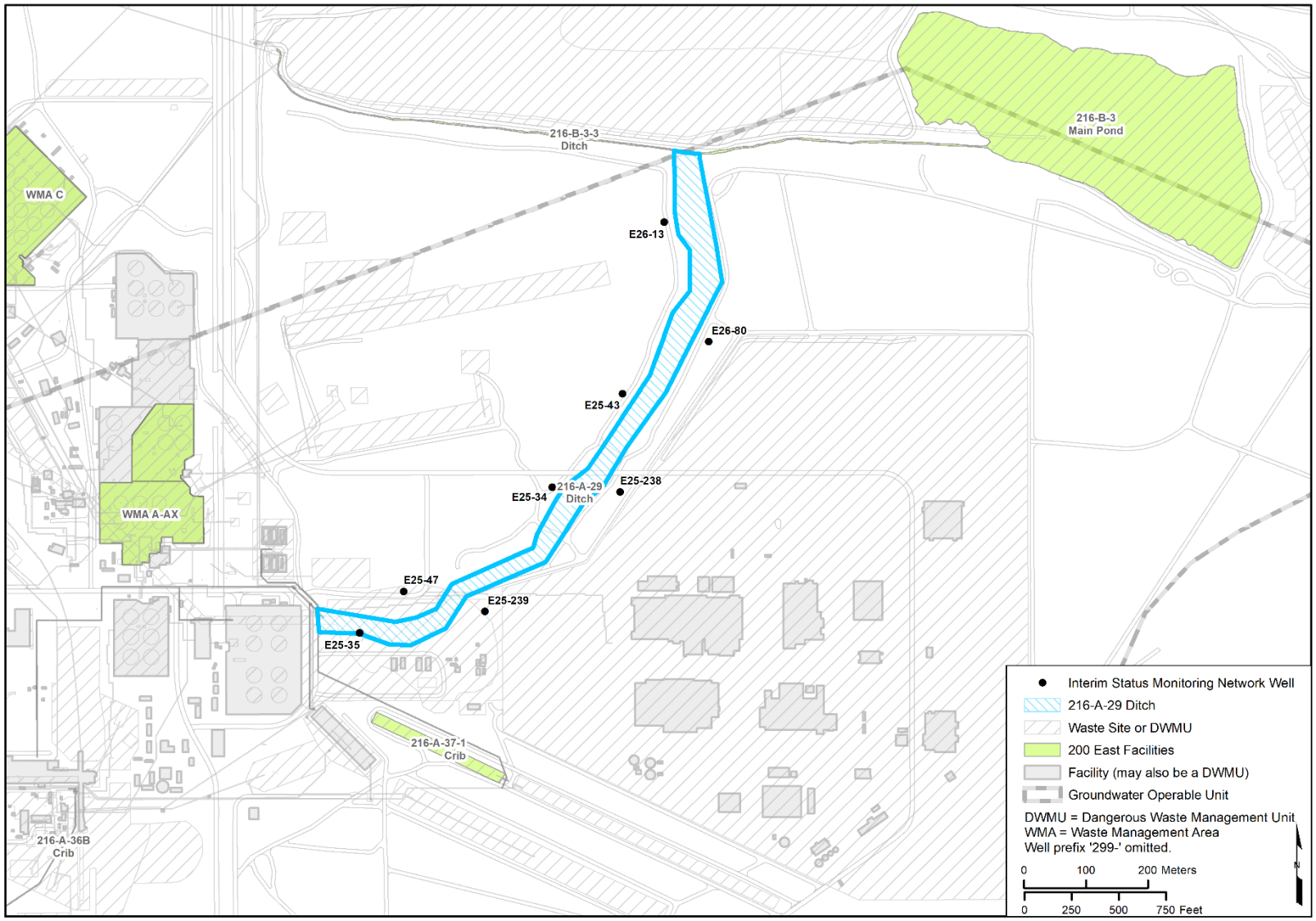

Figure C-1. Locations of Interim Status Groundwater Monitoring Wells at the 216-A-29 Ditch

C2 Facility-Specific Input for the 216-A-29 Ditch

Inputs used in the calculations that were specific to the 216-A-29 Ditch are described in this chapter.

C2.1 Particle Count Grid and Release Locations

To prepare particle count maps, a distribution of facility-specific starting locations is required. The starting locations for the particle-tracking calculations represent the area over which a potential release from a given facility would impact the underlying water table. The particle releases were located at plausible release sites throughout the facility. For the 216-A-29 Ditch, 46 release locations were specified along the centerline of the ditch (Figure C-2). Twenty particles were released and tracked from each release location to provide the density of particles in space and time required for the detailed facility-specific calculations, randomizing the seed values for the dispersion calculations. Thus, 920 [920 = 46 (release locations) × 20 (releases)] particles were tracked for each of the four simulations.

Contour maps of particle counts were generated by counting the number of particles that pass through a pre-defined uniform calculational grid (Figure C-2). The grid used to develop the relative particle density maps is defined by 10 by 10 m (33 by 33 ft) cells. The grid is oriented to be parallel to the predominant groundwater flow direction at the 216-A-29 Ditch.

C2.2 Migration Parameters

Parameters specific to the groundwater flow conditions at the 216-A-29 Ditch are reported throughout the various documents for the facility. The parameters used in the calculations performed herein to represent nonreactive dissolved contaminant migration are mobile (or effective) porosity and hydraulic conductivity. The parameters used in these calculations are representative of local conditions for a conservative (i.e., nonreactive) solute dissolved within groundwater.

A range of hydraulic conductivity values is reported in site literature for the 216-A-29 Ditch. Values range from 18 m/d (59 ft/d) (Table 2 in ECF-Hanford-16-0013, *Hydraulic Gradients and Velocity Calculations for RCRA Sites in 2015*) to 17,000 m/d (55,774 ft/d) for the Hanford formation and Cold Creek unit (channelized zones) (Table 4-4 in CP-57037, *Model Package Report: Plateau to River Groundwater Transport Model Version 7.1*). As described in Section 4.2.1.1 of the main text of this ECF, the hydraulic conductivity used in the work performed herein corresponds to the calibrated values from the Central Plateau Groundwater Model (CPGWM) (CP-47631, *Model Package Report: Central Plateau Groundwater Model, Version 8.4.5*). Figure 3-2 in the main text of this ECF indicates the 216-A-29 Ditch is located in the hydrostratigraphic unit zone corresponding to the Cold Creek unit. The value used for the hydraulic conductivity for the 216-A-29 Ditch is 18,200 m/d (59,711 ft/d), which corresponds to the Cold Creek unit as shown in Table 4-1 in the main text of this ECF. The mobile (effective) porosity defined for the Cold Creek unit, which underlies the 216-A-29 Ditch, is specified at 0.25.

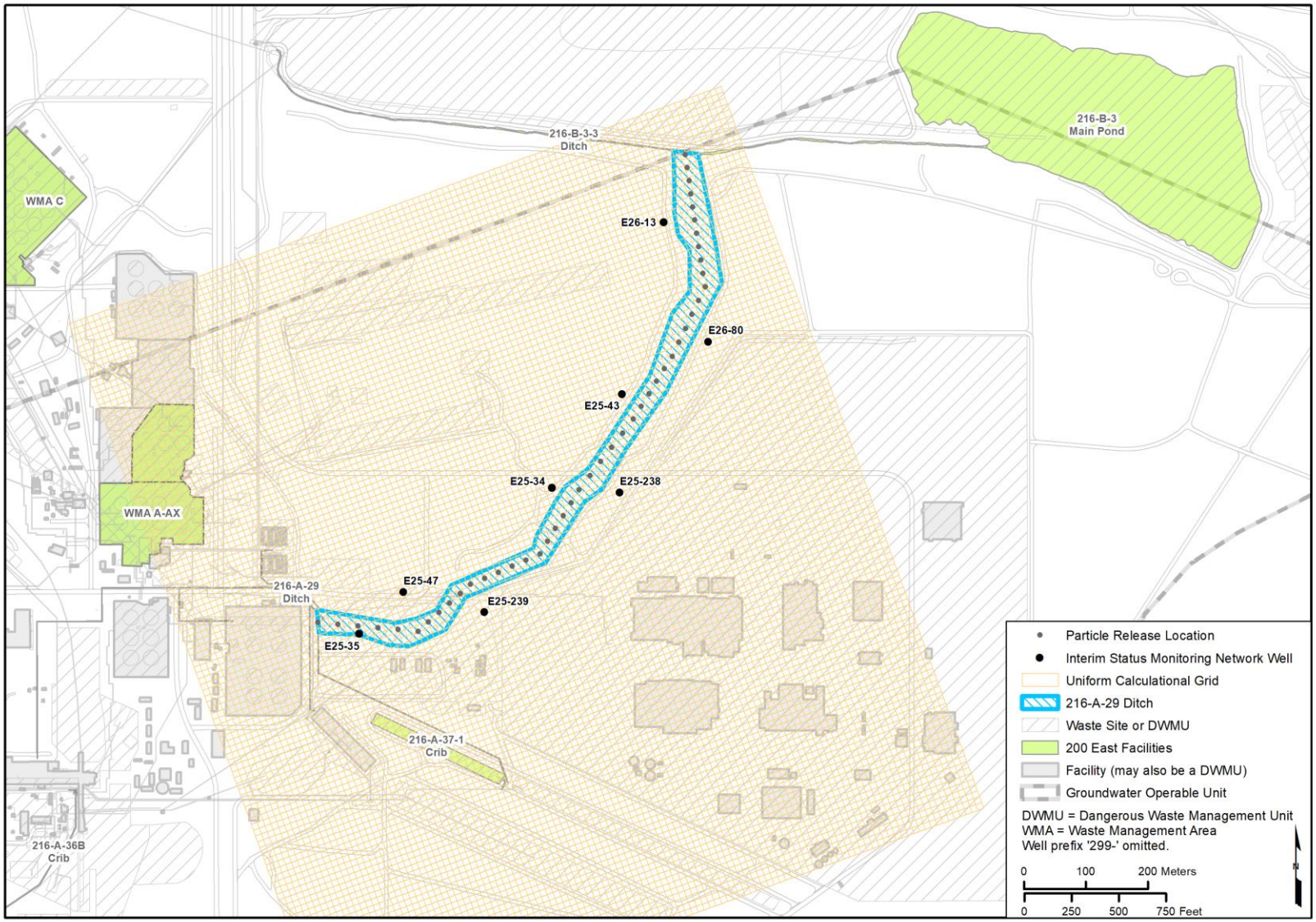

Figure C-2. Uniform Calculational Grid and Release Locations at the 216-A-29 Ditch

C3 Facility-Specific Results for the 216-A-29 Ditch

The groundwater elevation contours prepared in the vicinity of the 216-A-29 Ditch using the Tikhonov Regularized Inverse Method (TRIM) are presented in this chapter. In addition, the outputs of the particle tracking and particle count calculations are presented, including the following:

- Maps of calculated particle pathlines for the flow conditions determined for each of the four years (2013, 2014, 2015, and 2016). These are presented at the facility-specific scale considering advective and dispersive migration.
- Time-series plots, referred to as particle breakthrough curves, of the relative arrival, peak, and decline in particle counts at each interim status groundwater monitoring well location and each proposed monitoring location, where applicable.
- Tabulation of relative particle counts for each interim status groundwater monitoring well location and each proposed monitoring location, where applicable.
- Maps of particle counts downgradient of each facility based on the flow conditions determined for each of the four years.

The results of calculations of potential vertical migration of contaminants at the monitoring well locations are also presented.

C3.1 Groundwater Elevation Contours

Figures C-3 through C-6 show the results of the groundwater elevation analysis completed using TRIM in the vicinity of the 216-A-29 Ditch. The figures depict general patterns of groundwater elevations and hydraulic gradients for conditions represented by calendar years (CYs) 2013, 2014, 2015, and 2016. These groundwater elevation contours and associated hydraulic gradients form the basis for the facility-specific calculations performed for this ECF.

C3.2 Particle Tracking

Once the groundwater elevation contour maps and underlying piecewise continuous elevation grids were prepared using TRIM, particle tracking was implemented using both advection and dispersion.
The particle pathlines that were produced depict the patterns of spreading that might accompany the migration of contaminants near the ditch for the flow conditions calculated for CYs 2013, 2014, 2015, and 2016. Figures C-7 through C-10 depict the particle pathlines developed based on the groundwater elevations prepared throughout the 200 East Area using TRIM. The resulting maps were prepared based on the release of 20 particles from each starting location to provide the high density of particles in space and time required for these detailed facility-specific calculations. Figures C-7 through C-10 depict the particle pathlines calculated after 380 days of travel, by which time it was determined that most of the particles would have arrived at or passed by the interim status groundwater monitoring wells. Figures C-7 through C-10 depict an instantaneous release to the water table from the release locations in the 216-A-29 Ditch to illustrate the adequacy of the well network for monitoring the entire facility.

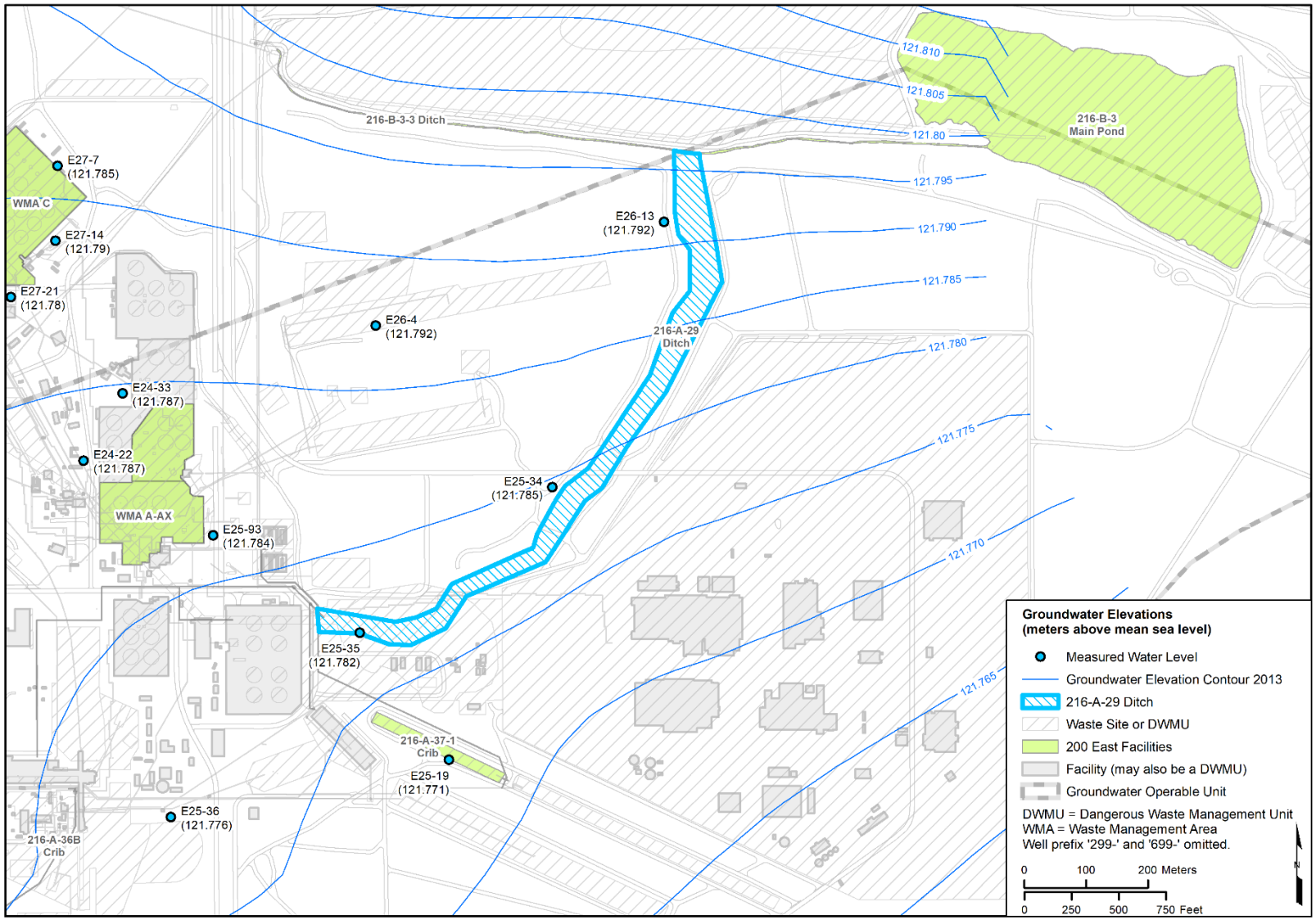

Figure C-3. Water-Level Elevation Map for the 216-A-29 Ditch, 2013

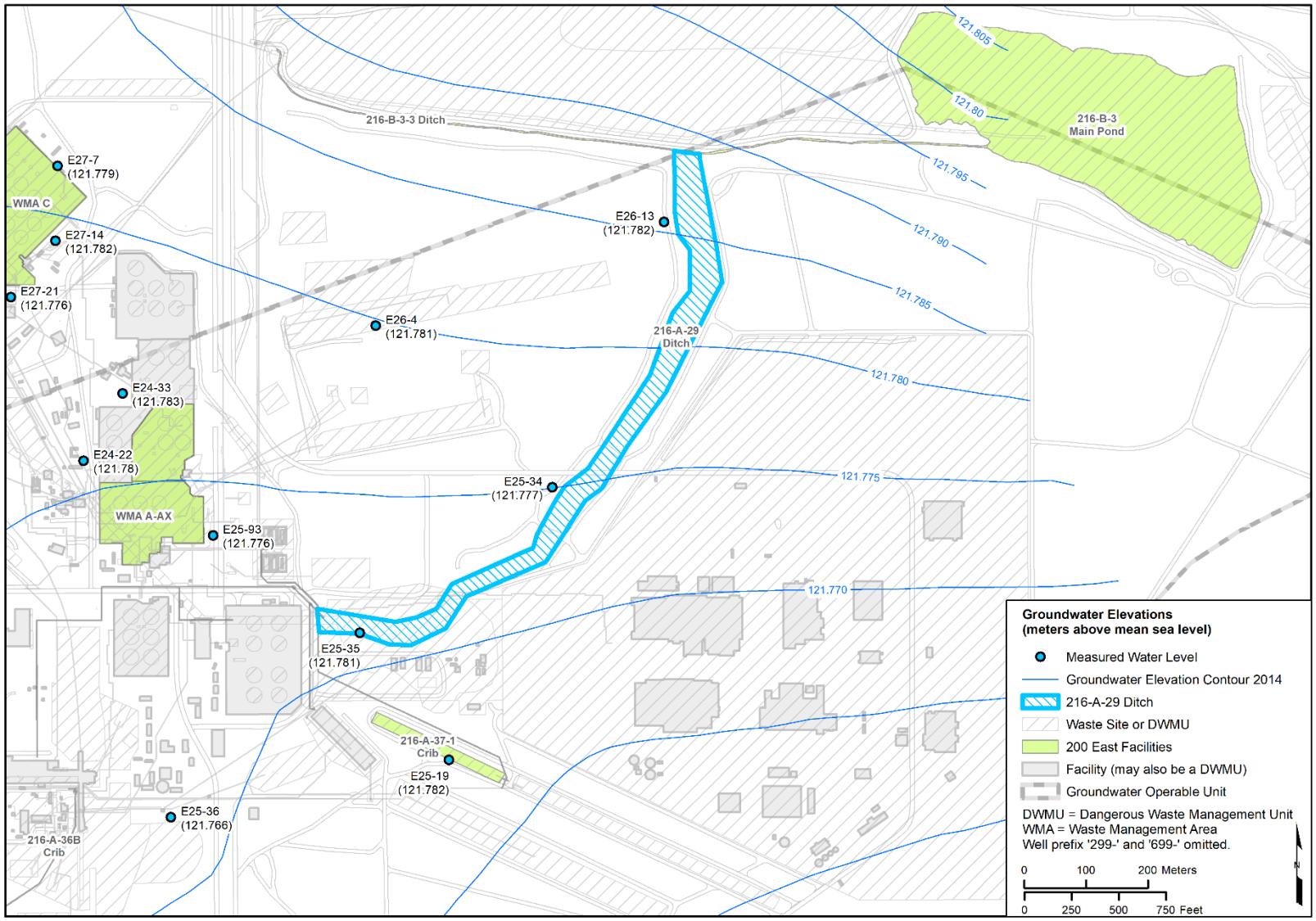

Figure C-4. Water-Level Elevation Map for the 216-A-29 Ditch, 2014

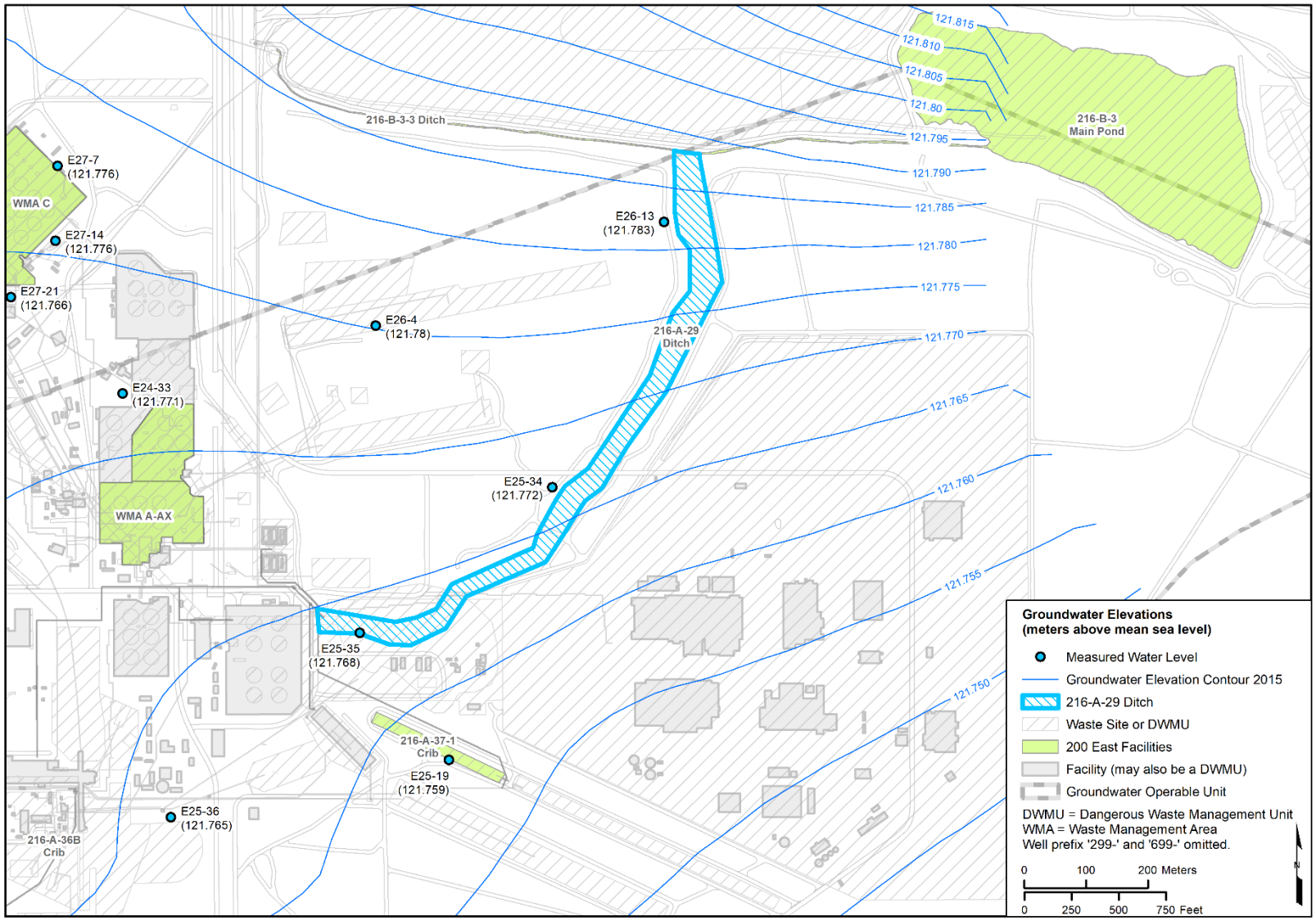

Figure C-5. Water-Level Elevation Map for the 216-A-29 Ditch, 2015

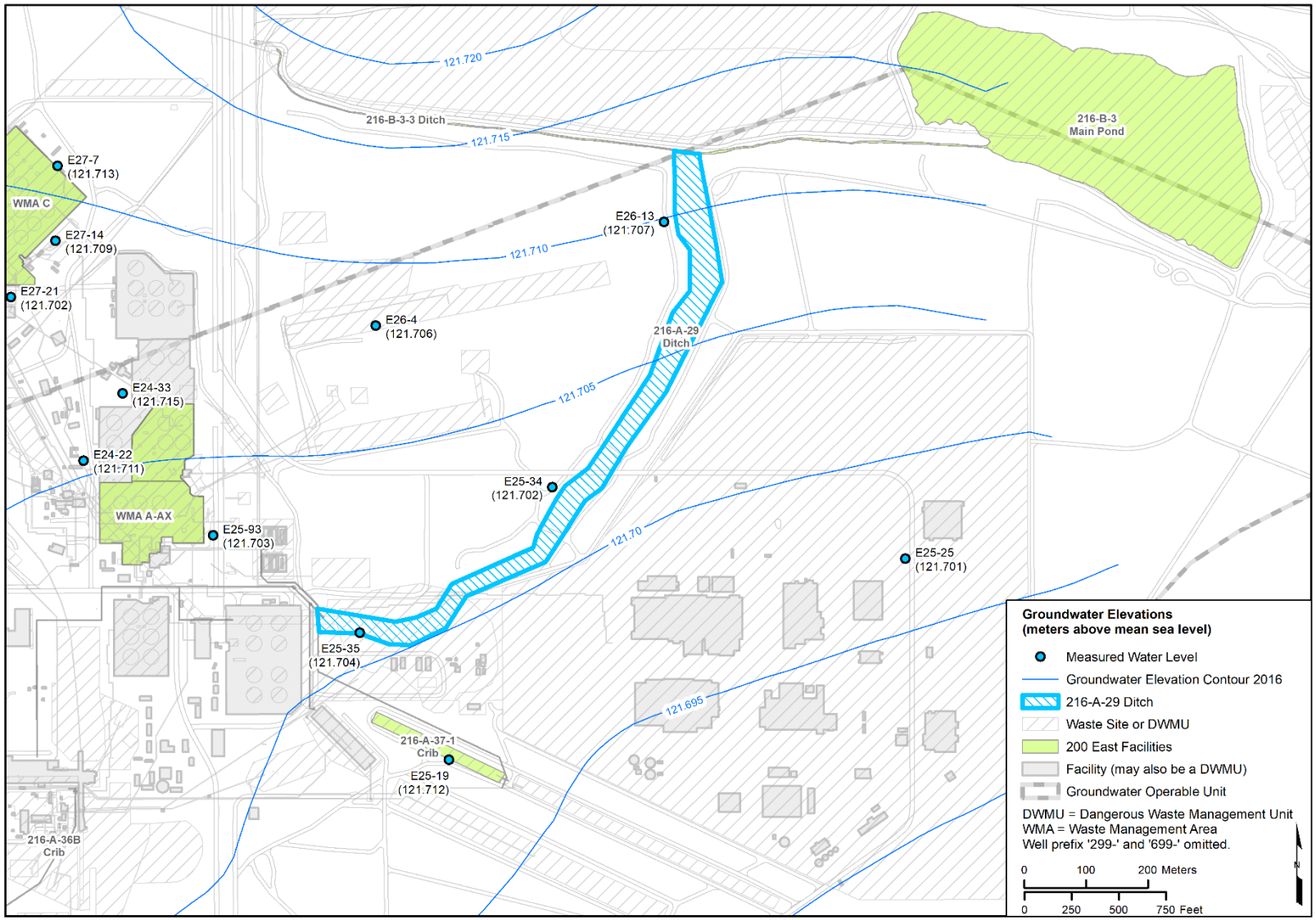

Figure C-6. Water-Level Elevation Map for the 216-A-29 Ditch, 2016

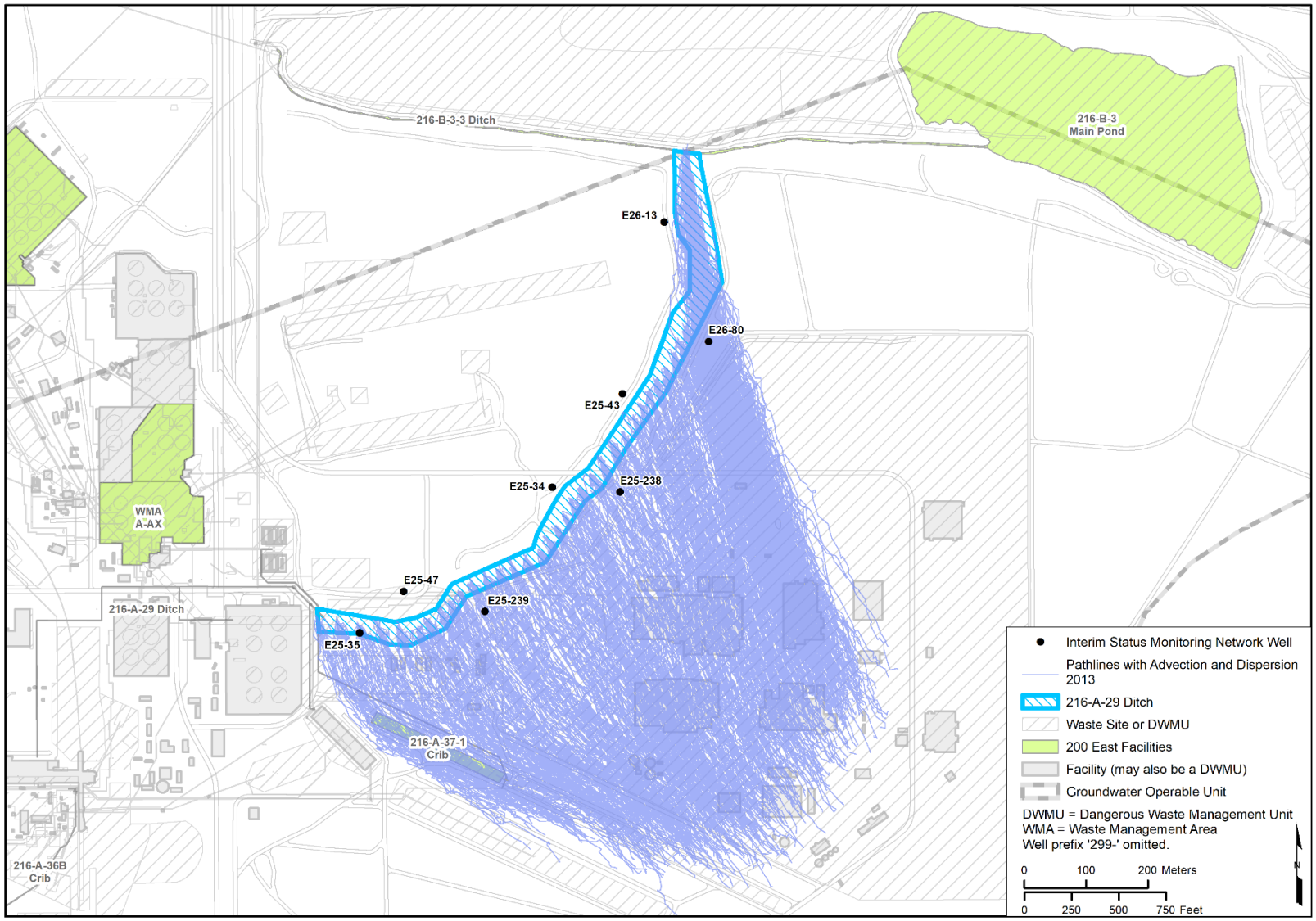

Figure C-7. Local-Scale Particle Pathlines, Advection and Dispersion – 216-A-29 Ditch, 2013

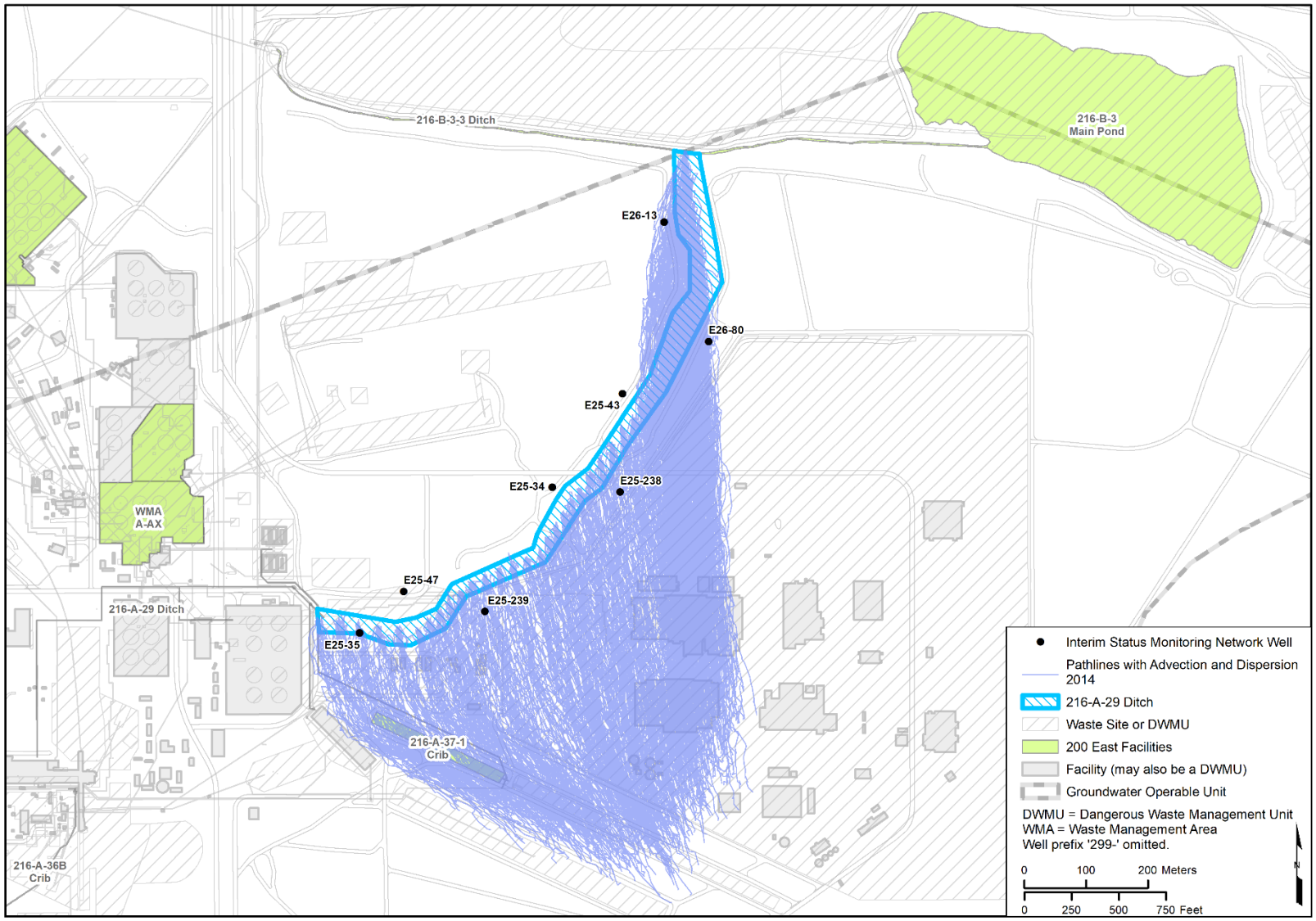

Figure C-8. Local-Scale Particle Pathlines, Advection and Dispersion – 216-A-29 Ditch, 2014

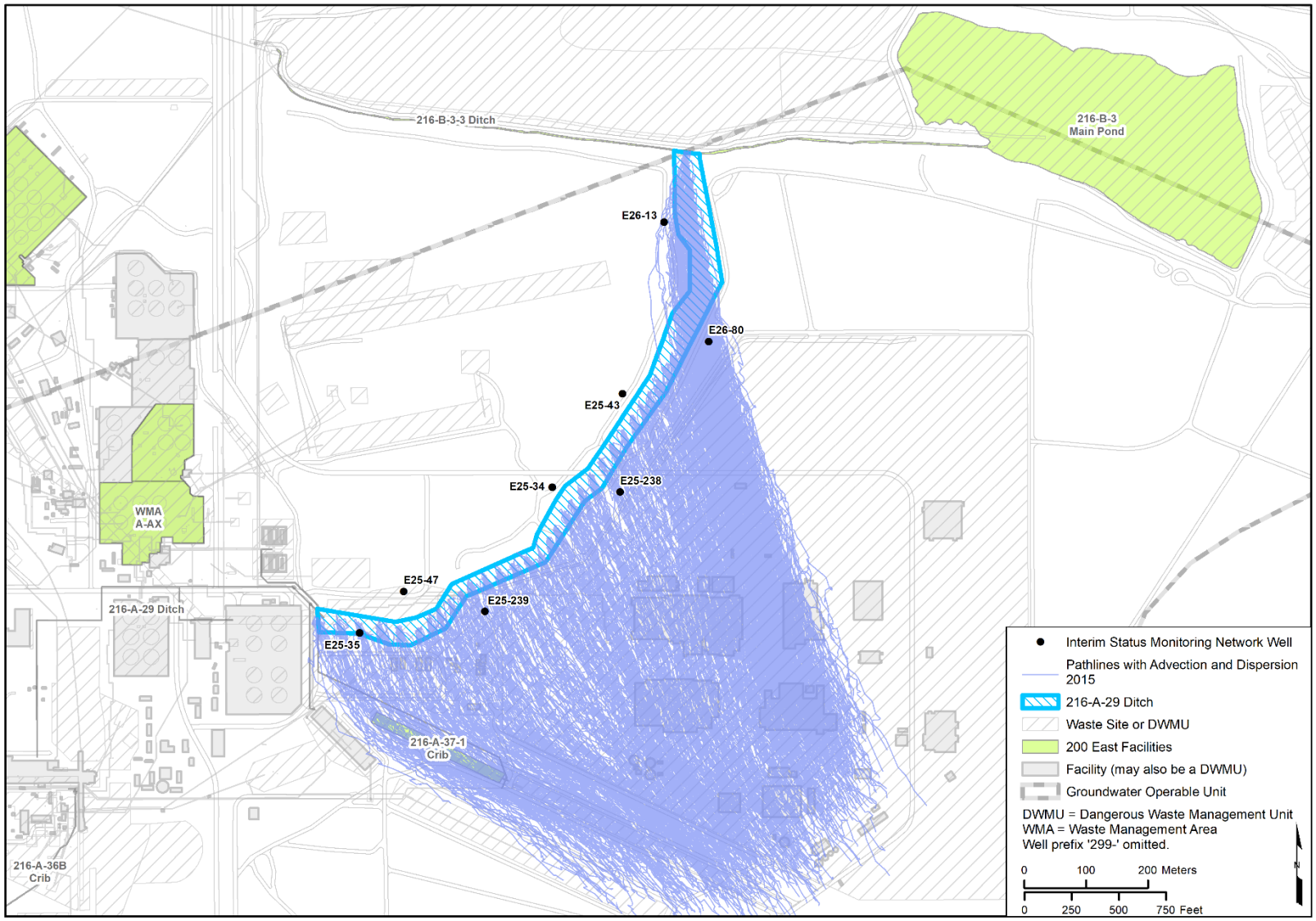

Figure C-9. Local-Scale Particle Pathlines, Advection and Dispersion – 216-A-29 Ditch, 2015

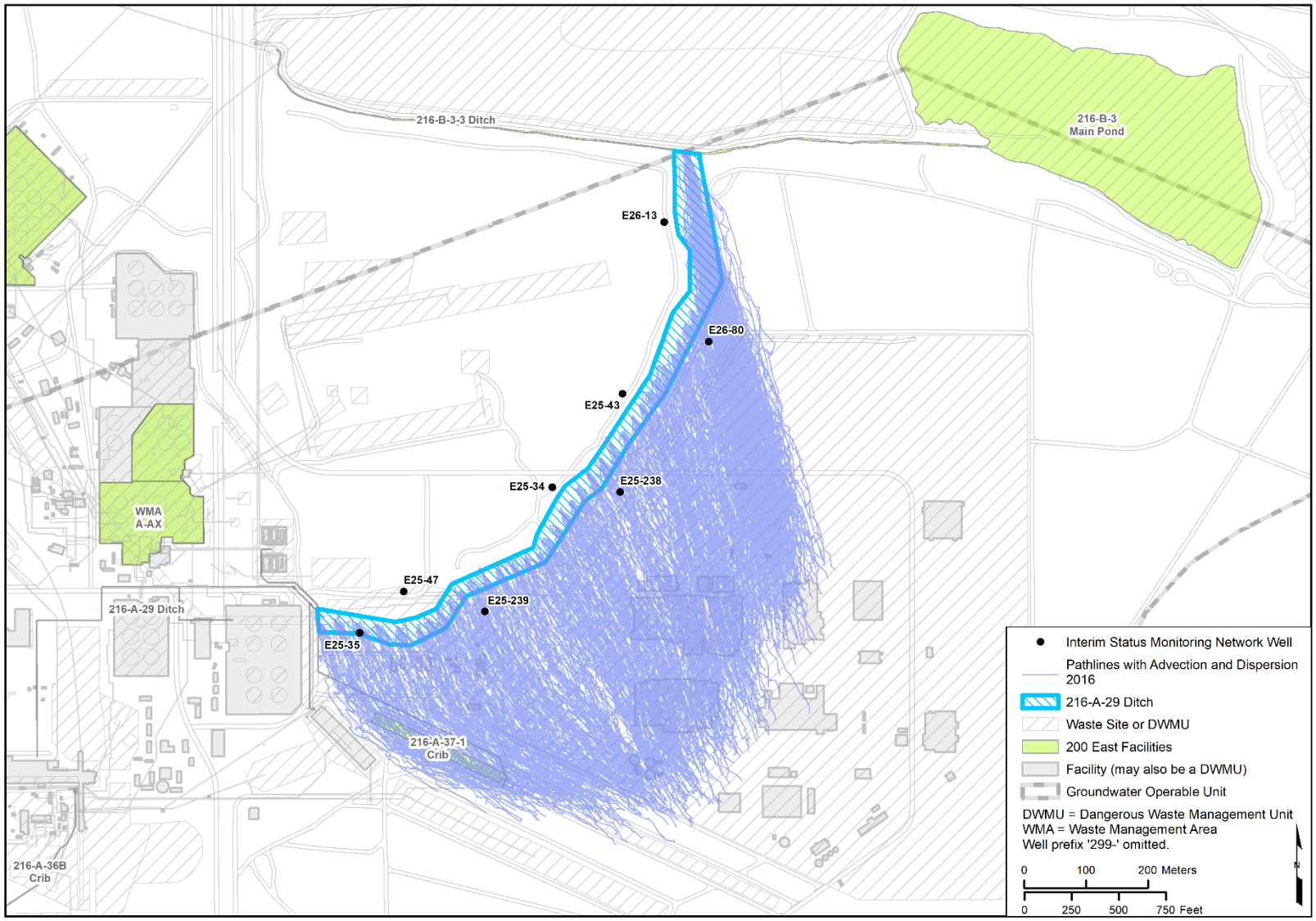

Figure C-10. Local-Scale Particle Pathlines, Advection and Dispersion – 216-A-29 Ditch, 2016

C3.3 Particle Counts

To compare the relative timing and density of the particles that pass by each monitoring well location, particle counts were calculated as described in Section 6.3 of the main text of this ECF. The particle counts were tabulated, particle breakthrough curves were created, and particle count maps were generated.

C3.3.1 Relative Particle Counts at Interim Status Groundwater Monitoring Wells

Tables C-1 through C-5 present the computed particle counts over time, binned into periods of 31 days, for each of the downgradient monitoring wells. Results for well 299-E26-13 are also included because this well, while upgradient of the majority of release locations, is located downgradient of the northernmost release locations within the 216-A-29 Ditch. The tables present four entries (one for each year) for each well. At the bottom of the column for each mapped event is the total number of particles that passed through the vicinity of the well, regardless of time, and the average of the totals for the four mapped years rounded to the nearest integer. Each table provides an indication of the relative timing of the expected detections at each well and the relative potential that each well would detect a release at the facility for the flow conditions calculated for CYs 2013, 2014, 2015, and 2016.

Table C-1. Particle Density (Count) Monitoring Well 299-E25-35

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
31	23	20	20	20	
62	1	2	0	3	
93	0	0	0	1	
124	0	0	0	0	
155	0	0	0	0	
186	0	0	0	0	
217	0	0	0	0	
248	0	0	0	0	
279	0	0	0	0	
310	0	0	0	0	
341	0	0	0	0	
372	0	0	0	0	Average
Total	24	22	20	24	**23**

Table C-2. Particle Density (Count) Monitoring Well 299-E25-238

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
31	24	18	33	18	
62	10	20	3	14	
93	0	3	0	0	
124	0	1	0	0	
155	0	1	0	0	
186	0	0	0	0	
217	0	0	0	0	
248	0	0	0	0	
279	0	0	0	0	
310	0	0	0	0	
341	0	0	0	0	
372	0	0	0	0	Average
Total	34	43	36	32	**36**

Table C-3. Particle Density (Count) Monitoring Well 299-E25-239

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
31	31	24	35	22	
62	3	13	3	14	
93	0	0	1	2	
124	0	0	0	0	
155	0	0	0	0	
186	0	0	0	0	
217	0	0	0	0	
248	0	0	0	0	
279	0	0	0	0	
310	0	0	0	0	
341	0	0	0	0	
372	0	0	0	0	Average
Total	34	37	39	38	**37**

Table C-4. Particle Density (Count) Monitoring Well 299-E26-13

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
31	2	13	19	0	
62	2	24	4	0	
93	0	4	0	0	
124	0	0	0	0	
155	0	0	0	0	
186	0	0	0	0	
217	0	0	0	0	
248	0	0	0	0	
279	0	0	0	0	
310	0	0	0	0	
341	0	0	0	0	
372	0	0	0	0	Average
Total	4	41	23	0	**17**

Table C-5. Particle Density (Count) Monitoring Well 299-E26-80

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
31	63	17	78	31	
62	78	28	87	25	
93	52	13	26	22	
124	21	4	4	16	
155	0	0	0	10	
186	0	0	0	2	
217	0	0	0	1	
248	0	0	0	0	
279	0	0	0	0	
310	0	0	0	0	
341	0	0	0	0	
372	0	0	0	0	Average
Total	214	62	195	107	**145**

The average values depicted at the base of each table can be used to assess the relative potential for each well to detect a release at the facility. These averages are summarized as follows:

- 299-E25-35 – Average = 23
- 299-E25-238 – Average = 36
- 299-E25-239 – Average = 37
- 299-E26-13 – Average = 17
- 299-E26-80 – Average = 145

C3.3.2 Relative Arrival Times at Interim Status Groundwater Monitoring Wells

Figures C-11 through C-15 depict plots of particle counts over time (particle breakthrough curves) for each downgradient well location. The underlying data plotted in Figures C-11 through C-15 are the same as the data in Tables C-1 through C-5, but the time interval over which particles are summed is not necessarily the same. Results for well 299-E26-13 are also included because this well, while upgradient of the majority of release locations, is located downgradient of the northernmost release locations within the 216-A-29 Ditch. Particle breakthrough curves show the relative timing and particle density for the arrival, peak, and decline in particle counts at each interim status monitoring location resulting from the hypothetical instantaneous release at the facility. The plots depict the relative potential at each well for detecting a release from the facility that reaches the water table for the flow conditions calculated for CYs 2013, 2014, 2015, and 2016. There is one figure for each well, with four lines shown on each plot (one for each year).

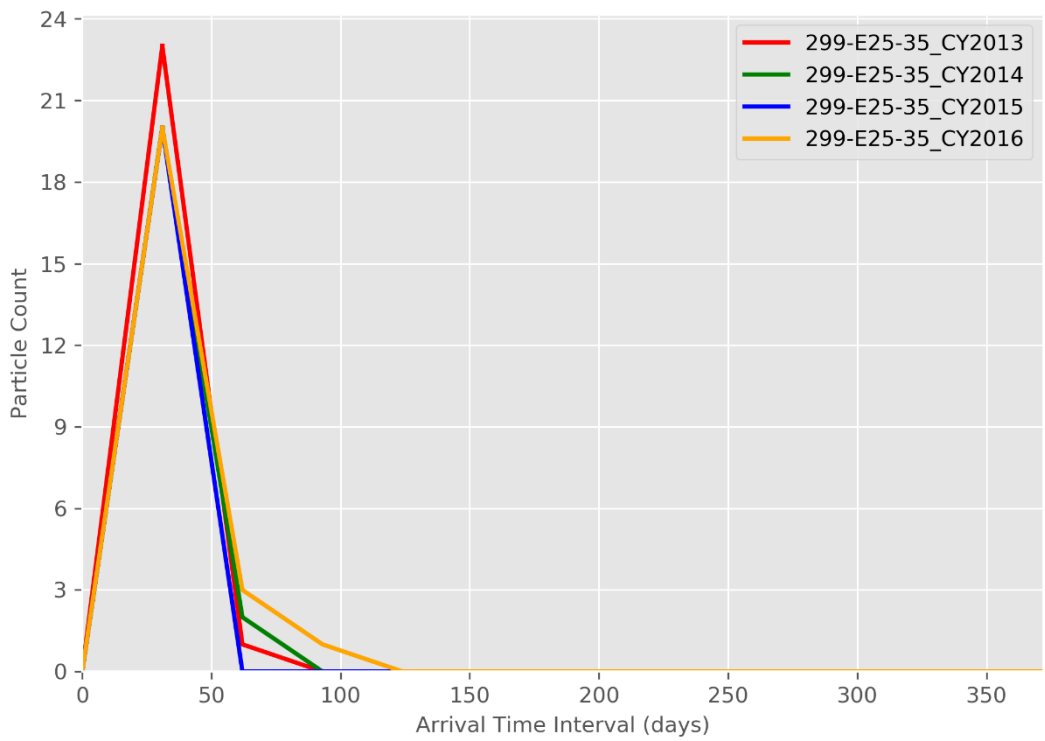

Figure C-11. Particle Breakthrough Curve at Monitoring Well 299-E25-35

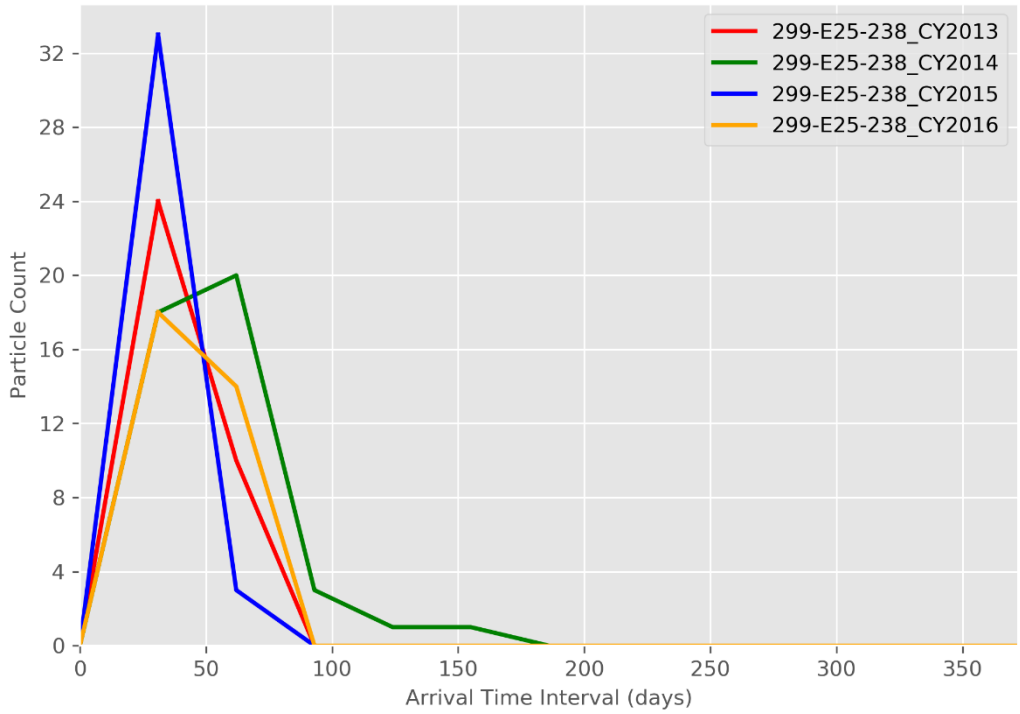

Figure C-12. Particle Breakthrough Curve at Monitoring Well 299-E25-238

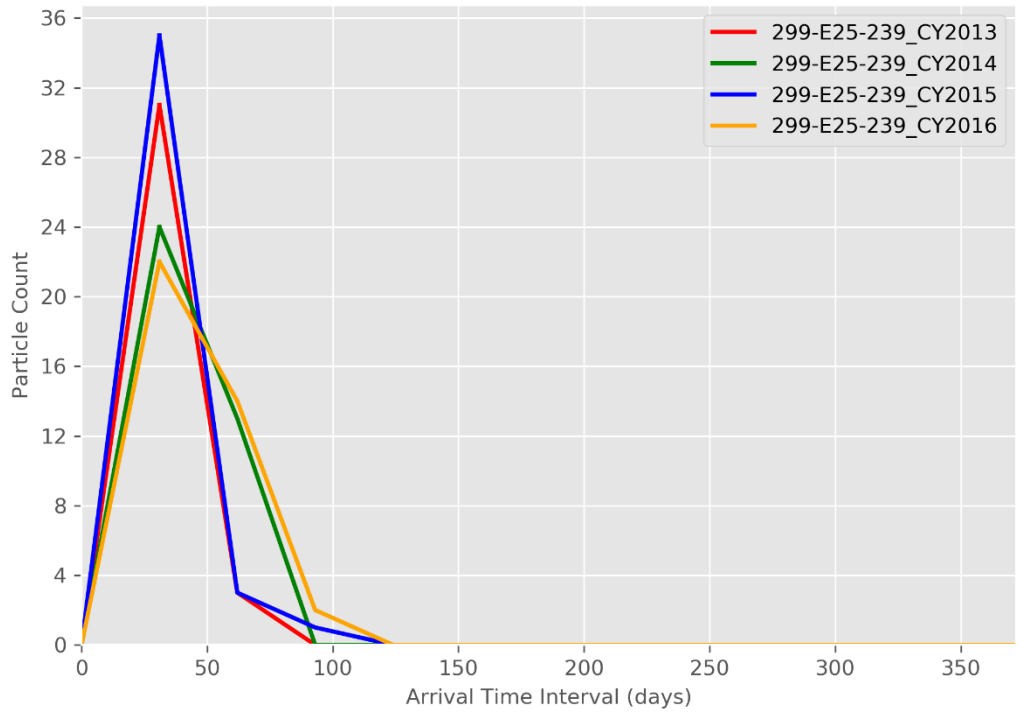

Figure C-13. Particle Breakthrough Curve at Monitoring Well 299-E25-239

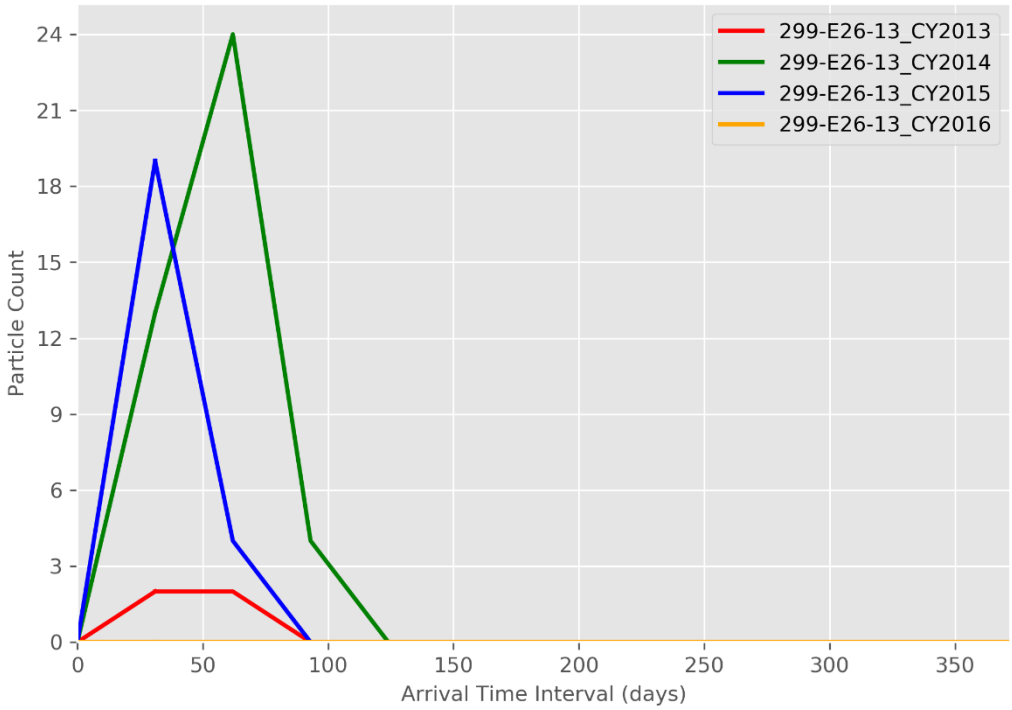

Figure C-14. Particle Breakthrough Curve at Monitoring Well 299-E26-13

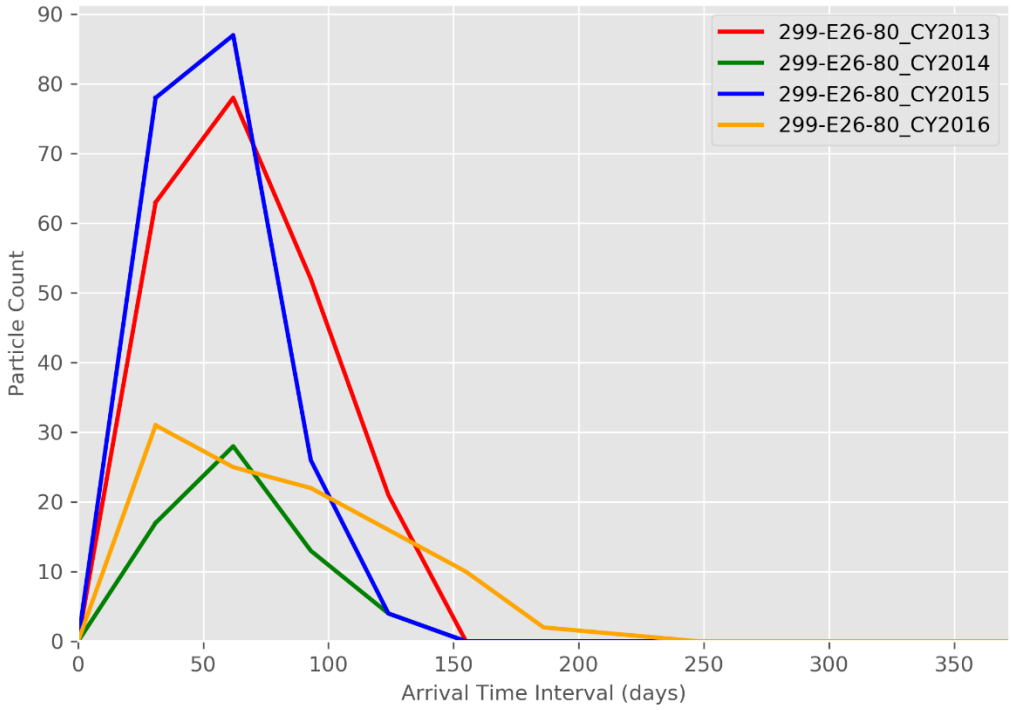

Figure C-15. Particle Breakthrough Curve at Monitoring Well 299-E26-80

C3.3.3 Particle Count Maps

Figures C-16 through C-19 depict the particle count maps developed based on the instantaneous release of a large number of particles at the facility. The particle count maps depict areas of relatively higher and lower potential impact from a release at the facility that reaches the water table, for conditions represented by CYs 2013, 2014, 2015, and 2016. Figures C-16 through C-19 depict the particle density after 380 days of calculated travel, by which time it was determined that all particles would have arrived at or passed by the interim status groundwater monitoring wells (see entries in Tables C-1 through C-5).

The goal of well placement is for the well locations to span the range of particle pathline distribution as released from the 216-A-29 Ditch. The particle count maps show that under the evaluated range of conditions, there are areas of high particle counts where there are no corresponding monitoring wells, indicating the need for additional monitoring wells. The location of the seven proposed wells (216-A-29_PW-1, 216-A-29_PW-2, 216-A-29_PW-3, 216-A-29_PW-4, 216-A-29_PW-5, 216-A-29_PW-6, and 216-A-37-1_PW-3) (proposed as a shared network well for the 216-A-37-1 Crib) are shown in Figures C-16 through C-19.

C3.4 Proposed Monitoring Wells

The locations of the proposed monitoring wells are shown in Figures C-16 through C-19. The particle counts tabulated for these locations (Tables C-6 through C-12) indicate the relative timing of expected detections at the wells and the relative potential of the wells for detecting a release at the facility.
The particle breakthrough curves (Figures C-20 and C-26) show the relative timing and particle density at the proposed monitoring well locations for the arrival, peak, and decline in particle counts resulting from the hypothetical instantaneous release to the water table beneath the facility.

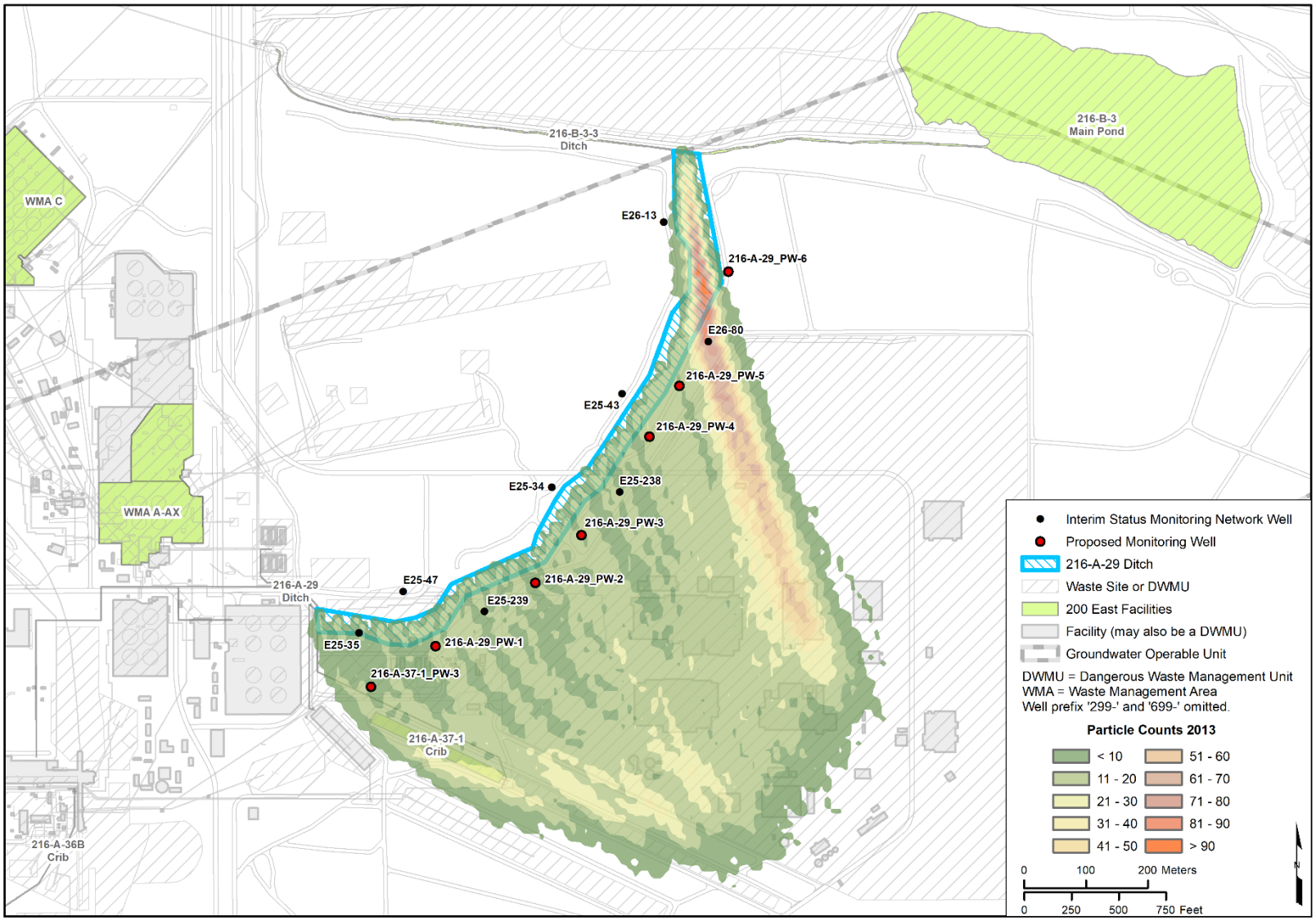

Figure C-16. Particle Count Map – 216-A-29 Ditch, 2013

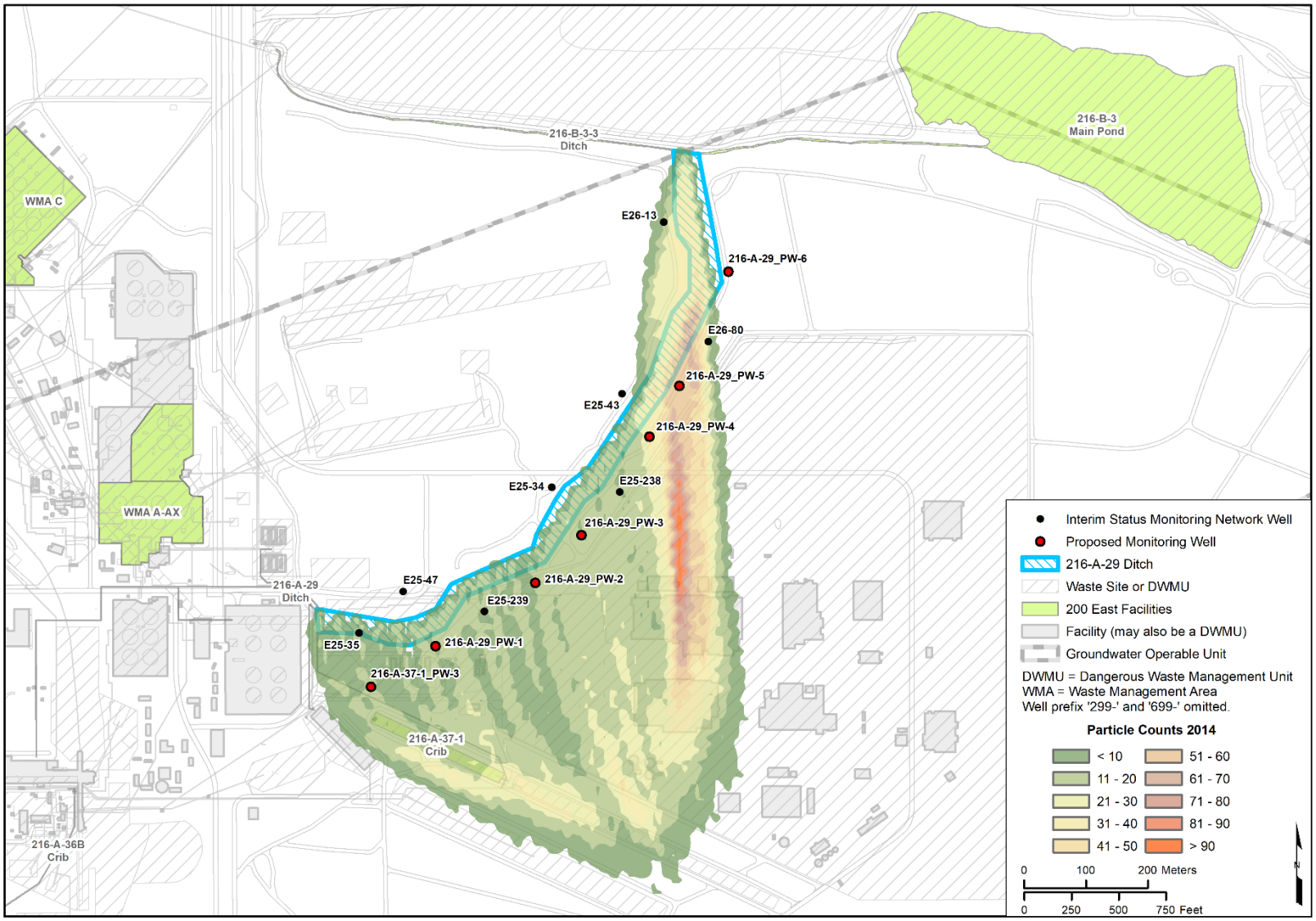

Figure C-17. Particle Count Map – 216-A-29 Ditch, 2014

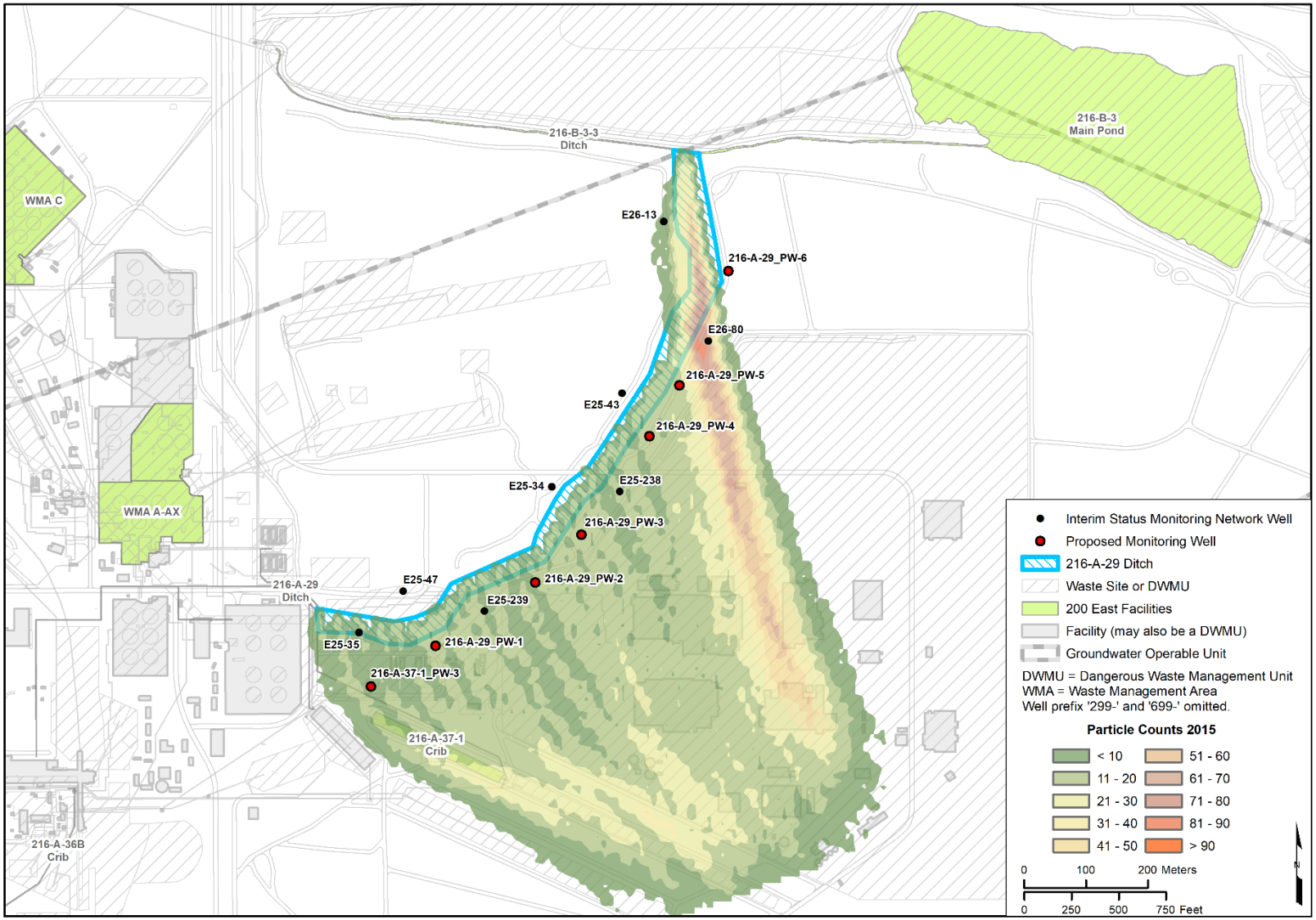

Figure C-18. Particle Count Map – 216-A-29 Ditch, 2015

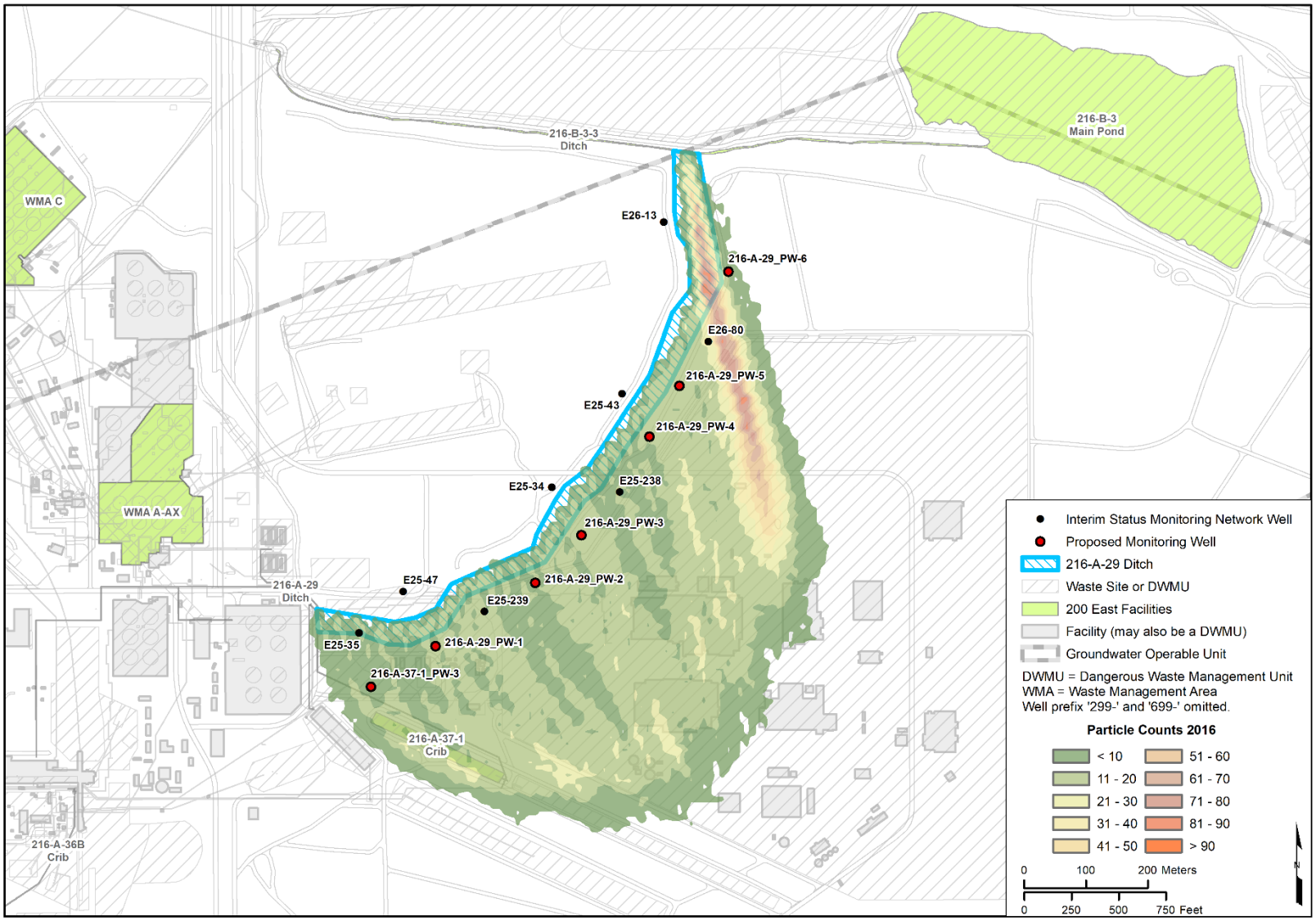

Figure C-19. Particle Count Map – 216-A-29 Ditch, 2016

Table C-6. Particle Density (Count) Proposed Monitoring Well 216-A-37-1_PW-3

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
31	1	0	2	0	
62	12	21	17	4	
93	13	11	11	15	
124	1	1	1	4	
155	0	0	0	6	
186	0	0	0	0	
217	0	0	0	0	
248	0	0	0	1	
279	0	0	0	0	
310	0	0	0	0	
341	0	0	0	0	
372	0	0	0	0	Average
Total	27	33	31	30	**30**

Table C-7. Particle Density (Count) Proposed Monitoring Well 216-A-29_PW-1

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
31	33	35	36	33	
62	5	8	2	7	
93	1	1	0	1	
124	0	0	0	0	
155	0	0	0	0	
186	0	0	0	0	
217	0	0	0	0	
248	0	0	0	0	
279	0	0	0	0	
310	0	0	0	0	
341	0	0	0	0	
372	0	0	0	0	Average
Total	39	44	38	41	**41**

Table C-8. Particle Density (Count) Proposed Monitoring Well 216-A-29_PW-2

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
31	29	34	35	26	
62	0	4	1	8	
93	0	0	0	0	
124	0	0	0	0	
155	0	0	0	0	
186	0	0	0	0	
217	0	0	0	0	
248	0	0	0	0	
279	0	0	0	0	
310	0	0	0	0	
341	0	0	0	0	
372	0	0	0	0	Average
Total	29	38	36	34	**34**

Table C-9. Particle Density (Count) Proposed Monitoring Well 216-A-29_PW-3

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
31	34	37	40	29	
62	8	15	2	13	
93	0	1	0	2	
124	0	1	0	0	
155	0	0	0	0	
186	0	0	0	0	
217	0	0	0	0	
248	0	0	0	0	
279	0	0	0	0	
310	0	0	0	0	
341	0	0	0	0	
372	0	0	0	0	Average
Total	42	54	42	44	**46**

Table C-10. Particle Density (Count) Proposed Monitoring Well 216-A-29_PW-4

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
31	45	35	43	31	
62	2	25	2	12	
93	0	1	0	1	
124	0	0	0	0	
155	0	1	0	0	
186	0	5	0	0	
217	0	12	0	0	
248	0	9	0	0	
279	0	3	0	0	
310	0	0	0	0	
341	0	0	0	0	
372	0	0	0	0	Average
Total	47	91	45	44	**57**

Table C-11. Particle Density (Count) Proposed Monitoring Well 216-A-29_PW-5

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
31	45	37	55	36	
62	1	27	4	12	
93	0	14	4	1	
124	1	31	7	0	
155	0	33	0	0	
186	0	22	0	0	
217	0	4	0	0	
248	0	1	0	0	
279	0	0	0	0	
310	0	0	0	0	
341	0	0	0	0	
372	0	0	0	0	Average
Total	47	169	70	49	**84**

Table C-12. Particle Density (Count) Proposed Monitoring Well 216-A-29_PW-6

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
31	1	1	0	2	
62	1	0	0	2	
93	2	0	0	19	
124	0	0	0	12	
155	0	0	0	2	
186	0	0	0	0	
217	0	0	0	0	
248	0	0	0	0	
279	0	0	0	0	
310	0	0	0	0	
341	0	0	0	0	
372	0	0	0	0	Average
Total	4	1	0	37	**11**

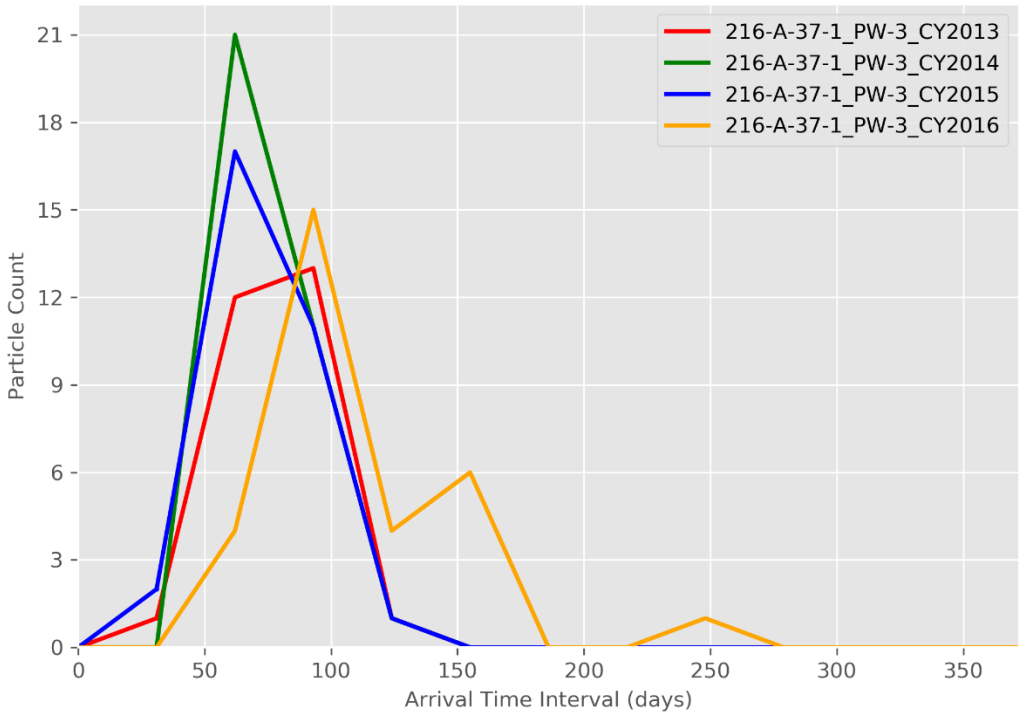

Figure C-20. Particle Breakthrough Curve at Monitoring Well 216-A-37-1_PW-3

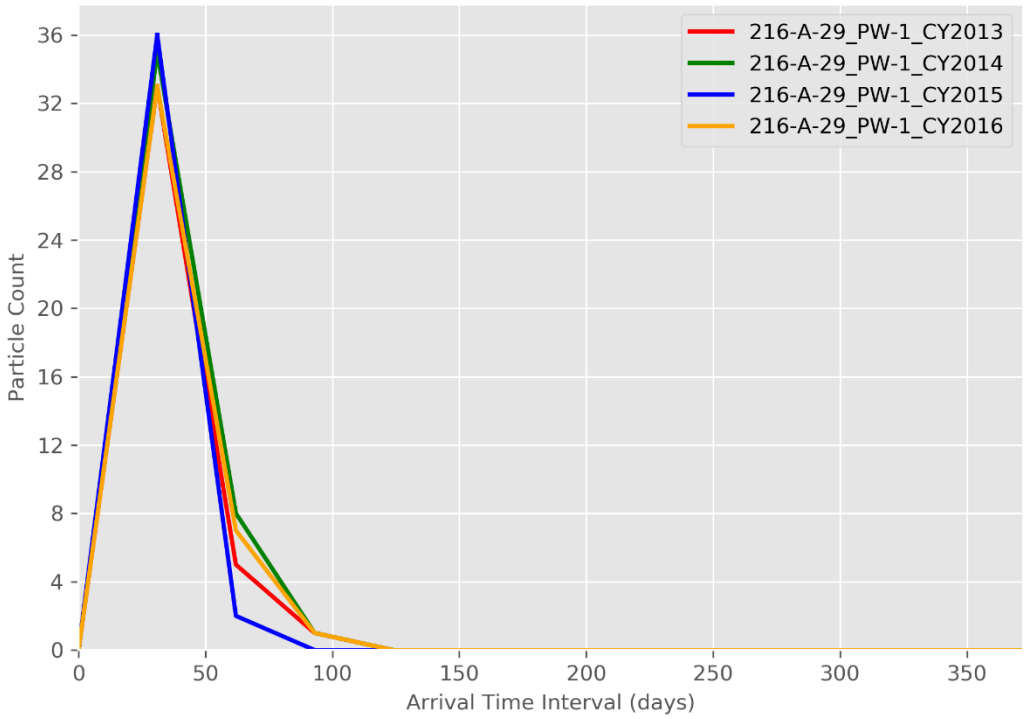

Figure C-21. Particle Breakthrough Curve at Monitoring Well 216-A-29_PW-1

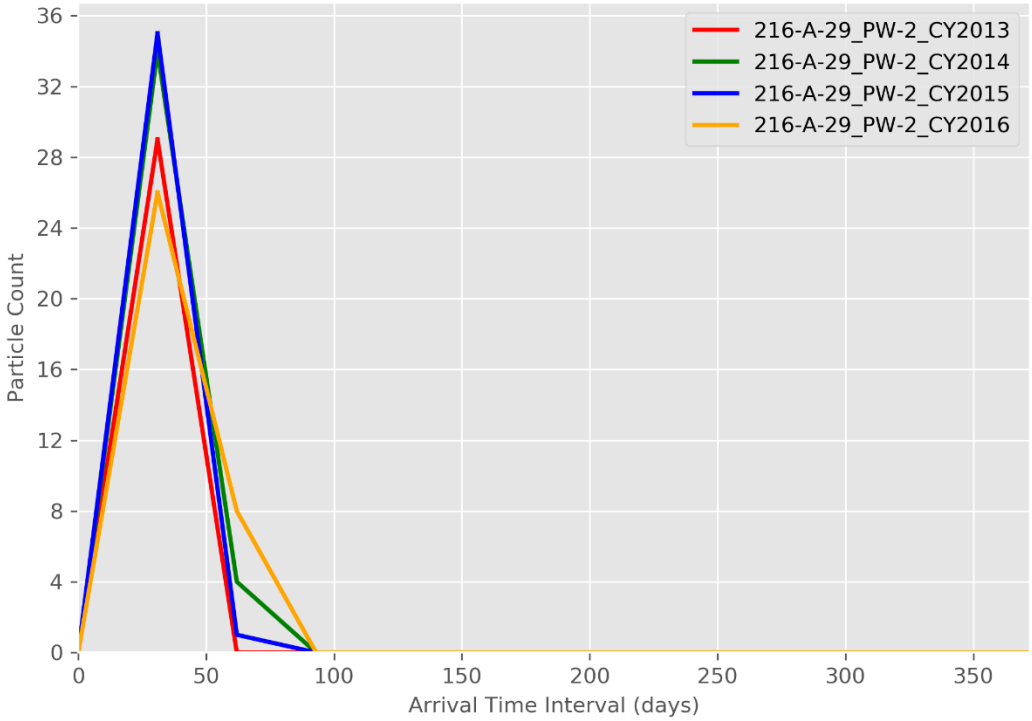

Figure C-22. Particle Breakthrough Curve at Monitoring Well 216-A-29_PW-2

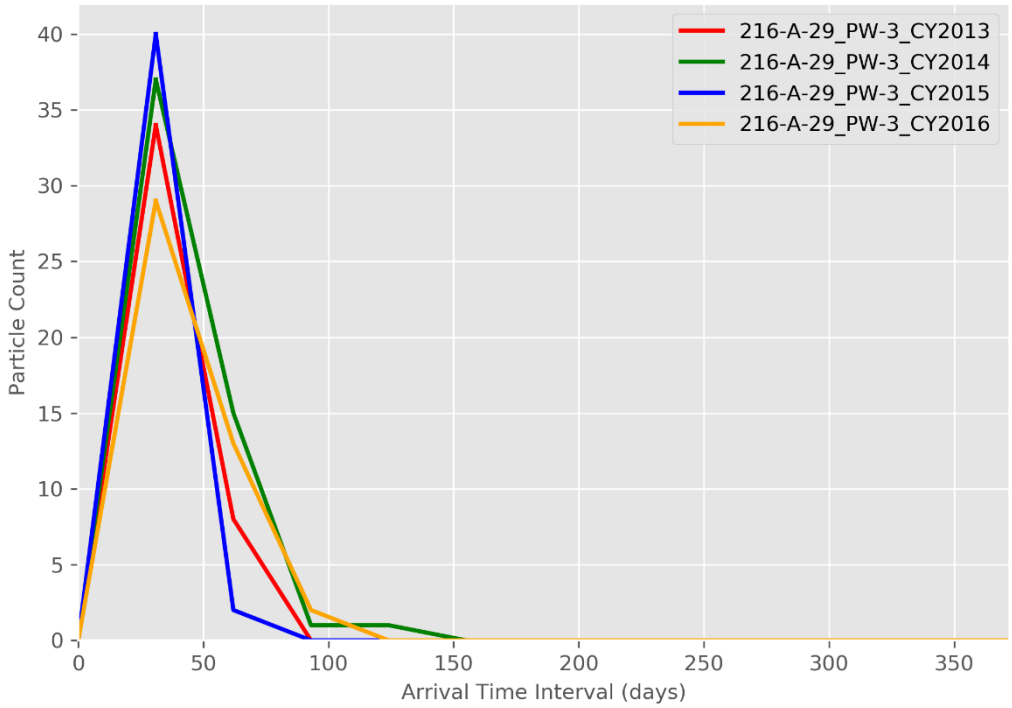

Figure C-23. Particle Breakthrough Curve at Monitoring Well 216-A-29_PW-3

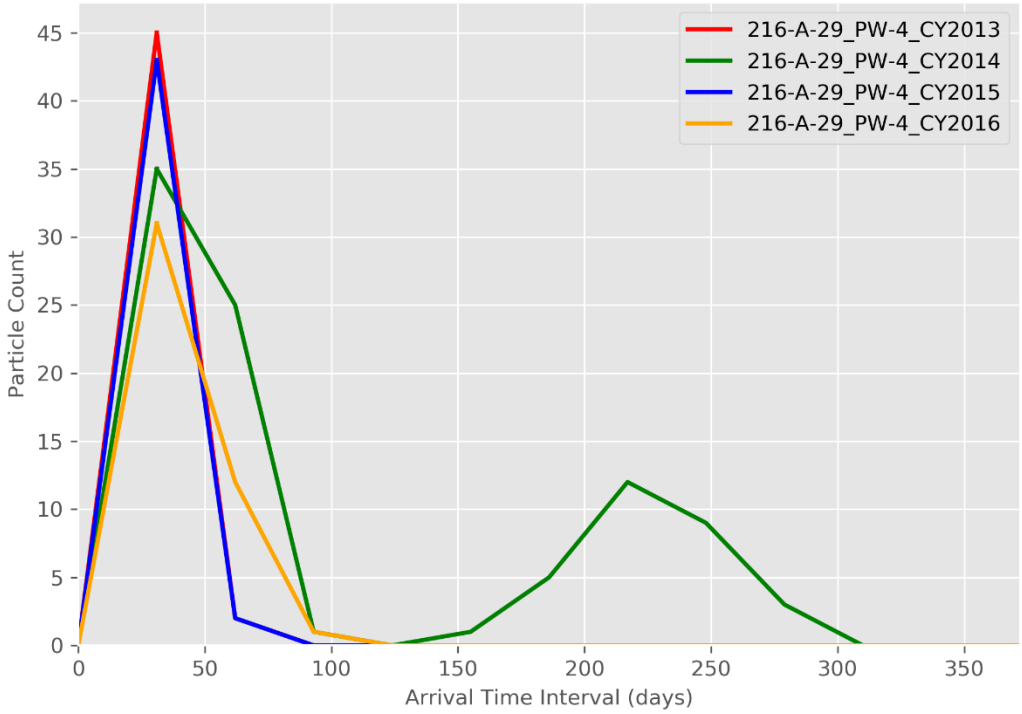

Figure C-24. Particle Breakthrough Curve at Monitoring Well 216-A-29_PW-4

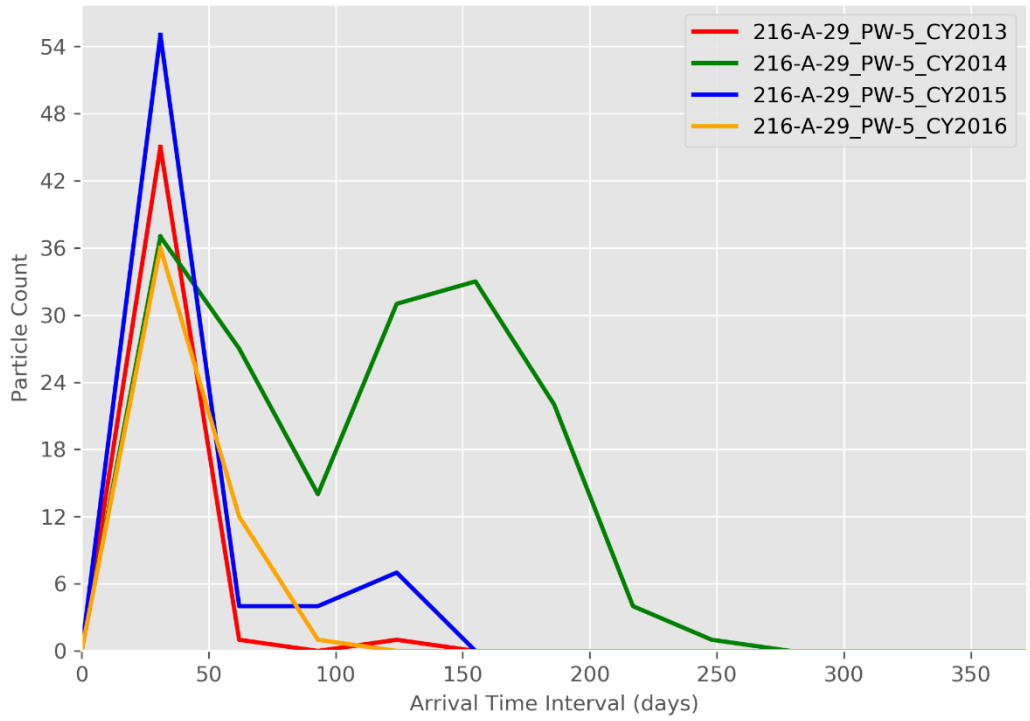

Figure C-25. Particle Breakthrough Curve at Monitoring Well 216-A-29_PW-5

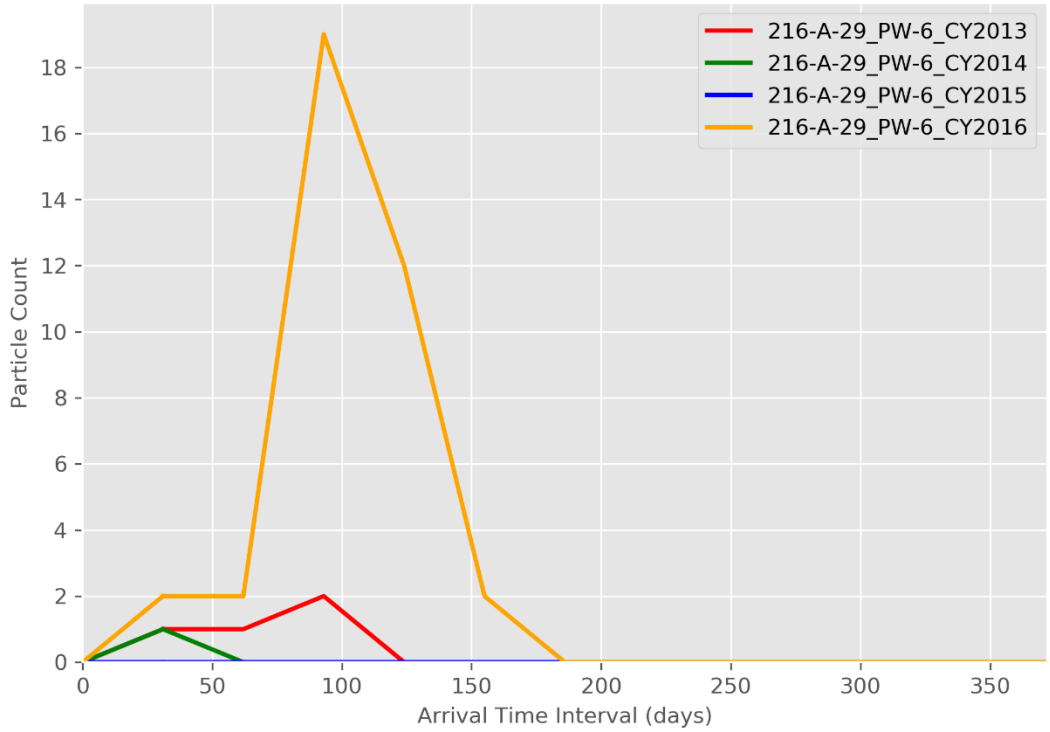

Figure C-26. Particle Breakthrough Curve at Monitoring Well 216-A-29_PW-6

C3.5 Analyses of Particle Pathlines for Each Area of the 216-A-29 Ditch

Particle pathline maps shown in Section C3.2 depict an instantaneous release to the water table from the release locations in the 216-A-29 Ditch. Particle tracking also was performed for smaller regions of the facility to evaluate well locations for detecting releases from various regions of the 216-A-29 Ditch. This section contains the results of analyses performed to examine how releases from the various areas of the 216-A-29 Ditch that reach the groundwater beneath those release areas relate to each individual monitoring well. A series of figures and tables are provided to illustrate the fate of releases originating from three different areas of the ditch. For these analyses, the particle release points presented in Figure C-2 are grouped into one of five areas based on their spatial location. Those areas are depicted in Figure C-27. Figures C-28 through C-31 illustrate the particle pathlines originating from each of the areas for CYs 2013 through 2016.

Figures C-32 through C-43 illustrate the particle count time series for each existing and proposed monitoring well from CY 2013 through CY 2016. Each figure has four panels, each of which depicts the particle counts for one CY (2013 through 2016). Additionally, each panel shows a separate breakthrough curve for particles emanating from each area. For example, Figure C-32 depicts the particle counts at well 299-E25-35, which receives particles from area 1 in 2013. In the figure, within the panel for 2013 (top row, left), the particle breakthrough curve from area 1 is depicted with a blue line.

C3.6 Vertical Migration Potential

As described in Section 3.3 of the main text of this ECF, the American Petroleum Institute (API) plume diving calculation was used to estimate the likely rate of vertical migration of dissolved constituents downward under the influence of recharge at the water table. At each well the slope of the plume dive was multiplied by the distance from the particle starting location to the well location to estimate the depth to which the dissolved constituents may be anticipated to have migrated by the time they reach the monitoring well location.

This estimated depth of the plume was then compared to the depth from the water table to the bottom of the monitoring well screen. If the depth of the plume is below the bottom of the monitoring well screen then the dissolved constituents may be anticipated to pass beneath the well screen. If it falls within the interval between the top of the water table and the bottom of the well screen, then the well depth is appropriate for detection of releases at the 216-A-29 Ditch.

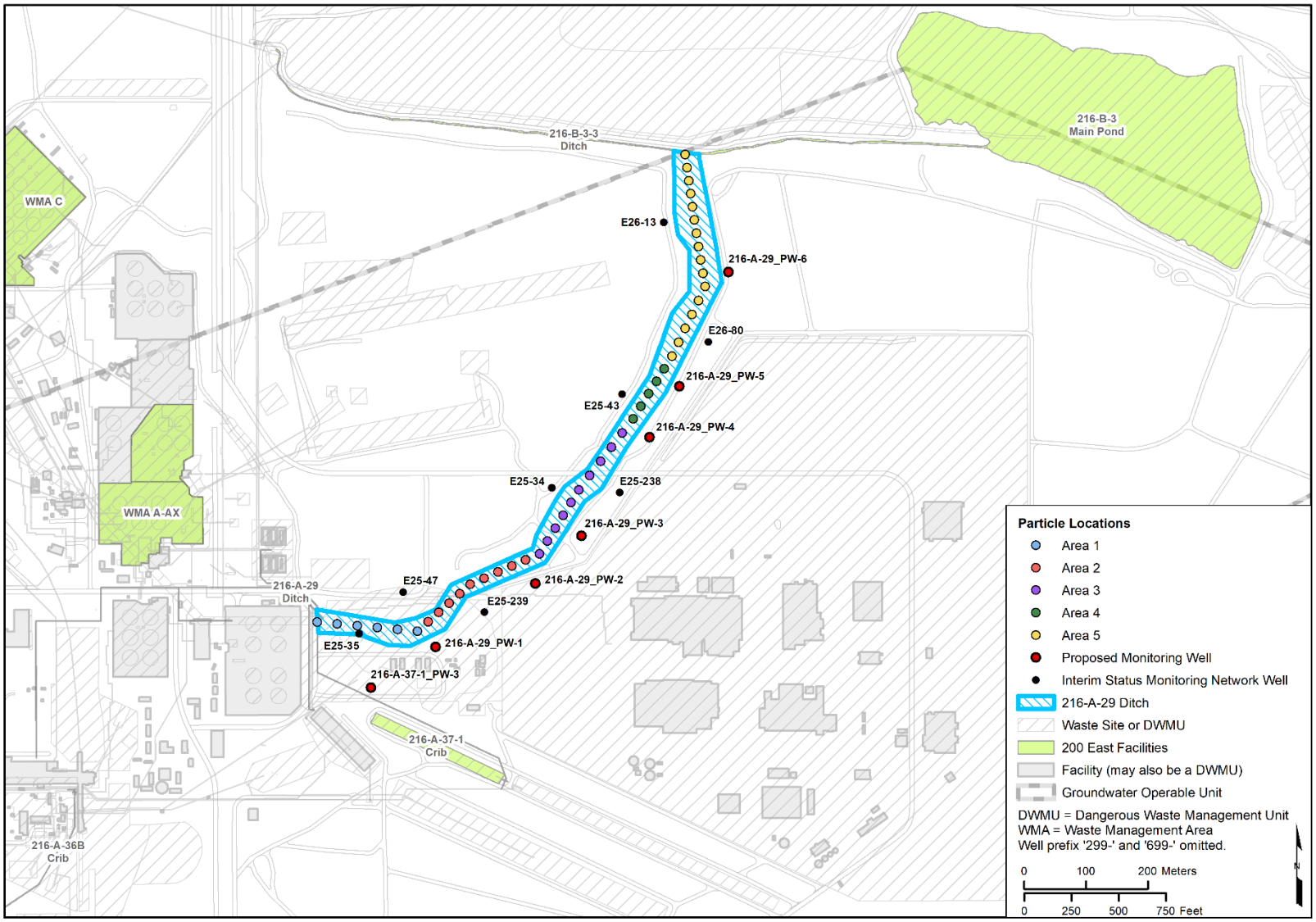

Figure C-27. Particle Release Locations and Areas of the 216-A-29 Ditch

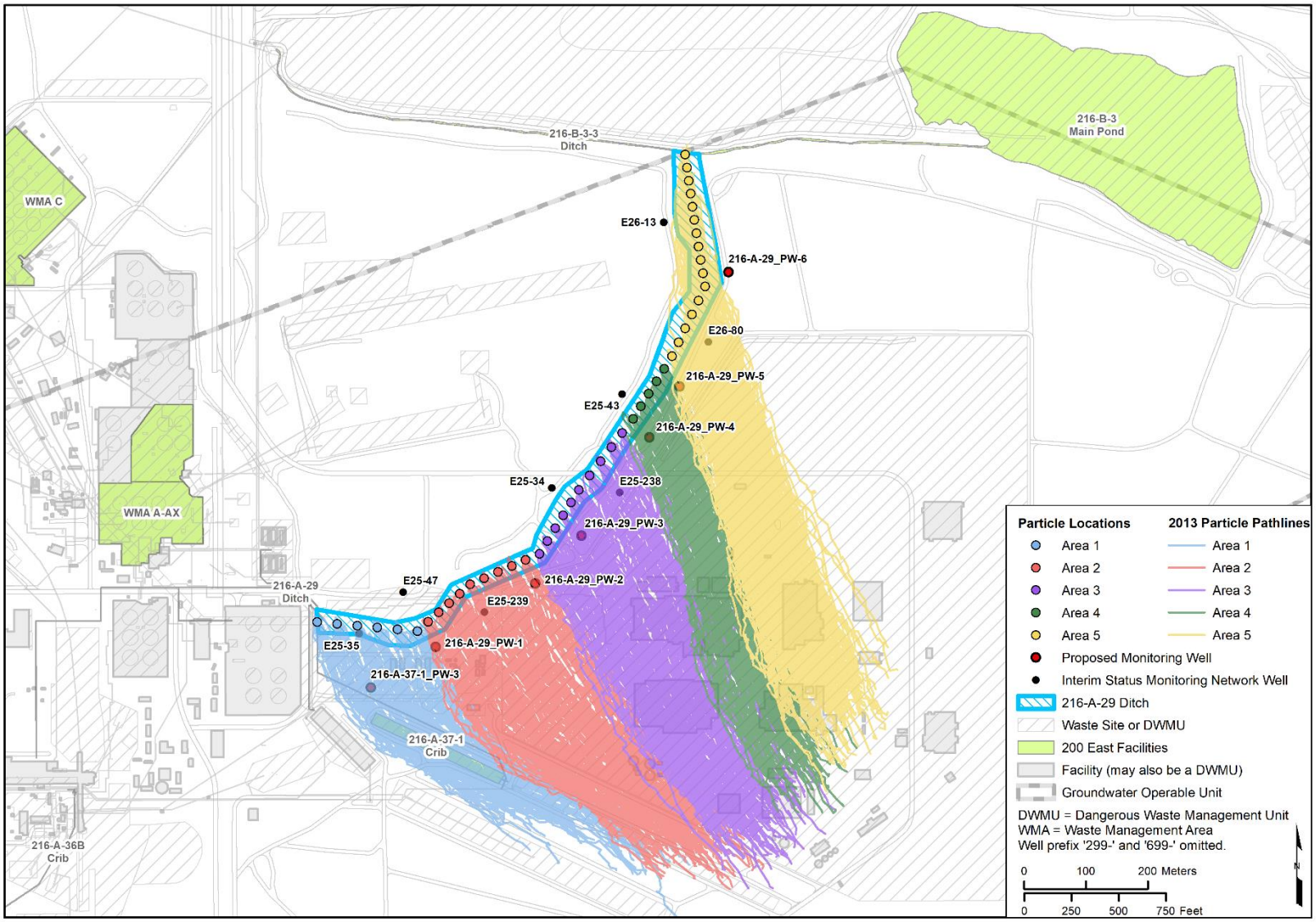

Figure C-28. CY 2013 Particle Pathlines per Area of the 216-A-29 Ditch

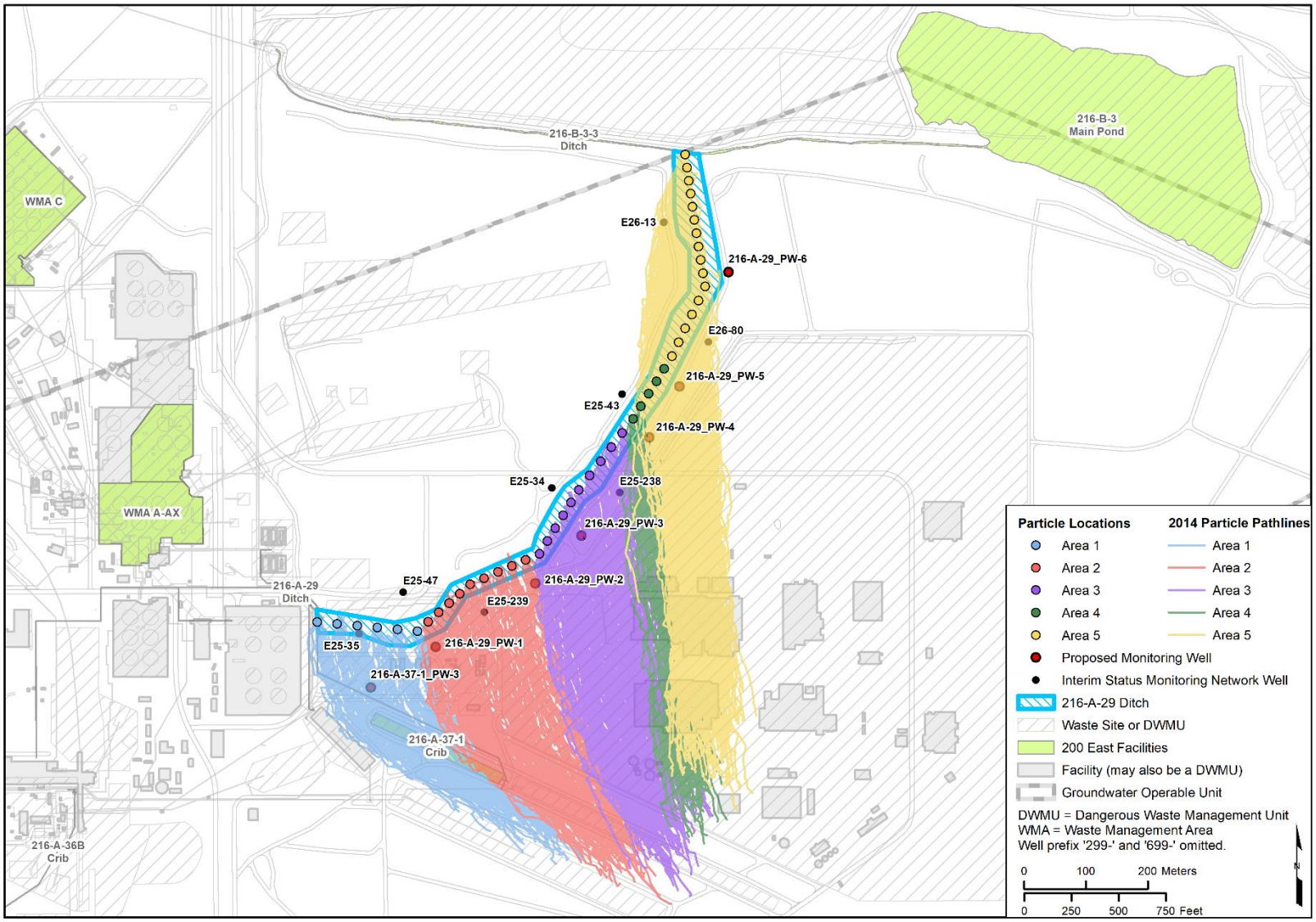

Figure C-29. CY 2014 Particle Pathlines per Area of the 216-A-29 Ditch

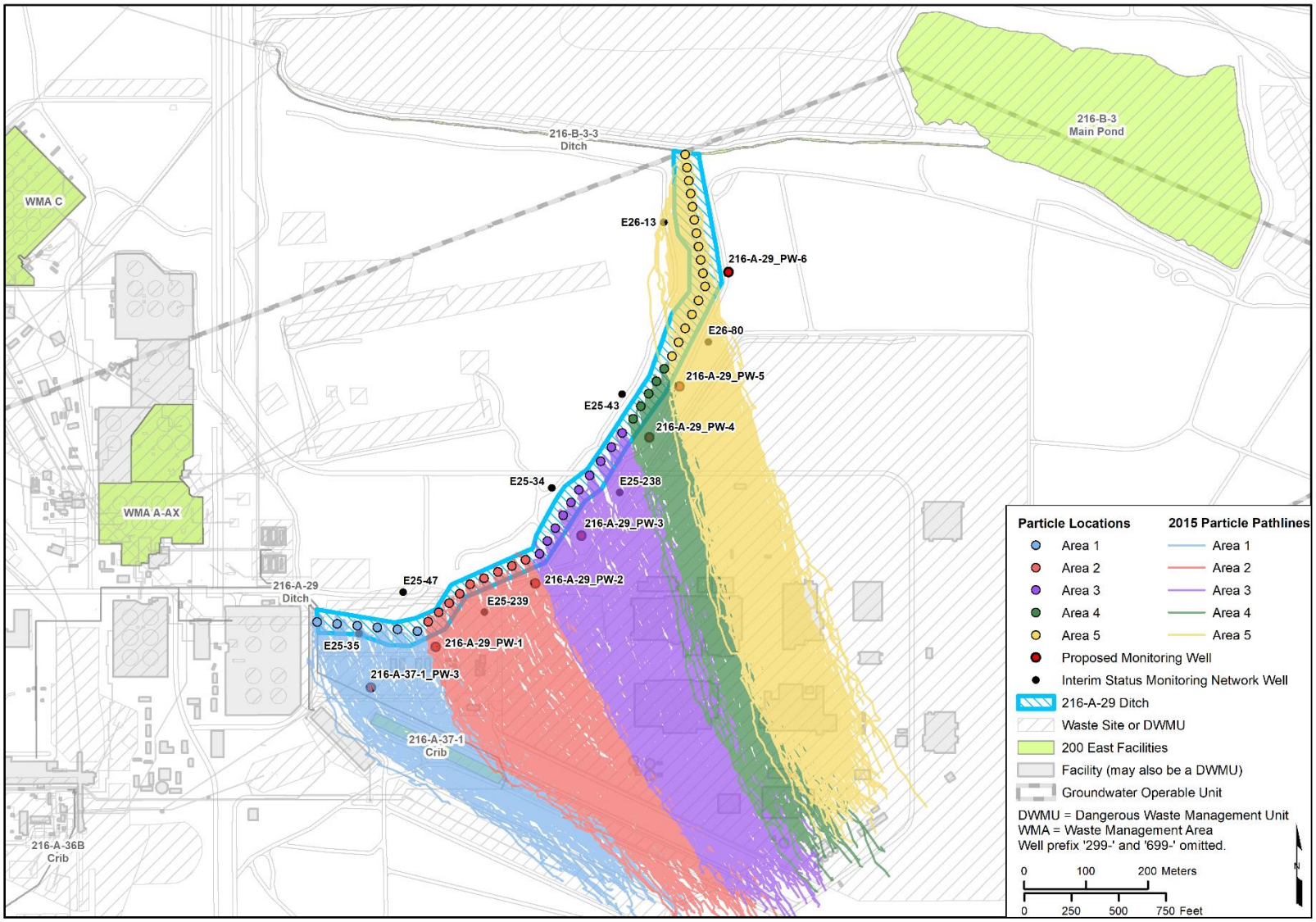

Figure C-30. CY 2015 Particle Pathlines per Area of the 216-A-29 Ditch

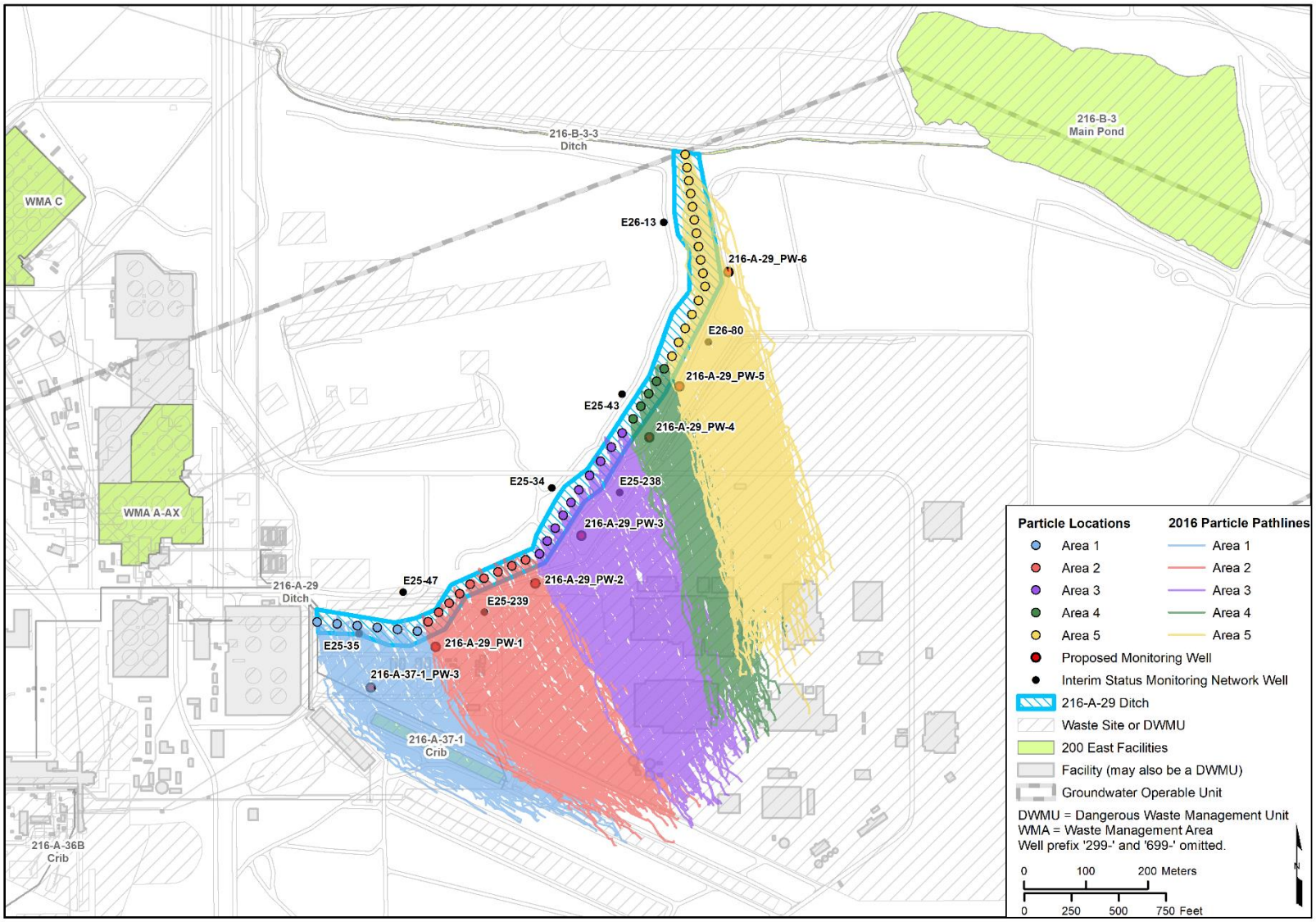

Figure C-31. CY 2016 Particle Pathlines per Area of the 216-A-29 Ditch

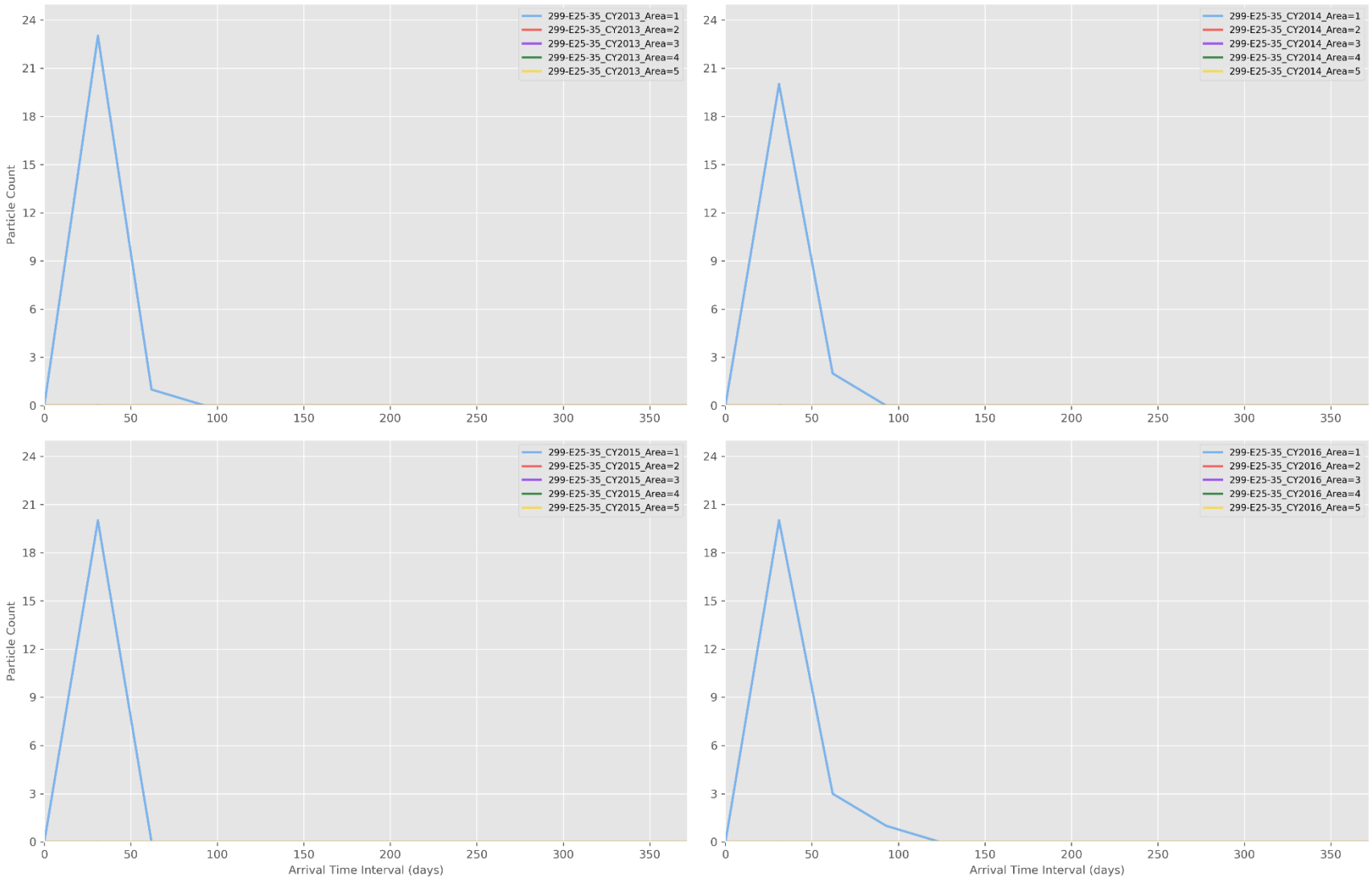

Figure C-32. Particle Breakthrough Curves per Area at Monitoring Well 299-E25-35

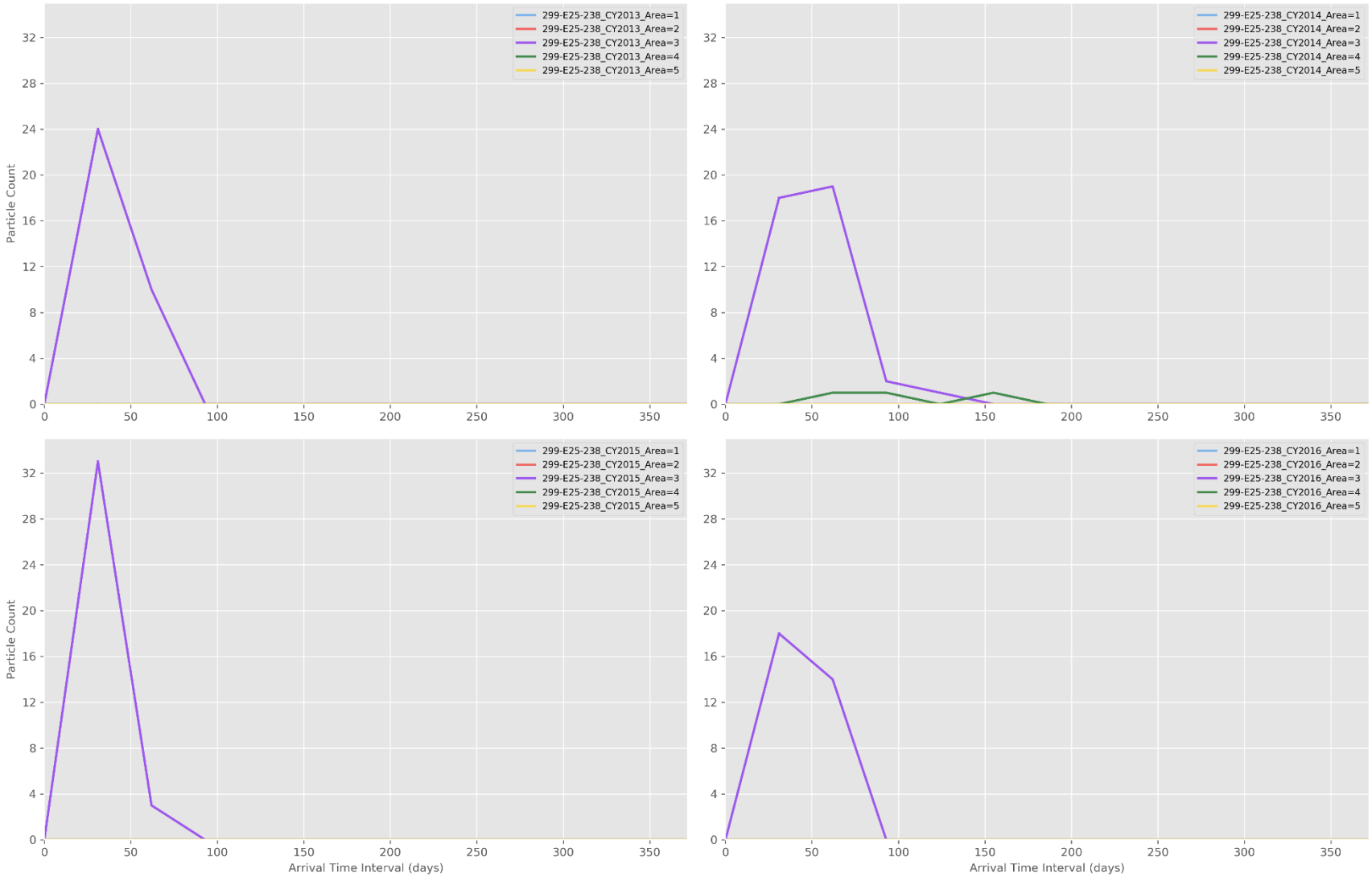

Figure C-33. Particle Breakthrough Curves per Area at Monitoring Well 299-E25-238

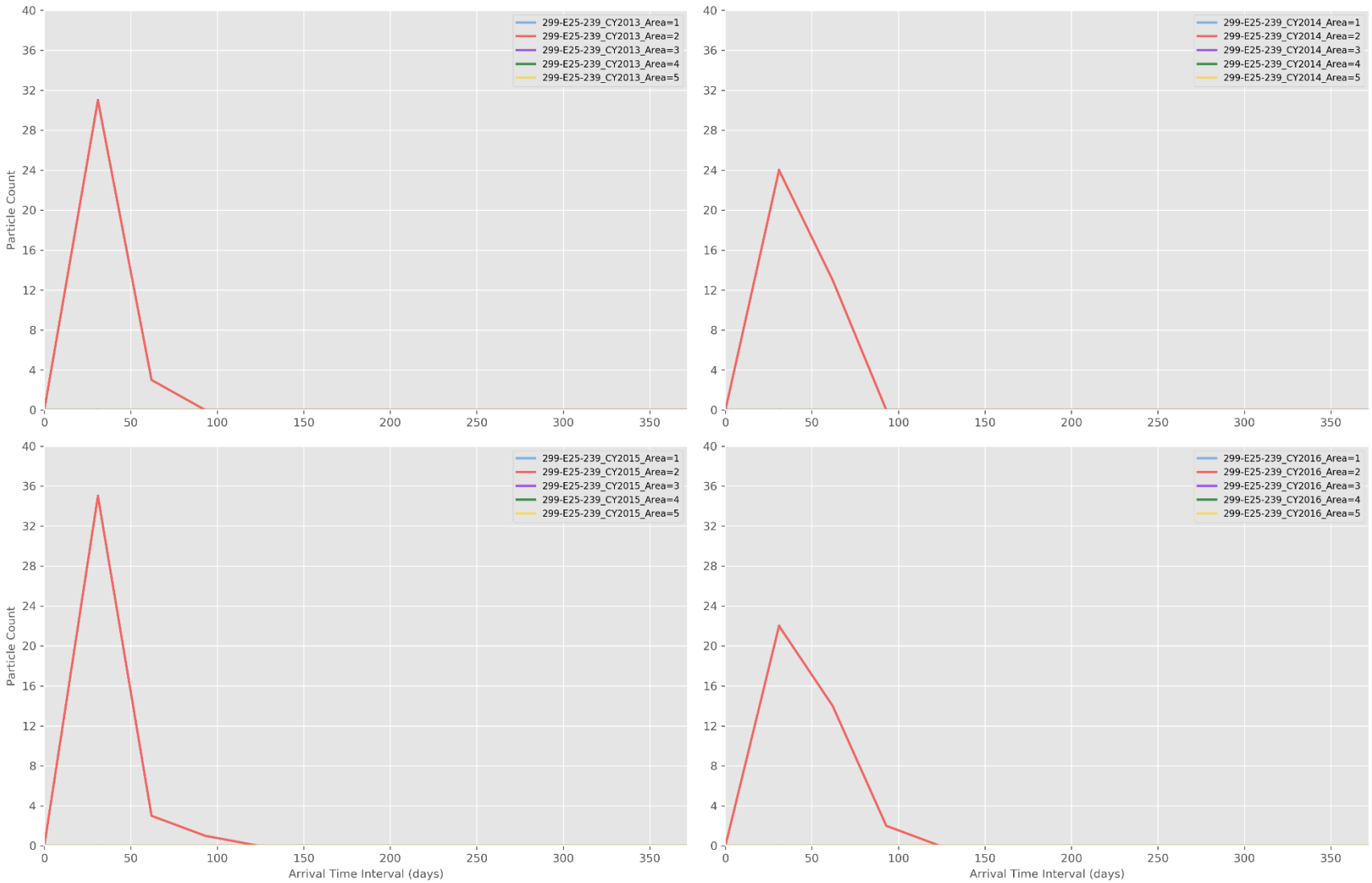

Figure C-34. Particle Breakthrough Curves per Area at Monitoring Well 299-E25-239

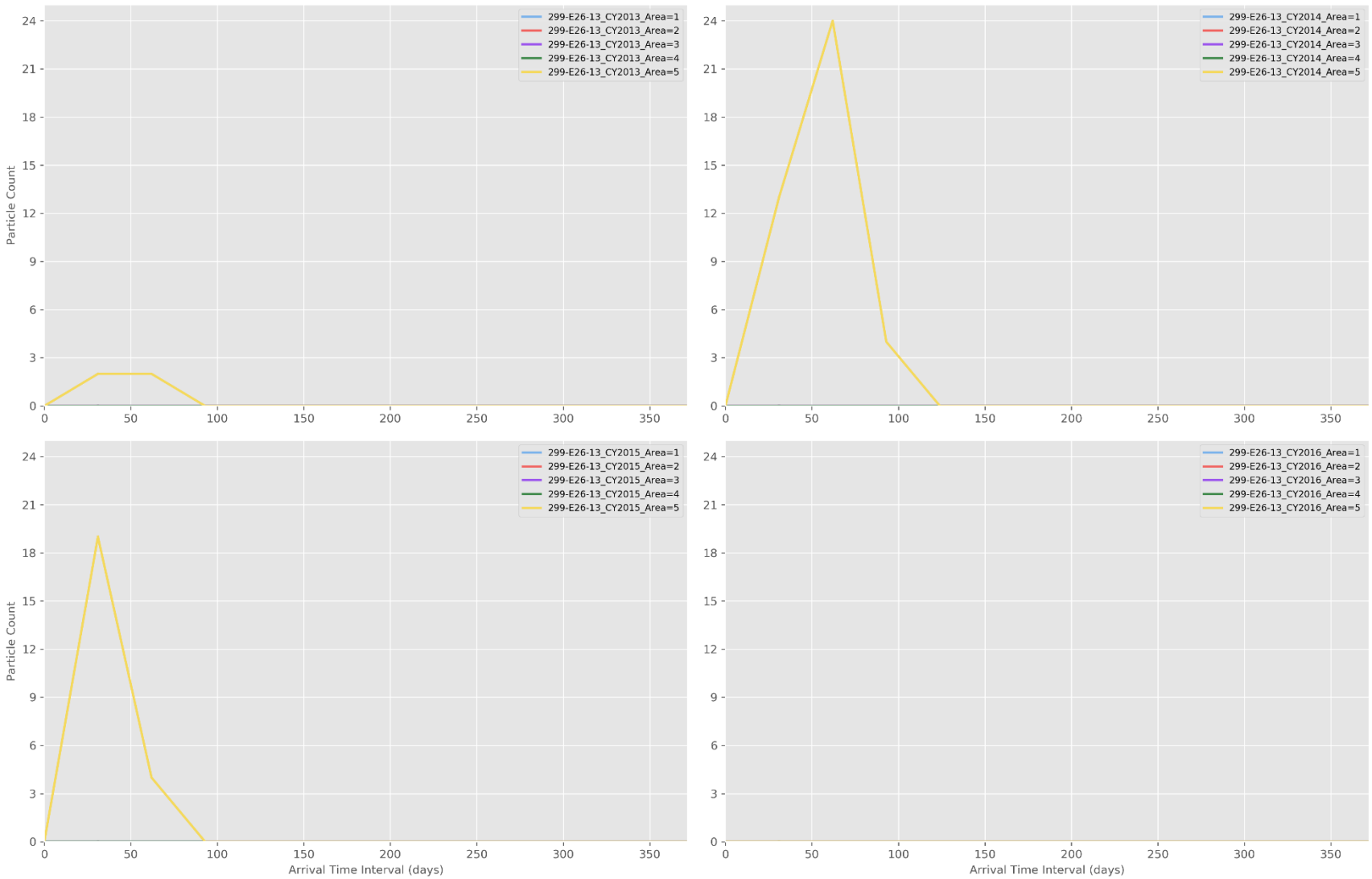

Figure C-35. Particle Breakthrough Curves per Area at Monitoring Well 299-E26-13

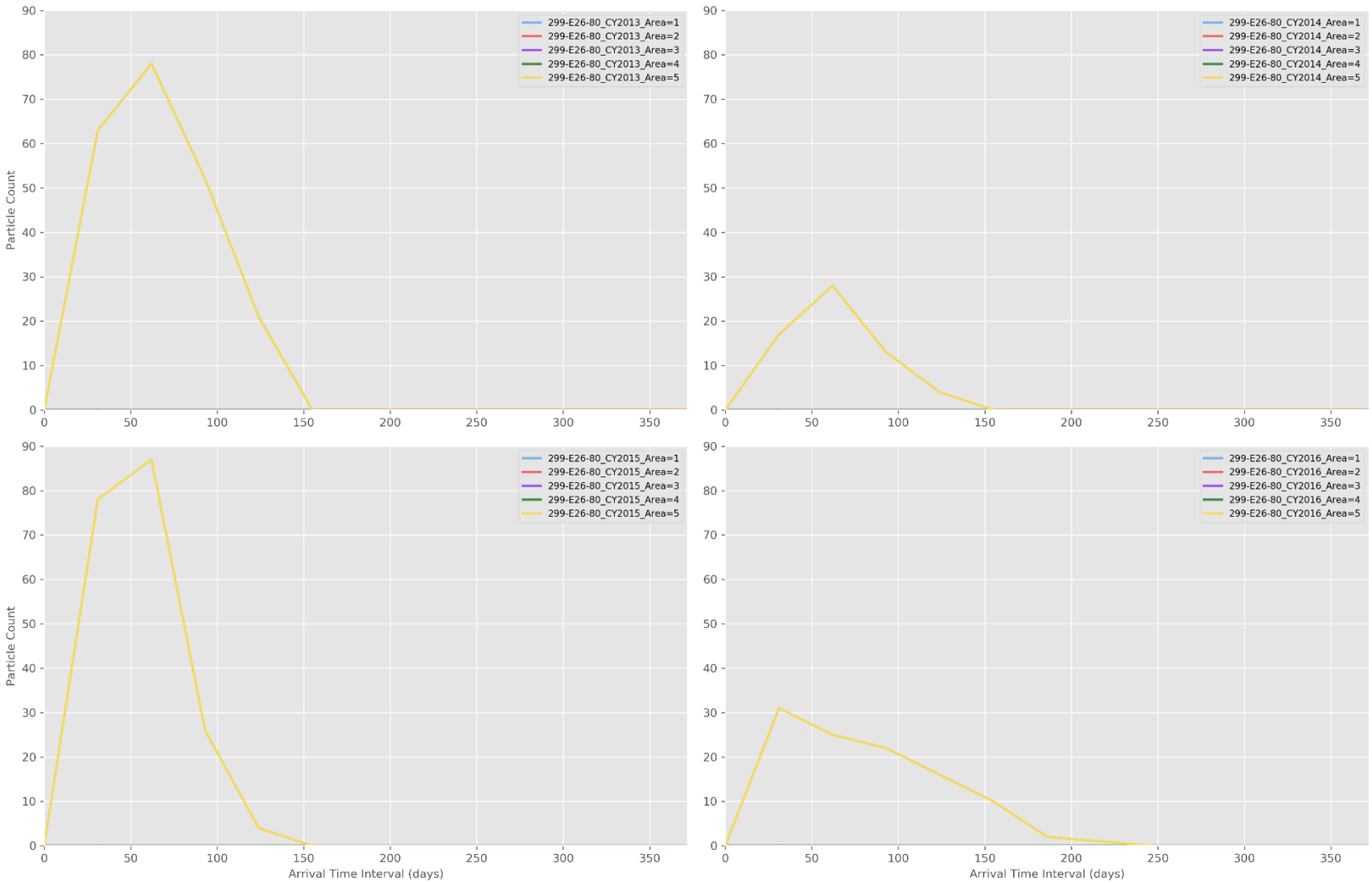

Figure C-36. Particle Breakthrough Curves per Area at Monitoring Well 299-E26-80

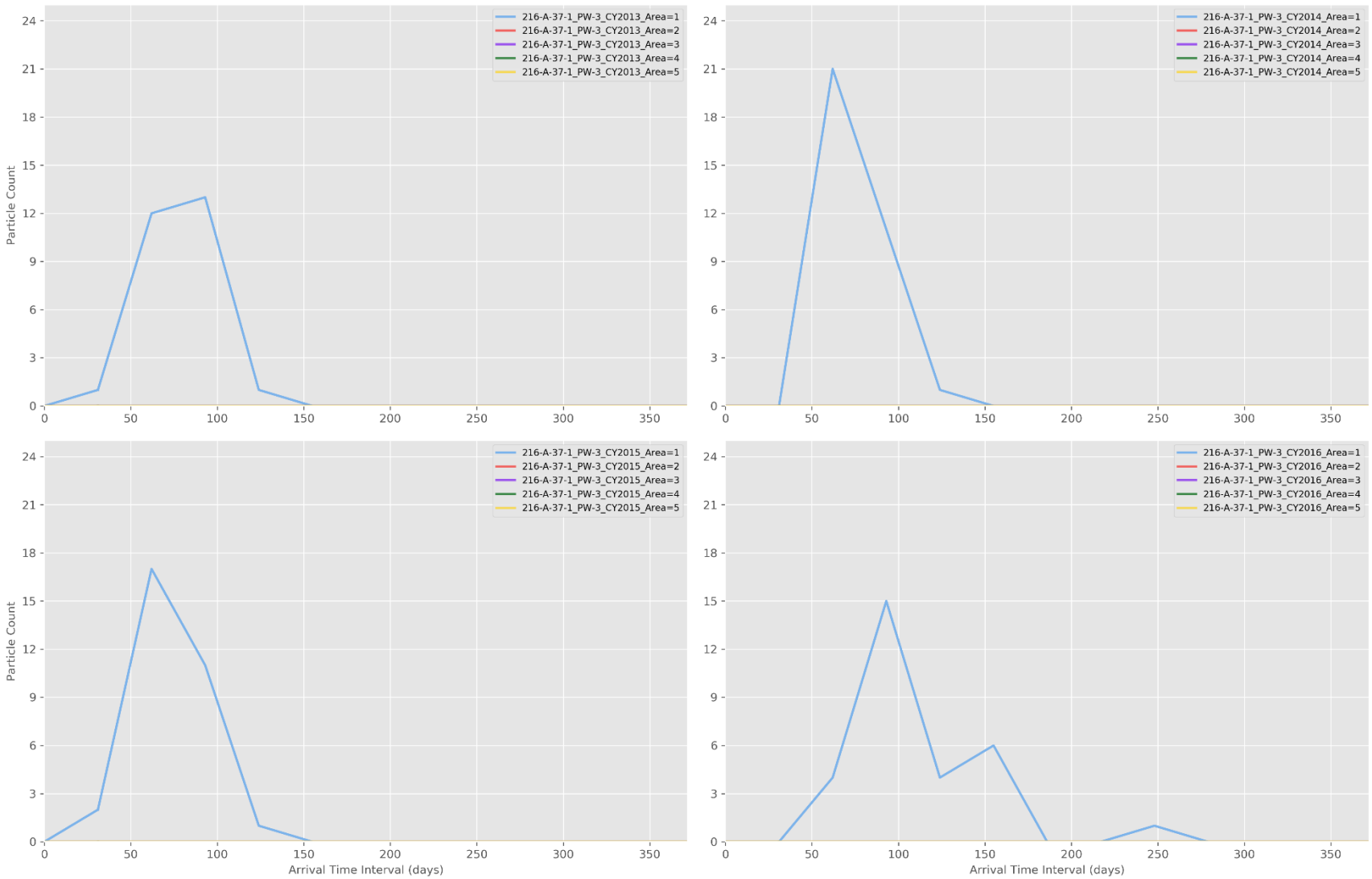

Figure C-37. Particle Breakthrough Curves per Area at Monitoring Well 216-A-37-1_PW-3

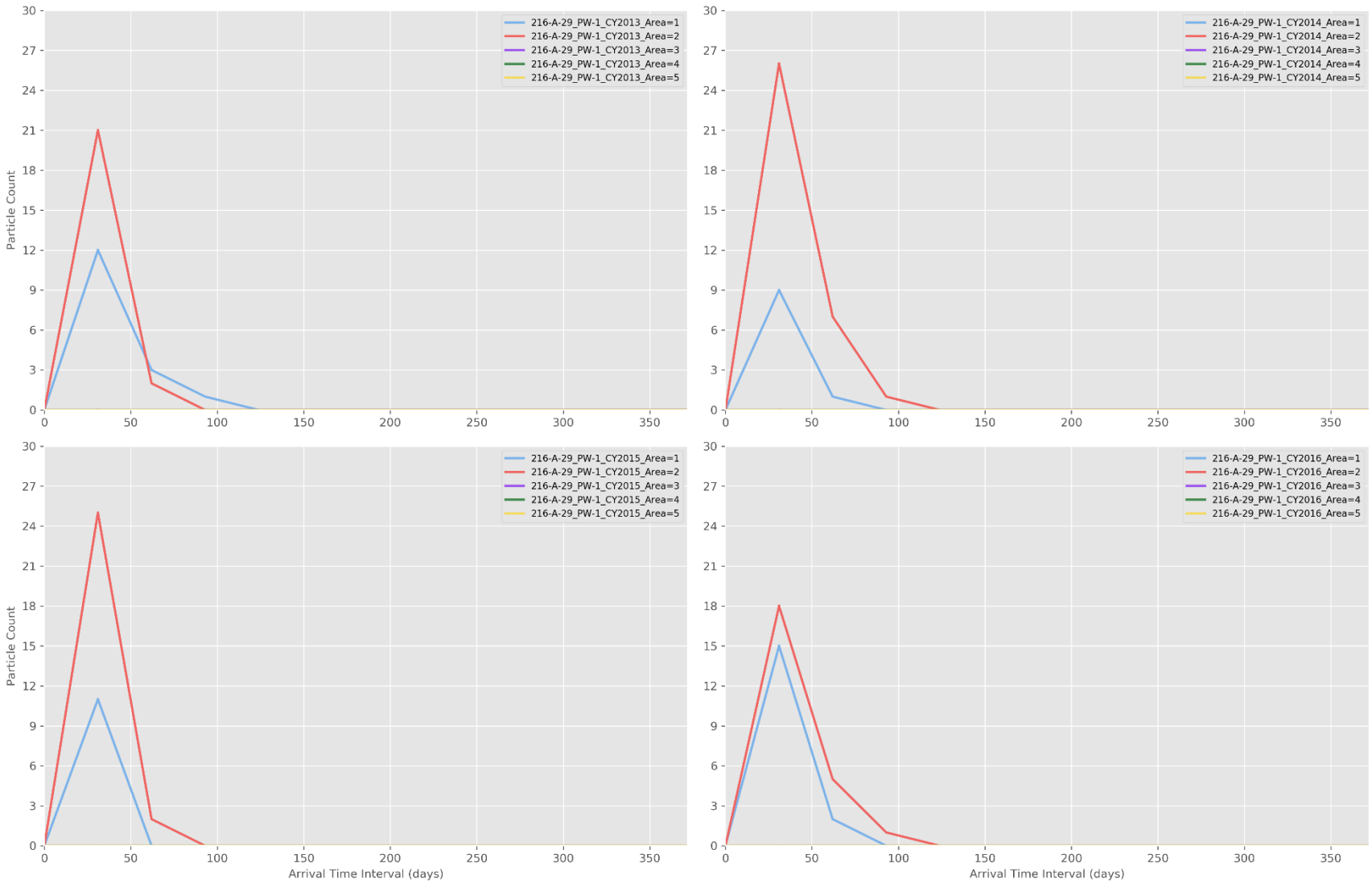

Figure C-38. Particle Breakthrough Curves per Area at Monitoring Well 216-A-29_PW-1

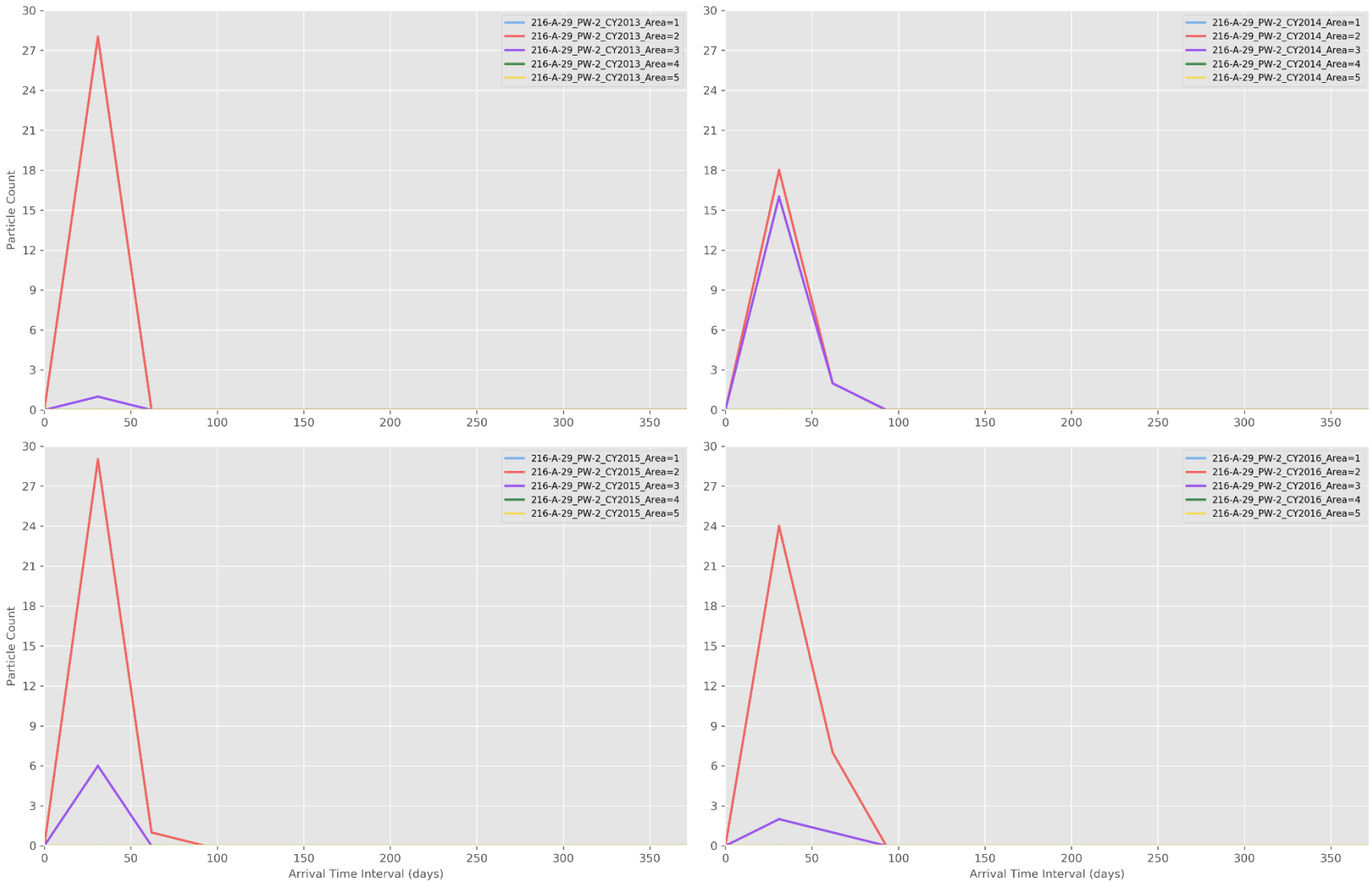

Figure C-39. Particle Breakthrough Curves per Area at Monitoring Well 216-A-29_PW-2

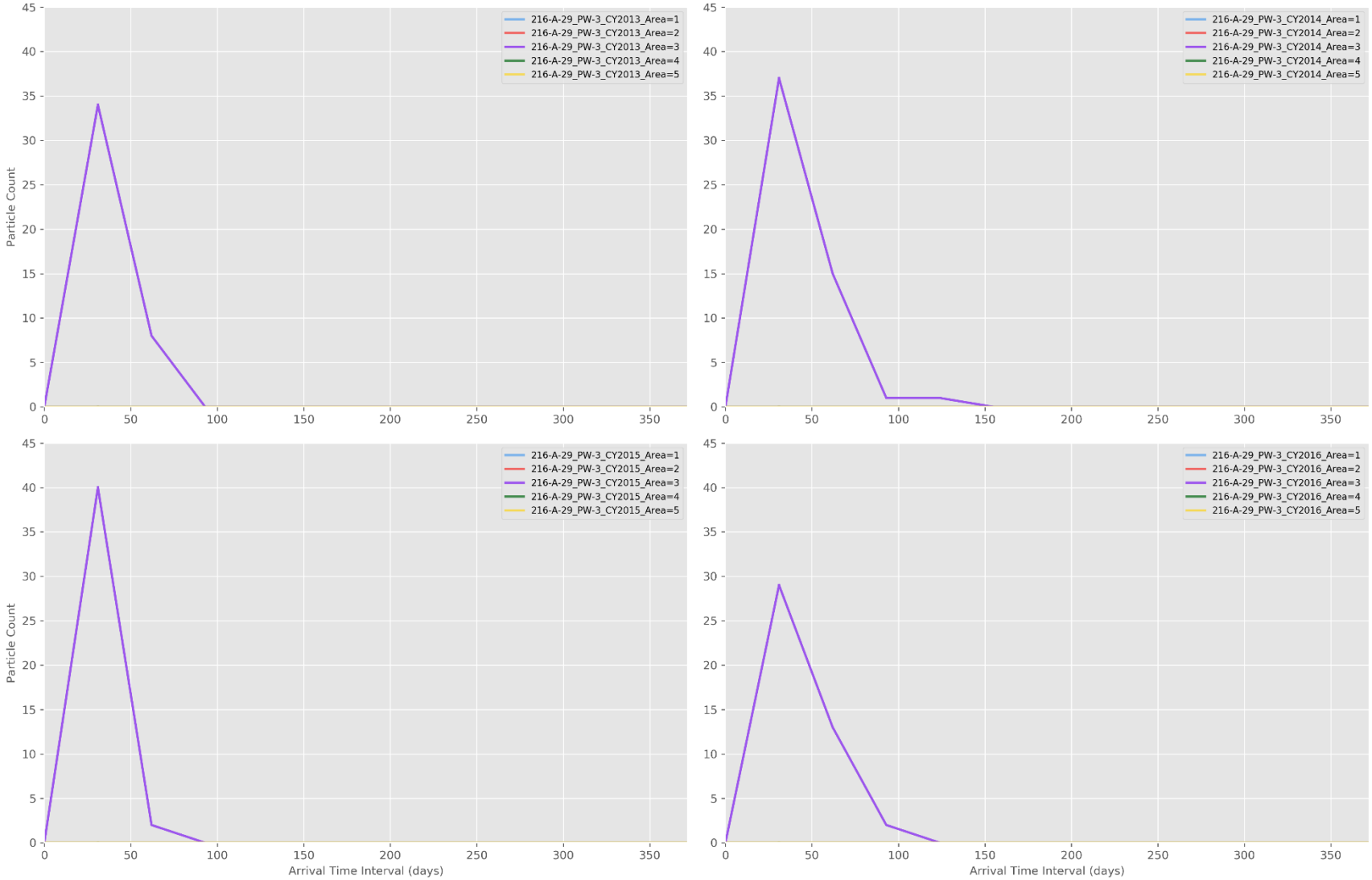

Figure C-40. Particle Breakthrough Curves per Area at Monitoring Well 216-A-29_PW-3

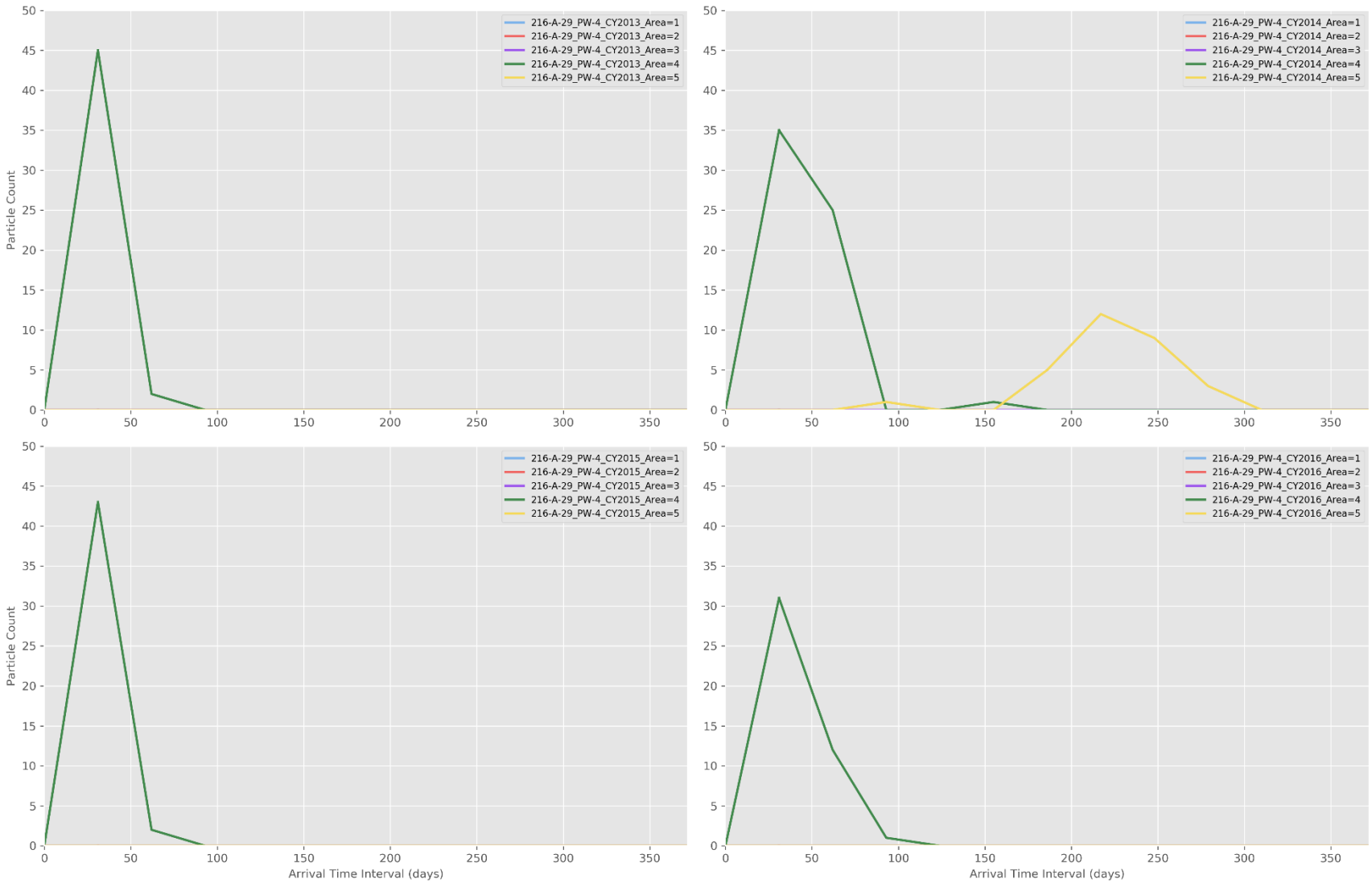

Figure C-41. Particle Breakthrough Curves per Area at Monitoring Well 216-A-29_PW-4

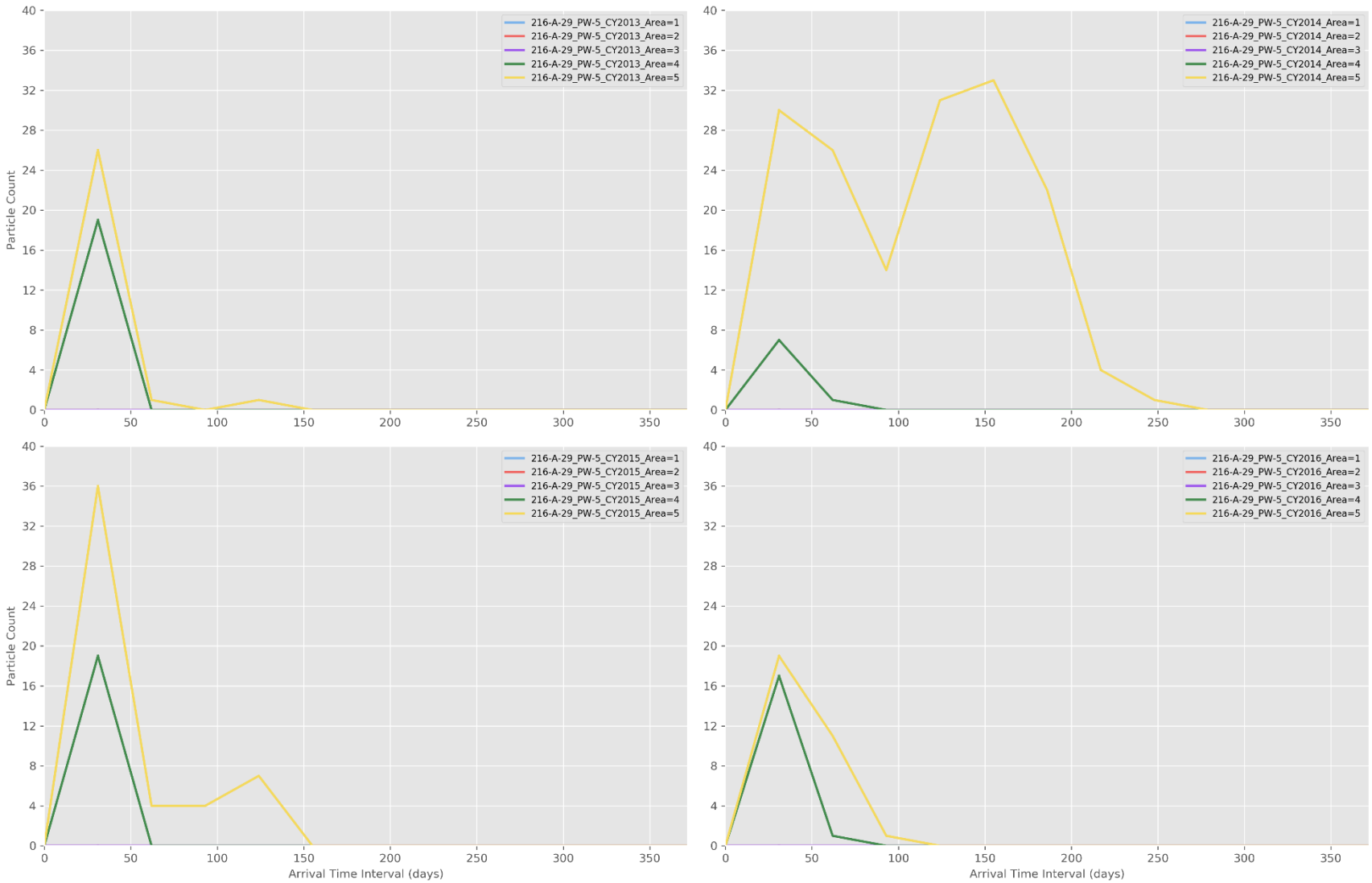

Figure C-42. Particle Breakthrough Curves per Area at Monitoring Well 216-A-29_PW-5

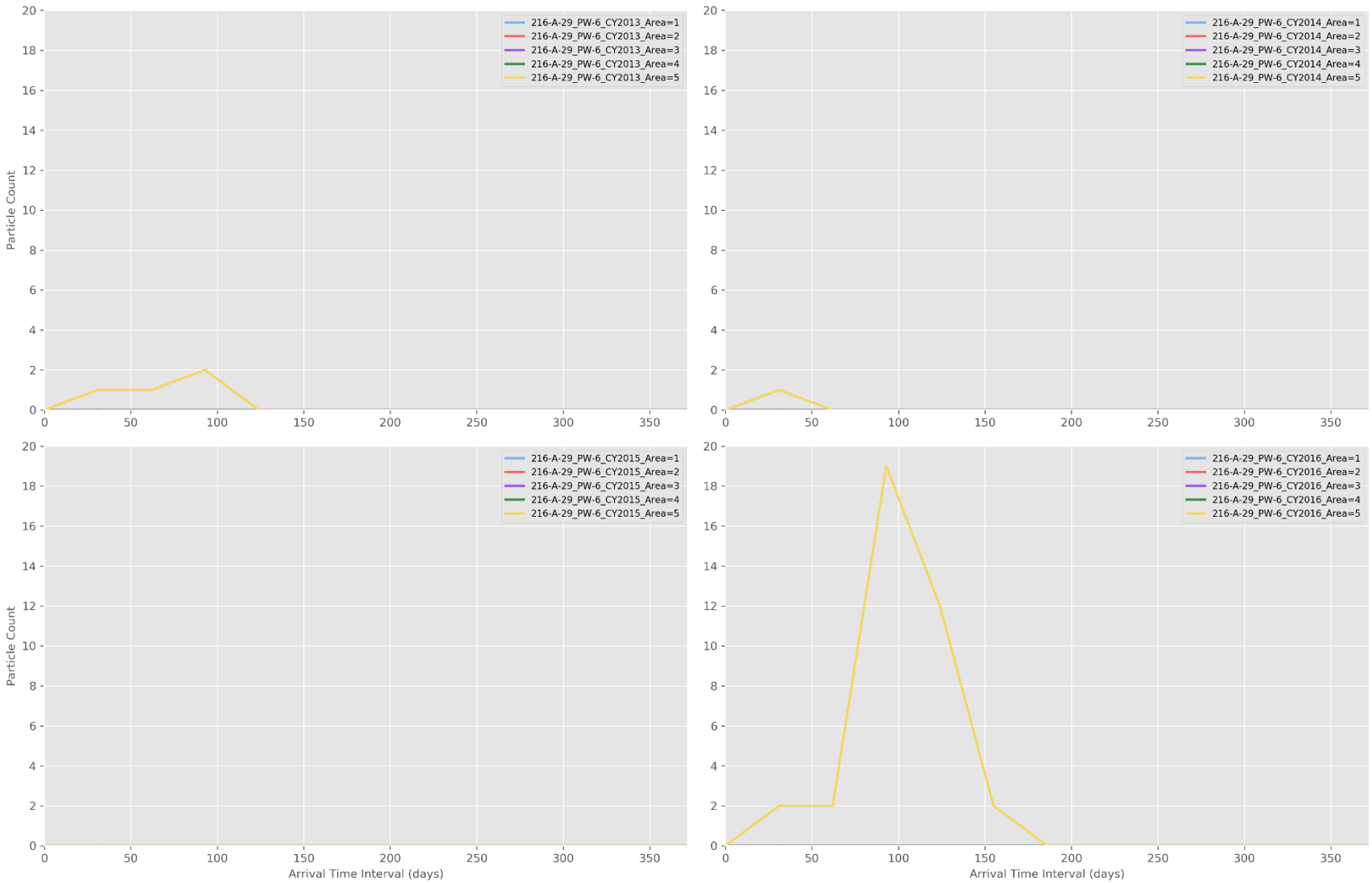

Figure C-43. Particle Breakthrough Curves per Area at Monitoring Well 216-A-29_PW-6

For each downgradient monitoring well at the 216-A-29 Ditch, the distance used in the calculation was the distance along the pathline from the facility to the well location. The hydraulic conductivity used in the calculation for the 216-A-29 Ditch, 18,200 m/d (59,711 ft/d), is the calibrated hydraulic conductivity from the CPGWM for the Cold Creek unit, which underlies the facility. The results of the API plume diving calculation for the downgradient wells for the 216-A-29 Ditch are shown in Table C-13. Results are included for well 299-E26-13, which is classified as upgradient but is potentially downgradient of releases from the northern extent of the 216-A-29 Ditch.

Table C-13. Summary of Well Screen Interval Evaluation for Downgradient Wells

Monitoring Well	Existing or Proposed Well?	Distance, D, (m)[a]	Recharge, *i*, (m/yr)[b]	Slope, S, of Plume Dive[c]	Estimated Depth of Plume Below Water Table (m)[d]	Depth from Water Table to Bottom of Well Screen (m)[e]	Is Plume Depth Above Bottom of the Screen? (Yes/No/N/A)
299-E25-35	Existing	17.8	8.62E-03	6.82E-05	1.21E-03	1.8	Yes
299-E25-238	Existing	74.7	8.62E-03	6.82E-05	5.10E-03	8.7	Yes
299-E25-239	Existing	63.0	8.62E-03	6.82E-05	4.30E-03	8.2	Yes
299-E26-13	Existing	93.3	8.62E-03	6.82E-05	6.36E-03	2.1	Yes
299-E26-80	Existing	211.8	8.62E-03	6.82E-05	1.45E-02	8.5	Yes
216-A-37-1_PW-3	Proposed	530.3	8.62E-03	6.82E-05	3.62E-02	N/A	N/A
216-A-29_PW-1	Proposed	65.8	8.62E-03	6.82E-05	4.49E-03	N/A	N/A
216-A-29_PW-2	Proposed	59.4	8.62E-03	6.82E-05	4.06E-03	N/A	N/A
216-A-29_PW-3	Proposed	53.8	8.62E-03	6.82E-05	3.67E-03	N/A	N/A
216-A-29_PW-4	Proposed	69.8	8.62E-03	6.82E-05	4.77E-03	N/A	N/A
216-A-29_PW-5	Proposed	384.6	8.62E-03	6.82E-05	2.62E-02	N/A	N/A
216-A-29_PW-6	Proposed	63.3	8.62E-03	6.82E-05	4.32E-03	N/A	N/A

a. Distance of a particle's pathline, from its starting location at the facility to its intersection with the well.

b. A representative number from the CPGWM. The recharge values represent fluxes from surface water discharge due to historical operations at the Hanford Site and are summarized in EMDT-BC-0002, *Vadose Zone Attenuated Recharge, Electronic Modeling Data Transmittal – Boundary Condition (Artificial Recharge)*-0002. The anthropogenic flux is added to the natural recharge component in order to establish the final total recharge flux used in the simulations. Discharges included in EMDT-BC-0002 have been attenuated to account for travel through the vadose zone.

c. Slope of the plume dive computed using the American Petroleum Institute plume diving calculation as detailed in the main text of this ECF. The migration parameters for the 216-A-29 Ditch used in the calculation of slope are as follows:

Hydraulic conductivity: 18,200 m/d (59,711 ft/d) (a calibrated value from the CPGWM)

Hydraulic gradient: 1.9E-05 (determined from 2016 water-level maps produced using TRIM)

d. Plume depth at monitoring well location computed from distance, D, times the slope, S.

e. Depths obtained from Table 3-4 in DOE/RL-2016-23, *216-A-29 Ditch Interim Status Groundwater Quality Assessment Monitoring Plan*.

CPGWM = Central Plateau Groundwater Model

ECF = environmental calculation file

N/A = not applicable

TRIM = Tikhonov Regularized Inverse Method

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Appendix D

Facility-Specific Results for the 216-A-36B Crib

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Terms

API	American Petroleum Institute
CPGWM	Central Plateau Groundwater Model
CY	calendar year
ECF	environmental calculation file
PUREX	Plutonium Uranium Extraction
Rwie	Ringold Formation member of Wooded Island – unit E
TRIM	Tikhonov Regularized Inverse Method

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D1 Purpose and Background

The primary purpose of the calculations presented here is to estimate directions of potential migration to assess the efficacy of the geographical distribution of wells in the proposed monitoring well network for the subject facility. The calculations described within the main text of this environmental calculation file (ECF) were performed for each of the 200 East Facilities. This appendix presents results developed from the calculations that are specific to the 216-A36B Crib.

Located in the southeastern part of the 200 East Area, the 216-A-36B Crib is a nonoperating treatment, storage, and disposal unit. The crib is approximately 150 m (490 ft) long, 2.3 to 3.4 m (7.5 to 11.2 ft) wide at its base, and 7 m (23 ft) deep (Section 2.4 in DOE/RL-2016-66, *Hanford Site RCRA Groundwater Monitoring Report for 2016*). At the bottom of the crib is a perforated, 15 cm (5.9 in.) diameter pipe that was used for discharging wastes. The pipe has 30 cm (11.8 in.) of gravel underlying and overlying it, and above the gravel, the crib is backfilled (Section 2.2.1 in PNNL-11523, *Combination RCRA Groundwater Monitoring Plan for the 216-A-10, 216-A-36B, and 216-A-37-1 PUREX Cribs*).

The 216-A-36B Crib was originally part of the 216-A-36 Crib that was used to percolate ammonia scrubber waste effluent from the Plutonium Uranium Extraction (PUREX) Plant operations to the soil column. The crib received PUREX effluent starting in September of 1965 (DOE/RL-2010-93, *Interim Status Groundwater Monitoring Plan for the 216-A-36B Purex Plant Crib*). In March 1966, a grout barrier was installed to isolate the northern portion of the crib, separating the crib into 216-A-36A (the northern section) and 216-A-36B (the southern section) (DOE/RL-2010-93). The 216-A-36B Crib received 2.9×10^8 L (7.7×10^7 gal) of PUREX ammonia scrubber distillate while it operated from September 1965 to October 1972 and November 1982 to September 1987 (Section 2.4 in DOE/RL-2016-66).

A groundwater quality assessment program for the 216-A-36B Crib was put in place in 1997 as required by WAC 173-303-400, “Dangerous Waste Regulations,” “Interim Status Facility Standards.” The 216-A-10 Crib, 216-A-36B Crib, and 216-A-37-1 Crib were combined into a single groundwater quality assessment program based on their proximity to one another, similar construction and waste history, and similar hydrogeologic regime (Chapter 1 in PNNL-11523). The three cribs were monitored together until March 2010 when the 216-A-10 Crib was officially closed and removed from the permit (Section 2.4 in DOE/RL-2016-66). In January 2011, the 216-A-36B Crib and the 216-A-37-1 Crib monitoring status changed to an indicator evaluation program because the constituent detected in the network monitoring wells, nitrate, is not a dangerous waste or dangerous waste constituent (Section 2.4 in DOE/RL-2016-66). Groundwater monitoring is ongoing at the 216-A-36B Crib for indicator parameters and water quality constituents.

The 216-A-36B Crib interim status monitoring network (Figure D-1) consists of two upgradient wells (299-E17-1 and 299-E17-19) and four downgradient wells (299-E17-14, 299-E17-15, 299-E17-16, and 299-E17-18) (DOE/RL-2010-93).

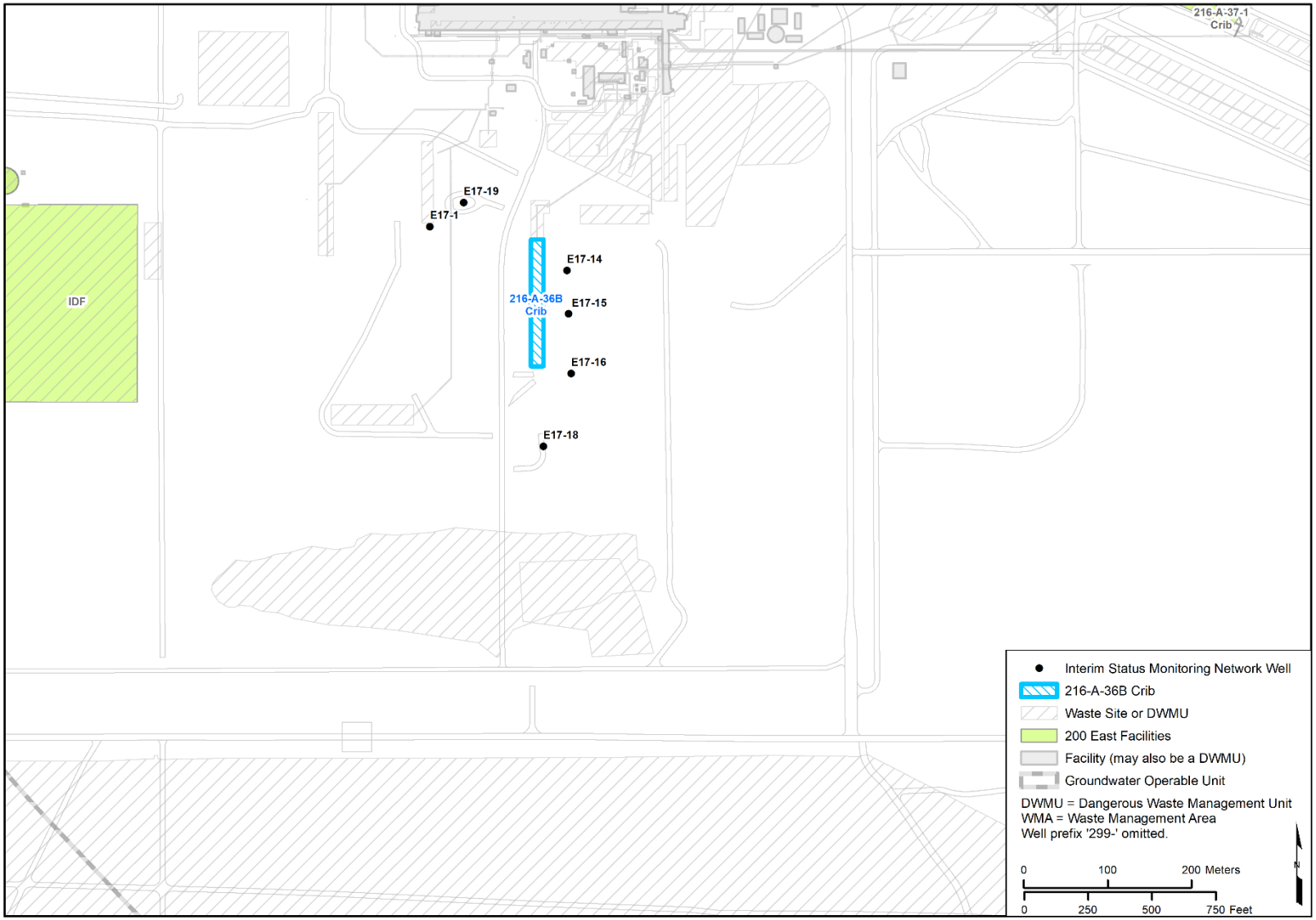

Figure D-1. Locations of Interim Status Groundwater Monitoring Wells at the 216-A-36B Crib

D2 Facility-Specific Input for the 216-A-36B Crib

Inputs used in the calculations that were specific to the 216-A-36B Crib are described in this chapter.

D2.1 Particle Count Grid and Release Locations

To prepare particle count maps, a distribution of facility-specific starting locations is required. The starting locations for the particle-tracking calculations represent the area over which a potential release from a given facility would impact the underlying water table. The particle releases were located at plausible release sites throughout the facility. For the 216-A-36B Crib, 10 release locations were specified along the centerline of the crib (Figure D-2). Twenty particles were released and tracked from each release location to provide the density of particles in space and time required for the detailed facility-specific calculations, randomizing the seed values for the dispersion calculations. Thus, 200 [200 = 10 (release locations) × 20 (releases)] particles were tracked for each of the four simulations.

Contour maps of particle counts were generated by counting the number of particles that pass through a pre-defined uniform calculational grid (Figure D-2). The grid used to develop the relative particle density maps is defined by 10 by 10 m (33 by 33 ft) cells. The grid is oriented to be parallel to the predominant groundwater flow direction at the 216-A-36B Crib.

D2.2 Migration Parameters

Parameters specific to the groundwater flow conditions at the 216-A-36B Crib are reported throughout the various documents for the facility. The parameters used in the calculations performed herein to represent nonreactive dissolved contaminant migration are mobile (or effective) porosity and hydraulic conductivity. The parameters used in these calculations are representative of local conditions for a conservative (i.e., nonreactive) solute dissolved within groundwater.

There is a range of hydraulic conductivity values reported in site literature for the 216-A36B Crib. Values range from 0.1 m/d (0.3 ft/d) for the Ringold Formation member of Wooded Island – unit E (Rwie) (Table 3-3 in DOE/RL-2009-85-ADD1, *Remedial Investigation Report for the 200-PO-1 Groundwater Operable Unit Addendum 1*) up to 3,000 m/d (55,774 ft/d) in the area near the PUREX cribs (216-A-36B, 216-A-10 and 216-A-37-1) (Section 3.2.3 of PNNL-11523). As described in Section 4.2.1.1 of the main text of this ECF, the hydraulic conductivity used in the work performed herein corresponds to the calibrated values from the Central Plateau Groundwater Model (CPGWM) (CP-47631, *Model Package Report: Central Plateau Groundwater Model, Version 8.4.5*). Figure 3-2 in the main text of this ECF indicates the 216-A-36B Crib is located in the hydrostratigraphic unit zone corresponding to the Rwie. The value used for the hydraulic conductivity for 216-A36B Crib is 35.6 m/d (117 ft/d), which corresponds to the Rwie as shown in Table 4-1 in the main text of this ECF. The mobile (effective) porosity defined for the Rwie, which underlies the 216-A-36B Crib, is specified at 0.08.

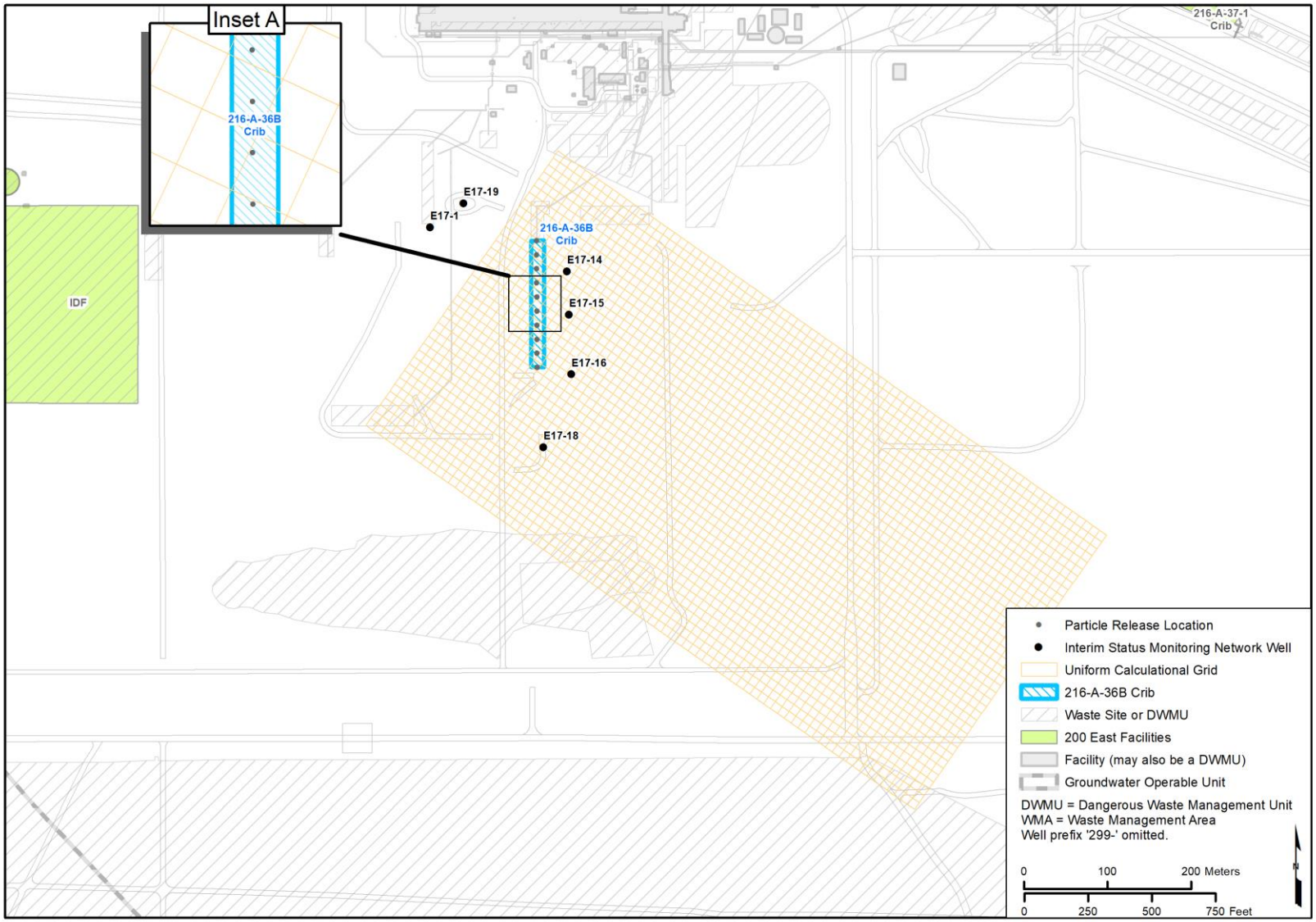

Figure D-2. Uniform Calculational Grid and Release Locations at the 216-A-36B Crib

D3 Facility-Specific Results for the 216-A-36B Crib

The groundwater elevation contours prepared in the vicinity of the 216-A-36B Crib using the Tikhonov Regularized Inverse Method (TRIM) are presented in this chapter. In addition, the outputs of the particle tracking and particle count calculations are presented, including the following:

- Maps of calculated particle pathlines for the flow conditions determined for each of the four years (2013, 2014, 2015, and 2016). These are presented at the facility-specific scale considering advective and dispersive migration.
- Time-series plots, referred to as particle breakthrough curves, of the relative arrival, peak, and decline in particle counts at each interim status groundwater monitoring well location and each proposed monitoring location, where applicable.
- Tabulation of relative particle counts for each interim status groundwater monitoring well location and each proposed monitoring location, where applicable.
- Maps of particle counts downgradient of each facility based on the flow conditions determined for each of the four years.

The results of calculations of potential vertical migration of contaminants at the monitoring well locations are also presented.

D3.1 Groundwater Elevation Contours

Figures D-3 through D-6 show the results of the groundwater elevation analysis completed using TRIM in the vicinity of the 216-A-36B Crib. The figures depict general patterns of groundwater elevations and hydraulic gradients for conditions represented by calendar years (CYs) 2013, 2014, 2015, and 2016. These groundwater elevation contours and associated hydraulic gradients form the basis for the facility-specific calculations performed for this ECF.

D3.2 Particle Tracking

Once the groundwater elevation contour maps and underlying piecewise continuous elevation grids were prepared using TRIM, particle tracking was implemented using both advection and dispersion.
The particle pathlines that were produced depict the patterns of spreading that might accompany the migration of contaminants near the crib for the flow conditions calculated for CYs 2013, 2014, 2015, and 2016. Figures D-7 through D-10 depict the particle pathlines developed based on the groundwater elevations prepared throughout the 200 East Area using TRIM. The resulting maps were prepared based on the release of 20 particles from each starting location to provide the high density of particles in space and time required for these detailed facility-specific calculations. Figures D-7 through D-10 depict the particle pathlines calculated after 274 years of travel, by which time it was determined that most of the particles would have arrived at or passed by the interim status groundwater monitoring wells. Figures D-7 through D-10 depict an instantaneous release to the water table from the release locations in the 216-A-36B Crib to illustrate the adequacy of the well network for monitoring the entire facility.

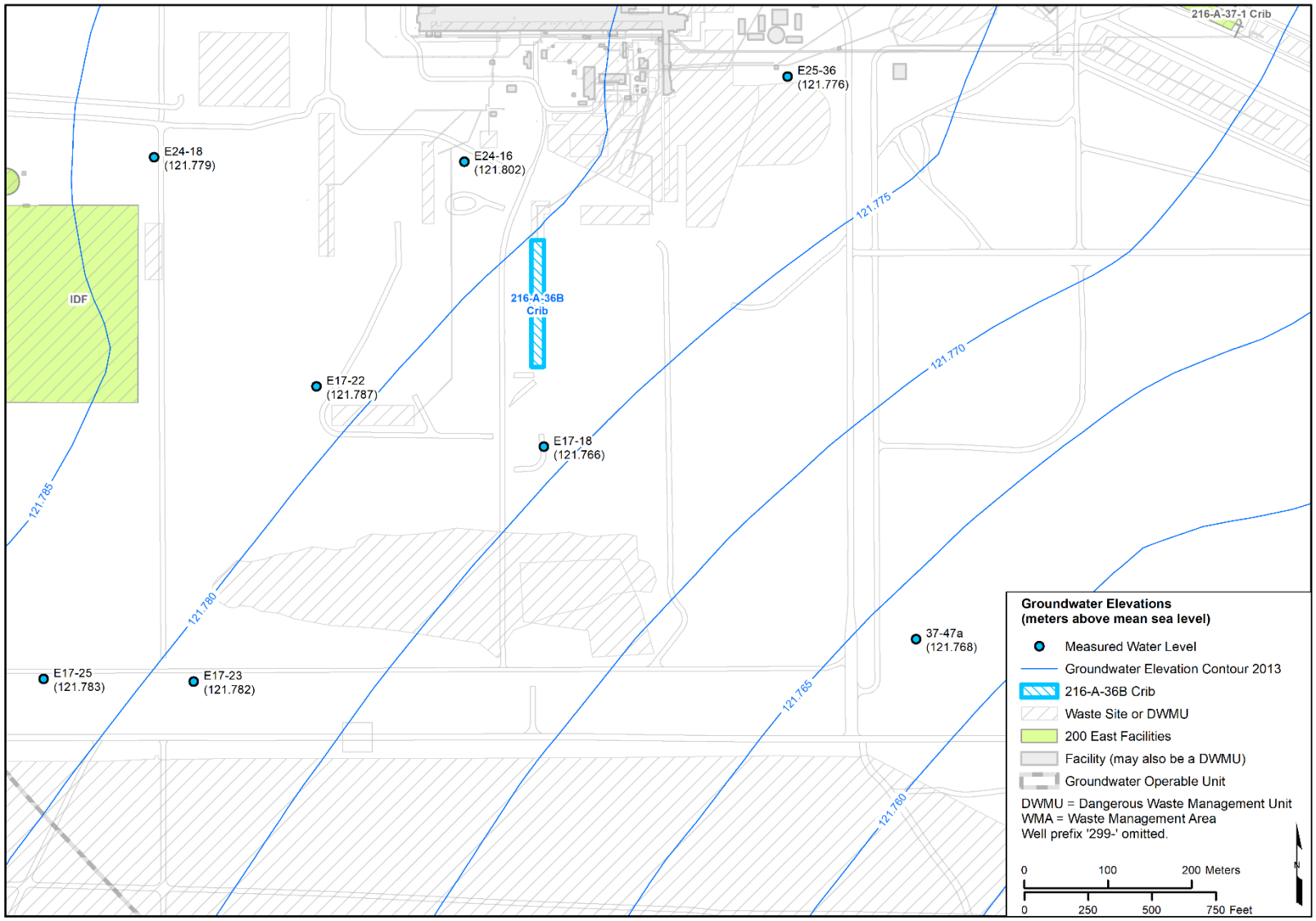

Figure D-3. Water-Level Elevation Map for the 216-A-36B Crib, 2013

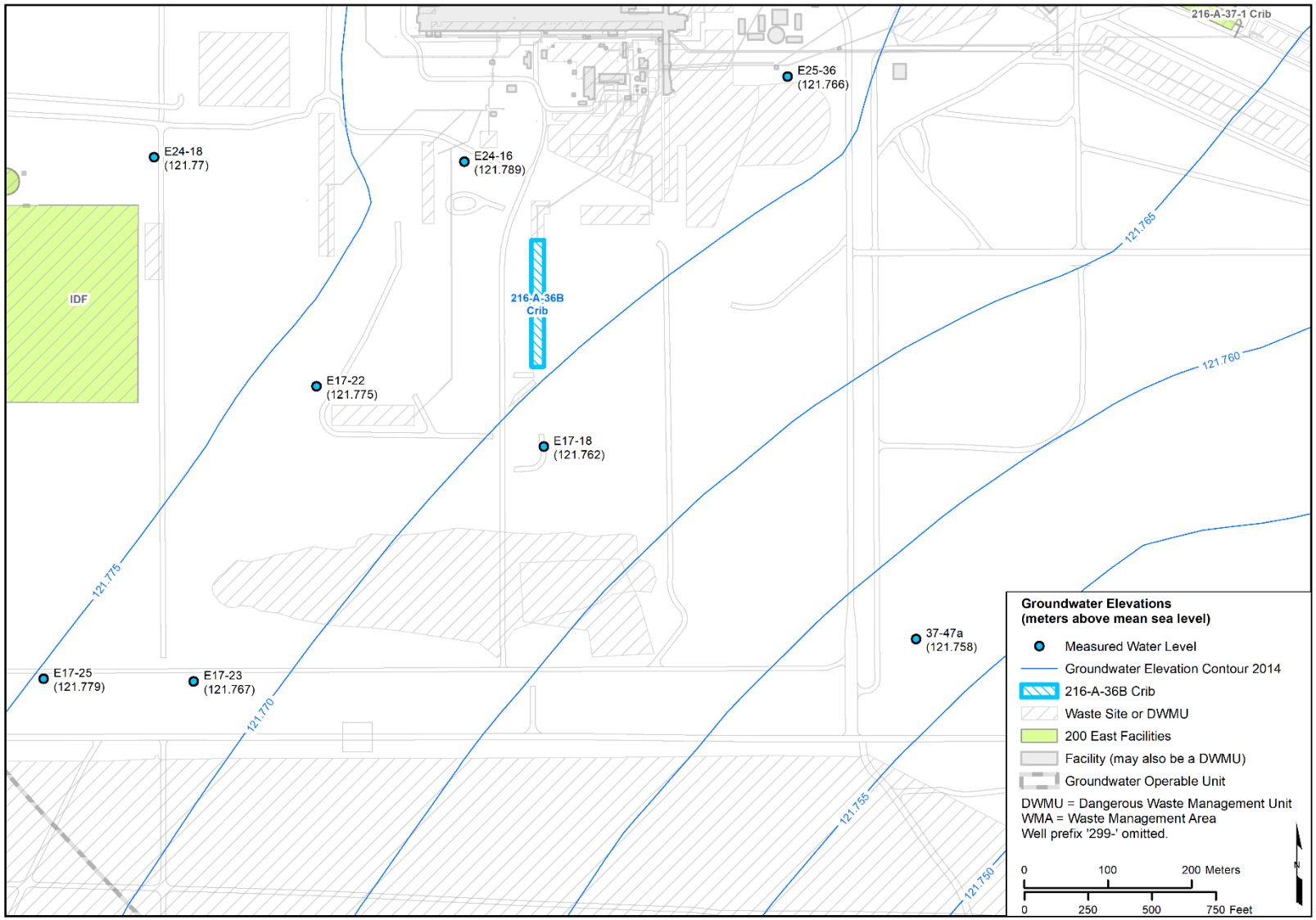

Figure D-4. Water-Level Elevation Map for the 216-A-36B Crib, 2014

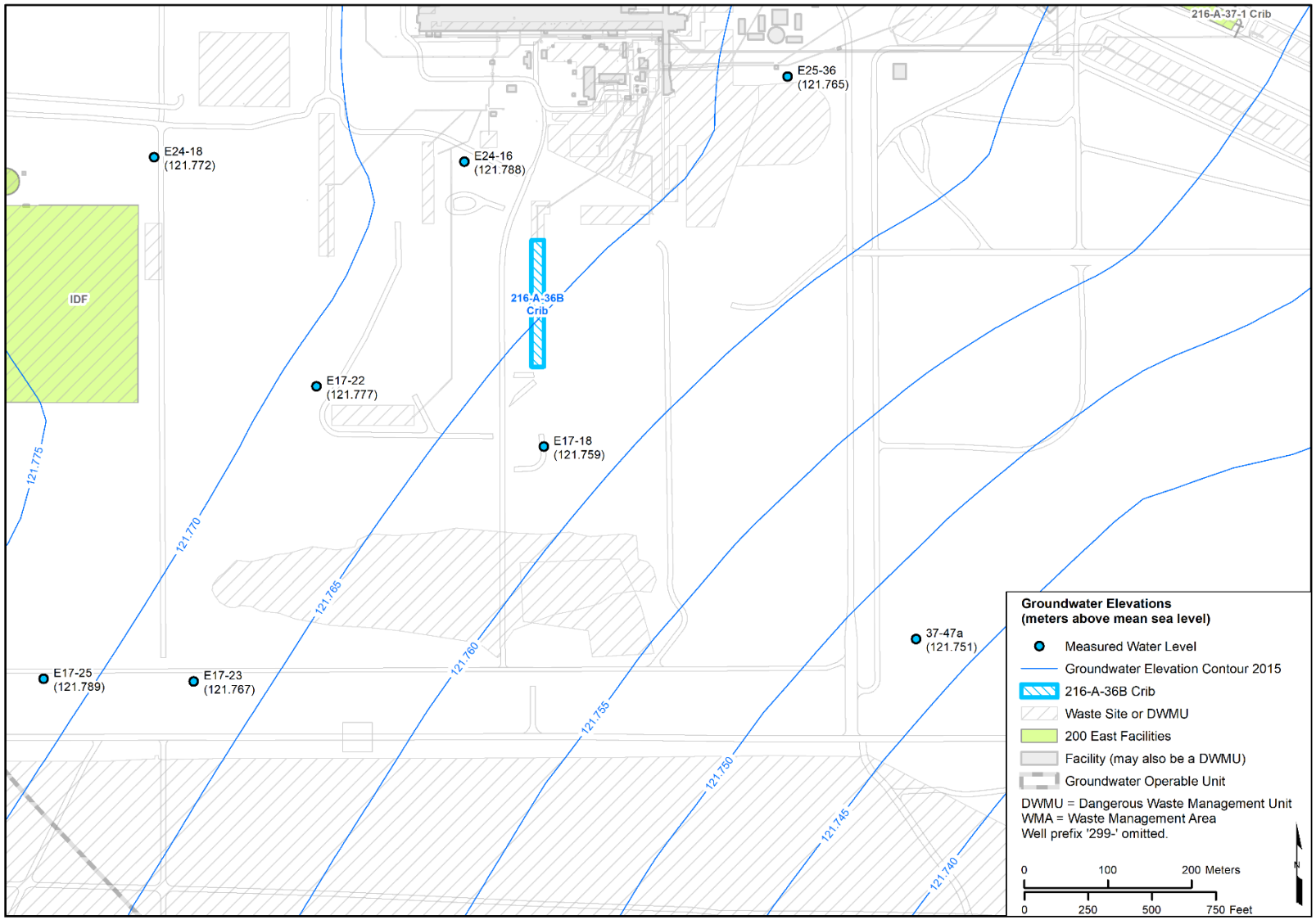

Figure D-5. Water-Level Elevation Map for the 216-A-36B Crib, 2015

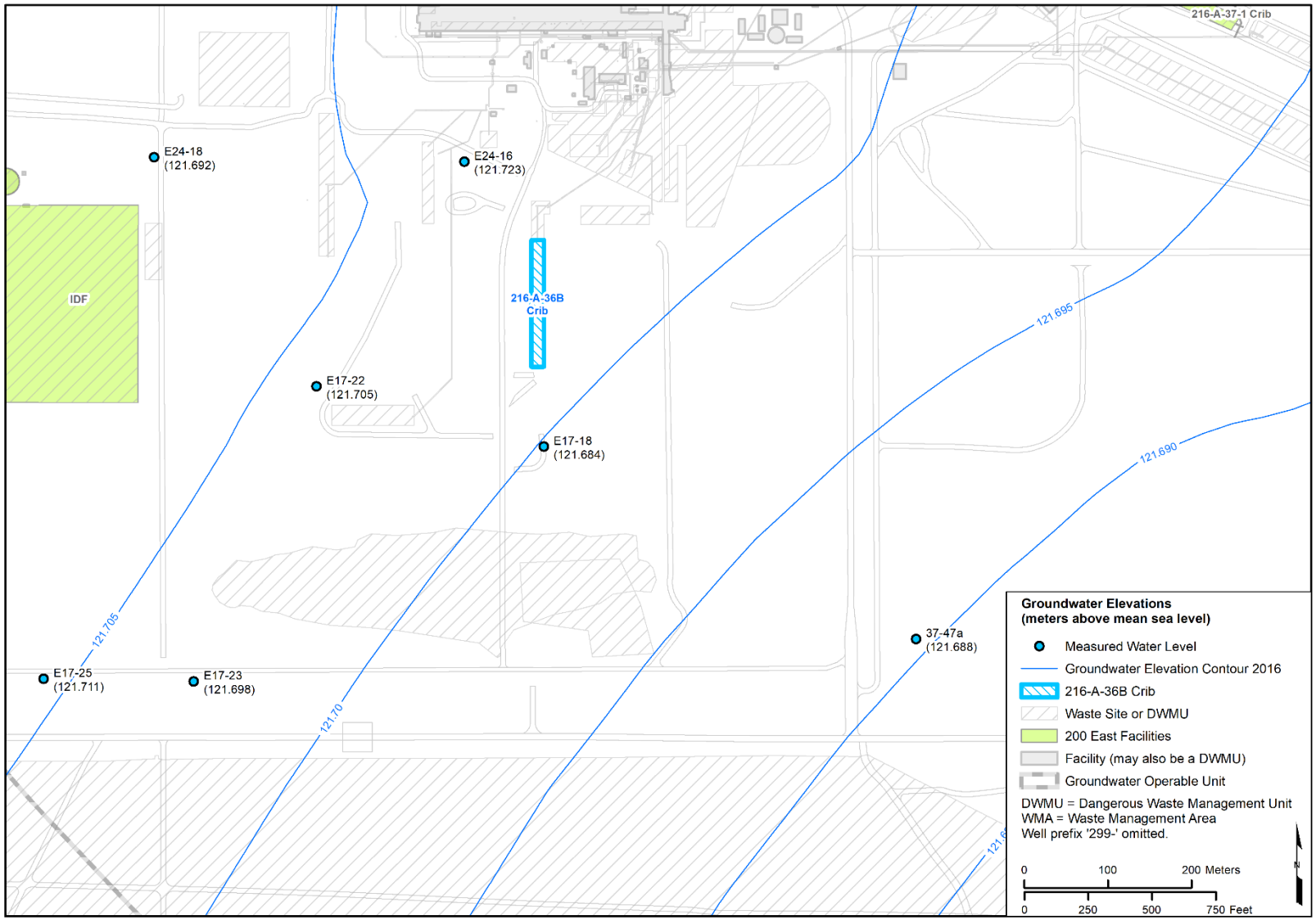

Figure D-6. Water-Level Elevation Map for the 216-A-36B Crib, 2016

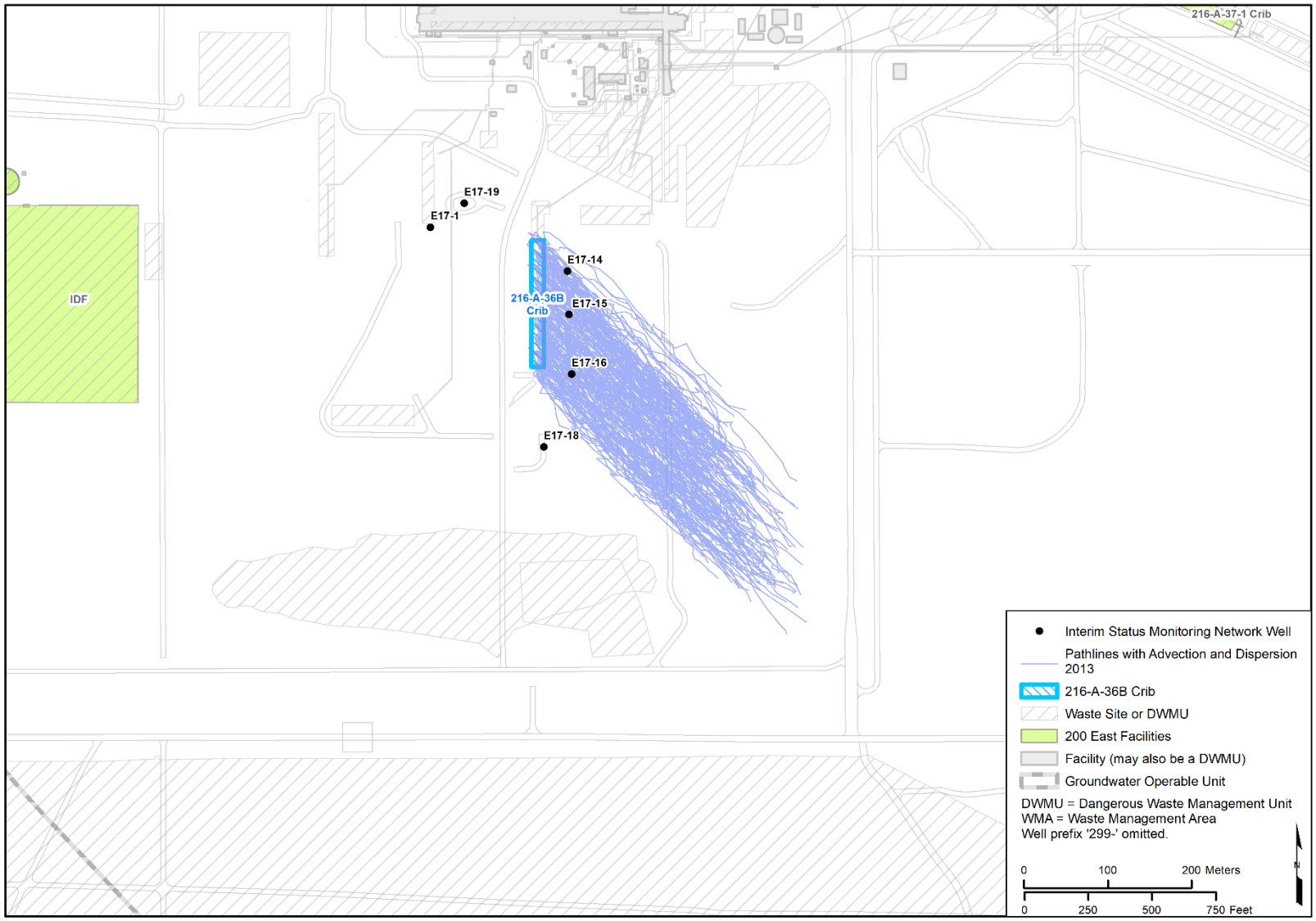

Figure D-7. Local-Scale Particle Pathlines, Advection and Dispersion – 216-A-36B Crib, 2013

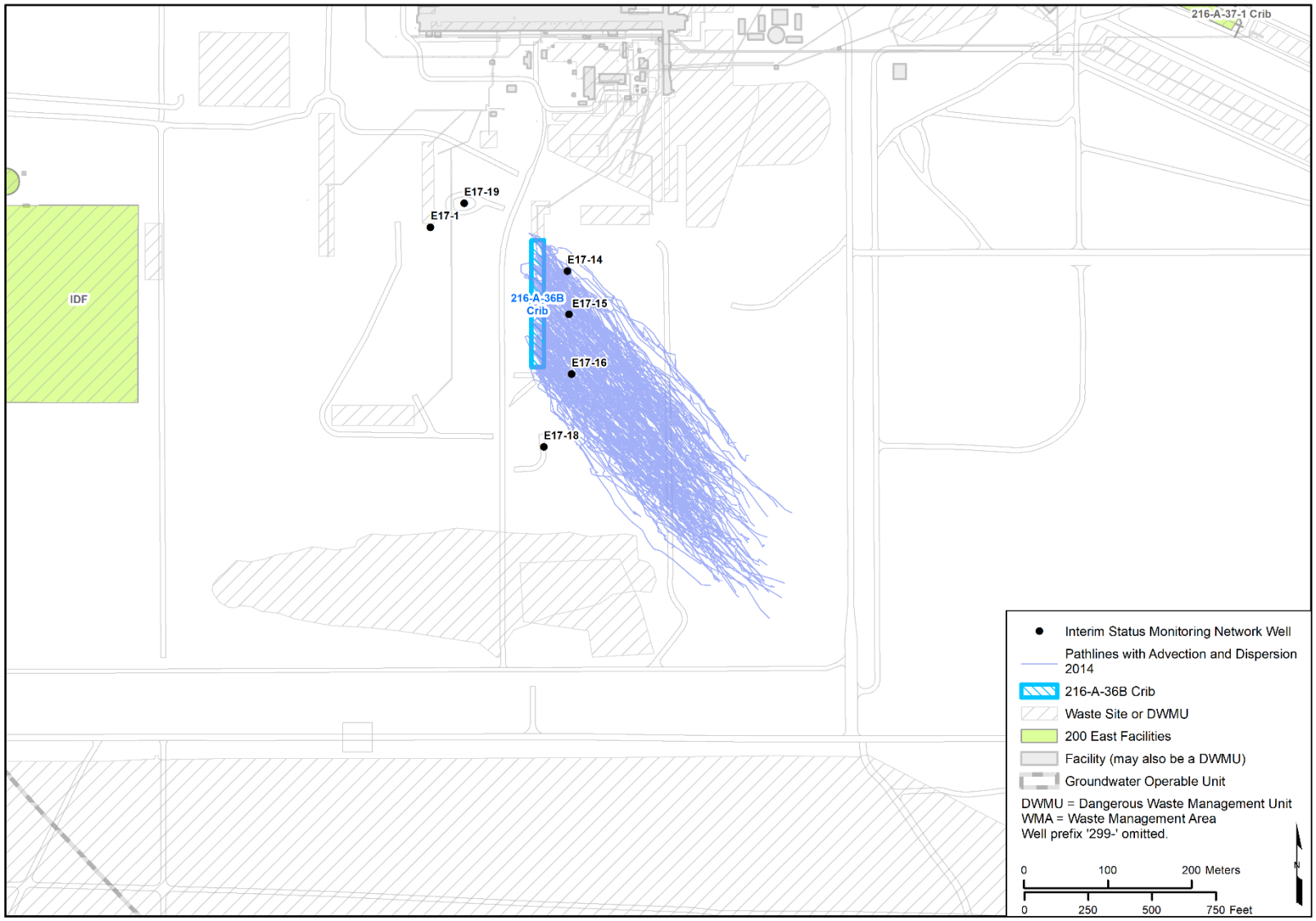

Figure D-8. Local-Scale Particle Pathlines, Advection and Dispersion – 216-A-36B Crib, 2014

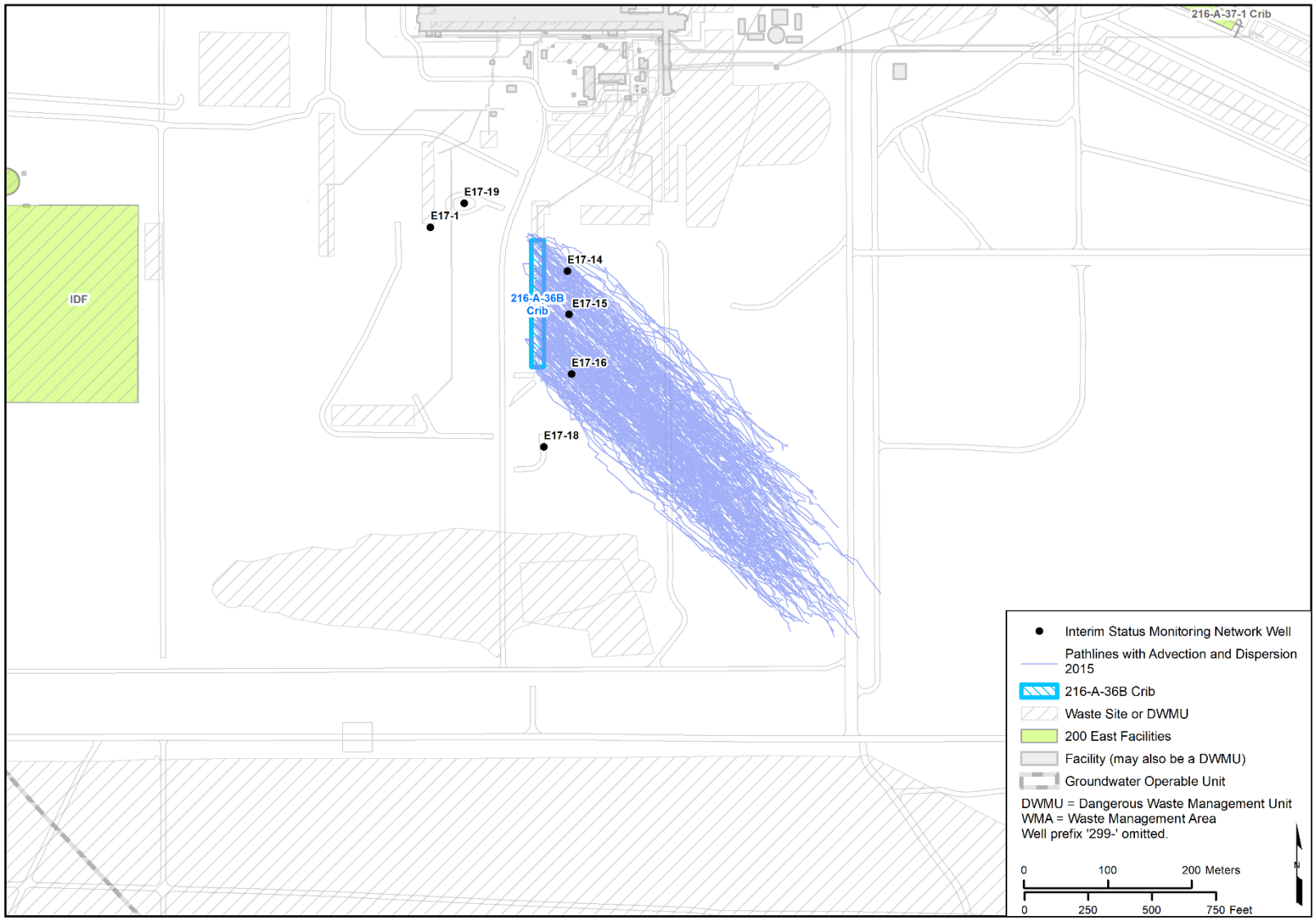

Figure D-9. Local-Scale Particle Pathlines, Advection and Dispersion – 216-A-36B Crib, 2015

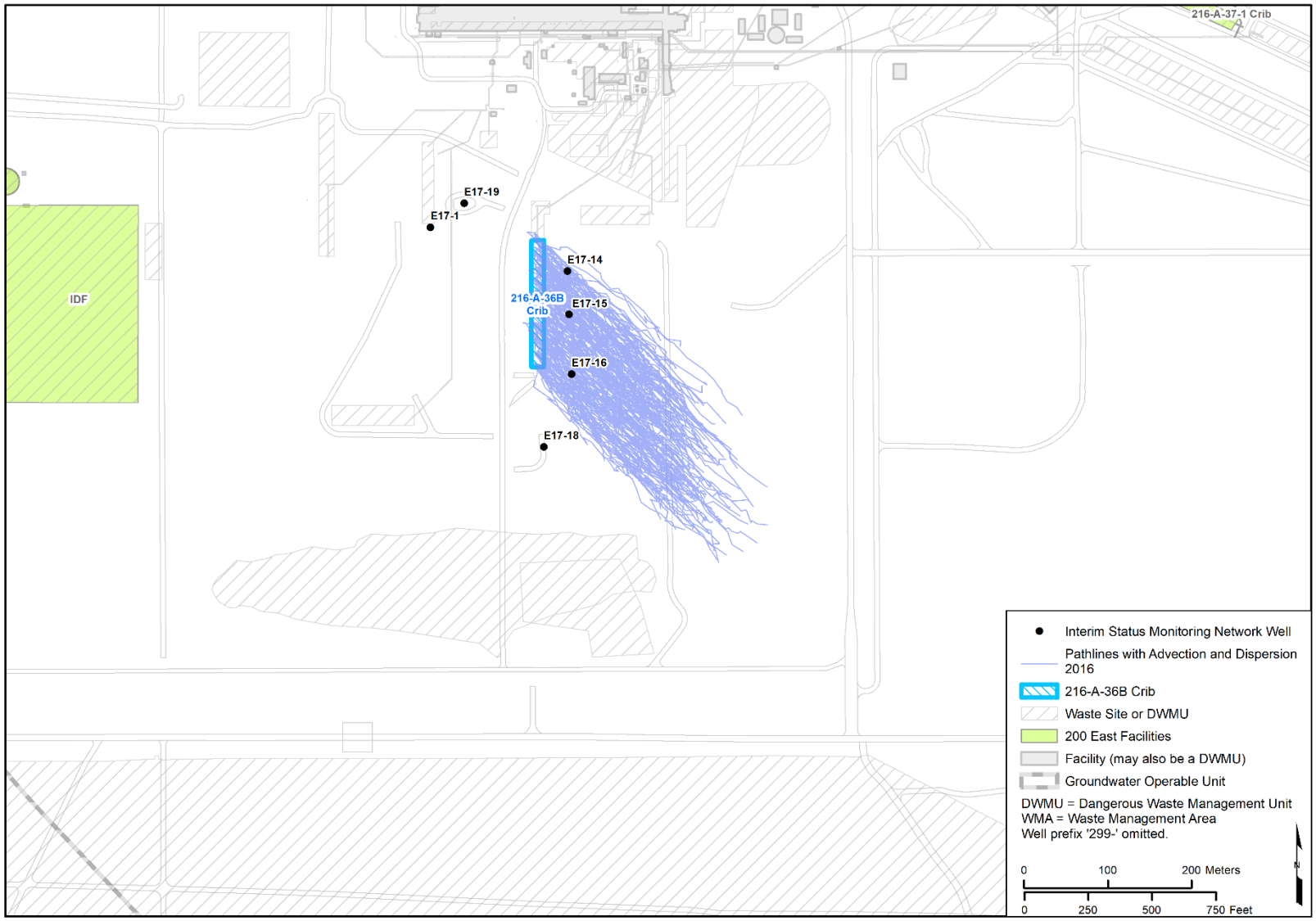

Figure D-10. Local-Scale Particle Pathlines, Advection and Dispersion – 216-A-36B Crib, 2016

D3.3 Particle Counts

To compare the relative timing and density of the particles that pass by each monitoring well location, particle counts were calculated as described in Section 6.3 of the main text of this ECF. The particle counts were tabulated, particle breakthrough curves were created, and particle count maps were generated.

D3.3.1 Relative Particle Counts at Interim Status Groundwater Monitoring Wells

Tables D-1 through D-3 present the computed particle counts over time, binned into periods of 11 years, for each of the downgradient monitoring wells. Results for well 299-E17-18 are not included because this well does not intercept particles under the flow conditions analyzed. The tables present four entries (one for each year) for each well. At the bottom of the column for each mapped event is the total number of particles that passed through the vicinity of the well, regardless of time, and the average of the totals for the four mapped years rounded to the nearest integer. Each table provides an indication of the relative timing of the expected detections at each well and the relative potential that each well would detect a release at the facility for the flow conditions calculated for CYs 2013, 2014, 2015, and 2016.

The average values depicted at the base of each table can be used to assess the relative potential for each well to detect a release at the facility. These averages are summarized as follows:

- 299-E17-14 – Average = 44
- 299-E17-15 – Average = 71
- 299-E17-16 – Average = 76

D3.3.2 Relative Arrival Times at Interim Status Groundwater Monitoring Wells

Figures D-11 through D-13 depict plots of particle counts over time (particle breakthrough curves) for each downgradient well location. Results for well 299-E17-18 are not included because this well does not intercept particles under the flow conditions analyzed. The underlying data plotted in Figures D-11 through D-13 are the same as the data in Tables D-1 through D-3, but the time interval over which particles are summed is not necessarily the same. Particle breakthrough curves show the relative timing and particle density for the arrival, peak, and decline in particle counts at each interim status monitoring location resulting from the hypothetical instantaneous release at the facility. The plots depict the relative potential at each well for detecting a release from the facility that reaches the water table for the flow conditions calculated for CYs 2013, 2014, 2015, and 2016. There is one figure for each well, with four lines shown on each plot (one for each year).

Table D-1. Particle Density (Count) Monitoring Well 299-E17-14

Time Interval (years)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
11	4	1	7	0	
22	13	14	16	11	
33	12	12	14	13	
44	6	6	5	6	
55	1	4	1	6	
66	3	1	0	5	
77	2	0	2	2	
88	1	1	0	2	
99	0	1	0	3	
110	0	0	0	0	
121	0	0	0	0	
132	0	0	0	0	
142	0	0	0	0	
153	0	0	0	0	
164	0	0	0	0	
175	0	0	0	0	
186	0	0	0	0	
197	0	0	0	0	
208	0	0	0	0	
219	0	0	0	0	
230	0	0	0	0	
241	0	0	0	0	
252	0	0	0	0	
263	0	0	0	0	
274	0	0	0	0	Average
Total	42	40	45	48	**44**

Table D-2. Particle Density (Count) Monitoring Well 299-E17-15

Time Interval (years)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
11	0	0	1	1	
22	16	10	20	8	
33	19	13	17	10	
44	13	17	12	14	
55	5	9	5	12	
66	5	14	6	7	
77	5	6	3	3	
88	2	1	3	5	
99	4	1	0	6	
110	2	2	0	3	
121	0	0	0	2	
132	0	0	0	0	
142	0	0	0	1	
153	0	1	0	0	
164	0	0	0	0	
175	0	0	0	0	
186	0	0	0	0	
197	0	0	0	0	
208	0	0	0	0	
219	0	0	0	0	
230	0	0	0	0	
241	0	0	0	0	
252	0	0	0	0	
263	0	0	0	0	
274	0	0	0	0	Average
Total	71	74	67	72	**71**

Table D-3. Particle Density (Count) Monitoring Well 299-E17-16

Time Interval (years)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
11	0	0	1	0	
22	7	6	14	3	
33	17	11	21	11	
44	13	18	16	14	
55	18	11	11	12	
66	8	20	4	10	
77	6	1	0	7	
88	4	8	3	4	
99	1	4	0	4	
110	2	6	2	3	
121	0	1	0	1	
132	0	0	0	1	
142	0	0	0	0	
153	0	0	0	0	
164	0	0	0	0	
175	0	0	0	0	
186	0	0	0	0	
197	0	0	0	0	
208	0	0	0	0	
219	0	0	0	0	
230	0	0	0	0	
241	0	0	0	0	
252	0	0	0	0	
263	0	0	0	0	
274	0	0	0	0	Average
Total	76	86	72	70	**76**

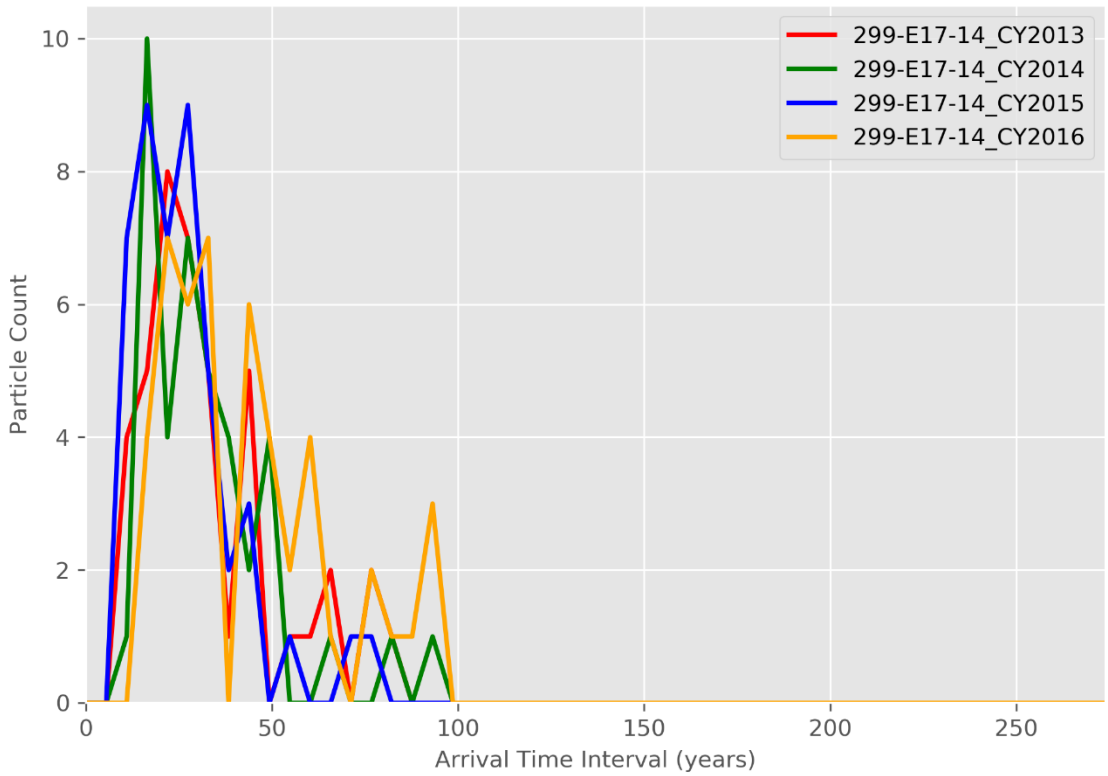

Figure D-11. Particle Breakthrough Curve at Monitoring Well 299-E17-14

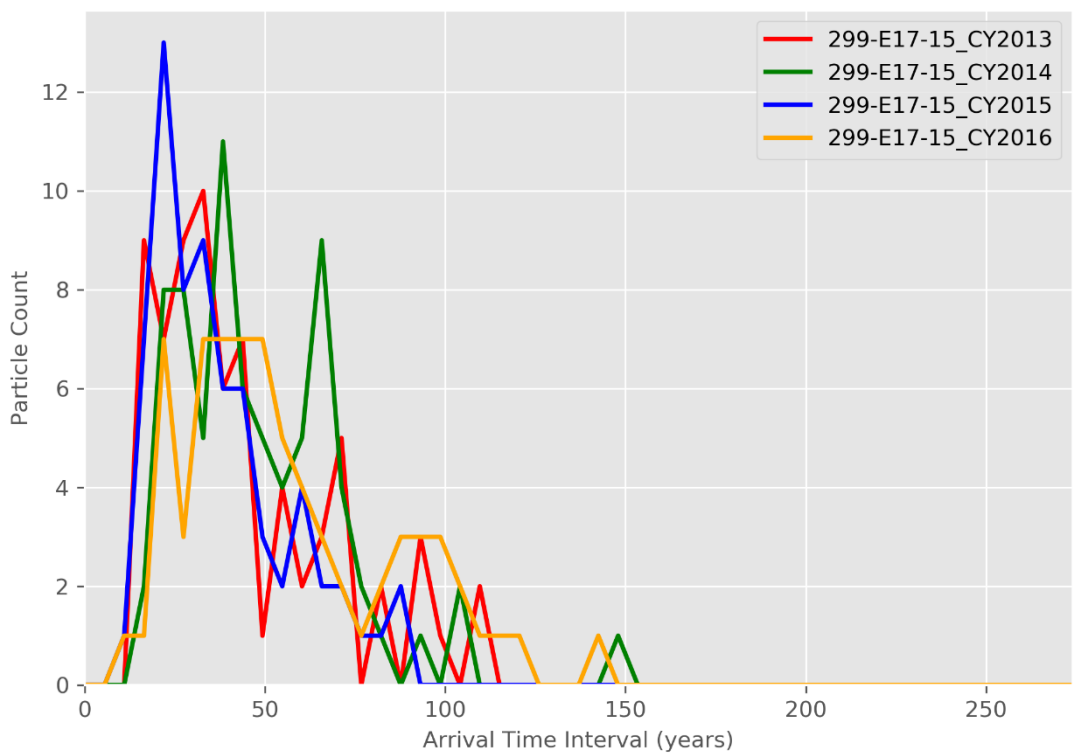

Figure D-12. Particle Breakthrough Curve at Monitoring Well 299-E17-15

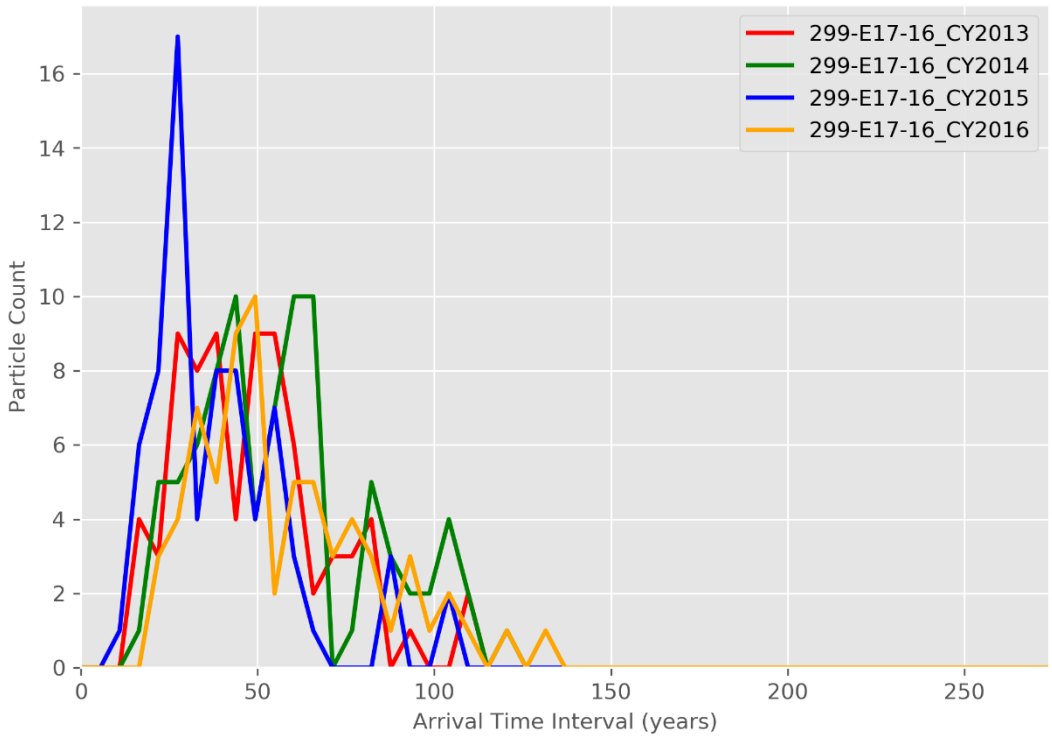

Figure D-13. Particle Breakthrough Curve at Monitoring Well 299-E17-16

D3.3.3 Particle Count Maps

Figures D-14 through D-17 depict the particle count maps developed based on the instantaneous release of a large number of particles at the facility. The particle count maps depict areas of relatively higher and lower potential impact from a release at the facility that reaches the water table, for conditions represented by CYs 2013, 2014, 2015, and 2016. Figures D-14 through D-17 depict the particle density after 274 years of calculated travel, by which time it was determined that all particles would have arrived at or passed by the interim status groundwater monitoring wells (see entries in Tables D-1 through D-3).

The goal of well placement is for the well locations to span the range of particle pathline distribution as released from the 216-A-36B Crib. The particle count maps indicate well placement is suitable for detecting releases to the water table under the evaluated range of conditions and no additional monitoring wells are proposed to monitor the 216-A-36B Crib.

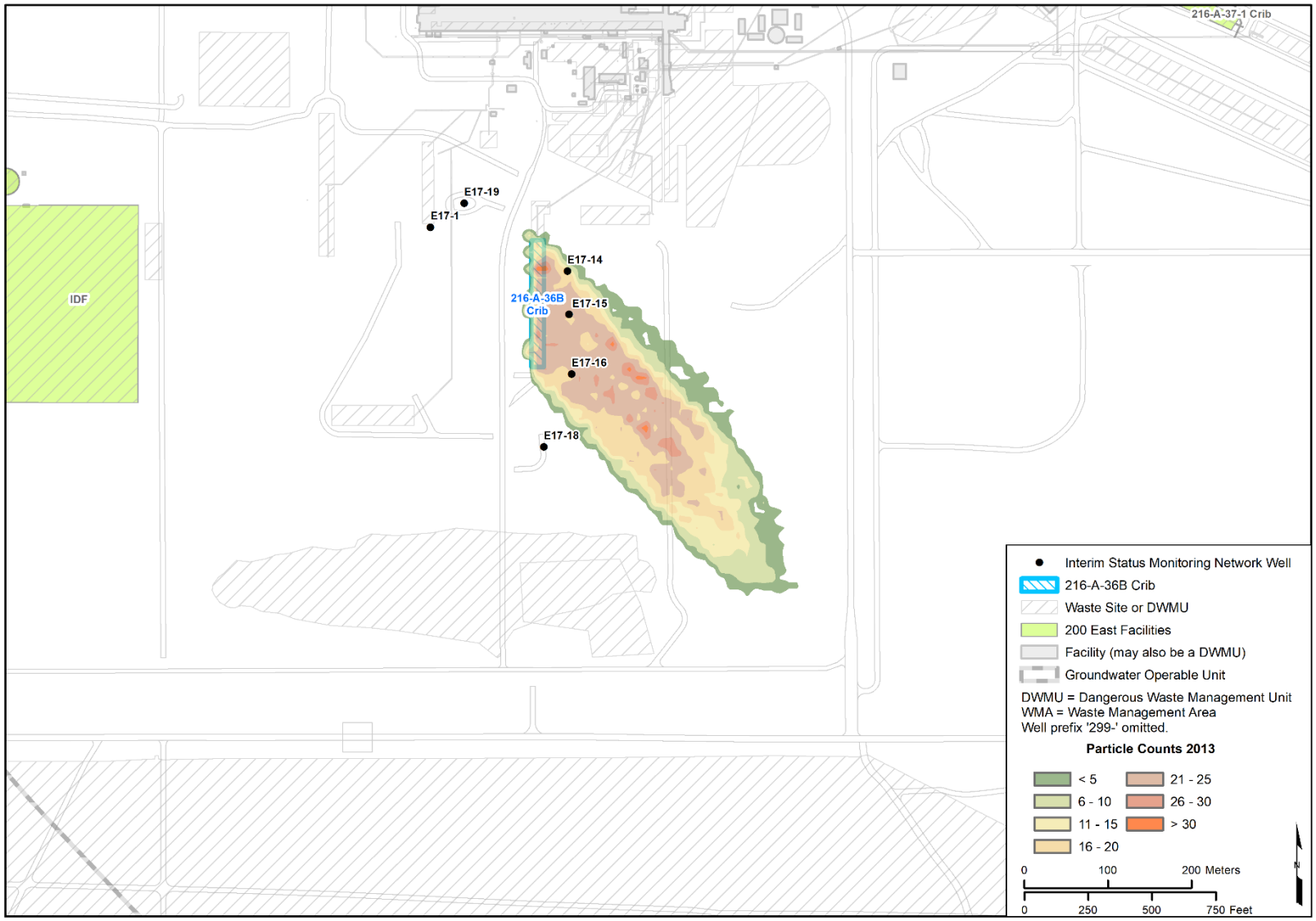

Figure D-14. Particle Count Map – 216-A-36B Crib, 2013

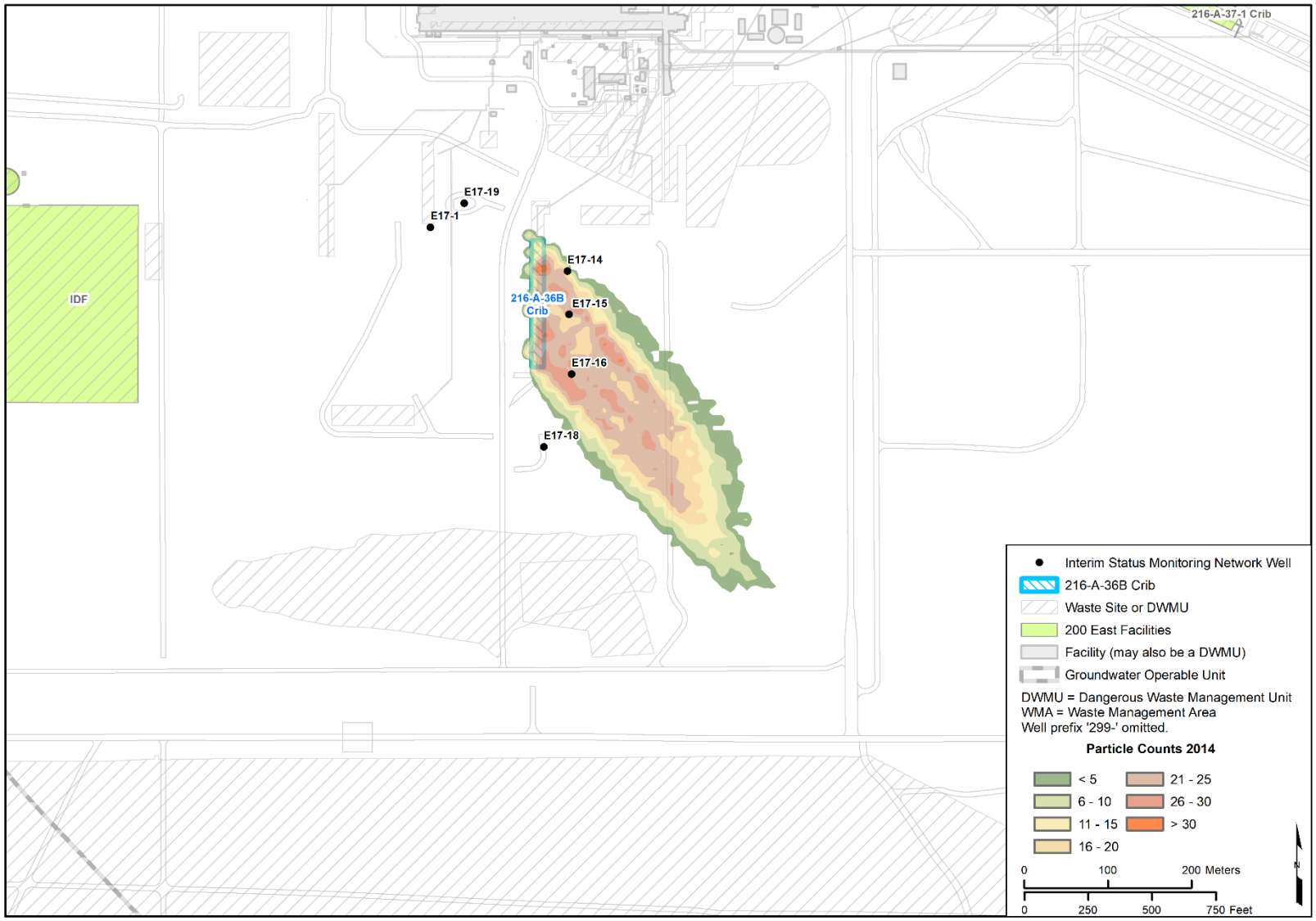

Figure D-15. Particle Count Map – 216-A-36B Crib, 2014

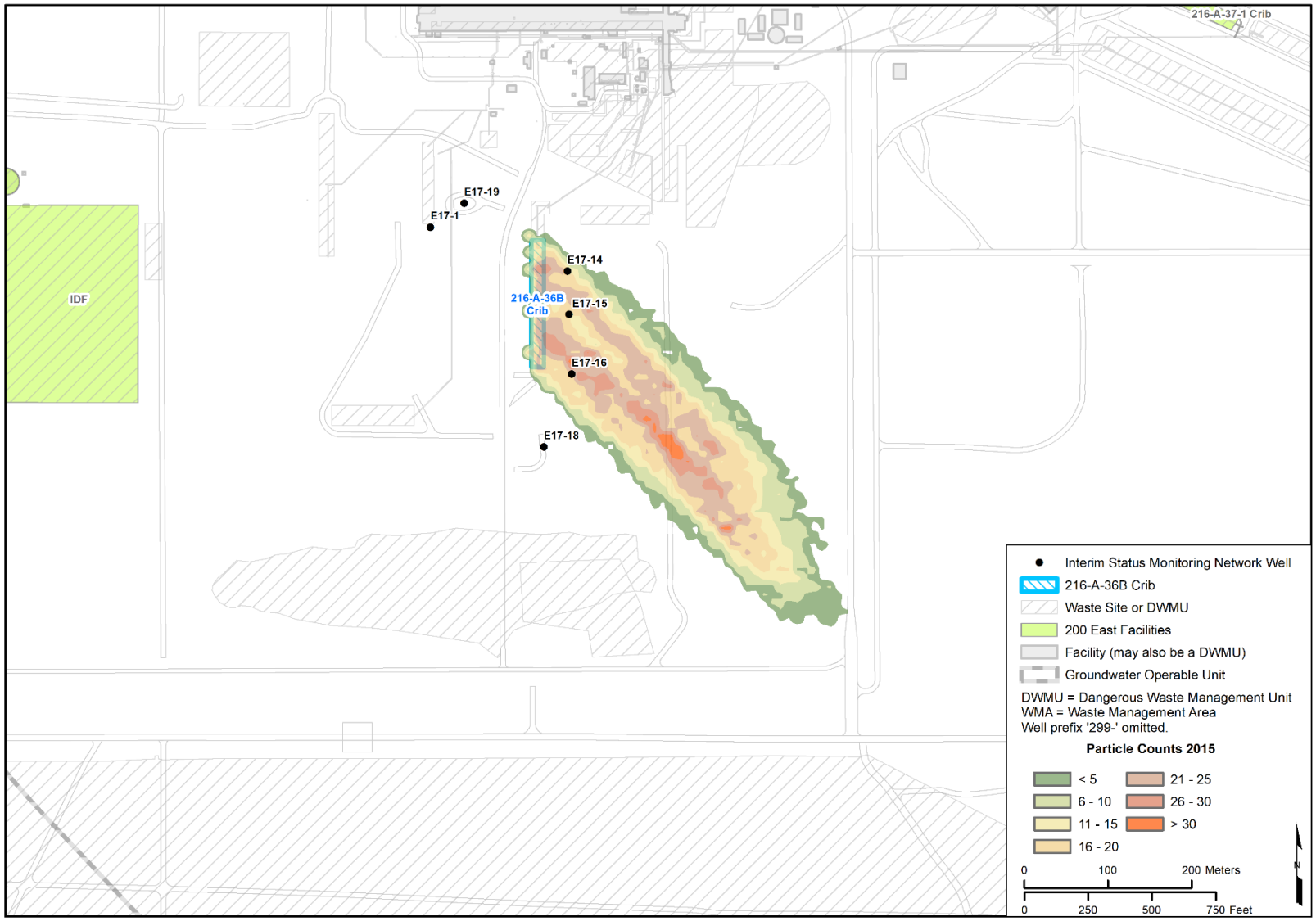

Figure D-16. Particle Count Map – 216-A-36B Crib, 2015

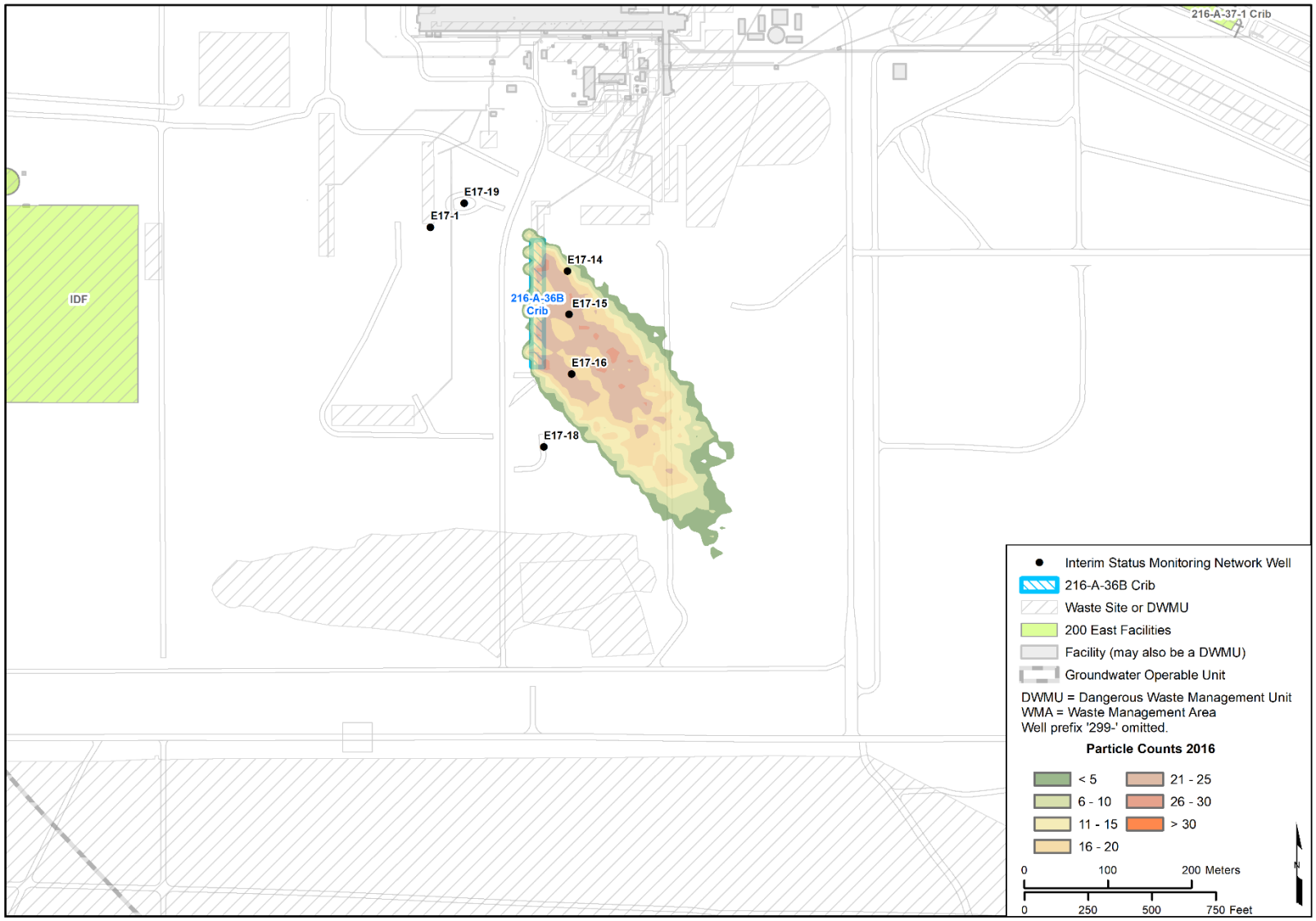

Figure D-17. Particle Count Map – 216-A-36B Crib, 2016

D3.4 Analyses of Particle Pathlines for Each Area of the 216-A-36B Crib

Particle pathline maps shown in Section D3.2 depict an instantaneous release to the water table from the release locations in the 216-A-36B Crib. Particle tracking also was performed for smaller regions of the facility to evaluate well locations for detecting releases from various regions of the 216-A-36B Crib. This section contains the results of analyses performed to examine how releases from the various areas of the 216-A-36B Crib that reach the groundwater beneath those release areas relate to each individual monitoring well. A series of figures and tables are provided to illustrate the fate of releases originating from three different areas of the crib. For these analyses, the particle release points presented in Figure D-2 are grouped into one of two areas based on their spatial location. Those areas are depicted in Figure D-18. Figures D-19 through D-22 illustrate the particle pathlines originating from each of the areas for CYs 2013 through 2016.

Figures D-23 through D-25 illustrate the particle count time series for each existing downgradient monitoring well from CY 2013 through CY 2016. Each figure has four panels, each of which depicts the particle counts for one CY (2013 through 2016). Additionally, each panel shows a separate breakthrough curve for particles emanating from each area. For example, Figure D-24 depicts the particle counts at well 299-E17-15, which receives particles from areas 1 and 2 in 2013. In the figure, within the panel for 2013 (top row, left), the particle breakthrough curve from area 1 is depicted with a blue line and the curve from area 2 with a red line.

D3.5 Vertical Migration Potential

As described in Section 3.3 of the main text of this ECF, the American Petroleum Institute (API) plume diving calculation was used to estimate the likely rate of vertical migration of dissolved constituents downward under the influence of recharge at the water table. At each well the slope of the plume dive was multiplied by the distance from the particle starting location to the well location to estimate the depth to which the dissolved constituents may be anticipated to have migrated by the time they reach the monitoring well location.

This estimated depth of the plume was then compared to the depth from the water table to the bottom of the monitoring well screen. If the depth of the plume is below the bottom of the monitoring well screen, then the dissolved constituents may be anticipated to pass beneath the well screen. If it falls within the interval between the top of the water table and the bottom of the well screen, then the well depth is appropriate for detection of releases at the 216-A-36B Crib.

For each downgradient monitoring well at the 216-A-36B Crib, the distance used in the calculation was the distance from the centroid of the facility to each well location. The hydraulic conductivity used in the calculation for the 216-A-36B Crib, 35.6 m/d (116.8 ft/d), is the calibrated hydraulic conductivity from the CPGWM for the Rwie, which underlies the facility. The results of the API plume diving calculation for the downgradient wells for the 216-A-36B Crib are shown in Table D-4.

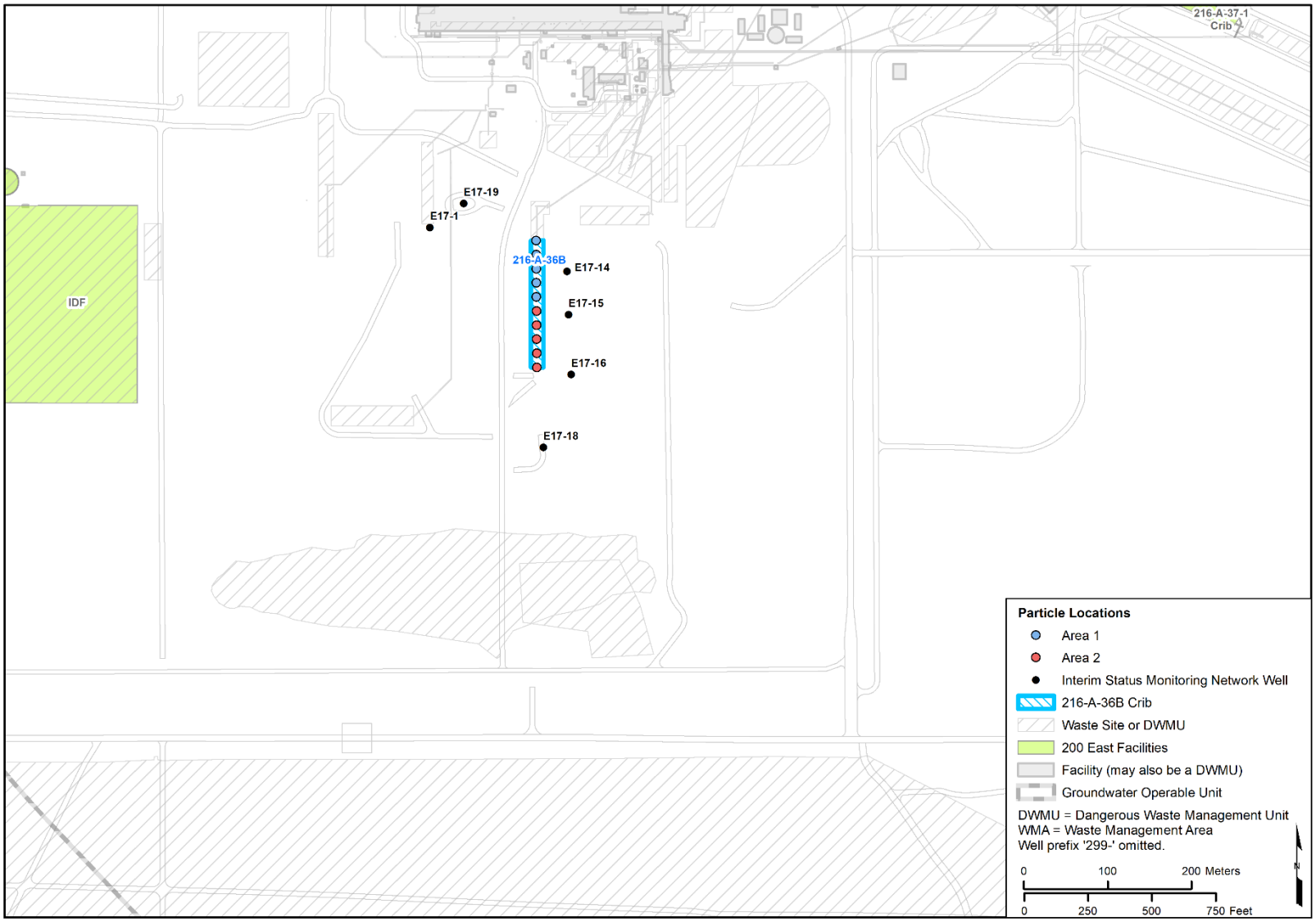

Figure D-18. Particle Release Locations and Areas of the 216-A-36B Crib

Figure D-19. CY 2013 Particle Pathlines per Area of the 216-A-36B Crib

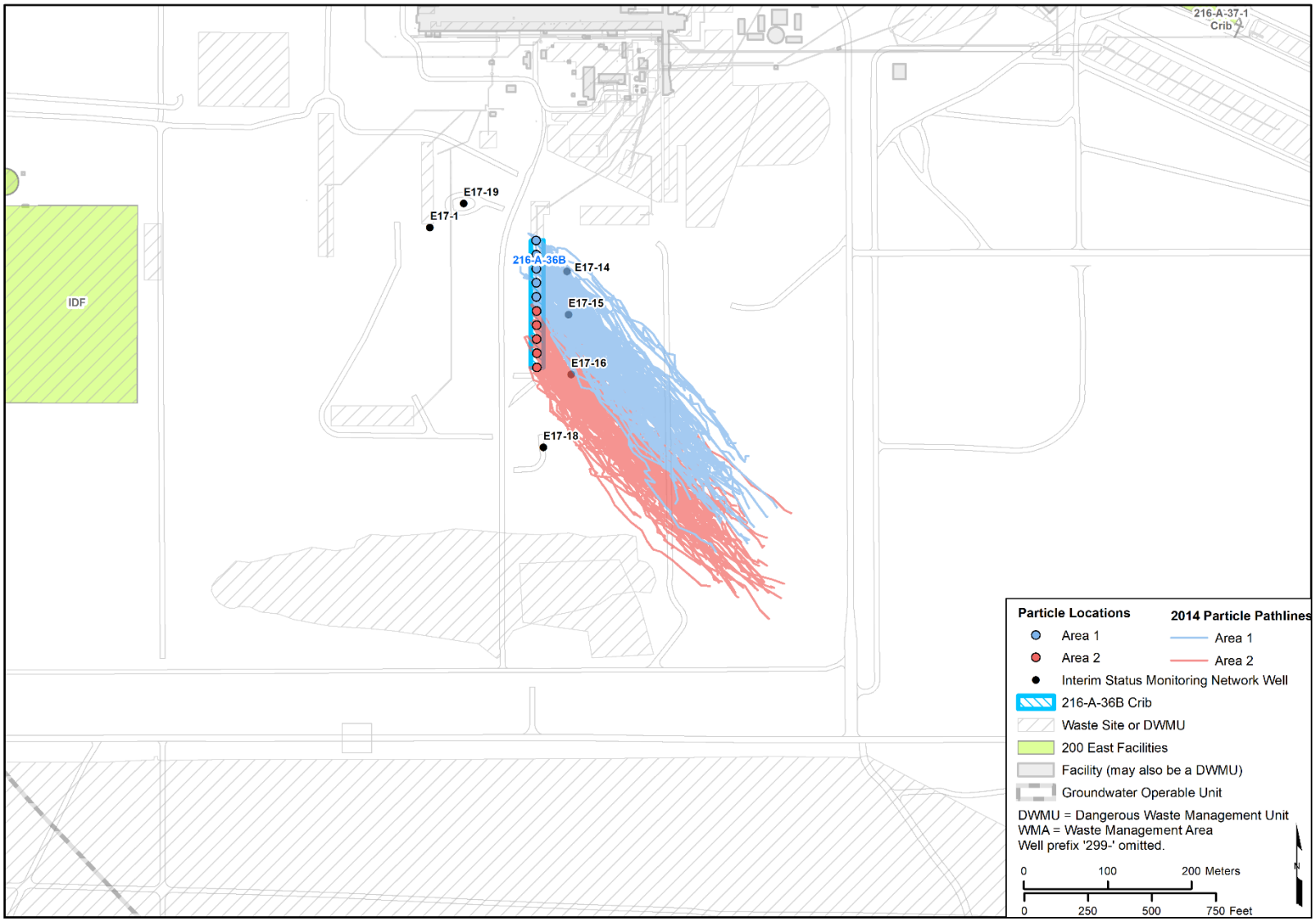

Figure D-20. CY 2014 Particle Pathlines per Area of the 216-A-36B Crib

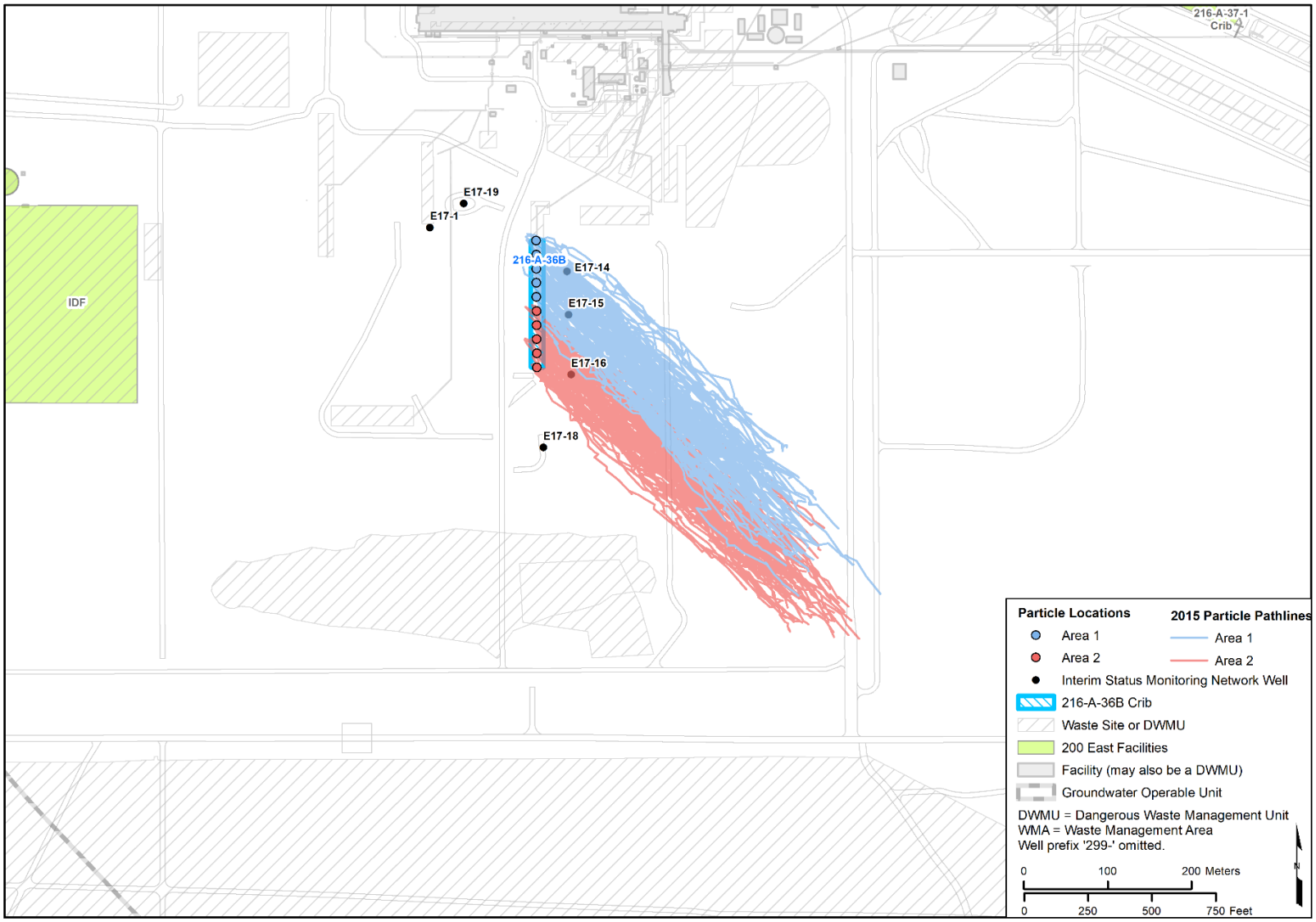

Figure D-21. CY 2015 Particle Pathlines per Area of the 216-A-36B Crib

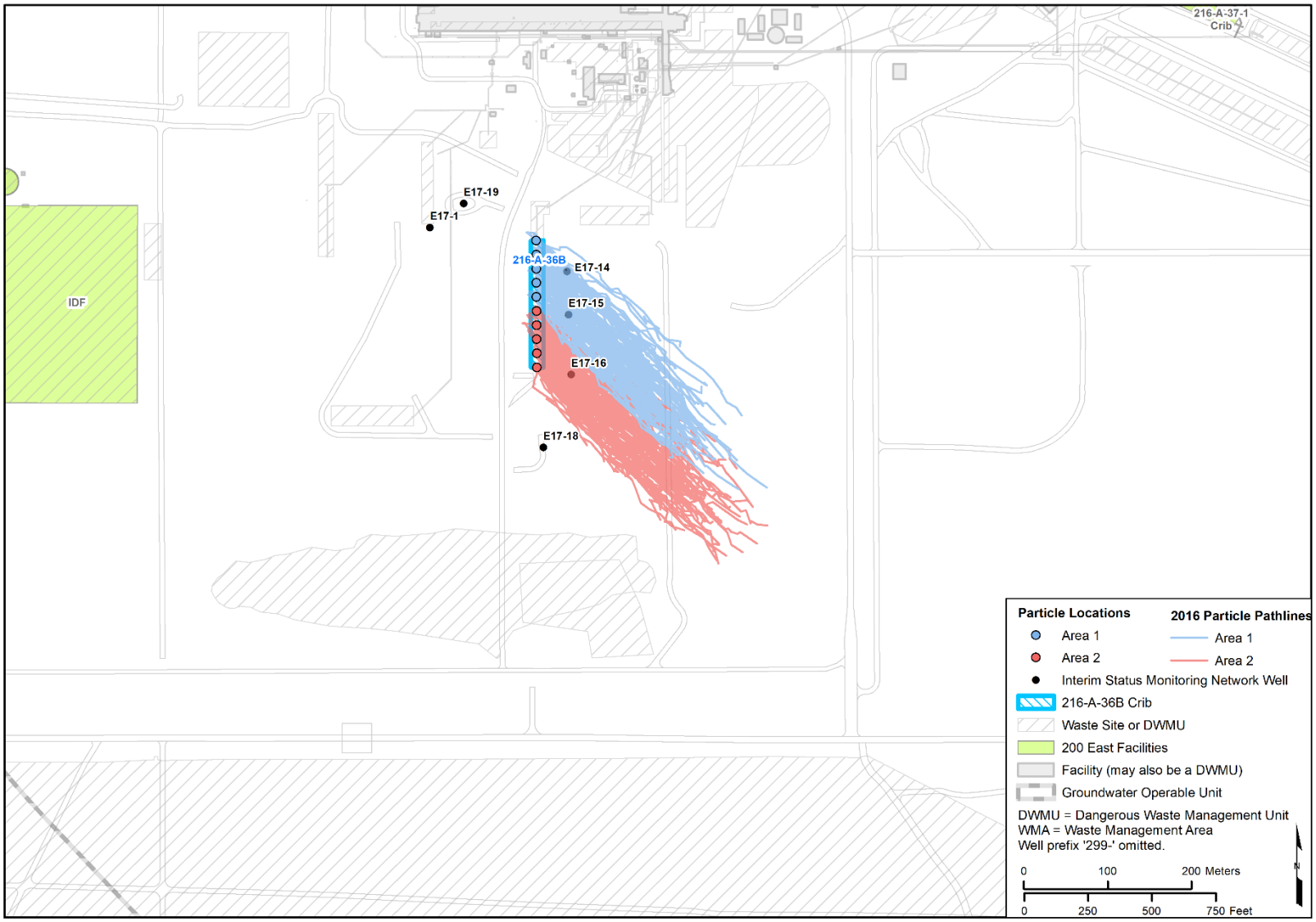

Figure D-22. CY 2016 Particle Pathlines per Area of the 216-A-36B Crib

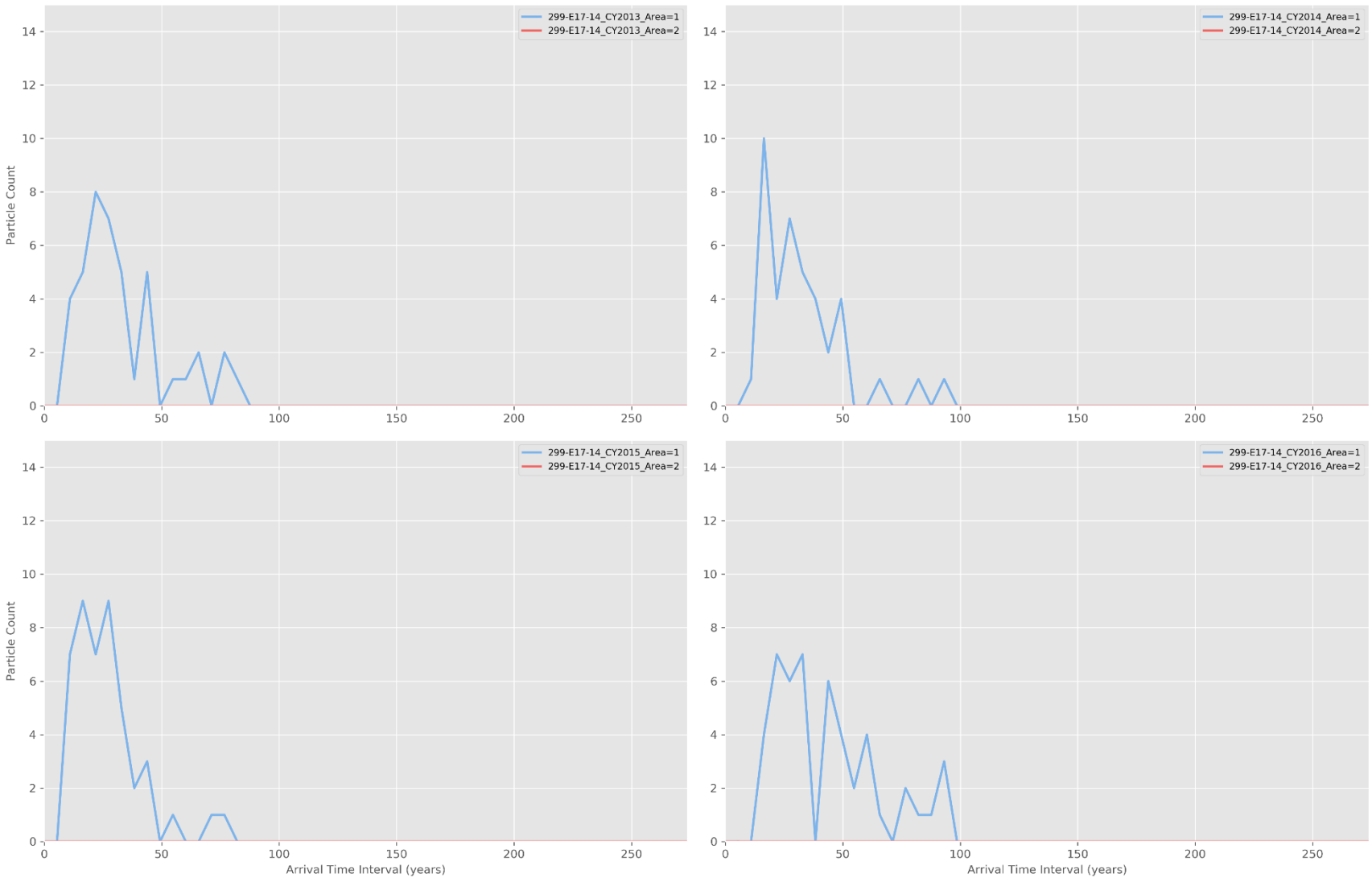

Figure D-23. Particle Breakthrough Curves per Area at Monitoring Well 299-E17-14

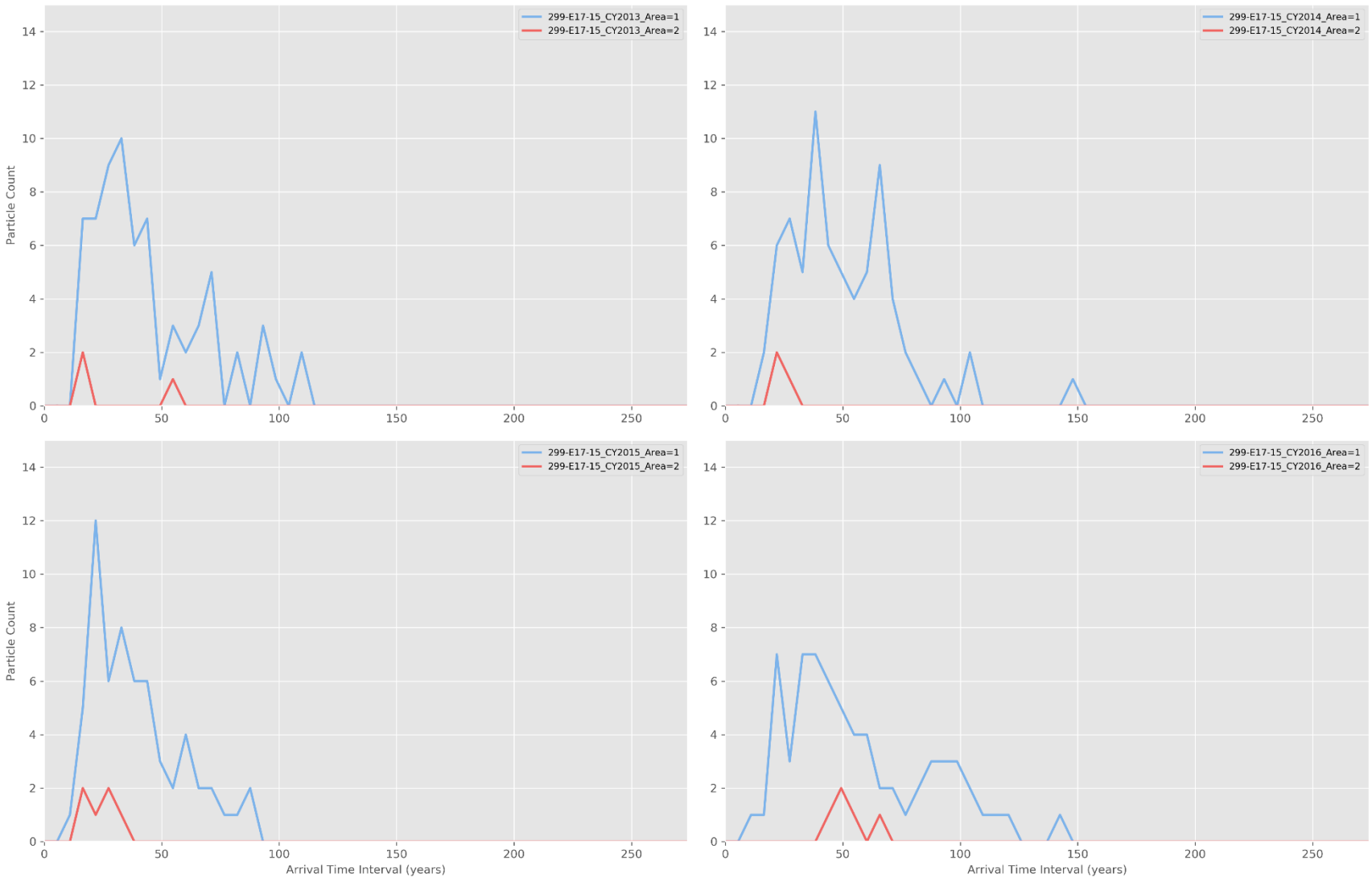

Figure D-24. Particle Breakthrough Curves per Area at Monitoring Well 299-E17-15

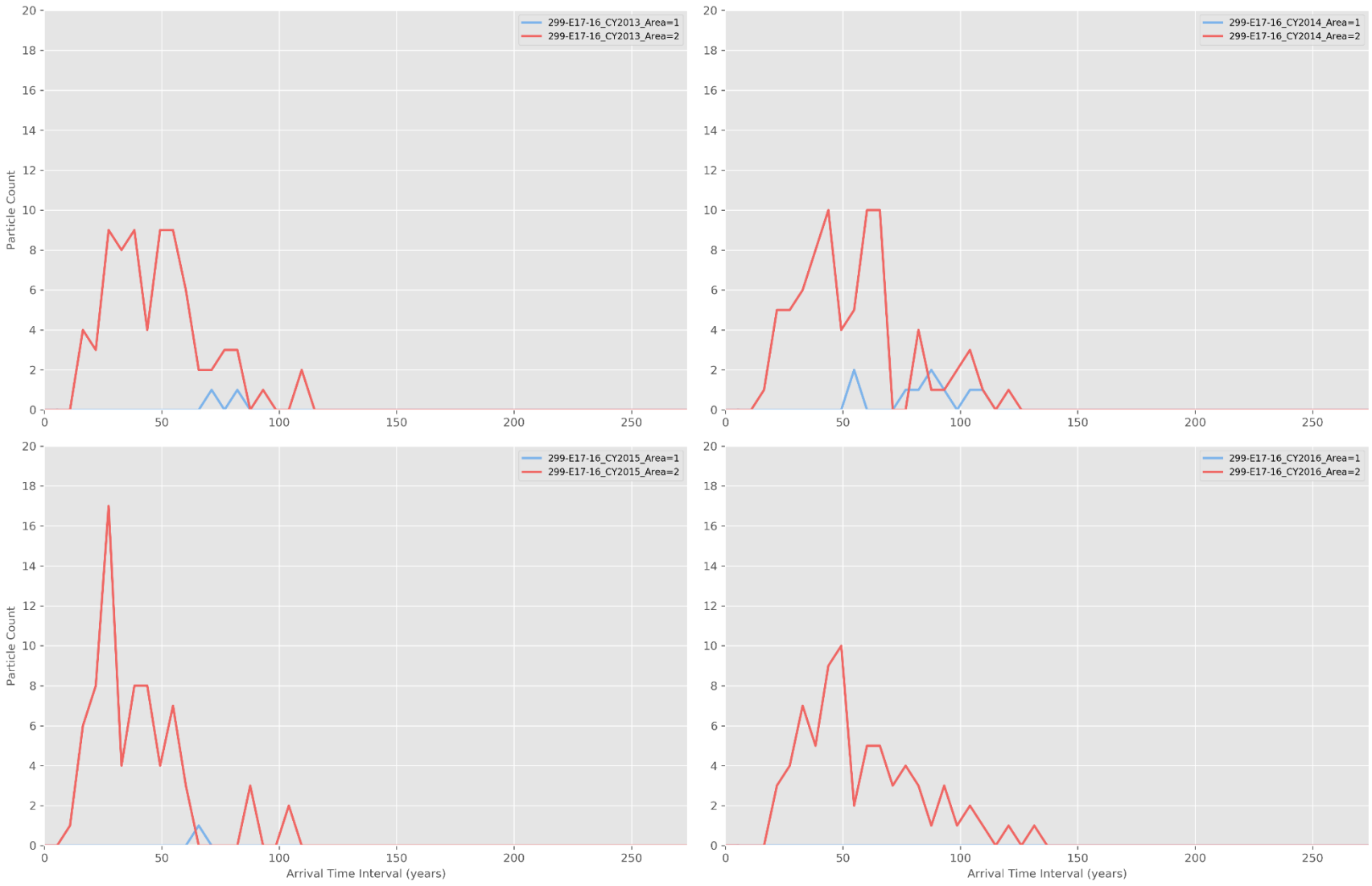

Figure D-25. Particle Breakthrough Curves per Area at Monitoring Well 299-E17-16

Table D-4. Summary of Well Screen Interval Evaluation for Downgradient Wells

Monitoring Well	Existing or Proposed Well?	Distance, D, (m)[a]	Recharge, *i*, (m/yr)[b]	Slope, S, of Plume Dive[c]	Estimated Depth of Plume Below Water Table (m)[d]	Depth from Water Table to Bottom of Well Screen (m)[e]	Is Plume Depth Above Bottom of the Screen? (Yes/No/N/A)
299-E17-14	Existing	52.6	1.70E-02	7.58E-02	3.99	2.5	No
299-E17-15	Existing	39.9	1.70E-02	7.58E-02	3.02	2.3	No
299-E17-16	Existing	93.5	1.70E-02	7.58E-02	7.08	2.4	No
299-E17-18	Existing	171.5	1.70E-02	7.58E-02	13.0	2.9	No

a. Distance of the well from centroid of dangerous waste management unit.

b. A representative number from the CPGWM. The recharge values represent fluxes from surface water discharge due to historical operations at the Hanford Site and are summarized in EMDT-BC-0002, *Vadose Zone Attenuated Recharge, Electronic Modeling Data Transmittal – Boundary Condition (Artificial Recharge)*-0002. The anthropogenic flux is added to the natural recharge component in order to establish the final total recharge flux used in the simulations. Discharges included in EMDT-BC-0002 have been attenuated to account for travel through the vadose zone.

c. Slope of the plume dive computed using the American Petroleum Institute plume diving calculation as detailed in the main text of this ECF. The migration parameters for the 216-A-36B Crib used in the calculation of slope are as follows:

Hydraulic conductivity: 35.6 m/d (117 ft/d) (a calibrated value from the CPGWM)

Hydraulic gradient: 1.72E-05 (determined from 2016 water-level maps produced using TRIM)

d. Plume depth at monitoring well location computed from distance, D, times the slope, S.

e. Depths obtained from Table 3-4 in DOE/RL-2010-93, *Interim Status Groundwater Monitoring Plan for the 216-A-36B Purex Plant Crib*.

CPGWM = Central Plateau Groundwater Model

ECF = environmental calculation file

N/A = not applicable

TRIM = Tikhonov Regularized Inverse Method

This calculation demonstrates that there may be sufficient vertical migration due to accrual of recharge that it could result in the screened interval of downgradient monitoring wells being too shallow to effectively detect releases from the 216-A-36B Crib. This determination relies upon the values for hydraulic conductivity and recharge used in the calculations; in particular, it assumes that the hydraulic conductivity in this area is substantially lower than in surrounding areas. Before committing resources to well deepening or replacement, it is recommended that field tests be conducted within these downgradient monitoring wells to verify that the hydraulic conductivity value used in these calculations (derived from calibration of the CPGWM) is representative of the Rwie formation in the vicinity of the facility. Depending on the local groundwater conditions, potentially applicable field tests include mechanical or pneumatic slug tests, single-well dilution tests, and single-well pumping tests. If it is found that the hydraulic conductivity in the vicinity of the facility is substantially higher, this may alter the conclusions of the vertical migration potential calculations to the extent that existing wells need not be deepened or replaced.

D4 References

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Appendix E

Facility-Specific Results for the 216-A-37-1 Crib

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Terms

API	American Petroleum Institute
CPGWM	Central Plateau Groundwater Model
CY	calendar year
ECF	environmental calculation file
TRIM	Tikhonov Regularized Inverse Method

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E1 Purpose and Background

The primary purpose of the calculations presented here is to estimate directions of potential migration to assess the efficacy of the geographical distribution of wells in the proposed monitoring well network for the subject facility. The calculations described within the main text of this environmental calculation file (ECF) were performed for each of the 200 East Facilities. This appendix presents results developed from the calculations that are specific to the 216-A-37-1 Crib.

Located in the eastern part of the 200 East Area, the 216-A-37-1 Crib is a nonoperating treatment, storage, and disposal unit. The crib is approximately 213 m (699 ft) long and 5.2 m (17.1 ft) deep (Section 2.5 of DOE/RL-2016-66, *Hanford Site RCRA Groundwater Monitoring Report for 2016*). Figure 2-2 in DOE/RL-2010-92, *Interim Status Groundwater Monitoring Plan for the 216-A-37-1 PUREX Plant Crib*, shows that the crib is 3 m (10 ft) wide at its base.

During its operation, the 216-A-37-1 Crib was used to percolate condensate from the 242-A Evaporator process to the soil column. The crib began receiving spent halogenated and nonhalogenated solvents and ammonia in March 1977 (DOE/RL-2010-92). It received 3.8E+08 L (9.8E+07 gal) of process condensate until April 1989 when it was removed from service. Since shutting down in 1989, the diversion box has been grout filled and crib vent risers have been sealed (Section 2.5 of DOE/RL-2016-66).

A groundwater quality assessment program for the 216-A-37-1 Crib was put in place in 1997 as required by WAC 173-303-400, "Dangerous Waste Regulations," "Interim Status Facility Standards." The 216-A-10 Crib, 216-A-36B Crib, and 216-A-37-1 Crib were combined into a single groundwater quality assessment program to evaluate the nitrate plume beneath the cribs (PNNL-11523, *Combination RCRA Groundwater Monitoring Plan for 216-A-10, 216-A-36B, and 216-A-37-1 PUREX Cribs*). The three cribs were monitored together until March 2010 when the 216-A-10 Crib was officially closed and removed from the permit (Section 2.5 of DOE/RL-2016-66). In January 2011, the 216-A-36B Crib and the 216-A-37-1 Crib monitoring status changed to an indicator evaluation program because the constituent detected in the network monitoring wells, nitrate, is not a dangerous waste or dangerous waste constituent (Section 2.5 of DOE/RL-2016-66). Groundwater monitoring is ongoing at the 216-A-37-1 Crib for indicator parameters and water quality constituents.

The 216-A-37-1 Crib interim status monitoring network (Figure E-1) consists of two upgradient wells (299-E25-35 and 299-E25-47) and four downgradient wells (299-E25-17, 299-E25-19, 299-E25-20, and 299-E25-95) (DOE/RL-2010-92).

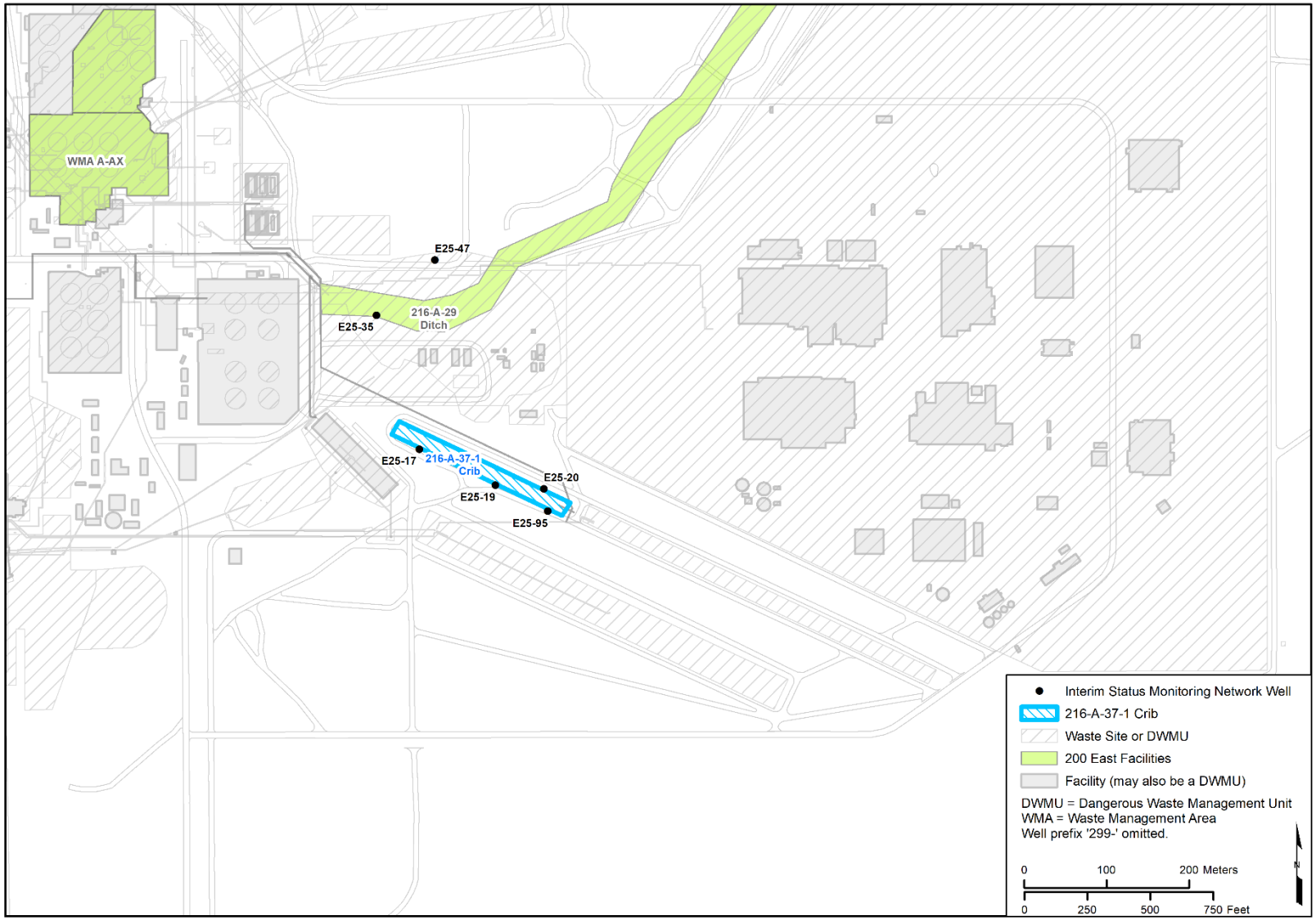

Figure E-1. Locations of Interim Status Groundwater Monitoring Wells at the 216-A-37-1 Crib

E2 Facility-Specific Input for the 216-A-37-1 Crib

Inputs used in the calculations that were specific to the 216-A-37-1 Crib are described in this chapter.

E2.1 Particle Count Grid and Release Locations

To prepare particle count maps, a distribution of facility-specific starting locations is required. The starting locations for the particle-tracking calculations represent the area over which a potential release from a given facility would impact the underlying water table. The particle releases were located at plausible release sites throughout the facility. For the 216-A-37-1 Crib, 17 release locations were specified along the centerline of the crib (Figure E-2). Twenty particles were released and tracked from each release location to provide the density of particles in space and time required for the detailed facility-specific calculations, randomizing the seed values for the dispersion calculations. Thus, 340 [340 = 17 (release locations) × 20 (releases)] particles were tracked for each of the four simulations.

Contour maps of particle counts were generated by counting the number of particles that pass through a pre-defined uniform calculational grid (Figure E-2). The grid used to develop the relative particle density maps is defined by 10 by 10 m (33 by 33 ft) cells. The grid is oriented to be parallel to the predominant groundwater flow direction at the 216-A-37-1 Crib.

E2.2 Migration Parameters

Parameters specific to the groundwater flow conditions at the 216-A-37-1 Crib are reported throughout the various documents for the facility. The parameters used in the calculations performed herein to represent nonreactive dissolved contaminant migration are mobile (or effective) porosity and hydraulic conductivity. The parameters used in these calculations are representative of local conditions for a conservative (i.e., nonreactive) solute dissolved within groundwater.

There is a range of hydraulic conductivity values reported in site literature for the 216-A37-1 Crib. Values range from 18 m/d (59 ft/d) for the Hanford formation (Section 3.2.3 of PNNL-11523) to 17,000 m/d (55,774 ft/d) (Table 1 in ECF-Hanford-17-0241, *Hydraulic Gradient and Velocity Calculations for RCRA Sites in 2017*). As described in Section 4.2.1.1 of the main text of this ECF, the hydraulic conductivity used in the work performed herein corresponds to the calibrated values from the Central Plateau Groundwater Model (CPGWM) (CP-47631, *Model Package Report: Central Plateau Groundwater Model, Version 8.4.5*). Figure 3-2 in the main text of this ECF indicates the 216-A-37-1 Crib is located in the hydrostratigraphic unit zone corresponding to the Cold Creek unit. The value used for the hydraulic conductivity for the 216-A37-1 Crib is 18,200 m/d (59,711 ft/d), which corresponds to the Cold Creek unit as shown in Table 4-1 in the main text of this ECF.

Similarly, there is a range of porosity values reported in site literature for the 216-A-37-1 Crib. Values range from 0.1 to 0.3 (Table 2 in Hanford-16-0013). As described in Section 4.2.1.1 of the main text of this ECF, the mobile (effective) porosity used in the work performed herein corresponds to the calibrated values from the CPGWM (CP-47631). The value for the 216-A37-1 Crib is specified at 0.25, which corresponds to the Hanford formation and the Cold Creek unit as shown in Table 4-1 in the main text of this ECF.

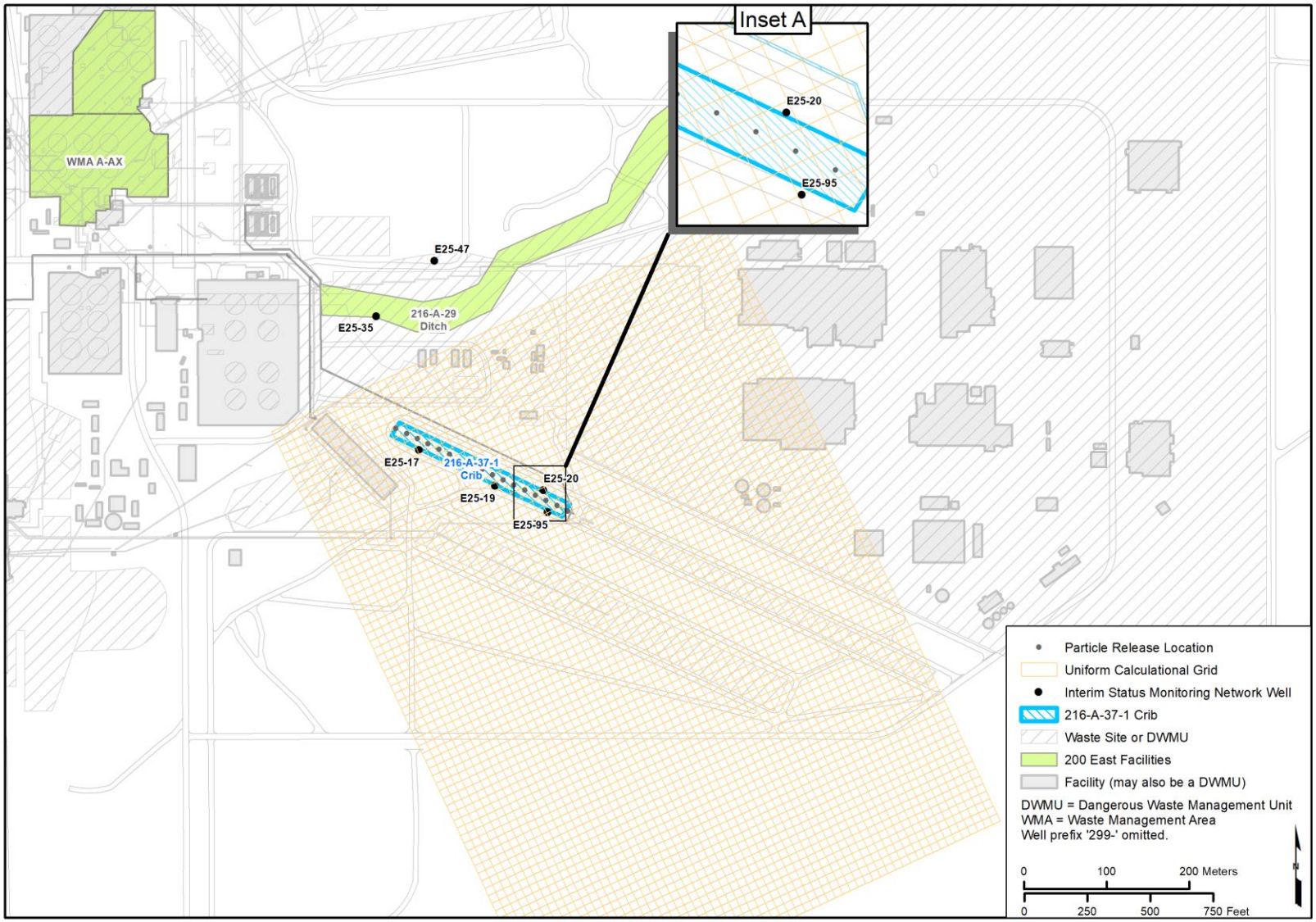

Figure E-2. Uniform Calculational Grid and Release Locations at the 216-A-37-1 Crib

E3 Facility-Specific Results for the 216-A-37-1 Crib

The groundwater elevation contours prepared in the vicinity of the 216-A-37-1 Crib using the Tikhonov Regularized Inverse Method (TRIM) are presented in this chapter. In addition, the outputs of the particle tracking and particle count calculations are presented, including the following:

- Maps of calculated particle pathlines for the flow conditions determined for each of the four years (2013, 2014, 2015, and 2016). These are presented at the facility-specific scale considering advective and dispersive migration.
- Time-series plots, referred to as particle breakthrough curves, of the relative arrival, peak, and decline in particle counts at each interim status groundwater monitoring well location and each proposed monitoring location, where applicable.
- Tabulation of relative particle counts for each interim status groundwater monitoring well location and each proposed monitoring location, where applicable.
- Maps of particle counts downgradient of each facility based on the flow conditions determined for each of the four years.

The results of calculations of potential vertical migration of contaminants at the monitoring well locations are also presented.

E3.1 Groundwater Elevation Contours

Figures E-3 through E-6 show the results of the groundwater elevation analysis completed using TRIM in the vicinity of the 216-A-37-1 Crib. The figures depict general patterns of groundwater elevations and hydraulic gradients for conditions represented by calendar years (CYs) 2013, 2014, 2015, and 2016. These groundwater elevation contours and associated hydraulic gradients form the basis for the facility-specific calculations performed for this ECF.

E3.2 Particle Tracking

Once the groundwater elevation contour maps and underlying piecewise continuous elevation grids were prepared using TRIM, particle tracking was implemented using both advection and dispersion.
The particle pathlines that were produced depict the patterns of spreading that might accompany the migration of contaminants near the crib for the flow conditions calculated for CYs 2013, 2014, 2015, and 2016. Figures E-7 through E-10 depict the particle pathlines developed based on the groundwater elevations prepared throughout the 200 East Area using TRIM. The resulting maps were prepared based on the release of 20 particles from each starting location to provide the high density of particles in space and time required for these detailed facility-specific calculations. Figures E-7 through E-10 depict the particle pathlines calculated after 425 days of travel, by which time it was determined that most of the particles would have arrived at or passed by the interim status groundwater monitoring wells. Figures E-7 through E-10 depict an instantaneous release to the water table from the release locations in the 216-A-37-1 Crib to illustrate the adequacy of the well network for monitoring the entire facility.

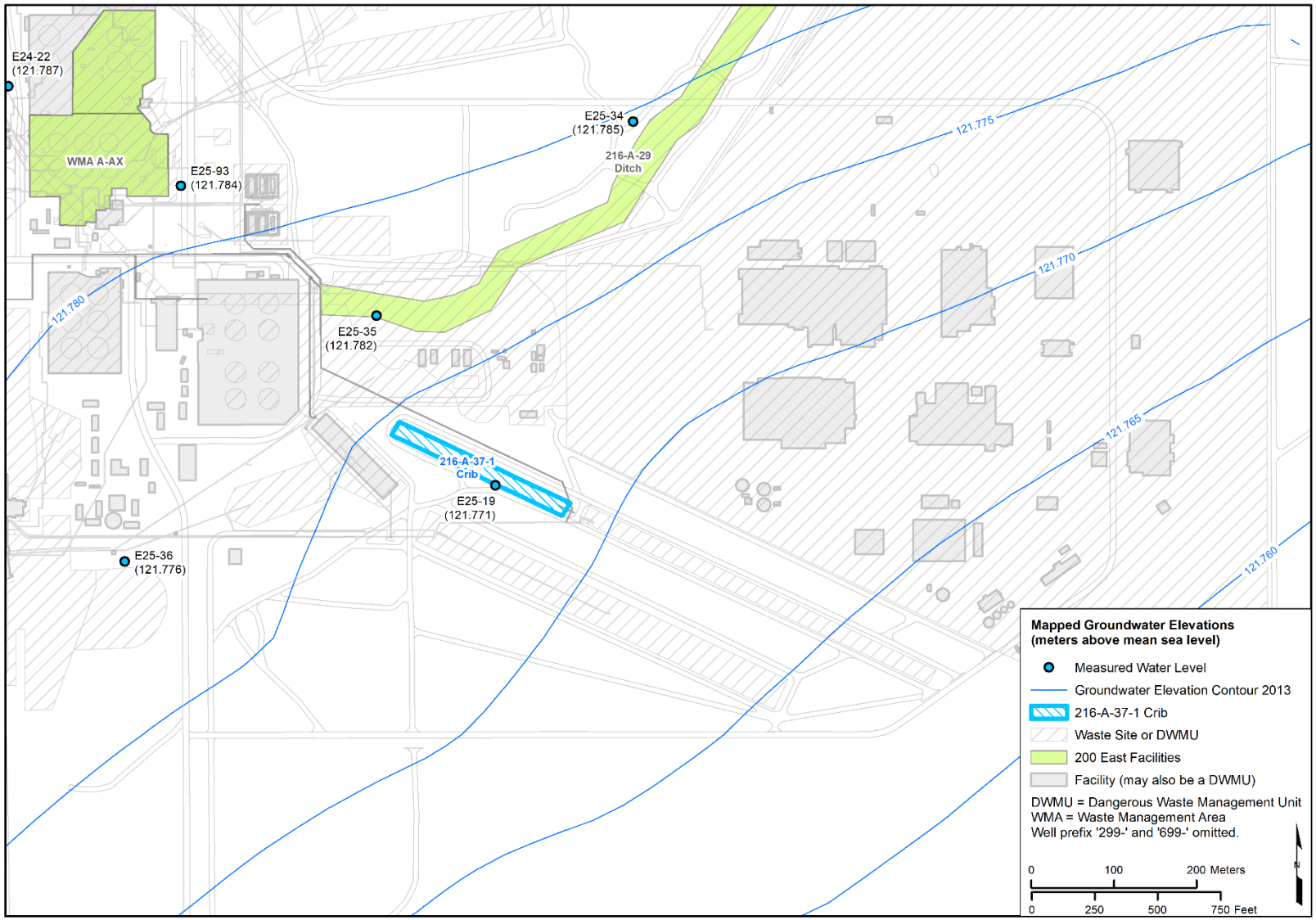

Figure E-3. Water-Level Elevation Map for the 216-A-37-1 Crib, 2013

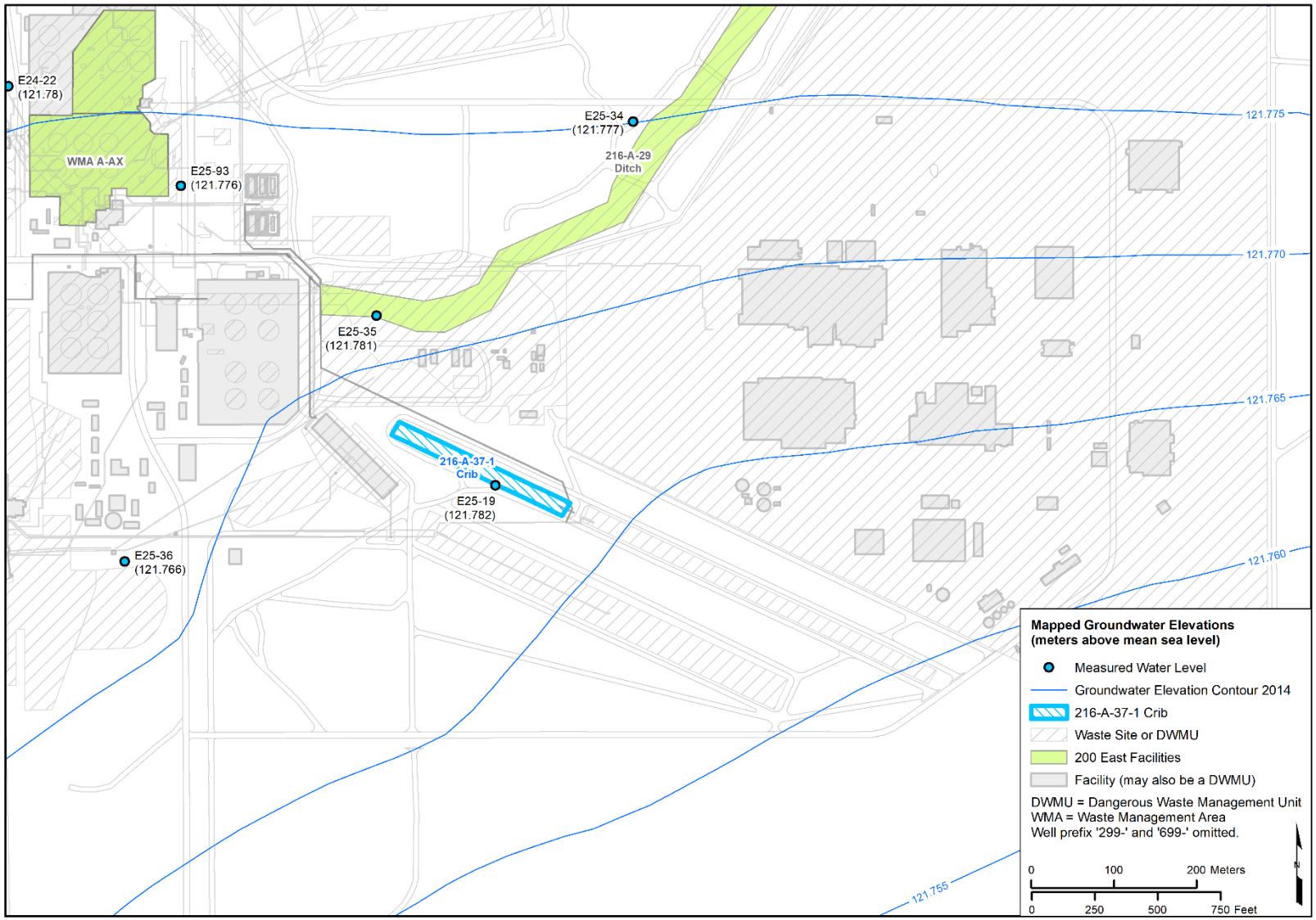

Figure E-4. Water-Level Elevation Map for the 216-A-37-1 Crib, 2014

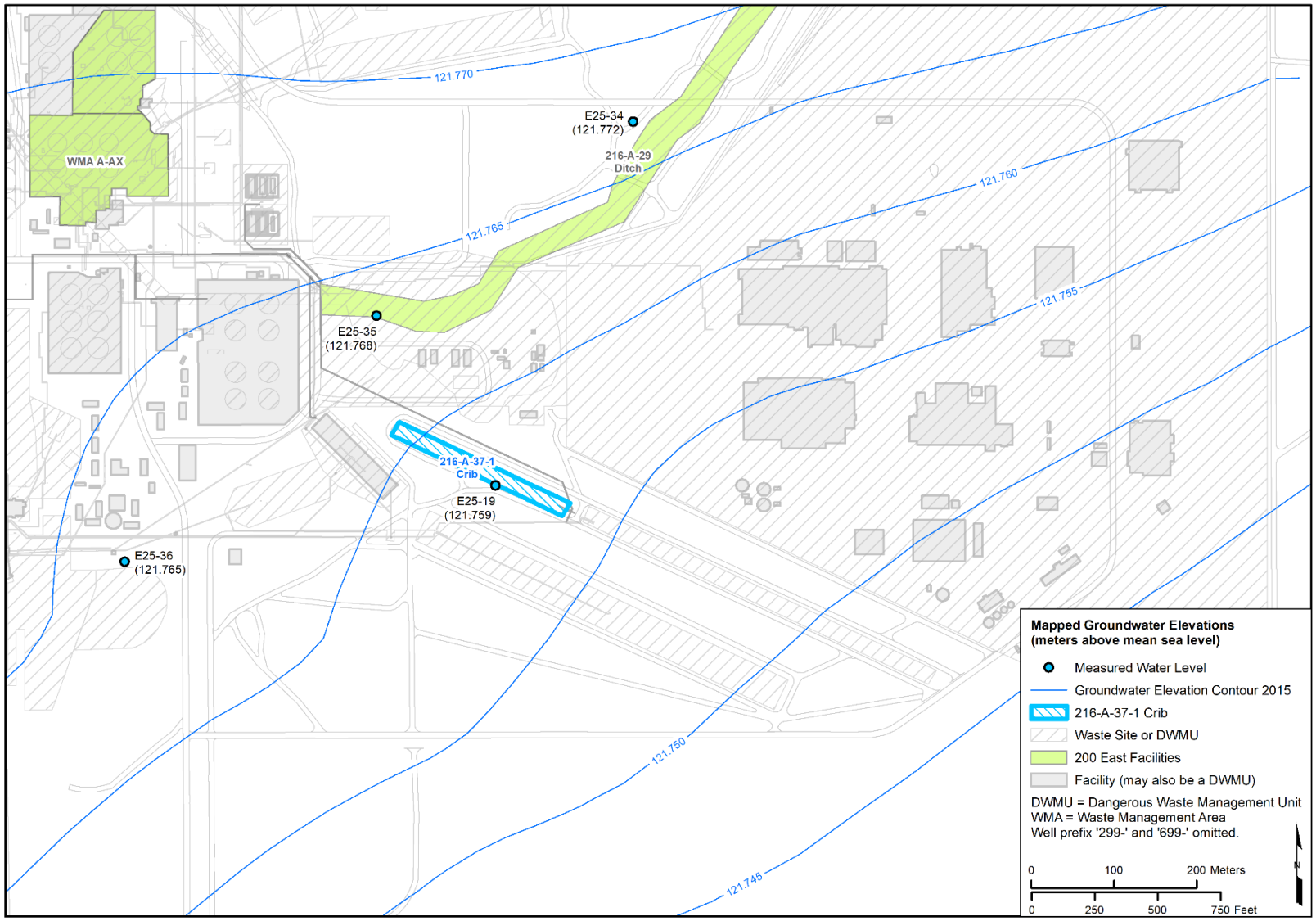

Figure E-5. Water-Level Elevation Map for the 216-A-37-1 Crib, 2015

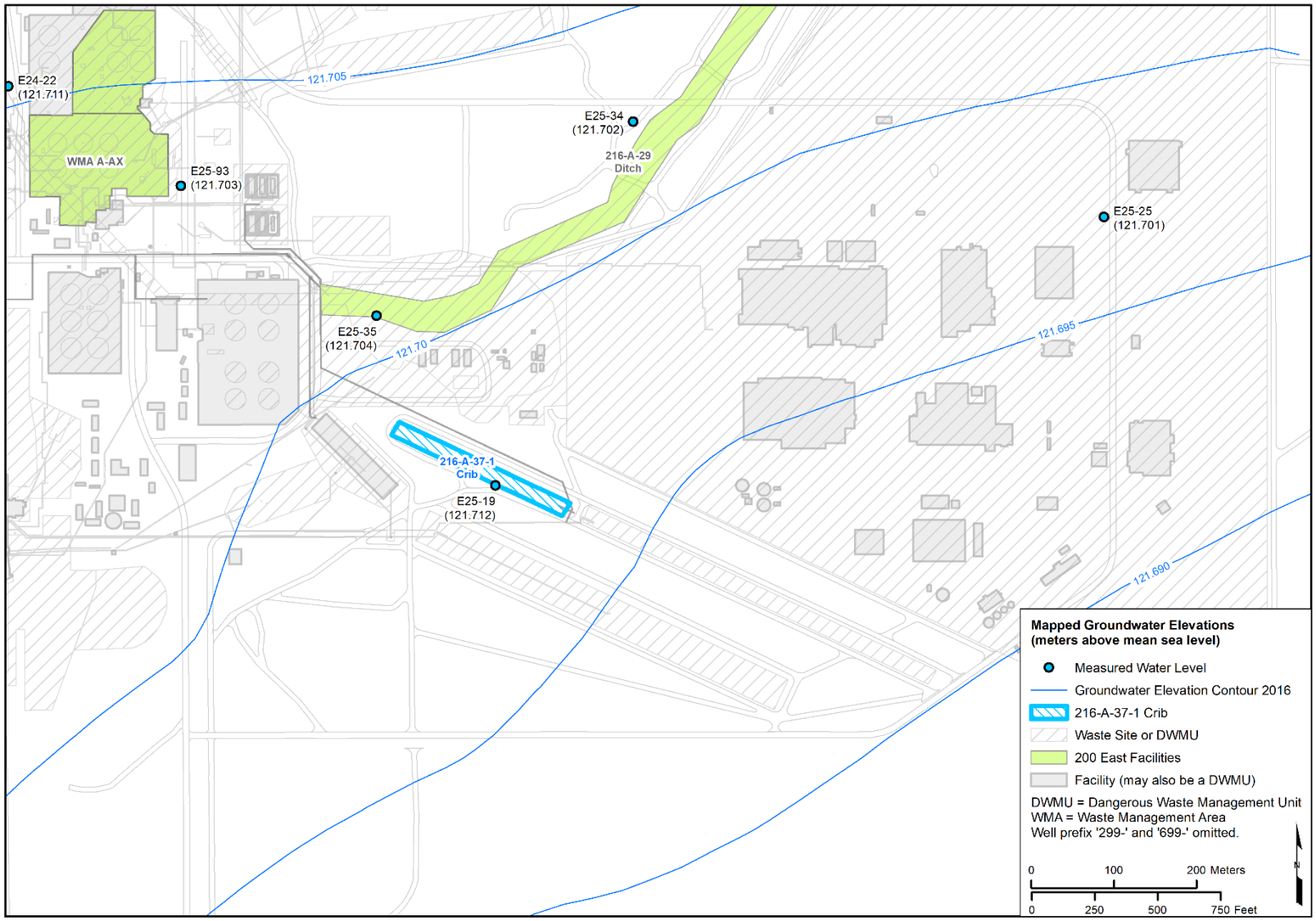

Figure E-6. Water-Level Elevation Map for the 216-A-37-1 Crib, 2016

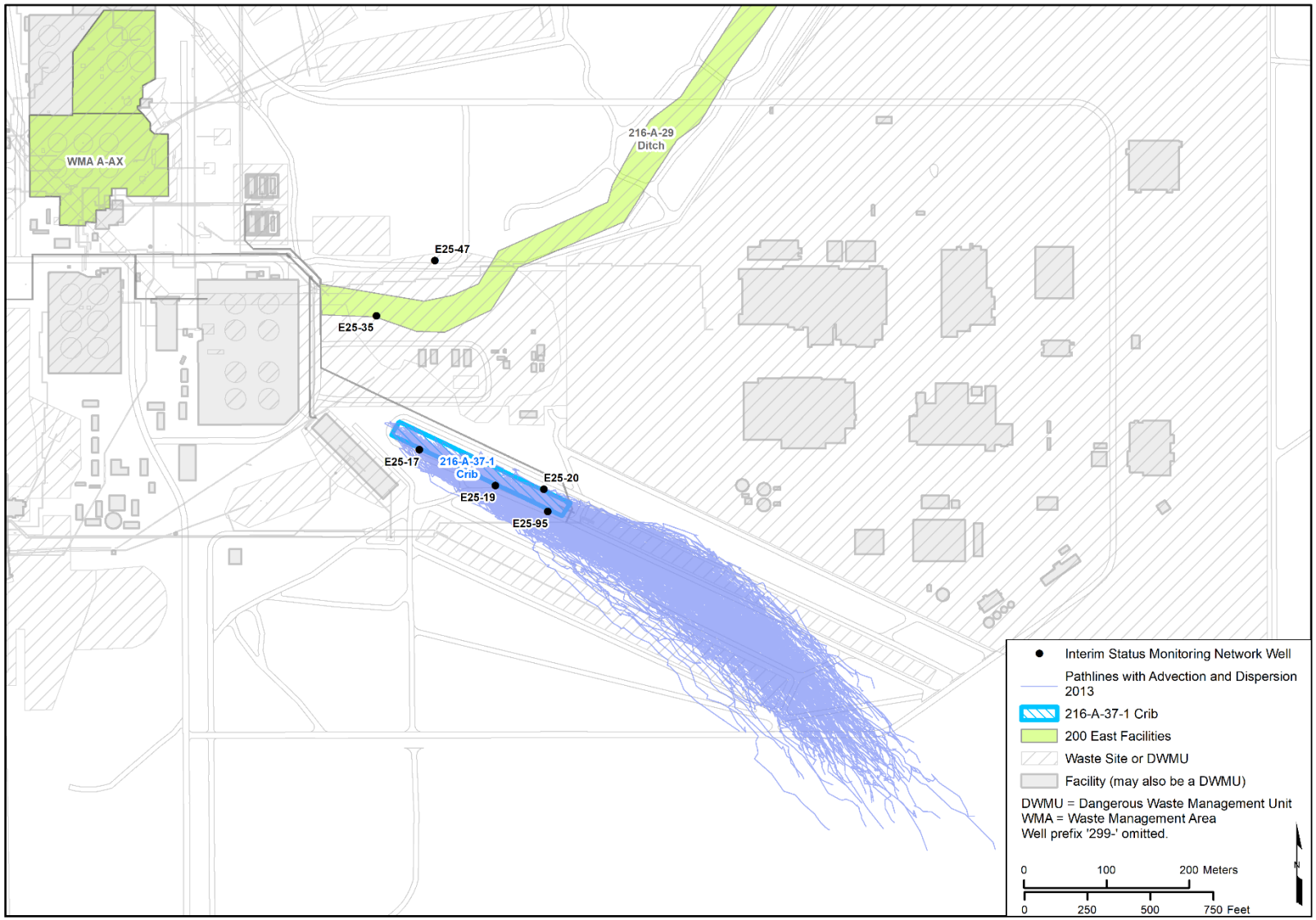

Figure E-7. Local-Scale Particle Pathlines, Advection and Dispersion – 216-A-37-1 Crib, 2013

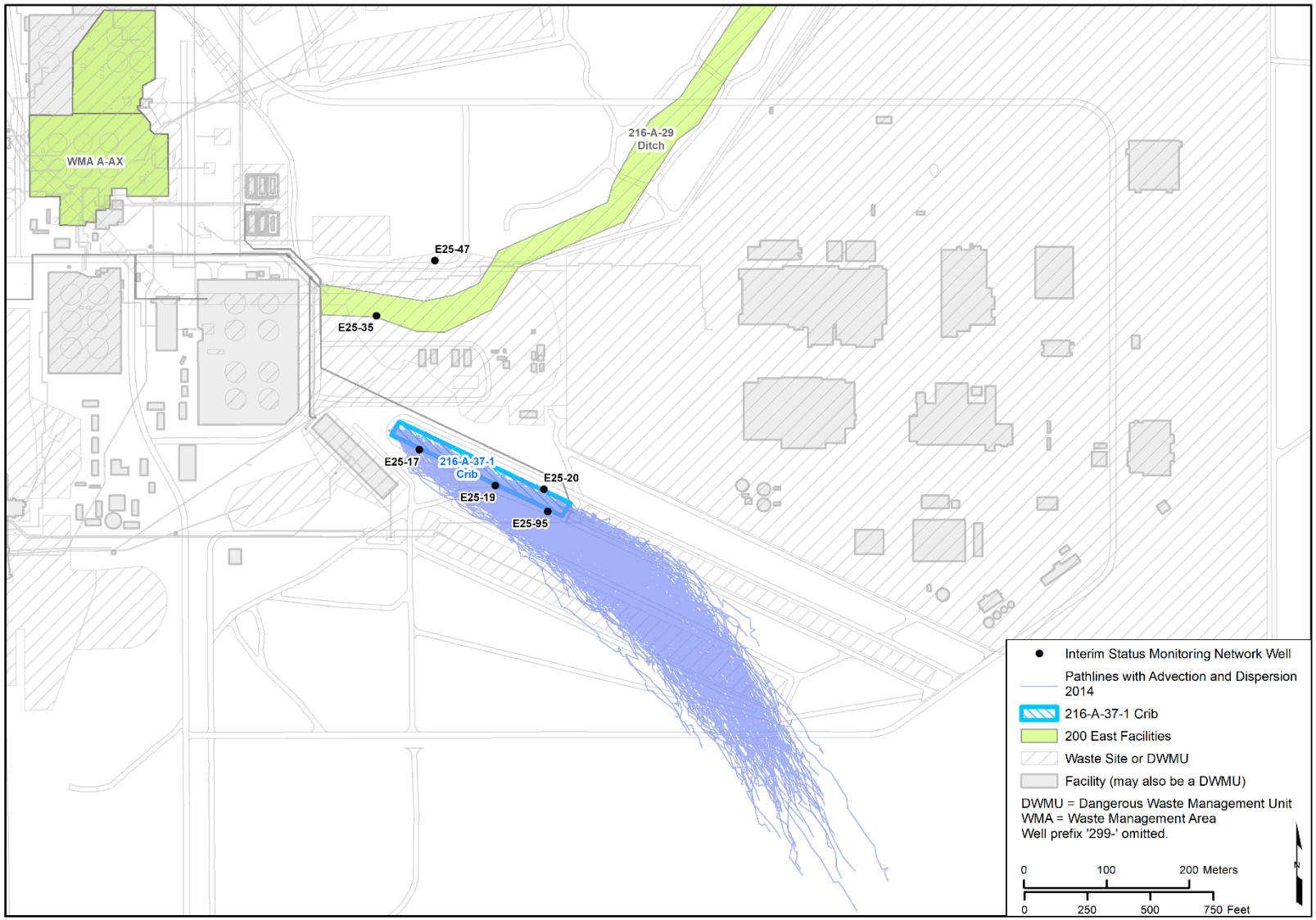

Figure E-8. Local-Scale Particle Pathlines, Advection and Dispersion – 216-A-37-1 Crib, 2014

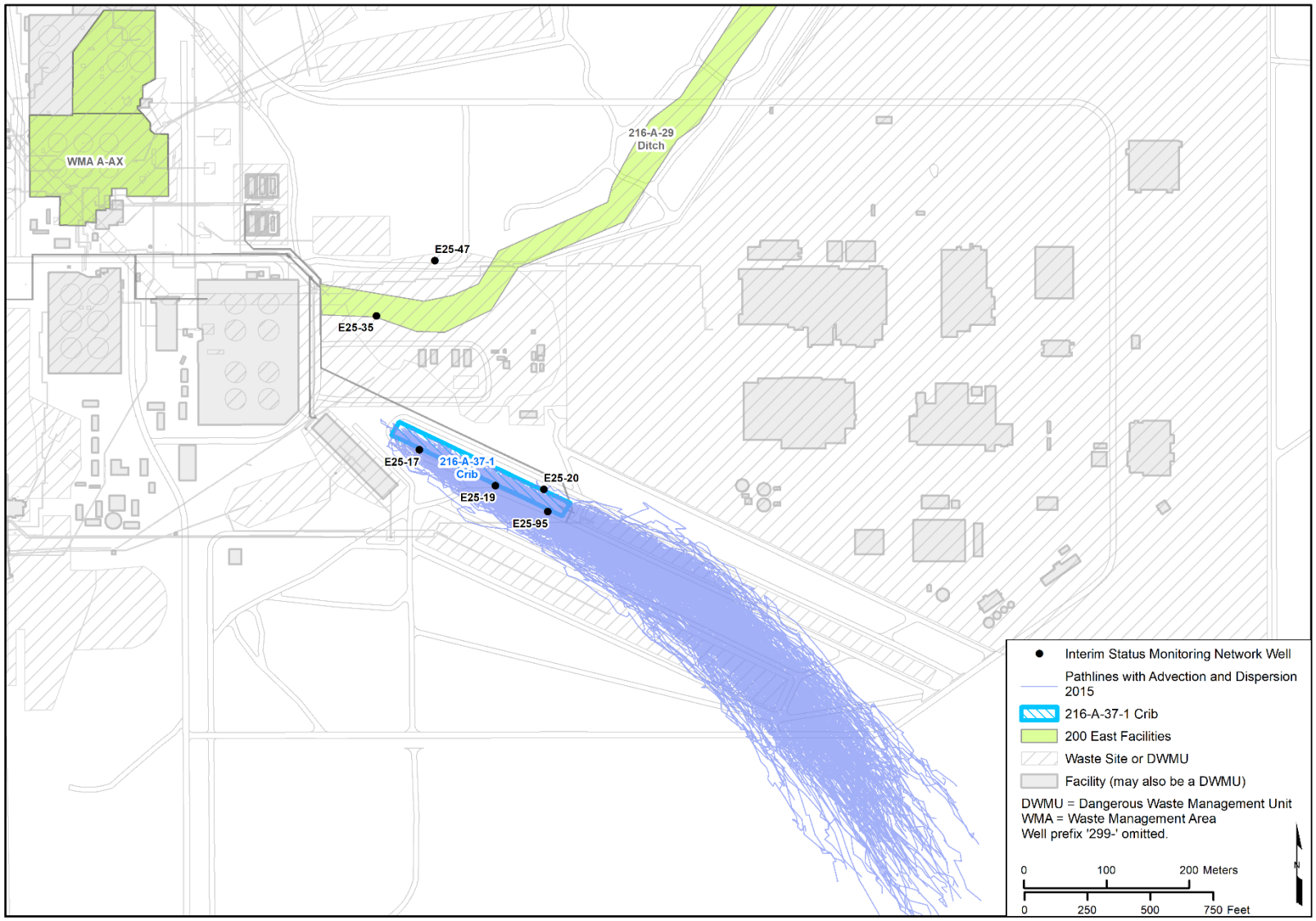

Figure E-9. Local-Scale Particle Pathlines, Advection and Dispersion – 216-A-37-1 Crib, 2015

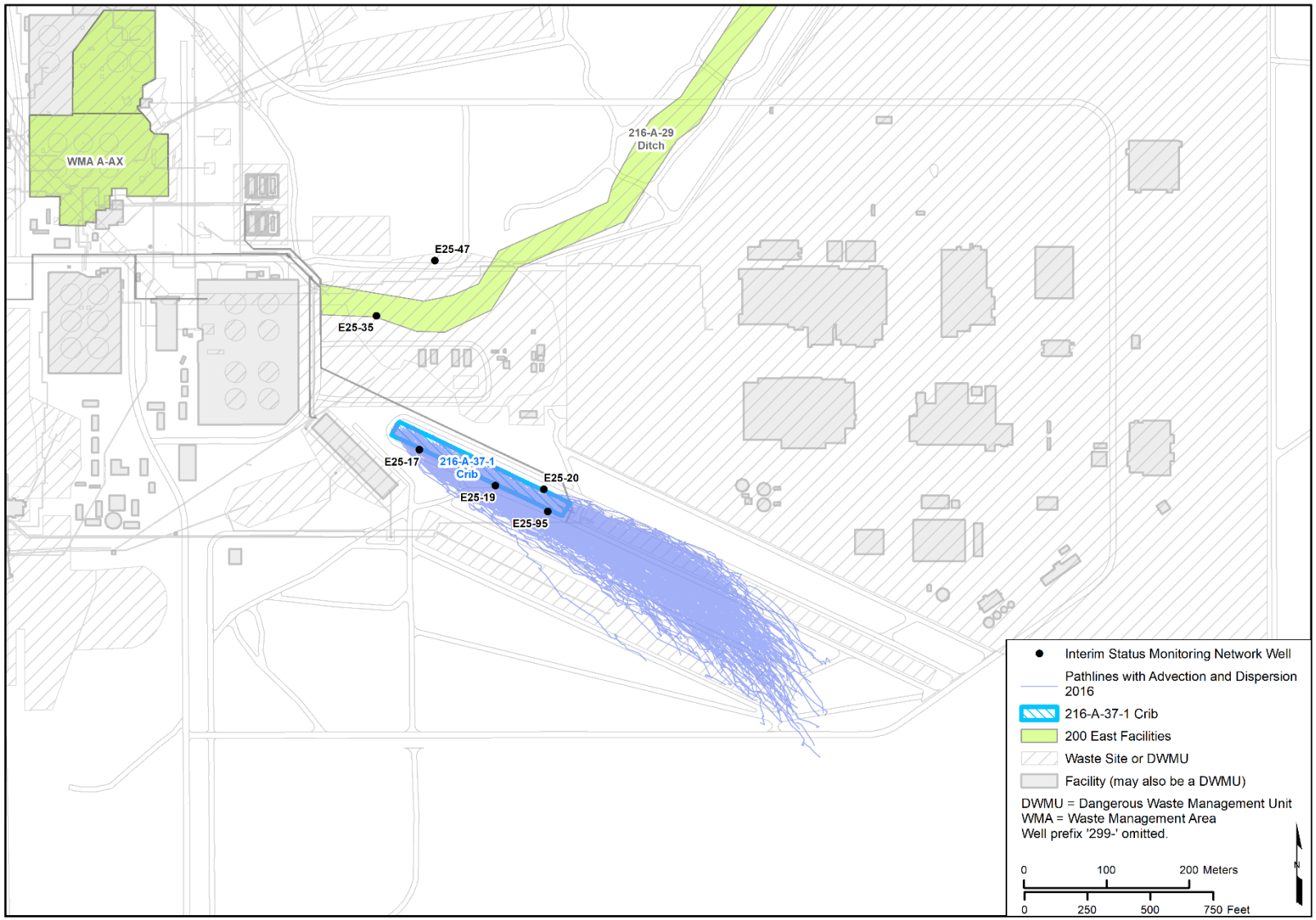

Figure E-10. Local-Scale Particle Pathlines, Advection and Dispersion – 216-A-37-1 Crib, 2016

E3.3 Particle Counts

To compare the relative timing and density of the particles that pass by each monitoring well location, particle counts were calculated as described in Section 6.3 of the main text of this ECF. The particle counts were tabulated, particle breakthrough curves were created, and particle count maps were generated.

E3.3.1 Relative Particle Counts at Interim Status Groundwater Monitoring Wells

Tables E-1 through E-4 present the computed particle counts over time, binned into periods of 33.3 days for each of the downgradient monitoring wells. The tables present four entries (one for each year) for each well. At the bottom of the column for each mapped event is the total number of particles that passed through the vicinity of the well, regardless of time, and the average of the totals for the four mapped years rounded to the nearest integer. Each table provides an indication of the relative timing of the expected detections at each well and the relative potential that each well would detect a release at the facility for the flow conditions calculated for CYs 2013, 2014, 2015, and 2016.

The average values depicted at the base of each table can be used to assess the relative potential for each well to detect a release at the facility. These averages are summarized below:

- 299-E25-17 – Average = 83
- 299-E25-19 – Average = 193
- 299-E25-20 – Average = 127
- 299-E25-95 – Average = 277

E3.3.2 Relative Arrival Times at Interim Status Groundwater Monitoring Wells

Figures E-11 through E-14 depict plots of particle counts over time (particle breakthrough curves) for each downgradient well location. The underlying data plotted in Figures E-11 through E-14 are the same as the data in Tables E-1 through E-4, but the time interval over which particles are summed is not necessarily the same. Particle breakthrough curves show the relative timing and particle density for the arrival, peak, and decline in particle counts at each interim status monitoring location resulting from the hypothetical instantaneous release at the facility. The plots depict the relative potential at each well for detecting a release from the facility that reaches the water table for the flow conditions calculated for CYs 2013, 2014, 2015, and 2016. There is one figure for each well, with four lines shown on each plot (one for each year).

Table E-1. Particle Density (Count) Monitoring Well 299-E25-17

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
33	80	81	77	78	
67	0	5	3	6	
100	1	0	0	0	
133	0	0	0	0	
167	0	0	0	0	
200	0	0	0	0	
233	0	0	0	0	
267	0	0	0	0	
300	0	0	0	0	
333	0	0	0	0	
367	0	0	0	0	
400	0	0	0	0	Average
Total	81	86	80	84	**83**

Table E-2. Particle Density (Count) Monitoring Well 299-E25-19

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
33	97	87	103	86	
67	44	27	53	32	
100	35	34	29	33	
133	18	12	13	20	
167	4	7	1	25	
200	0	2	1	7	
233	0	0	0	1	
267	0	0	0	0	
300	0	0	0	0	
333	0	0	0	0	
367	0	0	0	0	
400	0	0	0	0	Average
Total	198	169	200	204	**193**

Table E-3. Particle Density (Count) Monitoring Well 299-E25-20

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
33	88	70	87	77	
67	30	15	25	19	
100	12	4	16	13	
133	11	1	4	9	
167	7	3	1	6	
200	0	0	1	5	
233	0	0	0	2	
267	0	1	0	2	
300	0	0	0	0	
333	0	0	0	0	
367	0	0	0	0	
400	0	0	0	0	Average
Total	148	94	134	133	**127**

Table E-4. Particle Density (Count) Monitoring Well 299-E25-95

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
33	101	92	107	87	
67	58	42	58	40	
100	39	32	54	36	
133	47	18	40	35	
167	31	18	20	30	
200	10	15	8	27	
233	8	7	1	22	
267	1	3	0	13	
300	0	2	0	3	
333	0	0	0	3	
367	0	0	0	0	
400	0	0	0	0	Average
Total	295	229	288	296	**277**

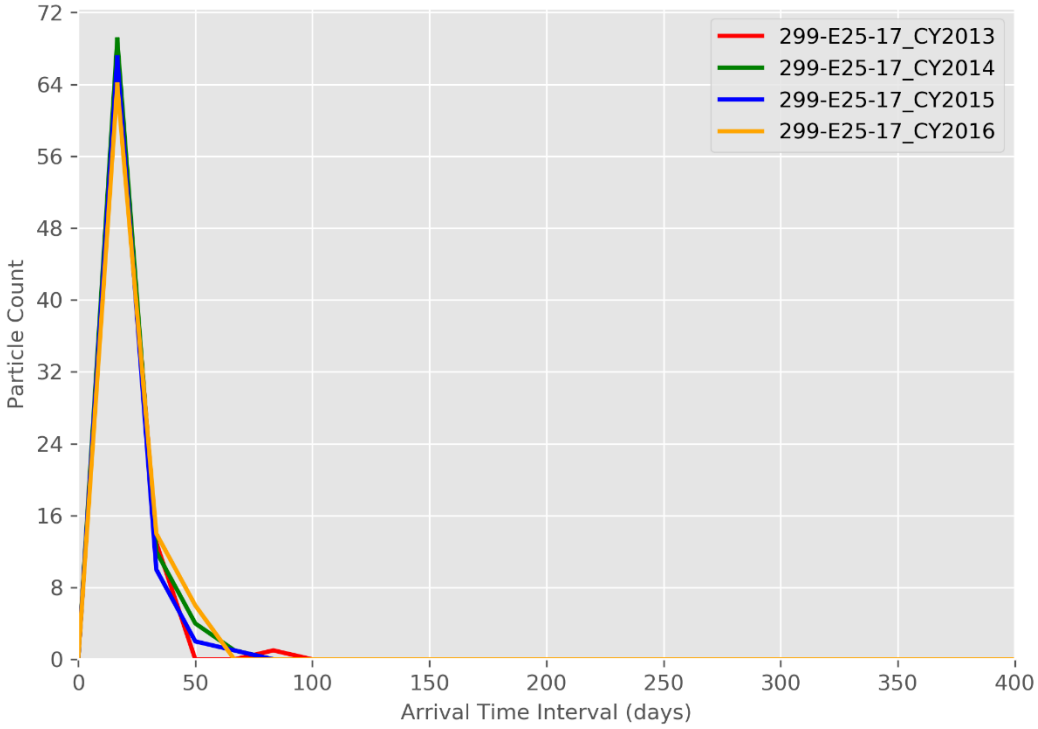

Figure E-11. Particle Breakthrough Curve at Monitoring Well 299-E25-17

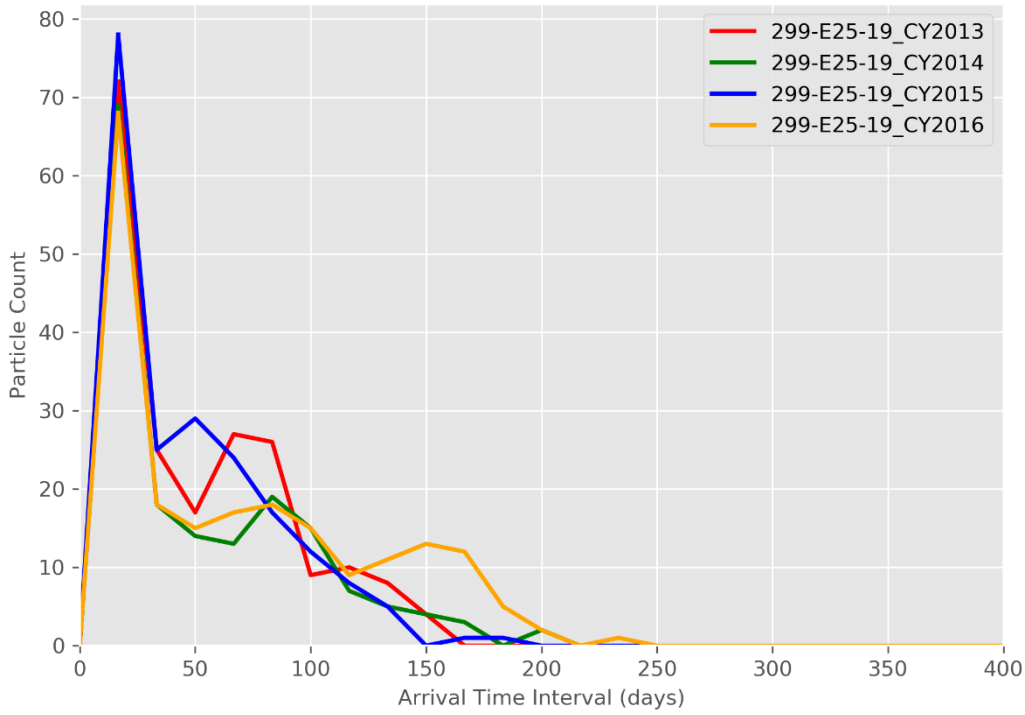

Figure E-12. Particle Breakthrough Curve at Monitoring Well 299-E25-19

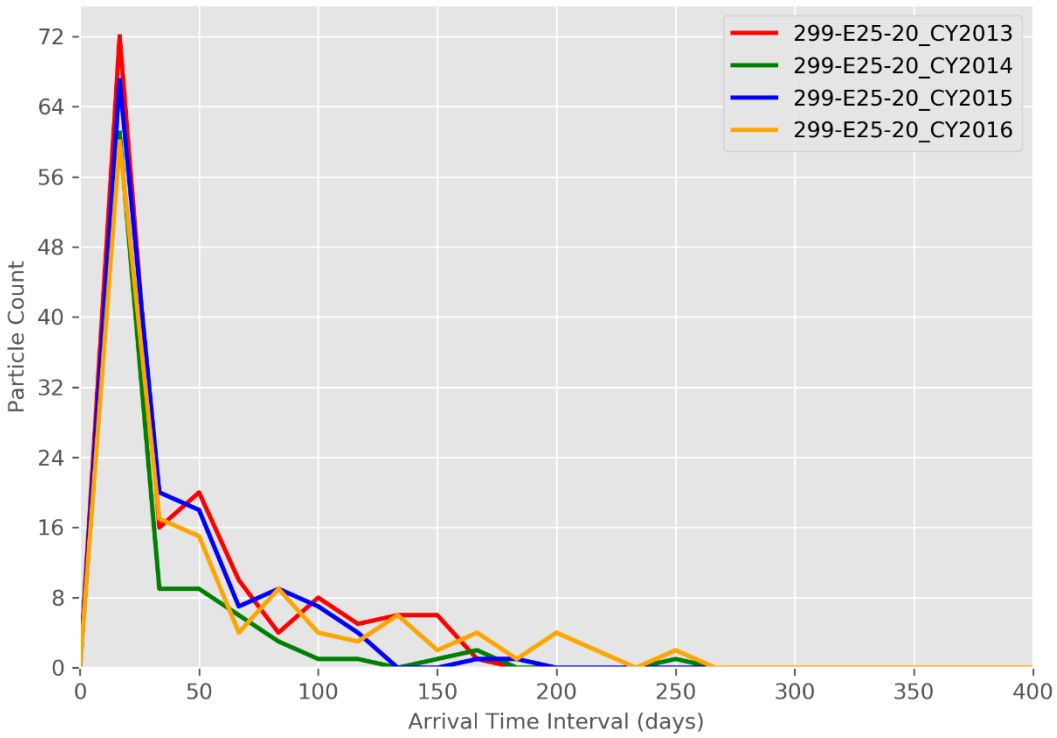

Figure E-13. Particle Breakthrough Curve at Monitoring Well 299-E25-20

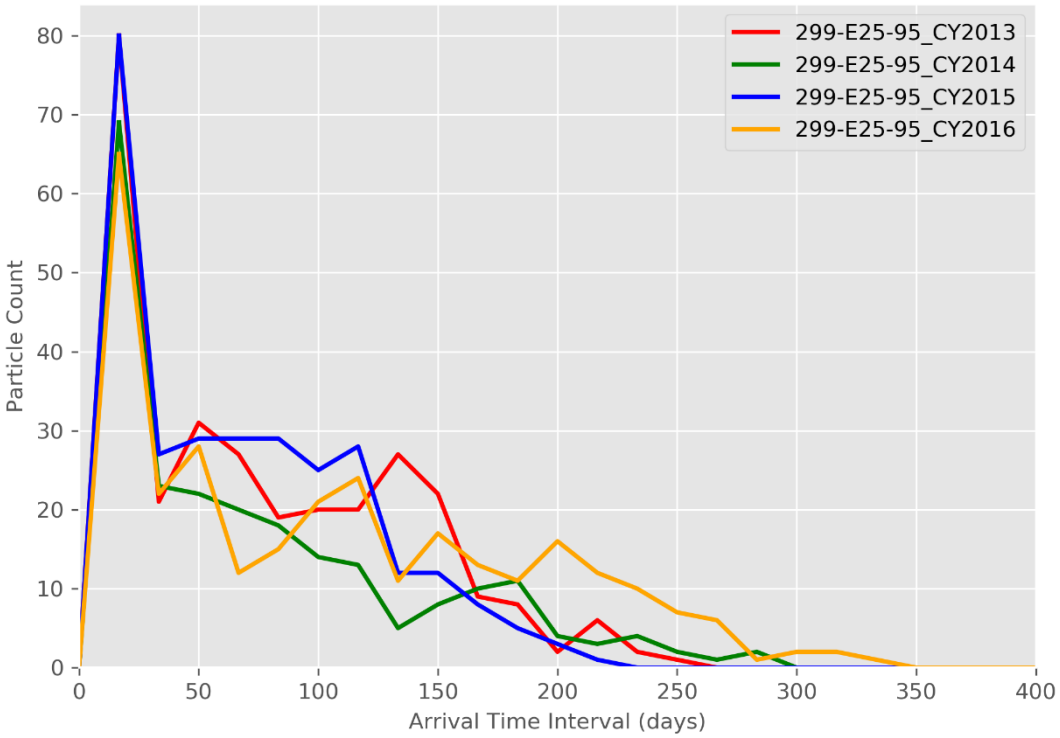

Figure E-14. Particle Breakthrough Curve at Monitoring Well 299-E25-95

E3.3.3 Particle Count Maps

Figures E-15 through E-18 depict the particle count maps developed based on the instantaneous release of a large number of particles at the facility. The particle count maps depict areas of relatively higher and lower potential impact from a release at the facility that reaches the water table, for conditions represented by CYs 2013, 2014, 2015, and 2016. Figures E-15 through E-18 depict the particle density after 425 days of calculated travel, by which time it was determined that all particles would have arrived at or passed by the interim status groundwater monitoring wells (see entries in Tables E-1 through E-4).

The goal of well placement is for the well locations to span the range of particle pathline distribution as released from the 216-A-37-1 Crib. The particle count maps show that under the evaluated range of conditions, there are areas of high particle counts where there are no corresponding monitoring wells, indicating the need for two additional downgradient monitoring wells (216-A-37-1_PW-1 and 216-A-37-1_PW-2). In addition, a new upgradient well (216-A-37-1_PW-3) is proposed to replace the existing upgradient wells with a well closer to and more directly upgradient of the 216-A-37-1 Crib. The locations of the proposed wells are shown in Figures E-15 through E-18. In addition, due to their age, wells 299-E25-17, 299-E25-19, and 299-E25-20 are not compliant with WAC 173-160, “Minimum Standards for Construction and Maintenance of Wells.” At this time, there are limited wells that are well placed for detecting potential releases. These wells are recommended to remain in the monitoring network until replacement wells can be installed near their locations.

E3.4 Proposed Monitoring Wells

The locations of the proposed monitoring wells are shown in Figures E-15 through E-18. The particle counts tabulated for these locations (Tables E-5 and E-6) indicate the relative timing of expected detections at the wells and the relative potential of the wells for detecting a release at the facility. The particle breakthrough curves (Figures E-19 and E-20) show the relative timing and particle density at the proposed monitoring well locations for the arrival, peak, and decline in particle counts resulting from the hypothetical instantaneous release to the water table beneath the facility.

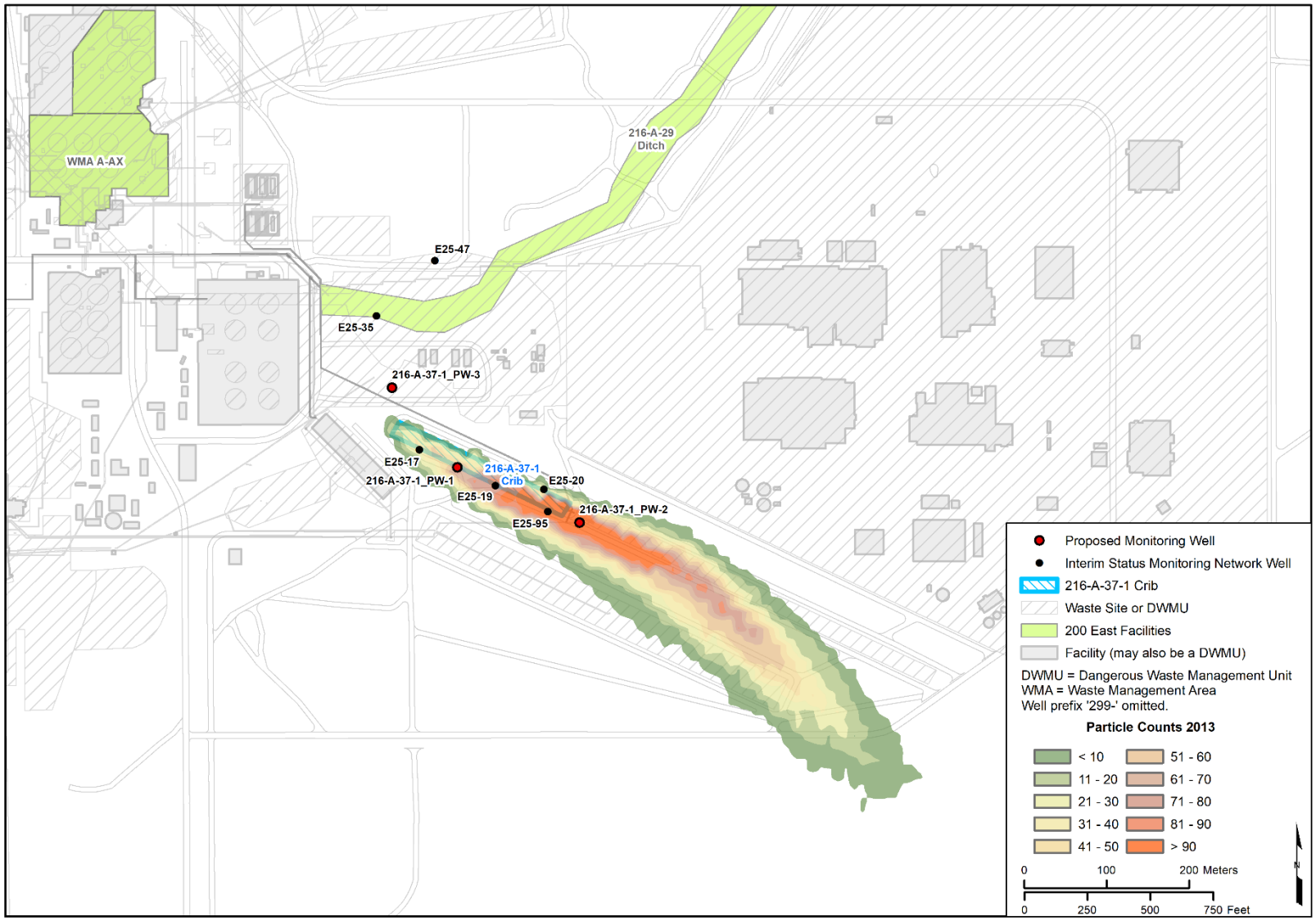

Figure E-15. Particle Count Map – 216-A-37-1 Crib, 2013

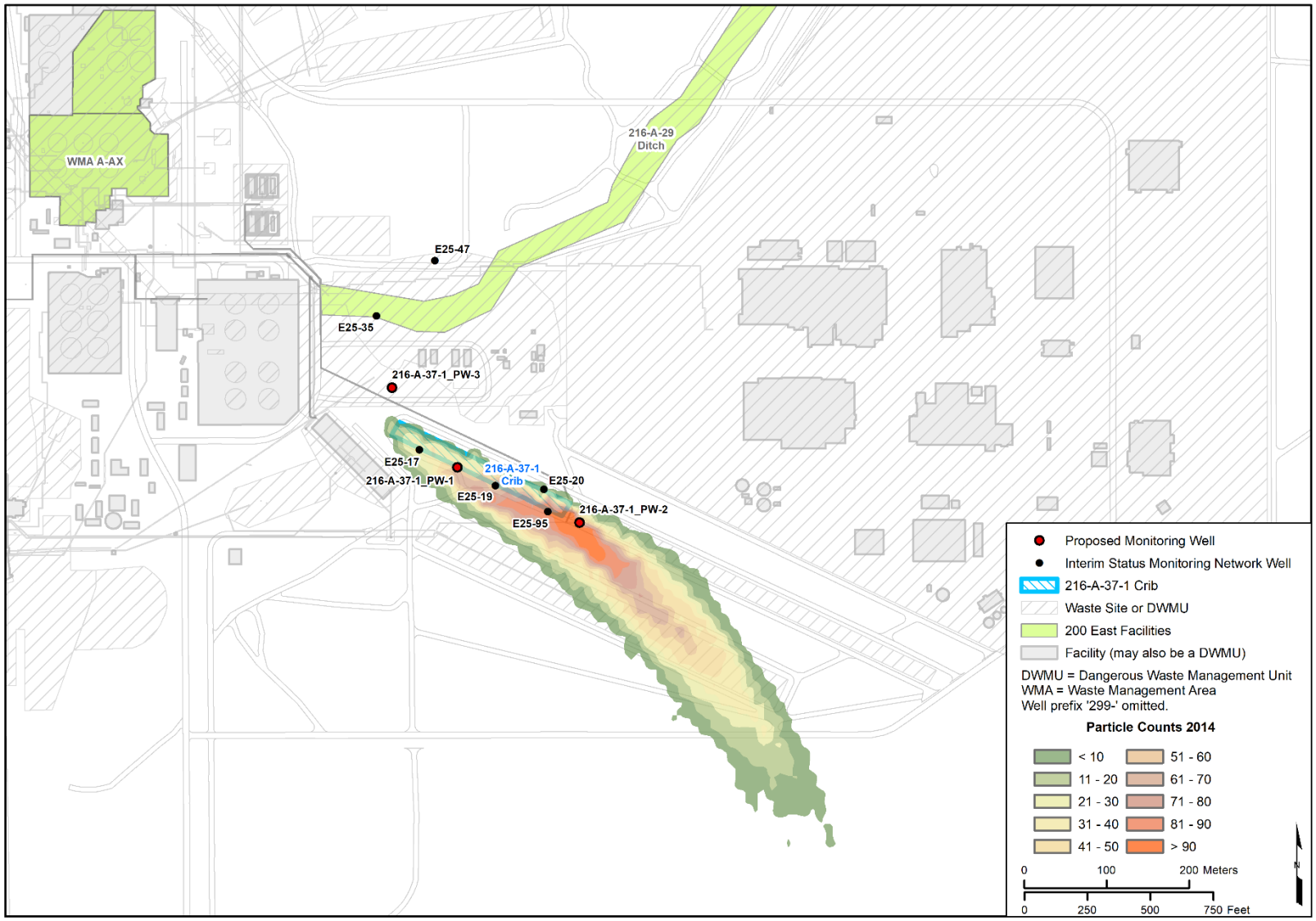

Figure E-16. Particle Count Map – 216-A-37-1 Crib, 2014

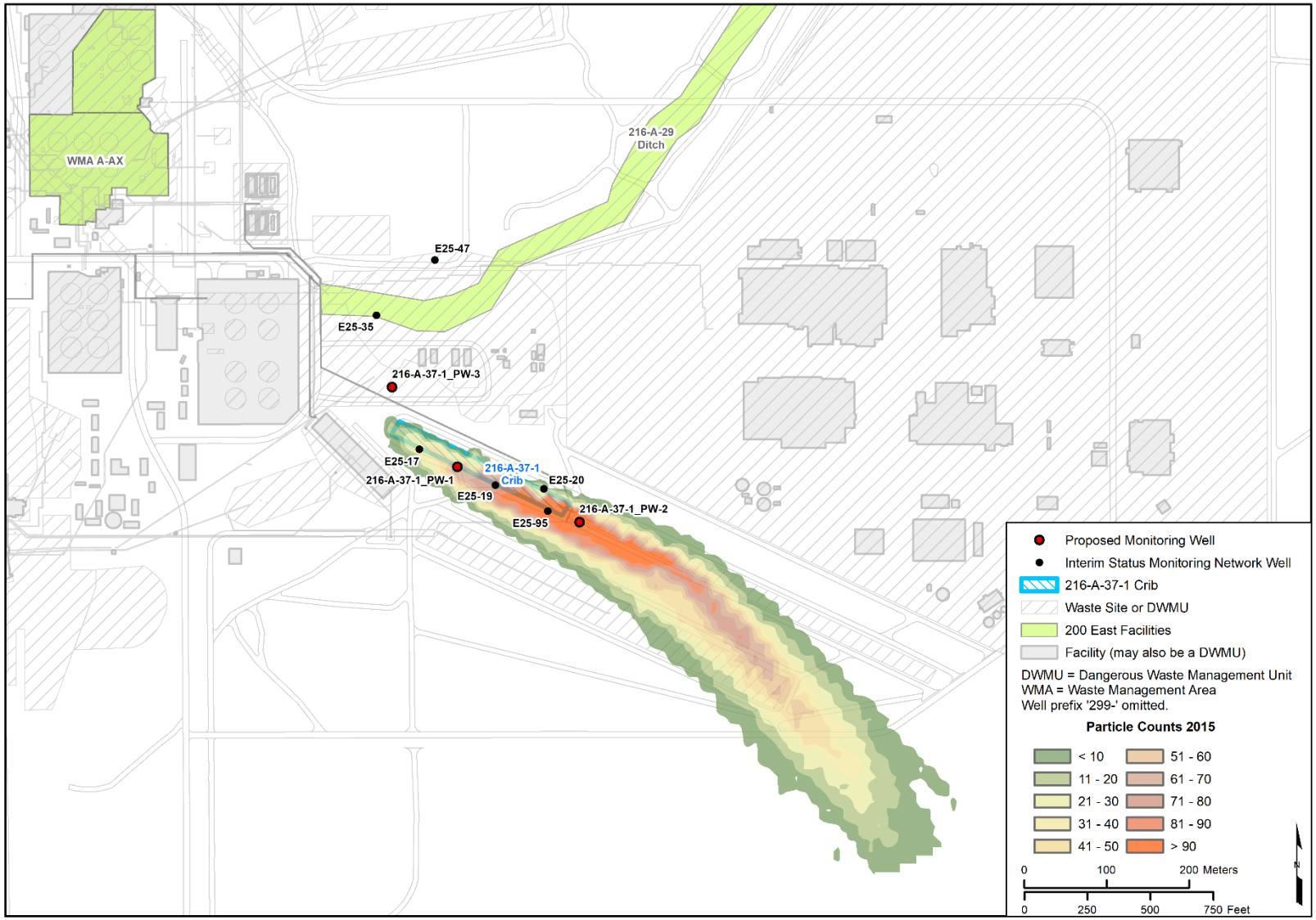

Figure E-17. Particle Count Map – 216-A-37-1 Crib, 2015

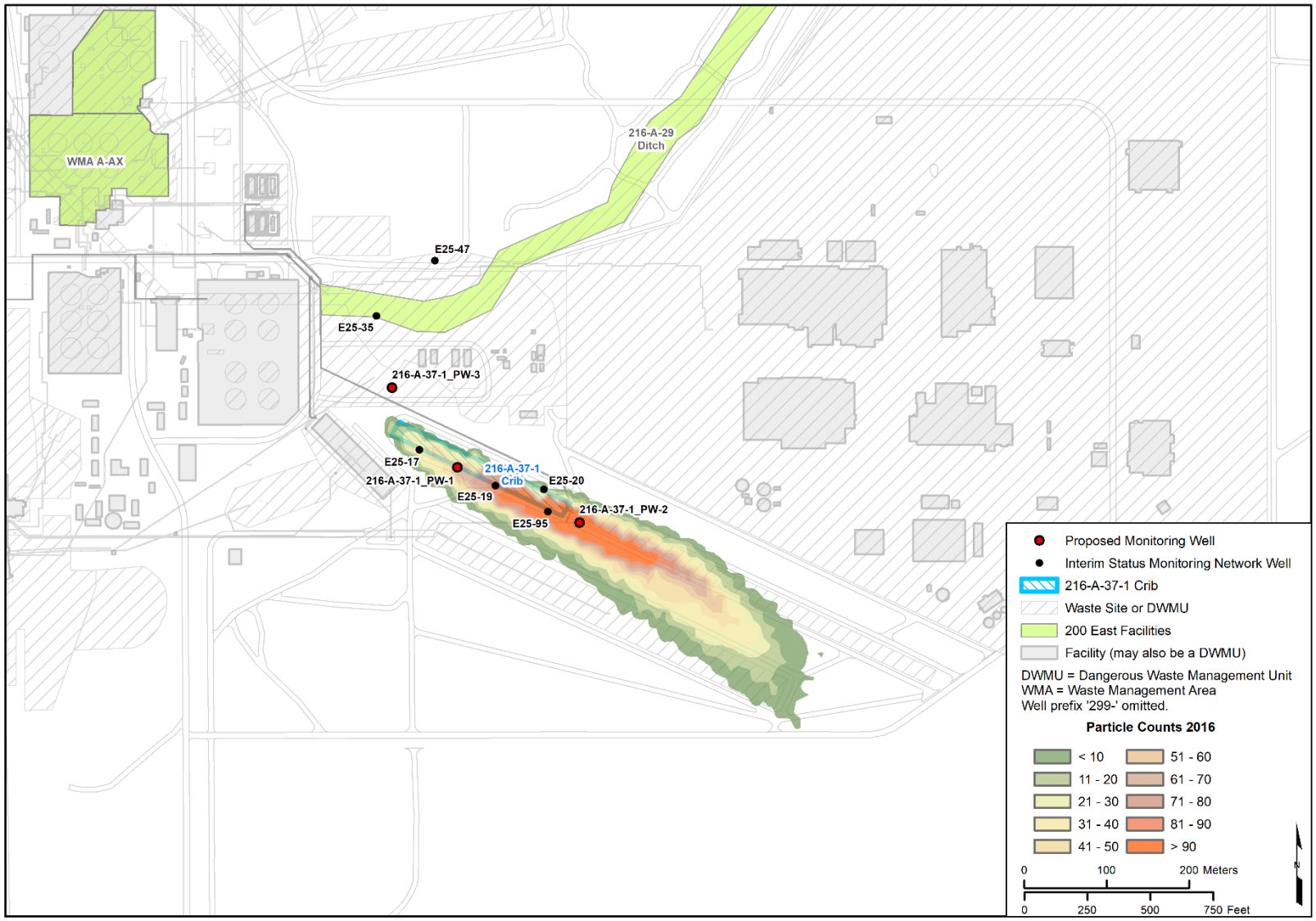

Figure E-18. Particle Count Map – 216-A-37-1 Crib, 2016

Table E-5. Particle Density (Count) Monitoring Well 216-A-37-1_PW-1

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
33	105	98	120	93	
67	39	25	24	40	
100	11	14	9	12	
133	2	5	0	7	
167	0	3	0	3	
200	0	0	0	0	
233	0	0	0	0	
267	0	0	0	0	
300	0	0	0	0	
333	0	0	0	0	
367	0	0	0	0	
400	0	0	0	0	Average
Total	157	145	153	155	**153**

Table E-6. Particle Density (Count) Monitoring Well 216-A-37-1_PW-2

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
33	60	50	72	49	
67	59	38	58	41	
100	53	41	49	37	
133	37	32	47	29	
167	39	17	27	38	
200	26	10	13	24	
233	7	9	3	22	
267	4	5	1	19	
300	1	4	0	16	
333	0	1	0	4	
367	0	0	0	4	
400	0	0	0	0	Average
Total	286	207	270	283	**262**

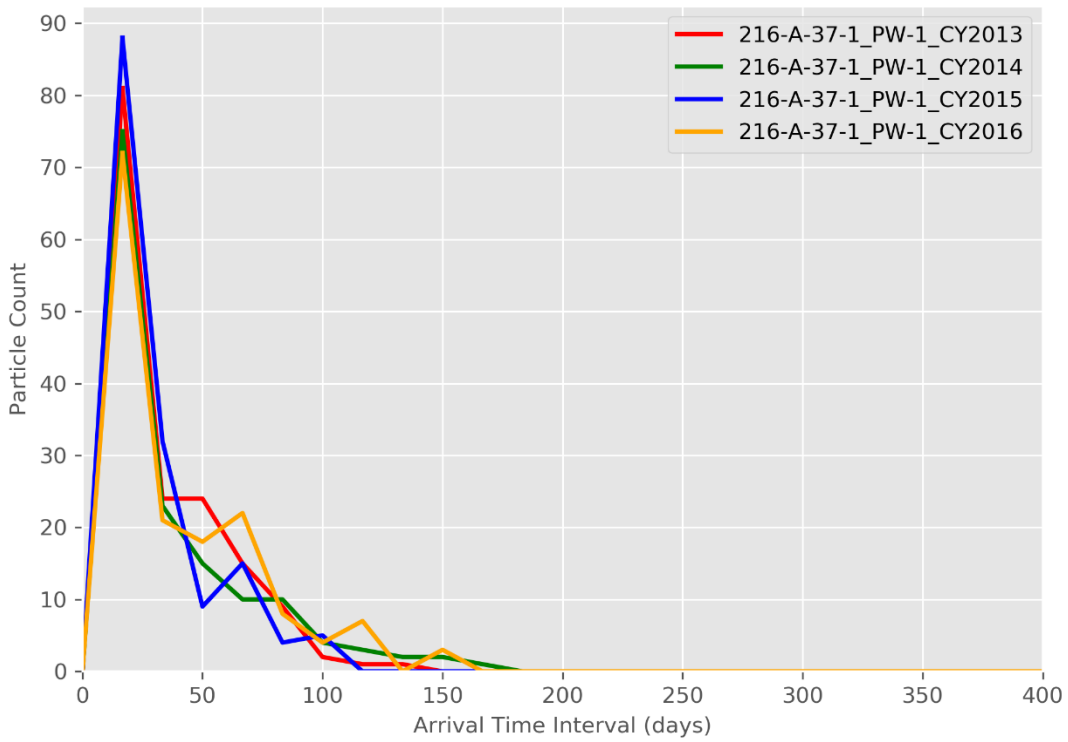

Figure E-19. Particle Breakthrough Curve at Monitoring Well 216-A-37-1_PW-1

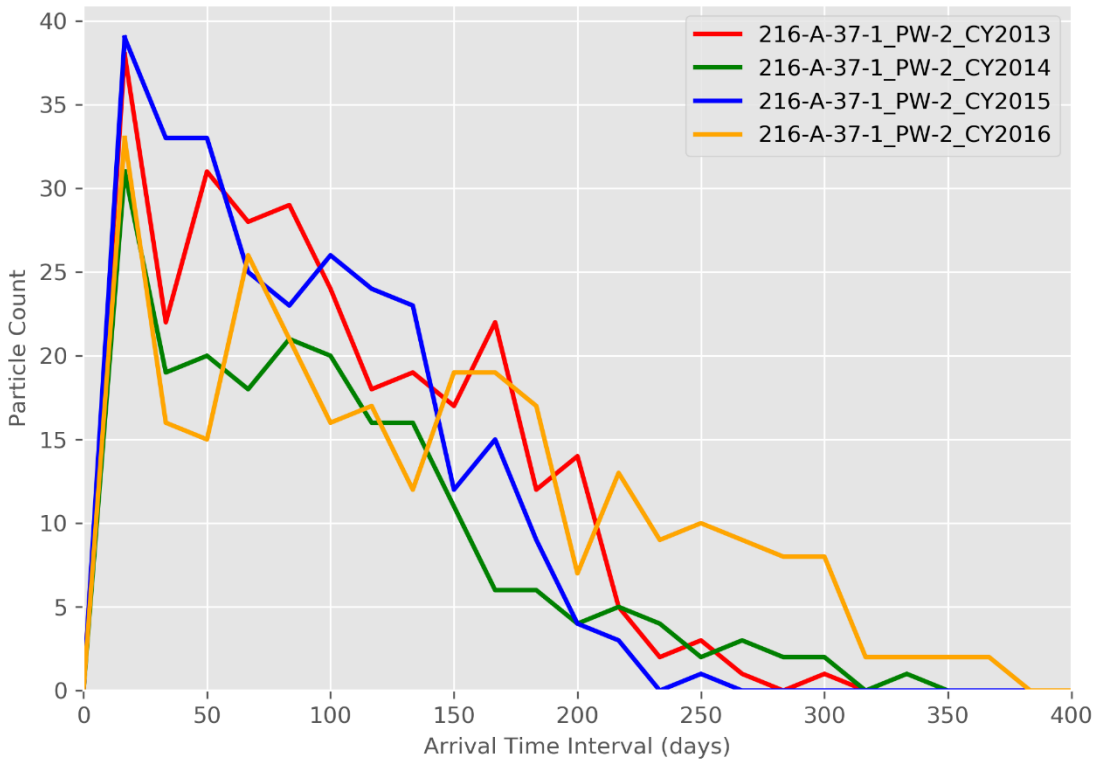

Figure E-20. Particle Breakthrough Curve at Monitoring Well 216-A-37-1_PW-2

E3.5 Analyses of Particle Pathlines for Each Area of the 216-A-37-1 Crib

Particle pathline maps shown in Section E3.2 depict an instantaneous release to the water table from the release locations in the 216-A-37-1 Crib. Particle tracking also was performed for smaller regions of the facility, to evaluate well locations for detecting releases from various regions of the 216-A-37-1 Crib. This section contains the results of analyses performed to examine how releases from the various areas of the 216-A-37-1 Crib that reach the groundwater beneath those release areas relate to each individual monitoring well. A series of figures and tables are provided to illustrate the fate of releases originating from three different areas of the crib. For these analyses, the particle release points presented in Figure E-2 are grouped into one of three areas based on their spatial location. Those areas are depicted in Figure E-21. Figures E-22 through E-25 illustrate the particle pathlines originating from each of the areas for CYs 2013 through 2016.

Figures E-26 through E-31 illustrate the particle count time series for each existing and proposed monitoring well from CY 2013 through CY 2016. Each figure has four panels with each of which depicts the particle counts for one CY (2013 through 2016). Additionally, each panel shows a separate breakthrough curve for particles emanating from each area. For example, Figure E-30 depicts the particle counts at well 216-A-37-1_PW-1, which receives particles from areas 1 and 2 in 2013. In the figure, within the panel for 2013 (top row, left), the particle breakthrough curve from area 1 is depicted with a blue line and the curve from area 2 with a red line.

E3.6 Vertical Migration Potential

As described in Section 3.3 of the main text of this ECF, the American Petroleum Institute (API) plume diving calculation was used to estimate the likely rate of vertical migration of dissolved constituents downward under the influence of recharge at the water table. At each well the slope of the plume dive was multiplied by the distance from the particle starting location to the well location to estimate the depth to which the dissolved constituents may be anticipated to have migrated by the time they reach the monitoring well location.

This estimated depth of the plume was then compared to the depth from the water table to the bottom of the monitoring well screen. If the depth of the plume is below the bottom of the monitoring well screen, then the dissolved constituents may be anticipated to pass beneath the well screen. If it falls within the interval between the top of the water table and the bottom of the well screen, then the well depth is appropriate for detection of releases at the 216-A-37-1 Crib.

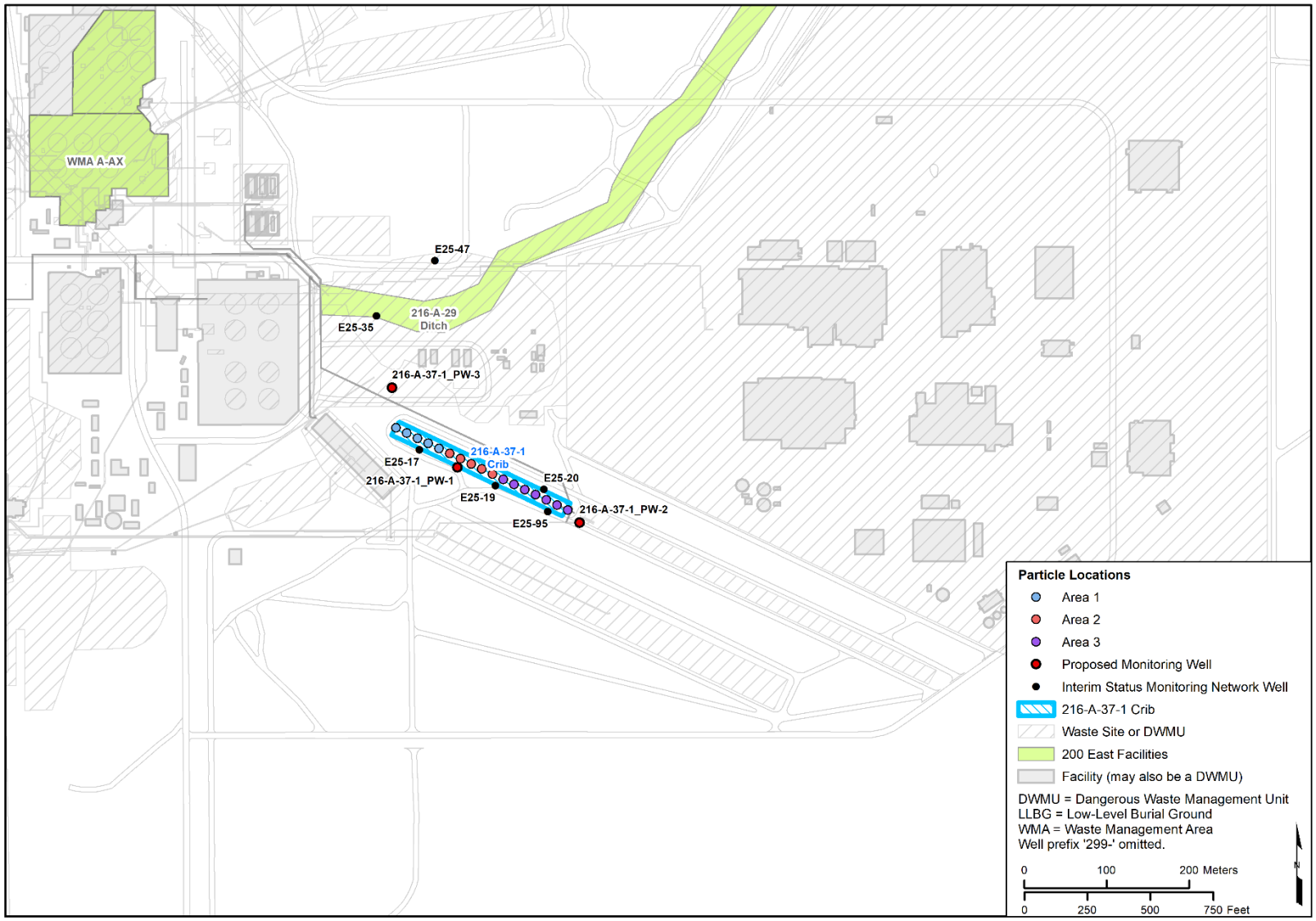

Figure E-21. Particle Release Locations and Areas of the 216-A-37 Crib

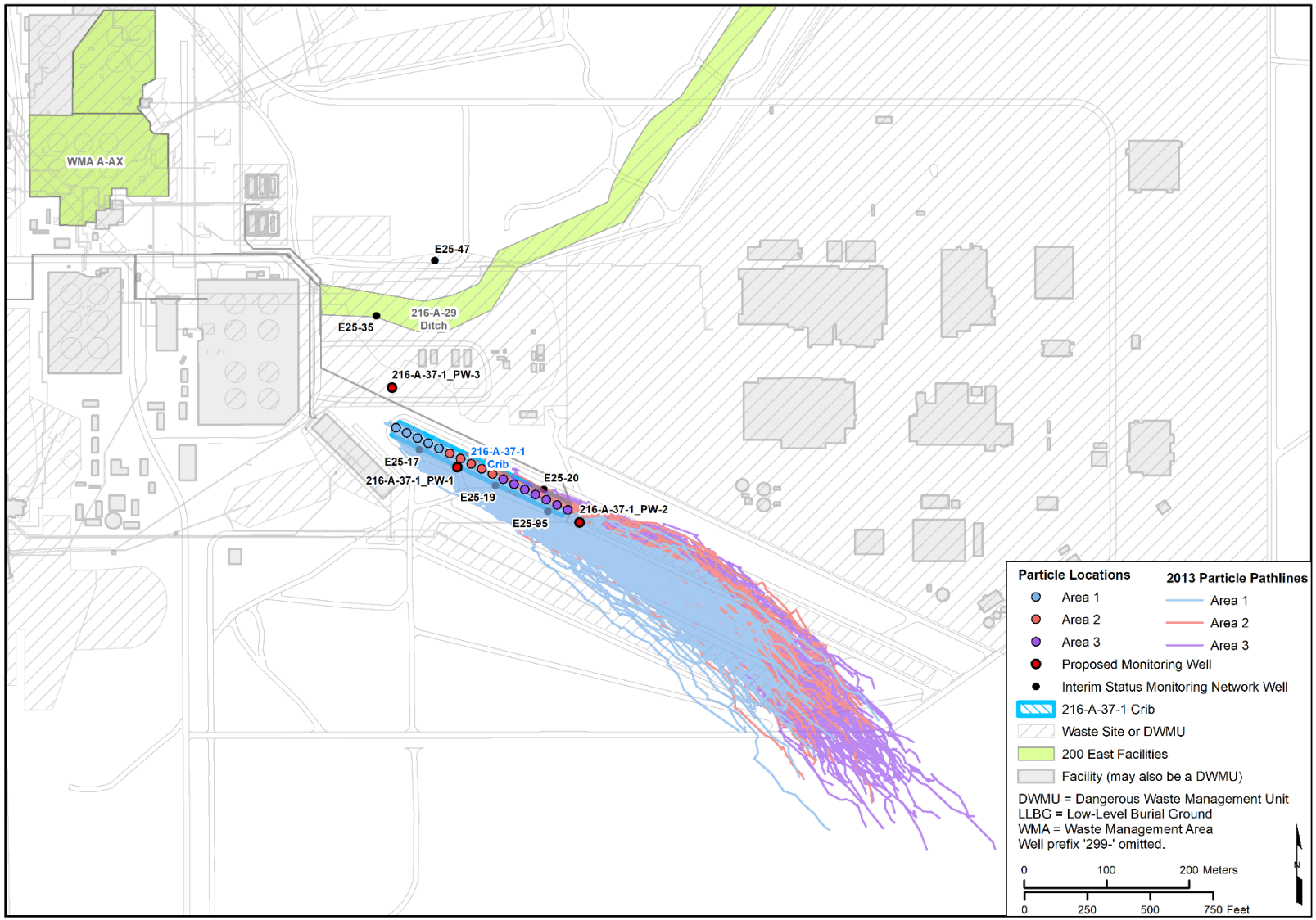

Figure E-22. CY 2013 Particle Pathlines per Area of the Crib

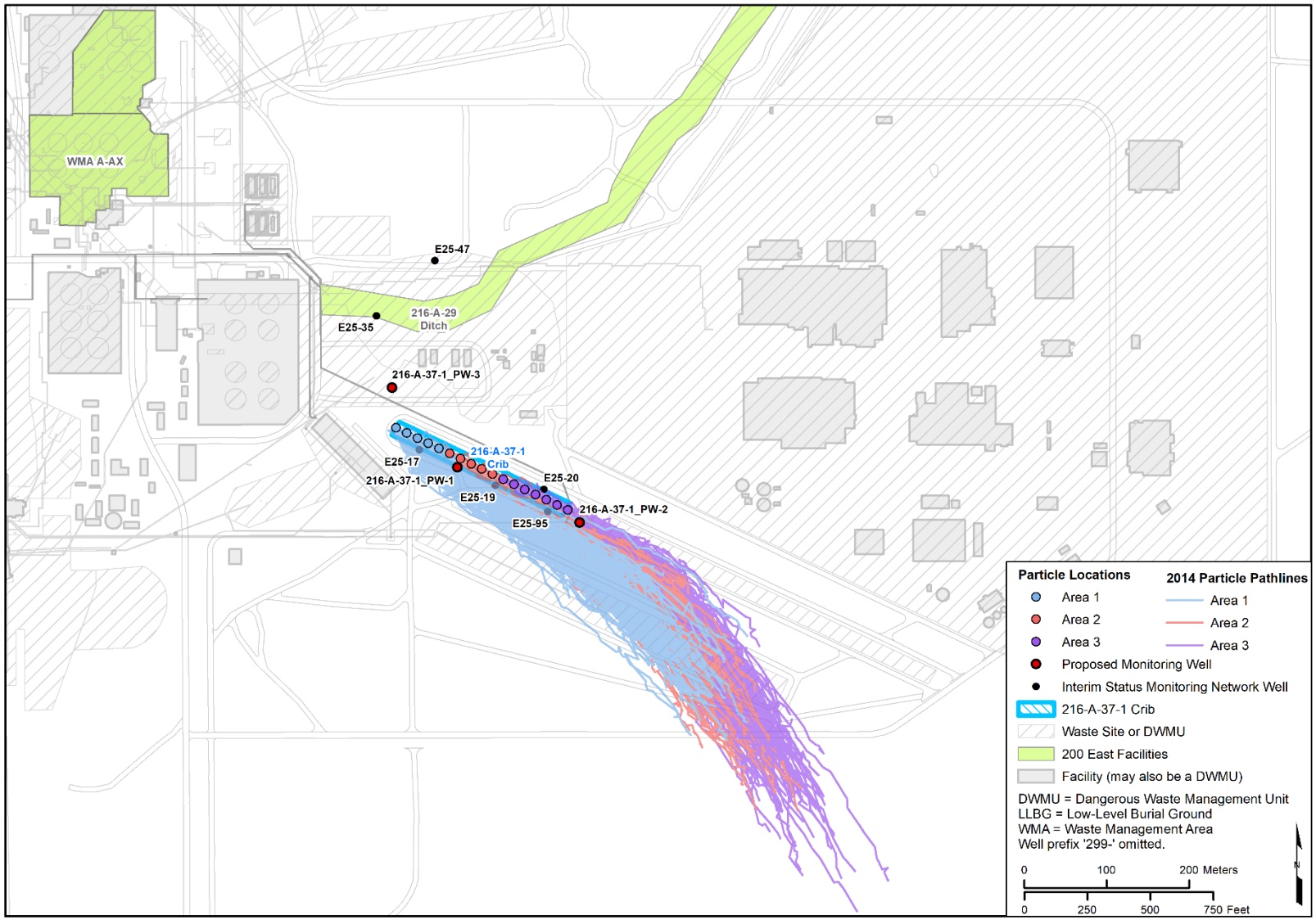

Figure E-23. CY 2014 Particle Pathlines per Area of the Crib

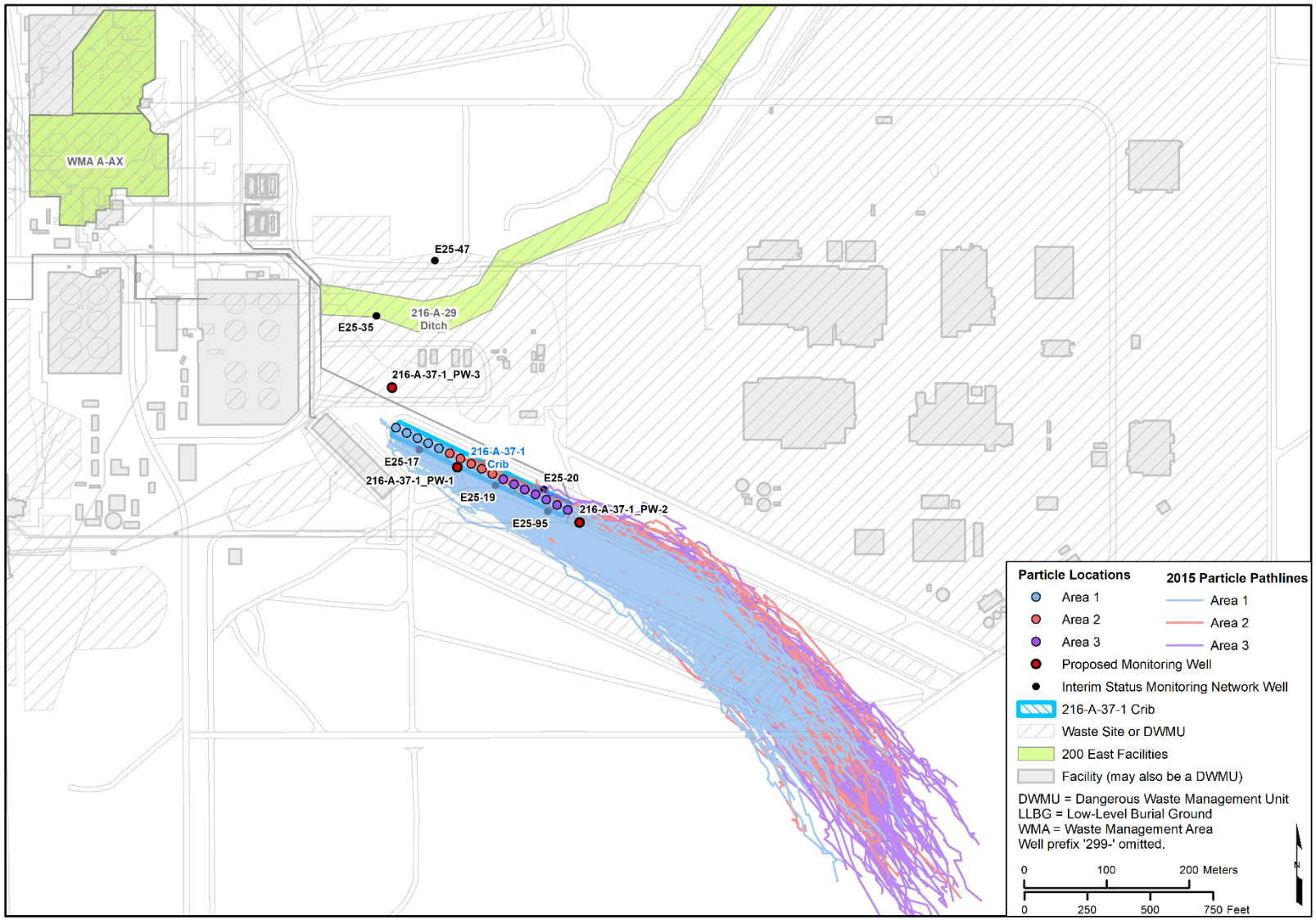

Figure E-24. CY 2015 Particle Pathlines per Area of the Crib

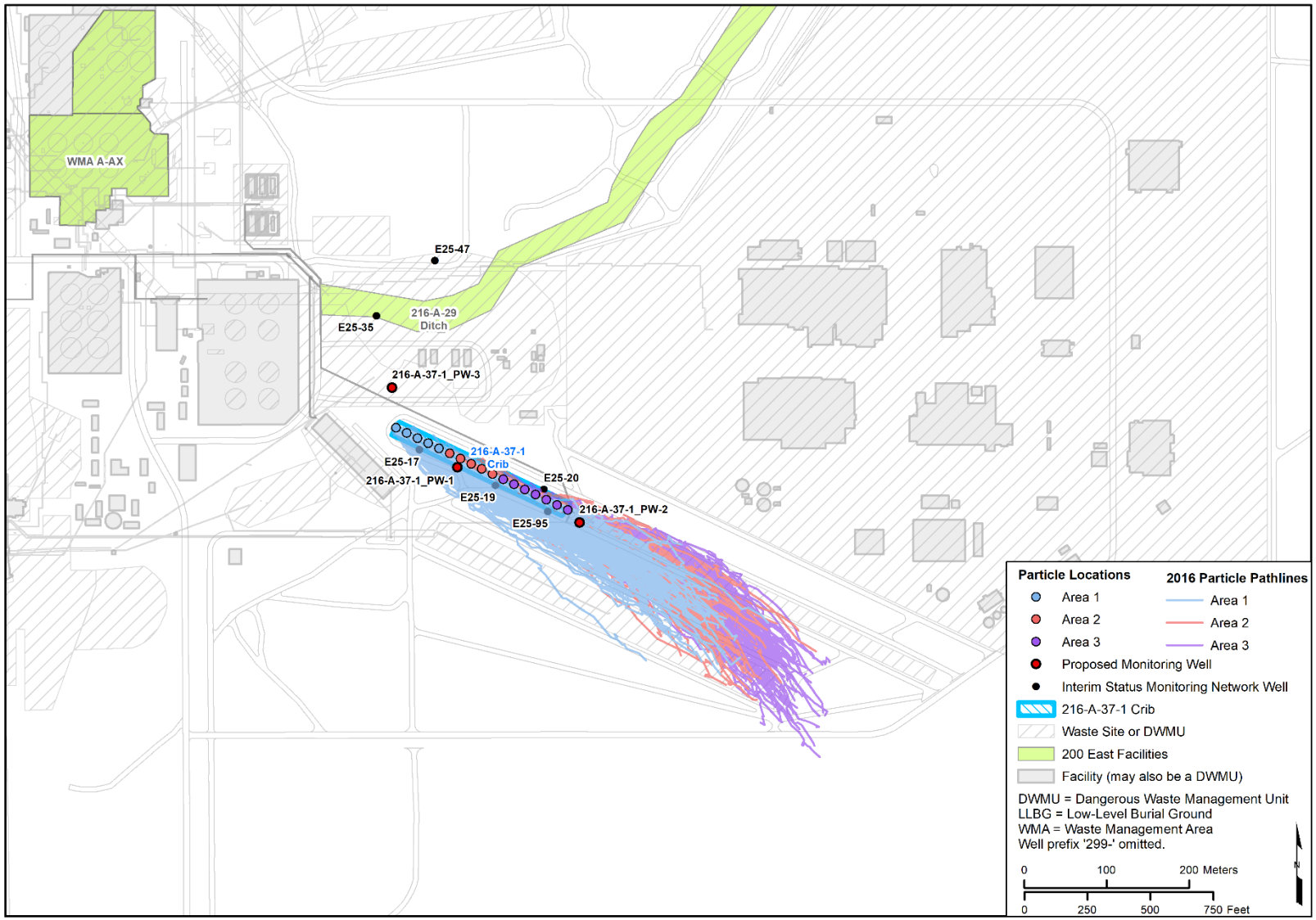

Figure E-25. CY 2016 Particle Pathlines per Area of the Crib

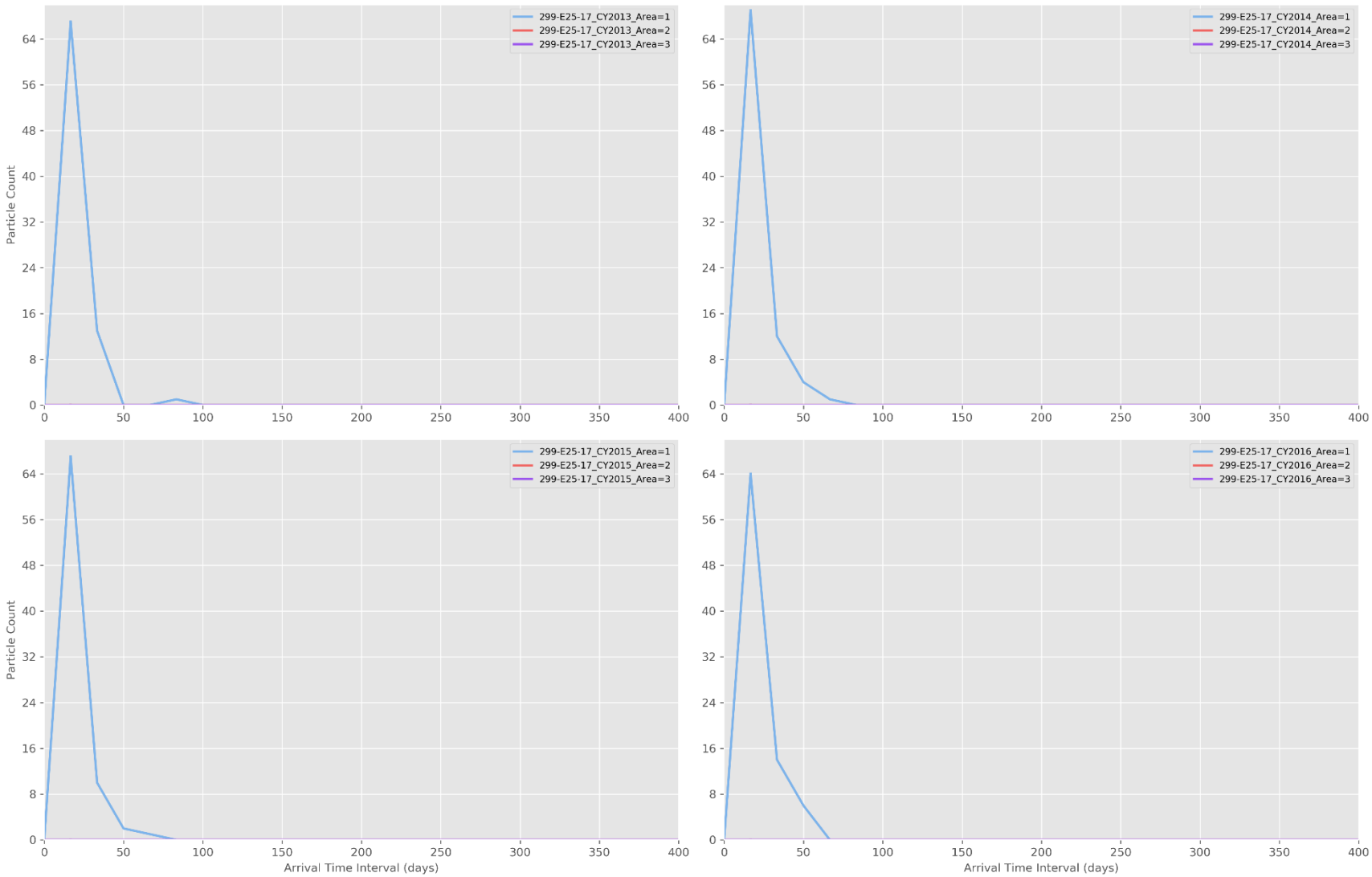

Figure E-26. Particle Breakthrough Curves per Area at Monitoring Well 299-E25-17

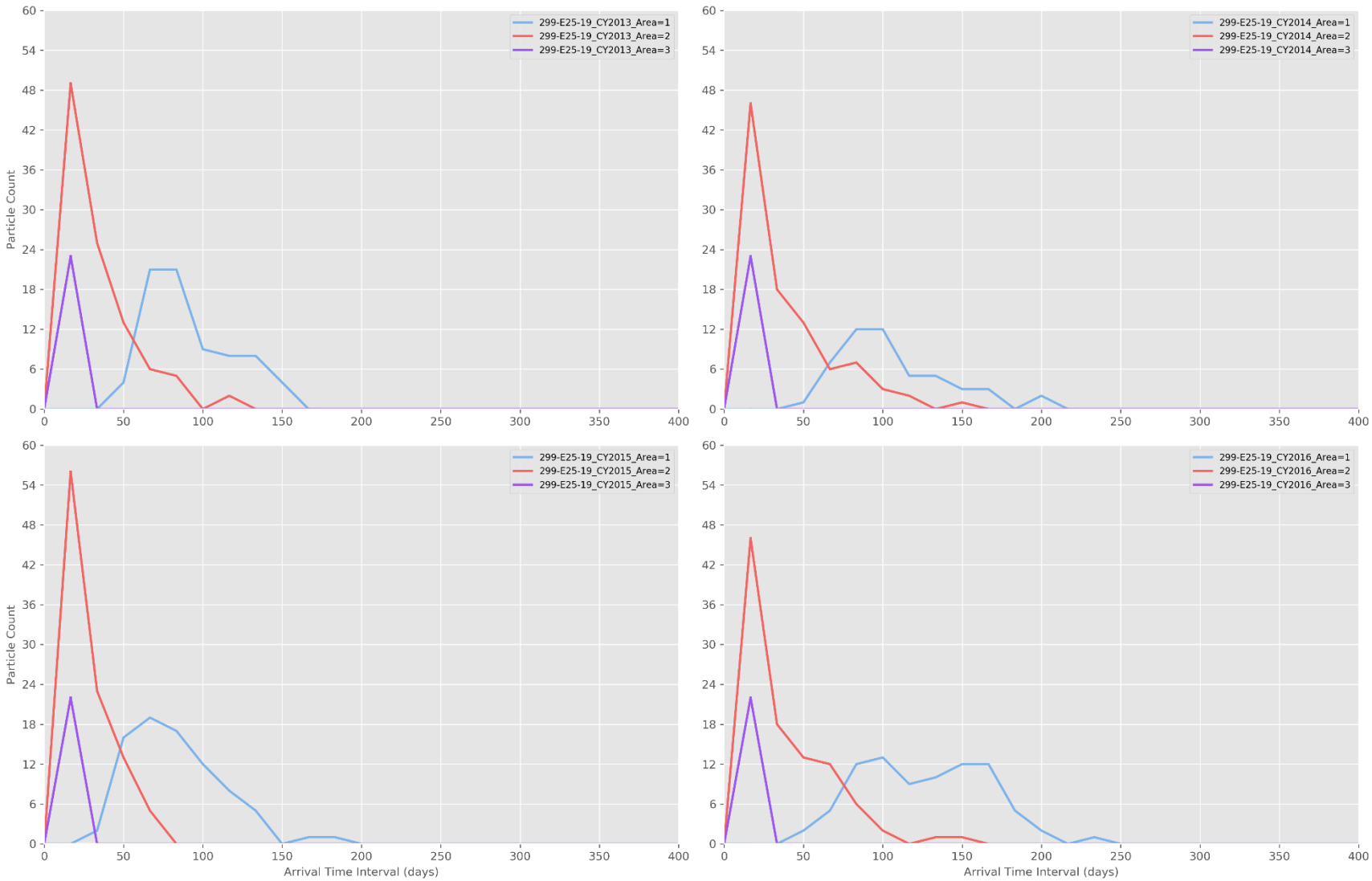

Figure E-27. Particle Breakthrough Curves per Area at Monitoring Well 299-E25-19

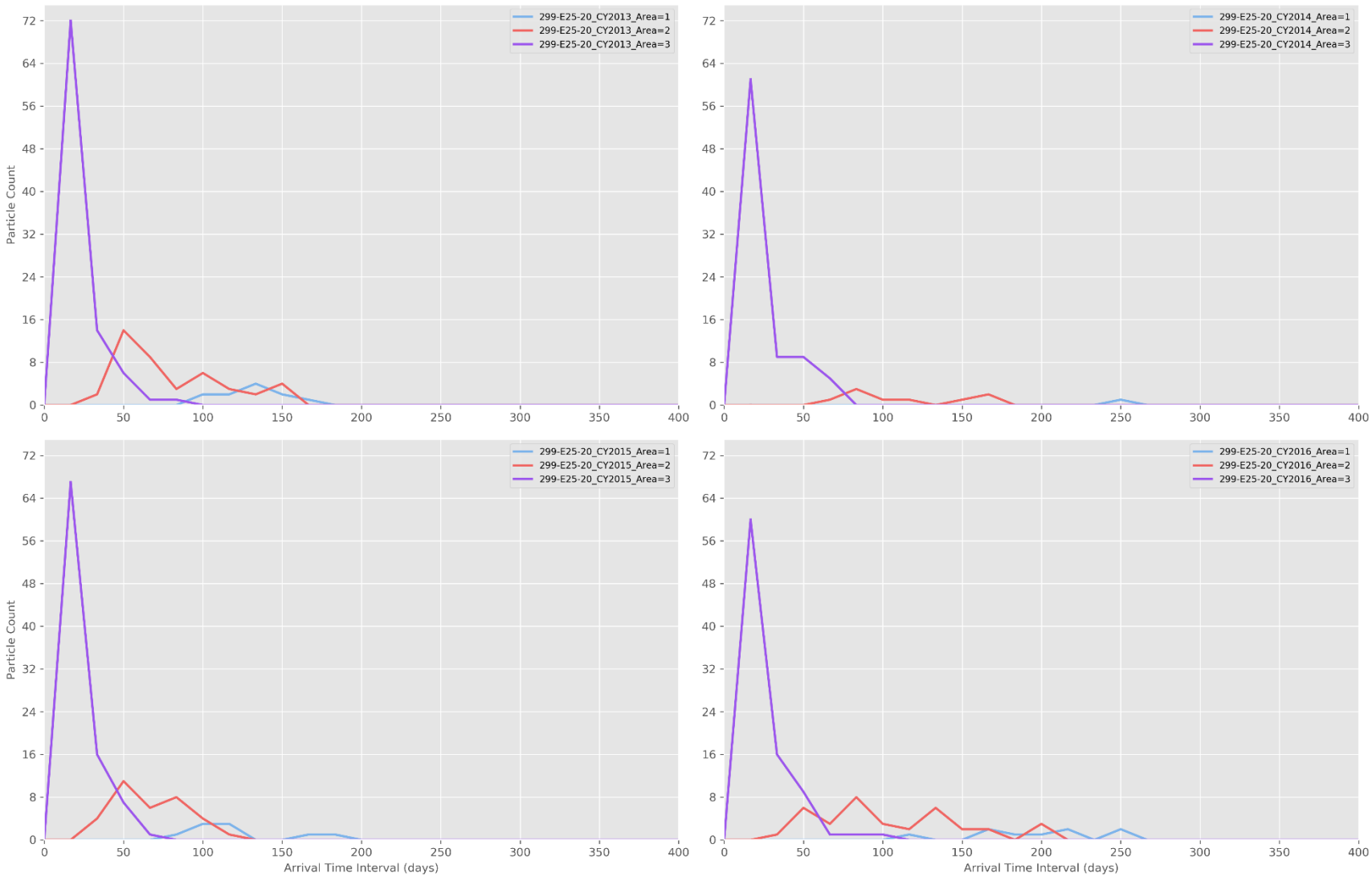

Figure E-28. Particle Breakthrough Curves per Area at Monitoring Well 299-E25-20

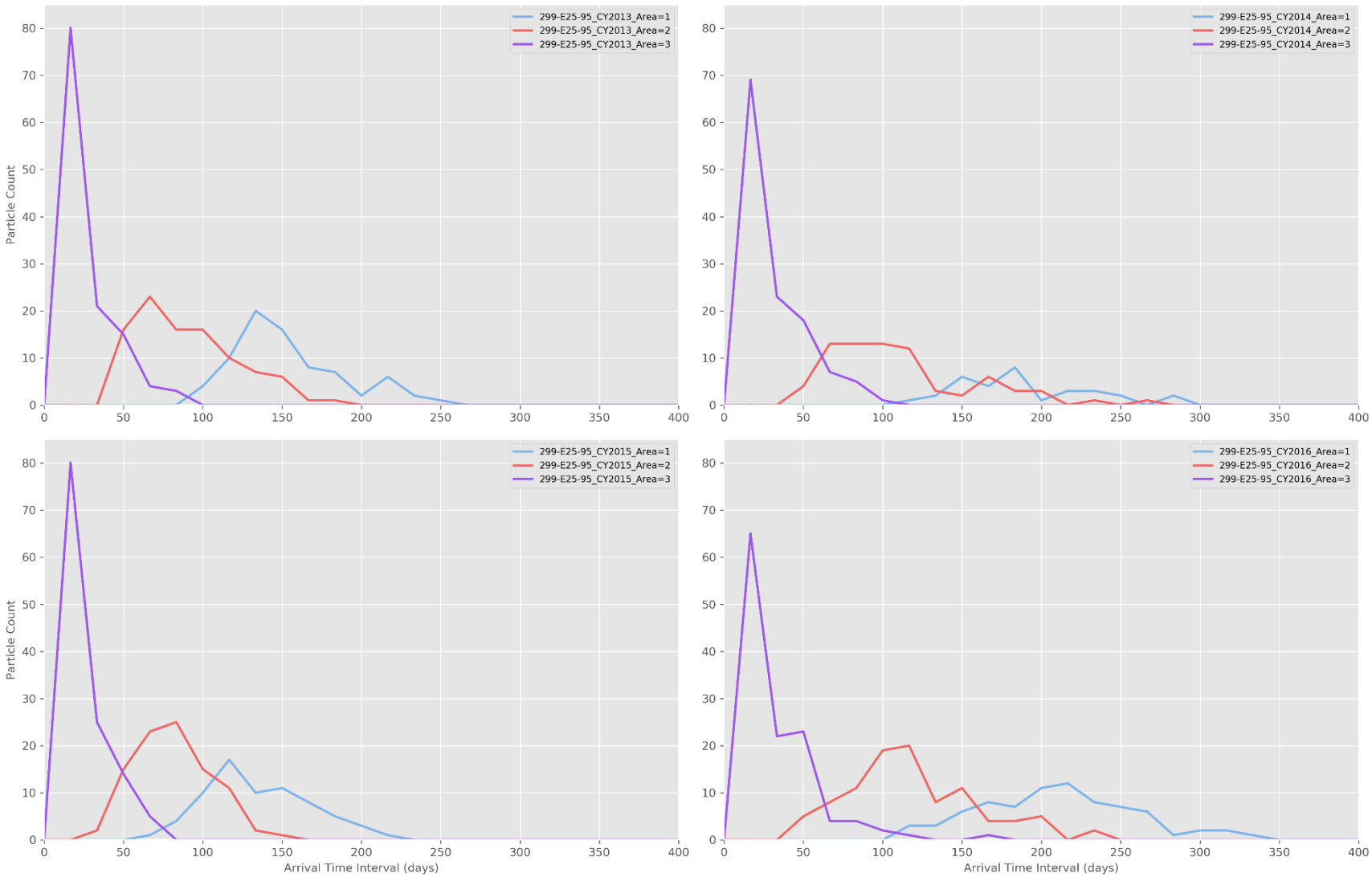

Figure E-29. Particle Breakthrough Curves per Area at Monitoring Well 299-E25-95

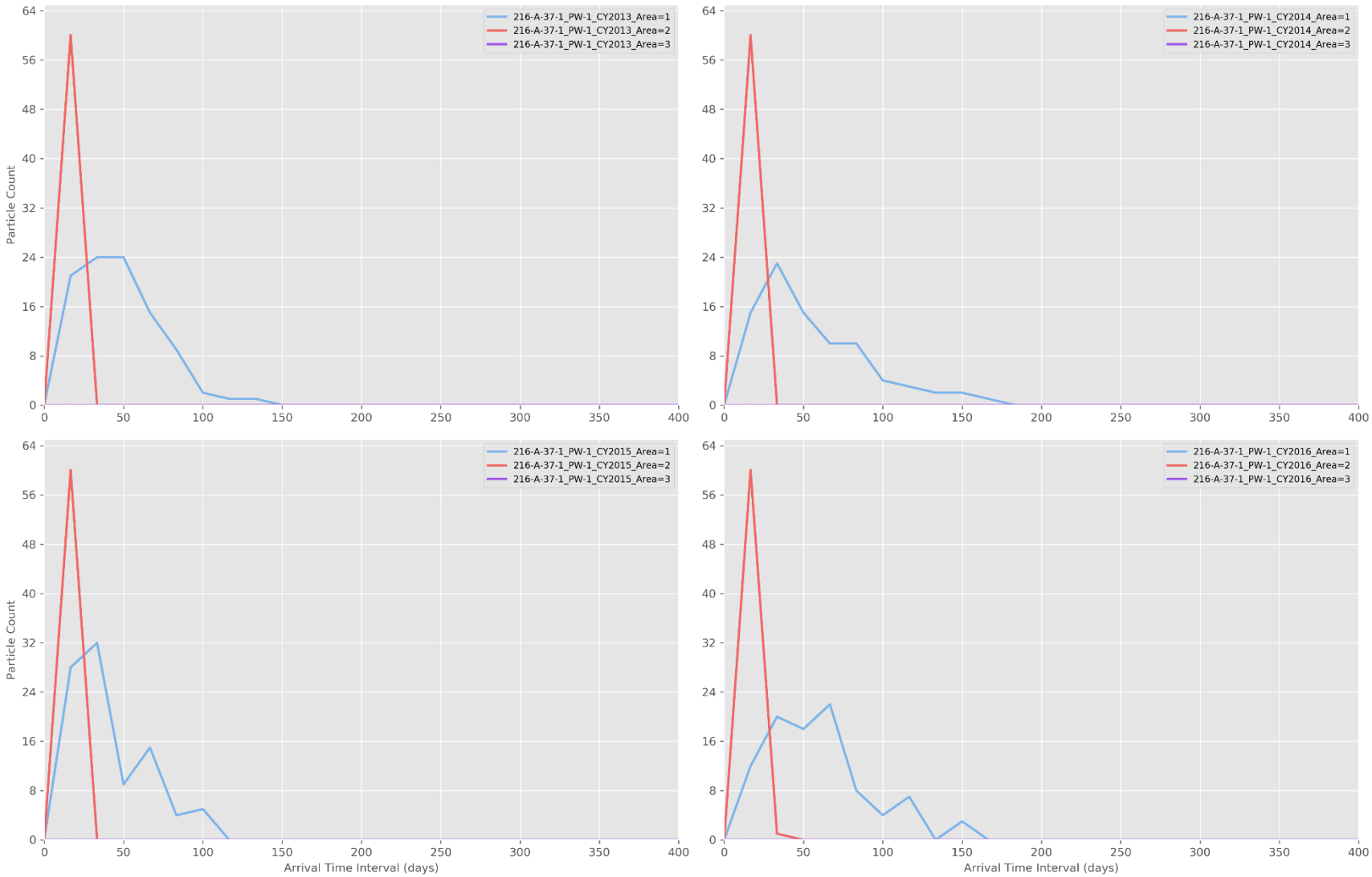

Figure E-30. Particle Breakthrough Curves per Area at Monitoring Well 216-A-37-1_PW-1

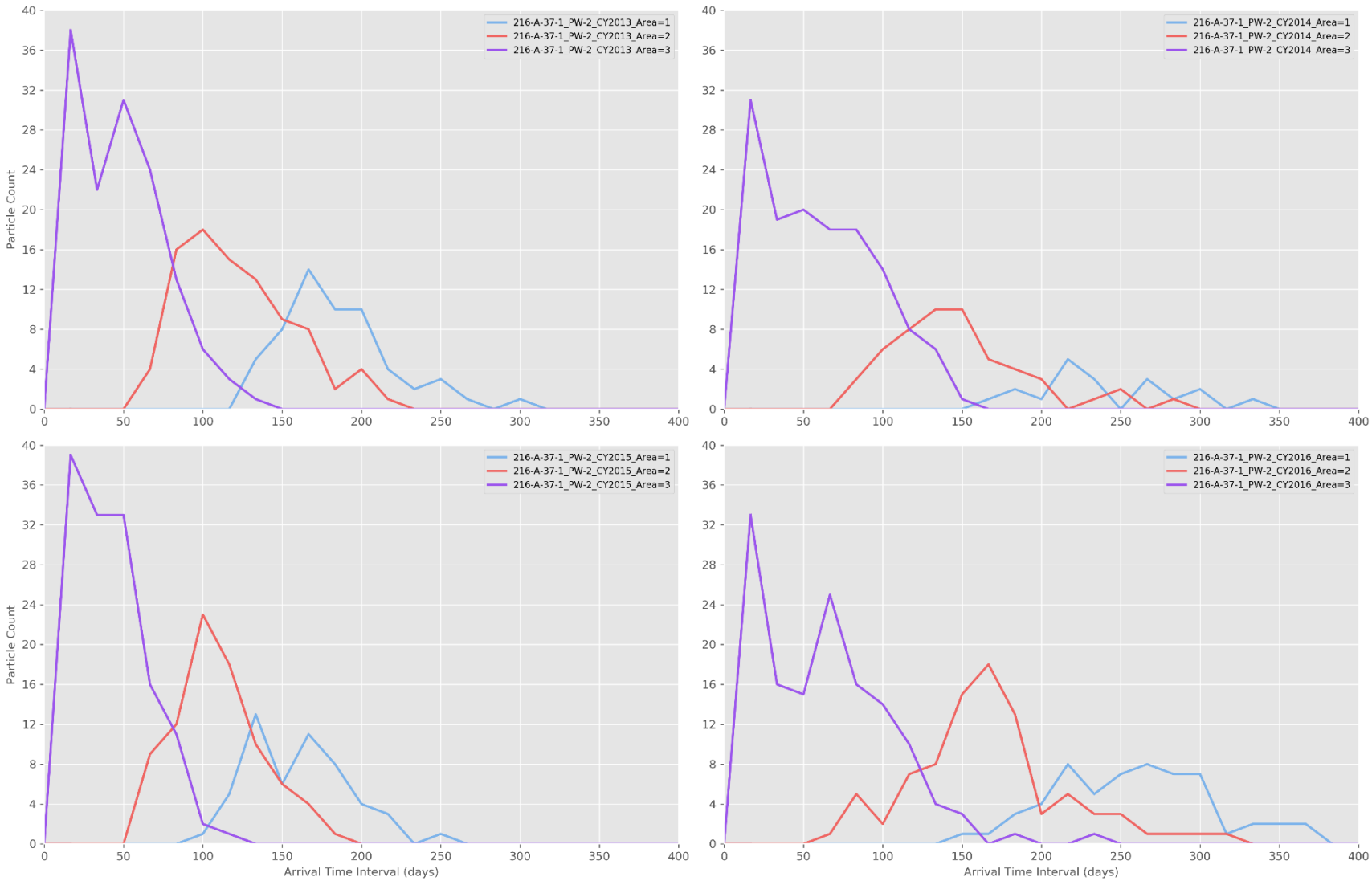

Figure E-31. Particle Breakthrough Curves per Area at Monitoring Well 216-A-37-1_PW-2

For each downgradient monitoring well at the 216-A-37-1 Crib, the distance used in the calculation was the distance from the centroid of the facility to each well location. The hydraulic conductivity used in the calculation for the 216-A-37-1 Crib, 18,200 m/d (59,711 ft/d), is the calibrated hydraulic conductivity from the CPGWM for the Cold Creek unit, which underlies the facility. The results of the API plume diving calculation for the downgradient wells for the 216-A-37-1 Crib are shown in Table E-7.

Table E-7. Summary of Well Screen Interval Evaluation for Downgradient Wells

Monitoring Well	Existing or Proposed Well?	Distance, D, (m)[a]	Recharge, *i*, (m/yr)[b]	Slope, S, of Plume Dive[c]	Estimated Depth of Plume Below Water Table (m)[d]	Depth from Water Table to Bottom of Well Screen (m)[e]	Is Plume Depth Above Bottom of the Screen? (Yes/No/N/A)
299-E25-17	Existing	78.6	1.16E-02	1.45E-04	1.14E-02	5.0	Yes
299-E25-19	Existing	26.1	1.16E-02	1.45E-04	3.79E-03	4.7	Yes
299-E25-20	Existing	79.7	1.16E-02	1.45E-04	1.16E-02	4.7	Yes
299-E25-95	Existing	95.8	1.16E-02	1.45E-04	1.39E-02	8.7	Yes
216-A-37_PW-1	Proposed	28.9	1.16E-02	1.45E-04	4.20 E-03	N/A	N/A
216-A-37_PW-2	Proposed	135.6	1.16E-02	1.45E-04	1.97E-02	N/A	N/A

a. Distance of the well from centroid of dangerous waste management unit.

b. A representative number from the CPGWM. The recharge values represent fluxes from surface water discharge due to historical operations at the Hanford Site and are summarized in EMDT-BC-0002, *Vadose Zone Attenuated Recharge, Electronic Modeling Data Transmittal – Boundary Condition (Artificial Recharge)*-0002. The anthropogenic flux is added to the natural recharge component in order to establish the final total recharge flux used in the simulations. Discharges included in EMDT-BC-0002 have been attenuated to account for travel through the vadose zone.

c. Slope of the plume dive computed using the American Petroleum Institute plume diving calculation as detailed in the main text of this ECF. The migration parameters for the 216-A-37-1 Crib used in the calculation of slope are as follows:

Hydraulic conductivity: 18,200 m/d (59,711 ft/d) (a calibrated value from the CPGWM)

Hydraulic gradient: 1.2E-05 (determined from 2016 water-level maps produced using TRIM)

d. Plume depth at monitoring well location computed from distance, D, times the slope, S.

e. Depths obtained from Table 3-3 in DOE/RL-2010-92, *Interim Status Groundwater Monitoring Plan for the 216-A-37-1 PUREX Plant Crib*.

CPGWM = Central Plateau Groundwater Model

ECF = environmental calculation file

N/A = not applicable

TRIM = Tikhonov Regularized Inverse Method

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Appendix F

Facility-Specific Results for 216-B-3 Pond

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Terms

API	American Petroleum Institute
CPGWM	Central Plateau Groundwater Model
CY	calendar year
ECF	environmental calculation file
PUREX	Plutonium Uranium Extraction
Rwia	Ringold Formation member of Wooded Island – unit A
TRIM	Tikhonov Regularized Inverse Method

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F1 Purpose and Background

The primary purpose of the calculations presented here is to estimate directions of potential migration to assess the efficacy of the geographical distribution of wells in the proposed monitoring well network for the subject facility. The calculations described within the main text of this environmental calculation file (ECF) were performed for each of the 200 East Facilities. This appendix presents results developed from the calculations that are specific to 216-B-3 Pond. The 216-B-3 Pond unit comprises the 216-B-3 Main Pond (hereinafter referred to as Main Pond) and the 216-B-3-3 Ditch. Main Pond and the 216-B-3-3 Ditch are collectively referred to as "216-B-3 Pond" in this appendix.

Located in the eastern part of the 200 East Area, Main Pond was constructed in a natural topographic depression. For groundwater monitoring of the unit, only Main Pond and the eastern portion of the 216-B-3-3 Ditch, from its juncture with the 216-A-29 Ditch to where the 216-B-3-3 Ditch enters Main Pond, are included (Chapter 1 in DOE/RL-2008-59, *Interim Status Groundwater Monitoring Plan for the 216-B-3 Pond*). As a result, for the analysis herein, the facility-specific representation of 216-B-3 Pond excludes the western portion of the 216-B-3-3 Ditch (Figure F-1).

During operations, Main Pond covered about 14.2 ha (35 ac) with a depth up to 6.1 m (20 ft). The total estimated discharge to the pond since 1945 exceeded 1.0 trillion L (260 billion gal) (Section 1.1.1 in PNNL-15479, *Groundwater Monitoring Plan for the Hanford Site 216-B-3 Pond RCRA Facility*). The pond was a receptacle for corrosive and dangerous waste from the regeneration of demineralizer columns at the Plutonium Uranium Extraction (PUREX) Plant, spills of dangerous or mixed waste from PUREX and other facilities, and off-specification chemical makeups of PUREX. The last known reportable discharge of chemical waste (sodium nitrite) occurred in 1987. In 1994, 216-B-3 Pond was backfilled with coarse-grained material and then covered with fine-grained material (Section 2.6 in DOE/RL-2016-66, *Hanford Site RCRA Groundwater Monitoring Report for 2016*).

Groundwater monitoring for 216-B-3 Pond started in 1988 under interim status requirements. In 1990, groundwater monitoring was changed to a groundwater quality assessment program due to elevated levels of total organic halogen detected in one downgradient monitoring well (DOE/RL-2008-59). Another downgradient well was identified to exceed total organic halogen and total organic carbon levels in a 1997 assessment report (PNNL-11604, Results *of RCRA Groundwater Quality Assessment at the 216-B-3 Pond Facility*). It was determined that these constituents did not result in dangerous waste or dangerous waste constituents, defined by WAC 173-303, "Dangerous Waste Regulations," entering the groundwater at 216-B-3 Pond; thus, it was returned to indicator parameter monitoring in 1998 (Section 7.0 in PNNL-11604). Groundwater monitoring is ongoing at 216-B-3 Pond under an indicator evaluation program for groundwater contamination detection.

The 216-B-3 Pond interim status monitoring network (Figure F-1) consists of two upgradient (699-44-39B and 699-44-43C) and three downgradient wells (699-42-42B, 699-43-44 [to be replaced by 699-43-43B], and 699-43-45), most of which are screened across the top 1.2 to 6.3 m (3.9 to 20.8 ft) of the aquifer (Section 2.6 in DOE/RL-2016-66 and DOE/RL-2008-59). Due to casing failure from corrosion, downgradient well 699-43-44 is being removed from the network and is scheduled for direct replacement with planned well 699-43-43B. This ECF presents calculations that evaluate the efficacy of the groundwater monitoring network for detecting hypothetical releases from 216-B-3 Pond at existing and potential new monitoring well locations.

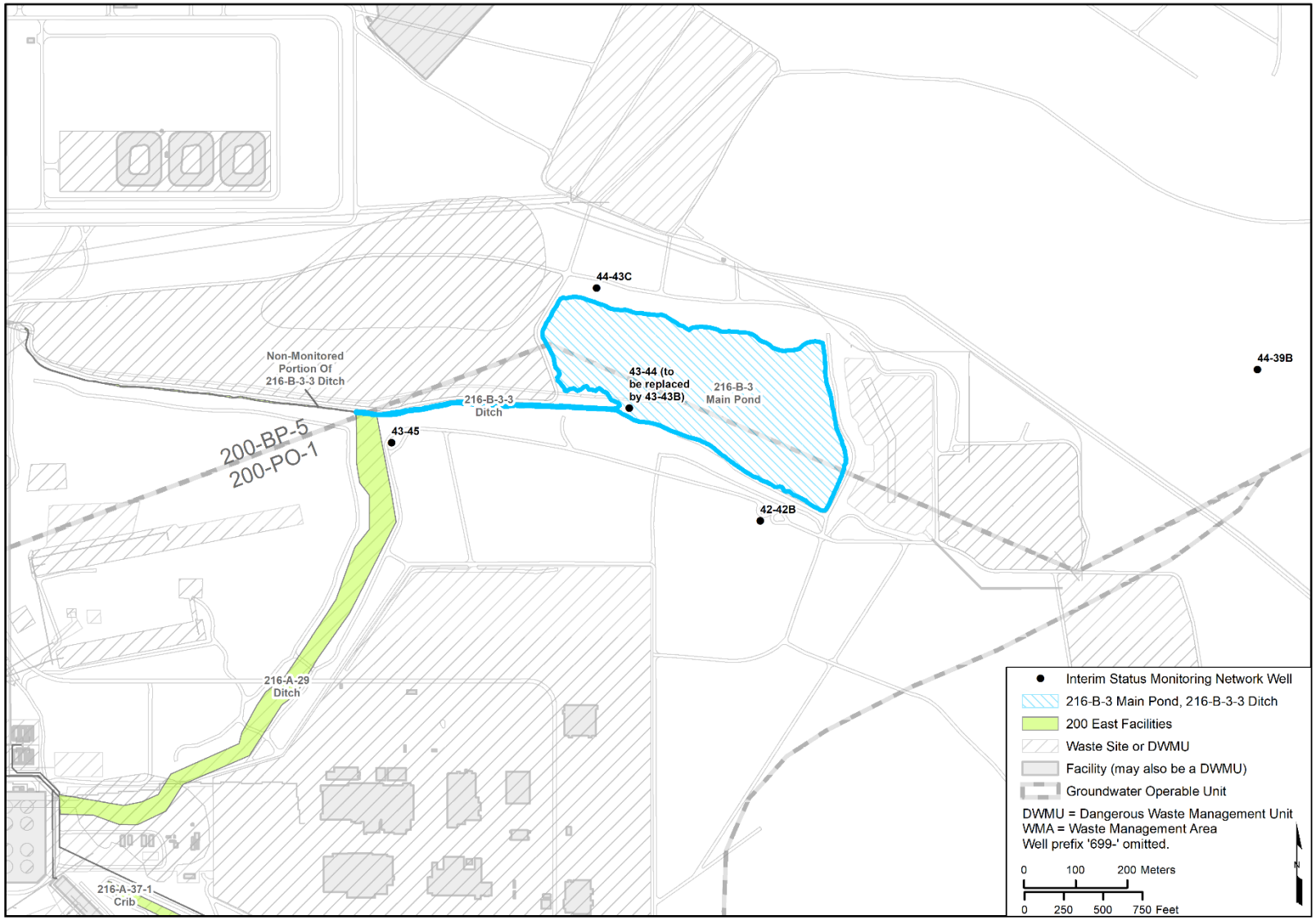

Figure F-1. Locations of Interim Status Groundwater Monitoring Wells at 216-B-3 Pond

F2 Facility-Specific Input for 216-B-3 Pond

Inputs used in the calculations that were specific to 216-B-3 Pond are described in this chapter.

F2.1 Particle Count Grid and Release Locations

To prepare particle count maps, a distribution of facility-specific starting locations is required. The starting locations for the particle-tracking calculations represent the area over which a potential release from a given facility would impact the underlying water table. Particles were not released in the eastern portion of the 216-B-3 Pond complex (i.e., eastern extent of 216-B-3 Main Pond) due to the hydrogeologic conditions encountered in that area. As described in Section 2.2 in PNNL-15479, the Lithologic and hydrologic data collected from drilling and groundwater monitoring indicates that the uppermost aquifer beneath the 216-B-3 Pond complex occurs in confined and unconfined conditions, depending upon location: the uppermost aquifer is unconfined to the west, southwest, and north of Main Pond and becomes progressively more confined to the east and southeast. The boundary between confined and unconfined conditions is not exactly known and may be gradational. The Ringold Formation member of Wooded Island – unit A (Rwia) comprises the bulk of the uppermost aquifer in the Main Pond area (with some Hanford formation in the far west). The Ringold Lower Mud unit forms a confining horizon and potential perching layer to the east. The saturated hydraulic conductivity of the Ringold Lower Mud is very low compared to the Rwia and Hanford formation: as a consequence, the potential for migration within the Ringold Lower Mud is anticipated to be vastly less than within the Rwia and Hanford formation, and the Ringold Lower Mud may isolate portions of the aquifer from contamination resulting from surface releases.

The particle releases were located at plausible release sites throughout the western extent of 216-B-3 Pond. Thirty-seven release locations were specified within Main Pond and the adjoining ditch (Figure F-2). Twenty particles were released and tracked from each release location to provide the density of particles in space and time required for the detailed facility-specific calculations, randomizing the seed values for the dispersion calculations. Thus, 740 [740 = 37 (release locations) × 20 (releases)] particles were tracked for each of the four simulations.

Contour maps of particle counts were generated by counting the number of particles that pass through a pre-defined uniform calculational grid (Figure F-2). The grid used to develop the relative particle density maps is defined by 10 by 10 m (33 by 33 ft) cells. The grid is oriented to be parallel to the predominant groundwater flow direction at 216-B-3 Pond.

F2.2 Migration Parameters

Parameters specific to the groundwater flow conditions at 216-B-3 Pond are reported throughout the various documents for the facility. The parameters used in the calculations performed herein to represent nonreactive dissolved contaminant migration are mobile (or effective) porosity and hydraulic conductivity. The parameters used in these calculations are representative of local conditions for a conservative (i.e., nonreactive) solute dissolved within groundwater.

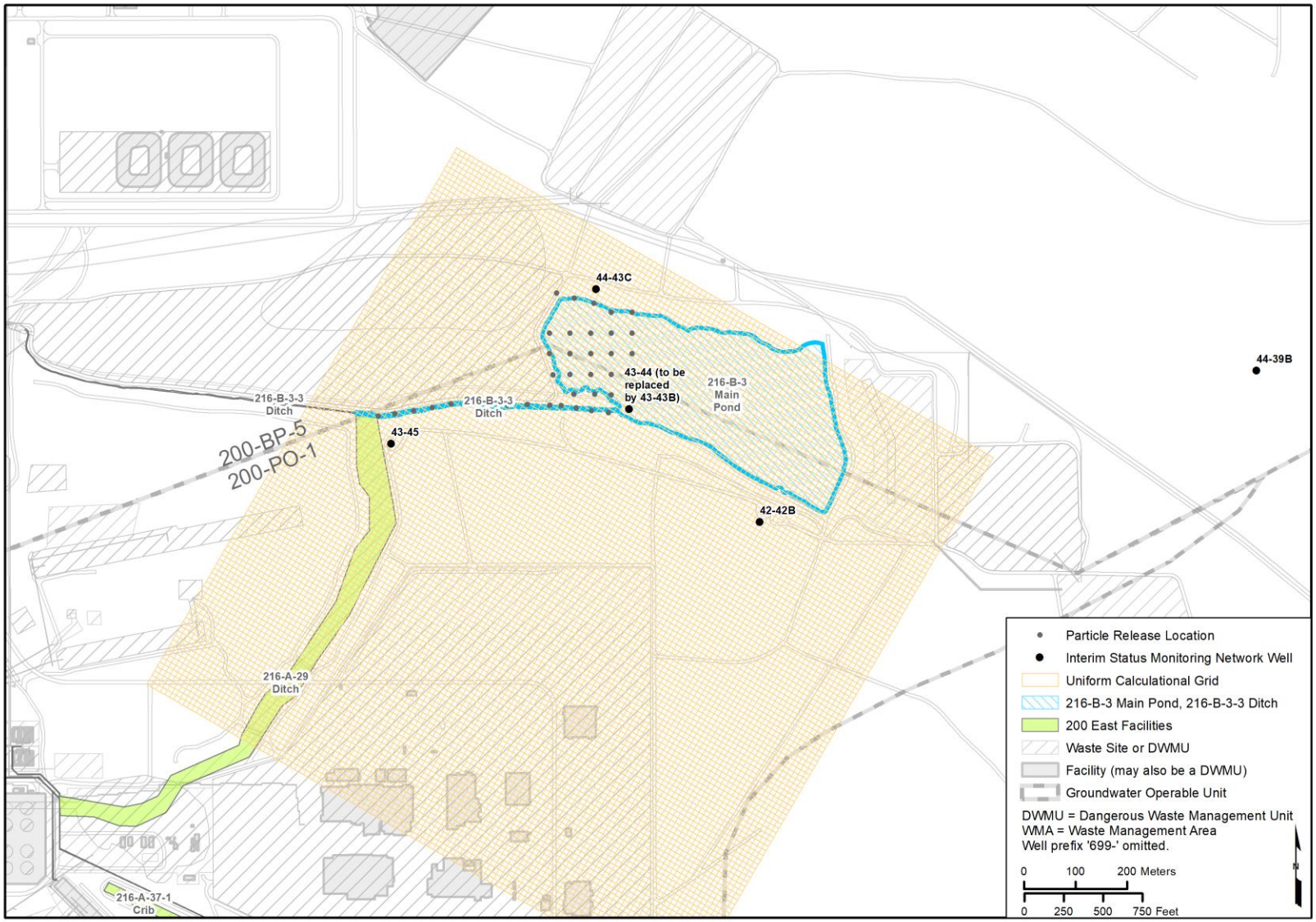

Figure F-2. Uniform Calculational Grid and Release Locations at 216-B-3 Pond

There is a range of hydraulic conductivity values reported in site literature for 216-B-3 Pond. Values range from 0.03 m/d (0.1 ft/d) for the Ringold Formation (Table 6-1 in WHC-SD-EN-EV-002, *Interim Hydrogeologic Characterization Report for the 216-B-3 Pond*) to 17,000 m/d (55,774 ft/d) for the Hanford formation (Table 1 in ECF-Hanford-17-0241, *Hydraulic Gradient and Velocity Calculations for RCRA Sites in 2017*). As described in Section 4.2.1.1 of the main text of this ECF, the hydraulic conductivity used in the work performed herein corresponds to the calibrated values from the Central Plateau Groundwater Model (CPGWM) (CP-47631, *Model Package Report: Central Plateau Groundwater Model, Version 8.4.5*). Figure 3-2 in the main text of this ECF indicates the northwestern extent of 216-B-3 Pond is located in the hydrostratigraphic unit zone corresponding to the Cold Creek unit. The value used for the hydraulic conductivity for 216-B-3 Pond is 18,200 m/d (59,711 ft/d), which corresponds to the Cold Creek unit as shown in Table 4-1 in the main text of this ECF.

Similarly, there is a range of porosity values reported in site literature for 216-B-3 Pond. Values range from 0.1 to 0.2 (Table 1 in ECF-Hanford-17-0241). As described in Section 4.2.1.1 of the main text of this ECF, the mobile (effective) porosity used in the work performed herein corresponds to the calibrated values from the CPGWM (CP-47631). The value for 216-B-3 Pond is 0.25, which corresponds to the Cold Creek unit as shown in Table 4-1 in the main text of this ECF.

F3 Facility-Specific Results for 216-B-3 Pond

The groundwater elevation contours prepared in the vicinity of 216-B-3 Pond using the Tikhonov Regularized Inverse Method (TRIM) are presented in this chapter. In addition, the outputs of the particle tracking and particle count calculations are presented, including the following:

- Maps of calculated particle pathlines for the flow conditions determined for each of the four years (2013, 2014, 2015, and 2016). These are presented at the facility-specific scale considering advective and dispersive migration.
- Time-series plots, referred to as particle breakthrough curves, of the relative arrival, peak, and decline in particle counts at each interim status groundwater monitoring well location and each proposed monitoring location, where applicable.
- Tabulation of relative particle counts for each interim status groundwater monitoring well location and each proposed monitoring location, where applicable.
- Maps of particle counts downgradient of each facility based on the flow conditions determined for each of the four years.

The results of calculations of potential vertical migration of contaminants at the monitoring well locations are also presented.

F3.1 Groundwater Elevation Contours

Figures F-3 through F-6 show the results of the groundwater elevation analysis completed using TRIM in the vicinity of 216-B-3 Pond. The figures depict general patterns of groundwater elevations and hydraulic gradients for conditions represented by calendar years (CYs) 2013, 2014, 2015, and 2016. These groundwater elevation contours and associated hydraulic gradients form the basis for the facility-specific calculations performed for this ECF.

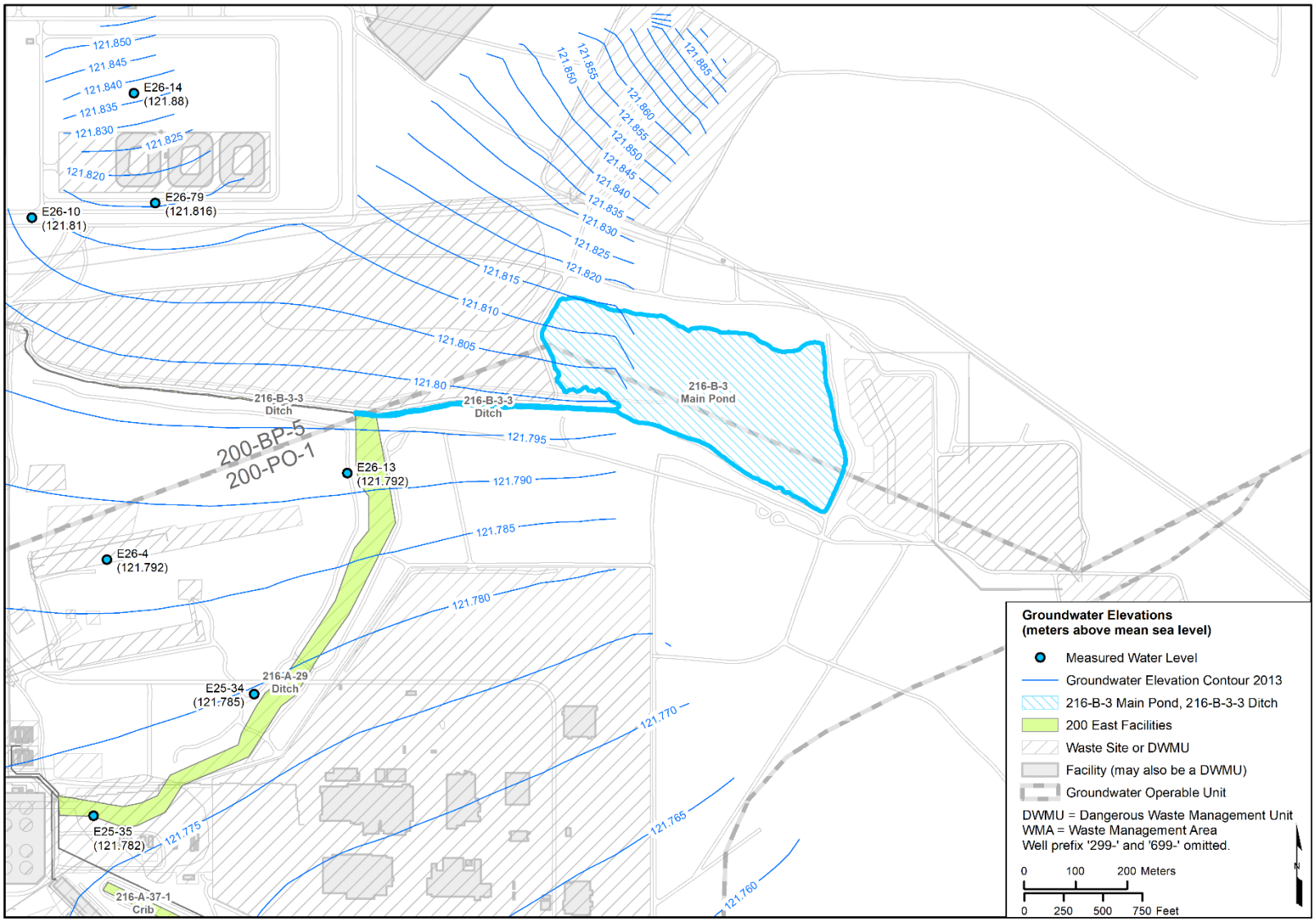

Figure F-3. Water-Level Elevation Map for 216-B-3 Pond, 2013

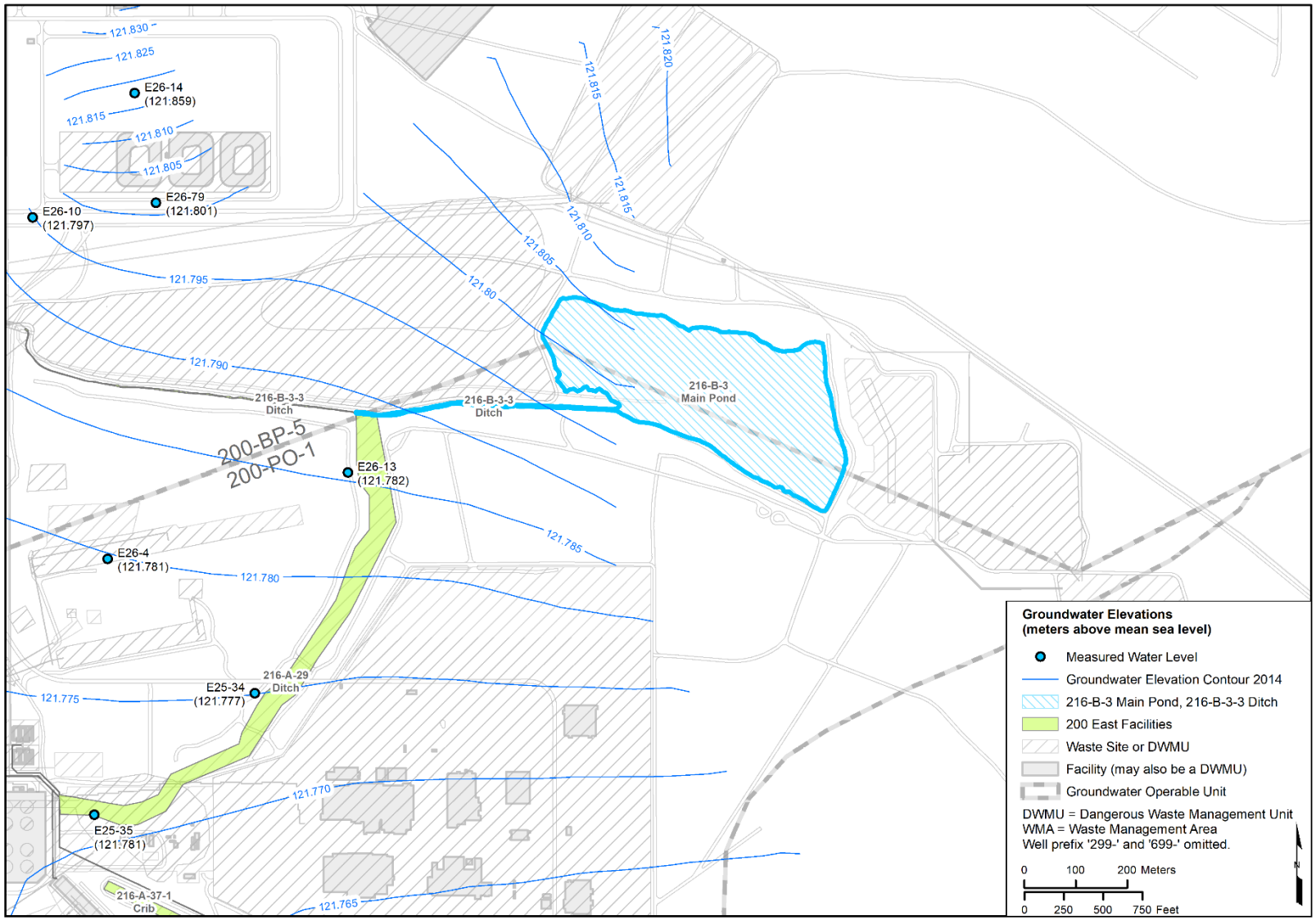

Figure F-4. Water-Level Elevation Map for 216-B-3 Pond, 2014

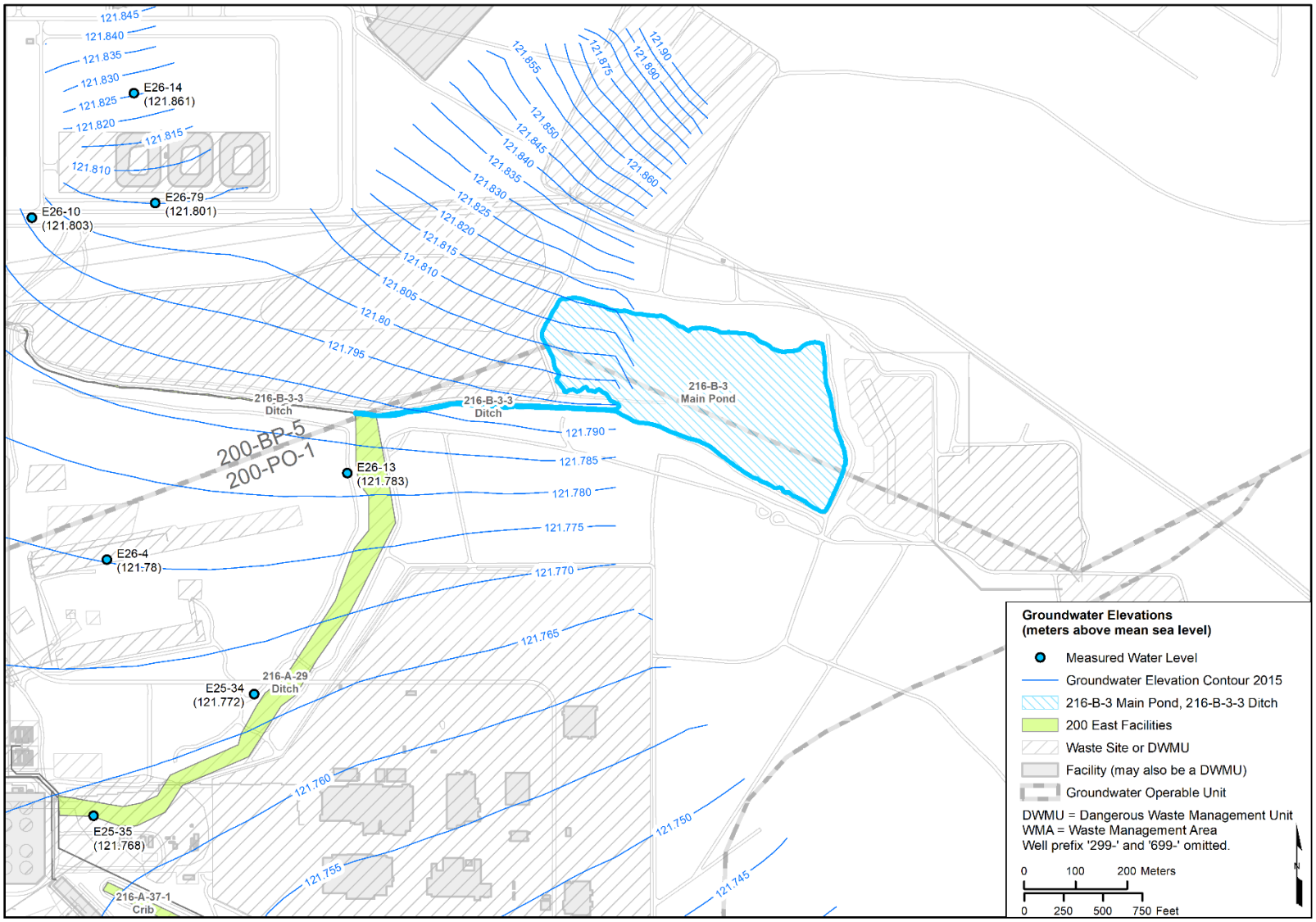

Figure F-5. Water-Level Elevation Map for 216-B-3 Pond, 2015

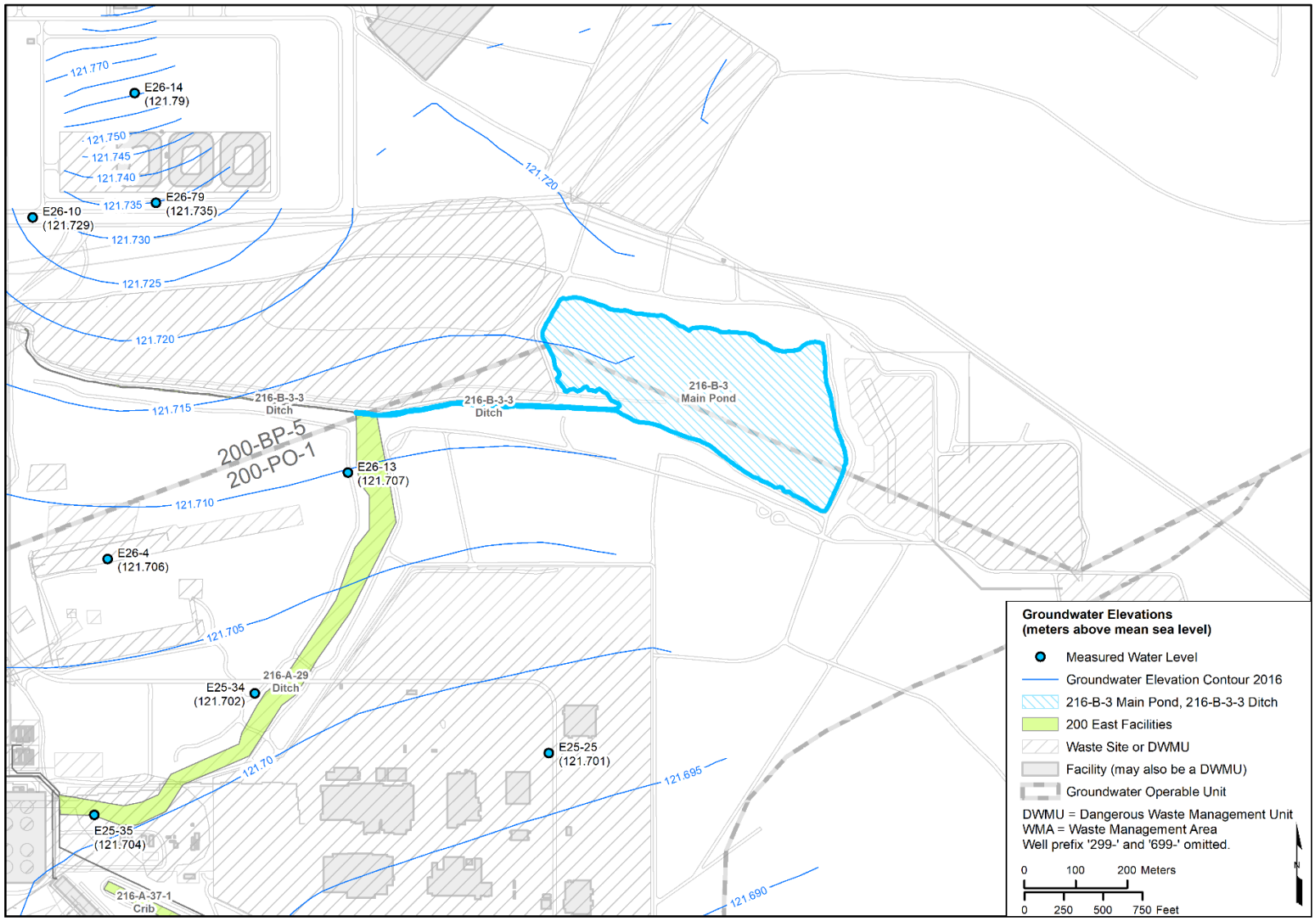

Figure F-6. Water-Level Elevation Map for 216-B-3 Pond, 2016

F3.2 Particle Tracking

Once the groundwater elevation contour maps and underlying piecewise continuous elevation grids were prepared using TRIM, particle tracking was implemented using both advection and dispersion.
The particle pathlines that were produced depict the patterns of spreading that might accompany the migration of contaminants near the pond for the flow conditions calculated for CYs 2013, 2014, 2015, and 2016. Figures F-7 through F-10 depict the particle pathlines developed based on the groundwater elevations prepared throughout the 200 East Area using TRIM. The resulting maps were prepared based on the release of 20 particles from each starting location to provide the high density of particles in space and time required for these detailed facility-specific calculations. Figures F-7 through F-10 depict the particle pathlines calculated after 500 days of travel, by which time it was determined that most of the particles would have arrived at or passed by the interim status groundwater monitoring wells. Figures F-7 through F-10 depict an instantaneous release to the water table from the release locations in 216-B-3 Pond to illustrate the adequacy of the well network for monitoring the entire facility.

F3.3 Particle Counts

To compare the relative timing and density of the particles that pass by each monitoring well location, particle counts were calculated as described in Section 6.3 of the main text of this ECF. The particle counts were tabulated, particle breakthrough curves were created, and particle count maps were generated. While the particles were run for 500 days, the particle count tables are truncated to 360 days by which time the particles had passed the vicinity of the wells.

F3.3.1 Relative Particle Counts at Interim Status Groundwater Monitoring Wells

Tables F-1 and F-2 present the computed particle counts over time, binned into periods of 15 days, for each of the downgradient monitoring wells. Since particles are not released in the eastern portion of 216-B-3 Pond, no particle was encountered at 699-42-42B and the counts are not presented for that well. The tables present four entries (one for each year) for each well. At the bottom of the column for each mapped event is the total number of particles that passed through the vicinity of the well, regardless of time, and the average of the totals for the four mapped years rounded to the nearest integer. Each table provides an indication of the relative timing of the expected detections at each well and the relative potential that each well would detect a release at the facility for the flow conditions calculated for CYs 2013, 2014, 2015, and 2016.

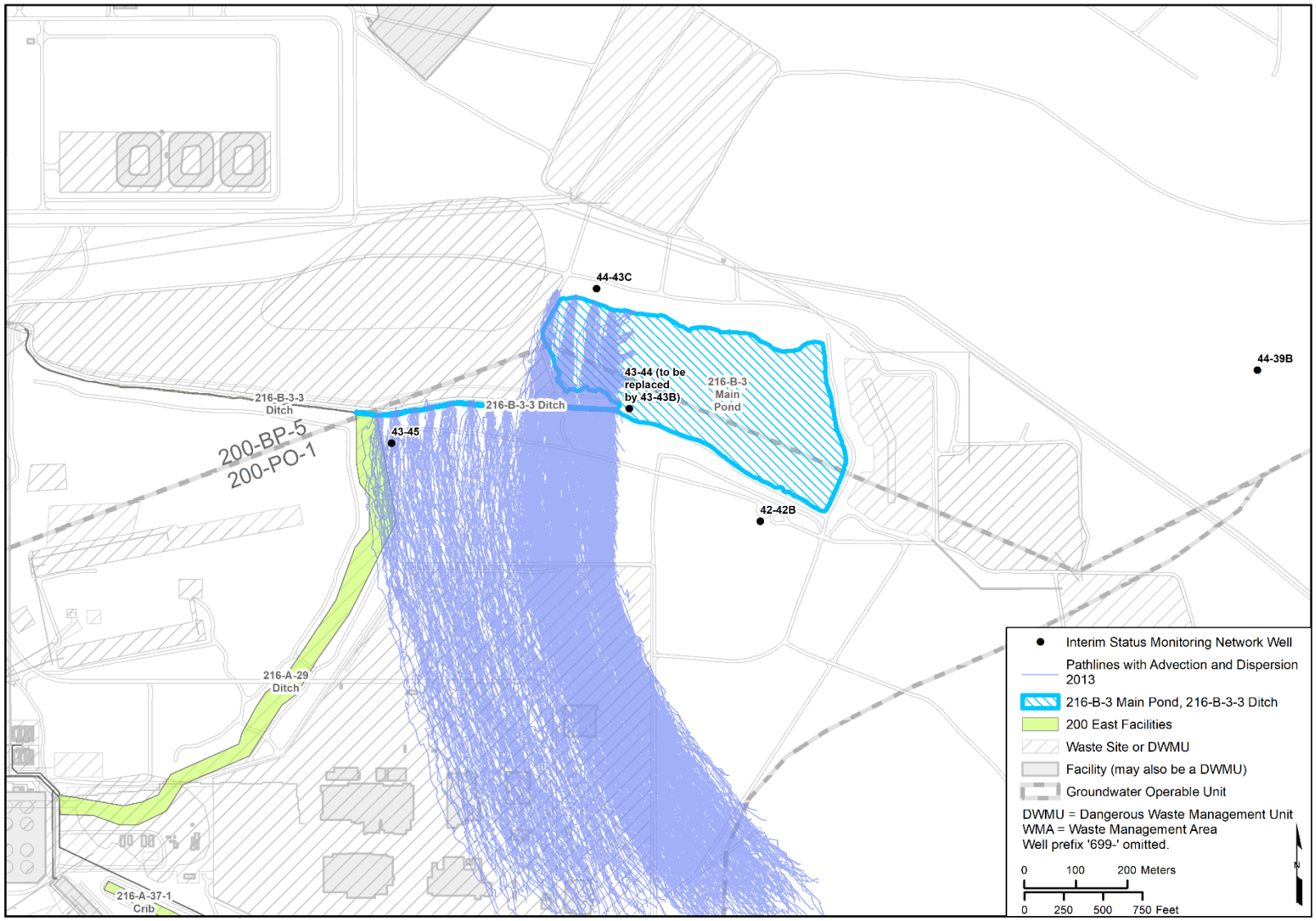

Figure F-7. Local-Scale Particle Pathlines, Advection and Dispersion – 216-B-3 Pond, 2013

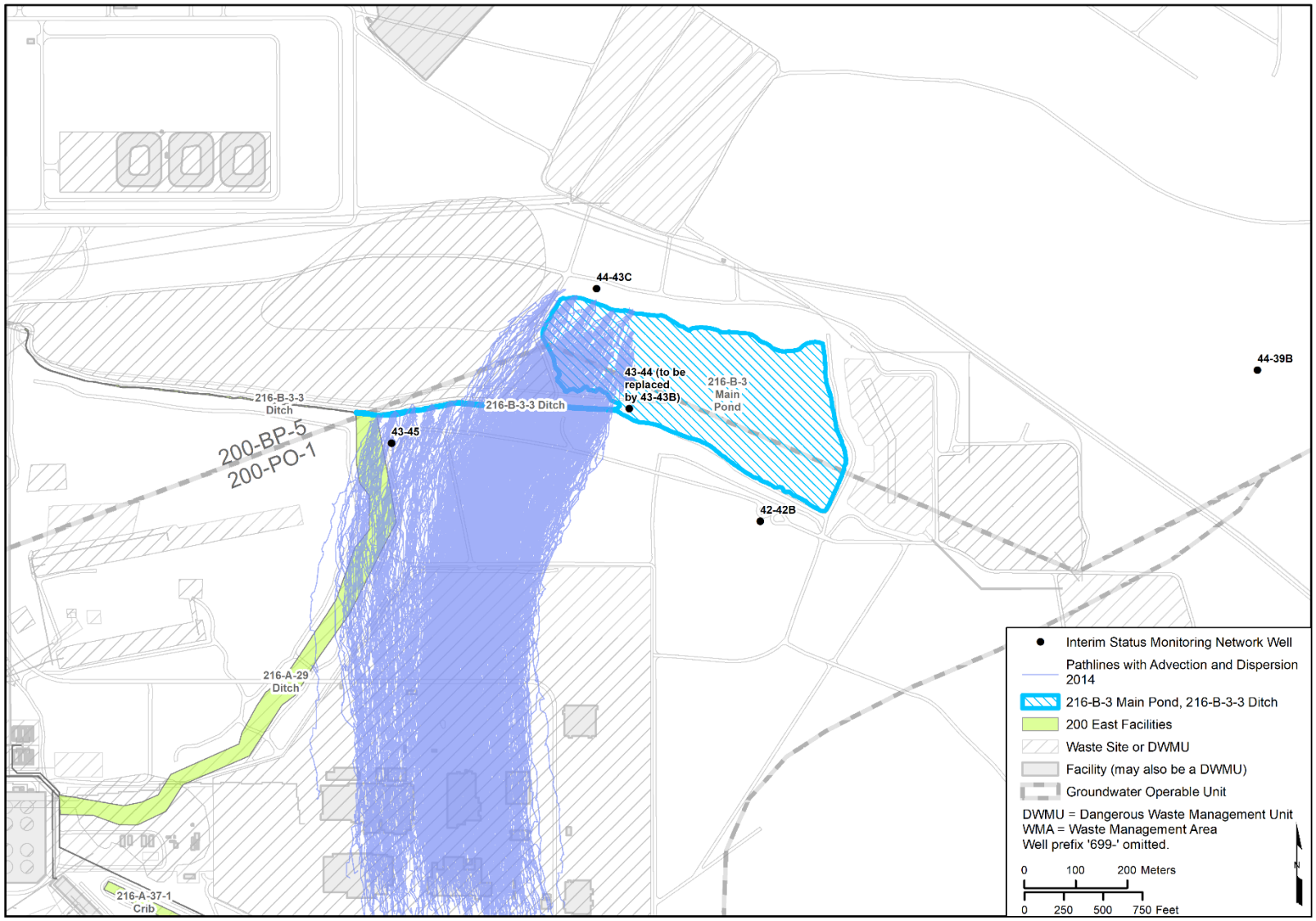

Figure F-8. Local-Scale Particle Pathlines, Advection and Dispersion – 216-B-3 Pond, 2014

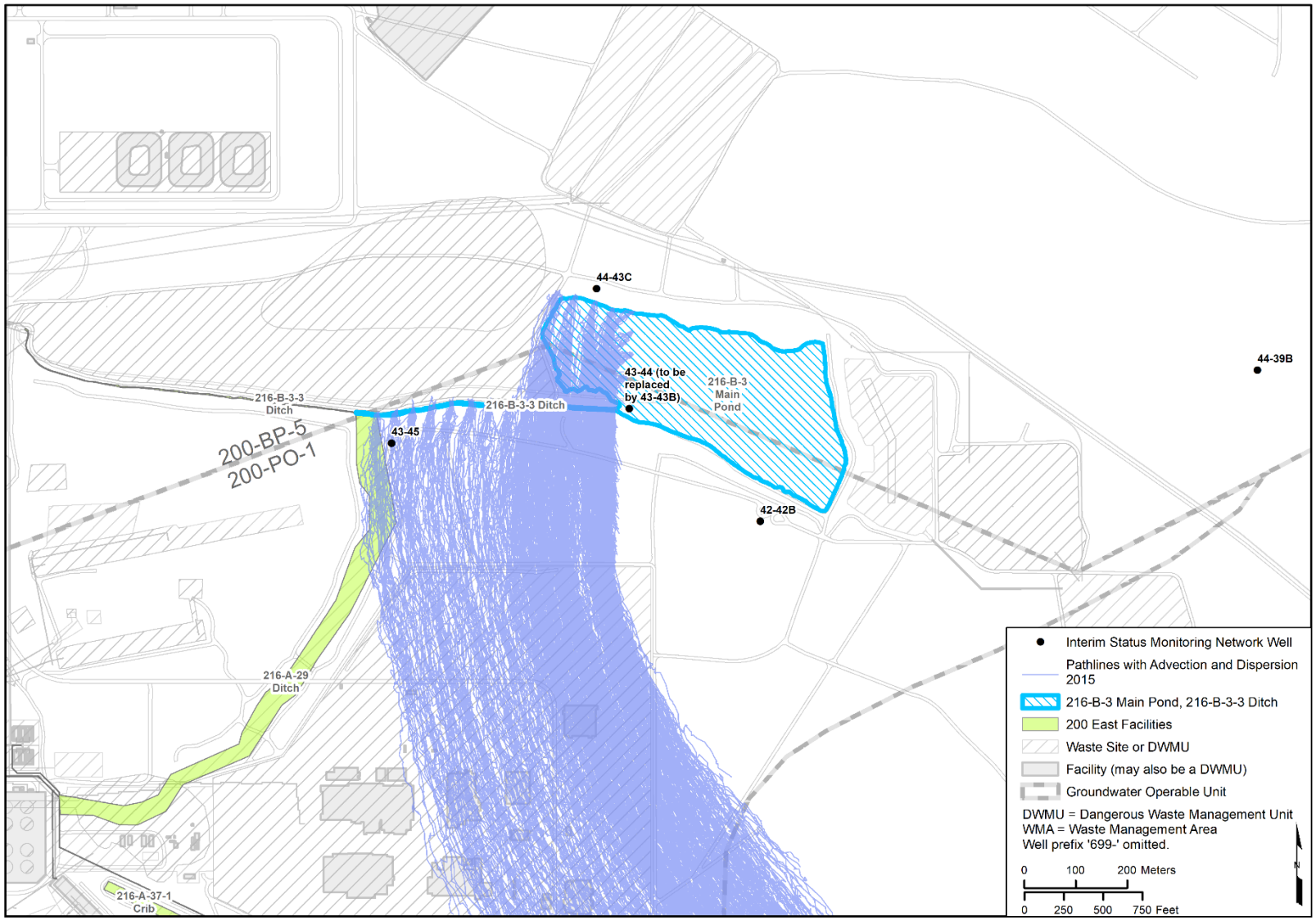

Figure F-9. Local-Scale Particle Pathlines, Advection and Dispersion – 216-B-3 Pond, 2015

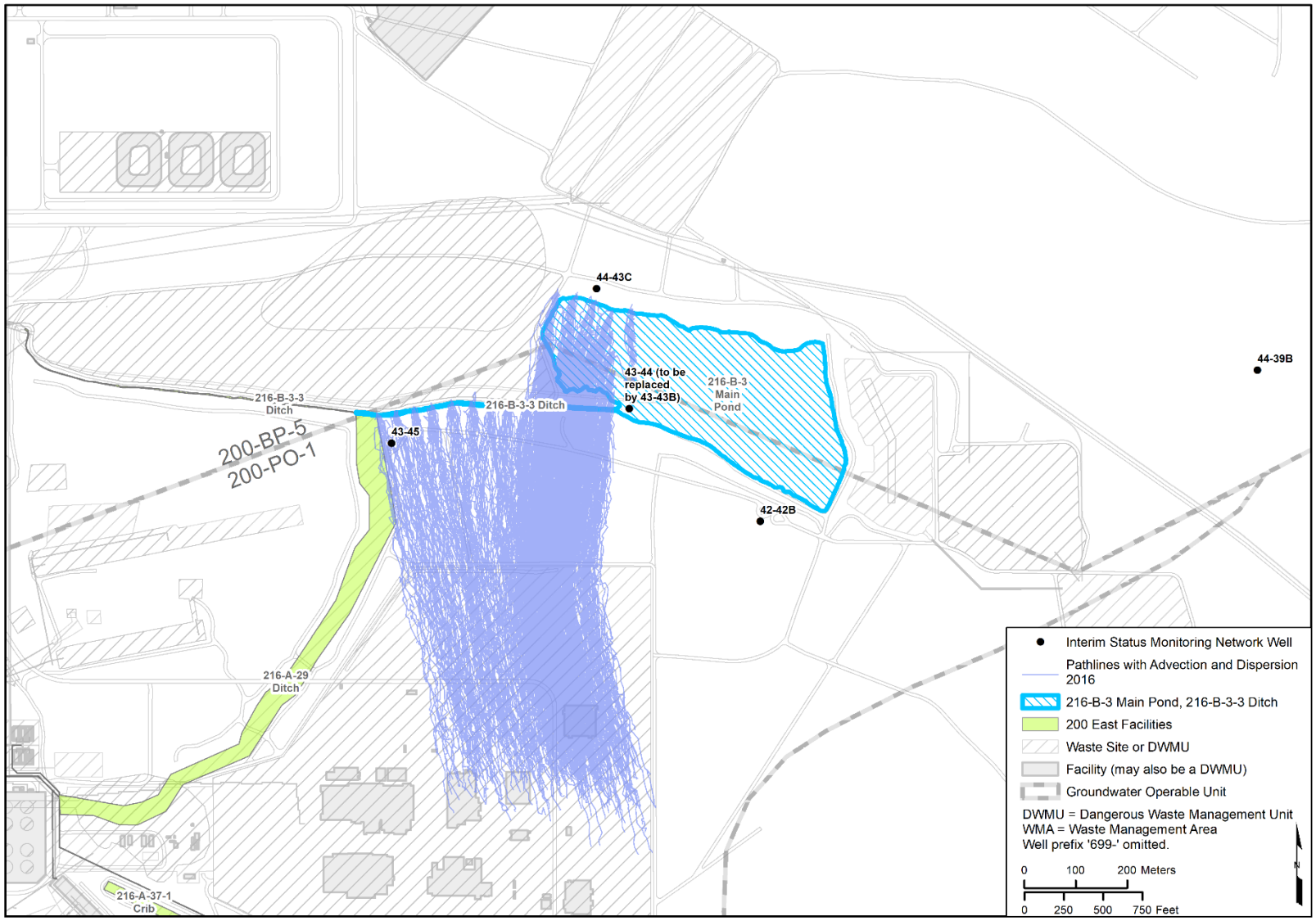

Figure F-10. Local-Scale Particle Pathlines, Advection and Dispersion – 216-B-3 Pond, 2016

Table F-1. Particle Density (Count) Monitoring Well 699-43-43B

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
30	1	0	1	0	
60	0	0	0	0	
90	0	0	0	0	
120	0	0	0	0	
150	0	0	0	0	
180	0	0	0	0	
210	0	0	0	0	
240	0	0	0	0	
270	0	0	0	0	
300	0	0	0	0	
330	0	0	0	0	
360	0	0	0	0	Average
Total	1	0	1	0	**0**

Table F-2. Particle Density (Count) Monitoring Well 699-43-45

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
30	27	26	22	20	
60	0	2	1	7	
90	0	0	0	0	
120	0	0	0	0	
150	0	0	0	0	
180	0	0	0	0	
210	0	0	0	0	
240	0	0	0	0	
270	0	0	0	0	
300	0	0	0	0	
330	0	0	0	0	
360	0	0	0	0	Average
Total	27	28	23	27	**26**

The average values depicted at the base of each table can be used to assess the relative potential for each well to detect a release at the facility. These averages are as follows:

- 699-43-43B – Average = 0
- 699-43-45 – Average = 26

F3.3.2 Relative Arrival Times at Interim Status Groundwater Monitoring Wells

Figures F-11 and F-12 depict plots of particle counts over time (particle breakthrough curves) for each downgradient well location. The underlying data plotted in Figures F-11 through F-12 are the same as the data in Tables F-1 through F-2, but the time interval over which particles are summed is not necessarily the same. Particle breakthrough curves show the relative timing and particle density for the arrival, peak, and decline in particle counts at each interim status monitoring location resulting from the hypothetical instantaneous release at the facility. The plots depict the relative potential at each well for detecting a release from the facility that reaches the water table for the flow conditions calculated for CYs 2013, 2014, 2015, and 2016. There is one figure for each well, with four lines shown on each plot (one for each year).

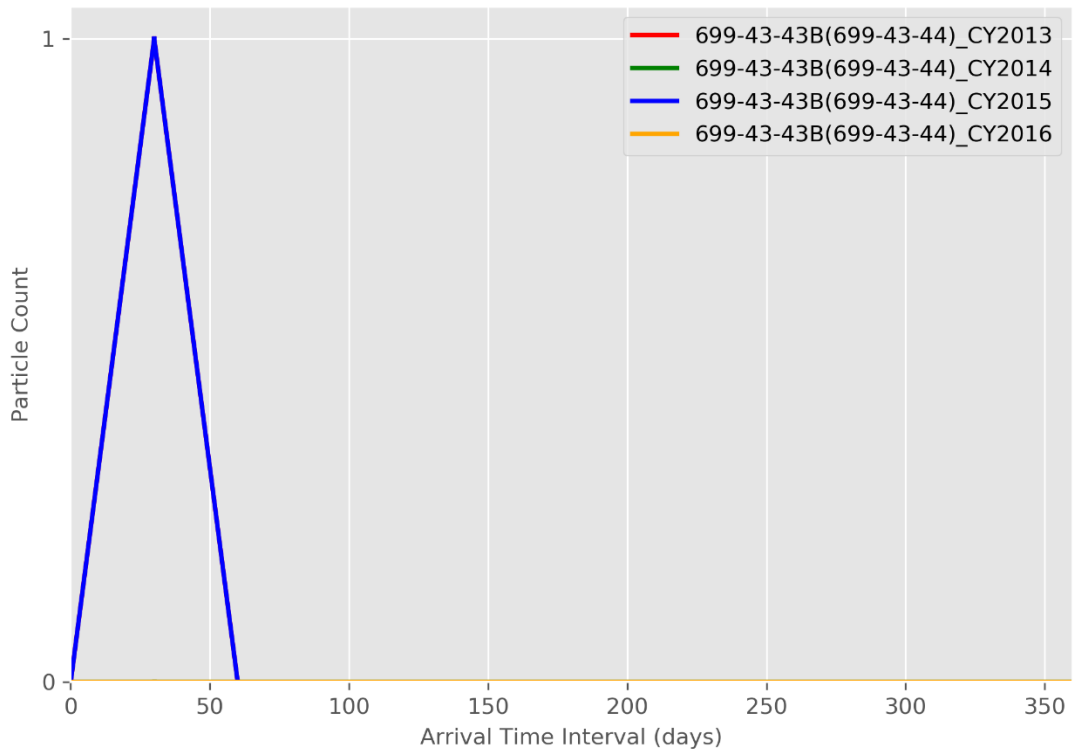

Figure F-11. Particle Breakthrough Curve at Monitoring Well 699-43-43B

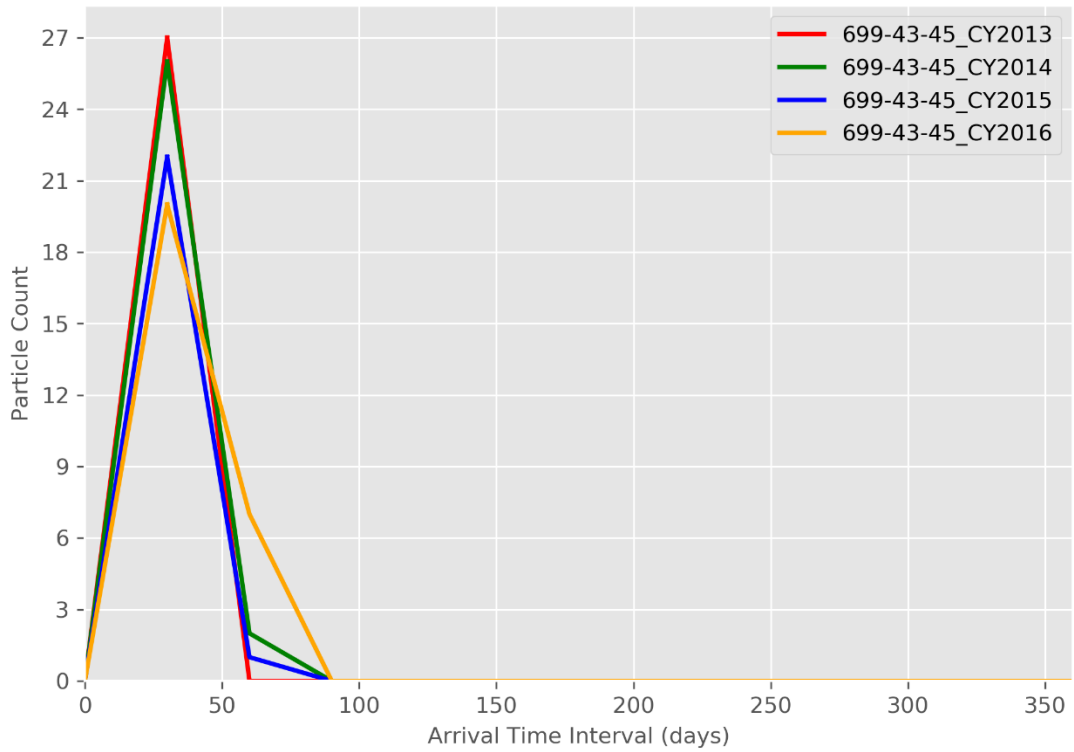

Figure F-12. Particle Breakthrough Curve at Monitoring Well 699-43-45

F3.3.3 Particle Count Maps

Figures F-13 through F-16 depict the particle count maps developed based on the instantaneous release of a large number of particles at the facility. The particle count maps depict areas of relatively higher and lower potential impact from a release at the facility that reaches the water table for conditions represented by CYs 2013, 2014, 2015, and 2016. Figures F-13 through F-16 depict the particle density after 500 days of calculated travel, by which time it was determined that all particles would have arrived at or passed by the interim status groundwater monitoring wells (see entries in Tables F-1 and F-2).

The goal of well placement is for the well locations to span the range of particle pathline distribution as released from 216-B-3 Pond. The particle count maps show that, under the evaluated range of conditions, there are areas of high particle counts where there are no corresponding monitoring wells, indicating the need for additional monitoring wells. In addition, a new upgradient well is recommended for the site to replace well 699-44-39B to provide upgradient monitoring closer to the site. This new upgradient well (216-B-3_PW-4) in combination with proposed downgradient well 216-B-3_PW-3 and existing downgradient well 699-42-42B will provide important information about groundwater flow directions in the eastern portion of 216-B-3 Pond. The locations of the four proposed wells (216-B-3_PW-1, 216-B-3_PW-2, 216-B-3_PW-3, and 216-B-3_PW-4) are shown in Figures F-13 through F-16.

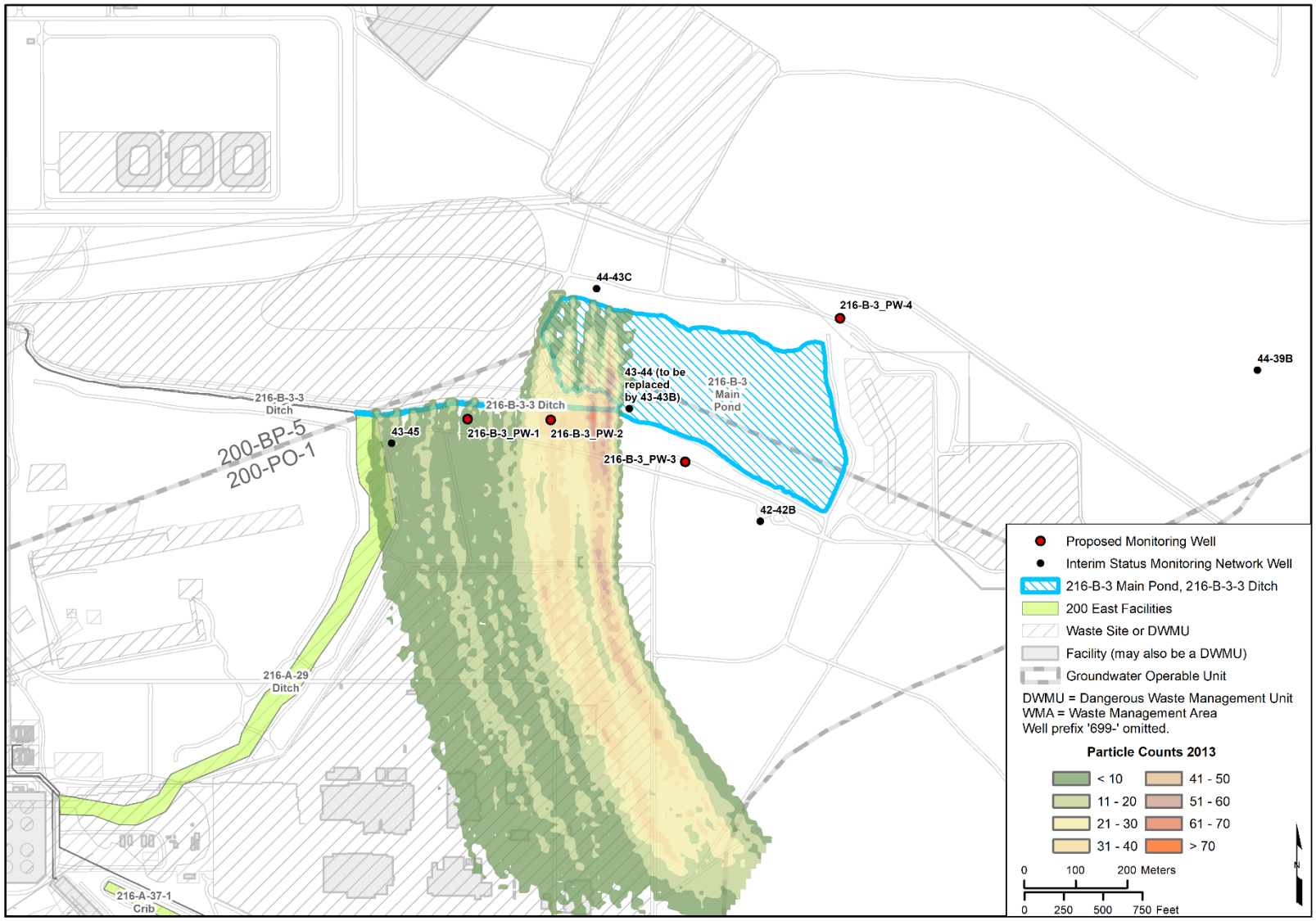

Figure F-13. Particle Count Map – 216-B-3 Pond, 2013

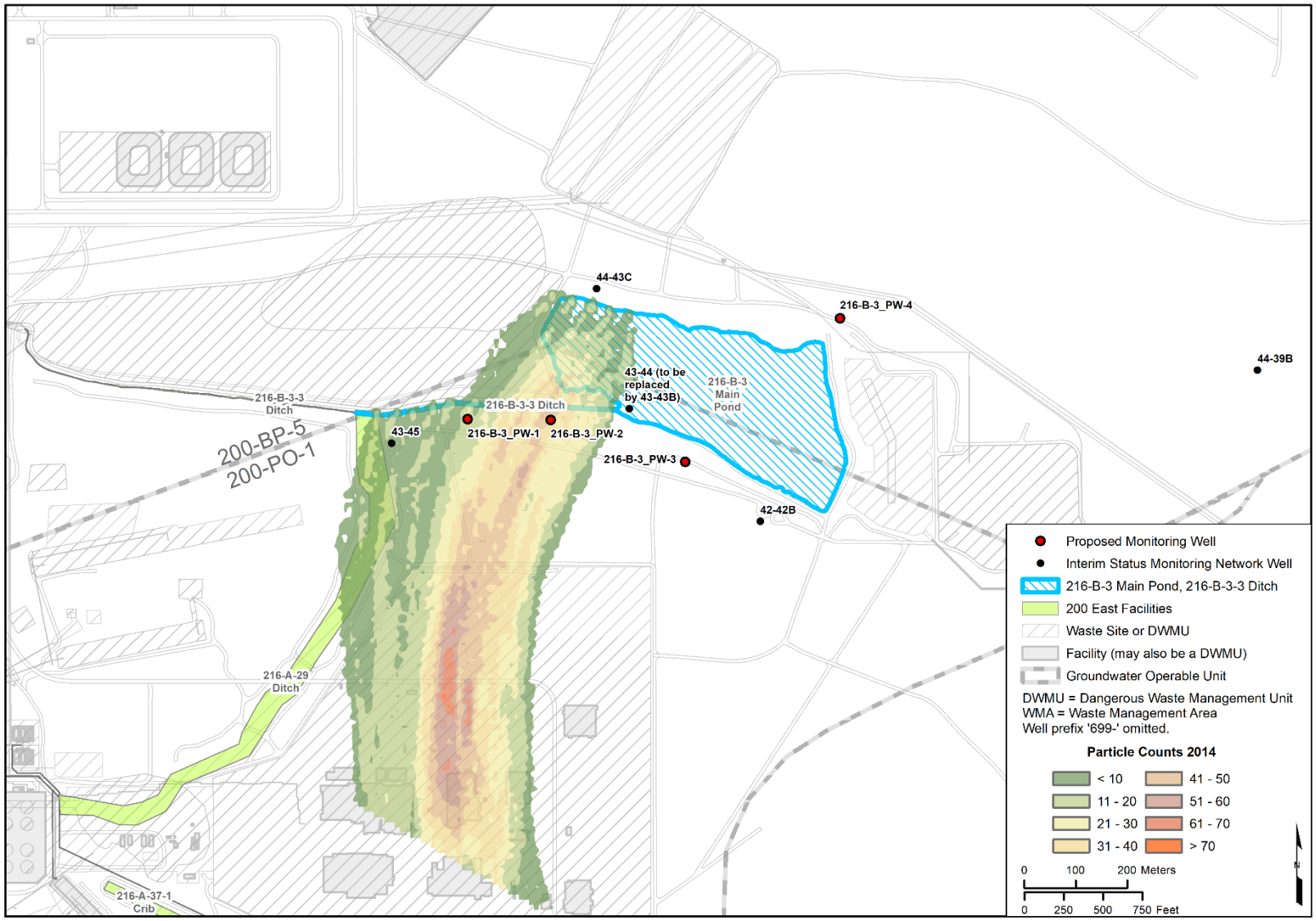

Figure F-14. Particle Count Map – 216-B-3 Pond, 2014

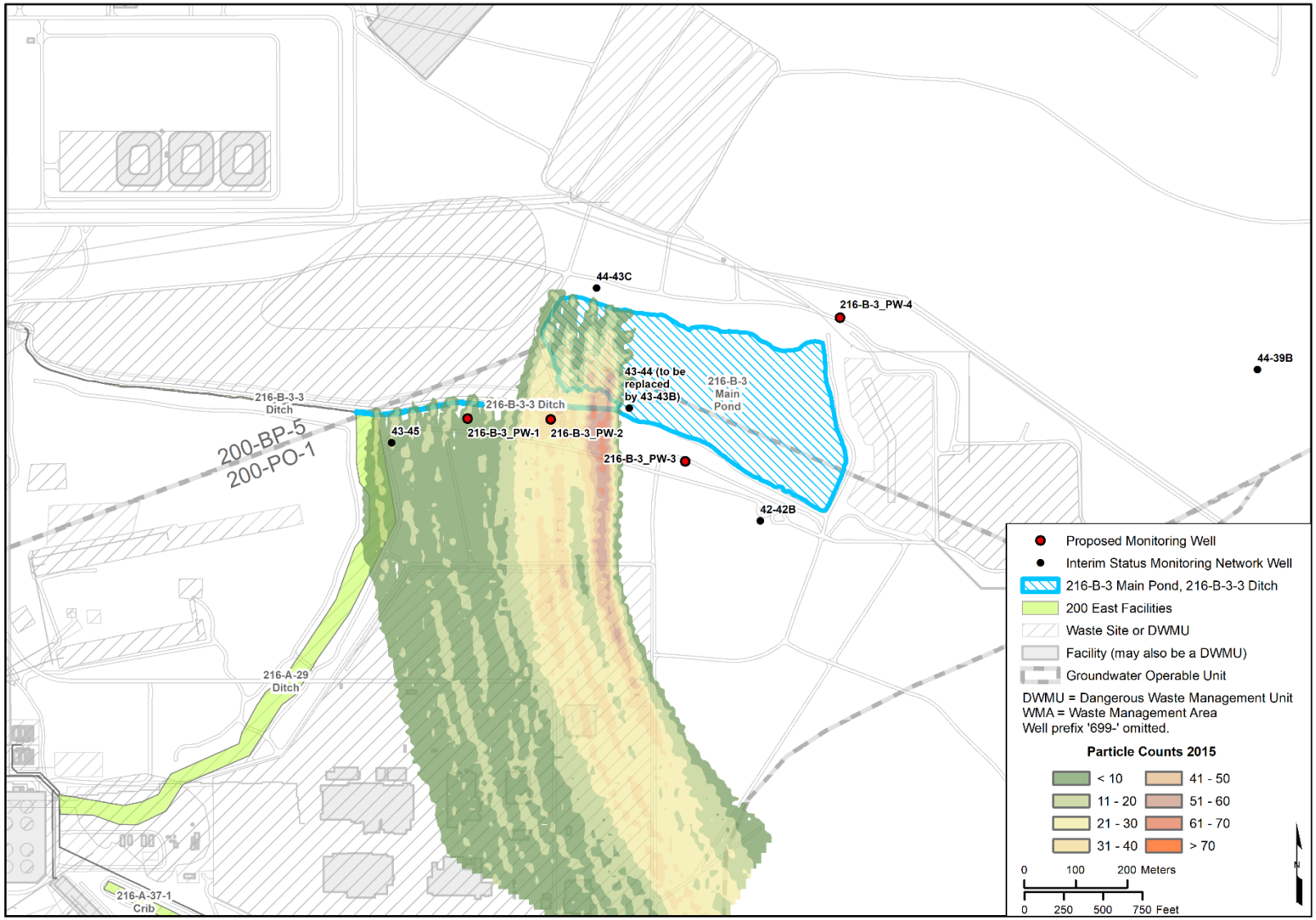

Figure F-15. Particle Count Map – 216-B-3 Pond, 2015

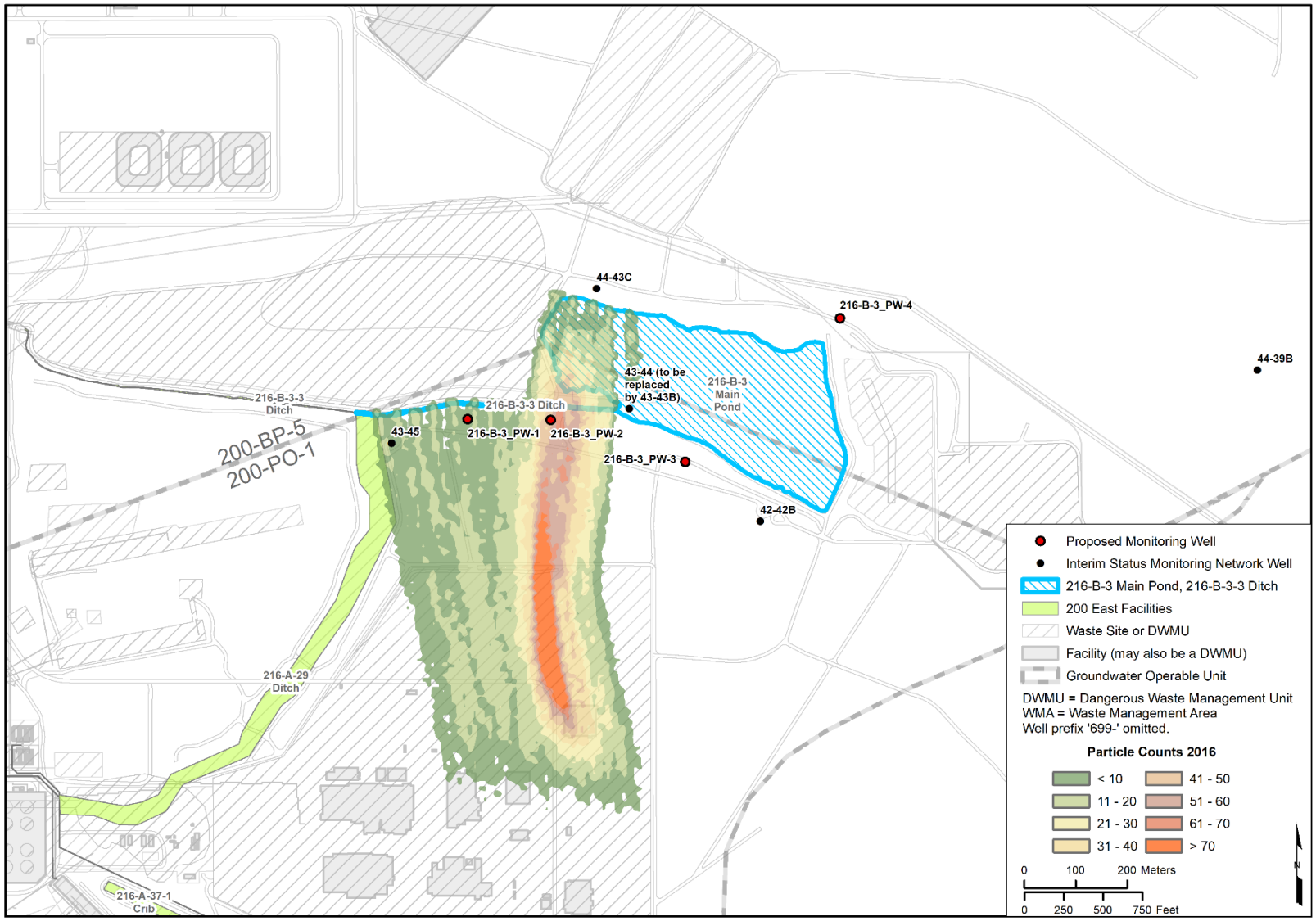

Figure F-16. Particle Count Map – 216-B-3 Pond, 2016

F3.4 Proposed Monitoring Wells

The locations of the proposed monitoring wells are shown in Figures F-13 through F-16. The particle counts tabulated for these downgradient proposed well locations (Tables F-3 and F-4) indicate the relative timing of expected detections at the wells and the relative potential of the wells for detecting a release at the facility.

As described in Section F2.1, particles were not released in the eastern portion of 216-B-3 Pond due to the hydrogeologic conditions encountered in that area. Since particles were not released in the eastern portion of 216-B-3 Pond, no particle was encountered at 216-B-3_PW-3 and particle counts are not presented for that well. Well 216-B-3_PW-3 is proposed, however, to monitor for potential releases from the eastern portion of 216-B-3 Pond within the region of potentially perched conditions. Information obtained during drilling will, in combination with proposed upgradient well 216-B-3_PW-4 and existing downgradient well 699-42-42B, provide important information about the hydrostratigraphic conditions and groundwater flow directions in the eastern portion of 216-B-3 Pond.

The particle breakthrough curves (Figures F-17 and F-18) show the relative timing and particle density at the proposed monitoring well locations for the arrival, peak, and decline in particle counts resulting from the hypothetical instantaneous release to the water table beneath the facility.

Table F-3. Particle Density (Count) Proposed Monitoring Well 216-B-3_PW-1

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
30	19	24	20	24	
60	0	1	0	1	
90	0	6	0	0	
120	0	10	0	0	
150	0	2	0	0	
180	0	0	0	0	
210	0	0	0	0	
240	0	0	0	0	
270	0	0	0	0	
300	0	0	0	0	
330	0	0	0	0	
360	0	0	0	0	Average
Total	19	43	20	25	**27**

Table F-4. Particle Density (Count) Proposed Monitoring Well 216-B-3_PW-2

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
30	79	71	94	38	
60	34	53	8	32	
90	1	19	0	33	
120	0	1	0	22	
150	0	0	0	21	
180	0	0	0	9	
210	0	0	0	1	
240	0	0	0	1	
270	0	0	0	0	
300	0	0	0	0	
330	0	0	0	0	
360	0	0	0	0	Average
Total	114	144	102	157	**129**

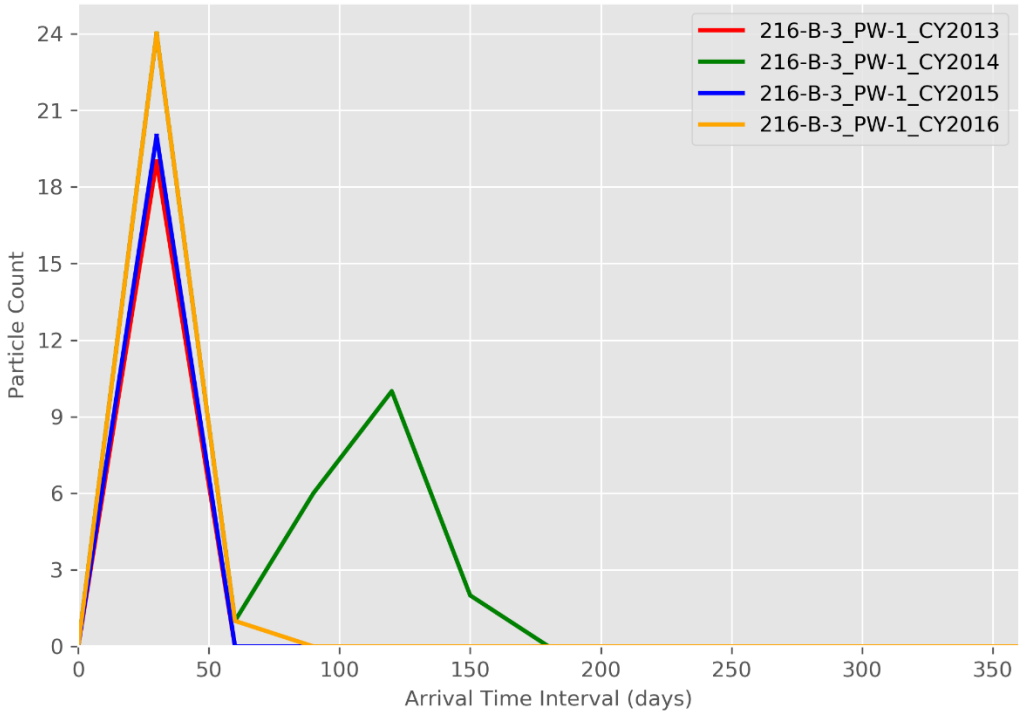

Figure F-17. Particle Breakthrough Curve at Monitoring Well 216-B-3_PW-1

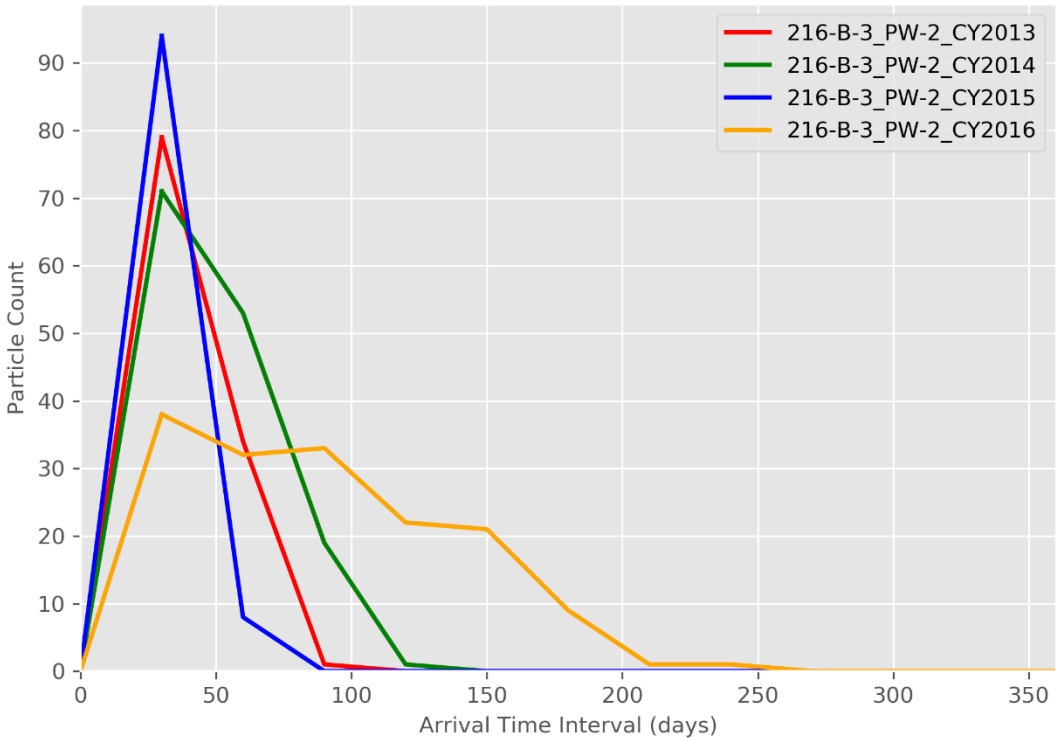

Figure F-18. Particle Breakthrough Curve at Monitoring Well 216-B-3_PW-2

F3.5 Analyses of Particle Pathlines for Each Area of 216-B-3 Pond

Particle pathline maps shown in Section F3.2 depict an instantaneous release to the water table from the release locations in 216-B-3 Pond. Particle tracking also was performed for smaller regions of the facility to evaluate well locations for detecting releases from various regions of 216-B-3 Pond. This section contains the results of analyses performed to examine how releases from the various areas of 216-B-3 Pond that reach the groundwater beneath those release areas relate to each individual monitoring well. A series of figures and tables are provided to illustrate the fate of releases originating from three different areas of the pond. For these analyses, the particle release points presented in Figure F-2 are grouped into one of three areas based on their spatial location. Those areas are depicted in Figure F-19. Figures F-20 through F-23 illustrate the particle pathlines originating from each of the areas for CYs 2013 through 2016.

Figures F-24 through F-28 illustrate the particle count time-series for each existing and proposed monitoring well from CY 2013 through CY 2016. Each figure has four panels, each of which depicts the particle counts for one CY (2013 through 2016). Additionally, each panel shows a separate breakthrough curve for particles emanating from each area. For example, Figure F-28 depicts the particle counts at well 216-B-3_PW-2, which receives particles from areas 2 and 3 in 2014. In the figure, within the panel for 2014 (top row, right), the particle breakthrough curve from area 2 is depicted with a red line and from area 3 with a purple line.

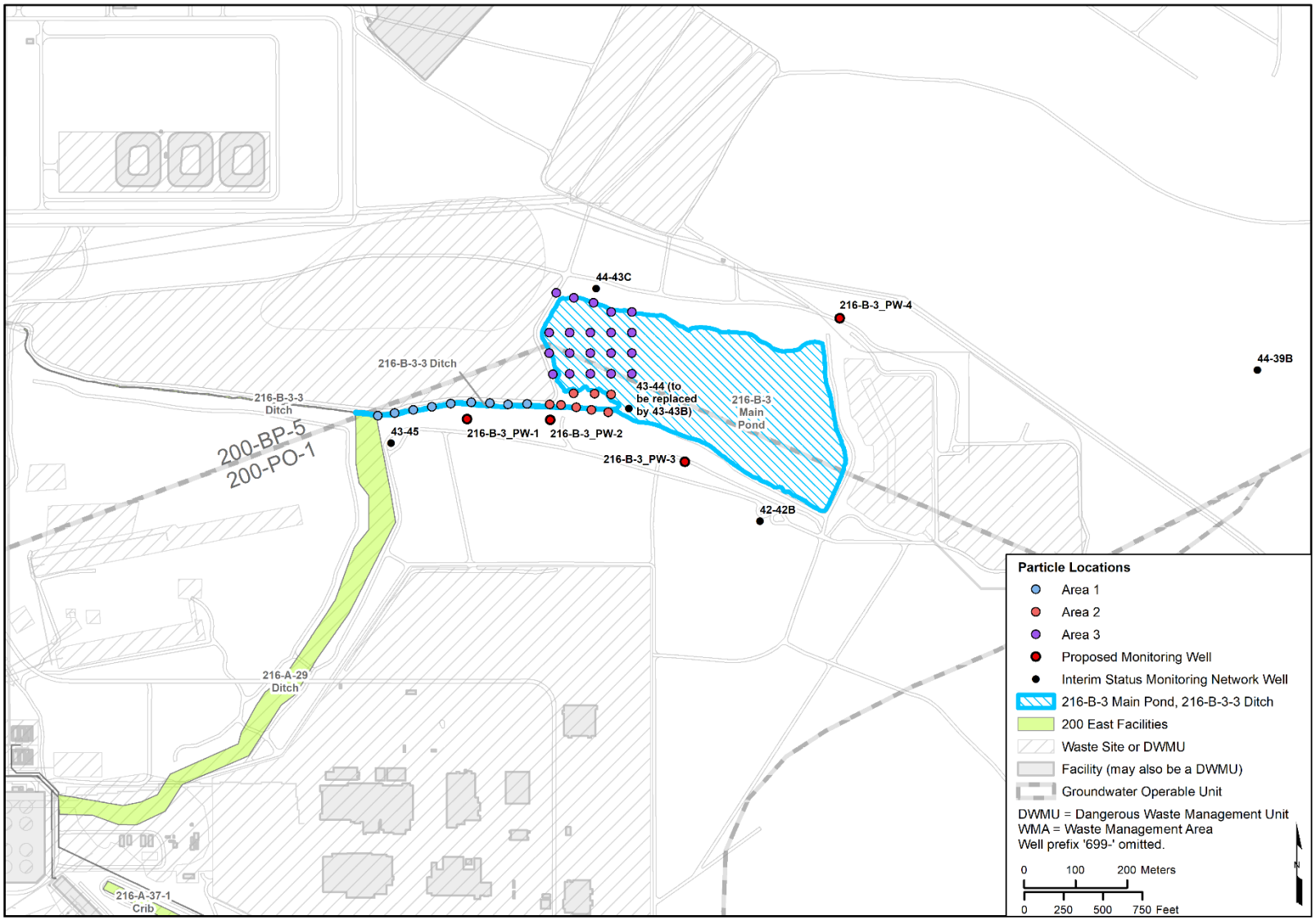

Figure F-19. Particle Release Locations and Areas of 216-B-3 Pond

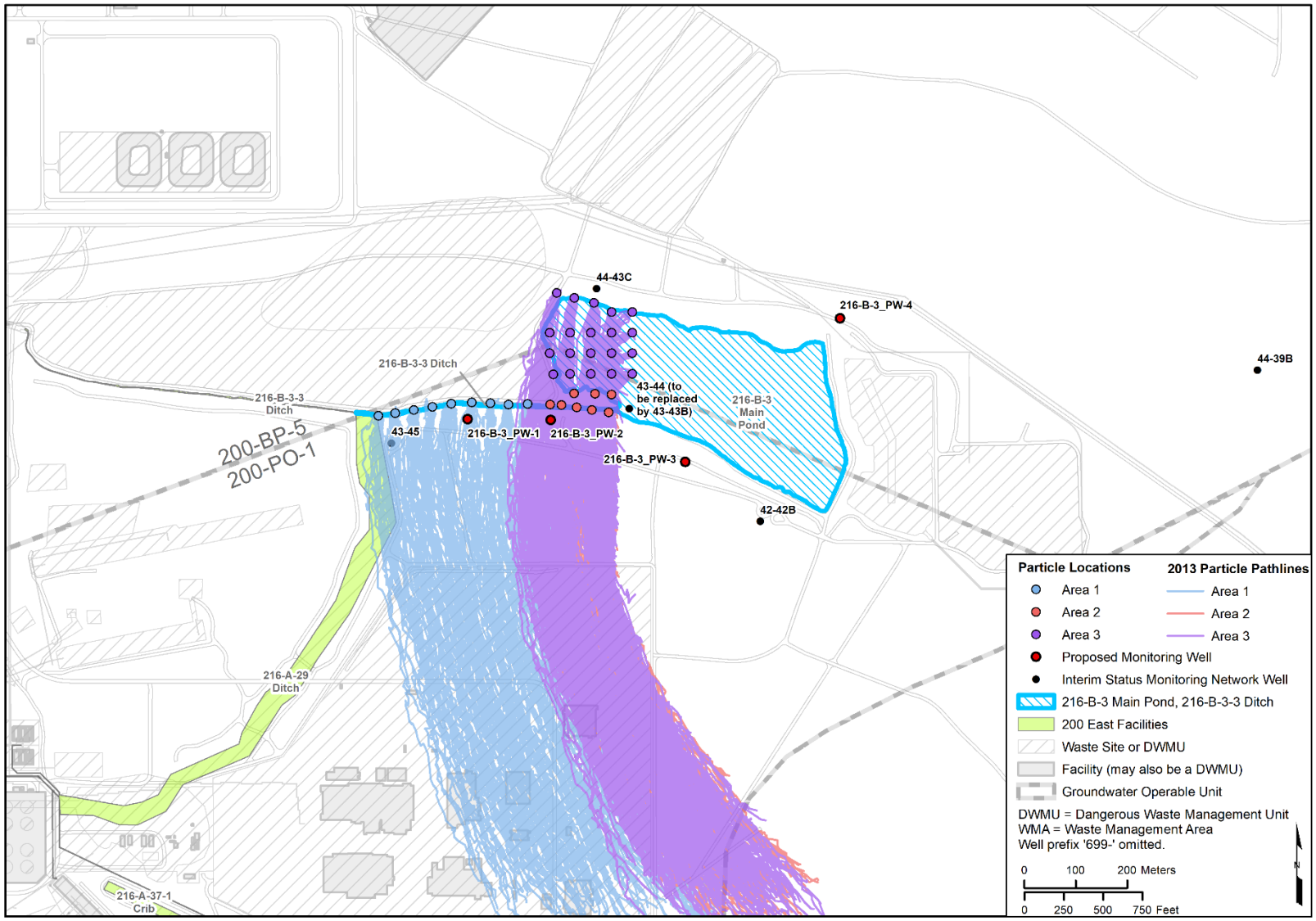

Figure F-20. CY 2013 Particle Pathlines per Area of 216-B-3 Pond

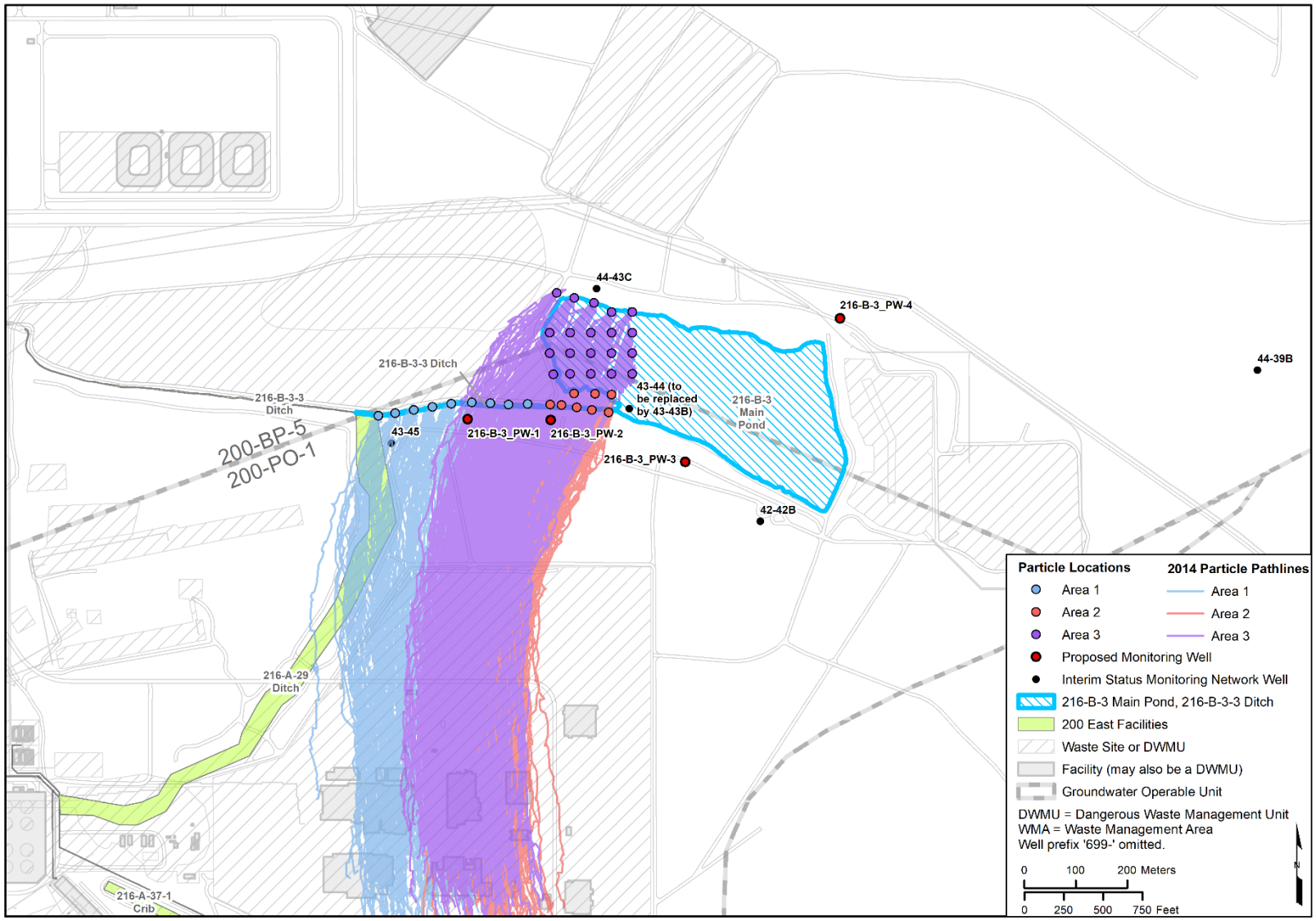

Figure F-21. CY 2014 Particle Pathlines per Area of 216-B-3 Pond

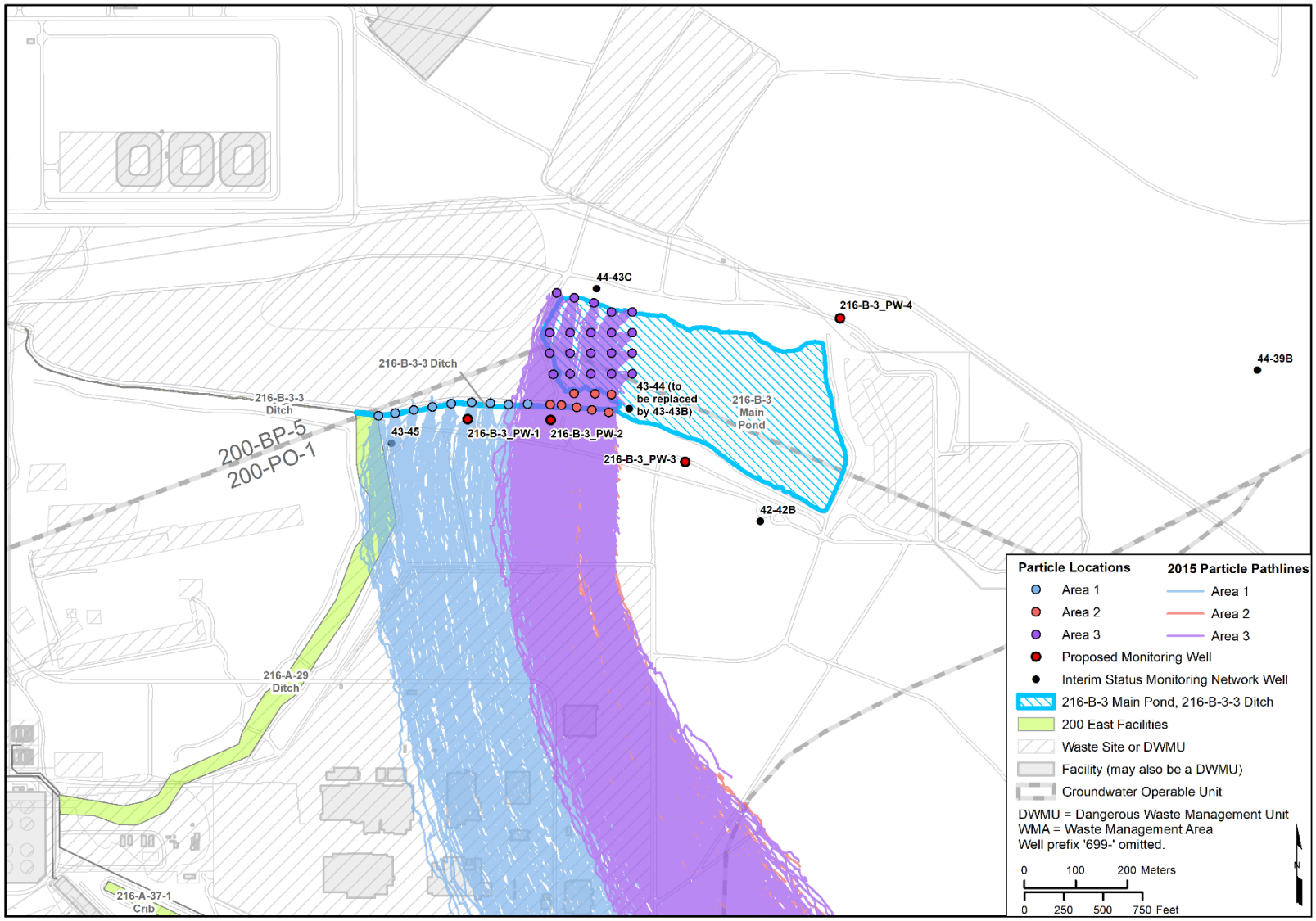

Figure F-22. CY 2015 Particle Pathlines per Area of 216-B-3 Pond

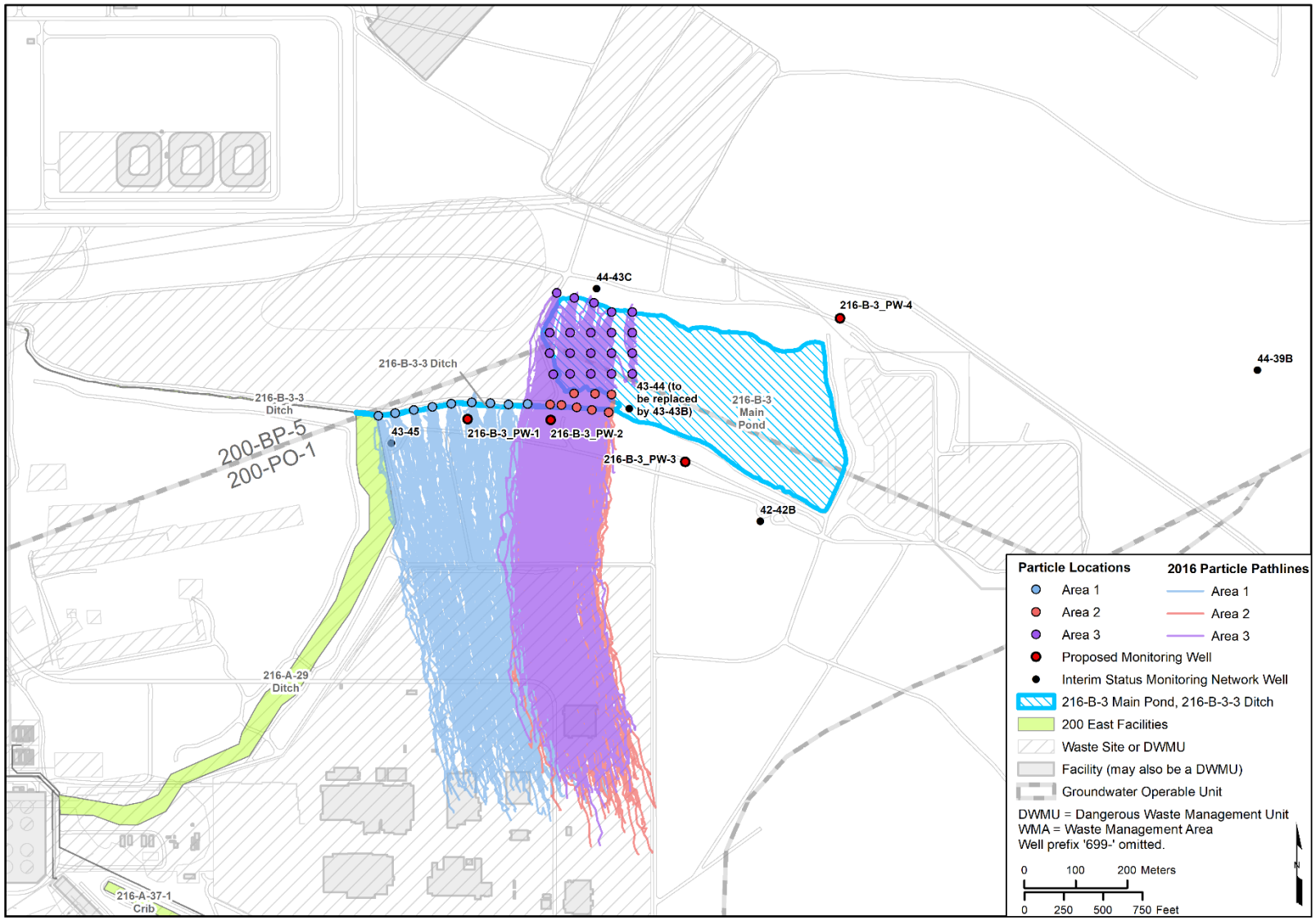

Figure F-23. CY 2016 Particle Pathlines per Area of 216-B-3 Pond

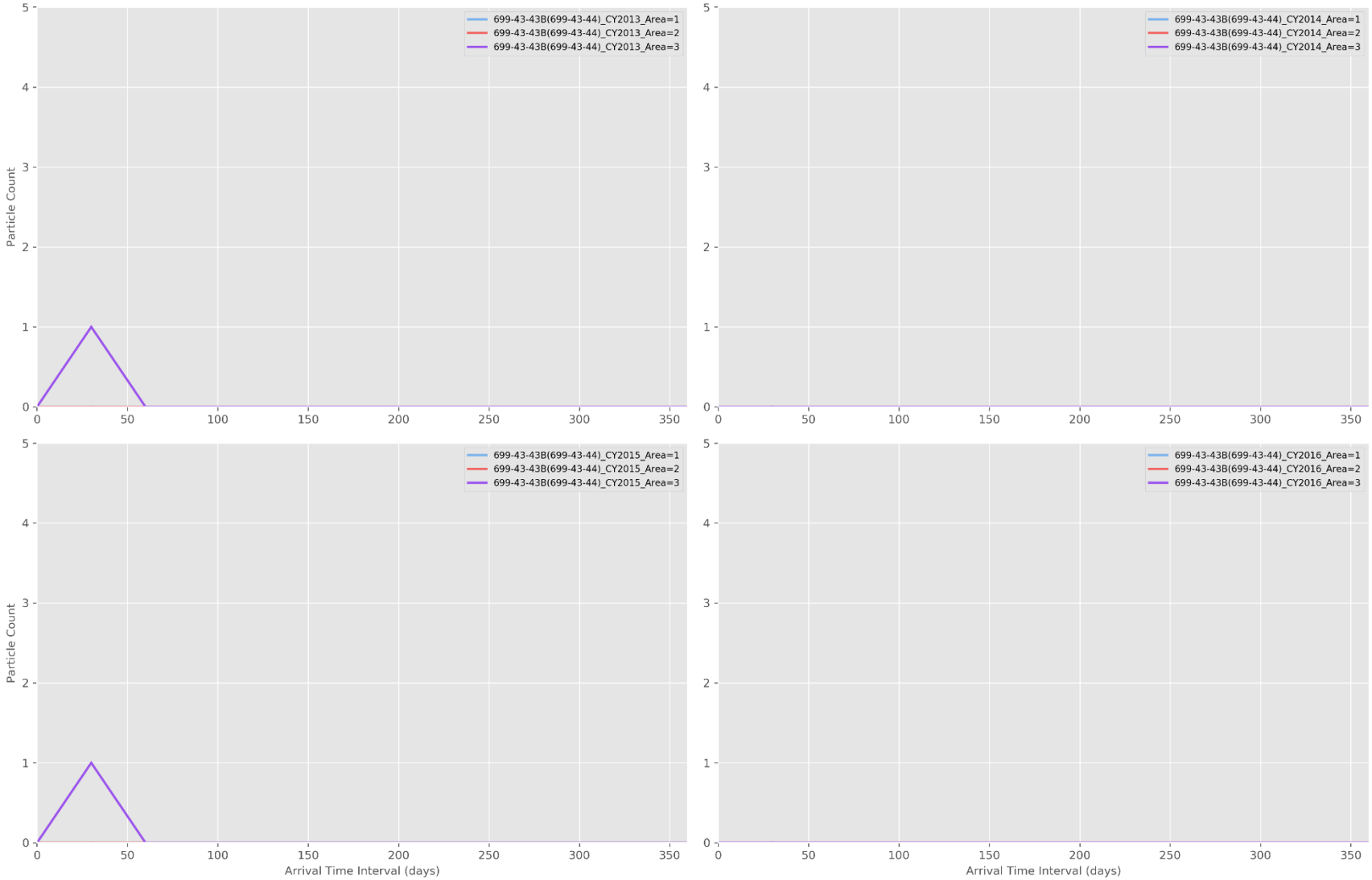

Figure F-24. Particle Breakthrough Curves per Area at Monitoring Well 699-43-43B

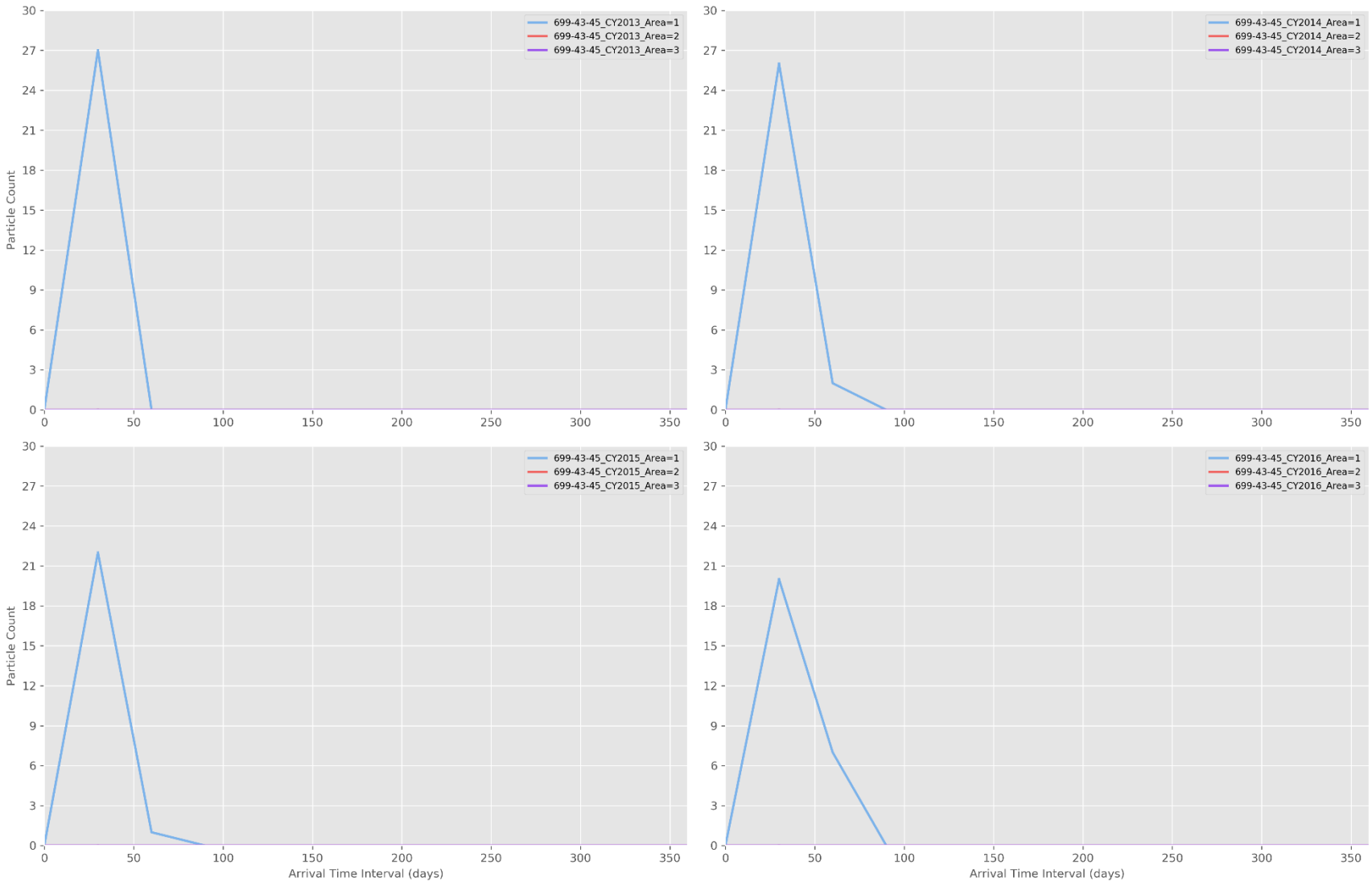

Figure F-25. Particle Breakthrough Curves per Area at Monitoring Well 699-43-45

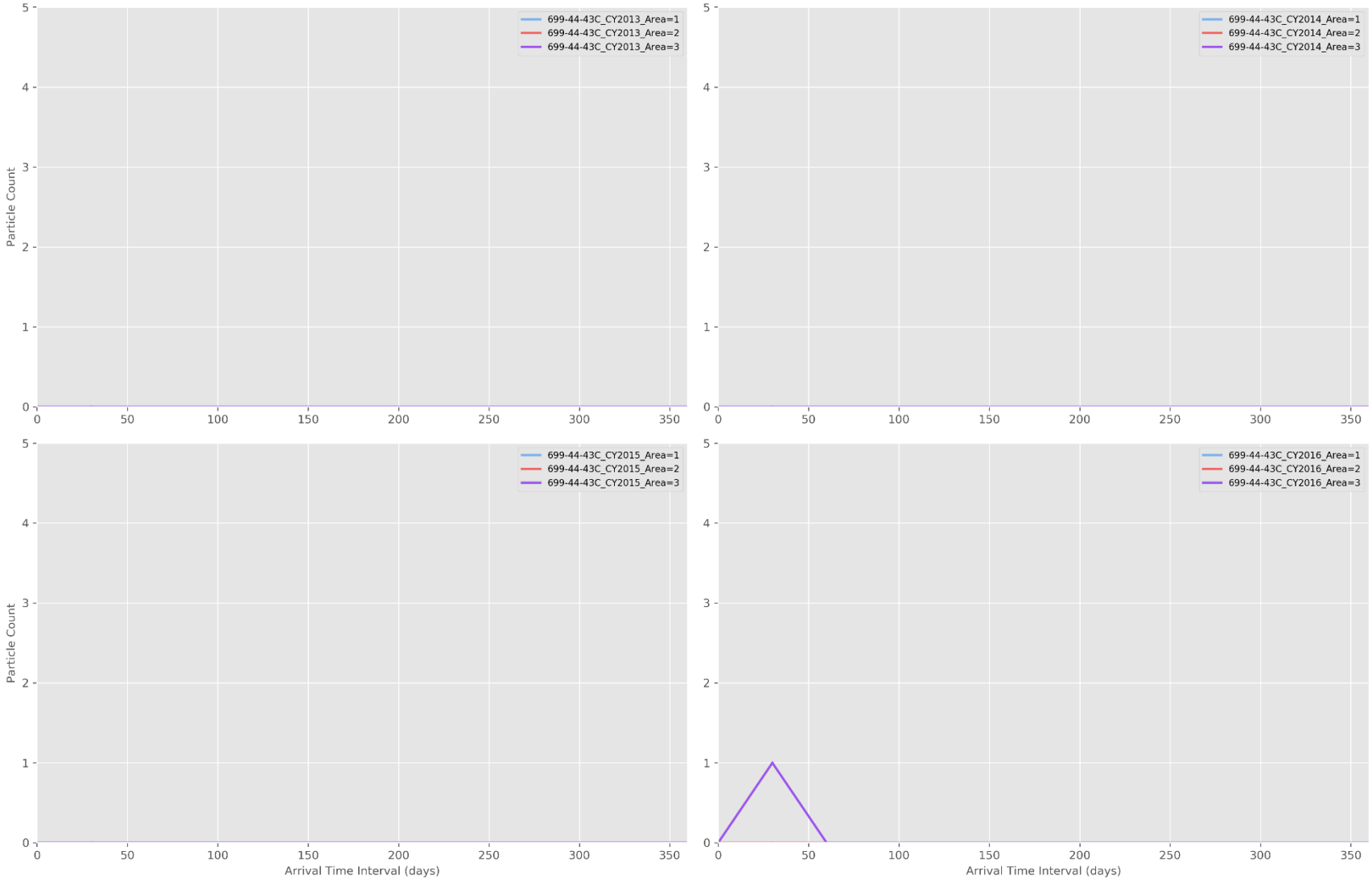

Figure F-26. Particle Breakthrough Curves per Area at Monitoring Well 699-44-43C

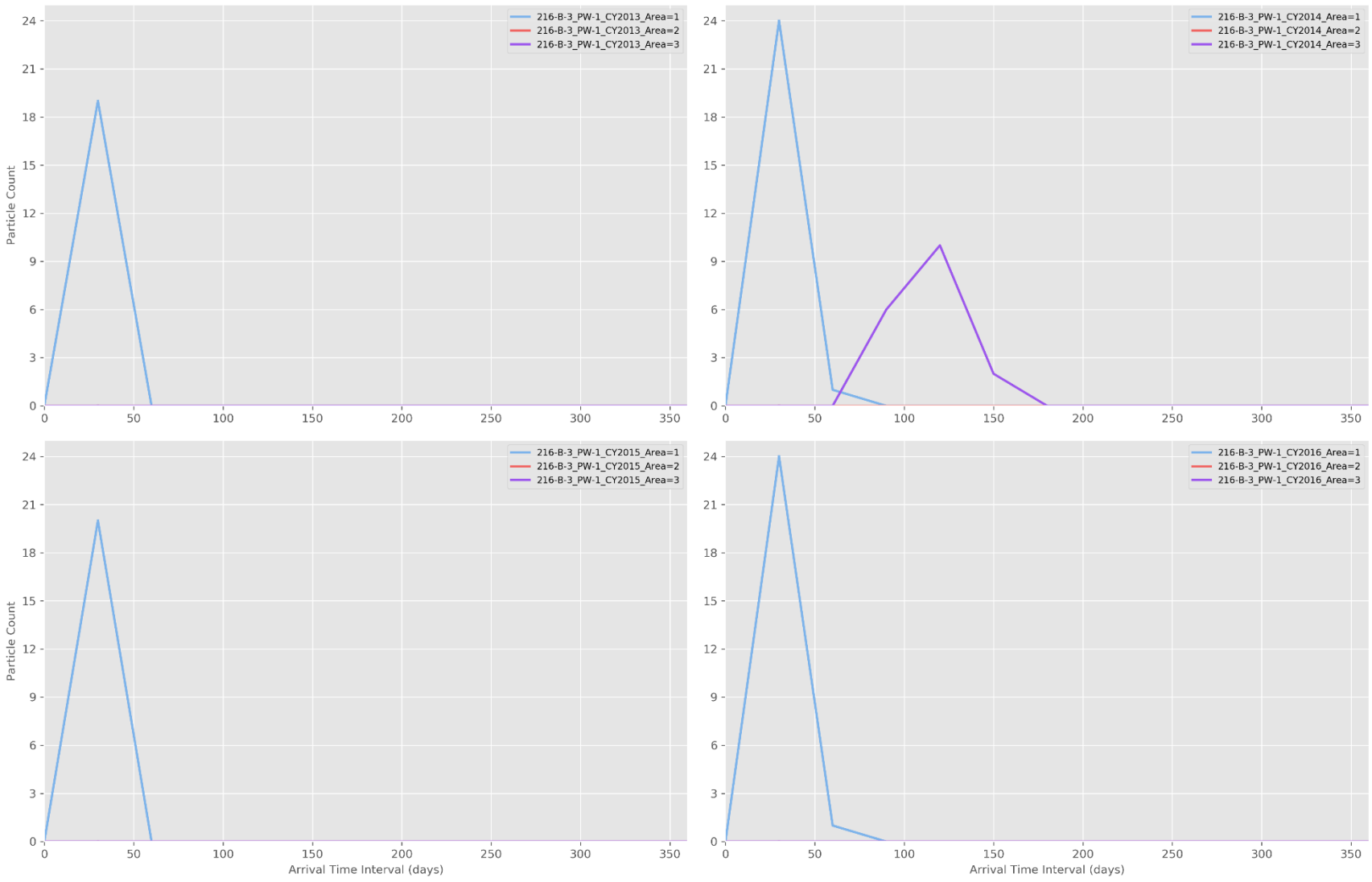

Figure F-27. Particle Breakthrough Curves per Area at Monitoring Well 216-B-3_PW-1

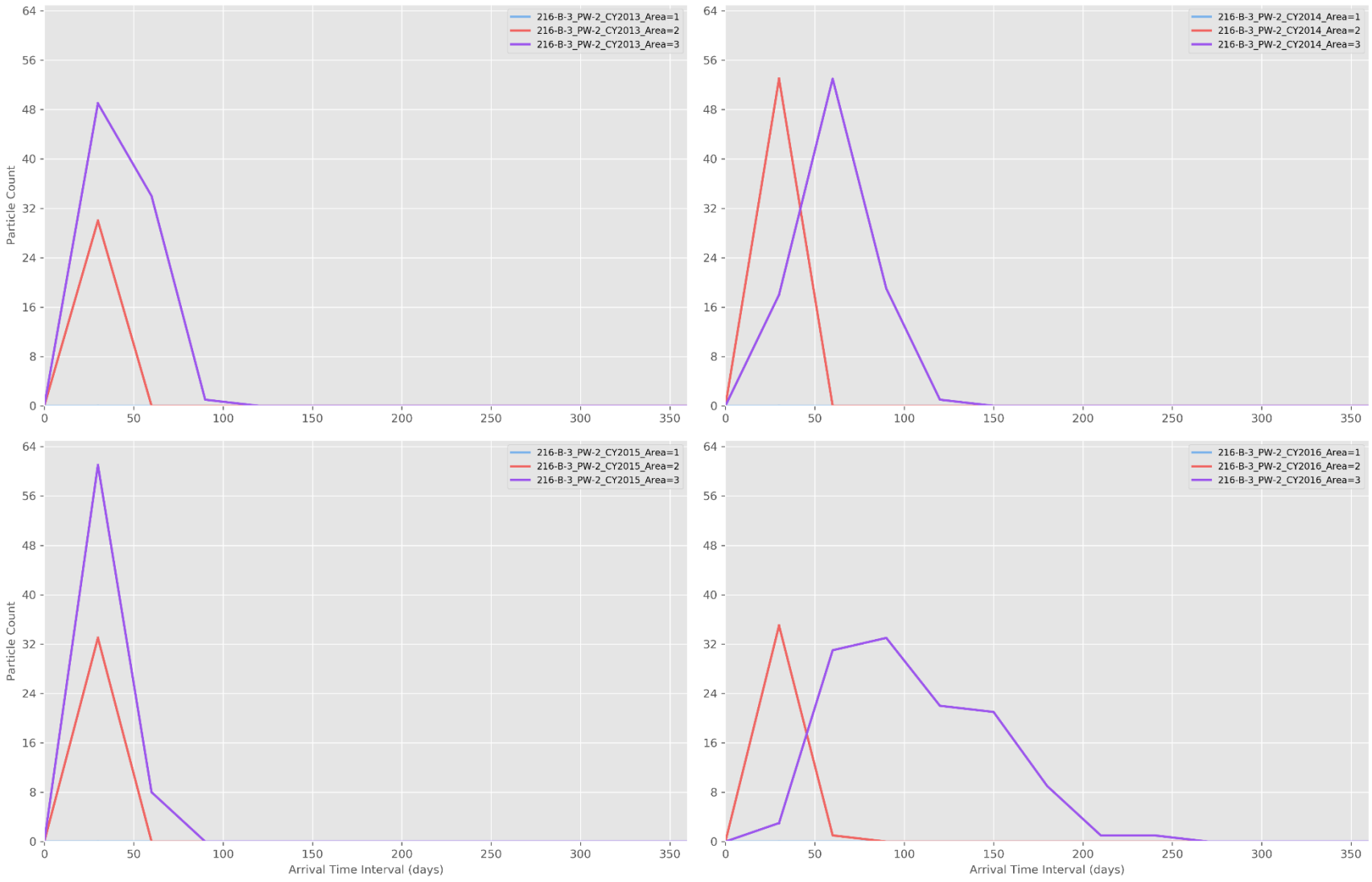

Figure F-28. Particle Breakthrough Curves per Area at Monitoring Well 216-B-3_PW-2

F3.6 Vertical Migration Potential

As described in Section 3.3 of the main text of this ECF, the American Petroleum Institute (API) plume diving calculation was used to estimate the likely rate of vertical migration of dissolved constituents downward under the influence of recharge at the water table. At each well the slope of the plume dive was multiplied by the distance from the particle starting location to the well location to estimate the depth to which the dissolved constituents may be anticipated to have migrated by the time they reach the monitoring well location.

This estimated depth of the plume was then compared to the depth from the water table to the bottom of the monitoring well screen. If the depth of the plume is below the bottom of the monitoring well screen, then the dissolved constituents may be anticipated to pass beneath the well screen. If it falls within the interval between the top of the water table and the bottom of the well screen, then the well depth is appropriate for detection of releases at 216-B-3 Pond.

For each downgradient monitoring well at 216-B-3 Pond, the distance from the centroid of the facility to each well was used in the calculation. The hydraulic conductivity used in the calculation for 216-B-3 Pond, 18,200 m/d (59,711 ft/d), is the calibrated hydraulic conductivity from the CPGWM for the Cold Creek unit, which underlies the facility. The results of the API plume diving calculation for the downgradient wells for 216-B-3 Pond are shown in Table F-5.

Table F-5. Summary of Well Screen Interval Evaluation for Downgradient Wells

Monitoring Well	Existing or Proposed Well?	Distance, D, (m)[a]	Recharge, *i*, (m/yr)[b]	Slope, S, of Plume Dive[c]	Estimated Depth of Plume Below Water Table (m)[d]	Depth from Water Table to Bottom of Well Screen (m)[e]	Is Plume Depth Above Bottom of the Screen? (Yes/No/N/A)
699-42-42B	Existing	277.5	1.21E-01	8.51E-04	2.36E-01	6.70	Yes
699-43-43B[f]	Installation scheduled for FY 2018	143.1	1.21E-01	8.51E-04	1.22E-01	N/A	N/A
699-43-45	Existing	608.3	1.21E-01	8.51E-04	5.18E-01	1.50	Yes
216-B-3_PW-1	Proposed	455.6	1.21E-01	8.51E-04	3.88E-01	N/A	N/A
216-B-3_PW-2	Proposed	297.0	1.21E-01	8.51E-04	2.53E-01	N/A	N/A
216-B-3_PW-3	Proposed	141.0	1.21E-01	8.51E-04	1.20E-01	N/A	N/A

a. Distance of the well from centroid of dangerous waste management unit.

b. A representative number from the CPGWM. The recharge values represent fluxes from surface water discharge due to historical operations at the Hanford Site and are summarized in EMDT-BC-0002, *Vadose Zone Attenuated Recharge, Electronic Modeling Data Transmittal – Boundary Condition (Artificial Recharge)*-0002. The anthropogenic flux is added to the natural recharge component in order to establish the final total recharge flux used in the simulations. Discharges included in EMDT-BC-0002 have been attenuated to account for travel through the vadose zone.

c. Slope of the plume dive computed using the American Petroleum Institute plume diving calculation as detailed in the main text of this ECF. The migration parameters for the 216-B-3Pond used in the calculation of slope are as follows:

Hydraulic conductivity: 18,200 m/d (59,711 ft/d) (a calibrated value from the CPGWM)

Hydraulic gradient: 2.1E-05 (determined from 2016 water-level maps produced using TRIM)

d. Plume depth at monitoring well location computed from distance, D, times the slope, S.

Table F-5. Summary of Well Screen Interval Evaluation for Downgradient Wells

Monitoring Well	Existing or Proposed Well?	Distance, D, (m)[a]	Recharge, *i*, (m/yr)[b]	Slope, S, of Plume Dive[c]	Estimated Depth of Plume Below Water Table (m)[d]	Depth from Water Table to Bottom of Well Screen (m)[e]	Is Plume Depth Above Bottom of the Screen? (Yes/No/N/A)

e. Depths obtained from Table 3-3 in DOE/RL-2008-59, *Interim Status Groundwater Monitoring Plan for the 216-B-3 Pond*.

f. Well to replace existing well 699-43-44. Assumed location will be at the current location of well 699-43-44.

CPGWM = Central Plateau Groundwater Model

ECF = environmental calculation file

FY = fiscal year

N/A = not applicable

TRIM = Tikhonov Regularized Inverse Method

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Appendix G

Facility-Specific Results for the 216-B-63 Trench

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Terms

API	American Petroleum Institute
CPGWM	Central Plateau Groundwater Model
CY	calendar year
ECF	environmental calculation file
TRIM	Tikhonov Regularized Inverse Method

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G1 Purpose and Background

The primary purpose of the calculations presented here is to estimate directions of potential migration to assess the efficacy of the geographical distribution of wells in the proposed monitoring well network for the subject facility. The calculations described within the main text of this environmental calculation file (ECF) were performed for each of the 200 East Facilities. This appendix presents results developed from the calculations that are specific to the 216-B-63 Trench.

Located in the north-central part of the 200 East Area, the 216-B-63 Trench (Figure G-1), beginning in 1970, was used as an emergency percolation trench for chemical sewer wastes from B Plant. Major contributors to this waste were the 2902-B High Tank (contains potable sanitary water), cooling water from B Plant and the 225-B Waste Encapsulation and Separation Facility, some 221-B steam condensate, and demineralizer effluent. Minor contributions may have included the chemical makeup overflow system (sodium hydroxide and sodium nitrite), air conditioning units, and space heaters (radiators). Discharges to the 216-B-63 Trench ceased in 1992 (Section 2.7 in DOE/RL-2016-66, *Hanford Site RCRA Groundwater Monitoring Report for 2016*).

The U.S. Department of Energy monitors the groundwater near the trench under an interim status indicator evaluation program in accordance with 40 CFR 265, Subpart F, “Interim Status Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities,” “Ground-Water Monitoring,” as defined in DOE/RL-2008-60, *Interim Status Groundwater Monitoring Plan for the 216-B-63 Trench*. An update of this plan was completed in 2012 to realign the upgradient and downgradient monitoring network to changing groundwater flow directions. Prior to this change, groundwater flow was predominantly north-northwest, and the current groundwater flow direction is to the southeast. Previously, there was no evidence of contaminant effects on groundwater quality from the 216-B-63 Trench (Section 2.7 in DOE/RL-2016-66).

The 216-B-63 Trench interim status monitoring network (Figure G-1) consists of three upgradient wells (299-E33-33, 299-E34-8, and 299-E34-12) and three downgradient wells (299-E27-16, 299-E27-18, and 299-E27-19). The wells are screened in the upper part of the aquifer at the water table (Section 2.7 in DOE/RL-2016-66). Most of the well screens extend to within 1.5 m (5 ft) of the underlying basalt surface. This ECF presents calculations that evaluate the efficacy of the groundwater monitoring network for detecting hypothetical releases from the 216-B-63 Trench at existing and potential new monitoring well locations.

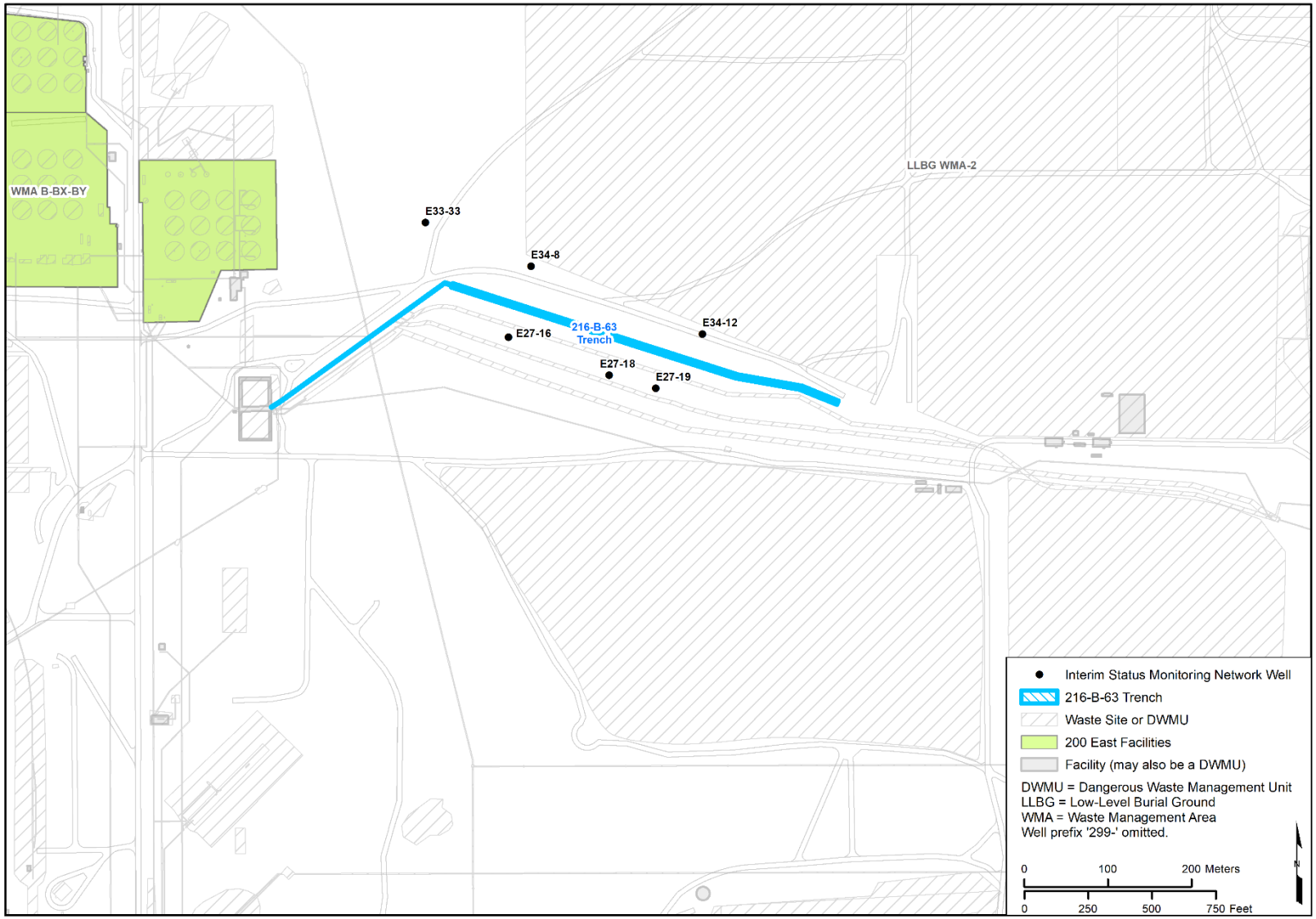

Figure G-1. Locations of Interim Status Groundwater Monitoring Wells at the 216-B-63 Trench

G2 Facility-Specific Input for the 216-B-63 Trench

Inputs used in the calculations that were specific to the 216-B-63 Trench are described in this chapter.

G2.1 Particle Count Grid and Release Locations

To prepare particle count maps, a distribution of facility-specific starting locations is required. The starting locations for the particle-tracking calculations represent the area over which a potential release from a given facility would impact the underlying water table. The particle releases were located at plausible release sites throughout the facility. For the 216-B-63 Trench, 31 release locations were specified along the centerline of the trench (Figure G-2). Twenty particles were released and tracked from each release location to provide the density of particles in space and time required for the detailed facility-specific calculations, randomizing the seed values for the dispersion calculations. Thus, 620 [620 = 31 (release locations) × 20 (releases)] particles were tracked for each of the four simulations

Contour maps of particle counts were generated by counting the number of particles that pass through a pre-defined uniform calculational grid (Figure G-2). The grid used to develop the relative particle density maps is defined by 10 by 10 m (33 by 33 ft) cells. The grid is oriented to be parallel to the predominant groundwater flow direction at the 216-B-63 Trench.

G2.2 Migration Parameters

Parameters specific to the groundwater flow conditions at the 216-B-63 Trench are reported throughout the various documents for the facility. The parameters used in the calculations performed herein to represent nonreactive dissolved contaminant migration are mobile (or effective) porosity and hydraulic conductivity. The parameters used in these calculations are representative of local conditions for a conservative (i.e., nonreactive) solute dissolved within groundwater.

There is a range of hydraulic conductivity values reported in site literature for the 216-B-63 Trench. Values range from 139 m/d (456 ft/d) (Table 2 in ECF-Hanford-16-0013, *Hydraulic Gradients and Velocity Calculations for RCRA Sites in 2015*) to 17,000 m/d (55,774 ft/d) (Table 1 in ECF-Hanford-17-0241, *Hydraulic Gradient and Velocity Calculations for RCRA Sites in 2017*). As described in Section 4.2.1.1 of the main text of this ECF, the hydraulic conductivity used in the work performed herein corresponds to the calibrated values from the Central Plateau Groundwater Model (CPGWM) (CP-47631, *Model Package Report: Central Plateau Groundwater Model, Version 8.4.5*). Figure 3-2 in the main text of this ECF indicates the 216-B-63 Trench is located in both the hydrostratigraphic unit zones corresponding to the Cold Creek Unit and the Hanford formation. The values used for the hydraulic conductivity for the 216-B-63 Trench are 18,200 m/d (59,711 ft/d) and 15,000 m/d (49,213 ft/d), which corresponds to the Cold Creek unit and the Hanford formation, respectively, as shown in Table 4-1 in the main text of this ECF. The mobile (effective) porosity defined for the Cold Creek unit and the Hanford formation, which underlie the 216-B-63 Trench, is specified at 0.25.

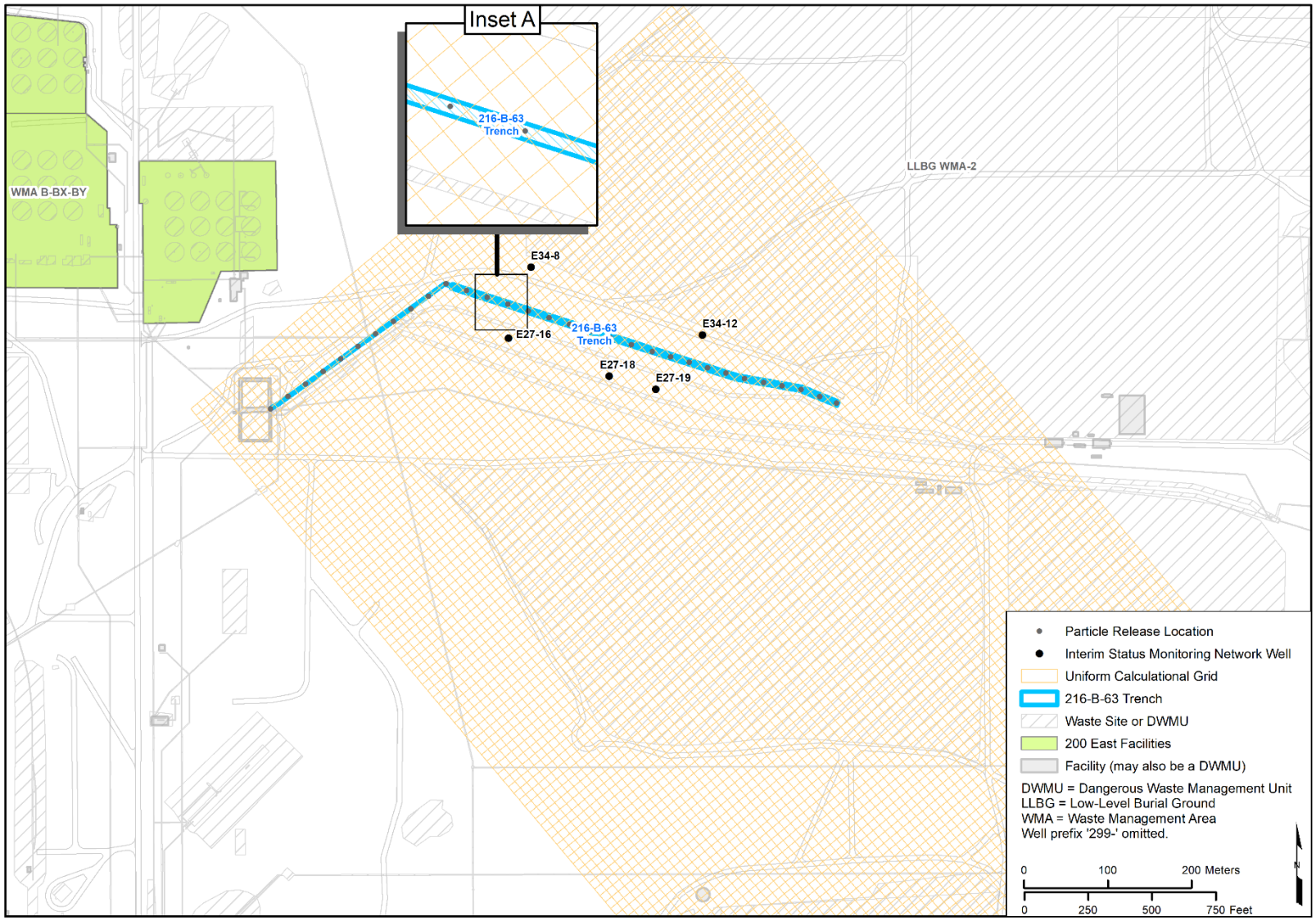

Figure G-2. Uniform Calculational Grid and Release Locations at the 216-B-63 Trench

G3 Facility-Specific Results for the 216-B-63 Trench

The groundwater elevation contours prepared in the vicinity of the 216-B-63 Trench using the Tikhonov Regularized Inverse Method (TRIM) are presented in this chapter. In addition, the outputs of the particle tracking and particle count calculations are presented including the following:

- Maps of calculated particle pathlines for the flow conditions determined for each of the four years (2013, 2014, 2015, and 2016). These are presented at the facility-specific scale considering advective and dispersive migration.
- Time-series plots, referred to as particle breakthrough curves, of the relative arrival, peak, and decline in particle counts at each interim status groundwater monitoring well location and each proposed monitoring location, where applicable.
- Tabulation of relative particle counts for each interim status groundwater monitoring well location and each proposed monitoring location, where applicable.
- Maps of particle counts downgradient of each facility based on the flow conditions determined for each of the four years.

The results of calculations of potential vertical migration of contaminants at the monitoring well locations are also presented.

G3.1 Groundwater Elevation Contours

Figures G-3 through G-6 show the results of the groundwater elevation analysis completed using TRIM in the vicinity of the 216-B-63 Trench. The figures depict general patterns of groundwater elevations and hydraulic gradients for conditions represented by calendar years (CYs) 2013, 2014, 2015, and 2016. These groundwater elevation contours and associated hydraulic gradients form the basis for the facility-specific calculations performed for this ECF.

G3.2 Particle Tracking

Once the groundwater elevation contour maps and underlying piecewise continuous elevation grids were prepared using TRIM, particle tracking was implemented using both advection and dispersion.
The particle pathlines that were produced depict the patterns of spreading that might accompany the migration of contaminants near the trench for the flow conditions calculated for CYs 2013, 2014, 2015, and 2016. Figures G-7 through G-10 depict the particle pathlines developed based on the groundwater elevations prepared throughout the 200 East Area using TRIM. The resulting maps were prepared based on the release of 20 particles from each starting location to provide the high density of particles in space and time required for these detailed facility-specific calculations. Figures G-7 through G-10 depict the particle pathlines calculated after 800 days of travel, by which time it was determined that most of the particles would have arrived at or passed by the interim status groundwater monitoring wells. Figures G-7 through G-10 depict an instantaneous release to the water table from the release locations in the 216-B-63 Trench to illustrate the adequacy of the well network for monitoring the entire facility.

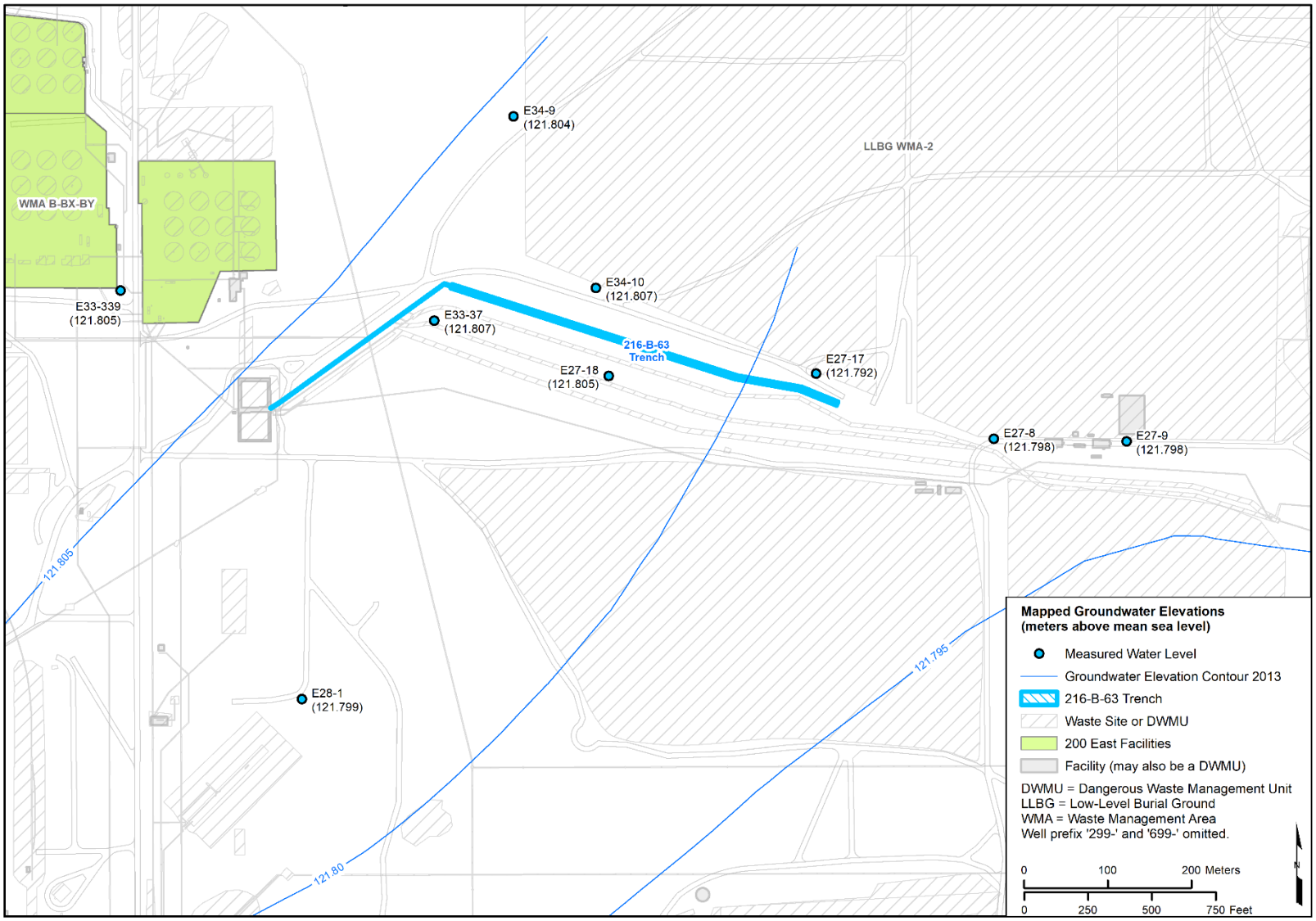

Figure G-3. Water-Level Elevation Map for the 216-B-63 Trench, 2013

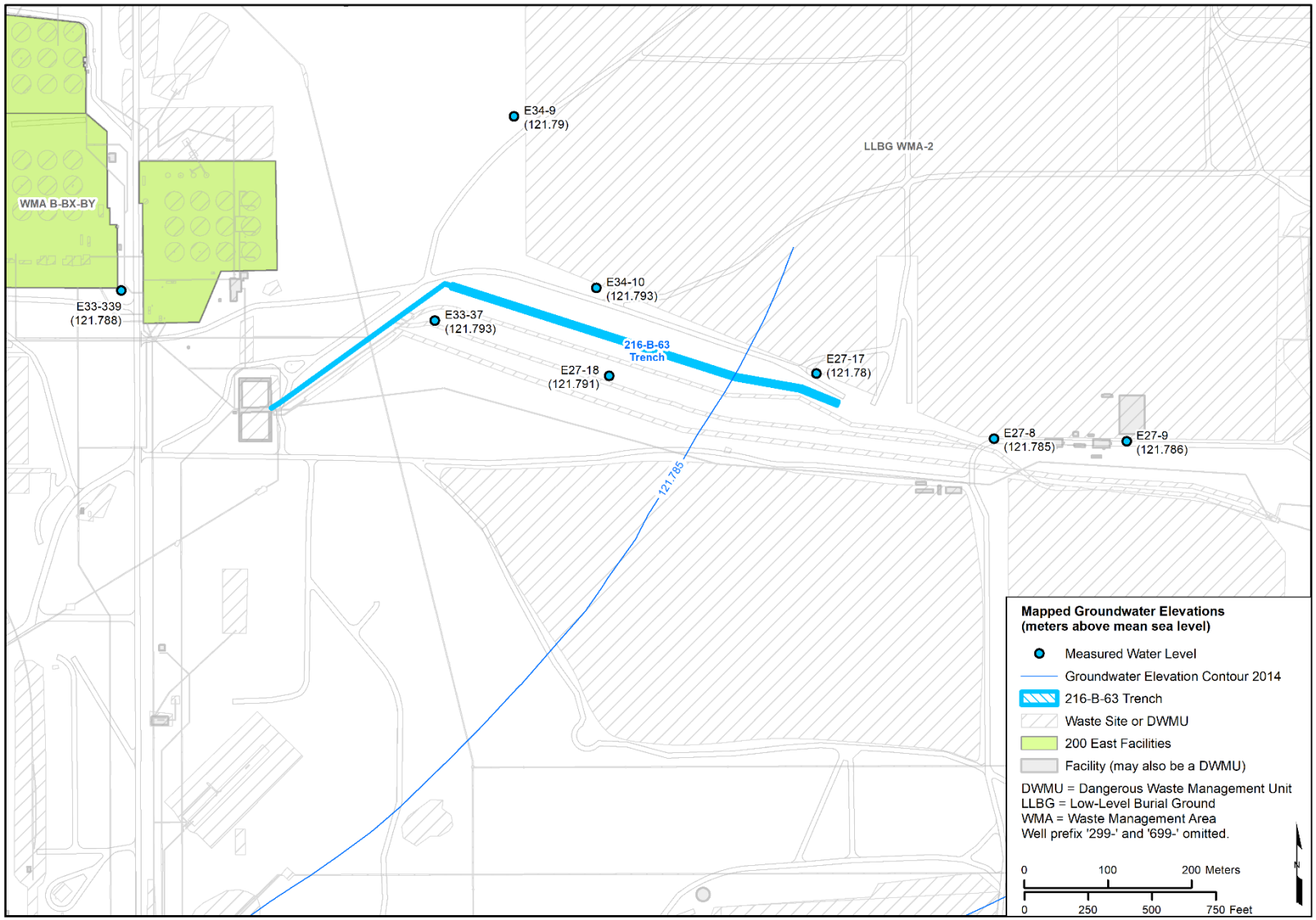

Figure G-4. Water-Level Elevation Map for the 216-B-63 Trench, 2014

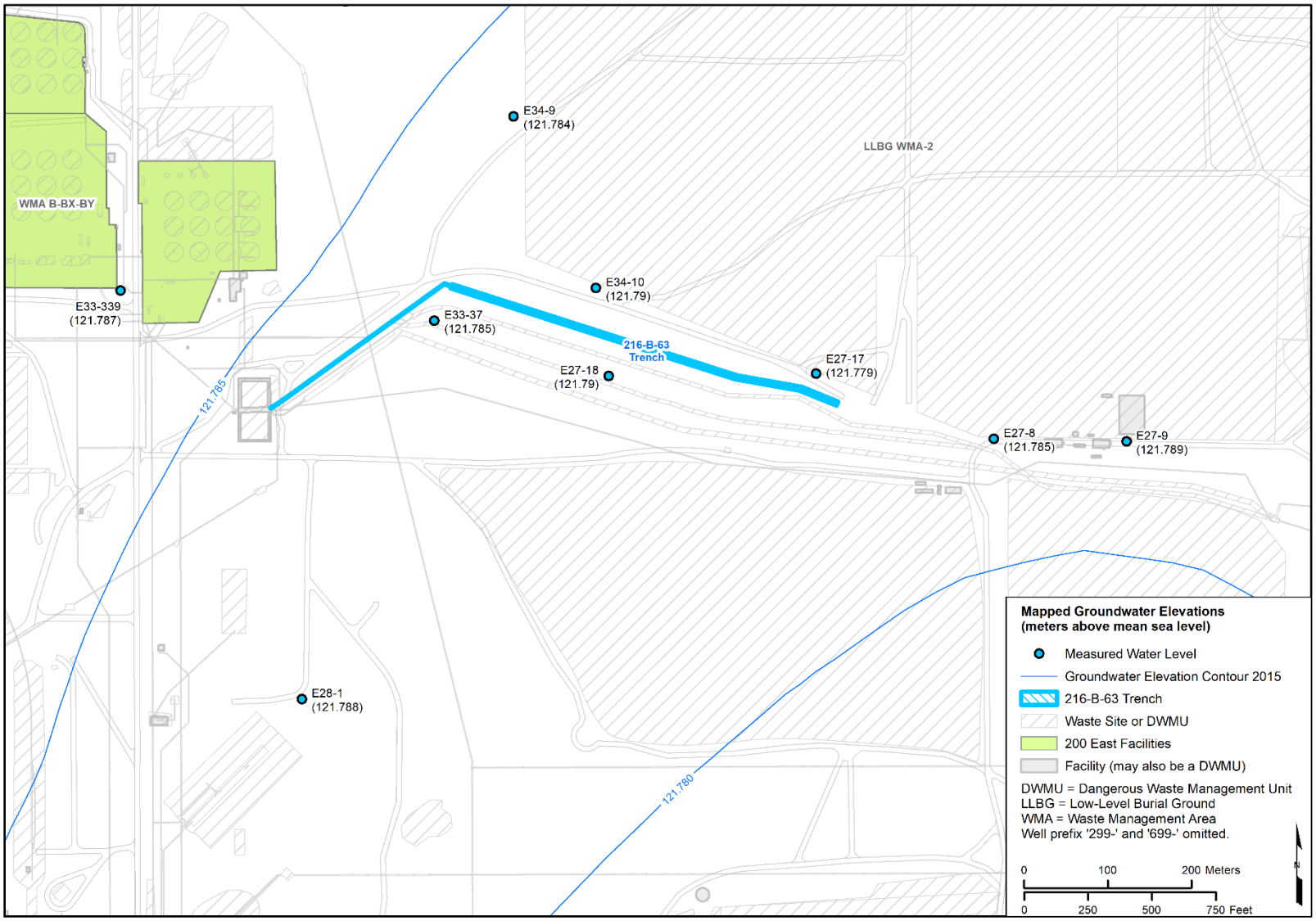

Figure G-5. Water-Level Elevation Map for the 216-B-63 Trench, 2015

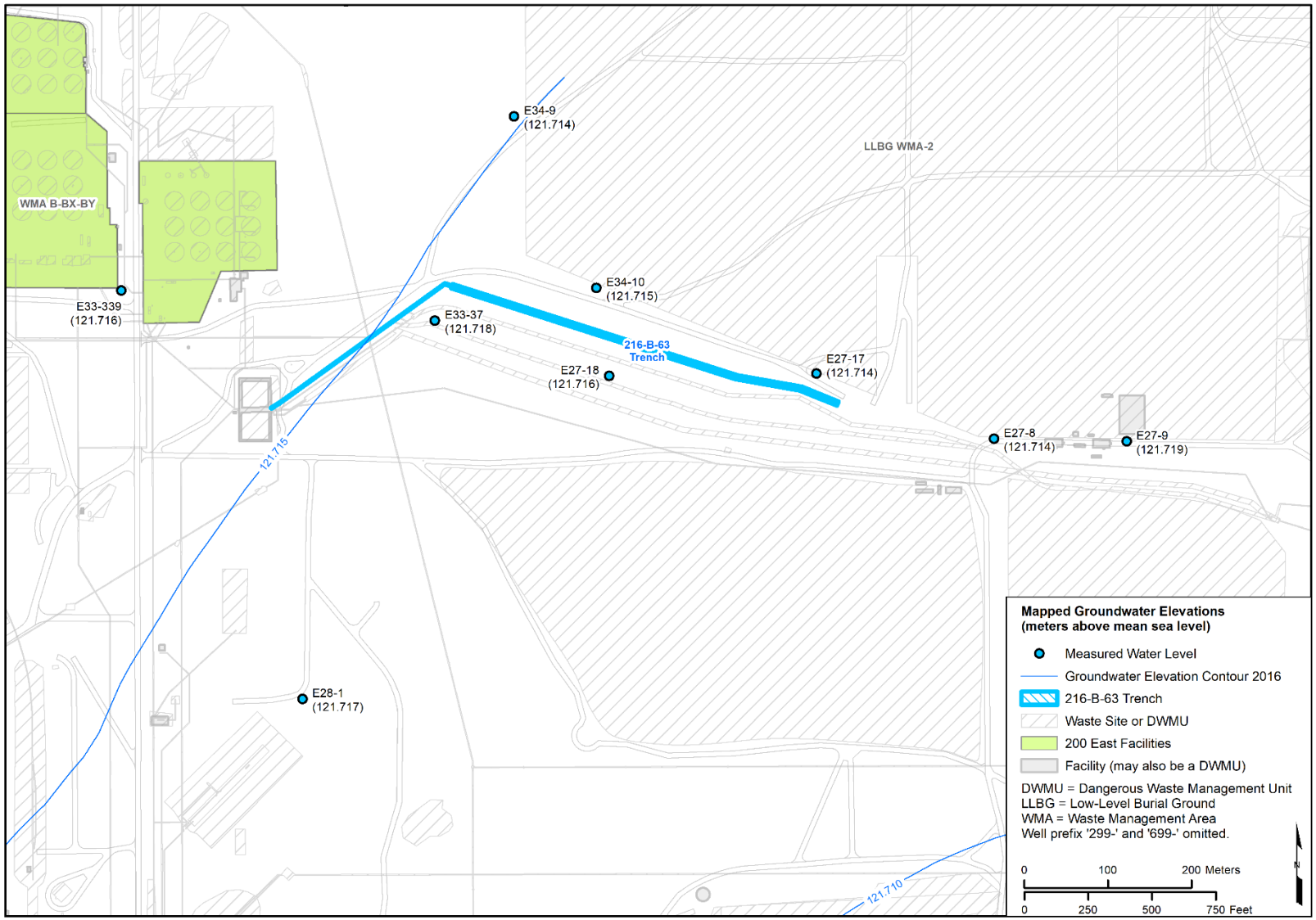

Figure G-6. Water-Level Elevation Map for the 216-B-63 Trench, 2016

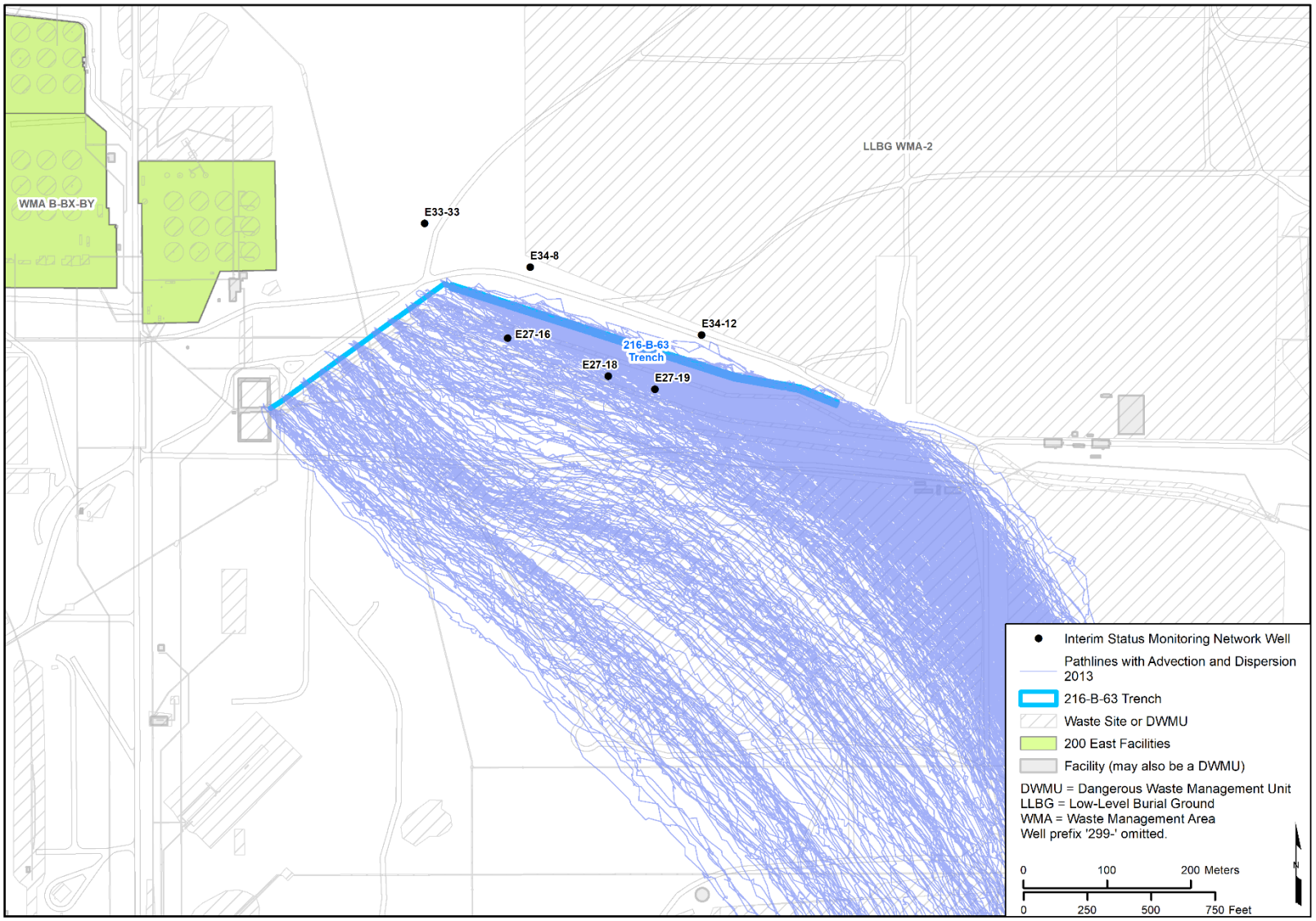

Figure G-7. Local-Scale Particle Pathlines, Advection and Dispersion – 216-B-63 Trench, 2013

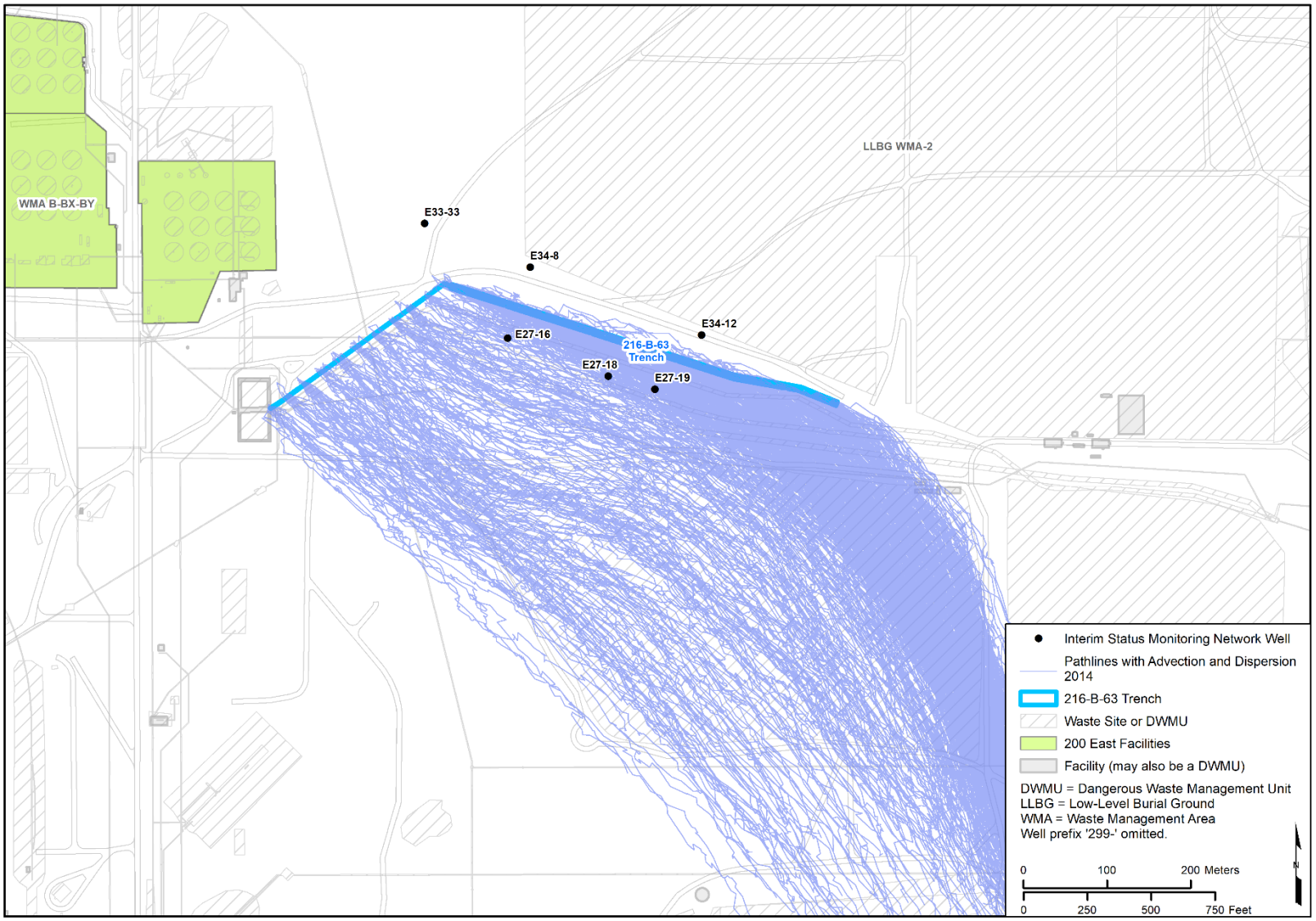

Figure G-8. Local-Scale Particle Pathlines, Advection and Dispersion – 216-B-63 Trench, 2014

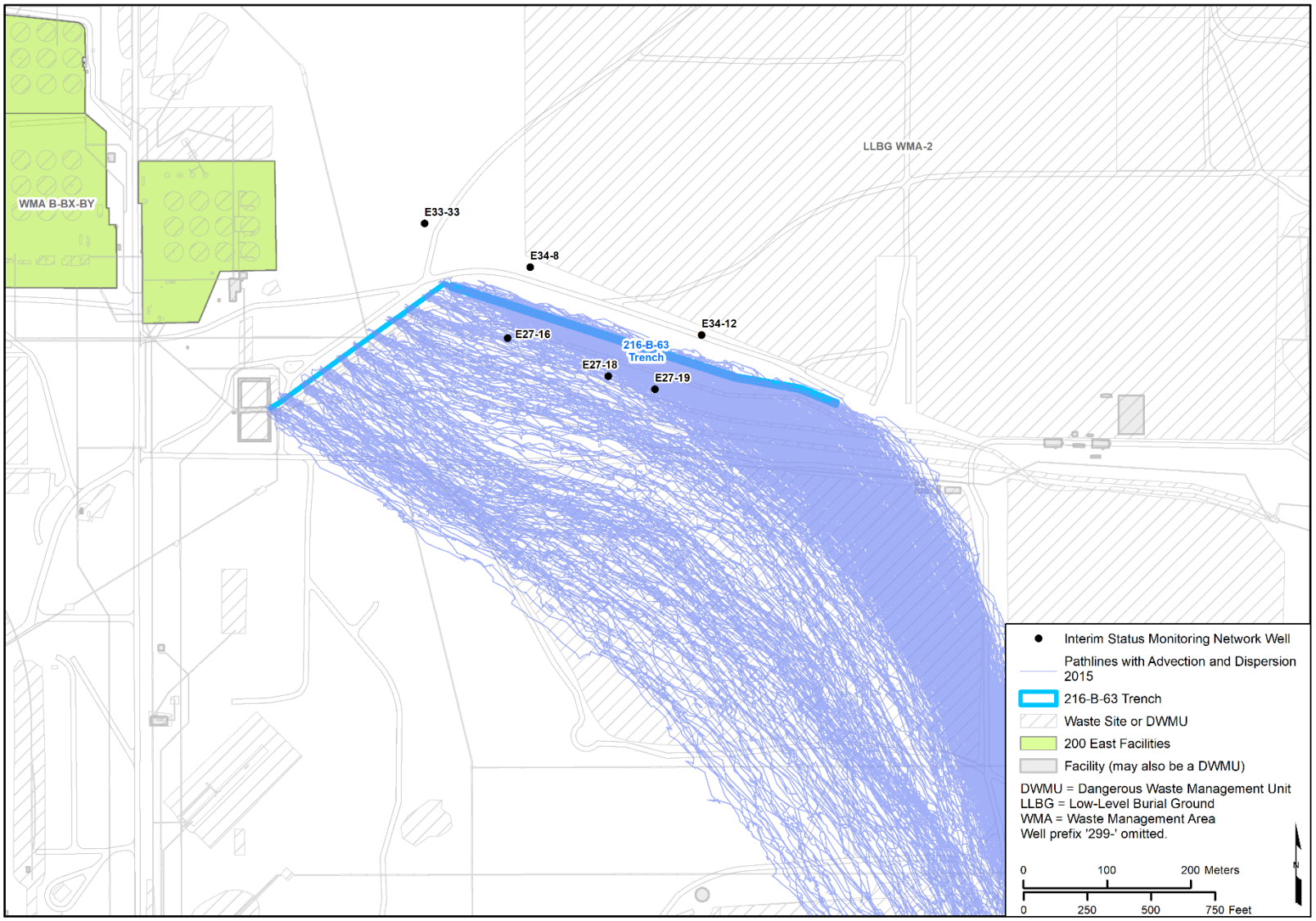

Figure G-9. Local-Scale Particle Pathlines, Advection and Dispersion – 216-B-63 Trench, 2015

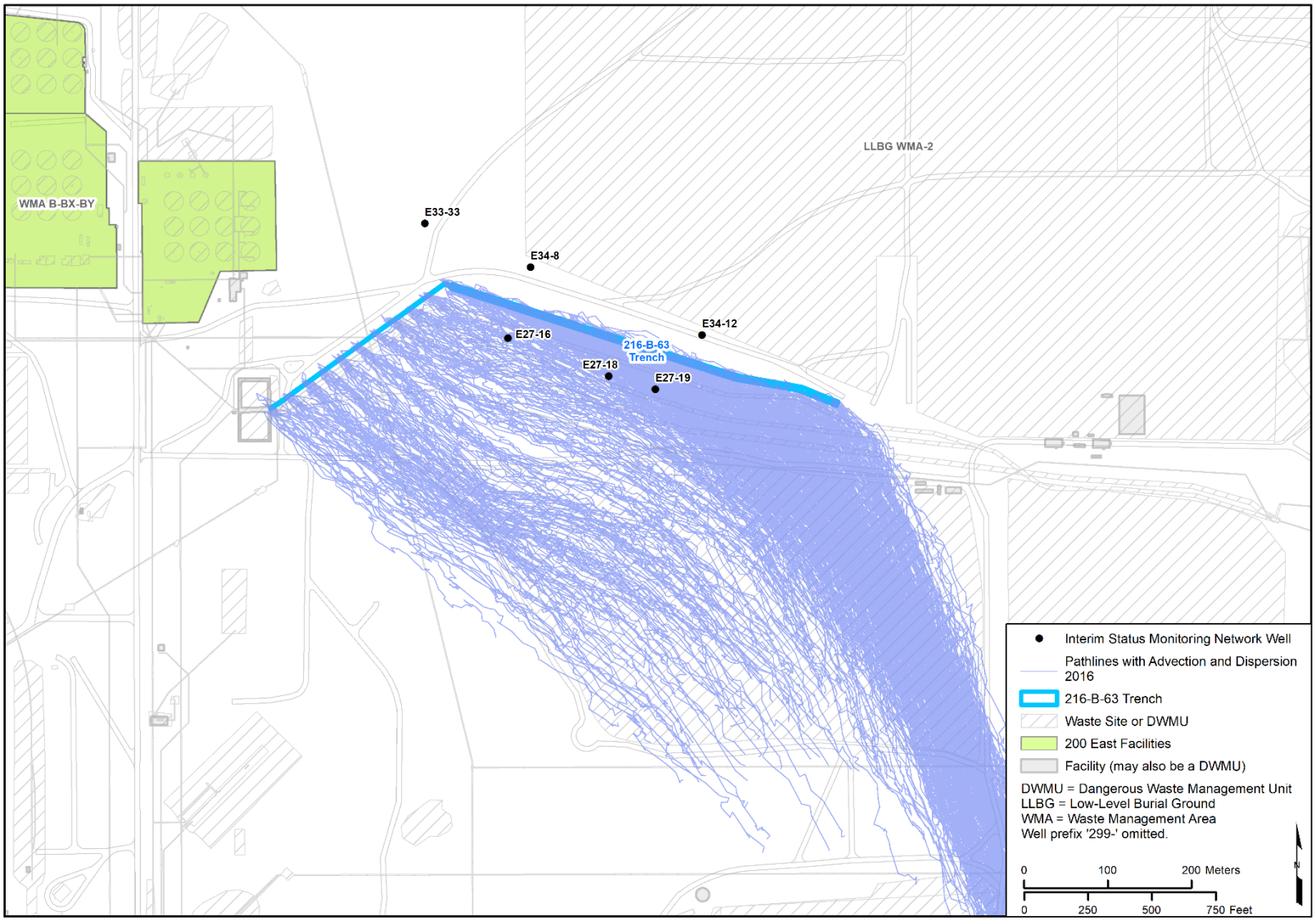

Figure G-10. Local-Scale Particle Pathlines, Advection and Dispersion – 216-B-63 Trench, 2016

G3.3 Particle Counts

To compare the relative timing and density of the particles that pass by each monitoring well location, particle counts were calculated as described in Section 6.3 of the main text of this ECF. The particle counts were tabulated, particle breakthrough curves were created, and particle count maps were generated.

G3.3.1 Relative Particle Counts at Interim Status Groundwater Monitoring Wells

Tables G-1 through G-3 present the computed particle counts over time binned into periods of 50 days for each of the downgradient monitoring wells. The tables present four entries (one for each year) for each well. At the bottom of the column for each mapped event is the total number of particles that passed through the vicinity of the well, regardless of time, and the average of the totals for the four mapped years rounded to the nearest integer. Each table provides an indication of the relative timing of the expected detections at each well and the relative potential that each well would detect a release at the facility for the flow conditions calculated for CYs 2013, 2014, 2015, and 2016.

The average values depicted at the base of each table can be used to assess the relative potential for each well to detect a release at the facility. These averages are summarized as follows:

- 299-E27-16 – Average = 45
- 299-E27-18 – Average = 86
- 299-E27-19 – Average = 134

G3.3.2 Relative Arrival Times at Interim Status Groundwater Monitoring Wells

Figures G-11 through G-13 depict plots of particle counts over time (particle breakthrough curves) for each downgradient well location. The underlying data plotted in Figures G-11 through G-13 are the same as the data in Tables G-1 through G-3, but the time interval over which particles are summed is not necessarily the same. Particle breakthrough curves show the relative timing and particle density for the arrival, peak, and decline in particle counts at each interim status monitoring location resulting from the hypothetical instantaneous release at the facility. The plots depict the relative potential at each well for detecting a release from the facility that reaches the water table for the flow conditions calculated for CYs 2013, 2014, 2015, and 2016. There is one figure for each well, with four lines shown on each plot (one for each year).

Table G-1. Particle Density (Count) Monitoring Well 299-E27-16

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
40	19	1	0	0	
80	24	10	10	1	
120	1	24	16	9	
160	0	7	8	19	
200	0	5	5	10	
240	0	1	0	5	
280	0	0	0	2	
320	0	0	0	0	
360	0	0	0	1	
400	0	0	0	0	
440	0	0	0	0	
480	0	0	0	0	
520	0	0	0	0	
560	0	0	0	0	
600	0	0	0	0	
640	0	0	0	0	
680	0	0	0	0	
720	0	0	0	0	
760	0	0	0	0	
800	0	0	0	0	Average
Total	44	48	39	47	**45**

Table G-2. Particle Density (Count) Monitoring Well 299-E27-18

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
40	5	0	0	0	
80	35	3	6	6	
120	37	15	6	6	
160	7	11	11	16	
200	0	19	20	12	
240	0	23	13	15	
280	0	9	12	8	
320	0	2	4	18	
360	0	2	3	9	
400	0	0	0	6	
440	0	0	0	2	
480	0	0	0	1	
520	0	0	0	0	
560	0	0	0	0	
600	0	0	0	0	
640	0	0	0	0	
680	0	0	0	0	
720	0	0	0	0	
760	0	0	0	0	
800	0	0	0	0	Average
Total	84	84	75	99	**86**

Table G-3. Particle Density (Count) Monitoring Well 299-E27-19

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
40	16	1	2	1	
80	47	9	17	8	
120	36	15	16	23	
160	24	21	19	14	
200	0	18	26	14	
240	0	23	19	19	
280	0	25	10	20	
320	0	14	15	16	
360	0	3	5	15	
400	0	1	2	9	
440	0	1	1	5	
480	0	0	0	3	
520	0	0	0	0	
560	0	0	0	1	
600	0	0	0	0	
640	0	0	0	0	
680	0	0	0	0	
720	0	0	0	0	
760	0	0	0	0	
800	0	0	0	0	Average
Total	123	131	132	148	**134**

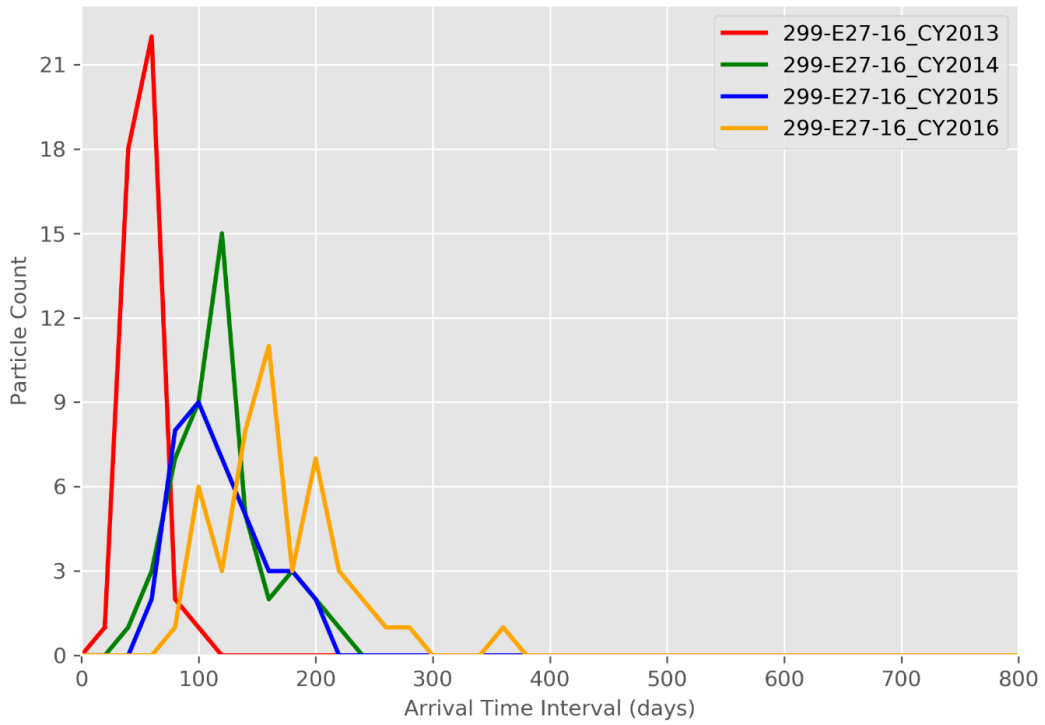

Figure G-11. Particle Breakthrough Curve at Monitoring Well 299-E27-16

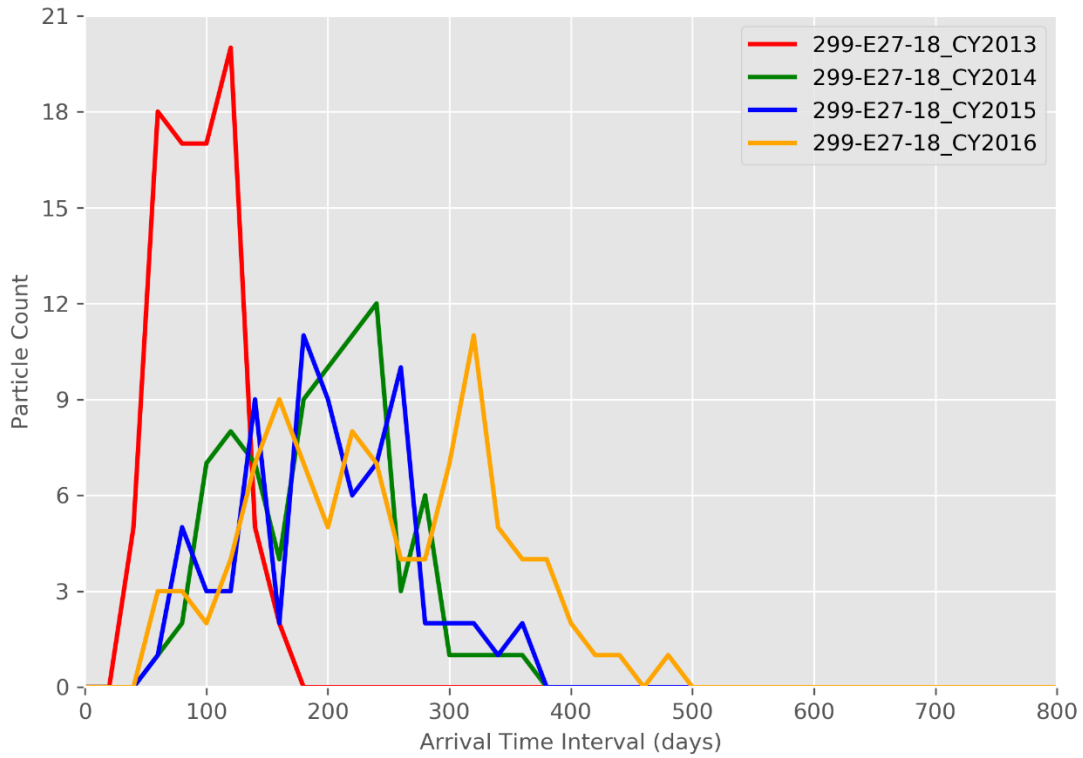

Figure G-12. Particle Breakthrough Curve at Monitoring Well 299-E27-18

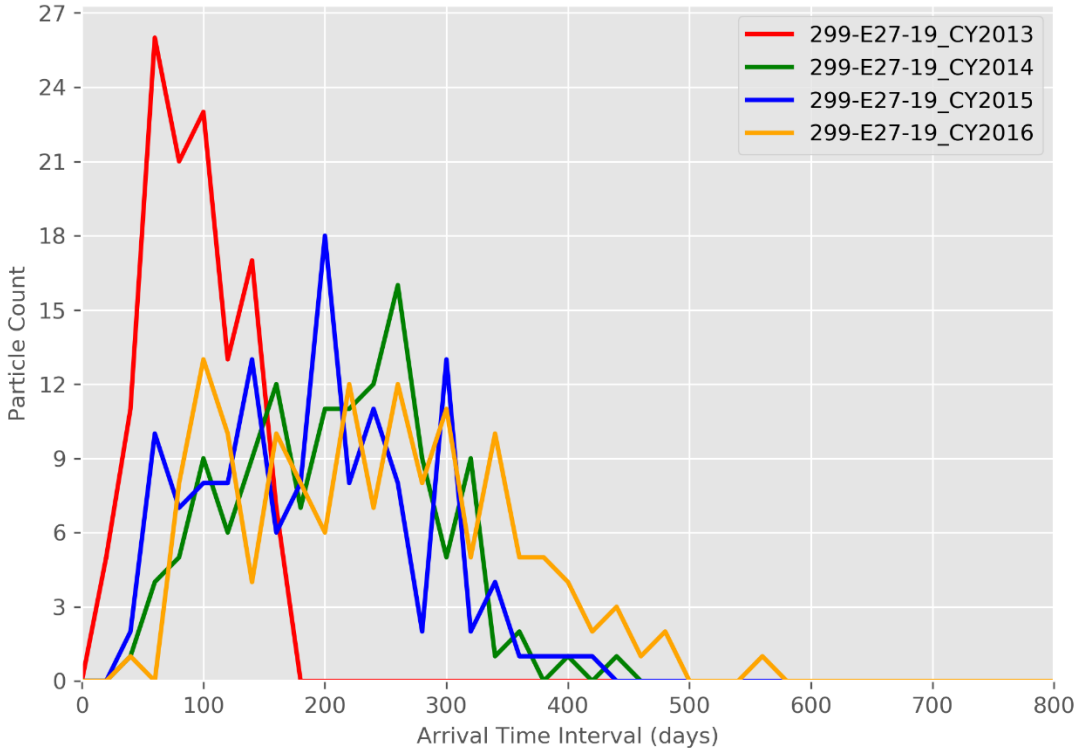

Figure G-13. Particle Breakthrough Curve at Monitoring Well 299-E27-19

G3.3.3 Particle Count Maps

Figures G-14 through G-17 depict the particle count maps developed based on the instantaneous release of a large number of particles at the facility. The particle count maps depict areas of relatively higher and lower potential impact from a release at the facility that reaches the water table, for conditions represented by CYs 2013, 2014, 2015, and 2016. Figures G-14 through G-17 depict the particle density after 800 days of calculated travel, by which time it was determined that all particles would have arrived at or passed by the interim status groundwater monitoring wells (see entries in Tables G-1 through G-3).

The goal of well placement is for the well locations to span the range of particle pathline distribution as released from the 216-B-63 Trench. The particle count maps show that under the evaluated range of conditions, there are areas of high particle counts where there are no corresponding monitoring wells, indicating the need for additional monitoring wells. In addition a new upgradient well is proposed to monitor upgradient of the pipeline portion of the 216-B-63 Trench. Six additional wells are proposed for monitoring downgradient of the site; these include five wells proposed to be installed and one well (299-E27-11) that is an existing well that is part of the interim monitoring well network for the Low-Level Burial Ground Waste Management Area-2. This existing well is recommended to become a part of the final monitoring network for the 216-B-63 Trench. The location of the five proposed downgradient wells (216-B-63_PW-1, 216-B-63_PW-2, 216-B-63_PW-3, 216-B-63_PW-5, and 216-B-63_PW-6), the location of the proposed upgradient well (216-B-63_PW-4), and the location of well 299-E27-11 are shown in Figures G-14 through G-17.

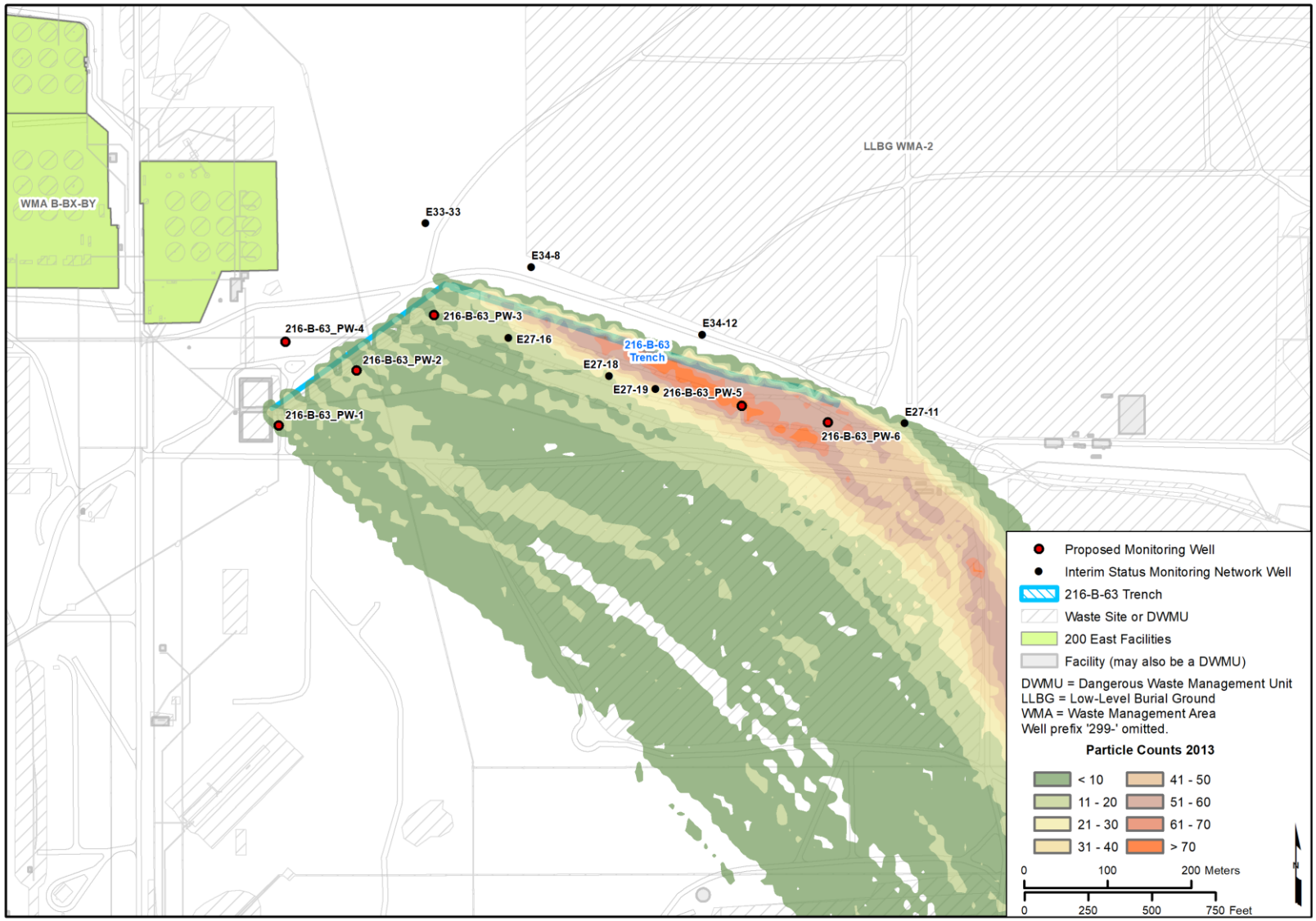

Figure G-14. Particle Count Map – 216-B-63 Trench, 2013

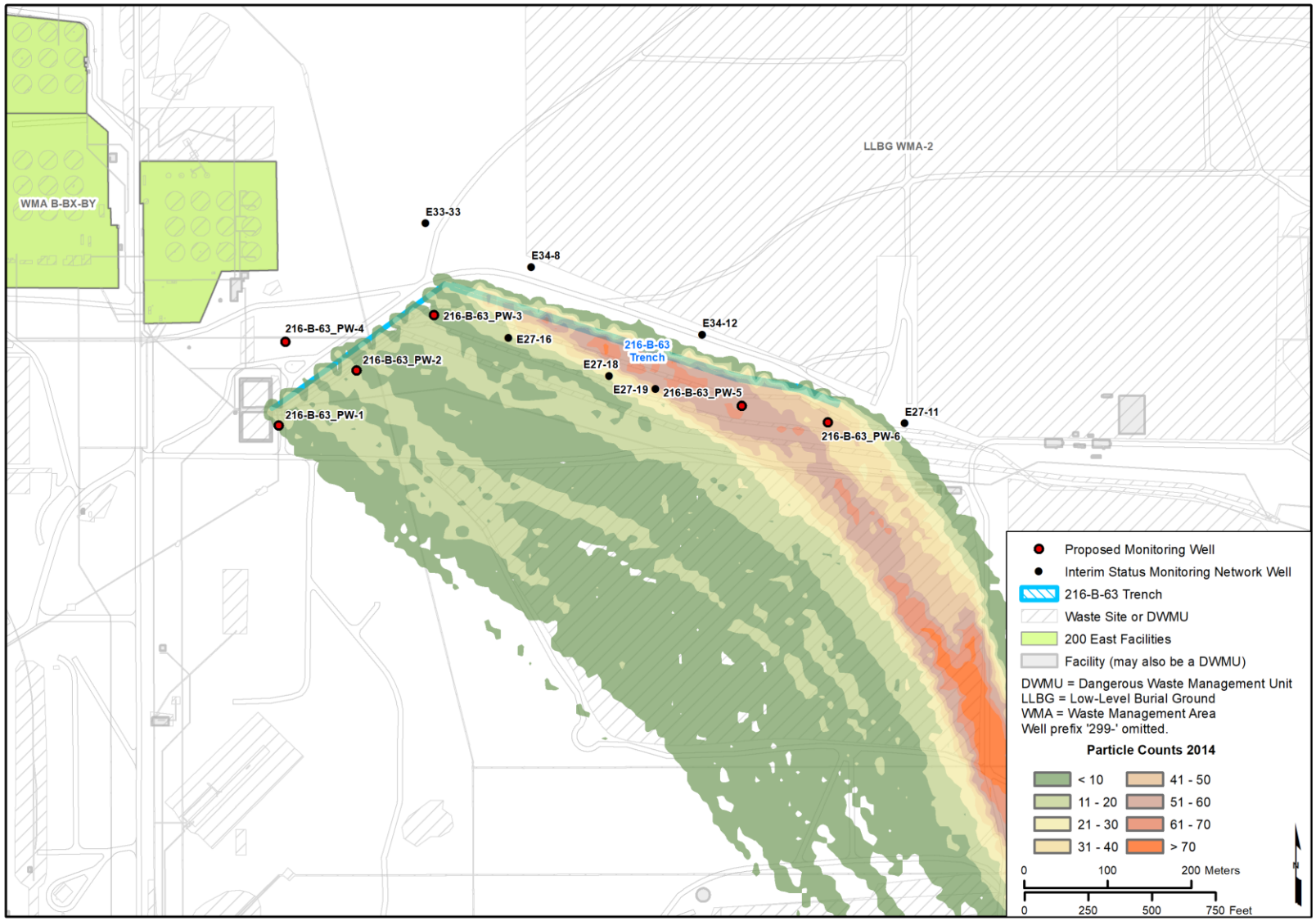

Figure G-15. Particle Count Map – 216-B-63 Trench, 2014

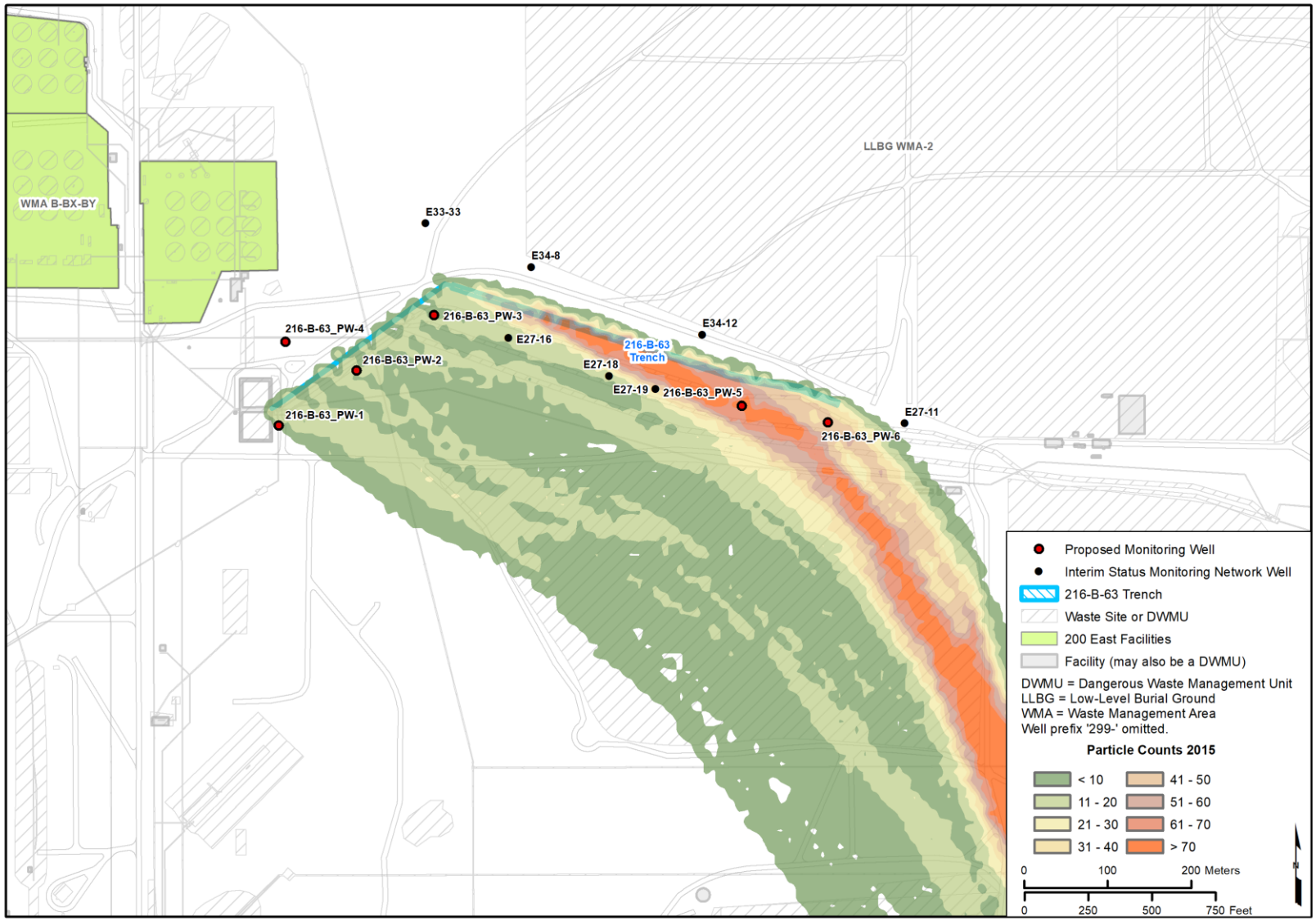

Figure G-16. Particle Count Map – 216-B-63 Trench, 2015

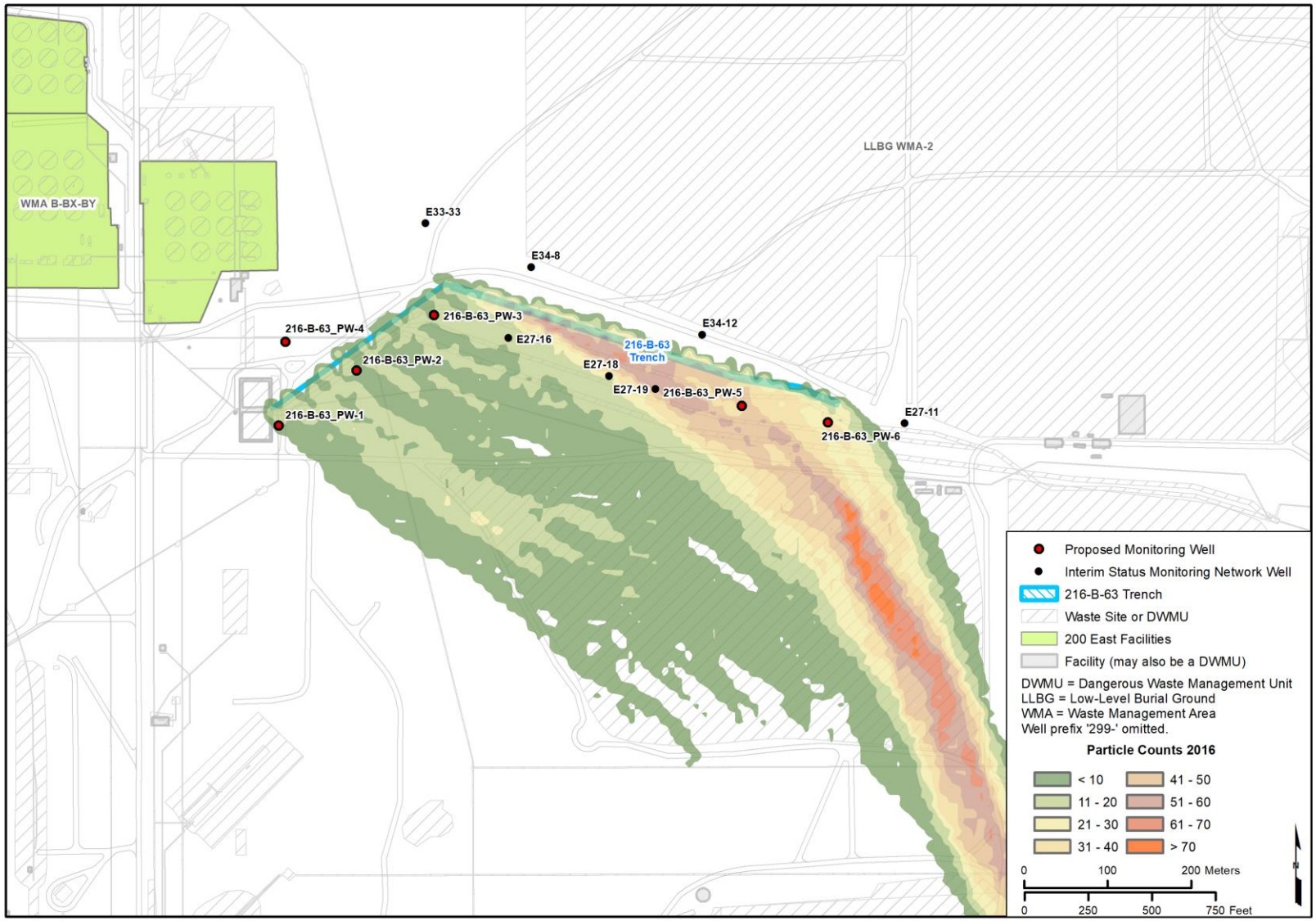

Figure G-17. Particle Count Map – 216-B-63 Trench, 2016

G3.4 Proposed Monitoring Wells

The locations of the proposed monitoring wells are shown in Figures G-14 through G-17. The particle counts tabulated for these locations (Tables G-4 through G-9) indicate the relative timing of expected detections at the wells and the relative potential of the wells for detecting a release at the facility. The particle breakthrough curves (Figures G-18 through G-23) show the relative timing and particle density at the proposed monitoring well locations for the arrival, peak, and decline in particle counts resulting from the hypothetical instantaneous release to the water table beneath the facility.

Table G-4. Particle Density (Count) Proposed Monitoring Well 216-B-63_PW-1

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
40	20	20	20	18	
80	0	0	0	2	
120	0	0	0	0	
160	0	0	0	0	
200	0	0	0	0	
240	0	0	0	0	
280	0	0	0	0	
320	0	0	0	0	
360	0	0	0	0	
400	0	0	0	0	
440	0	0	0	0	
480	0	0	0	0	
520	0	0	0	0	
560	0	0	0	0	
600	0	0	0	0	
640	0	0	0	0	
680	0	0	0	0	
720	0	0	0	0	
760	0	0	0	0	
800	0	0	0	0	Average
Total	20	20	20	20	**20**

Table G-5. Particle Density (Count) Proposed Monitoring Well 216-B-63_PW-2

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
40	33	23	33	22	
80	0	6	2	3	
120	0	0	0	2	
160	0	0	0	0	
200	0	0	0	0	
240	0	0	0	0	
280	0	0	0	0	
320	0	0	0	0	
360	0	0	0	0	
400	0	0	0	0	
440	0	0	0	0	
480	0	0	0	0	
520	0	0	0	0	
560	0	0	0	0	
600	0	0	0	0	
640	0	0	0	0	
680	0	0	0	0	
720	0	0	0	0	
760	0	0	0	0	
800	0	0	0	0	Average
Total	33	29	35	27	**31**

Table G-6. Particle Density (Count) Proposed Monitoring Well 216-B-63_PW-3

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
40	38	37	33	34	
80	0	1	4	2	
120	0	1	0	2	
160	0	0	0	1	
200	0	0	0	0	
240	0	0	0	0	
280	0	0	0	0	
320	0	0	0	0	
360	0	0	0	0	
400	0	0	0	0	
440	0	0	0	0	
480	0	0	0	0	
520	0	0	0	0	
560	0	0	0	0	
600	0	0	0	0	
640	0	0	0	0	
680	0	0	0	0	
720	0	0	0	0	
760	0	0	0	0	
800	0	0	0	0	Average
Total	38	39	37	39	**38**

Table G-7. Particle Density (Count) Proposed Monitoring Well 216-B-63_PW-5

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
40	58	16	22	8	
80	65	42	35	36	
120	50	31	47	26	
160	21	25	26	22	
200	4	17	27	18	
240	0	15	18	6	
280	0	12	17	9	
320	0	6	9	5	
360	0	9	6	3	
400	0	3	5	1	
440	0	2	3	2	
480	0	0	0	1	
520	0	0	0	2	
560	0	0	0	0	
600	0	0	0	0	
640	0	0	0	0	
680	0	0	0	0	
720	0	0	0	0	
760	0	0	0	0	
800	0	0	0	0	Average
Total	198	178	215	139	**183**

Table G-8. Particle Density (Count) Proposed Monitoring Well 216-B-63_PW-6

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
40	74	38	51	39	
80	58	39	42	30	
120	21	22	20	12	
160	14	12	12	6	
200	4	7	4	3	
240	1	5	5	3	
280	0	4	1	0	
320	0	1	4	3	
360	0	1	2	0	
400	0	1	1	1	
440	0	0	0	0	
480	0	1	0	0	
520	0	0	1	0	
560	0	0	0	0	
600	0	0	0	0	
640	0	0	0	0	
680	0	0	0	0	
720	0	0	0	0	
760	0	0	0	0	
800	0	0	0	0	Average
Total	172	131	143	97	**136**

Table G-9. Particle Density (Count) Proposed Monitoring Well 299-E27-11

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
40	8	0	0	0	
80	20	2	2	0	
120	1	2	1	0	
160	2	0	0	0	
200	0	0	0	0	
240	0	0	0	0	
280	0	0	0	0	
320	0	0	0	0	
360	0	0	0	0	
400	0	0	0	0	
440	0	0	0	0	
480	0	0	0	0	
520	0	0	0	0	
560	0	0	0	0	
600	0	0	0	0	
640	0	0	0	0	
680	0	0	0	0	
720	0	0	0	0	
760	0	0	0	0	
800	0	0	0	0	Average
Total	31	4	3	0	**10**

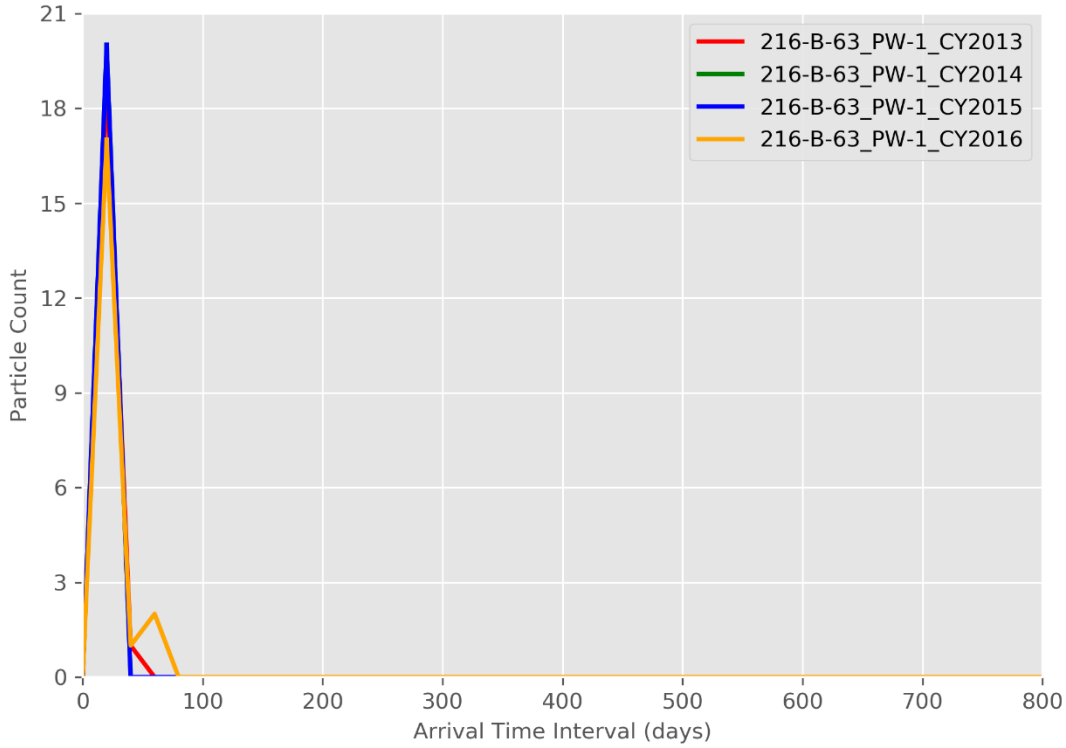

Figure G-18. Particle Breakthrough Curve at Monitoring Well 216-B-63_PW-1

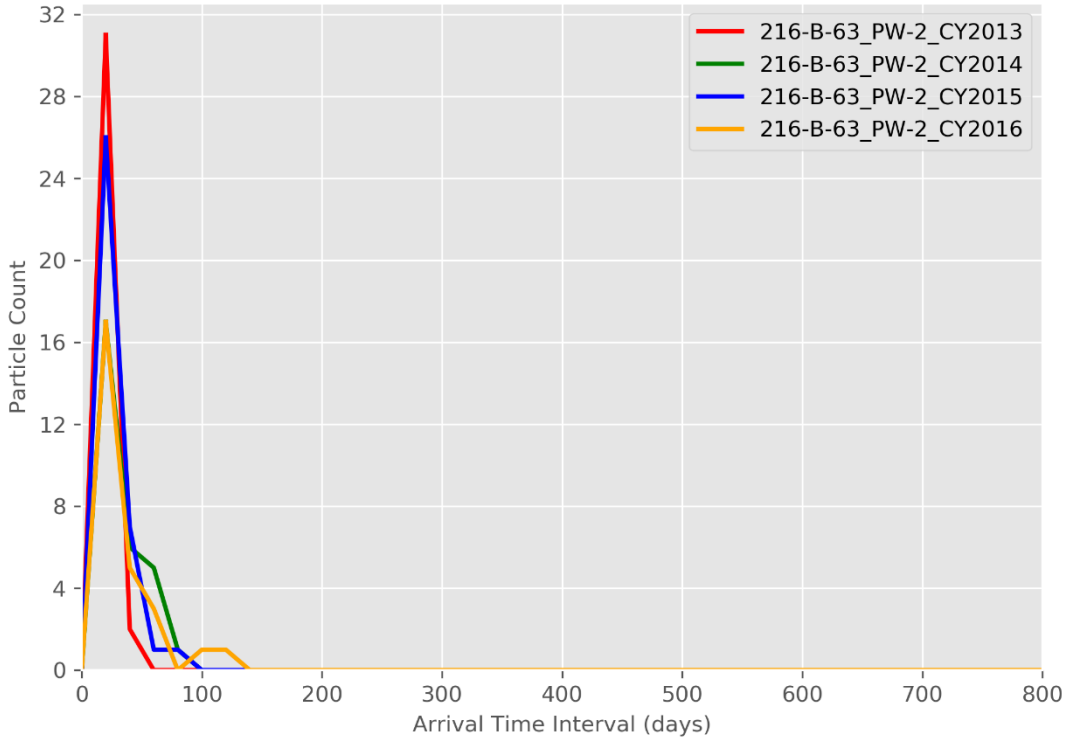

Figure G-19. Particle Breakthrough Curve at Monitoring Well 216-B-63_PW-2

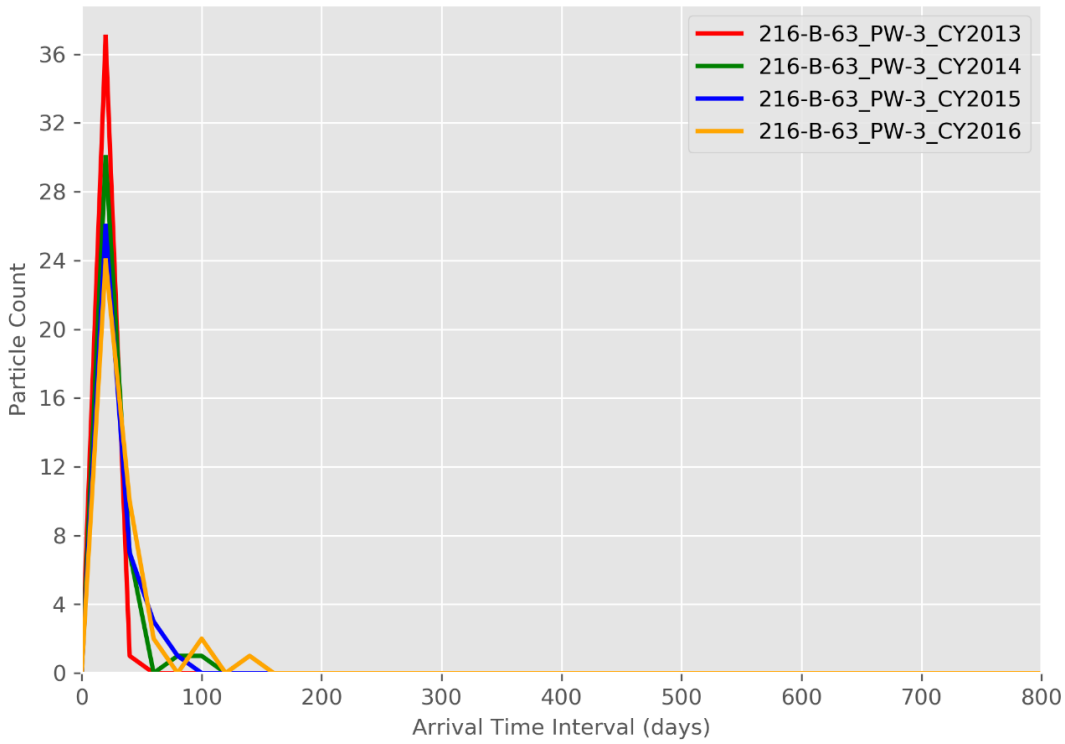

Figure G-20. Particle Breakthrough Curve at Monitoring Well 216-B-63_PW-3

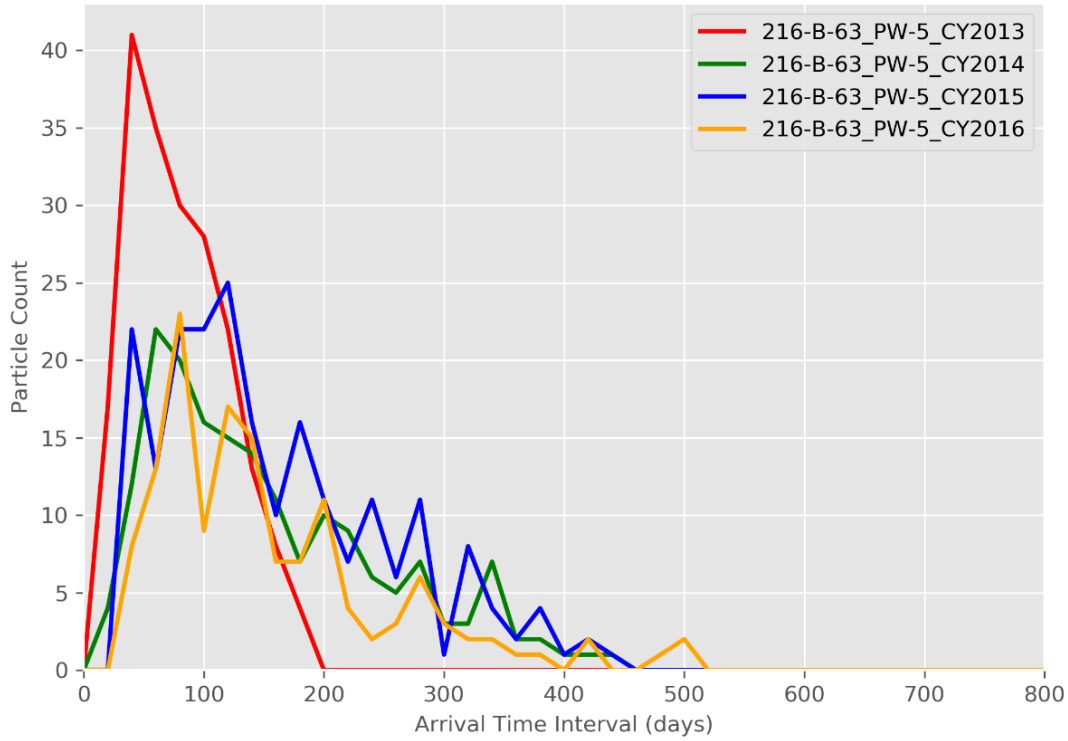

Figure G-21. Particle Breakthrough Curve at Monitoring Well 216-B-63_PW-5

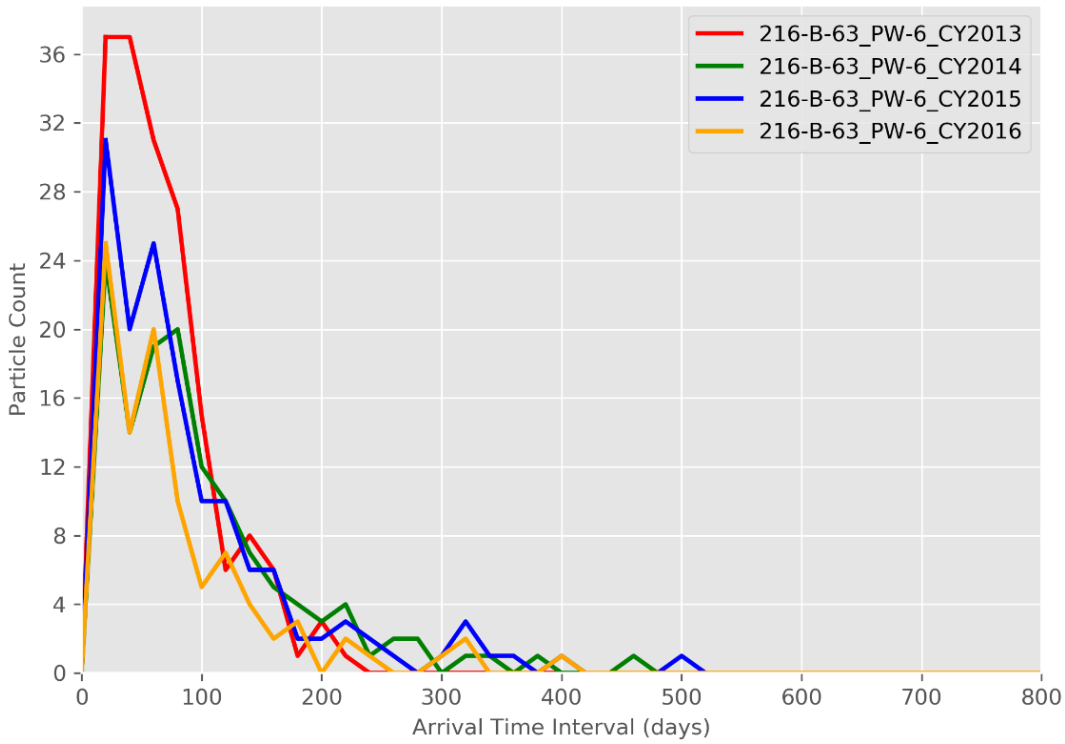

Figure G-22. Particle Breakthrough Curve at Monitoring Well 216-B-63_PW-6

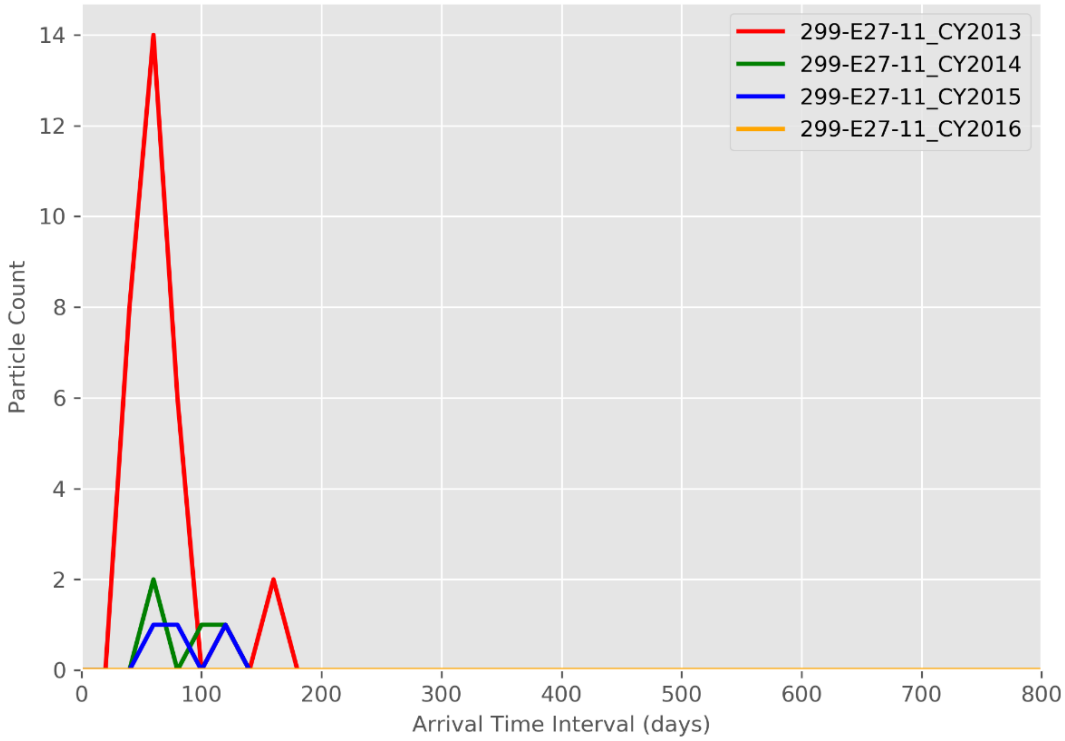

Figure G-23. Particle Breakthrough Curve at Monitoring Well 299-E27-11

G3.5 Analyses of Particle Pathlines for Each Area of the 216-B-63 Trench

Particle pathline maps shown in Section G3.2 depict an instantaneous release to the water table from the release locations in the 216-B-63 Trench. Particle tracking also was performed for smaller regions of the facility to evaluate well locations for detecting releases from various regions of the 216-B-63 Trench. This section contains the results of analyses performed to examine how releases from the various areas of the 216-B-63 Trench that reach the groundwater beneath those release areas relate to each individual monitoring well. A series of figures and tables are provided to illustrate the fate of releases originating from three different areas of the trench. For these analyses, the particle release points presented in Figure G-2 are grouped into one of four areas based on their spatial location. Those areas are depicted in Figure G-24. Figures G-25 through G-28 illustrate the particle pathlines originating from each of the areas for CYs 2013 through 2016.

Figures G-29 through G-37 illustrate the particle count time series for each existing and proposed monitoring well from CY 2013 through CY 2016. Each figure has four panels, each of which depicts the particle counts for one CY (2013 through 2016). Additionally, each panel shows a separate breakthrough curve for particles emanating from each area. For example, Figure G-33 depicts the particle counts at well 216-B-63_PW-6, which receives particles from areas 2, 3, and 4 in 2013. In the figure, within the panel for 2013 (top row, left), the particle breakthrough curve from area 2 is depicted with a red line, area 3 with a purple line, and area 4 with a green line.

G3.6 Vertical Migration Potential

As described in Section G3.3 of the main text of this ECF, the American Petroleum Institute (API) plume diving calculation was used to estimate the likely rate of vertical migration of dissolved constituents downward under the influence of recharge at the water table. At each well the slope of the plume dive was multiplied by the distance from the particle starting location to the well location to estimate the depth to which the dissolved constituents may be anticipated to have migrated by the time they reach the monitoring well location.

This estimated depth of the plume was then compared to the depth from the water table to the bottom of the monitoring well screen. If the depth of the plume is below the bottom of the monitoring well screen, then the dissolved constituents may be anticipated to pass beneath the well screen. If it falls within the interval between the top of the water table and the bottom of the well screen, then the well depth is appropriate for detection of releases at the 216-B-63 Trench.

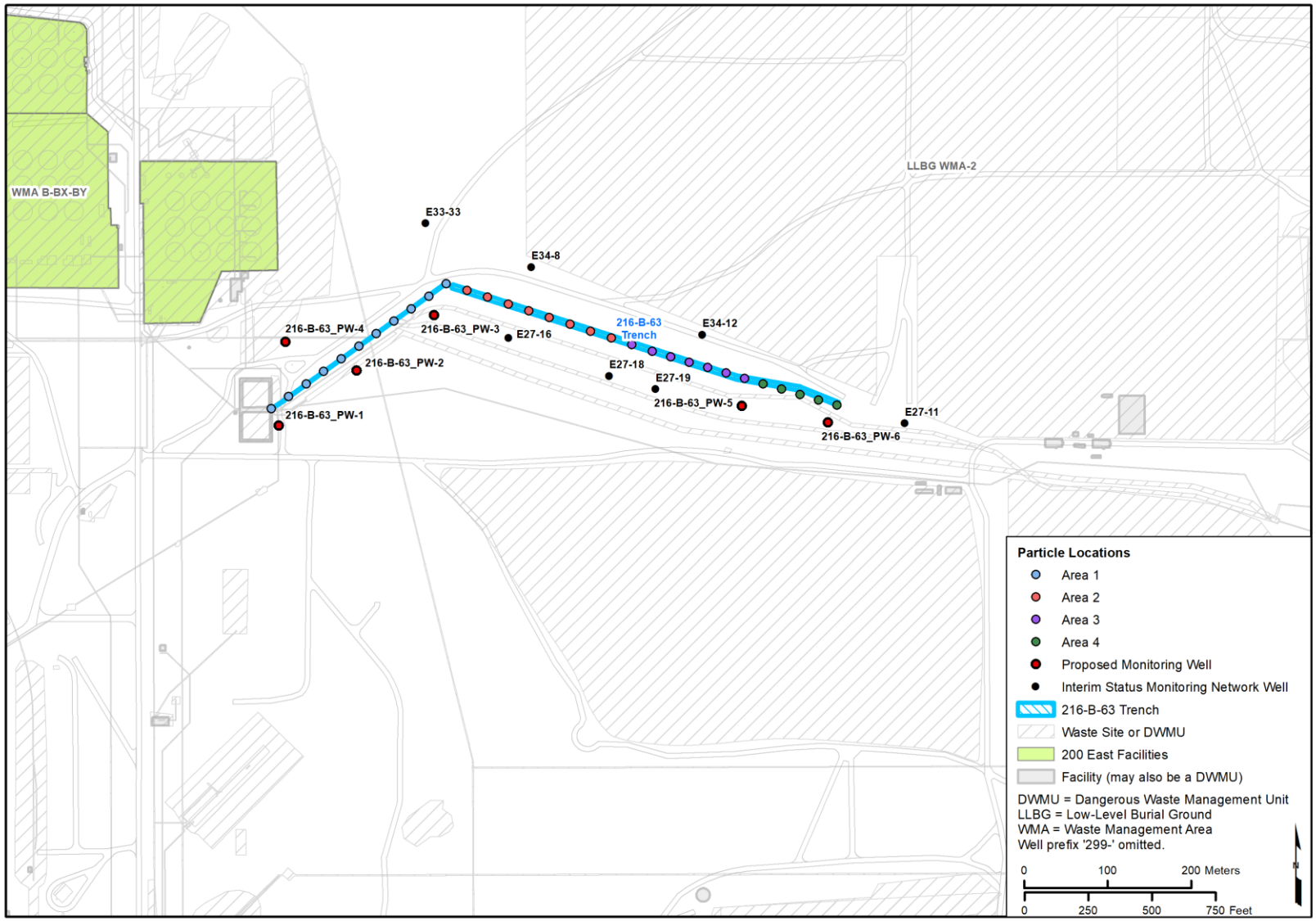

Figure G-24. Particle Release Locations and Areas of the 216-B-63 Trench

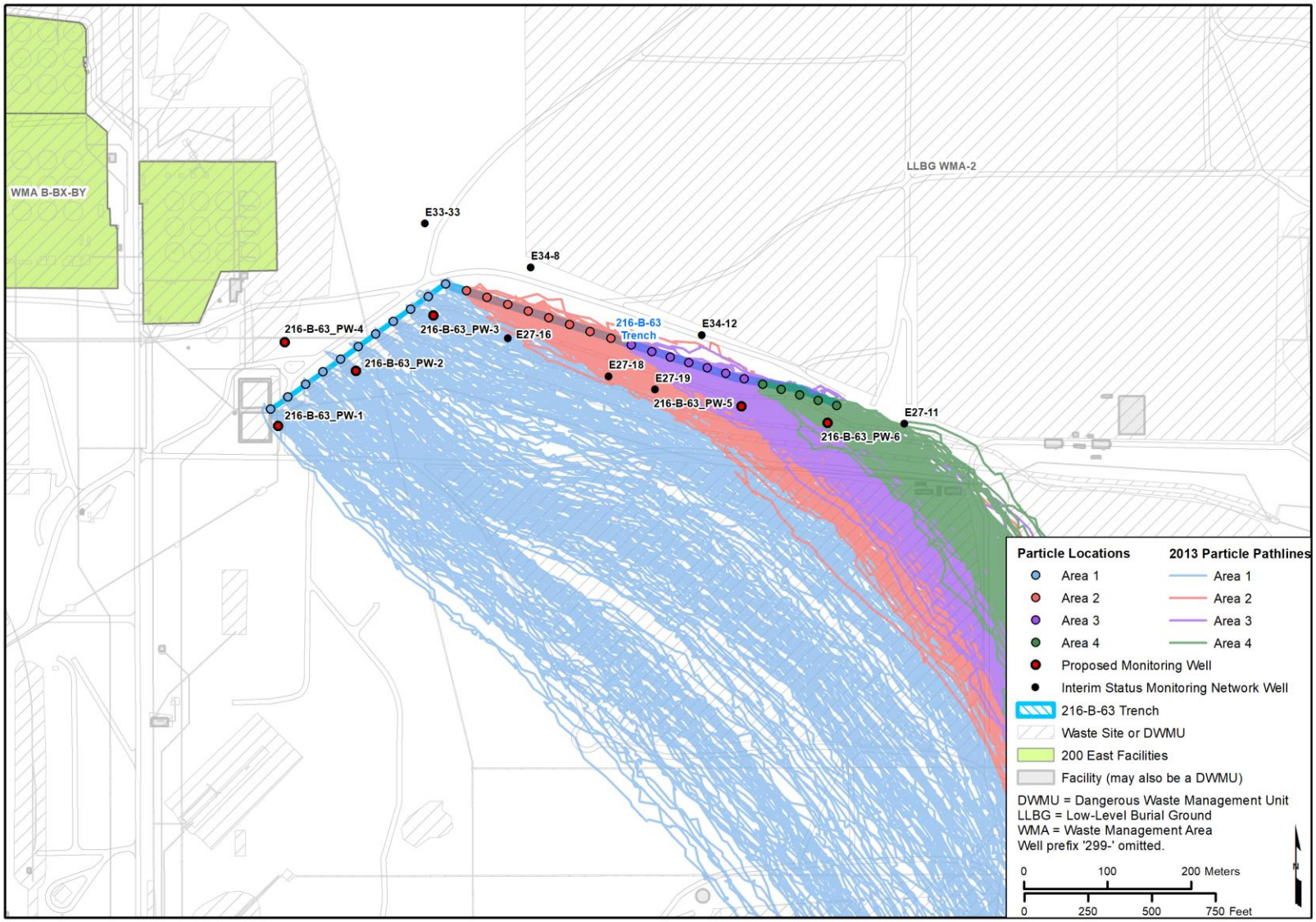

Figure G-25. CY 2013 Particle Pathlines per Area of the 216-B-63 Trench

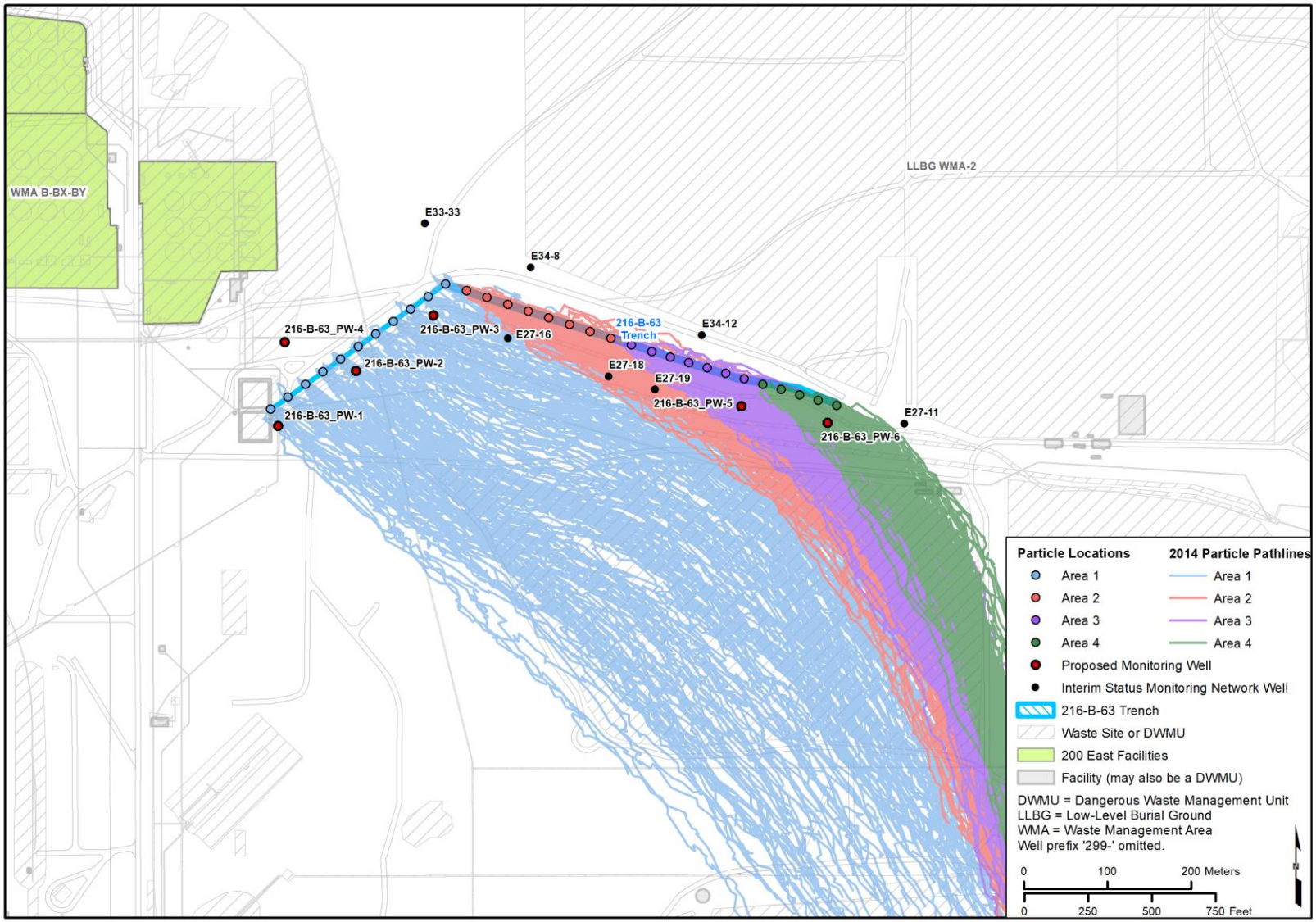

Figure G-26. CY 2014 Particle Pathlines per Area of the 216-B-63 Trench

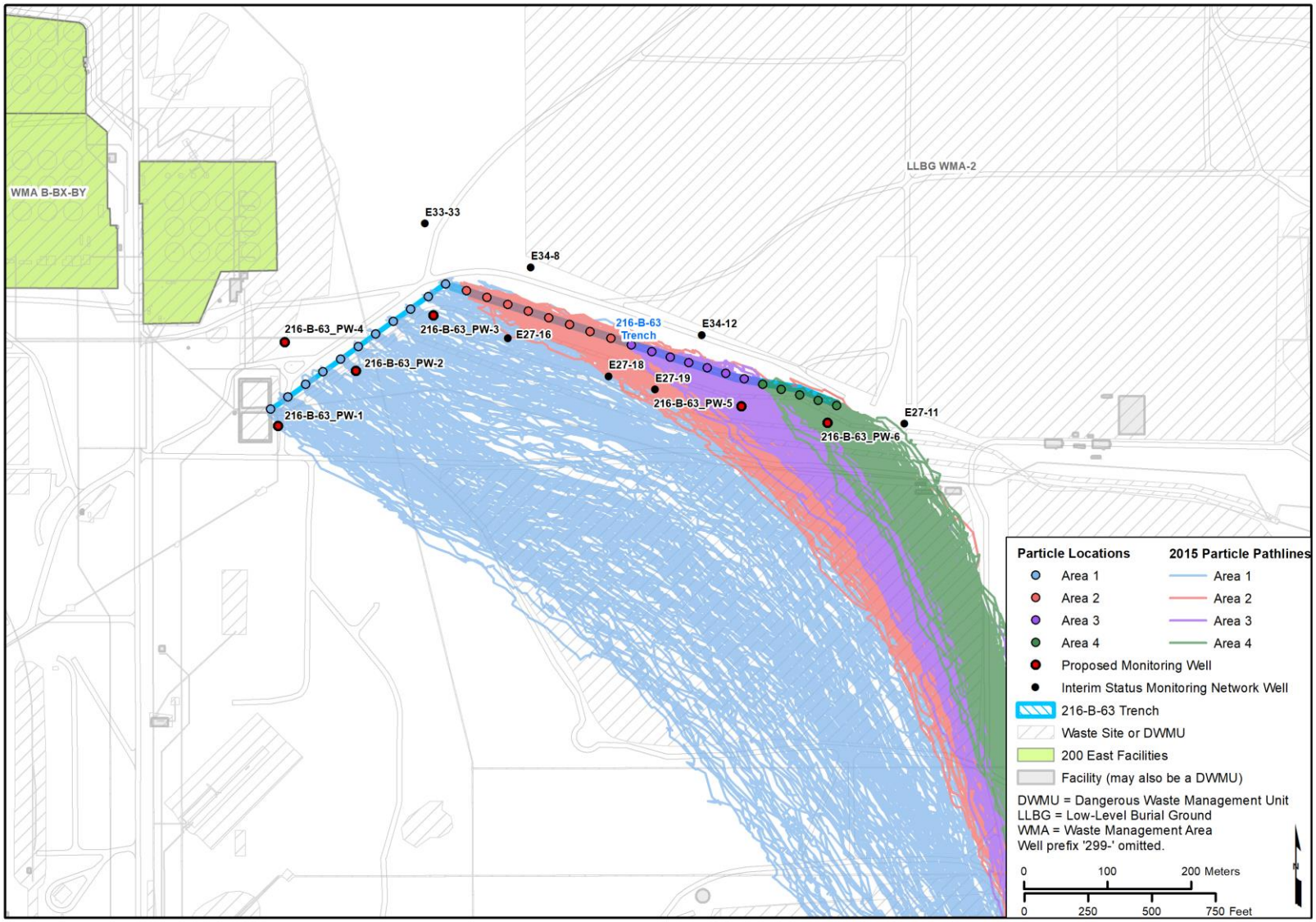

Figure G-27. CY 2015 Particle Pathlines per Area of the 216-B-63 Trench

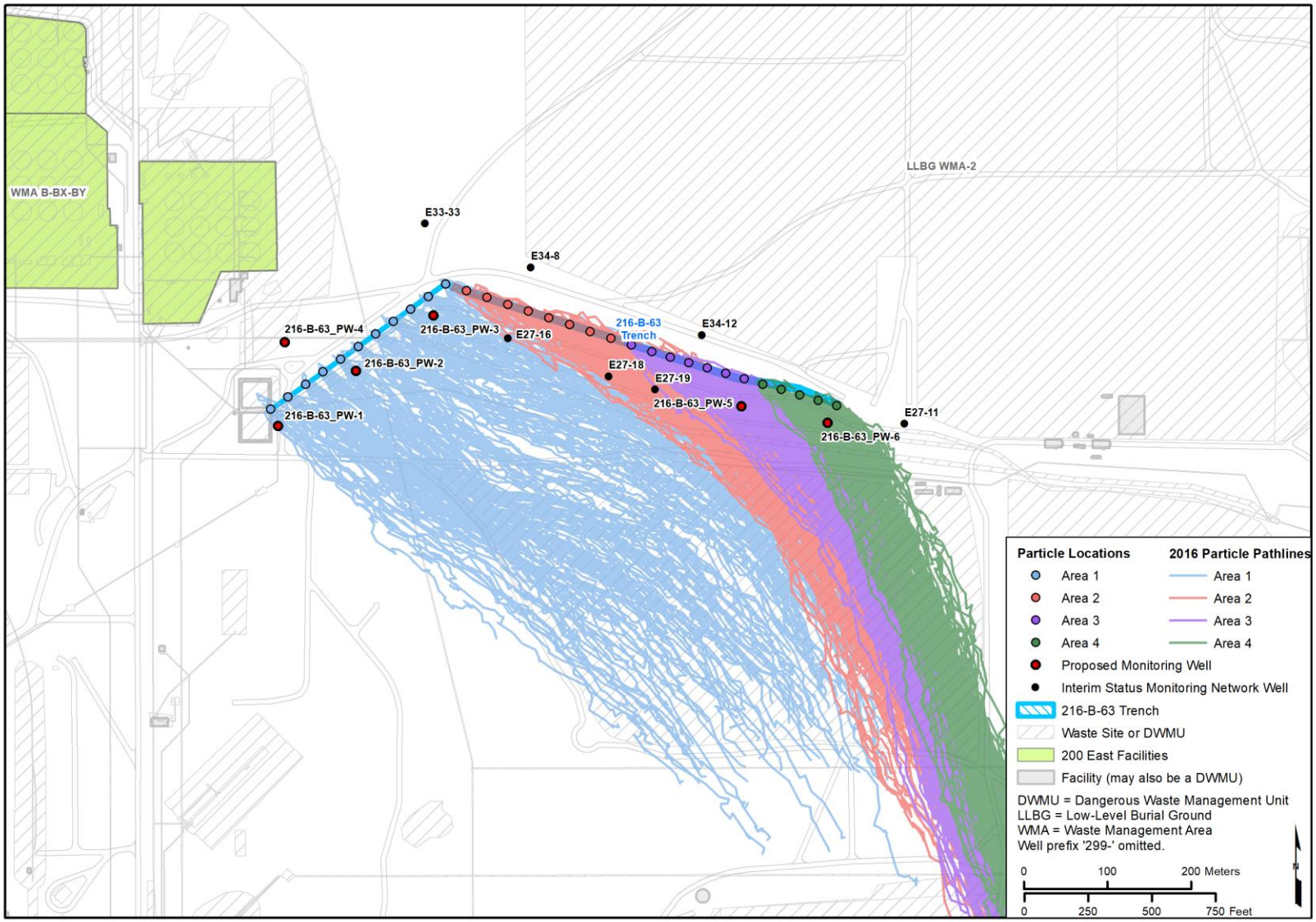

Figure G-28. CY 2016 Particle Pathlines per Area of the 216-B-63 Trench

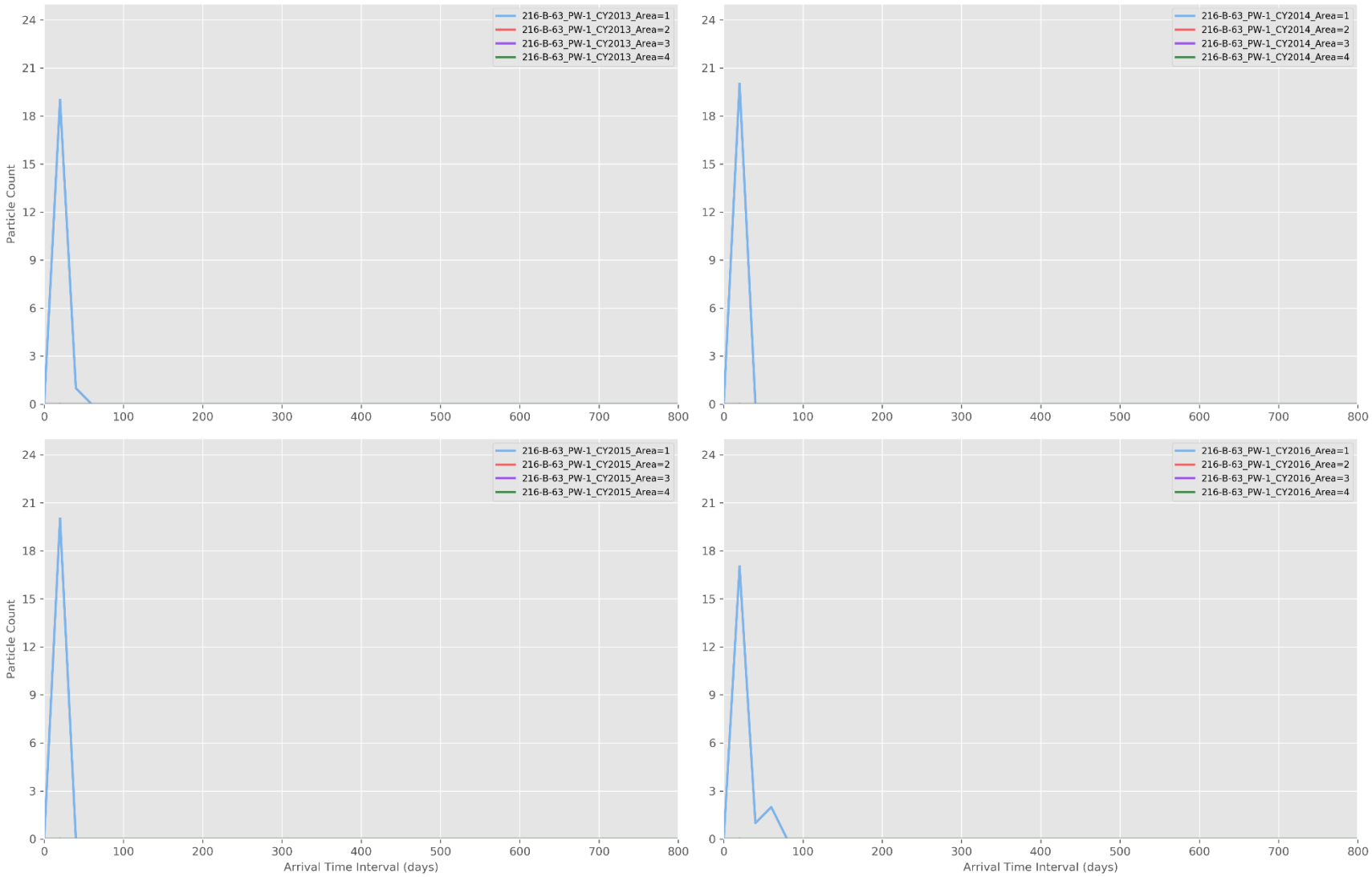

Figure G-29. Particle Breakthrough Curves per Area at Monitoring Well 216-B-63_PW-1

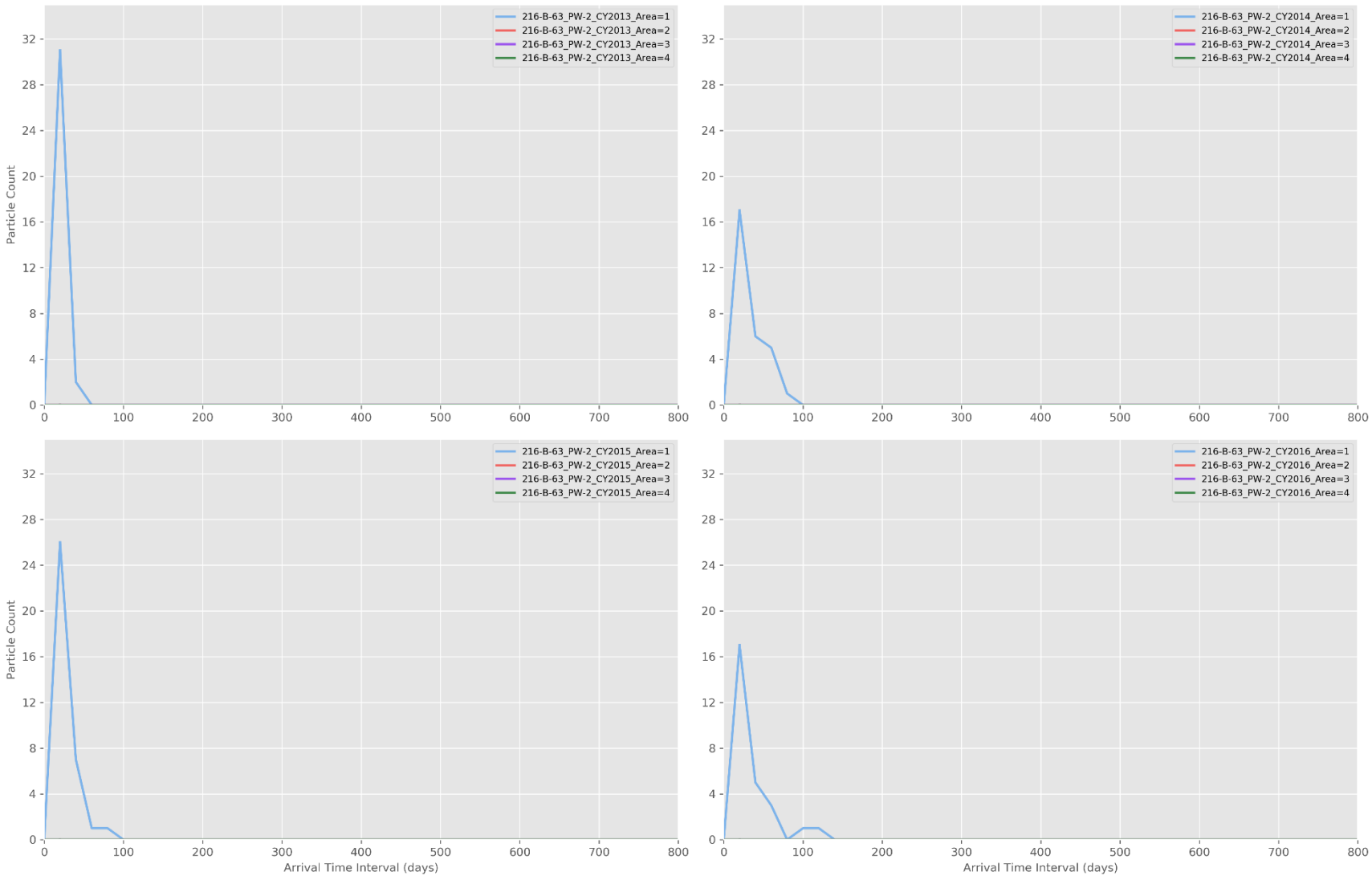

Figure G-30. Particle Breakthrough Curves per Area at Monitoring Well 216-B-63_PW-2

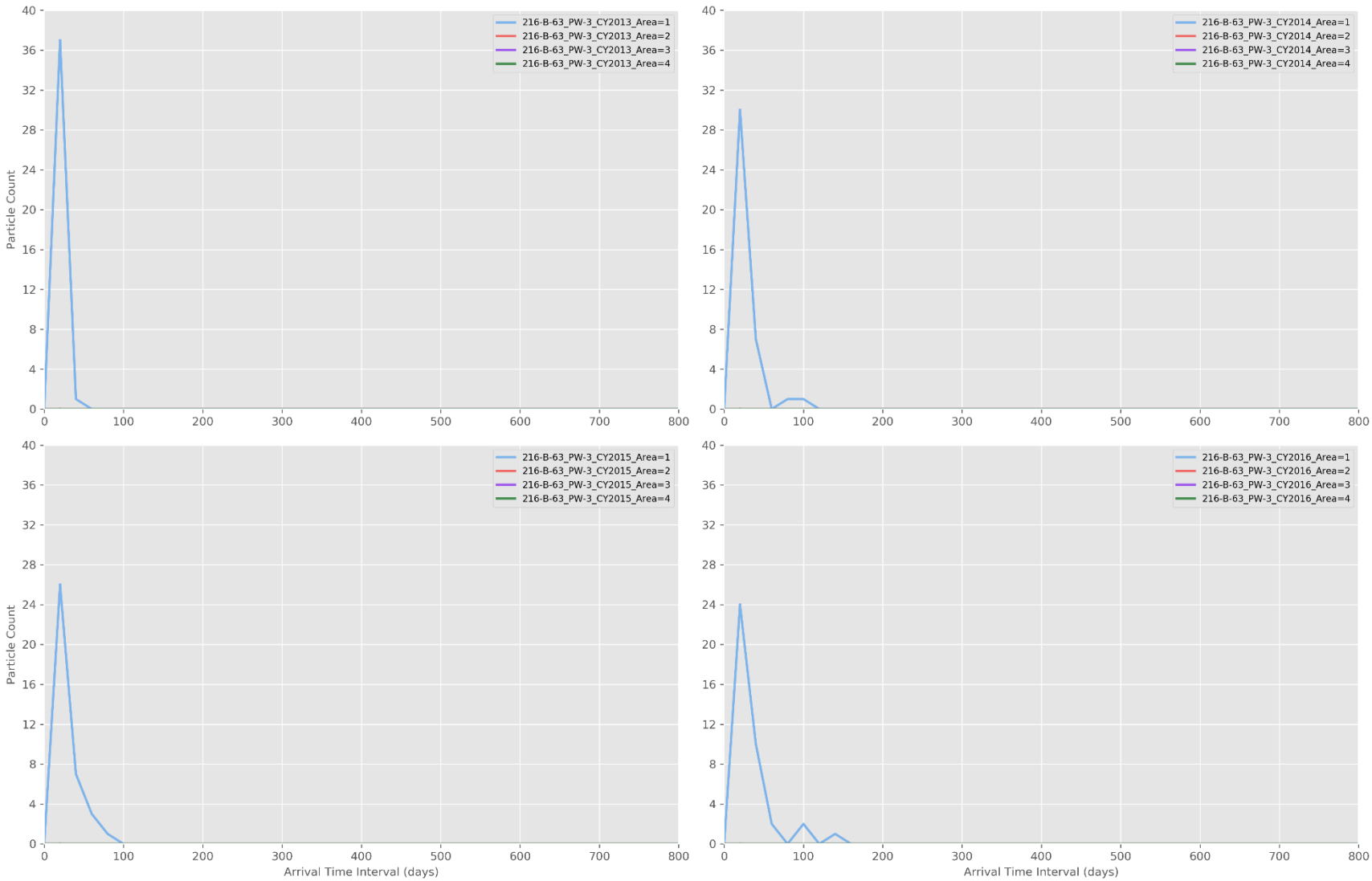

Figure G-31. Particle Breakthrough Curves per Area at Monitoring Well 216-B-63_PW-3

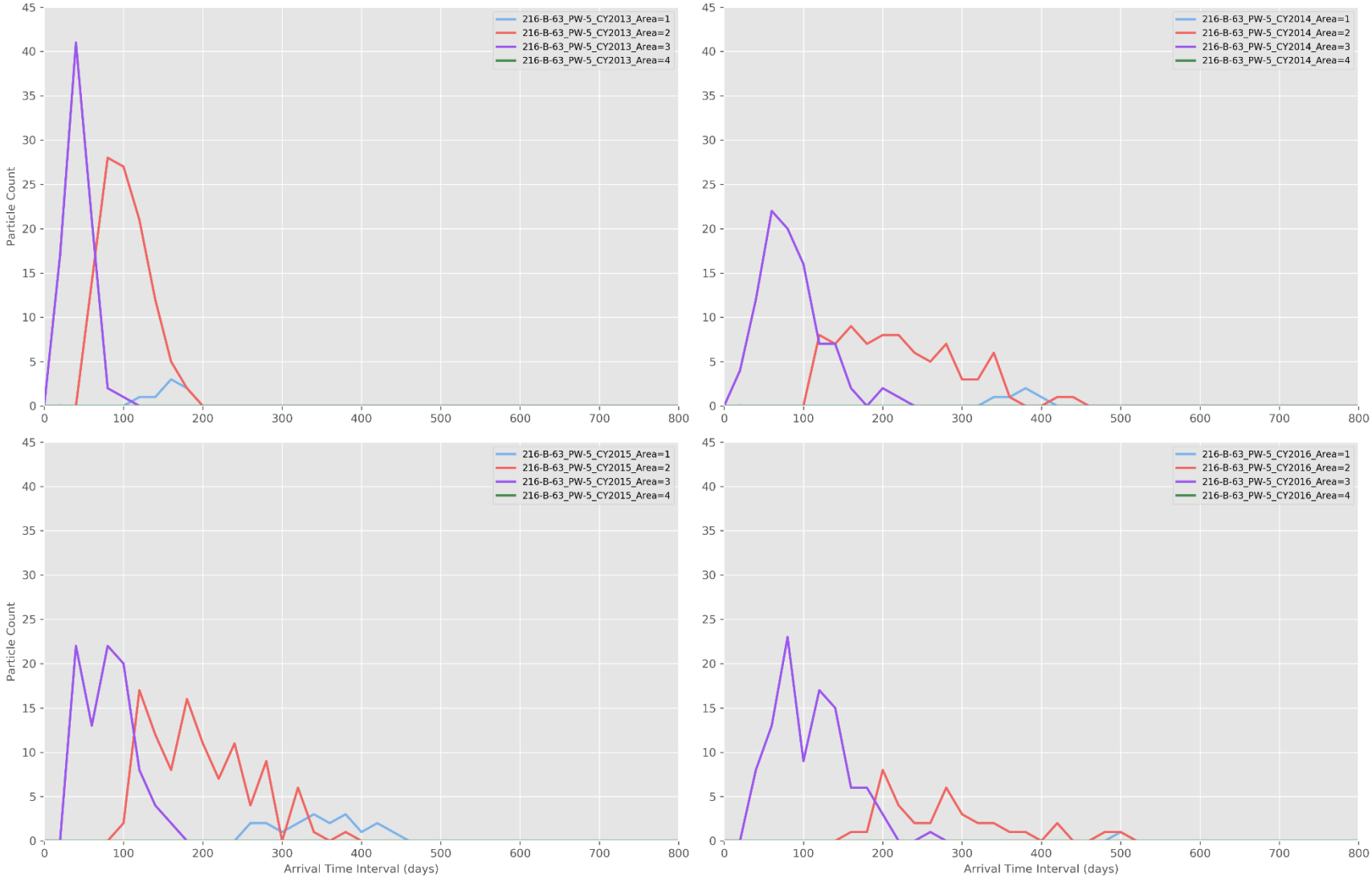

Figure G-32. Particle Breakthrough Curves per Area at Monitoring Well 216-B-63_PW-5

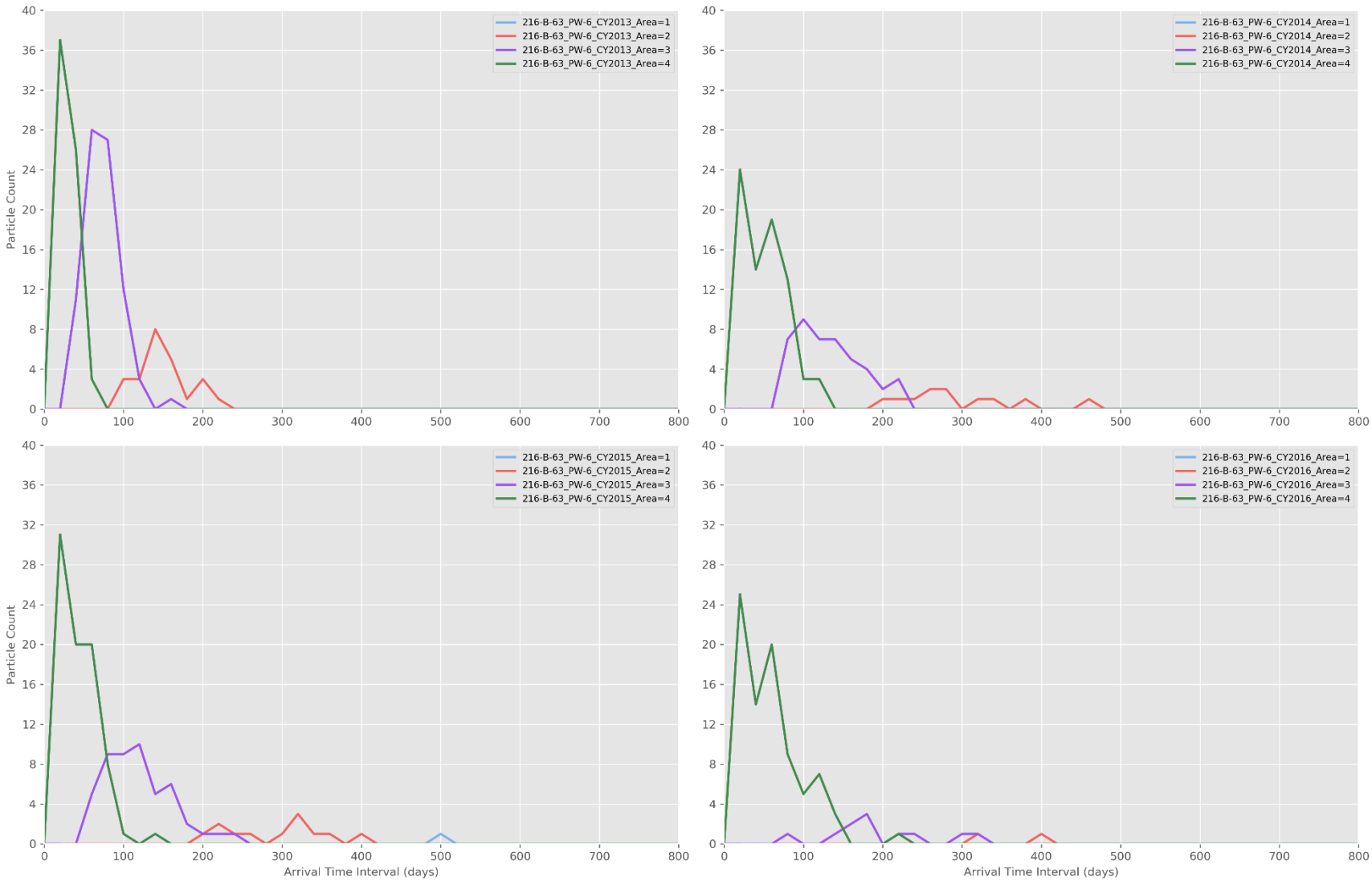

Figure G-33. Particle Breakthrough Curves per Area at Monitoring Well 216-B-63_PW-6

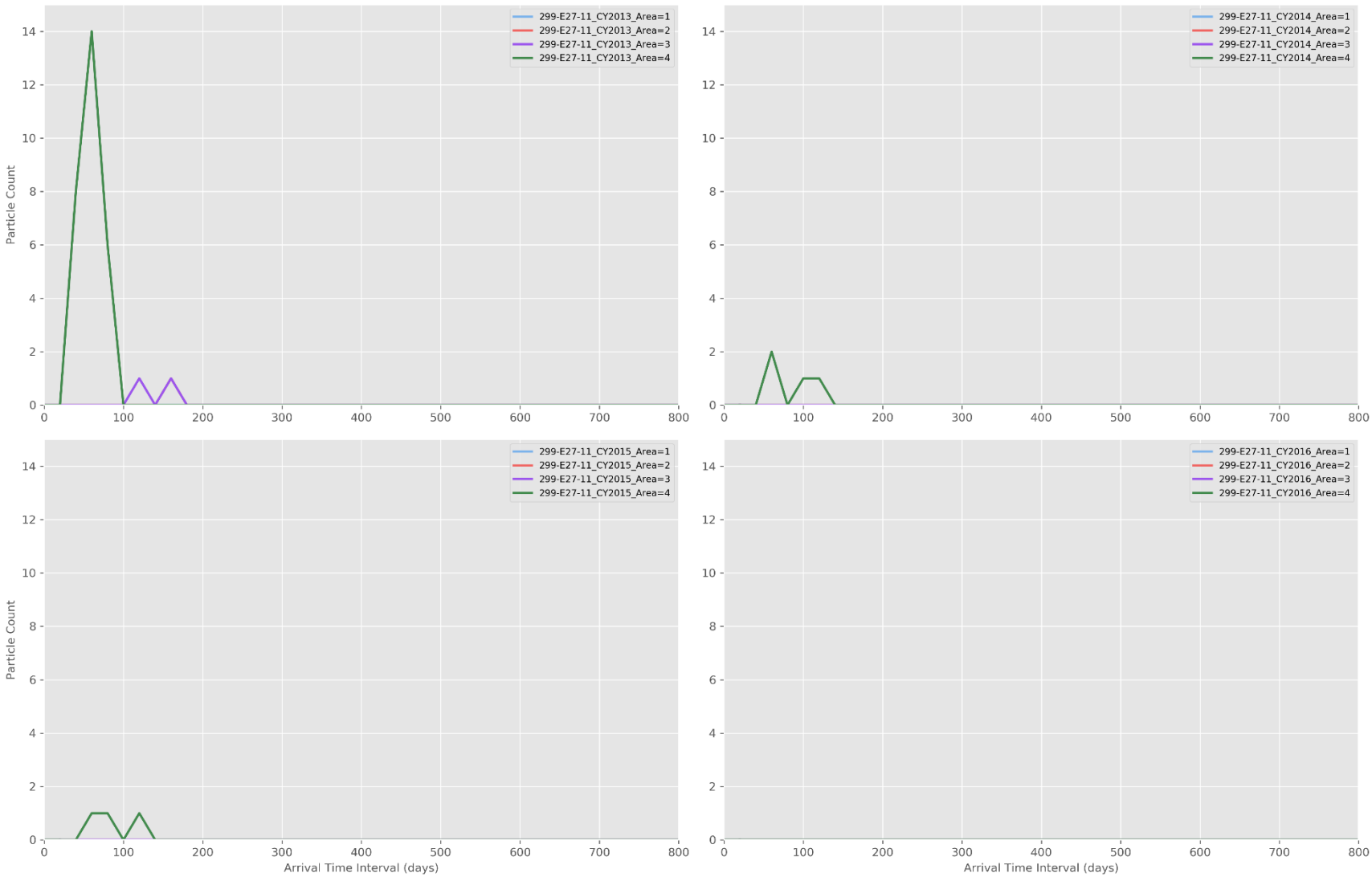

Figure G-34. Particle Breakthrough Curves per Area at Monitoring Well 299-E27-11

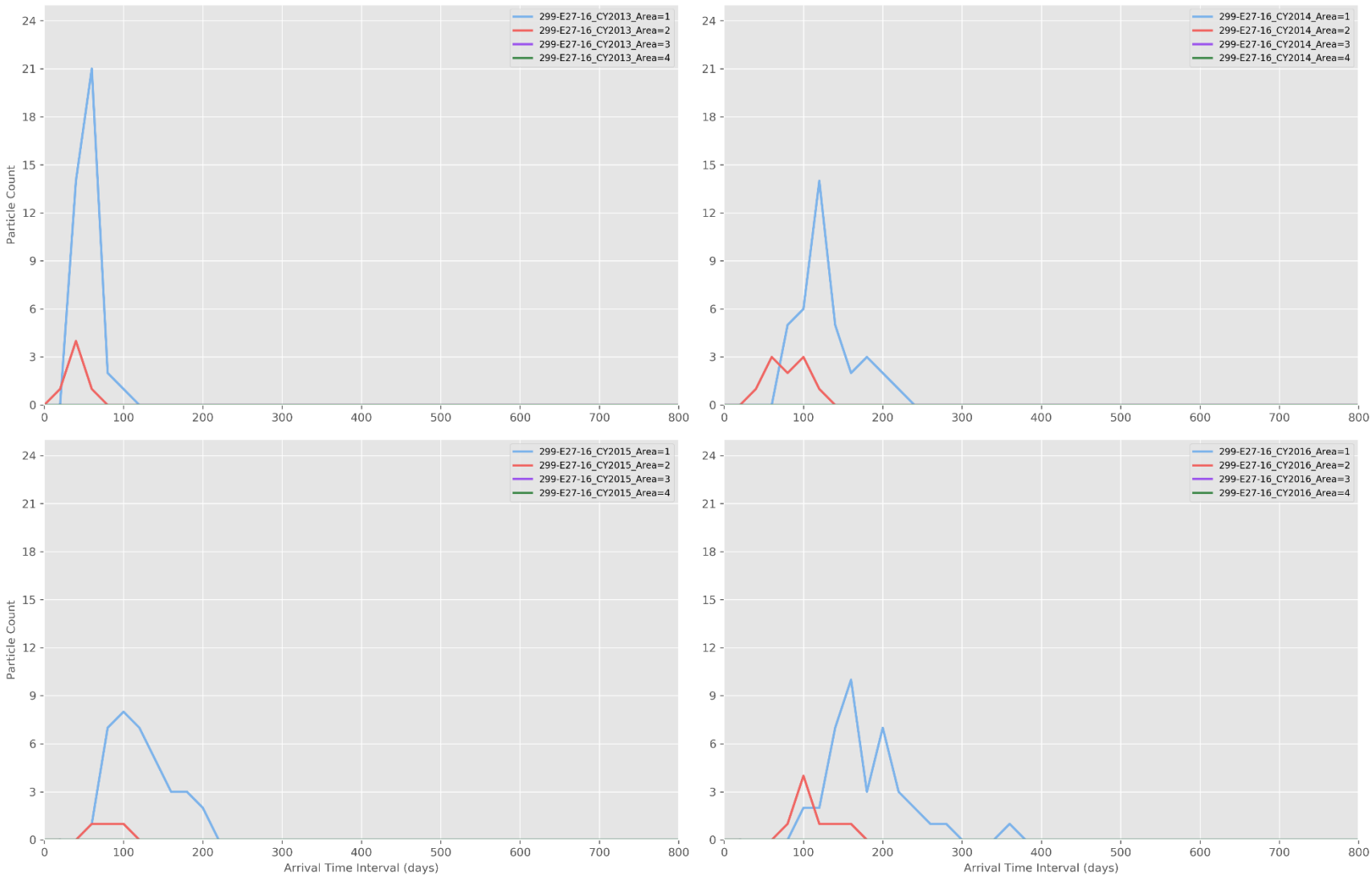

Figure G-35. Particle Breakthrough Curves per Area at Monitoring Well 299-E27-16

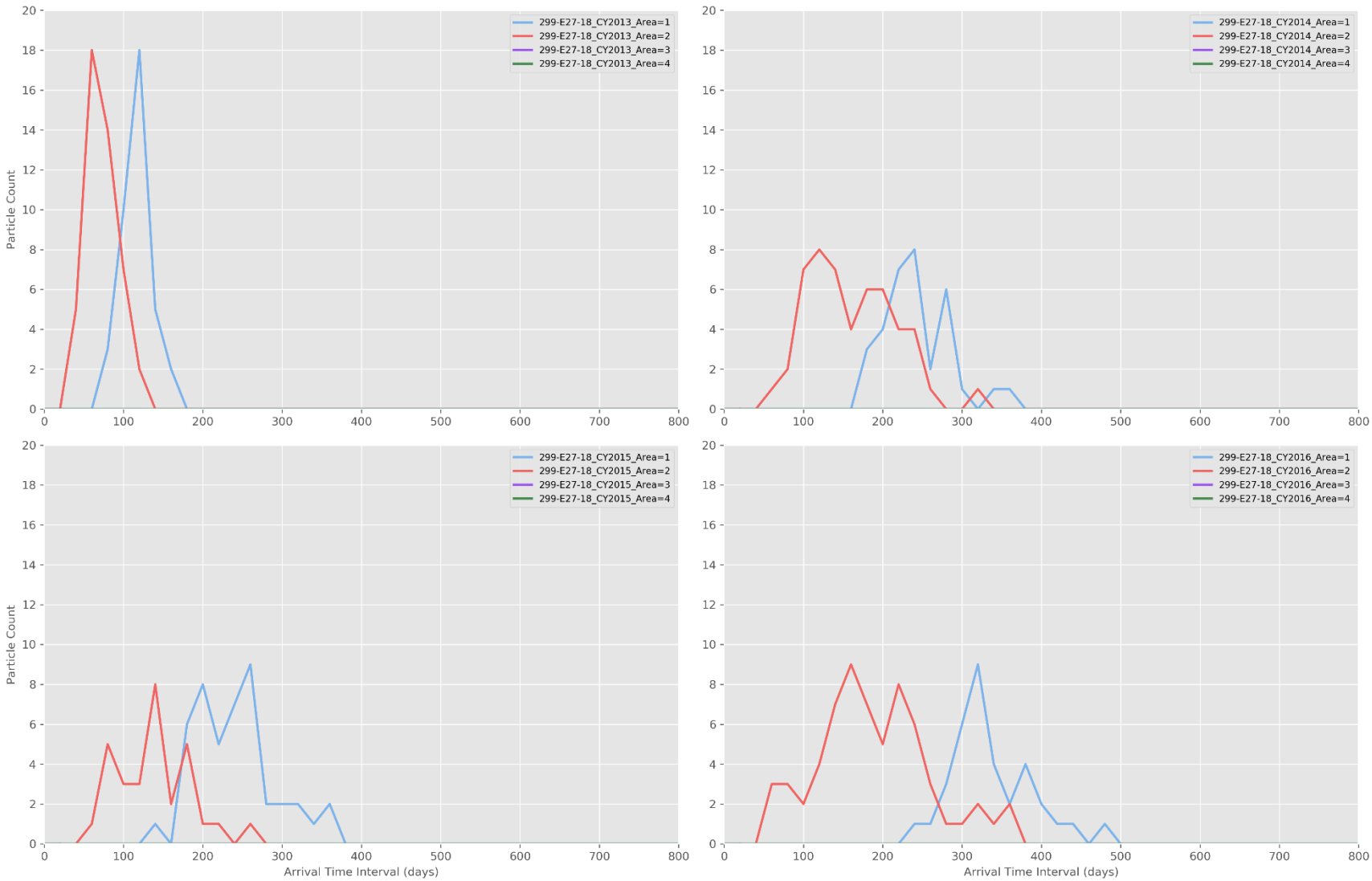

Figure G-36. Particle Breakthrough Curves per Area at Monitoring Well 299-E27-18

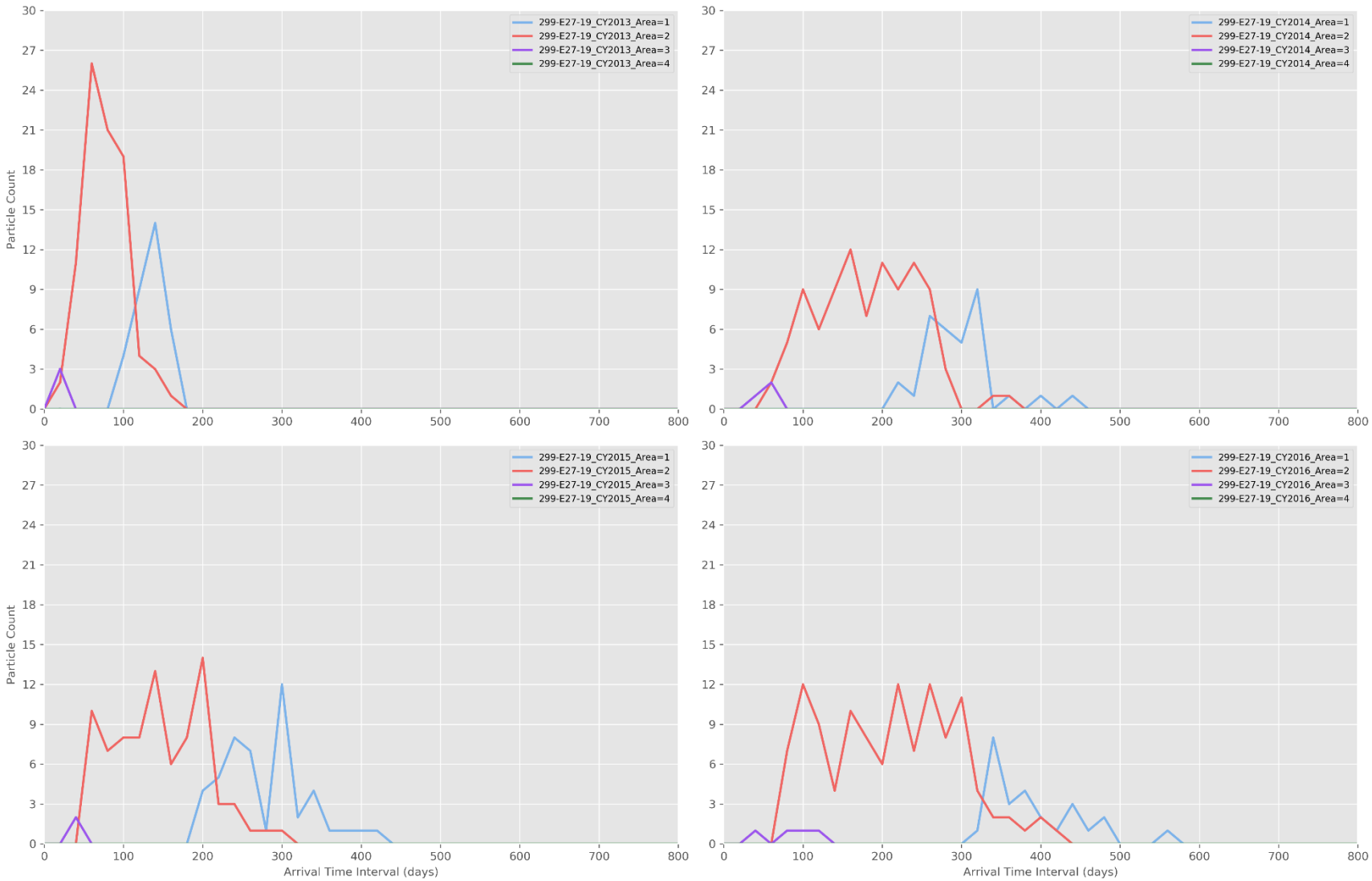

Figure G-37. Particle Breakthrough Curves per Area at Monitoring Well 299-E27-19

For each downgradient monitoring well at the 216-B-63 Trench, the distance used in the calculation was the distance from the centroid of the facility to each well location. The hydraulic conductivity used in the calculation for the 216-B-63 Trench, 15,000 m/d (49,213 ft/d), is a calibrated, conservative value from the CPGWM. The value is the hydraulic conductivity for the Hanford formation, which underlies part of the facility. The facility is also underlain by the Cold Creek unit, but the CPGWM hydraulic conductivity value for the Cold Creek unit was not used for this calculation because its higher value would result in a lower calculated vertical migration estimate, which is less conservative. The results of the API plume diving calculation for the downgradient wells for the 216-B-63 Trench are shown in Table G-10.

Table G-10. Summary of Well Screen Interval Evaluation for Downgradient Wells

Monitoring Well	Existing or Proposed Well?	Distance, D, (m)[a]	Recharge, *i*, (m/yr)[b]	Slope, S, of Plume Dive[c]	Estimated Depth of Plume Below Water Table (m)[d]	Depth from Water Table to Bottom of Well Screen (m)[e]	Is Plume Depth Above Bottom of the Screen? (Yes/No/N/A)
299-E27-11	Existing[f]	355.4	1.07E-01	5.28E-03	1.88	2.00	Yes
299-E27-16	Existing	130.9	1.07E-01	5.28E-03	6.91E-01	1.80	Yes
299-E27-18	Existing	37.1	1.07E-01	5.28E-03	1.96E-01	3.10	Yes
299-E27-19	Existing	68.5	1.07E-01	5.28E-03	3.62E-01	2.70	Yes
216-B-63_PW-1	Proposed	416.2	1.07E-01	5.28E-03	2.20	N/A	N/A
216-B-63_PW-2	Proposed	313.8	1.07E-01	5.28E-03	1.66	N/A	N/A
216-B-63_PW-3	Proposed	222.8	1.07E-01	5.28E-03	1.18	N/A	N/A
216-B-63_PW-5	Proposed	164.4	1.07E-01	5.28E-03	8.68E-01	N/A	N/A
216-B-63_PW-6	Proposed	267.1	1.07E-01	5.28E-03	1.41	N/A	N/A

a. Distance of the well from centroid of dangerous waste management unit.

b. A representative number from the CPGWM. The recharge values represent fluxes from surface water discharge due to historical operations at the Hanford Site and are summarized in EMDT-BC-0002, *Vadose Zone Attenuated Recharge, Electronic Modeling Data Transmittal – Boundary Condition (Artificial Recharge)*-0002. The anthropogenic flux is added to the natural recharge component in order to establish the final total recharge flux used in the simulations. Discharges included in EMDT-BC-0002 have been attenuated to account for travel through the vadose zone.

c. Slope of the plume dive computed using the American Petroleum Institute plume diving calculation as detailed in the main text of this ECF. The migration parameters for the 216-B-63 Trench used in the calculation of slope are as follows:

Hydraulic conductivity: 15,000 m/d (49,213 ft/d) (a calibrated value from the CPGWM)

Hydraulic gradient: 3.70E-06 (determined from 2016 water-level maps produced using TRIM)

d. Plume depth at monitoring well location computed from distance, D, times the slope, S.

e. Depths obtained from Tables 2-22 and 2-42 in DOE/RL-2016-66, *Hanford Site RCRA Groundwater Monitoring Report for 2016.*

f. Well 299-E27-11 is an existing well in the interim monitoring well network for Low-Level Burial Grounds Waste Management Area-2. It is proposed for inclusion in the final well network for the 216-B-63 Trench.

CPGWM = Central Plateau Groundwater Model

ECF = environmental calculation file

N/A = not applicable

TRIM = Tikhonov Regularized Inverse Method

G4 References

40 CFR 265, "Interim Status Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities," Subpart F, "Ground-Water Monitoring," *Code of Federal Regulations*. Available at: http://www.gpo.gov/fdsys/pkg/CFR-2010-title40-vol25/xml/CFR-2010-title40-vol25-part265-subpartF.xml.

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Appendix H

Facility-Specific Results for the Integrated Disposal Facility

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Terms

API	American Petroleum Institute
CPGWM	Central Plateau Groundwater Model
CY	calendar year
ECF	environmental calculation file
IDF	Integrated Disposal Facility
TRIM	Tikhonov Regularized Inverse Method

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H1 Purpose and Background

The primary purpose of the calculations presented here is to estimate directions of potential migration to assess the efficacy of the geographical distribution of wells in the proposed monitoring well network for the subject facility. The calculations described within the main text of this environmental calculation file (ECF) were performed for each of the 200 East Facilities. This appendix presents results developed from the calculations that are specific to the Integrated Disposal Facility (IDF).

IDF is a double-lined landfill consisting of two disposal areas called cells, although the facility can be expanded as needed to a total capacity of six cells. Construction of the first two cells for IDF was completed in April 2006 (Section 1.1 in DOE/RL-2012-57, *Annual Summary of the Integrated Disposal Facility Performance Assessment 2012*). The cells were designed to accept mixed low-level waste, possibly including the treated low-level/low-activity waste, that will have gone through the vitrification process at the Hanford Site waste treatment plant.

IDF is approximately 457 m (1,500 ft) wide by 233 m (765 ft) long by 12.8 m (42 ft) deep for the "first expansion" with a capacity of nearly 165,000 m^3 (215,000 yd^3) (Section 1.1 in DOE/RL-2012-57). The design includes two leachate collection systems, which are compliant with the *Resource Conservation and Recovery Act of 1976* and designed to catch liquid that may seep through the waste. Once liquid reaches this liner, it is removed and taken to a facility where the liquid is treated, the contaminants removed, and the liquid then safely returned to the soil. Because the IDF is designed to allow for future expansion, construction of additional liners in the future will connect to the previously constructed liner. The disposal landfill cover will be designed and located to satisfy the dangerous waste disposal requirements once a decision is made to construct the final cover over the landfill.

The start date for IDF operations has not been determined, but it is monitored under a detection monitoring program described in Section III.11.E.1.b of 10-EMD-0080, Enclosure 1, "Class 1 Modifications to the Hanford Facility Resource Conservation and Recovery Act Permit, Quarter Ending June 30, 2010."

The IDF monitoring network consists of one upgradient well (299-E24-24), two crossgradient wells (299-E18-1 and 299-E24-21), and four downgradient wells (299-E17-22, 299-E17-23, 299-E17-25, and 299-E17-26) (Figure H-1). Since IDF is not operational, the current monitoring objective is to collect baseline groundwater information. All of the network wells are screened across the water table (Table 2-30 in DOE/RL-2016-66, *Hanford Site RCRA Groundwater Monitoring Report for 2016*).

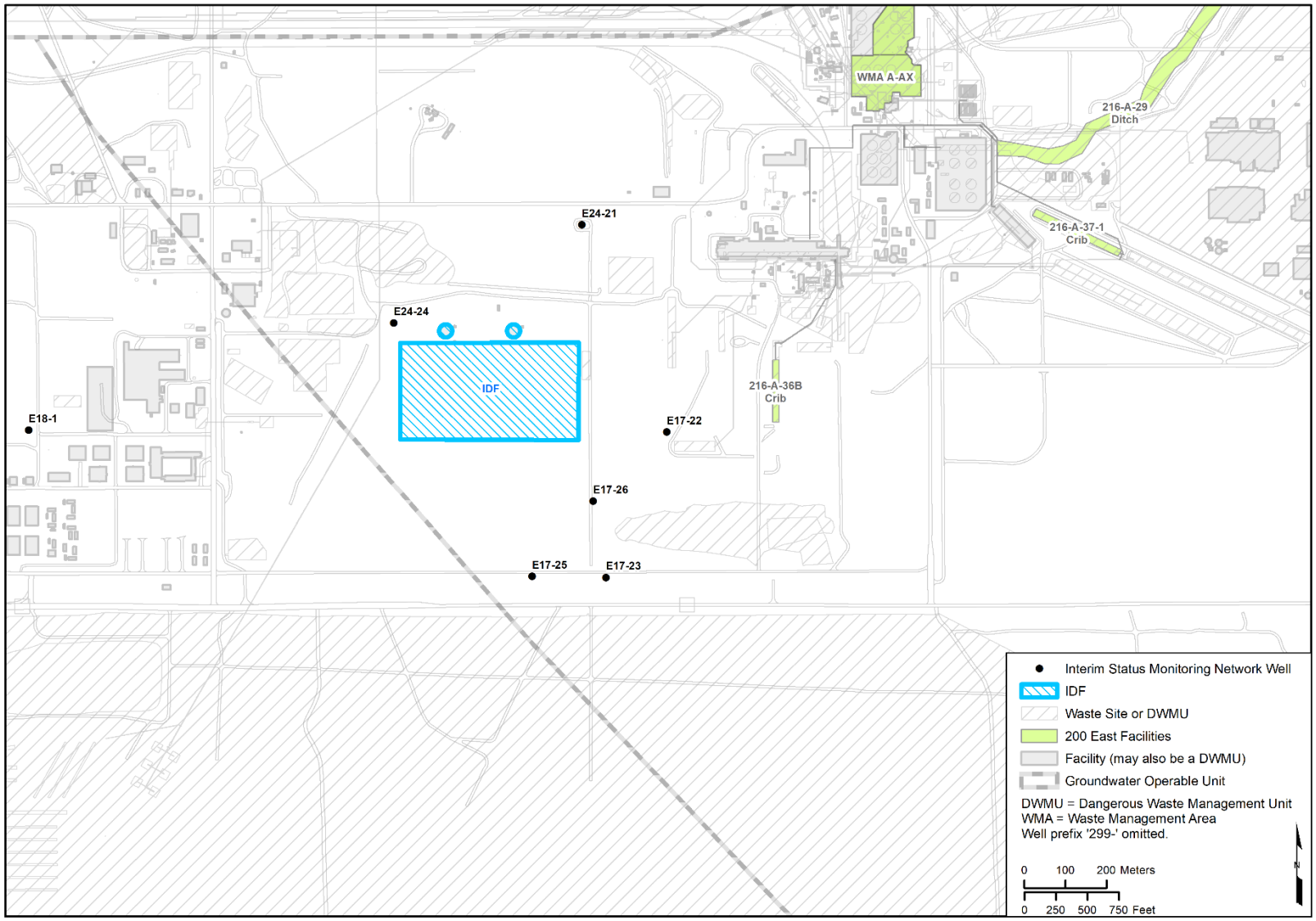

Figure H-1. Locations of Interim Status Groundwater Monitoring Wells at IDF

H2 Facility-Specific Input for the Integrated Disposal Facility

Inputs used in the calculations that were specific to IDF are described in this chapter.

H2.1 Particle Count Grid and Release Locations

To prepare particle count maps, a distribution of facility-specific starting locations is required. The starting locations for the particle-tracking calculations represent the area over which a potential release from a given facility would impact the underlying water table. The particle releases were located at plausible release sites throughout the facility. For IDF, 66 release locations were specified around the leachate collection sumps and tanks at IDF (Figure H-2). Twenty particles were released and tracked from each release location to provide the density of particles in space and time required for the detailed facility-specific calculations, randomizing the seed values for the dispersion calculations. Thus, 1,320 [1,320 = 66 (release locations) × 20 (releases)] particles were tracked for each of the four simulations.

Contour maps of particle counts were generated by counting the number of particles that pass through a pre-defined uniform calculational grid (Figure H-2). The grid used to develop the relative particle density maps is defined by 10 by 10 m (33 by 33 ft) cells. The grid is oriented to be parallel to the predominant groundwater flow direction at IDF.

H2.2 Migration Parameters

Parameters specific to the groundwater flow conditions at IDF are reported throughout the various documents for the facility. The parameters used in the calculations performed herein to represent nonreactive dissolved contaminant migration are mobile (or effective) porosity and hydraulic conductivity. The parameters used in these calculations are representative of local conditions for a conservative (i.e., nonreactive) solute dissolved within groundwater.

There is a range of hydraulic conductivity values reported in site literature for IDF. Values range from 3.26 m/d (10.7 ft/d) to 17,000 m/d (55,774 ft/d) for the Ringold Formation and Hanford formation (Table 1 in ECF-Hanford-17-0241, *Hydraulic Gradient and Velocity Calculations for RCRA Sites in 2017*). As described in Section 4.2.1.1 of the main text of this ECF, the hydraulic conductivity used in the work performed herein corresponds to the calibrated values from the Central Plateau Groundwater Model (CPGWM) (CP-47631, *Model Package Report: Central Plateau Groundwater Model, Version 8.4.5*). Figure 3-2 in the main text of this ECF indicates IDF is located in the hydrostratigraphic unit zone corresponding to the Hanford formation. The value used for the hydraulic conductivity for IDF is 15,000 m/d (49,213 ft/d), which corresponds to the Hanford formation as shown in Table 4-1 in the main text of this ECF. The range in values for mobile (effective) porosity for IDF reported in Table 1 in ECF-Hanford-17-0241 is 0.01 to 0.2. The mobile (effective) porosity defined for the Hanford formation, which underlies IDF, is specified at 0.25.

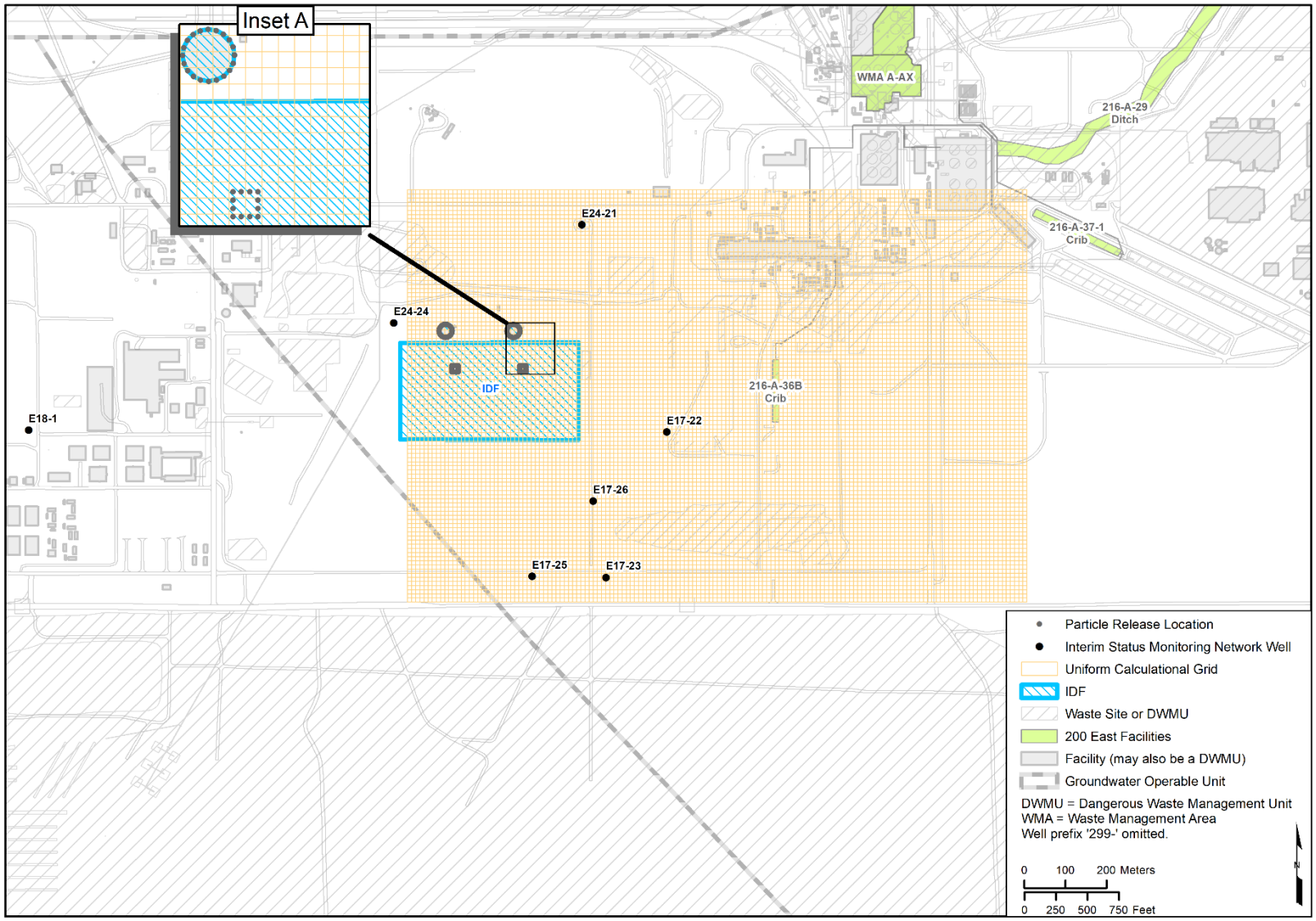

Figure H-2. Uniform Calculational Grid and Release Locations at the IDF

H3 Facility-Specific Results for the Integrated Disposal Facility

The groundwater elevation contours prepared in the vicinity of IDF using the Tikhonov Regularized Inverse Method (TRIM) are presented in this section. In addition, the outputs of the particle tracking and particle count calculations are presented, including the following:

- Maps of calculated particle pathlines for the flow conditions determined for each of the four years (2013, 2014, 2015, and 2016). These are presented at the facility-specific scale considering advective and dispersive migration.
- Time-series plots, referred to as particle breakthrough curves, of the relative arrival, peak, and decline in particle counts at each interim status groundwater monitoring well location and each proposed monitoring location, where applicable.
- Tabulation of relative particle counts for each interim status groundwater monitoring well location and each proposed monitoring location, where applicable.
- Maps of particle counts downgradient of each facility based on the flow conditions determined for each of the four years.

The results of calculations of potential vertical migration of contaminants at the monitoring well locations are also presented.

H3.1 Groundwater Elevation Contours

Figures H-3 through H-6 show the results of the groundwater elevation analysis completed using TRIM in the vicinity of IDF. The figures depict general patterns of groundwater elevations and hydraulic gradients for conditions represented by calendar years (CYs) 2013, 2014, 2015, and 2016. These groundwater elevation contours and associated hydraulic gradients form the basis for the facility-specific calculations performed for this ECF.

H3.2 Particle Tracking

Once the groundwater elevation contour maps and underlying piecewise continuous elevation grids were prepared using TRIM, particle tracking was implemented using both advection and dispersion.
The particle pathlines that were produced depict the patterns of spreading that might accompany the migration of contaminants near IDF for the flow conditions calculated for CYs 2013, 2014, 2015, and 2016. Figures H-7 through H-10 depict the particle pathlines developed based on the groundwater elevations prepared throughout the 200 East Area using TRIM. The resulting maps were prepared based on the release of 20 particles from each starting location to provide the high density of particles in space and time required for these detailed facility-specific calculations. Figures H-7 through H-10 depict the particle pathlines calculated after 200 years of travel, by which time it was determined that most of the particles would have arrived at or passed by the interim status groundwater monitoring wells. Figures H-7 through H-10 depict an instantaneous release to the water table from the release locations in IDF to illustrate the adequacy of the well network for monitoring the entire facility.

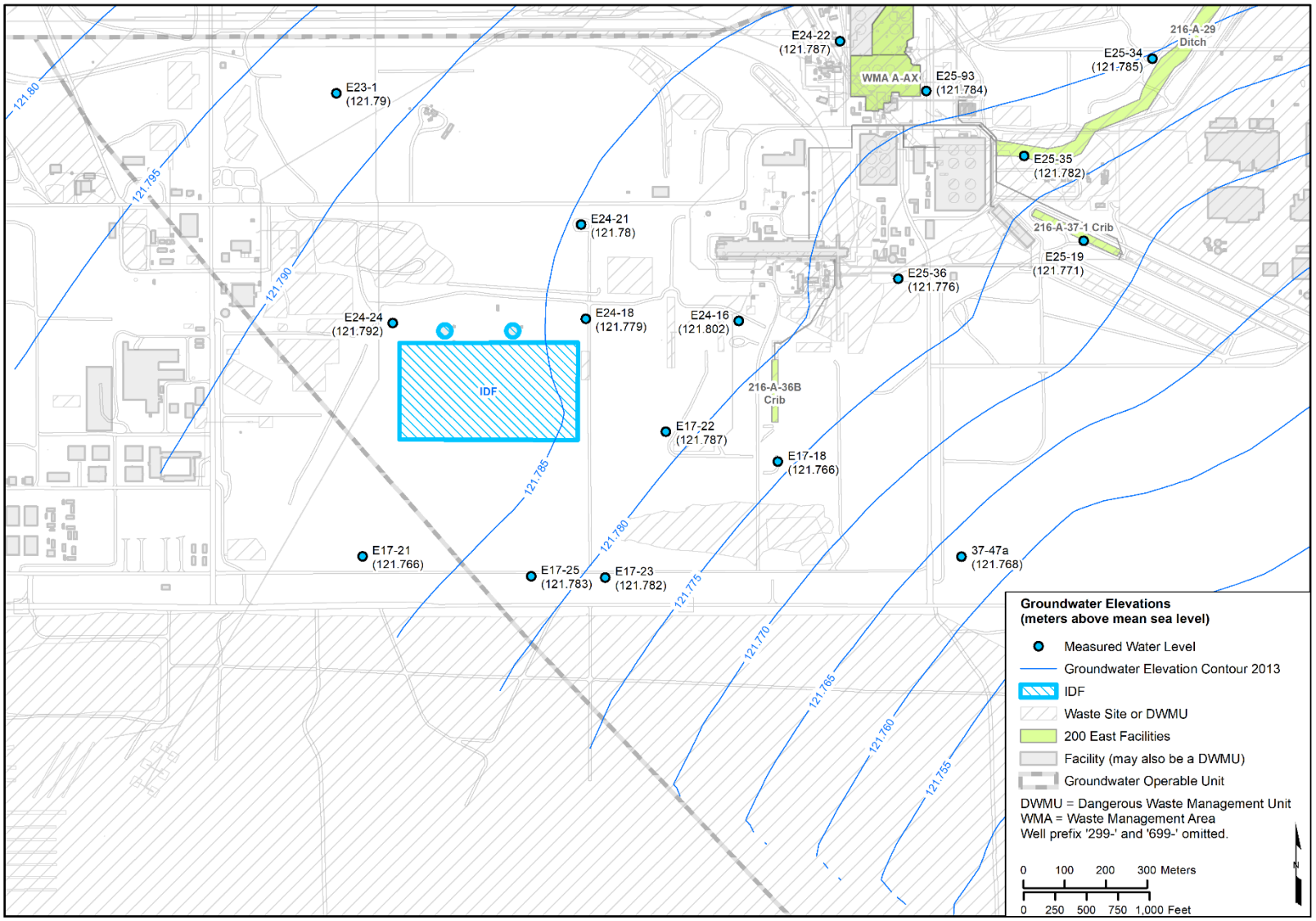

Figure H-3. Water-Level Elevation Map for IDF, 2013

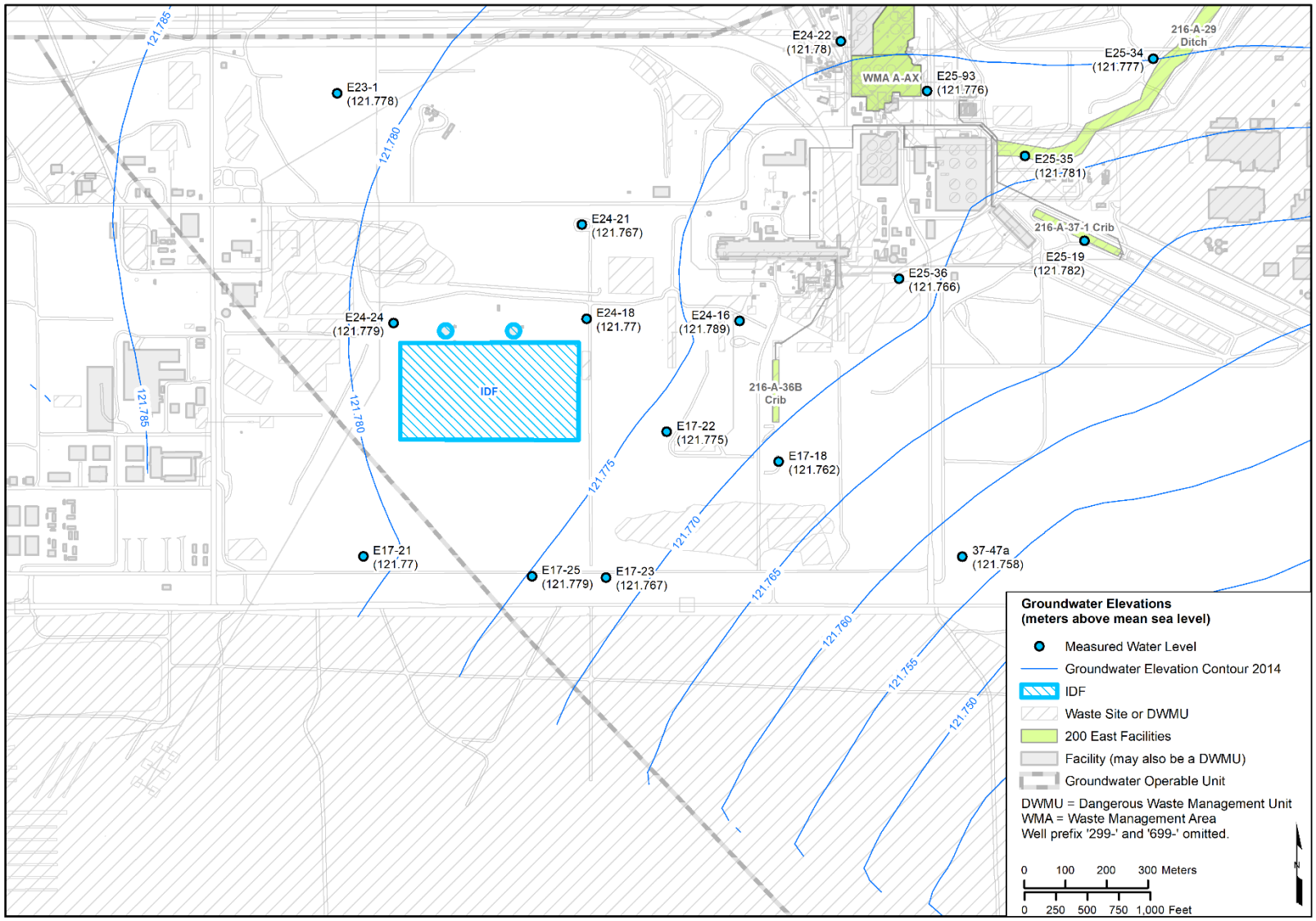

Figure H-4. Water-Level Elevation Map for IDF, 2014

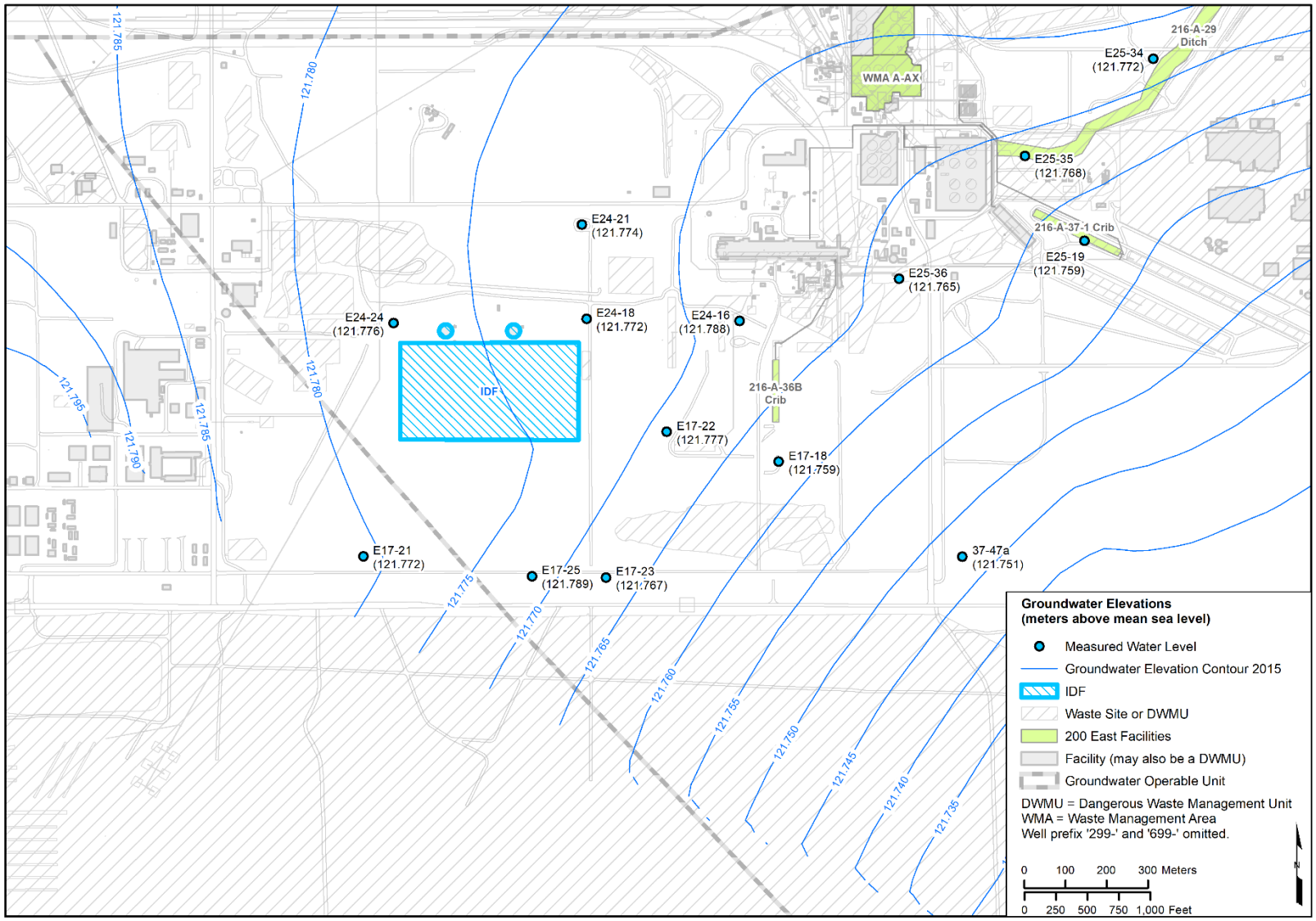

Figure H-5. Water-Level Elevation Map for IDF, 2015

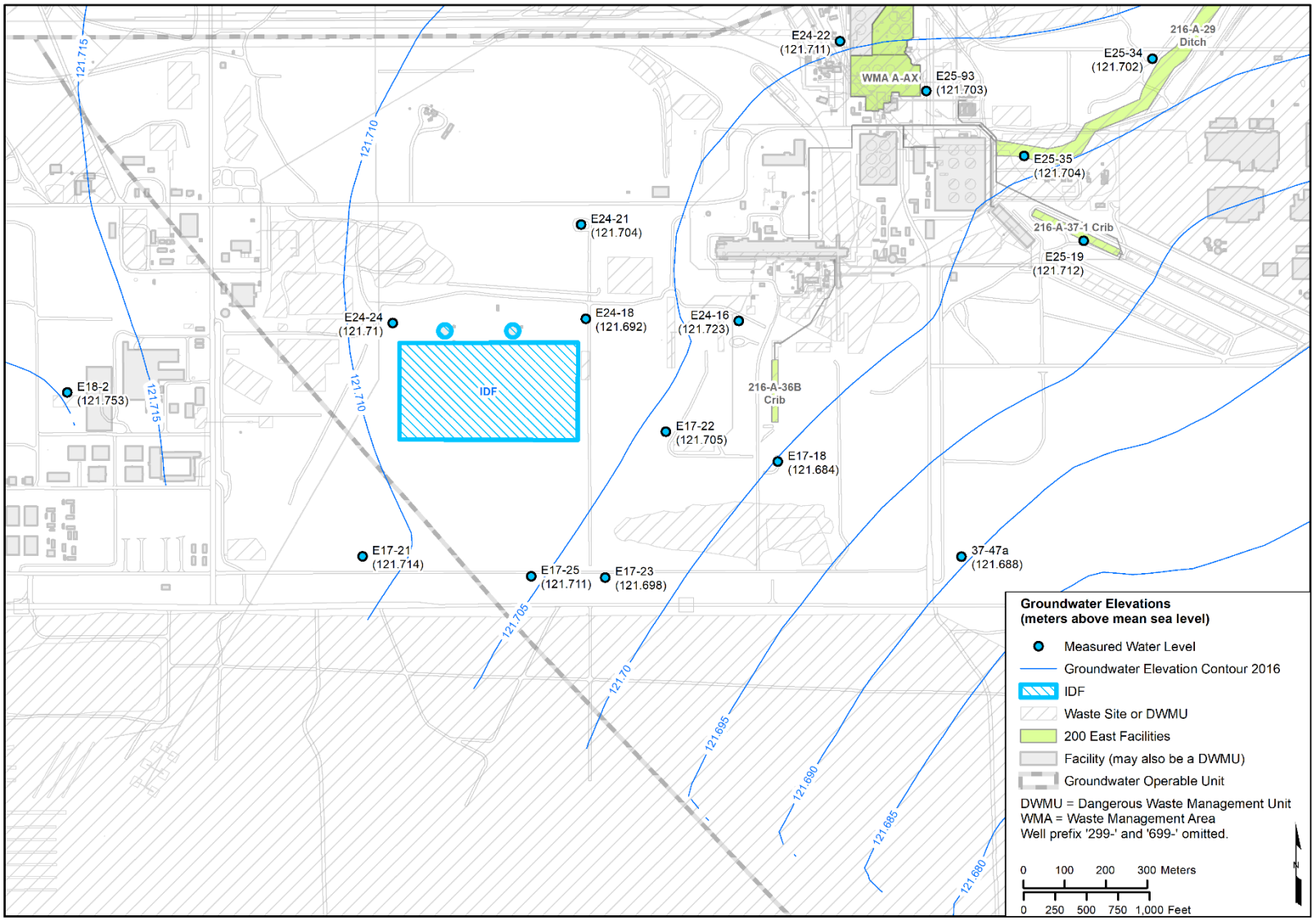

Figure H-6. Water-Level Elevation Map for IDF, 2016

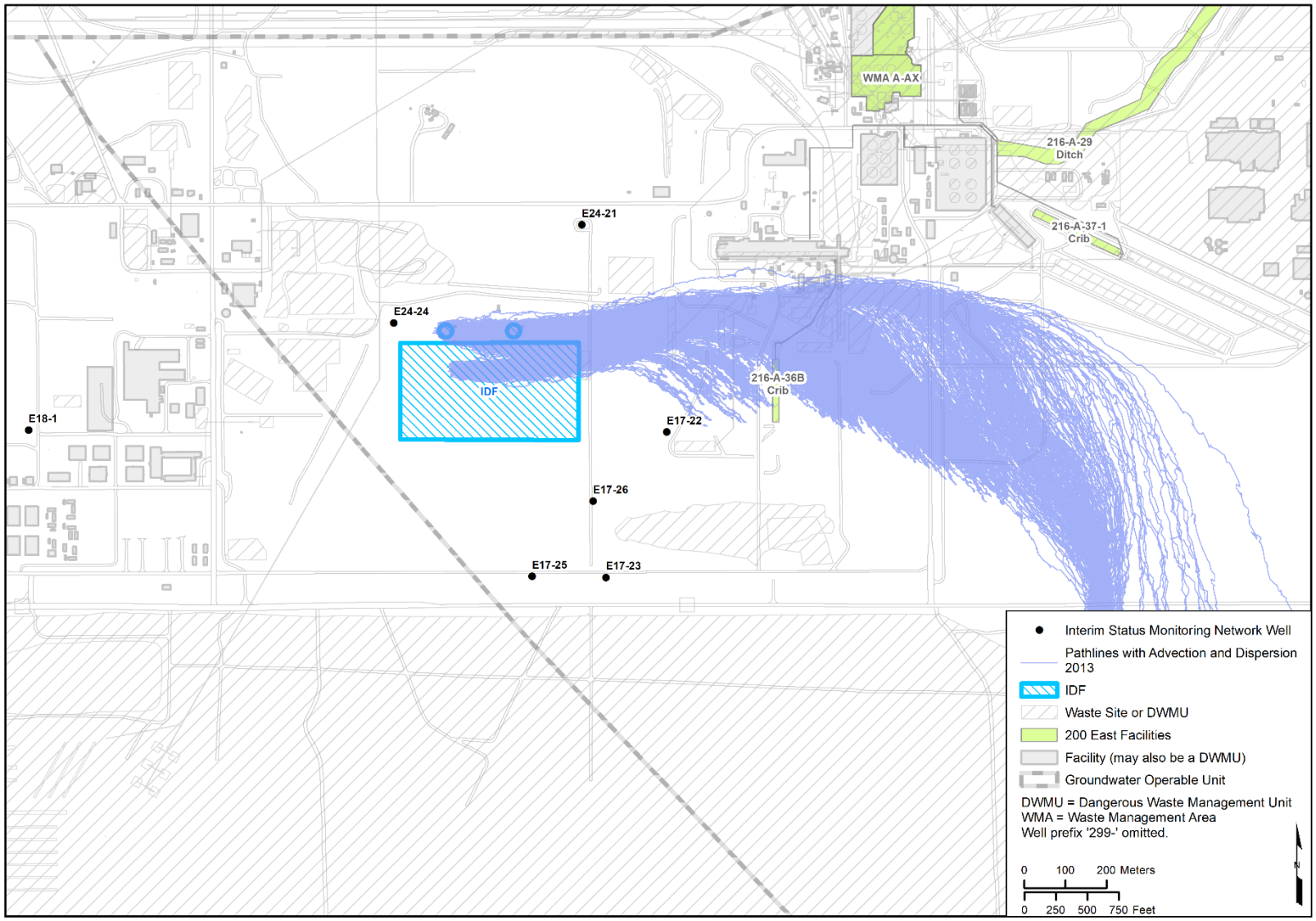

Figure H-7. Local-Scale Particle Pathlines, Advection and Dispersion – IDF, 2013

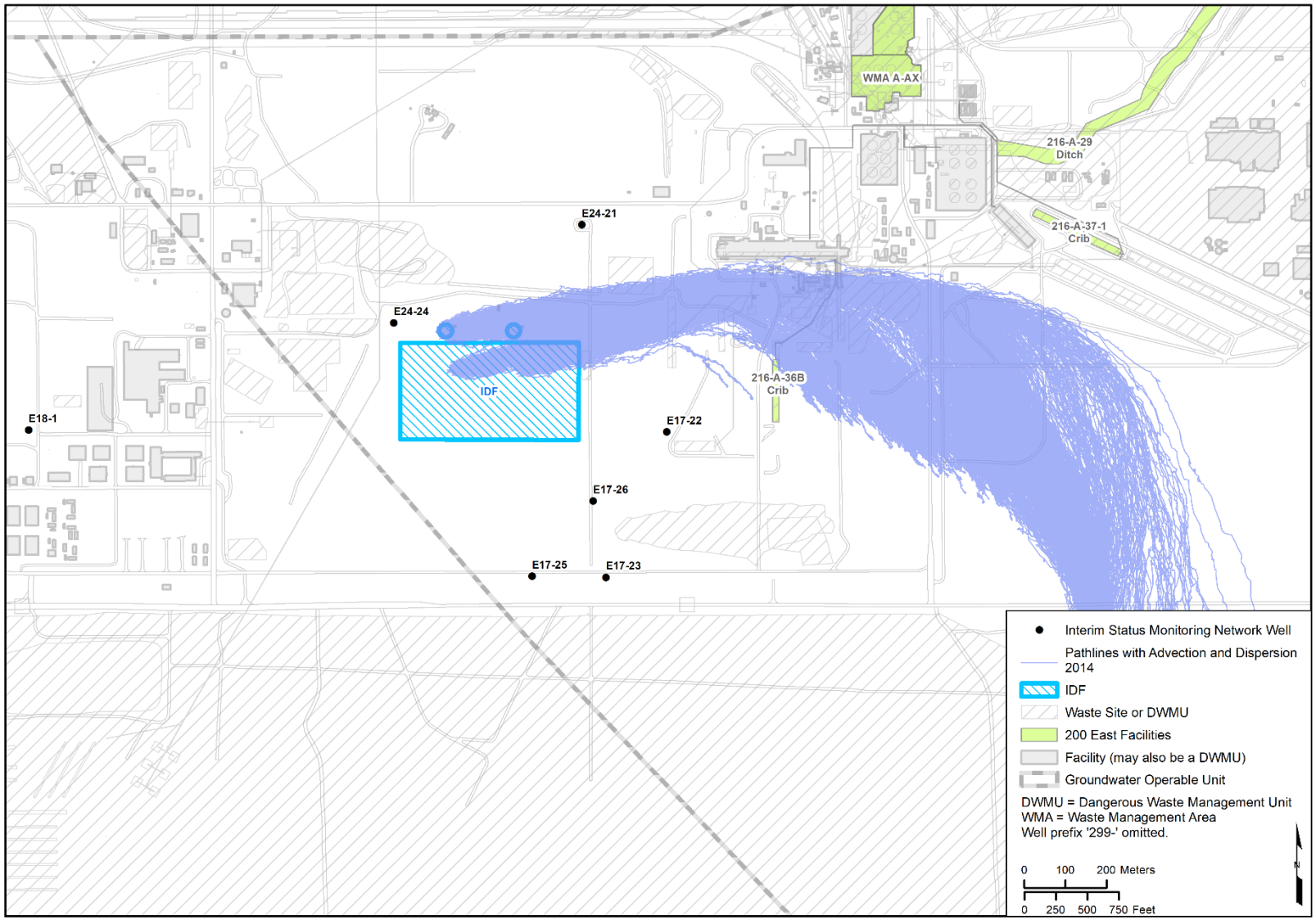

Figure H-8. Local-Scale Particle Pathlines, Advection and Dispersion – IDF, 2014

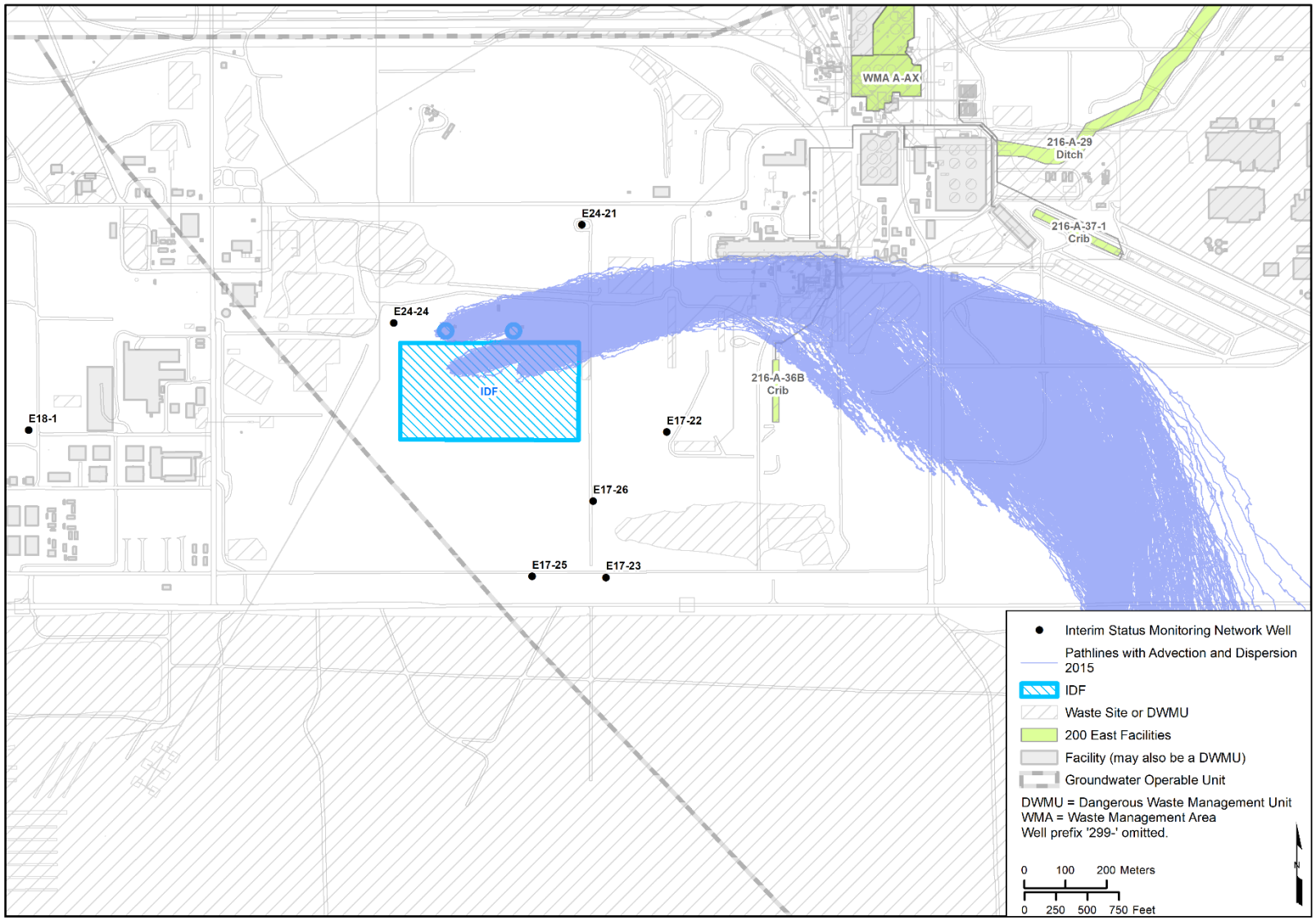

Figure H-9. Local-Scale Particle Pathlines, Advection and Dispersion – IDF, 2015

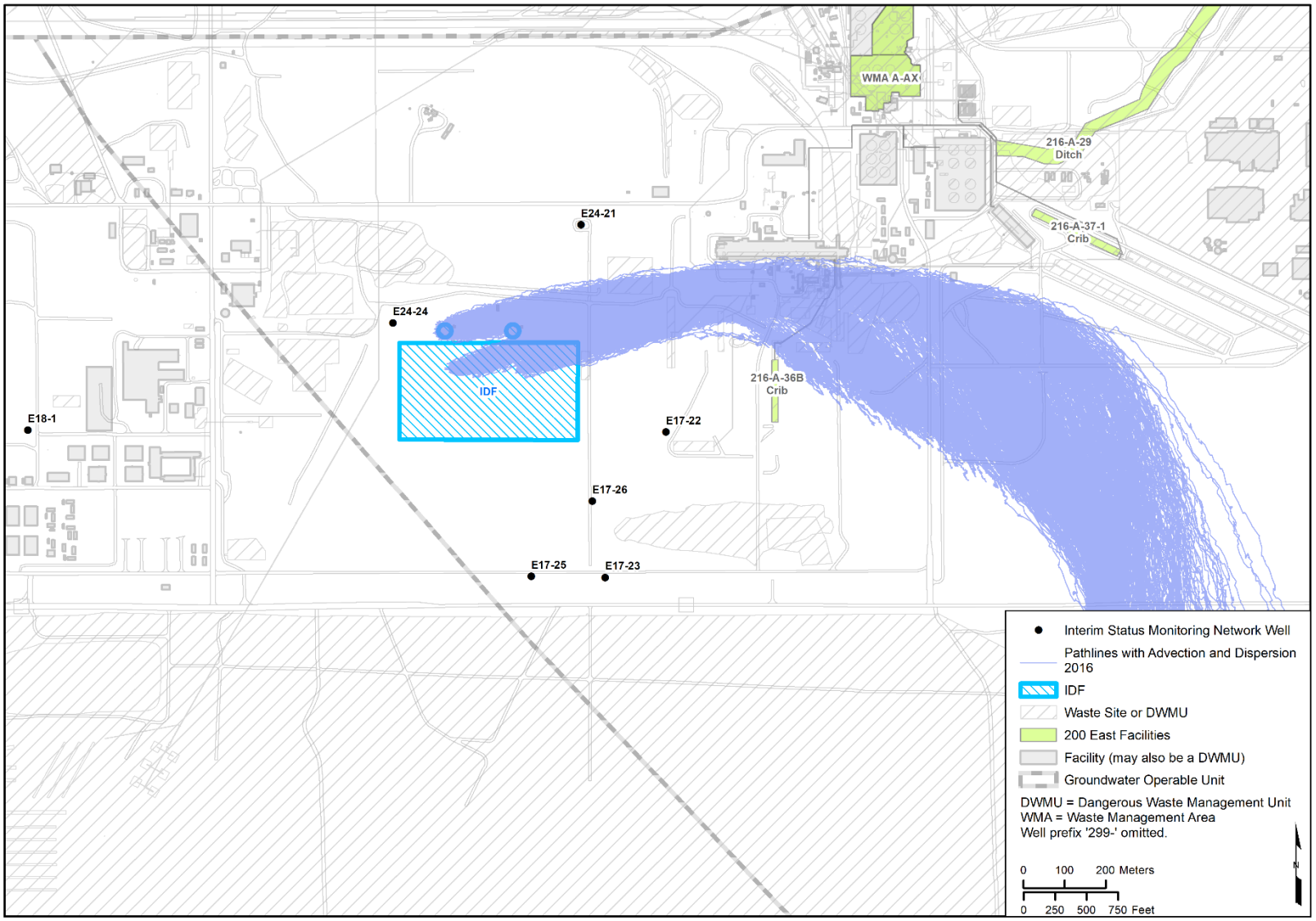

Figure H-10. Local-Scale Particle Pathlines, Advection and Dispersion – IDF, 2016

H3.3 Particle Counts

To compare the relative timing and density of the particles that pass by each monitoring well location, particle counts were calculated as described in Section 6.3 of the main text of this ECF. At the well locations for IDF no particle passed through the vicinity of the wells for the flow conditions calculated for CYs 2013, 2014, 2015, and 2016, so no particle count table or particle breakthrough curve were generated for the wells at IDF.

Figures H-11 through H-14 depict the particle count maps developed based on the instantaneous release of a large number of particles at the facility. The particle count maps depict areas of relatively higher and lower potential impact from a release at the facility that reaches the water table for conditions represented by CYs 2013, 2014, 2015, and 2016. Figures H-11 through H-14 depict the particle density after 200 years of calculated travel.

The goal of well placement is for the well locations to span the range of particle pathline distribution as released from IDF. The particle count maps show areas of high particle counts where there are no corresponding monitoring wells, indicating the need for additional monitoring wells. In addition, a new upgradient well is recommended for the site to replace well 299-E18-2 to provide upgradient monitoring closer to the site. The location of the four proposed wells (IDF_PW-1, IDF_PW-2, IDF_PW-3, and IDF_PW-4) are shown in Figures H-11 through H-14.

H3.4 Proposed Monitoring Wells

The locations of the proposed monitoring wells are shown in Figures H-11 through H-14. Tables H-1 through H-3 present the computed particle counts over time, binned into periods of 1 year, for each of the proposed downgradient monitoring wells. While the particles were run for 200 years, the particle count tables are truncated to 10 years by which time the particles had passed the vicinity of the wells. The tables present four entries (one for each year) for each well. At the bottom of the column for each mapped event is the total number of particles that passed through the vicinity of the well, regardless of time, and the average of the totals for the four mapped years rounded to the nearest integer. Each table provides an indication of the relative timing of the expected detections at each well and the relative potential that each well would detect a release at the facility for the flow conditions calculated for CYs 2013, 2014, 2015, and 2016.

H3.4.1 Relative Arrival Times at Interim Status Groundwater Monitoring Wells

Figures H-15 through H-17 depict plots of particle counts over time (particle breakthrough curves) for each proposed downgradient well location. The underlying data plotted in Figures H-15 through H-17 are the same as the data in Tables H-1 through H-3, but the time interval over which particles are summed is not necessarily the same. Particle breakthrough curves show the relative timing and particle density for the arrival, peak, and decline in particle counts at each interim status monitoring location resulting from the hypothetical instantaneous release at the facility. The plots depict the relative potential at each well for detecting a release from the facility that reaches the water table for the flow conditions calculated for CYs 2013, 2014, 2015, and 2016. There is one figure for each well with four lines shown on each plot (one for each year).

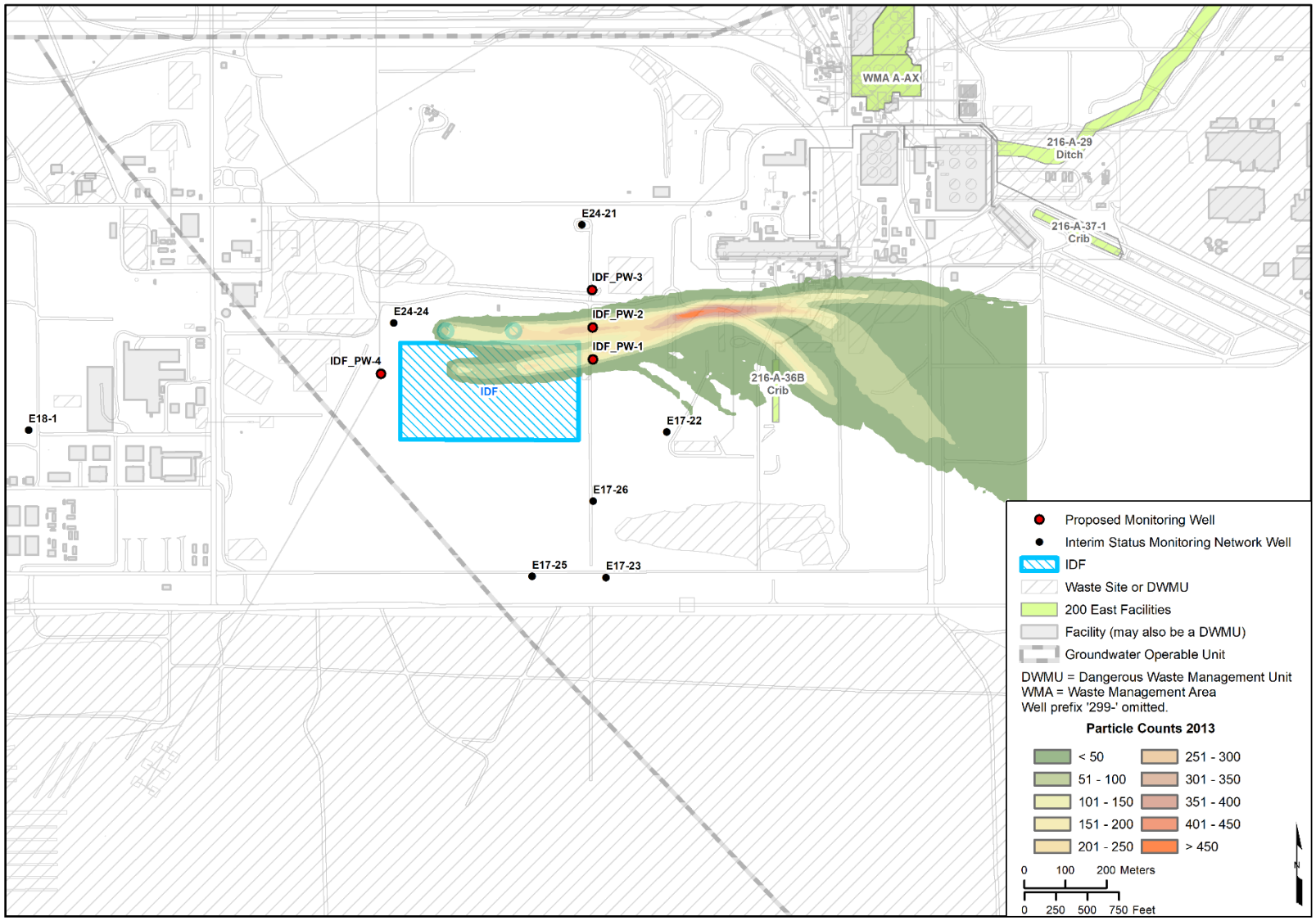

Figure H-11. Particle Count Map – IDF, 2013

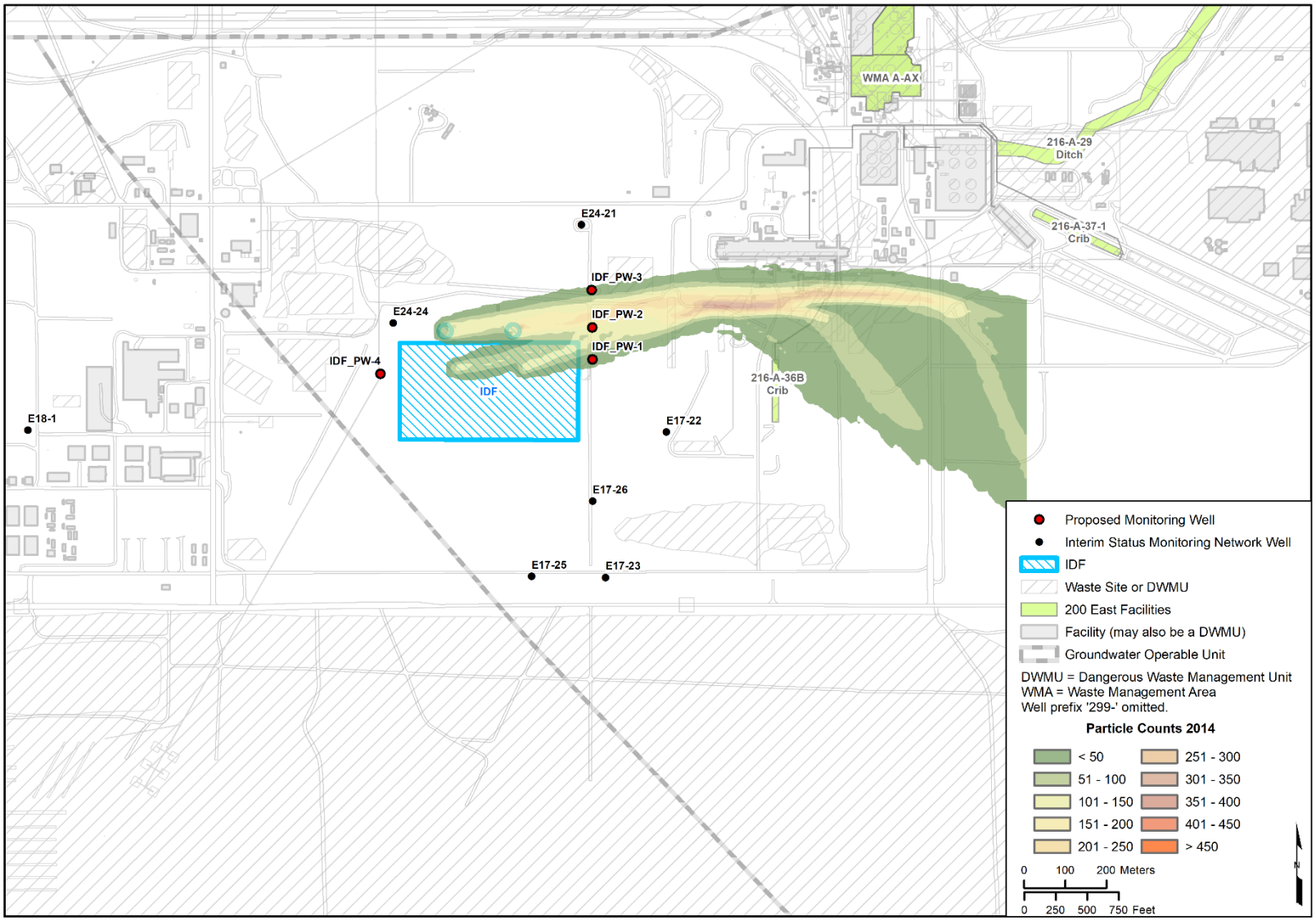

Figure H-12. Particle Count Map – IDF, 2014

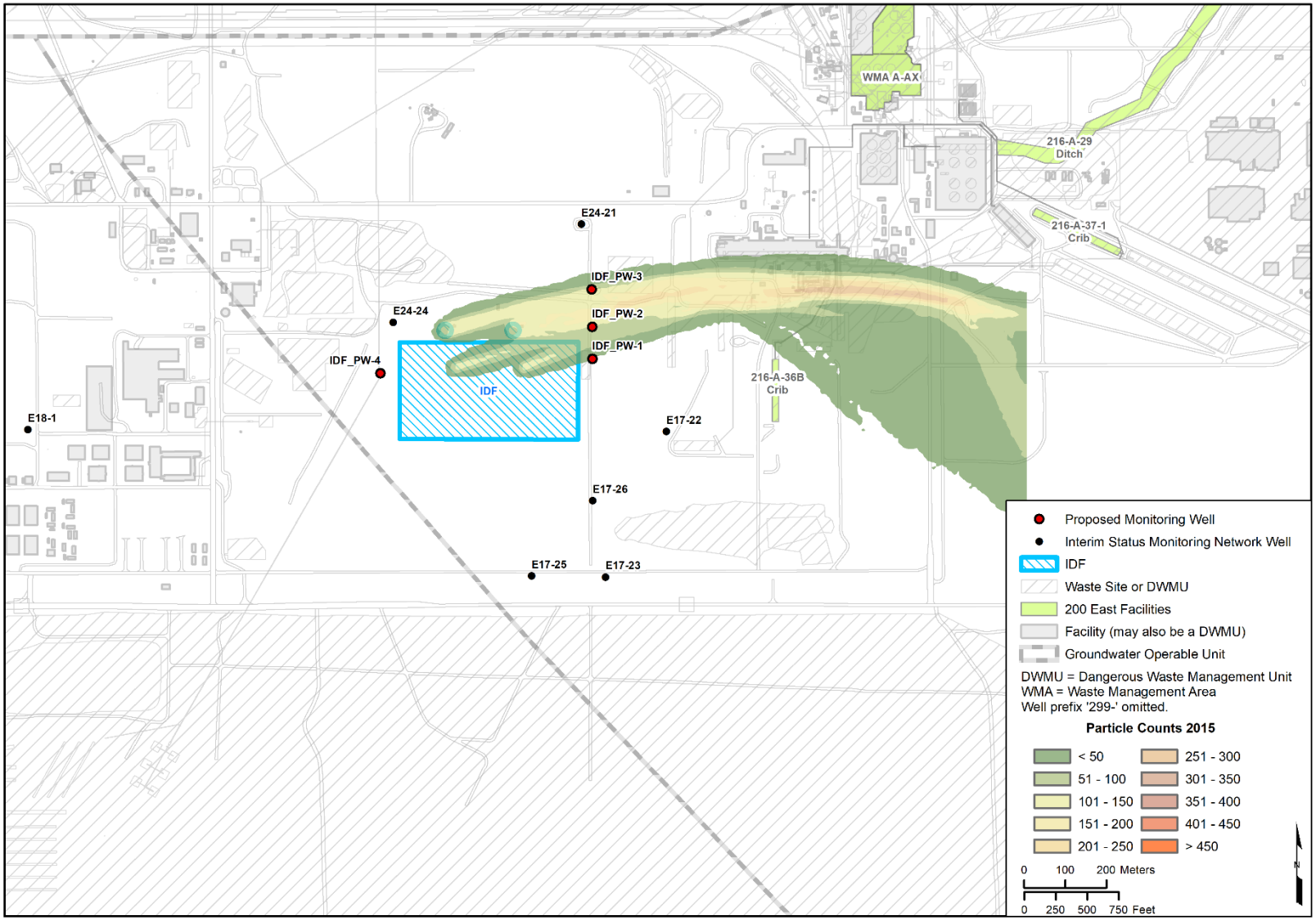

Figure H-13. Particle Count Map – IDF, 2015

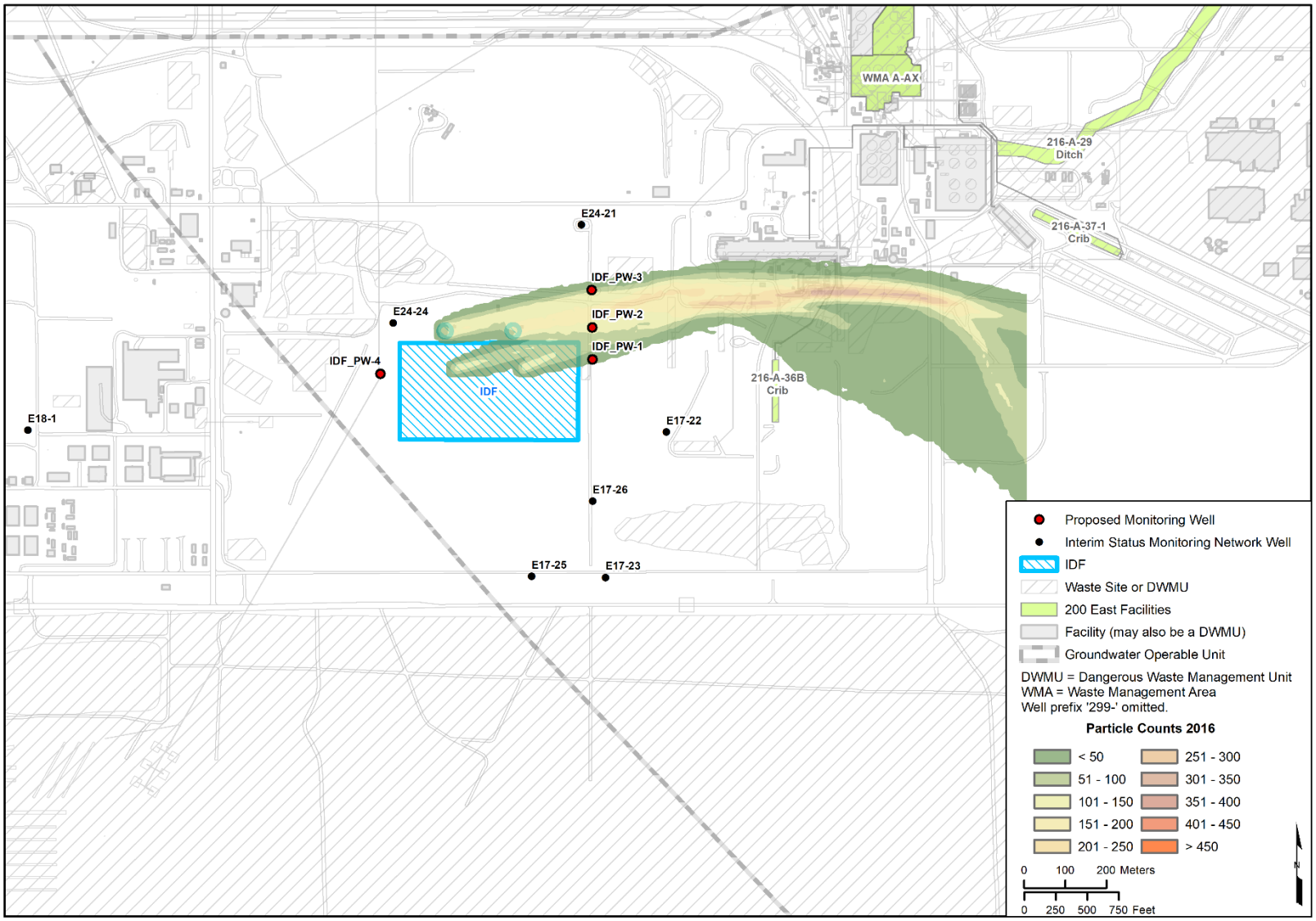

Figure H-14. Particle Count Map – IDF, 2016

Table H-1. Particle Density (Count) Proposed Monitoring Well IDF_PW-1

Time Interval (yr)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
1	69	11	28	14	
2	140	52	0	34	
3	148	2	0	1	
4	19	0	0	0	
5	0	0	0	0	
6	0	0	0	0	
7	0	0	0	0	
8	0	0	0	0	
9	0	0	0	0	
10	0	0	0	0	Average
Total	376	65	28	49	**130**

Table H-2. Particle Density (Count) Proposed Monitoring Well IDF_PW-2

Time Interval (yr)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
1	65	16	109	16	
2	324	200	204	156	
3	250	186	3	176	
4	21	33	0	26	
5	0	2	0	0	
6	0	0	0	0	
7	0	0	0	0	
8	0	0	0	0	
9	0	0	0	0	
10	0	0	0	0	Average
Total	660	437	316	374	**447**

Table H-3. Particle Density (Count) Proposed Monitoring Well IDF_PW-3

Time Interval (yr)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
1	0	0	13	0	
2	0	9	276	15	
3	0	49	10	166	
4	0	21	0	32	
5	0	0	0	0	
6	0	0	0	0	
7	0	0	0	0	
8	0	0	0	0	
9	0	0	0	0	
10	0	0	0	0	Average
Total	0	79	299	213	**148**

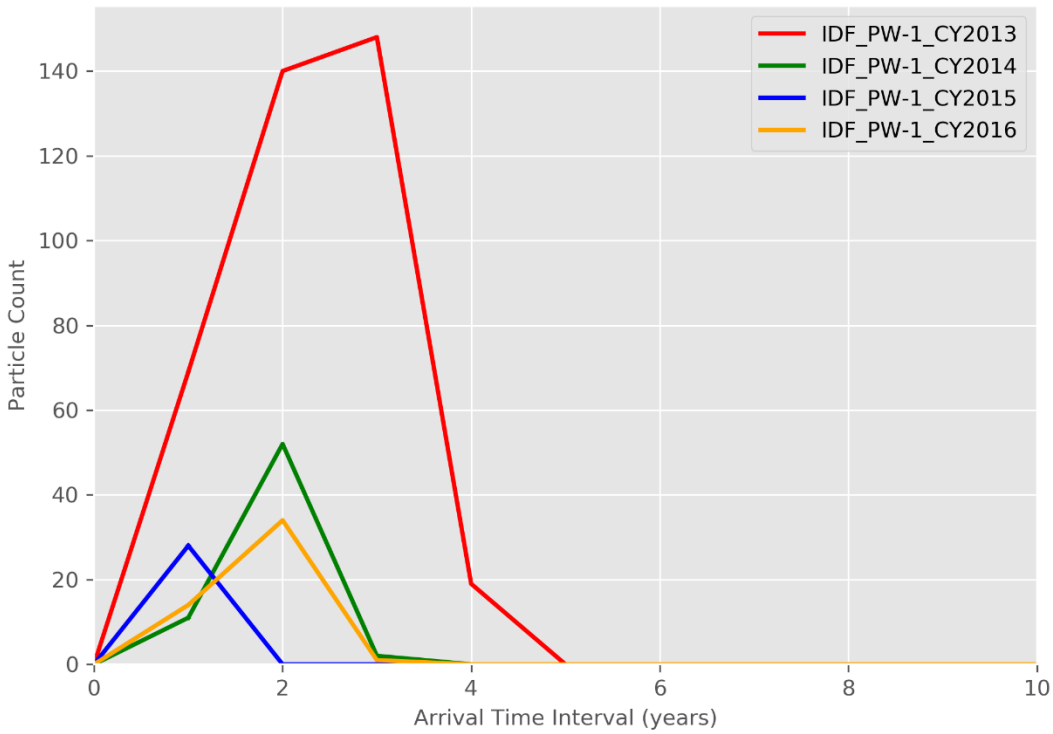

Figure H-15. Particle Breakthrough Curve at Monitoring Well IDF_PW-1

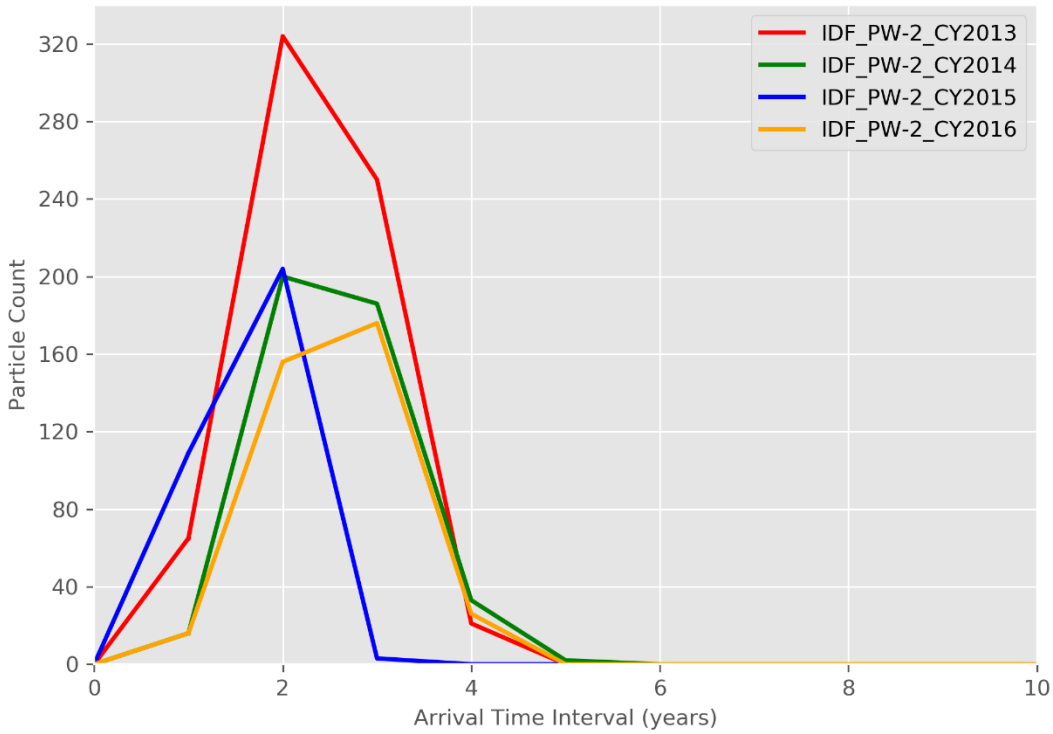

Figure H-16. Particle Breakthrough Curve at Monitoring Well IDF_PW-2

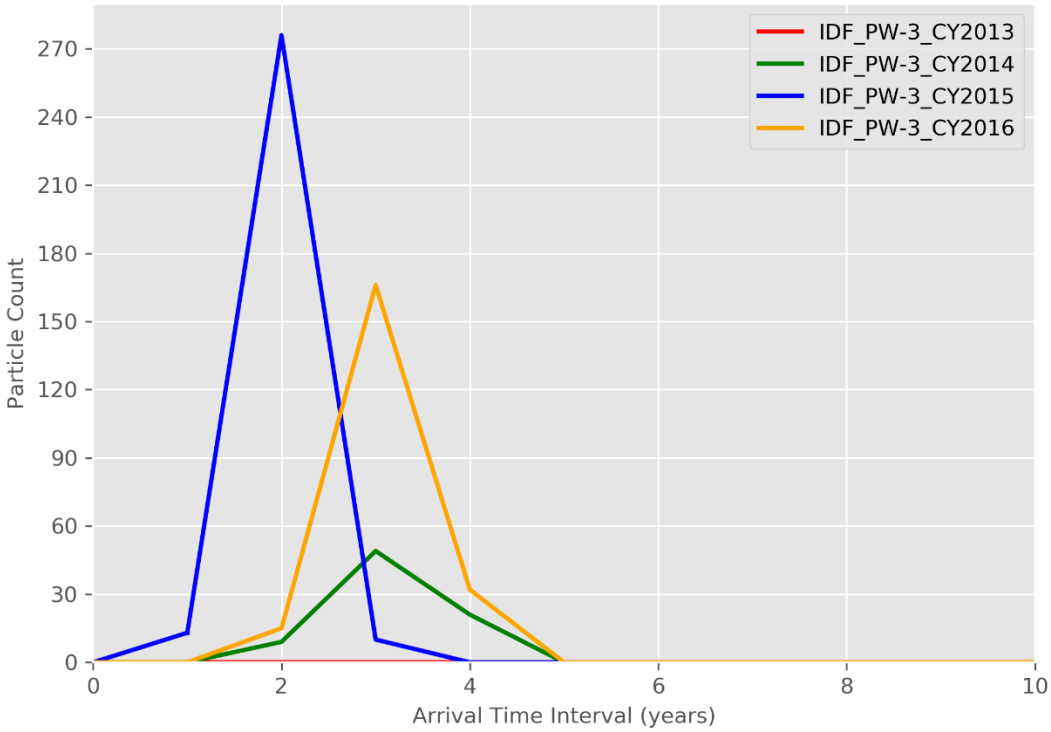

Figure H-17. Particle Breakthrough Curve at Monitoring Well IDF_PW-3

H3.5 Analyses of Particle Pathlines for Each Area of IDF

Particle pathline maps shown in Section H3.2 depict an instantaneous release to the water table from the release locations in IDF. Particle tracking also was performed for smaller regions of the facility to evaluate well locations for detecting releases from various regions of IDF. This section contains the results of analyses performed to examine how releases from the various areas of IDF that reach the groundwater beneath those release areas relate to each individual monitoring well. A series of figures and tables are provided to illustrate the fate of releases originating from three different areas of IDF. For these analyses, the particle release points presented in Figure H-2 are grouped into one of four areas based on their spatial location. Those areas are depicted in Figure H-18. Figures H-19 through H-22 illustrate the particle pathlines originating from each of the areas for CYs 2013 through 2016.

Figures H-23 through H-25 illustrate the particle count time series for each proposed downgradient monitoring well from CY 2013 through CY 2016. Each figure has four panels, each of which depicts the particle counts for one CY (2013 through 2016). Additionally, each panel shows a separate breakthrough curve for particles emanating from each area. For example, Figure H-23 depicts the particle counts at well IDF_PW-1, which receives particles from areas 1, 3, and 4 in 2013. In the figure, within the panel for 2013 (top row, left), the particle breakthrough curve from area 1 is depicted with a blue line, from area 3 with a purple line, and from area 4 with a green line.

H3.6 Vertical Migration Potential

As described in Section 3.3 of the main text of this ECF, the American Petroleum Institute (API) plume diving calculation was used to estimate the likely rate of vertical migration of dissolved constituents downward under the influence of recharge at the water table. At each well the slope of the plume dive was multiplied by the distance from the particle starting location to the well location to estimate the depth to which the dissolved constituents may be anticipated to have migrated by the time they reach the monitoring well location.

This estimated depth of the plume was then compared to the depth from the water table to the bottom of the monitoring well screen. If the depth of the plume is below the bottom of the monitoring well screen, then the dissolved constituents may be anticipated to pass beneath the well screen. If it falls within the interval between the top of the water table and the bottom of the well screen, then the well depth is appropriate for detection of releases at IDF.

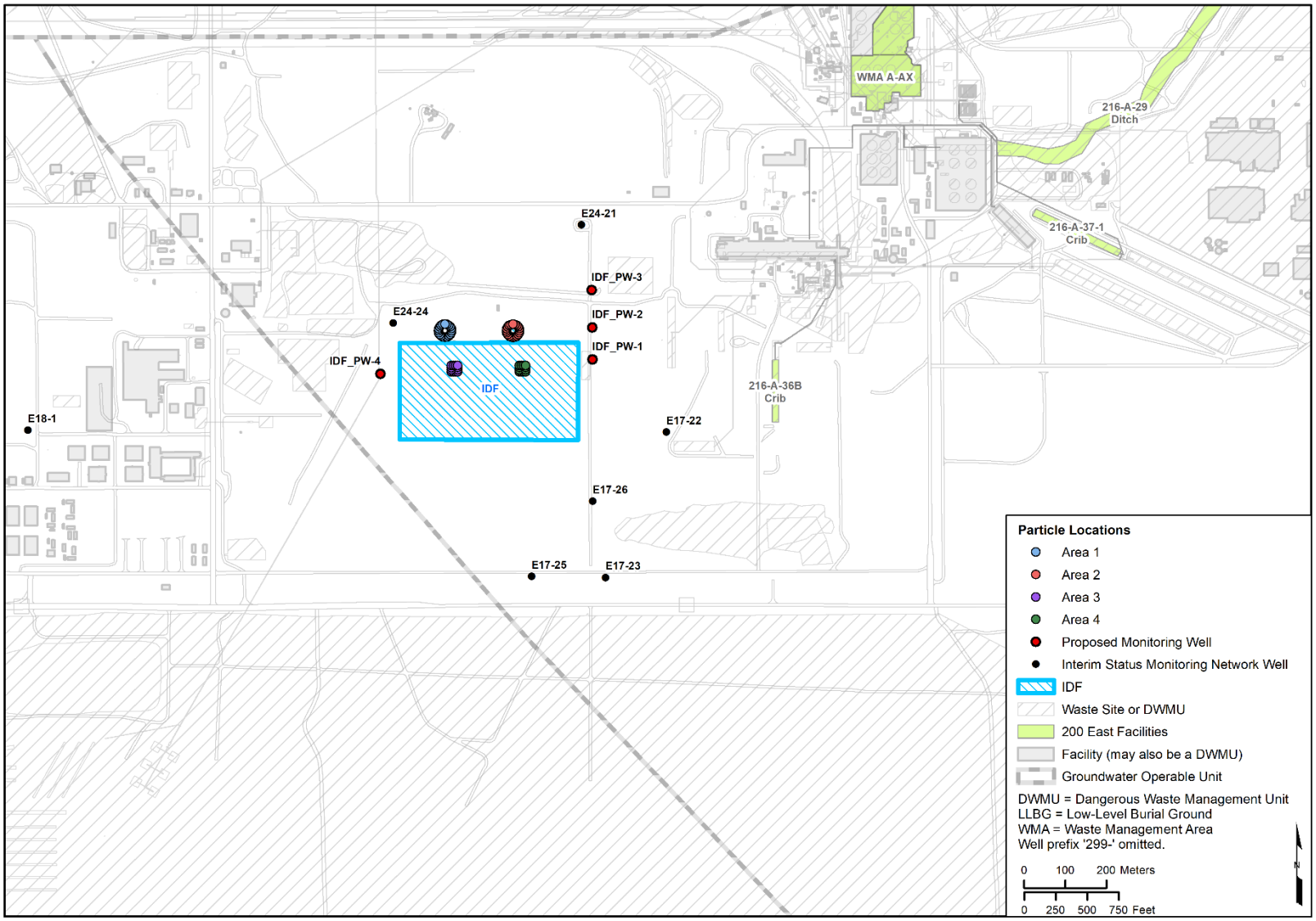

Figure H-18. Particle Release Locations and Areas of IDF

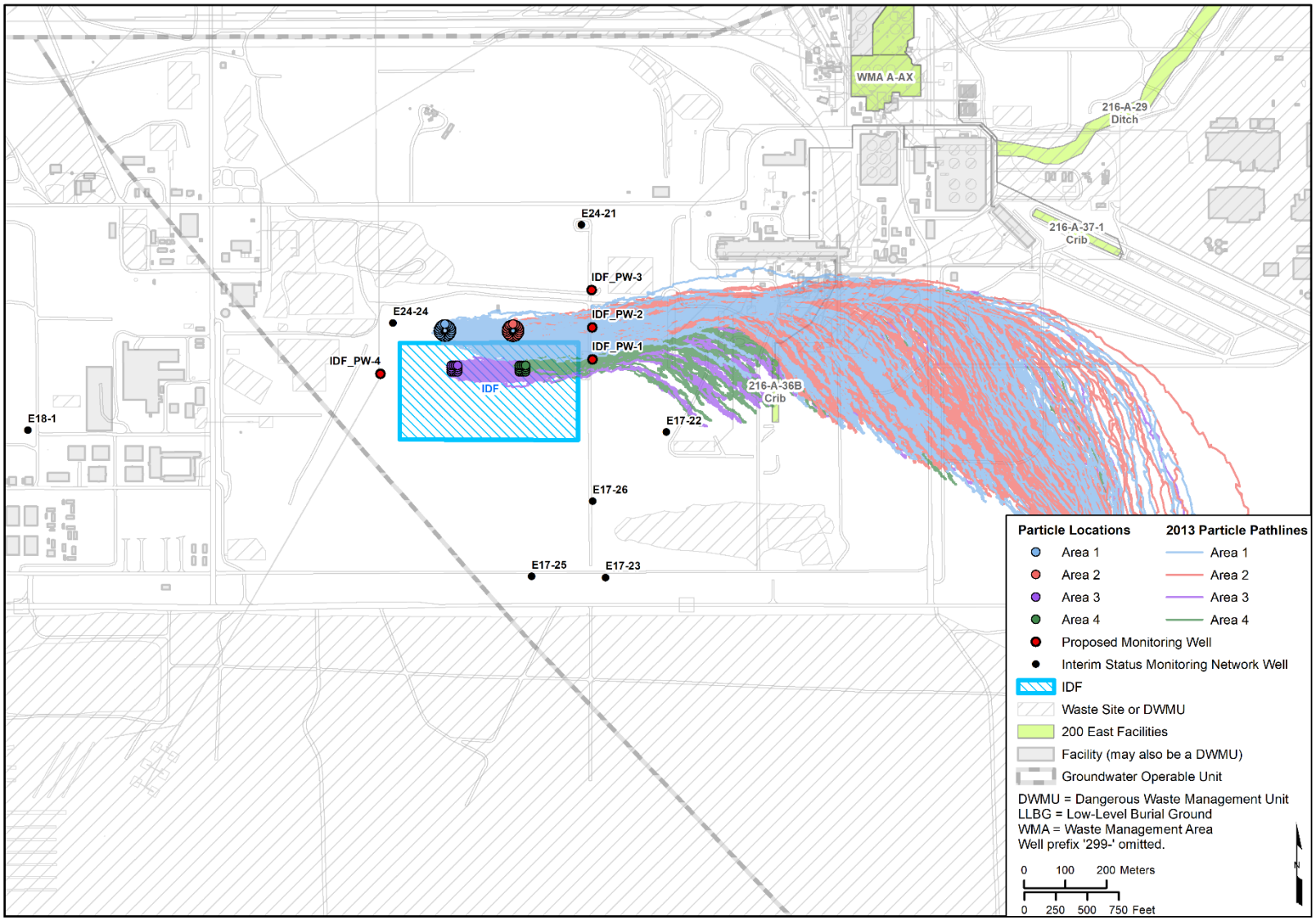

Figure H-19. CY 2013 Particle Pathlines per Area of IDF

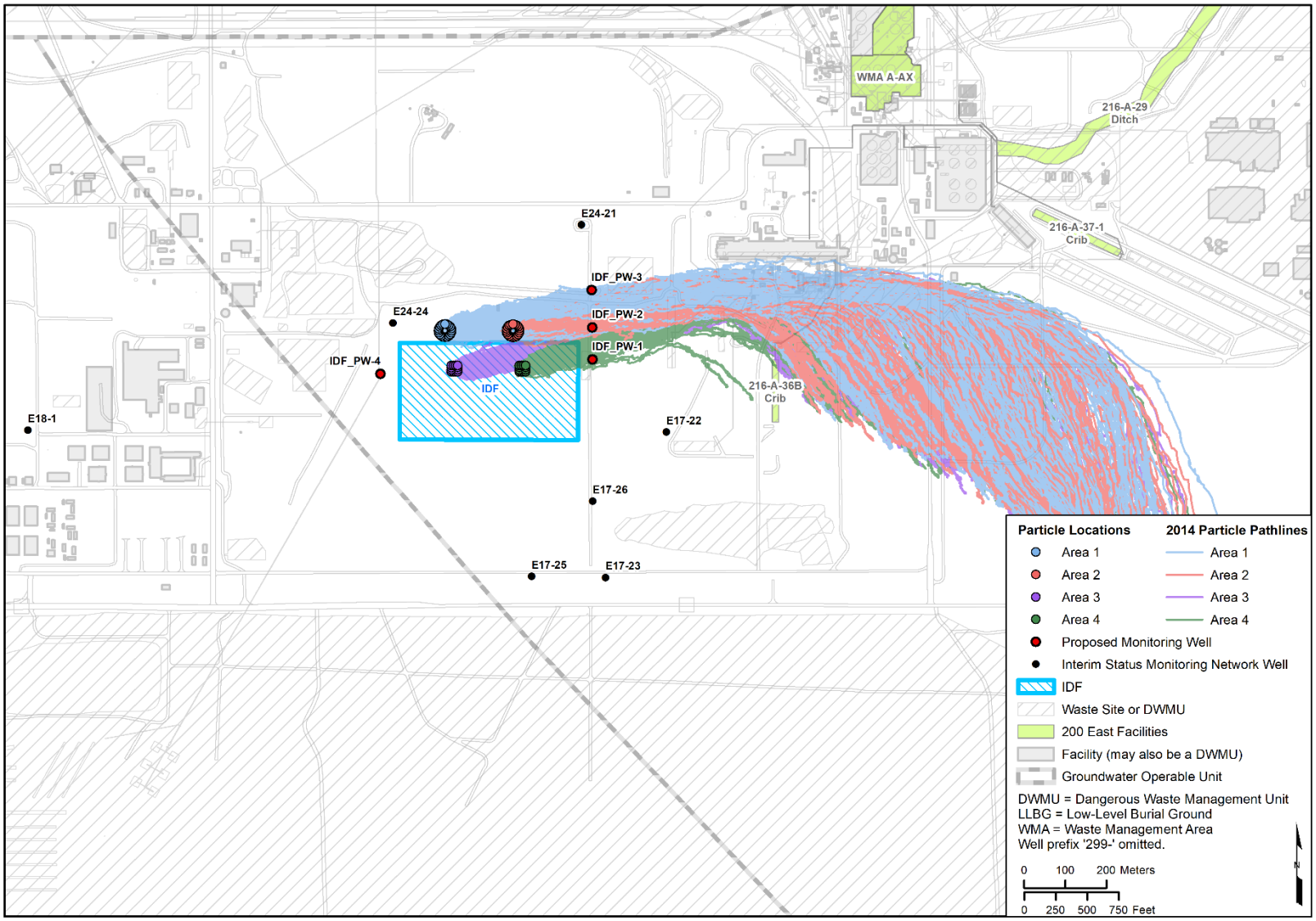

Figure H-20. CY 2014 Particle Pathlines per Area of IDF

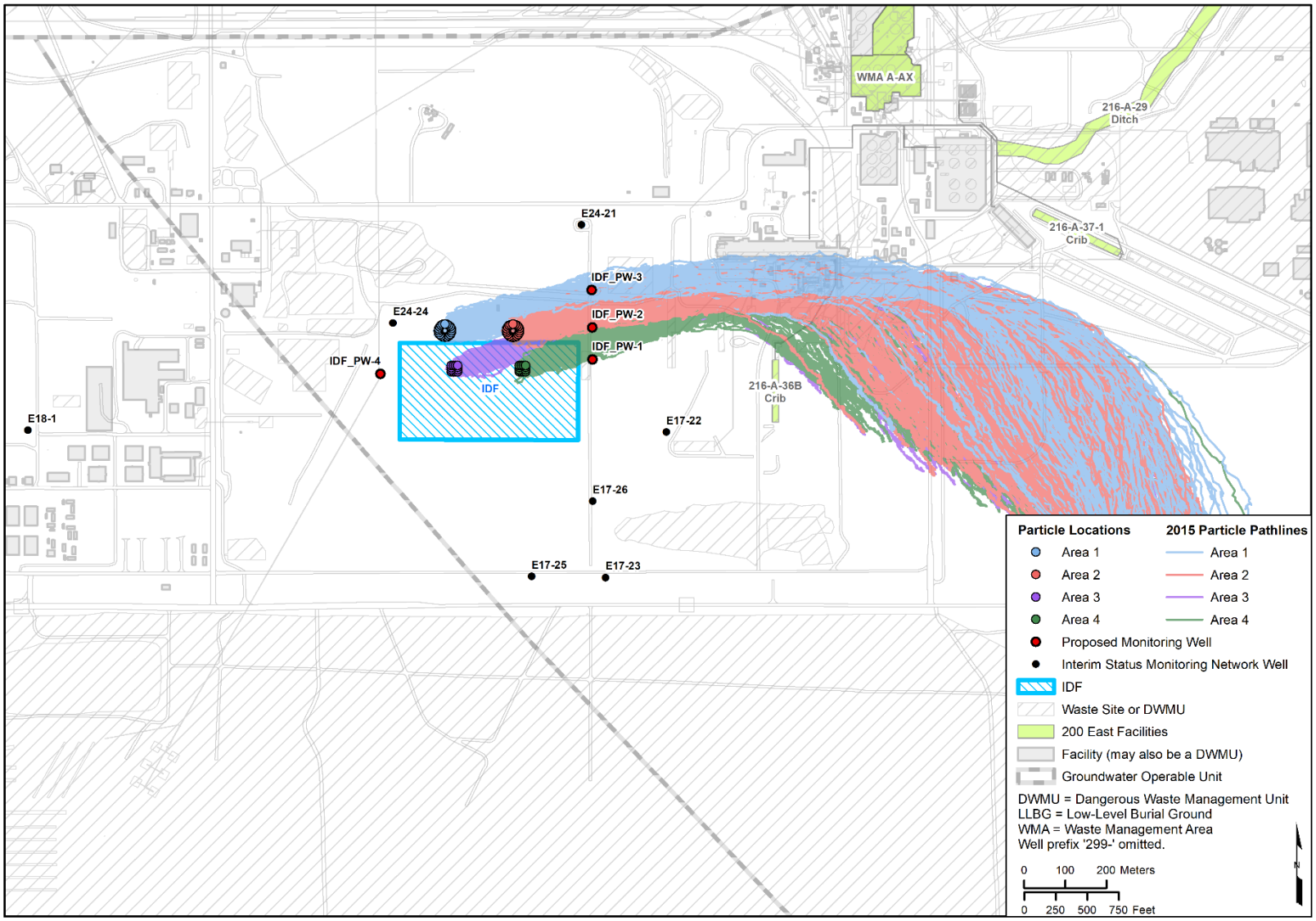

Figure H-21. CY 2015 Particle Pathlines per Area of IDF

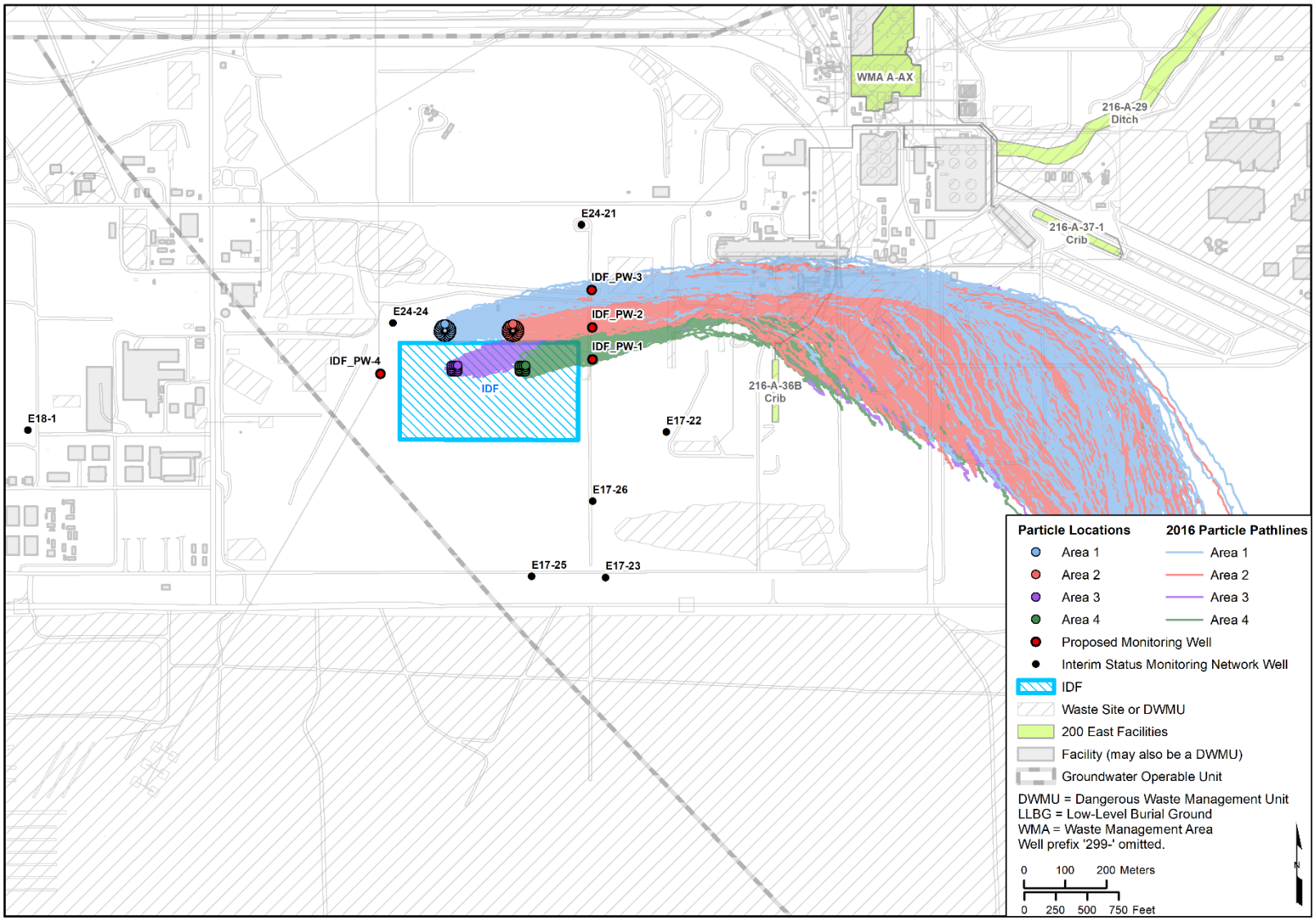

Figure H-22. CY 2016 Particle Pathlines per Area of IDF

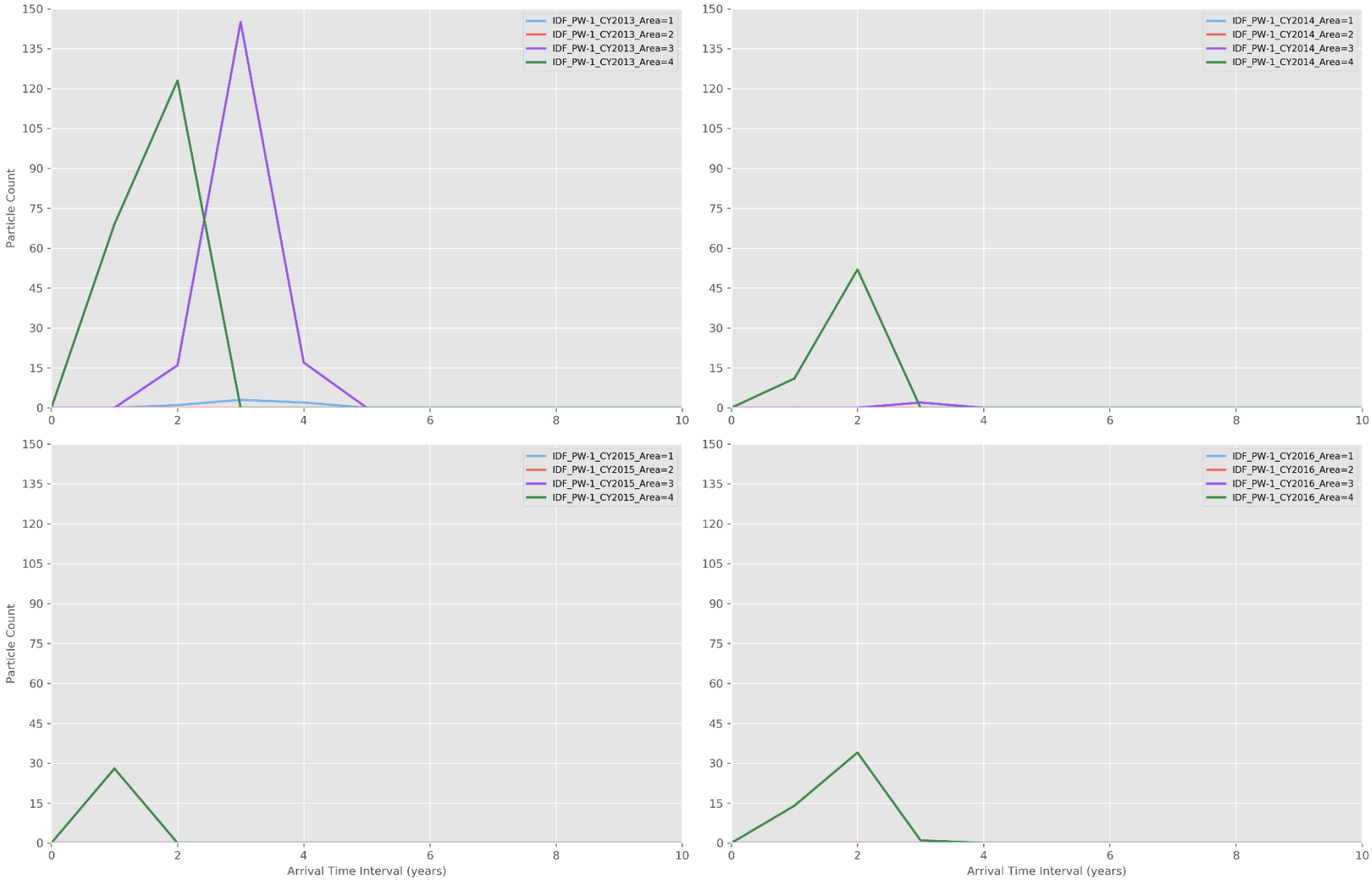

Figure H-23. Particle Breakthrough Curves per Area at Monitoring Well IDF_PW-1

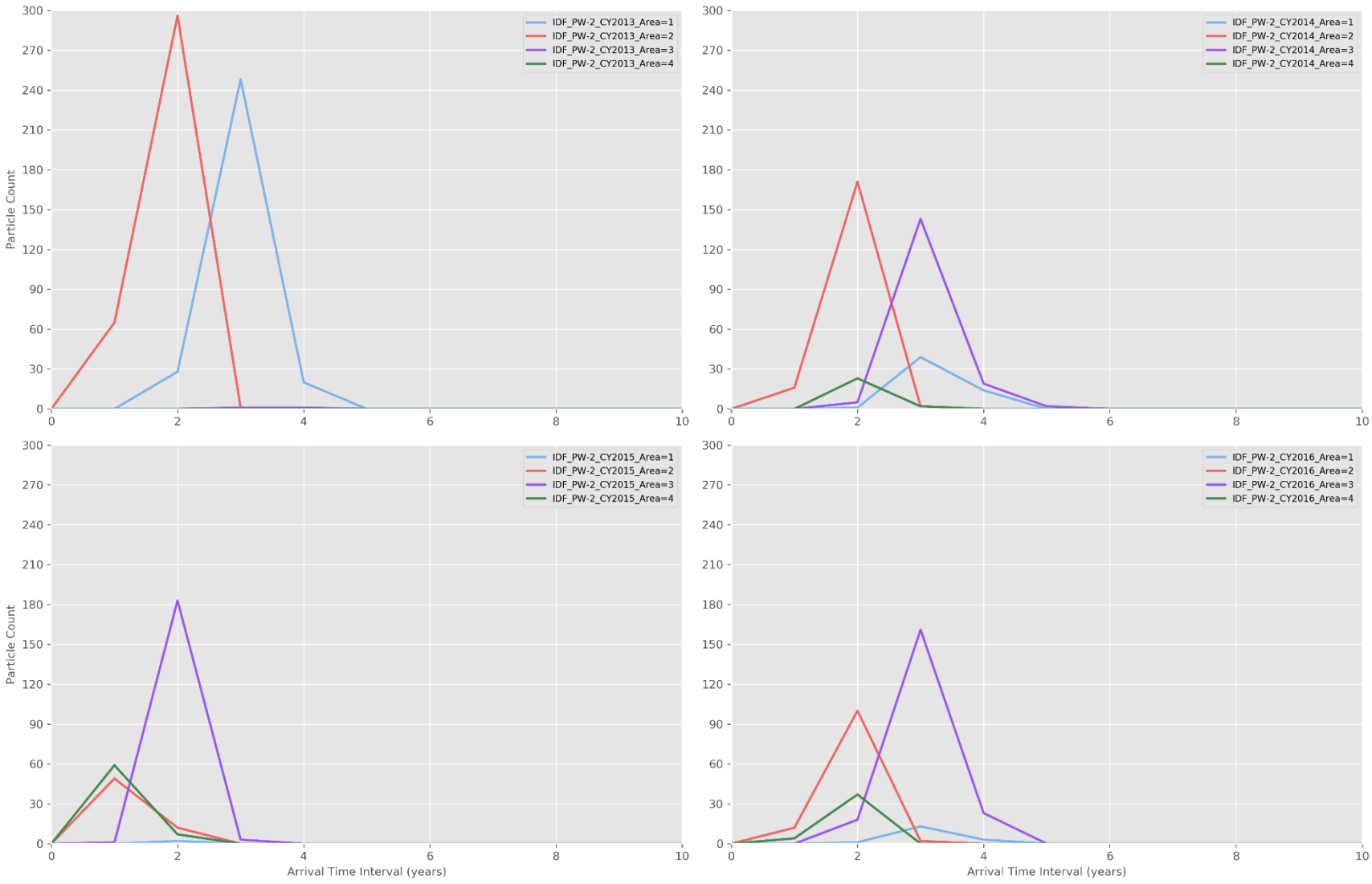

Figure H-24 Particle Breakthrough Curves per Area at Monitoring Well IDF_PW-2

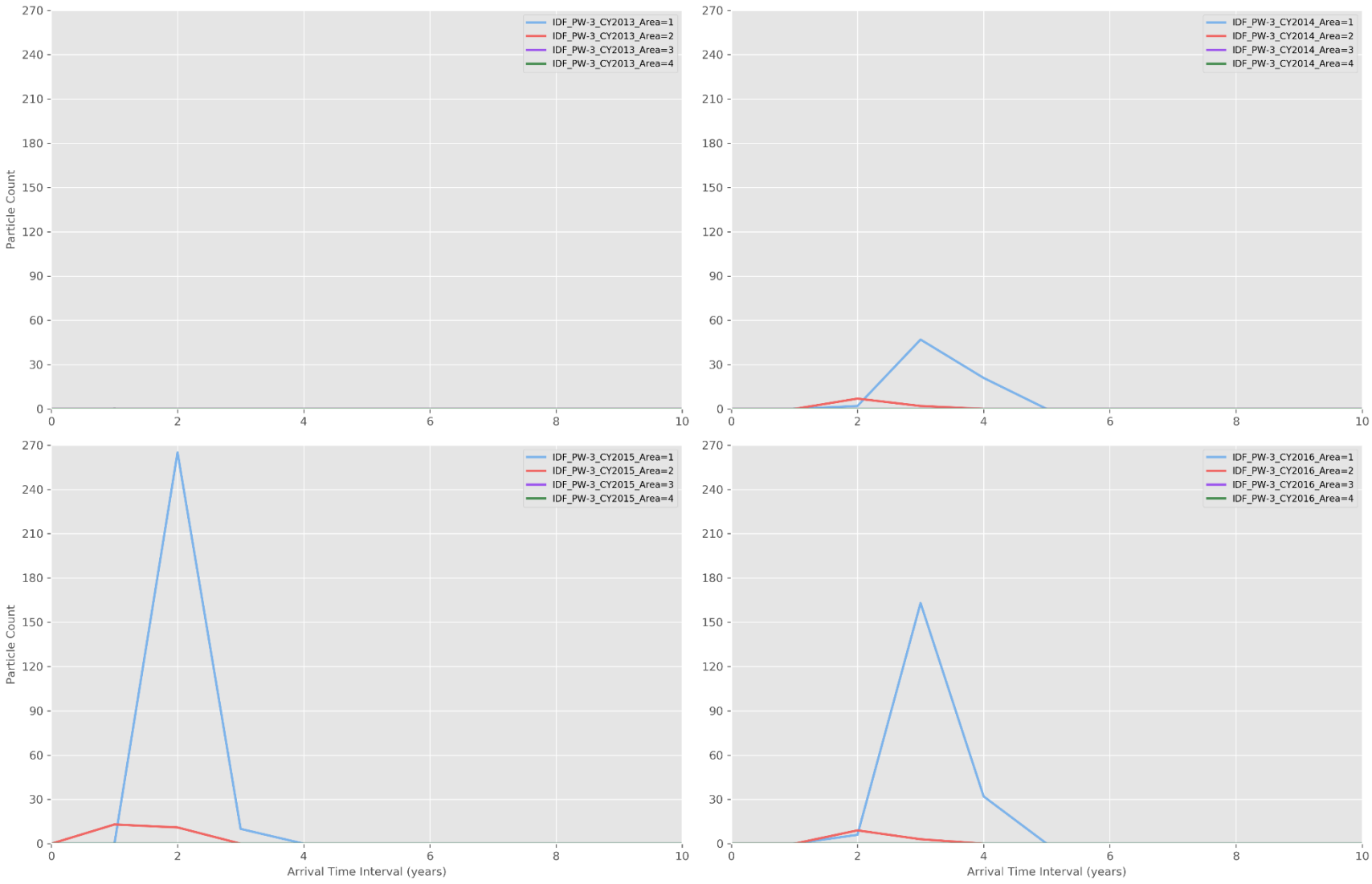

Figure H-25. Particle Breakthrough Curves per Area at Monitoring Well IDF_PW-3

For each downgradient monitoring well at IDF, the distance used in the calculation was the distance from the centroid of the facility to each well location. The hydraulic conductivity used in the calculation for IDF, 15,000 m/d (49,213 ft/d), is the calibrated hydraulic conductivity from the CPGWM for the Hanford formation, which underlies the facility. The results of the API plume diving calculation for the downgradient wells for IDF are shown in Table H-4.

Table H-4. Summary of Well Screen Interval Evaluation for Downgradient Wells

Monitoring Well	Existing or Proposed Well?	Distance, D, (m)[a]	Recharge, *i*, (m/yr)[b]	Slope, S, of Plume Dive[c]	Estimated Depth of Plume Below Water Table (m)[d]	Depth from Water Table to Bottom of Well Screen (m)[e]	Is Plume Depth Above Bottom of the Screen? (Yes/No/N/A)
299-E17-22	Existing	441.1	8.61E-03	2.59E-04	1.14E-01	9.8	Yes
299-E17-23	Existing	535.1	8.61E-03	2.59E-04	1.39E-01	9.7	Yes
299-E17-25	Existing	462.9	8.61E-03	2.59E-04	1.20E-01	9.9	Yes
299-E17-26	Existing	368.2	8.61E-03	2.59E-04	9.55E-02	11.0	Yes
299-E24-21	Existing	459.7	8.61E-03	2.59E-04	1.19E-01	5.1	Yes
IDF_PW-1	Proposed	261.7	8.61E-03	2.59E-04	6.79E-02	N/A	N/A
IDF_PW-2	Proposed	292.9	8.61E-03	2.59E-04	7.60E-02	N/A	N/A
IDF_PW-3	Proposed	347.5	8.61E-03	2.59E-04	9.02E-02	N/A	N/A

a. Distance of the well from centroid of dangerous waste management unit.

b. A representative number from the CPGWM. The recharge values represent fluxes from surface water discharge due to historical operations at the Hanford Site and are summarized in EMDT-BC-0002, *Vadose Zone Attenuated Recharge, Electronic Modeling Data Transmittal – Boundary Condition (Artificial Recharge)*-0002. The anthropogenic flux is added to the natural recharge component in order to establish the final total recharge flux used in the simulations. Discharges included in EMDT-BC-0002 have been attenuated to account for travel through the vadose zone.

c. Slope of the plume dive computed using the American Petroleum Institute plume diving calculation as detailed in the main text of this ECF. The migration parameters for the IDF used in the calculation of slope are as follows:

Hydraulic conductivity: 15,000 m/d (49,213 ft/d) (a calibrated value from the CPGWM)

Hydraulic gradient: 6.06E-06 (determined from 2016 water-level maps produced using TRIM)

d. Plume depth at monitoring well location computed from distance, D, times the slope, S.

e. Depths obtained from Table 2-30 in DOE/RL-2016-66, *Hanford Site RCRA Groundwater Monitoring Report for 2016*.

CPGWM = Central Plateau Groundwater Model

ECF = environmental calculation file

IDF = Integrated Disposal Facility

N/A = not applicable

TRIM = Tikhonov Regularized Inverse Method

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Appendix I

Facility-Specific Results for the Low-Level Burial Grounds Waste Management Area-1

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Terms

API	American Petroleum Institute
CPGWM	Central Plateau Groundwater Model
CY	calendar year
ECF	environmental calculation file
LLBG	Low-Level Burial Grounds
TRIM	Tikhonov Regularized Inverse Method
WMA	waste management area

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I1 Purpose and Background

The primary purpose of the calculations presented here is to estimate directions of potential migration to assess the efficacy of the geographical distribution of wells in the proposed monitoring well network for the subject facility. The calculations described within the main text of this environmental calculation file (ECF) were performed for each of the 200 East Facilities. This appendix presents results developed from the calculations that are specific to the Low-Level Burial Grounds (LLBG) Waste Management Area (WMA)-1.

Located in the northwest corner of the 200 East Area, LLBG WMA-1 is an inactive interim status treatment, storage, and disposal unit that is regulated as a landfill (Figure I-1). It contains the 218-E-10 Burial Ground that comprises 14 unlined and covered trenches that operated between 1955 and 2000.

Beginning in 1955, LLBG WMA-1 was used for disposal of low-level radioactive waste, with some areas receiving low-level mixed waste (waste with both a radioactive and dangerous waste component). The low-level mixed waste was disposed to discrete areas within LLBG WMA-1 (within trench 9) that are referred to as "Green Islands." Because the Green Islands contain dangerous waste, they are subject to regulation under RCW 70.105, "Hazardous Waste Management," and its Washington State implementing regulations (Washington Administrative Code [WAC] 173-303, "Dangerous Waste Regulations"). The Green Islands do not include the entire trench, but only the portions of the trench where mixed waste is buried (17-AMRP-0062, "Proposal to Address Mixed Waste Containers in the Low-Level Burial Grounds Operating Group"). Trench 9 of LLBG WMA-1 contains Green Islands that received low-level mixed waste consisting of di-octyl phthalate and lead (Chapter 1 and Section 2.1 in DOE/RL-2009-75, *Interim Status Groundwater Monitoring Plan for the LLBG WMA-1*).

Groundwater monitoring at LLBG WMA-1 was initiated in 1986. Multiple revisions to the groundwater monitoring plan have occurred since, with the most recently updated plan issued in 2016 (DOE/RL-2009-75).

The LLBG WMA-1 interim status monitoring network (Figure I-1) consists of two upgradient wells (299-E32-3 and 299-E33-266) and five downgradient wells (299-E28-26, 299-E28-27, 299-E28-28, 299-E33-28, and 299-E33-29) (Section 3.2 in DOE/RL-2009-75), all of which are screened at the top of the unconfined aquifer (Section 2.11 in DOE/RL-2016-66, *Hanford Site RCRA Groundwater Monitoring Report for 2016*). This appendix presents calculations that evaluate the efficacy of the groundwater monitoring network for detecting hypothetical releases from LLBG WMA-1 at existing and potential new monitoring well locations.

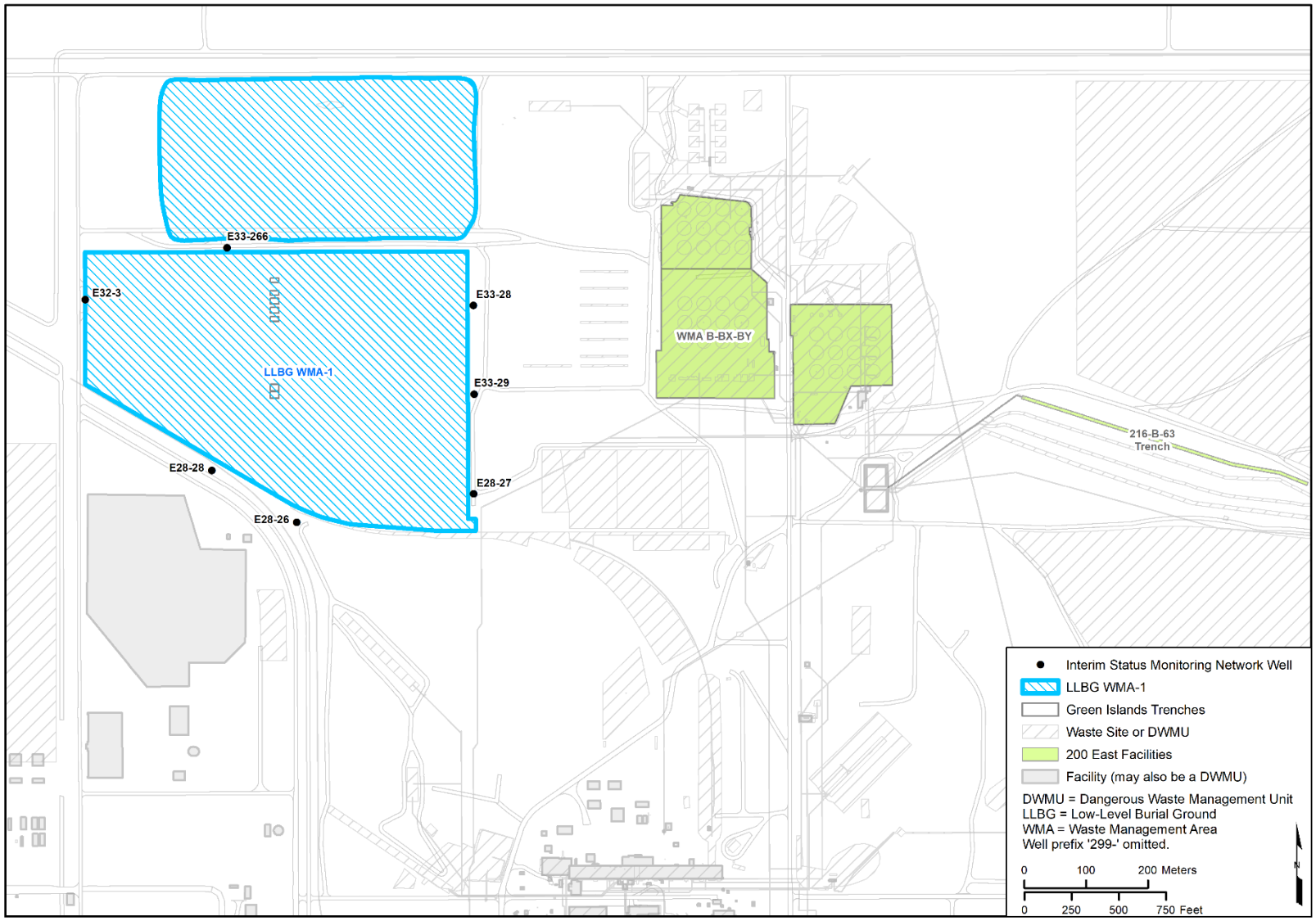

Figure I-1. Locations of Interim Status Groundwater Monitoring Wells at LLBG WMA-1

I2 Facility-Specific Input for LLBG WMA-1

Inputs used in the calculations that were specific to LLBG WMA-1 are described in this chapter.

I2.1 Particle Count Grid and Release Locations

To prepare particle count maps, a distribution of facility-specific starting locations is required. The starting locations for the particle-tracking calculations represent the area over which a potential release from a given facility would impact the underlying water table. The particle releases were located at plausible release sites throughout the facility. For LLBG WMA-1, 73 release locations were specified around the Green Islands trenches within the waste management area (Figure I-2). Twenty particles were released and tracked from each release location to provide the density of particles in space and time required for the detailed facility-specific calculations, randomizing the seed values for the dispersion calculations. Thus, 1,460 [1,460 = 73 (release locations) × 20 (releases)] particles were tracked for each of the four simulations.

Contour maps of particle counts were generated by counting the number of particles that pass through a pre-defined uniform calculational grid (Figure I-2). The grid used to develop the relative particle density maps is defined by 10 by 10 m (33 by 33 ft) cells. The grid is oriented to be parallel to the predominant groundwater flow direction at LLBG WMA-1.

I2.2 Migration Parameters

Parameters specific to the groundwater flow conditions at LLBG WMA-1 are reported throughout the various documents for the facility. The parameters used in the calculations performed herein to represent nonreactive dissolved contaminant migration are mobile (or effective) porosity and hydraulic conductivity. The parameters used in these calculations are representative of local conditions for a conservative (i.e., nonreactive) solute dissolved within groundwater.

The hydraulic conductivity value reported in site literature for LLBG WMA-1 is 17,000 m/d (55,774 ft/d) (Table 1 in ECF-Hanford-17-0241, *Hydraulic Gradient and Velocity Calculations for RCRA Sites in 2017*). As described in Section 4.2.1.1 of the main text of this ECF, the hydraulic conductivity used in the work performed herein corresponds to the calibrated values from the Central Plateau Groundwater Model (CPGWM) (CP-47631, *Model Package Report: Central Plateau Groundwater Model Version 8.4.5*). Figure 3-2 in the main text of this ECF indicates LLBG WMA-1 is located in the hydrostratigraphic unit zones corresponding to the Cold Creek unit and the Hanford formation. The values used for the hydraulic conductivity for LLBG WMA-1 are 18,200 m/d (59,711 ft/d) and 15,000 m/d (49,213 ft/d), which correspond to the Cold Creek unit and the Hanford formation, respectively, as shown in Table 4-1 in the main text of this ECF. The mobile (effective) porosity defined for the Cold Creek unit and the Hanford formation, which underlie LLBG WMA-1, is specified at 0.25.

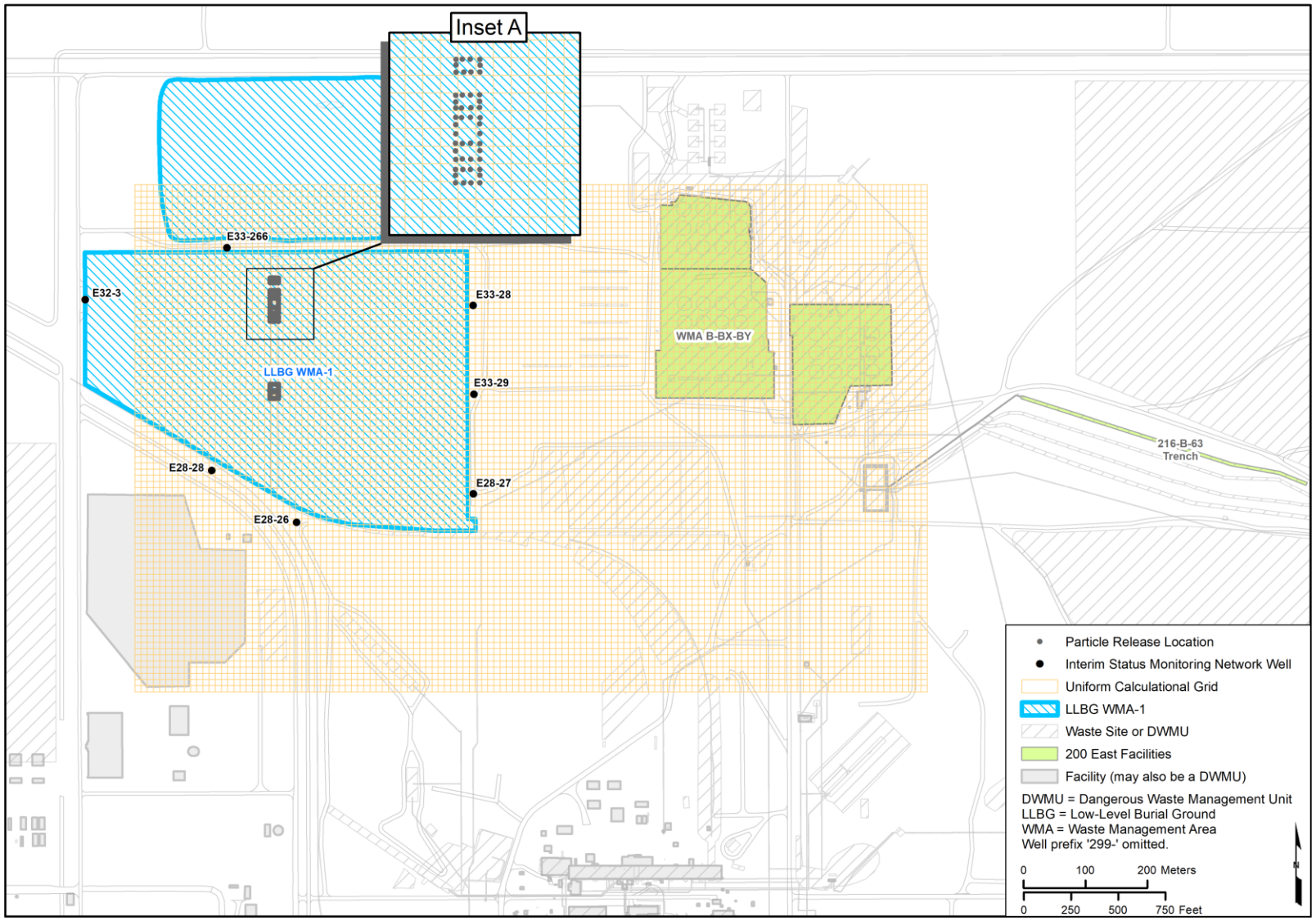

Figure I-2. Uniform Calculational Grid and Release Locations at LLBG WMA-1

I3 Facility-Specific Results for LLBG WMA-1

The groundwater elevation contours prepared in the vicinity of LLBG WMA-1 using the Tikhonov Regularized Inverse Method (TRIM) are presented in this section. In addition, the outputs of the particle tracking and particle count calculations are presented, including the following:

- Maps of calculated particle pathlines for the flow conditions determined for each of the four years (2013, 2014, 2015, and 2016). These are presented at the facility-specific scale considering advective and dispersive migration.
- Time-series plots, referred to as particle breakthrough curves, of the relative arrival, peak, and decline in particle counts at each interim status groundwater monitoring well location and each proposed monitoring location, where applicable.
- Tabulation of relative particle counts for each interim status groundwater monitoring well location and each proposed monitoring location, where applicable.
- Maps of particle counts downgradient of each facility based on the flow conditions determined for each of the four years.

The results of calculations of potential vertical migration of contaminants at the monitoring well locations are also presented.

I3.1 Groundwater Elevation Contours

Figures I-3 through I-6 show the results of the groundwater elevation analysis completed using TRIM in the vicinity of LLBG WMA-1. The figures depict general patterns of groundwater elevations and hydraulic gradients for conditions represented by calendar years (CYs) 2013, 2014, 2015, and 2016. These groundwater elevation contours and associated hydraulic gradients form the basis for the facility-specific calculations performed for this ECF.

I3.2 Particle Tracking

Once the groundwater elevation contour maps and underlying piecewise continuous elevation grids were prepared using TRIM, particle tracking was implemented using both advection and dispersion.
The particle pathlines that were produced depict the patterns of spreading that might accompany the migration of contaminants near the waste management area for the flow conditions calculated for CYs 2013, 2014, 2015, and 2016. Figures I-7 through I-10 depict the particle pathlines developed based on the groundwater elevations prepared throughout the 200 East Area using TRIM. The resulting maps were prepared based on the release of 20 particles from each starting location to provide the high density of particles in space and time required for these detailed facility-specific calculations. Figures I-7 through I-10 depict the particle pathlines calculated after 3 years of travel, by which time it was determined that most of the particles would have arrived at or passed by the interim status groundwater monitoring wells. Figures I-7 through I-10 depict an instantaneous release to the water table from the release locations in LLBG WMA-1 to illustrate the adequacy of the well network for monitoring the entire facility.

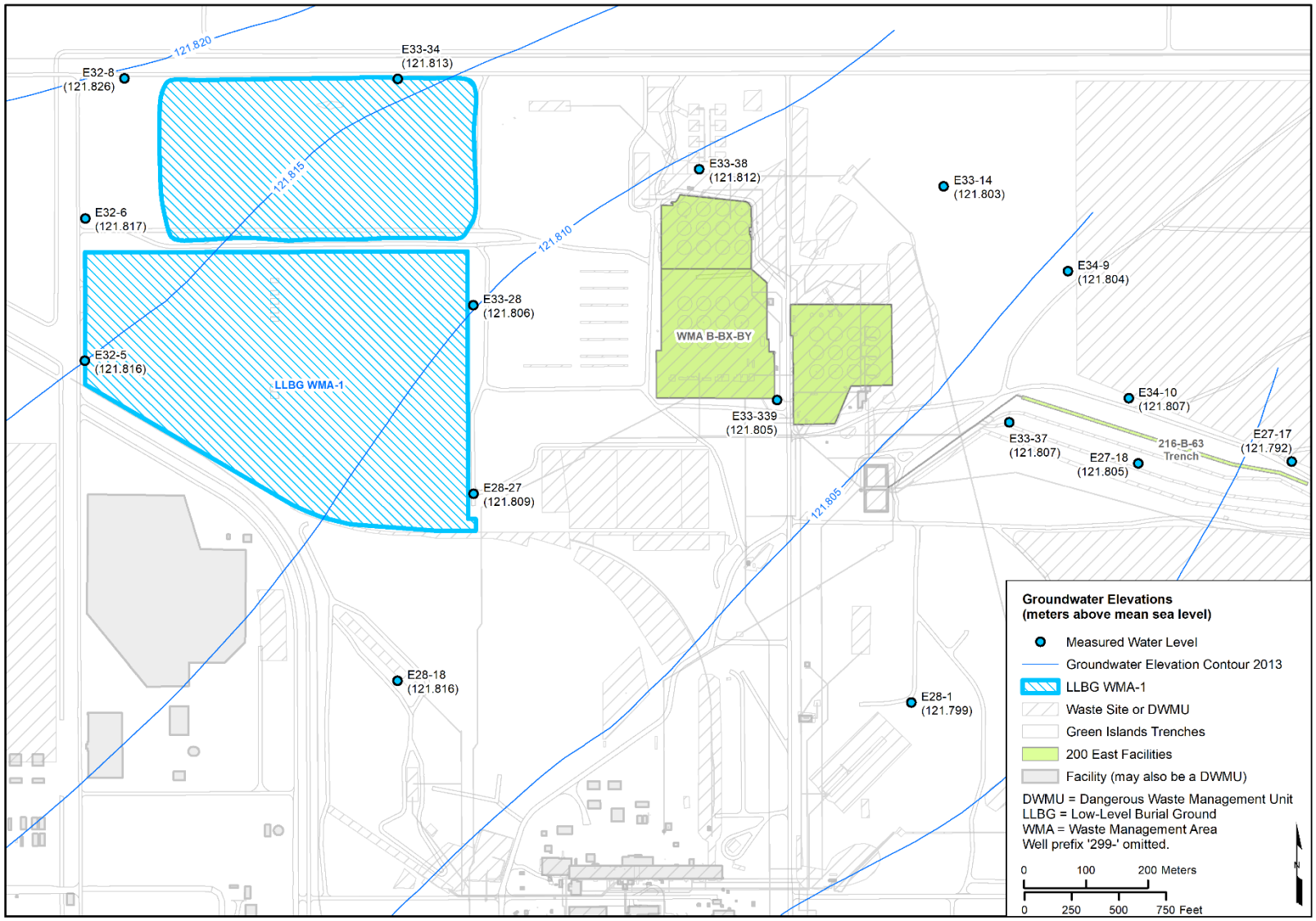

Figure I-3. Water-Level Elevation Map for LLBG WMA-1, 2013

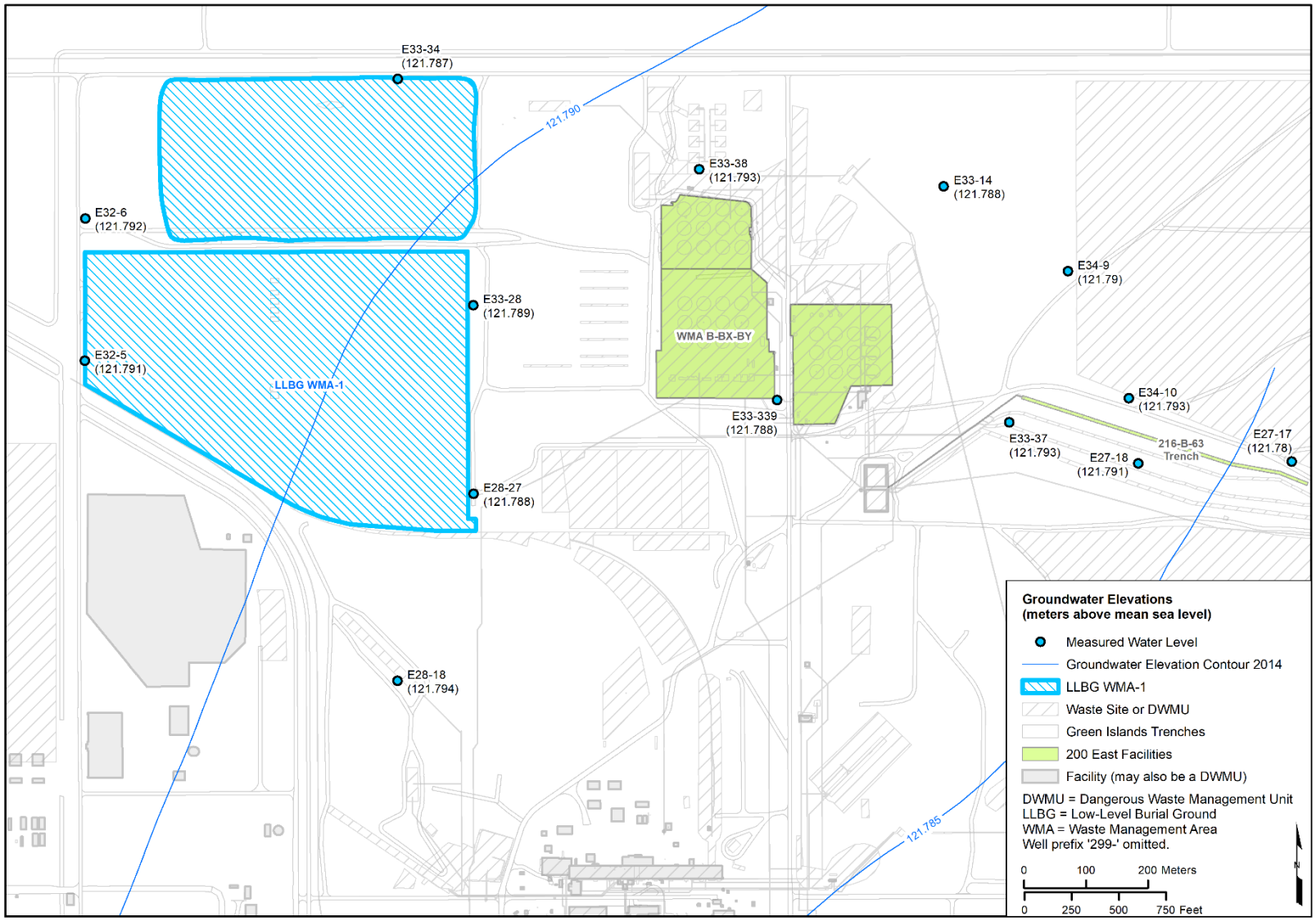

Figure I-4. Water-Level Elevation Map for LLBG WMA-1, 2014

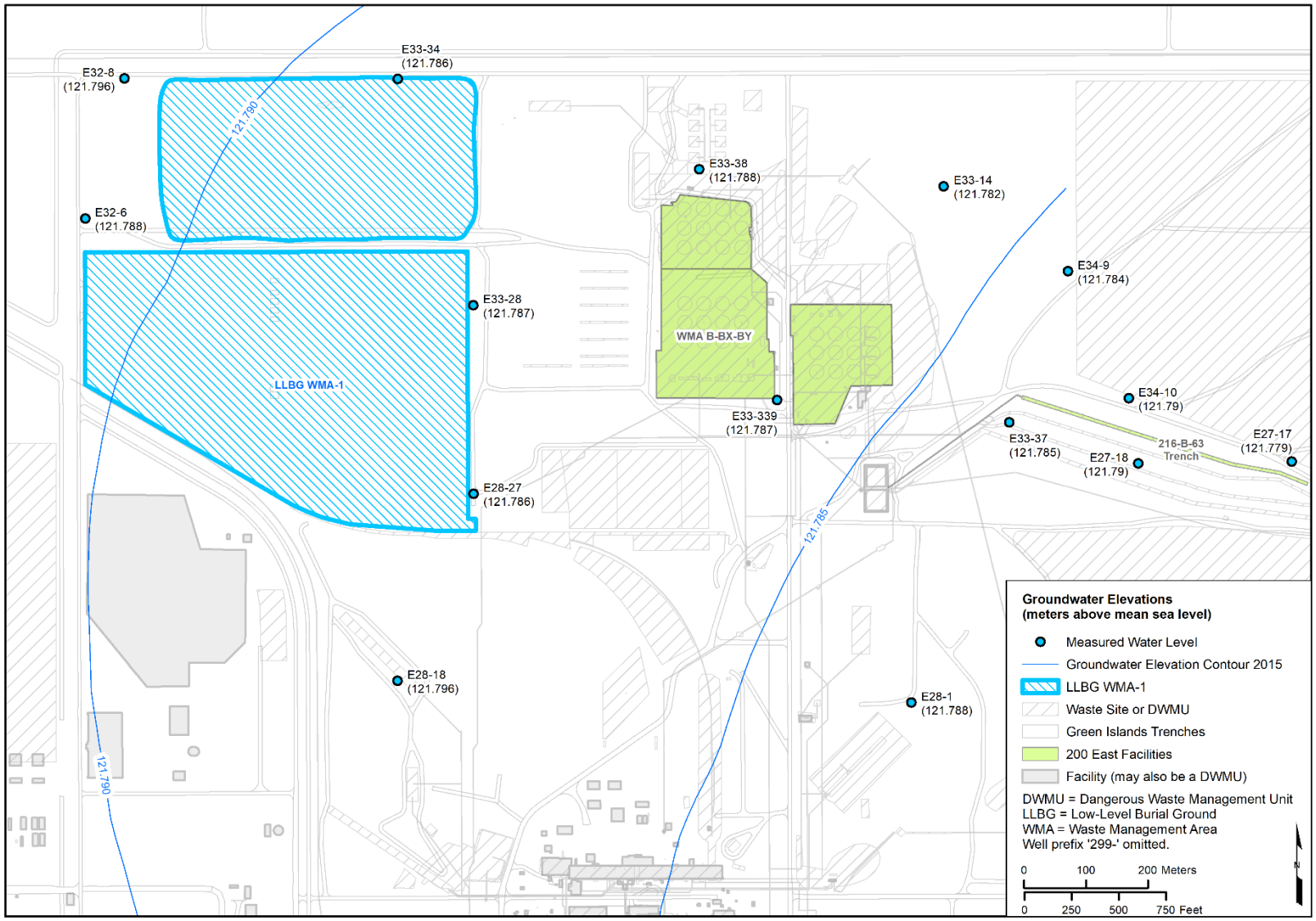

Figure I-5. Water-Level Elevation Map for LLBG WMA-1, 2015

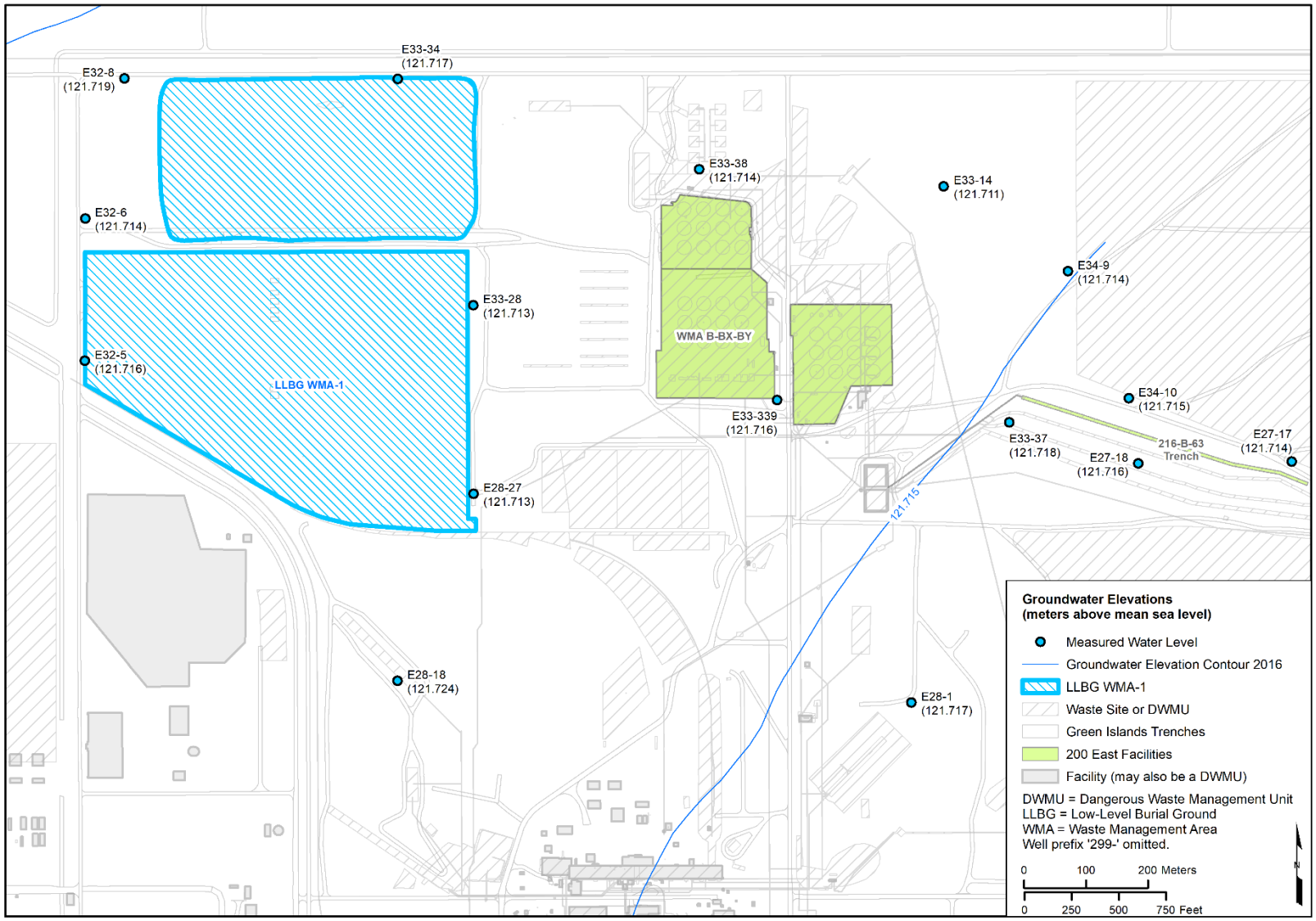

Figure I-6. Water-Level Elevation Map for LLBG WMA-1, 2016

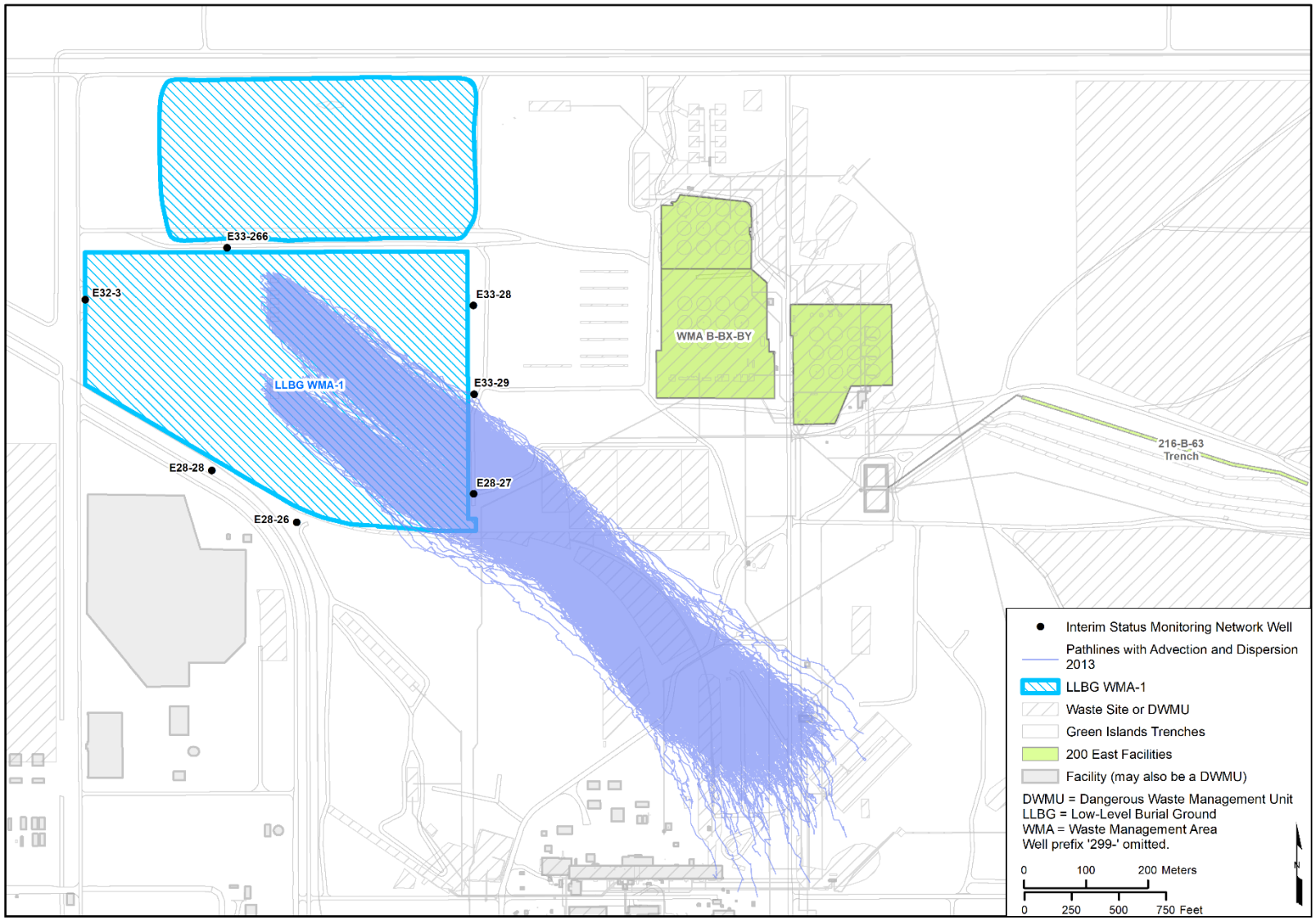

Figure I-7. Local-Scale Particle Pathlines, Advection and Dispersion – LLBG WMA-1, 2013

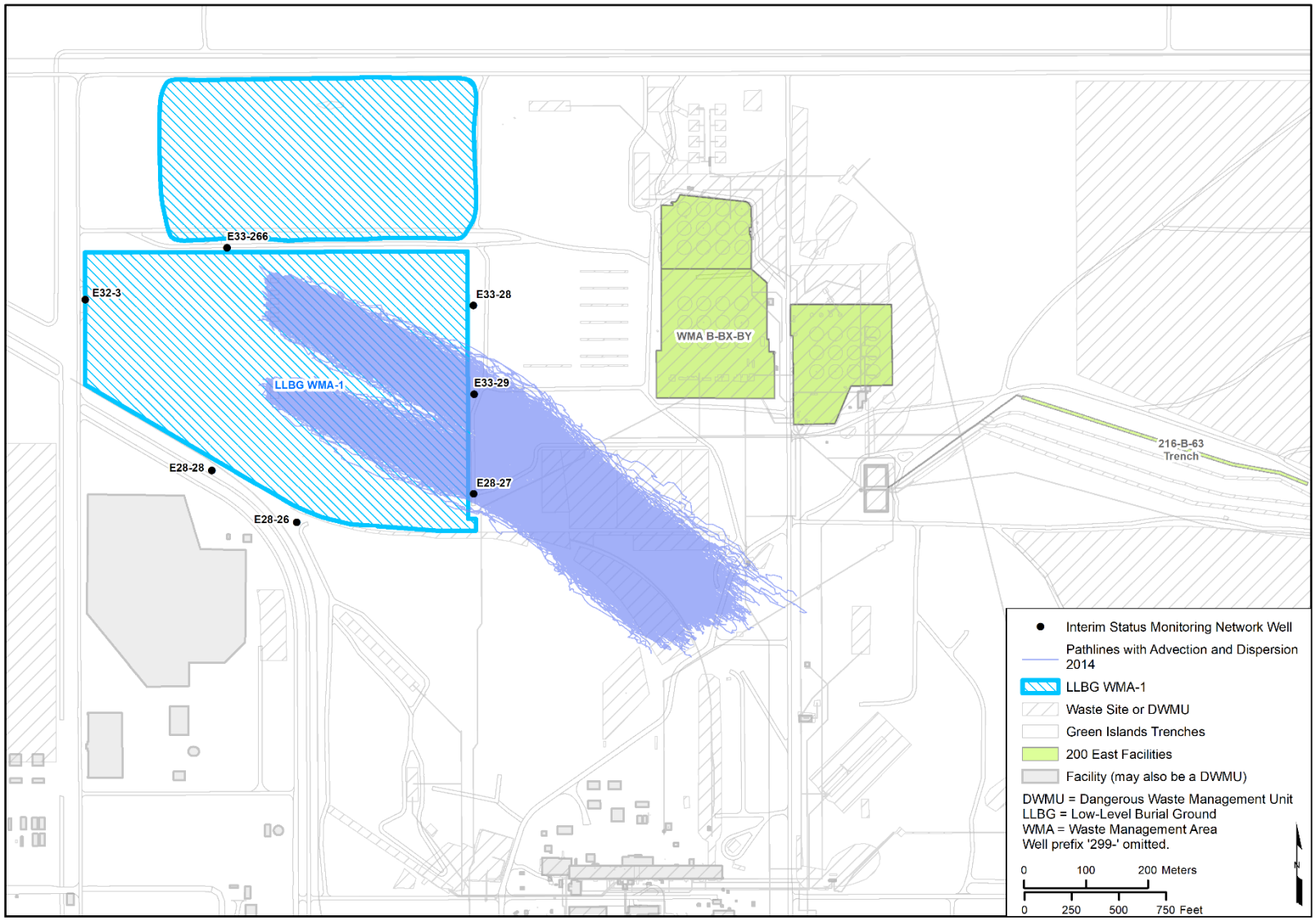

Figure I-8. Local-Scale Particle Pathlines, Advection and Dispersion – LLBG WMA-1, 2014

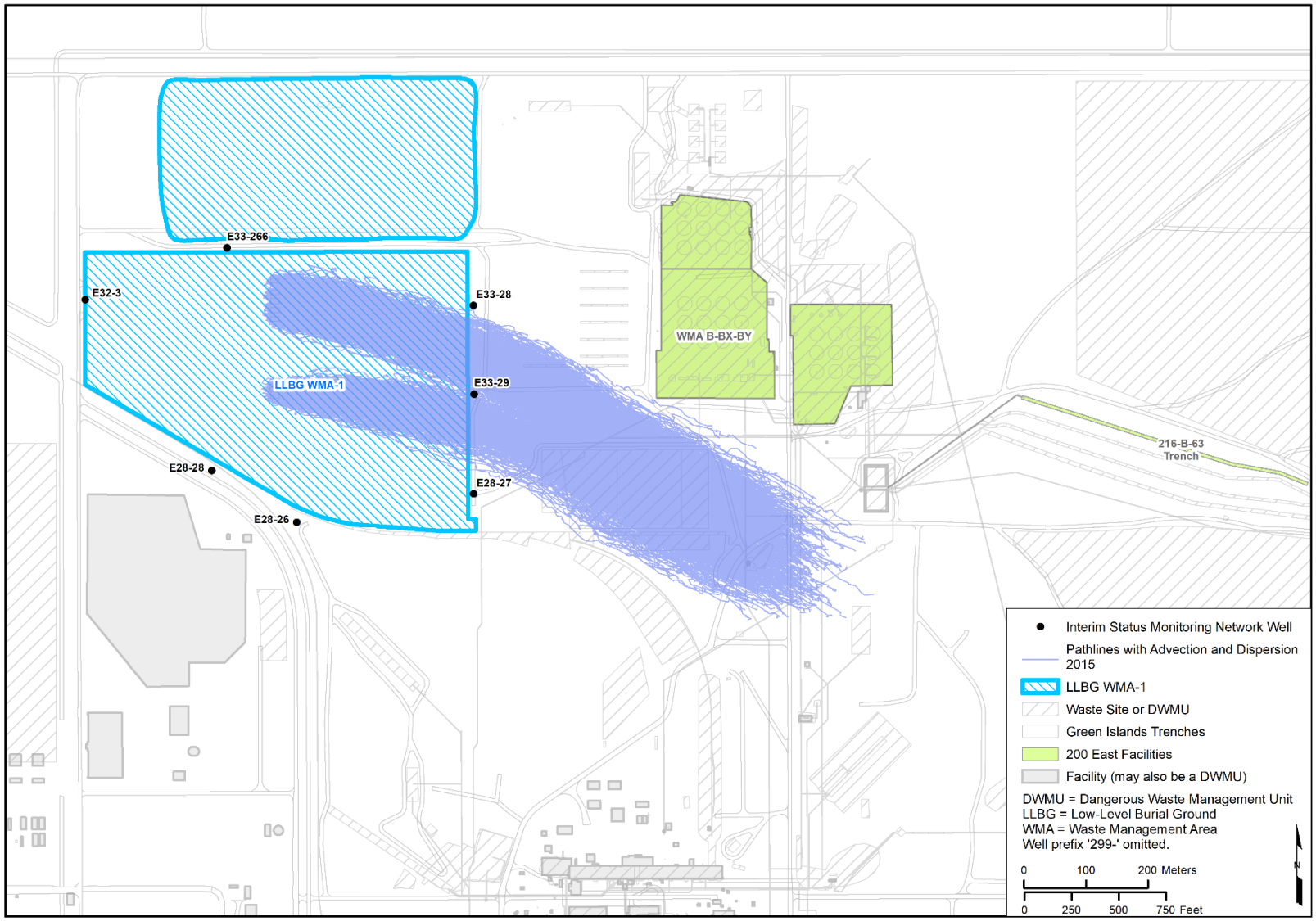

Figure I-9. Local-Scale Particle Pathlines, Advection and Dispersion – LLBG WMA-1, 2015

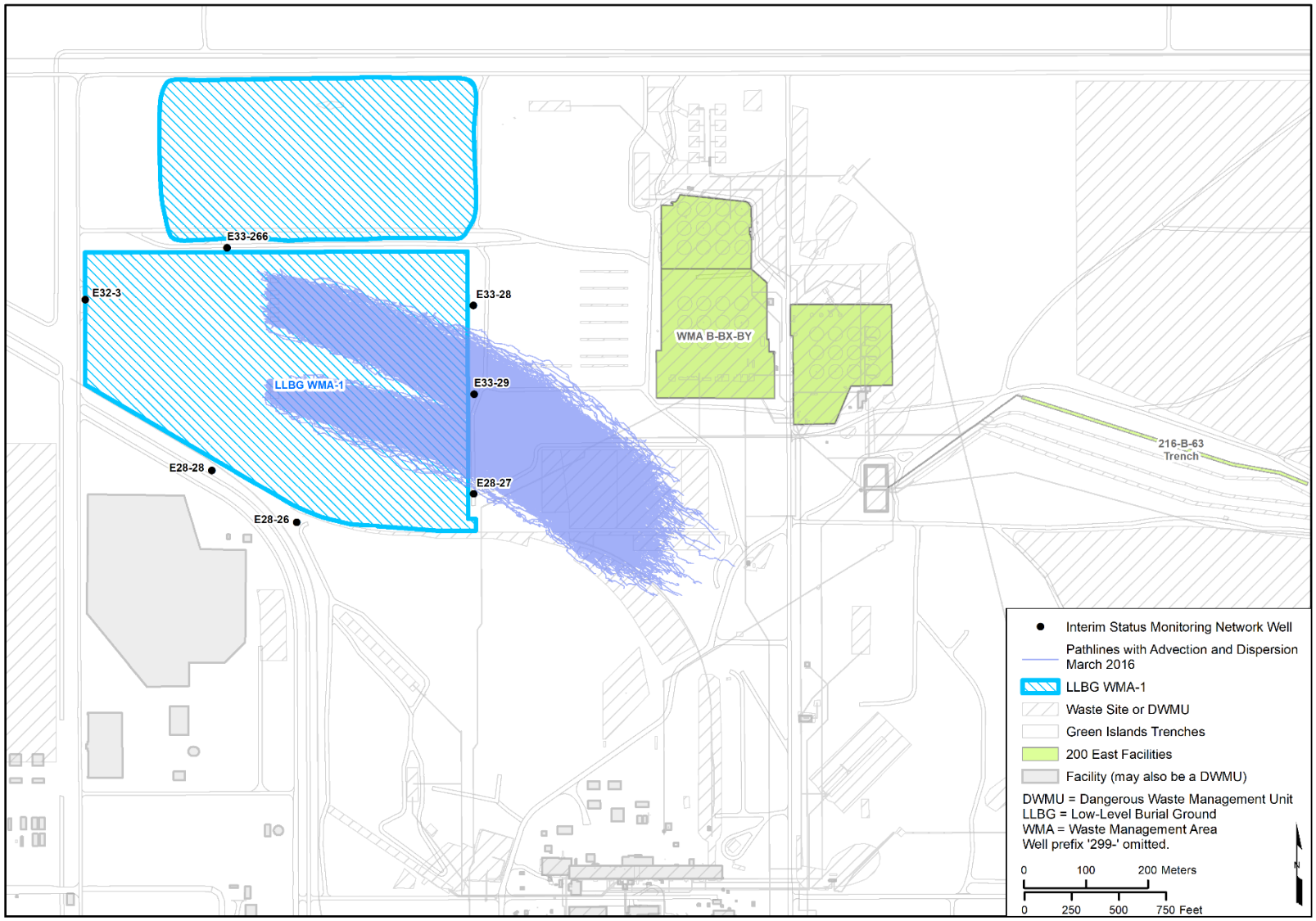

Figure I-10. Local-Scale Particle Pathlines, Advection and Dispersion – LLBG WMA-1, 2016

I3.3 Particle Counts

To compare the relative timing and density of the particles that pass by each monitoring well location, particle counts were calculated as described in Section 6.3 of the main text of this ECF. The particle counts were tabulated, particle breakthrough curves were created, and particle count maps were generated.

I3.3.1 Relative Particle Counts at Interim Status Groundwater Monitoring Wells

Tables I-1 through I-3 present the computed particle counts over time, binned into periods of 50 days, for each of the downgradient monitoring wells. Particle count tables are not included for downgradient wells 299-E28-26 and 299-E28-28 because no particle passed through the vicinity of these wells under the simulated flow conditions. The tables present four entries (one for each year) for each well. At the bottom of the column for each mapped event is the total number of particles that passed through the vicinity of the well, regardless of time, and the average of the totals for the four mapped years rounded to the nearest integer. Each table provides an indication of the relative timing of the expected detections at each well and the relative potential that each well would detect a release at the facility for the flow conditions calculated for CYs 2013, 2014, 2015, and 2016.

The average values depicted at the base of each table can be used to assess the relative potential for each well to detect a release at the facility. These averages are summarized as follows:

- 299-E28-27 – Average = 94
- 299-E33-28 – Average = 1
- 299-E33-29 – Average = 277

I3.3.2 Relative Arrival Times at Interim Status Groundwater Monitoring Wells

Figures I-11 through I-13 depict plots of particle counts over time (particle breakthrough curves) for each downgradient well location. The underlying data plotted in Figures I-11 through I-13 are the same as the data in Tables I-1 through I-3, but the time interval over which particles are summed is not necessarily the same. Particle breakthrough curves show the relative timing and particle density for the arrival, peak, and decline in particle counts at each interim status monitoring location resulting from the hypothetical instantaneous release at the facility. The plots depict the relative potential at each well for detecting a release from the facility that reaches the water table for the flow conditions calculated for CYs 2013, 2014, 2015, and 2016. There is one figure for each well, with four lines shown on each plot (one for each year). Breakthrough curves are not included for downgradient wells 299-E28-26 and 299-E28-28 because no particle passed through the vicinity of these wells under the simulated flow conditions.

Table I-1. Particle Density (Count) Monitoring Well 299-E28-27

Time Interval (day)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
50	0	0	0	0	
100	0	0	0	0	
150	34	0	0	0	
200	140	0	0	0	
250	40	1	0	0	
300	2	11	0	0	
350	0	32	0	0	
400	0	66	0	0	
450	0	31	0	1	
500	0	9	0	1	
550	0	1	0	1	
600	0	0	0	3	
650	0	0	0	0	
700	0	0	0	1	
750	0	0	0	0	
800	0	0	0	0	
850	0	0	0	0	
900	0	0	0	0	
950	0	0	0	0	
1000	0	0	0	0	Average
Total	216	151	0	7	**94**

Table I-2. Particle Density (Count) Monitoring Well 299-E33-28

Time Interval (day)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
50	0	0	0	0	
100	0	0	0	0	
150	0	0	0	0	
200	0	0	0	0	
250	0	0	0	0	
300	0	0	2	0	
350	0	0	0	0	
400	0	0	0	0	
450	0	0	0	0	
500	0	0	0	0	
550	0	0	0	0	
600	0	0	0	0	
650	0	0	0	0	
700	0	0	0	0	
750	0	0	0	0	
800	0	0	0	0	
850	0	0	0	0	
900	0	0	0	0	
950	0	0	0	0	
1000	0	0	0	0	Average
Total	0	0	2	0	**1**

Table I-3. Particle Density (Count) Monitoring Well 299-E33-29

Time Interval (day)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
50	0	0	0	0	
100	0	0	0	0	
150	3	0	0	0	
200	3	0	0	0	
250	1	4	7	0	
300	0	84	30	0	
350	0	214	39	12	
400	0	154	17	85	
450	0	65	2	123	
500	0	13	0	110	
550	0	5	0	79	
600	0	0	0	33	
650	0	0	0	21	
700	0	0	0	2	
750	0	0	0	0	
800	0	0	0	0	
850	0	0	0	0	
900	0	0	0	0	
950	0	0	0	0	
1000	0	0	0	0	Average
Total	7	539	95	465	**277**

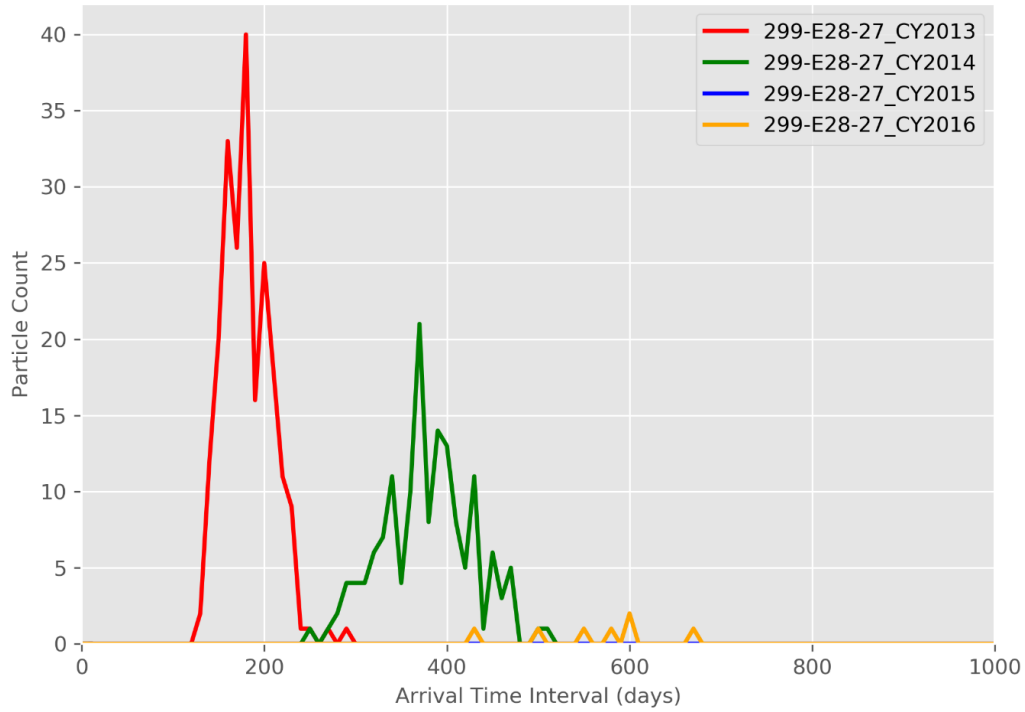

Figure I-11. Particle Breakthrough Curve at Monitoring Well 299-E28-27

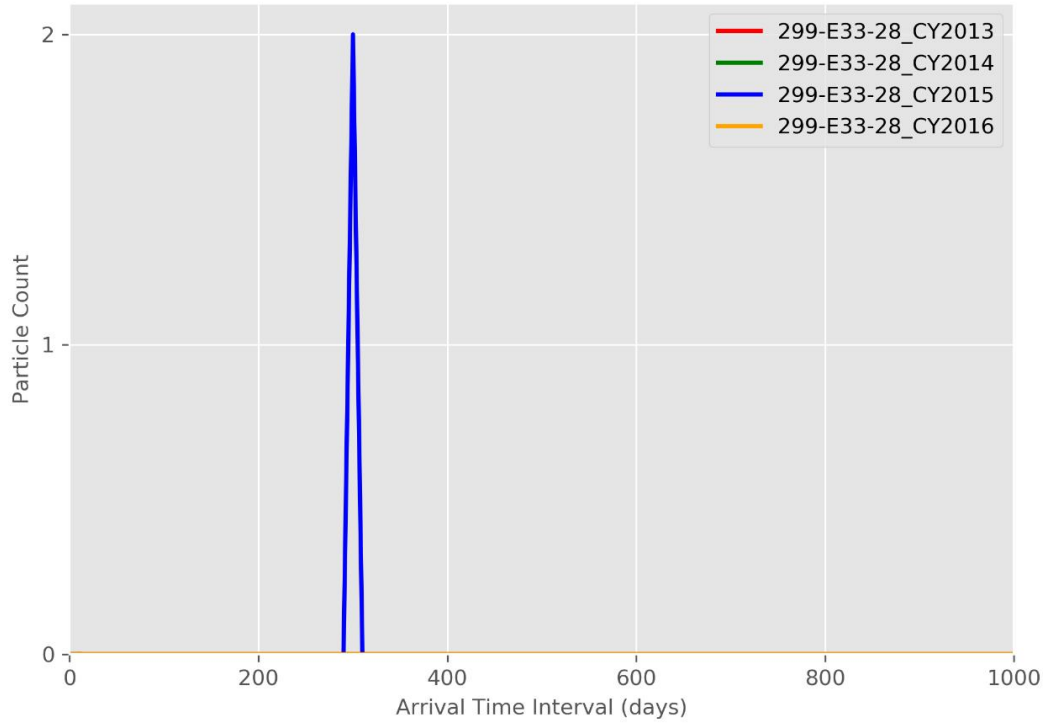

Figure I-12. Particle Breakthrough Curve at Monitoring Well 299-E33-28

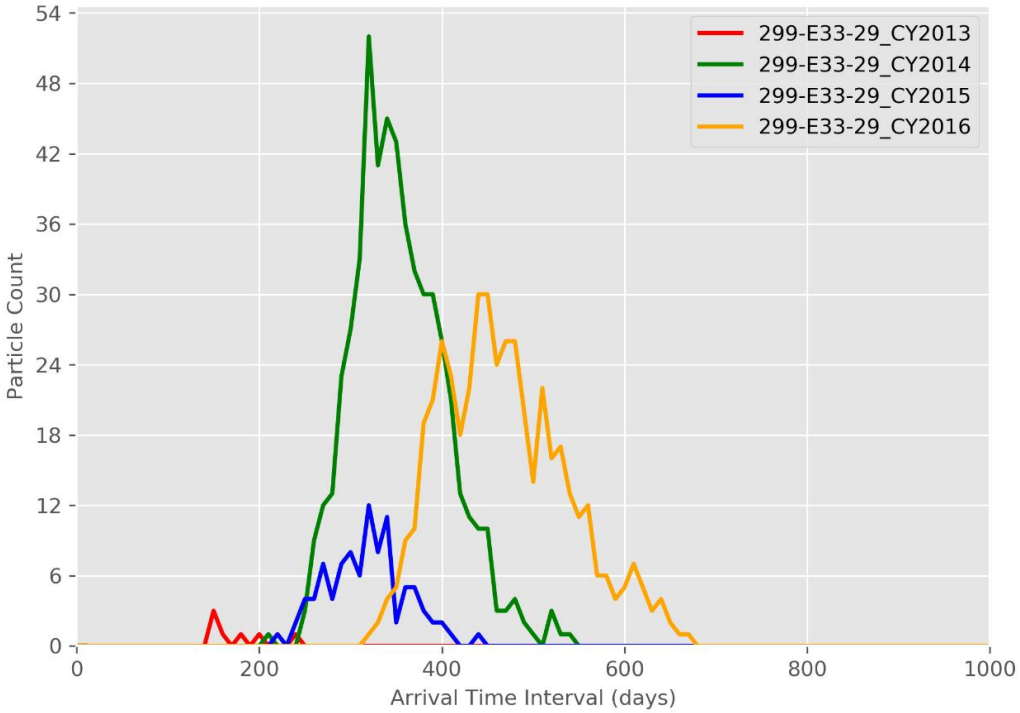

Figure I-13. Particle Breakthrough Curve at Monitoring Well 299-E33-29

I3.3.3 Particle Count Maps

Figures I-14 through I-17 depict the particle count maps developed based on the instantaneous release of a large number of particles at the facility. The particle count maps depict areas of relatively higher and lower potential impact from a release at the facility that reaches the water table, for conditions represented by CYs 2013, 2014, 2015, and 2016. Figures I-14 through I-17 depict the particle density after 3 years of calculated travel, by which time it was determined that all particles would have arrived at or passed by the interim status groundwater monitoring wells (see entries in Tables I-1 through I-3).

The goal of well placement is for the well locations to span the range of particle pathline distribution as released from LLBG WMA-1. The particle count maps show that under the evaluated range of conditions, there are areas of high particle counts where there are no corresponding monitoring wells, indicating the need for additional monitoring wells. The location of the proposed wells (LLBGWMA-1_PW-1, LLBGWMA-1_PW-2, and LLBGWMA-1_PW-3) are shown in Figures I-14 through I-17.

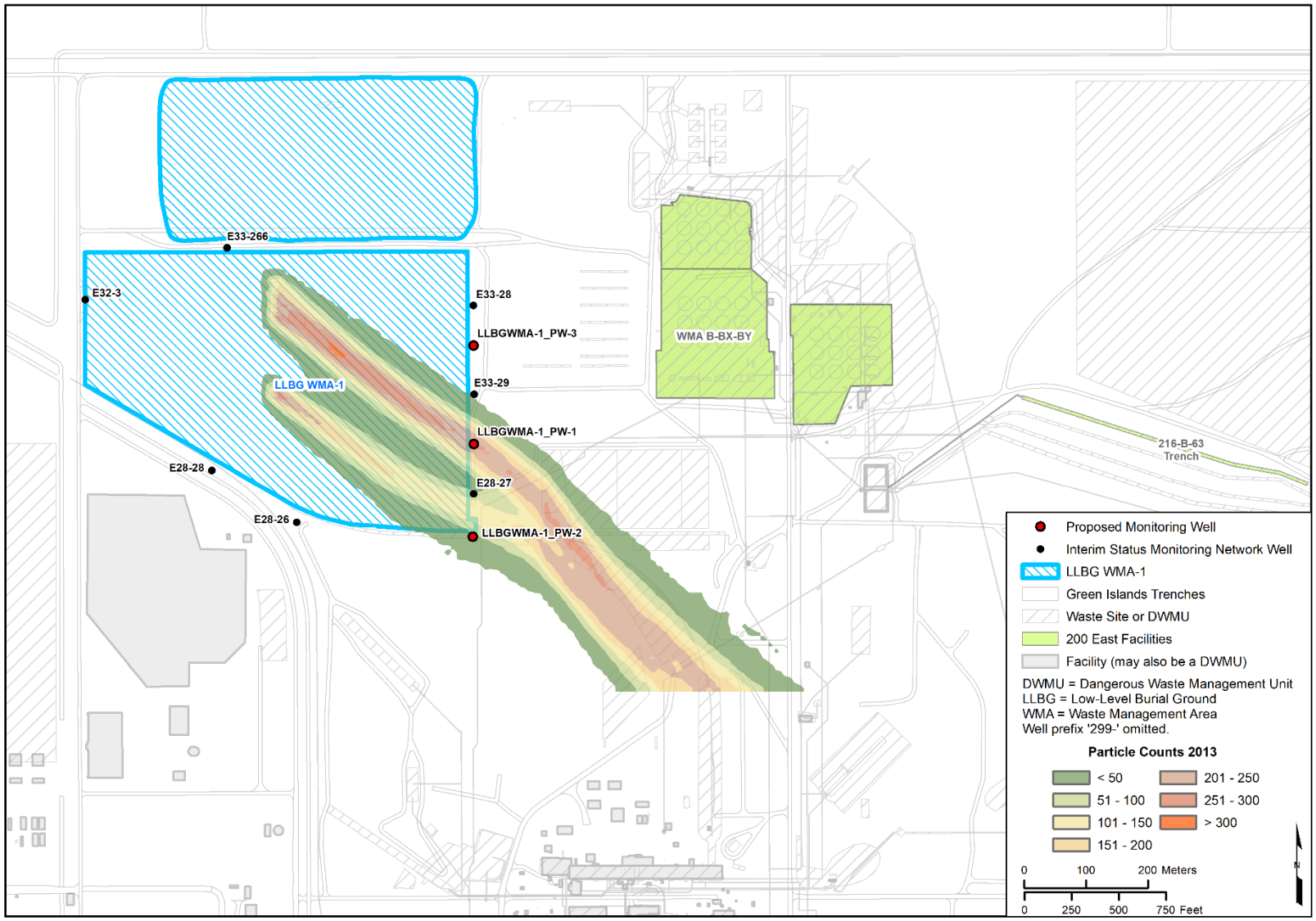

Figure I-14. Particle Count Map – LLBG WMA-1, 2013

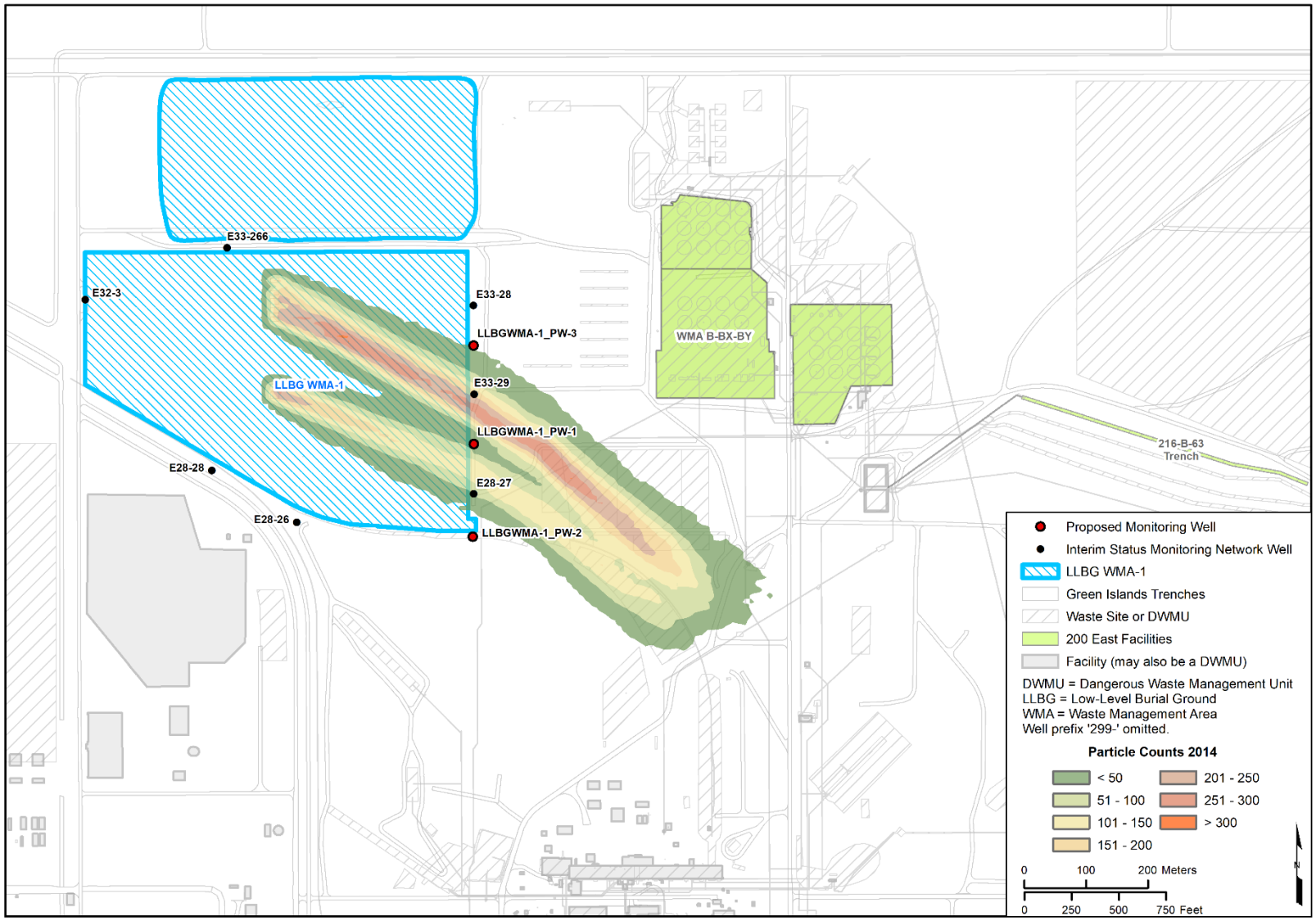

Figure I-15. Particle Count Map – LLBG WMA-1, 2014

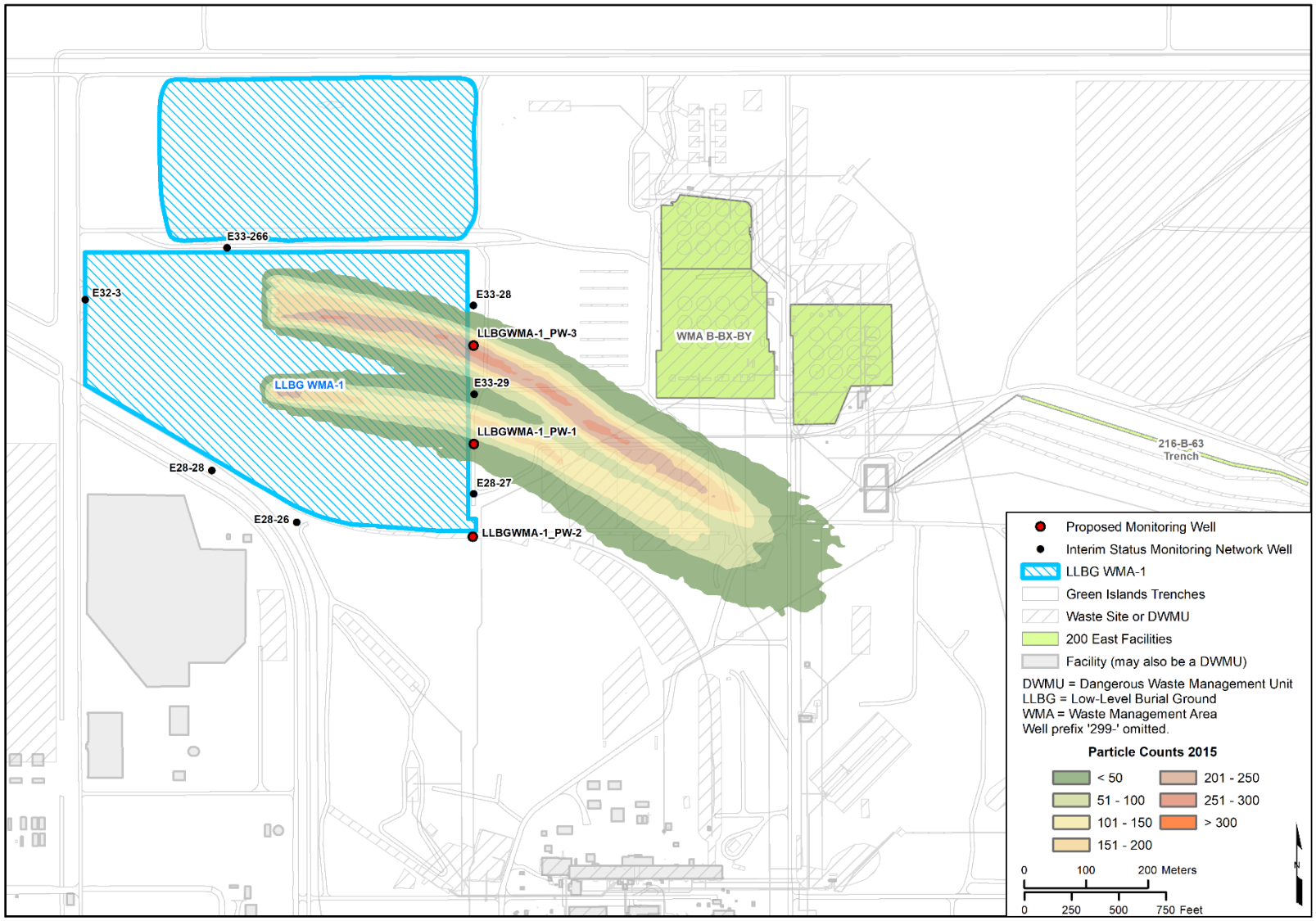

Figure I-16. Particle Count Map – LLBG WMA-1, 2015

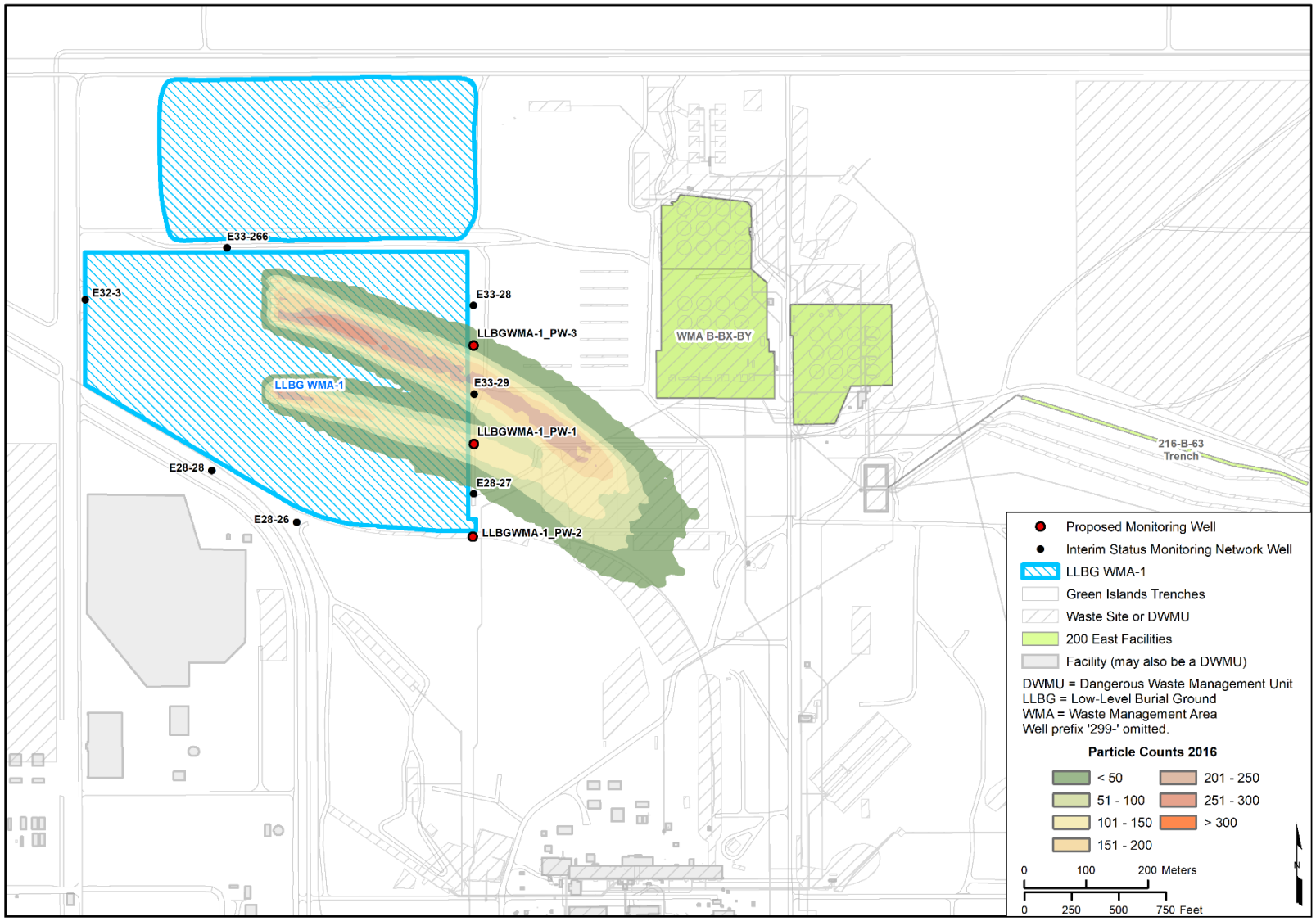

Figure I-17. Particle Count Map – LLBG WMA-1, 2016

I3.4 Proposed Monitoring Wells

The locations of the proposed monitoring wells are shown in Figures I-14 through I-17. The particle counts tabulated for these locations (Tables I-4 through I-6) indicate the relative timing of expected detections at the wells and the relative potential of the wells for detecting a release at the facility.
The particle breakthrough curves (Figures I-18 through I-20) show the relative timing and particle density at the proposed monitoring well locations for the arrival, peak, and decline in particle counts resulting from the hypothetical instantaneous release to the water table beneath the facility.

Table I-4. Particle Density (Count) Proposed Monitoring Well LLBGWMA-1_PW-1

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
50	0	0	0	0	
100	0	0	0	0	
150	110	0	0	0	
200	453	0	0	0	
250	85	3	9	0	
300	1	19	45	1	
350	0	39	49	16	
400	0	34	17	65	
450	0	27	5	103	
500	0	10	0	83	
550	0	0	0	48	
600	0	0	0	17	
650	0	0	0	11	
700	0	0	0	1	
750	0	0	0	0	
800	0	0	0	0	
850	0	0	0	0	
900	0	0	0	0	
950	0	0	0	0	
1000	0	0	0	0	Average
Total	649	132	125	345	**313**

Table I-5. Particle Density (Count) Proposed Monitoring Well LLBGWMA-1_PW-2

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
50	0	0	0	0	
100	0	0	0	0	
150	2	0	0	0	
200	77	0	0	0	
250	43	0	0	0	
300	3	0	0	0	
350	0	0	0	0	
400	0	0	0	0	
450	0	0	0	0	
500	0	0	0	0	
550	0	0	0	0	
600	0	0	0	0	
650	0	0	0	0	
700	0	0	0	0	
750	0	0	0	0	
800	0	0	0	0	
850	0	0	0	0	
900	0	0	0	0	
950	0	0	0	0	
1000	0	0	0	0	Average
Total	125	0	0	0	**31**

Table I-6. Particle Density (Count) Proposed Monitoring Well LLBGWMA-1_PW-3

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
50	0	0	0	0	
100	0	0	0	0	
150	0	0	0	0	
200	0	0	1	0	
250	0	0	72	0	
300	0	3	231	0	
350	0	2	214	7	
400	0	2	90	23	
450	0	0	19	31	
500	0	0	2	39	
550	0	0	0	17	
600	0	0	0	3	
650	0	0	0	1	
700	0	0	0	0	
750	0	0	0	0	
800	0	0	0	0	
850	0	0	0	0	
900	0	0	0	0	
950	0	0	0	0	
1000	0	0	0	0	Average
Total	0	7	629	121	**189**

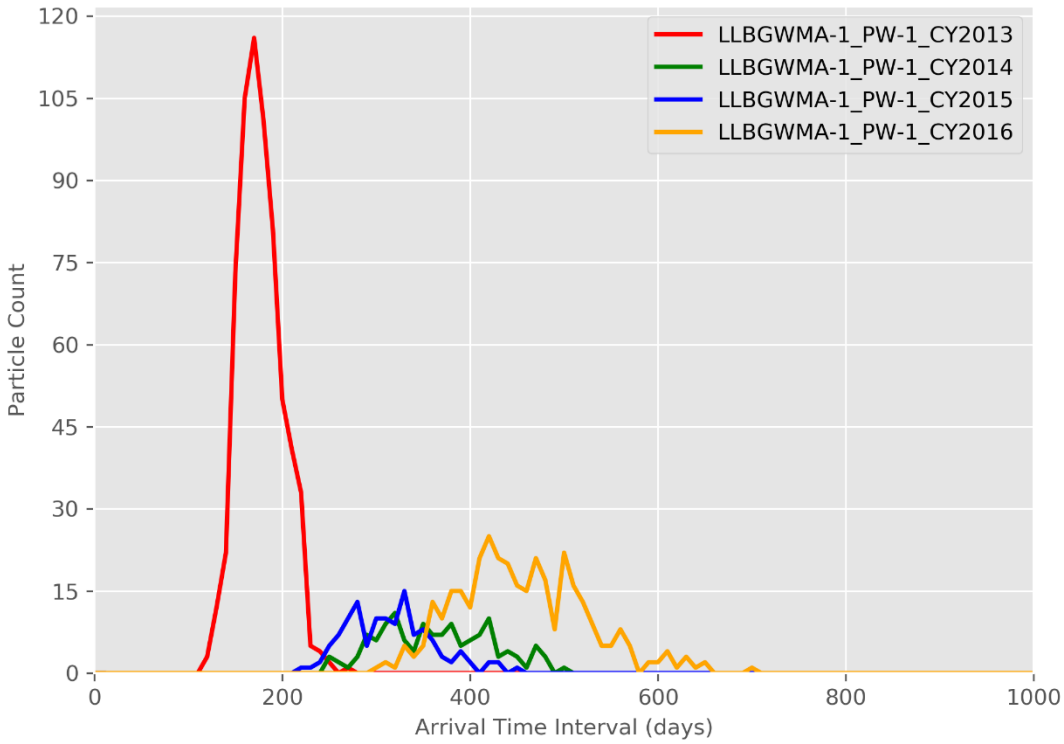

Figure I-18. Particle Breakthrough Curve at Monitoring Well LLBGWMA-1_PW-1

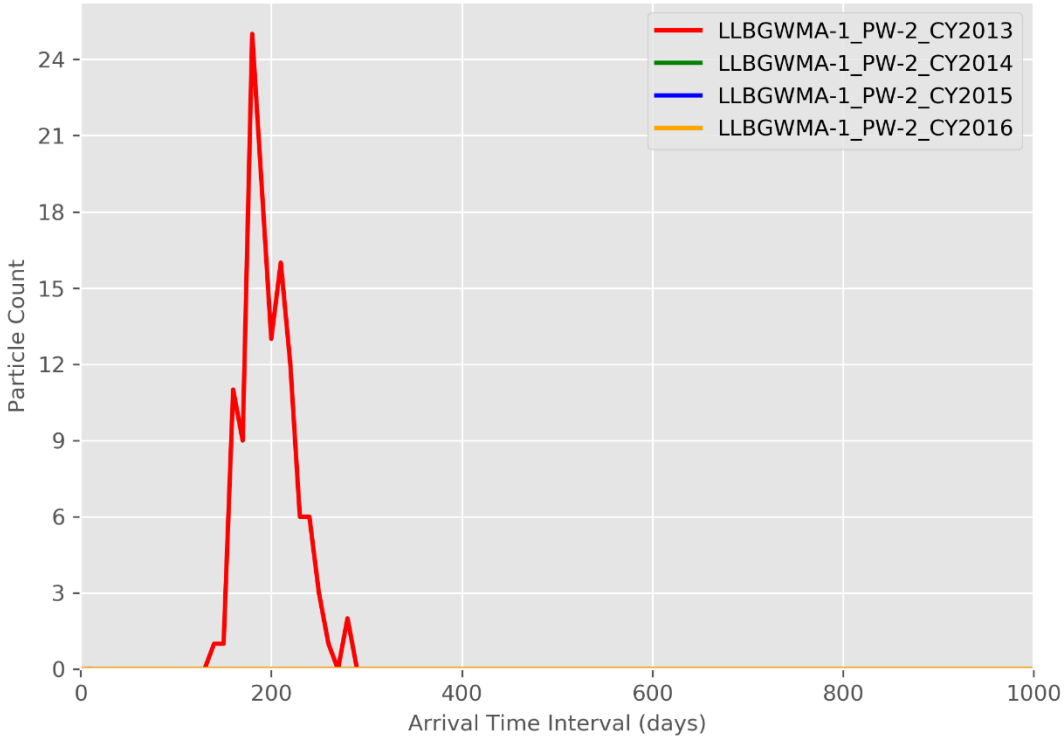

Figure I-19. Particle Breakthrough Curve at Monitoring Well LLBGWMA-1_PW-2

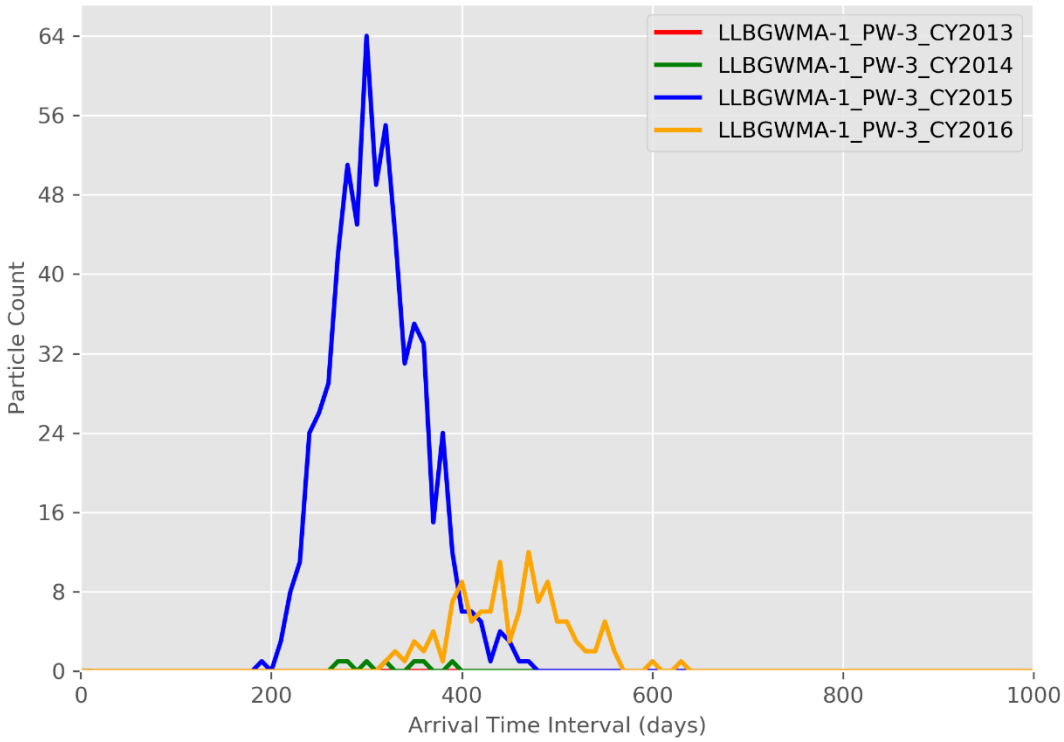

Figure I-20. Particle Breakthrough Curve at Monitoring Well LLBGWMA-1_PW-3

I3.5 Analyses of Particle Pathlines for Each Area of LLBG WMA-1

Particle pathline maps shown in Section I3.2 depict an instantaneous release to the water table from the release locations in LLBG WMA-1. Particle tracking also was performed for smaller regions of the facility to evaluate well locations for detecting releases from various regions of LLBG WMA-1. This section contains the results of analyses performed to examine how releases from the various areas of LLBG WMA-1 that reach the groundwater beneath those release areas relate to each individual monitoring well. A series of figures and tables are provided to illustrate the fate of releases originating from three different areas of the waste management area. For these analyses, the particle release points presented in Figure I-2 are grouped into one of two areas based on their spatial location. Those areas are depicted in Figure I-21. Figures I-22 through I-25 illustrate the particle pathlines originating from each of the areas for CYs 2013 through 2016.

Figures I-26 through I-31 illustrate the particle count time series for each existing and proposed monitoring well from CY 2013 through CY 2016. Each figure has four panels, each of which depicts the particle counts for one CY (2013 through 2016). Additionally, each panel shows a separate breakthrough curve for particles emanating from each area. For example, Figure I-26 depicts the particle counts at well LLBGWMA-1_PW-1, which receives particles from areas 1 and 2 in 2014. In the figure, within the panel for 2014 (top row, right), the particle breakthrough curve from area 1 is depicted with a blue line and area 2 with a red line.

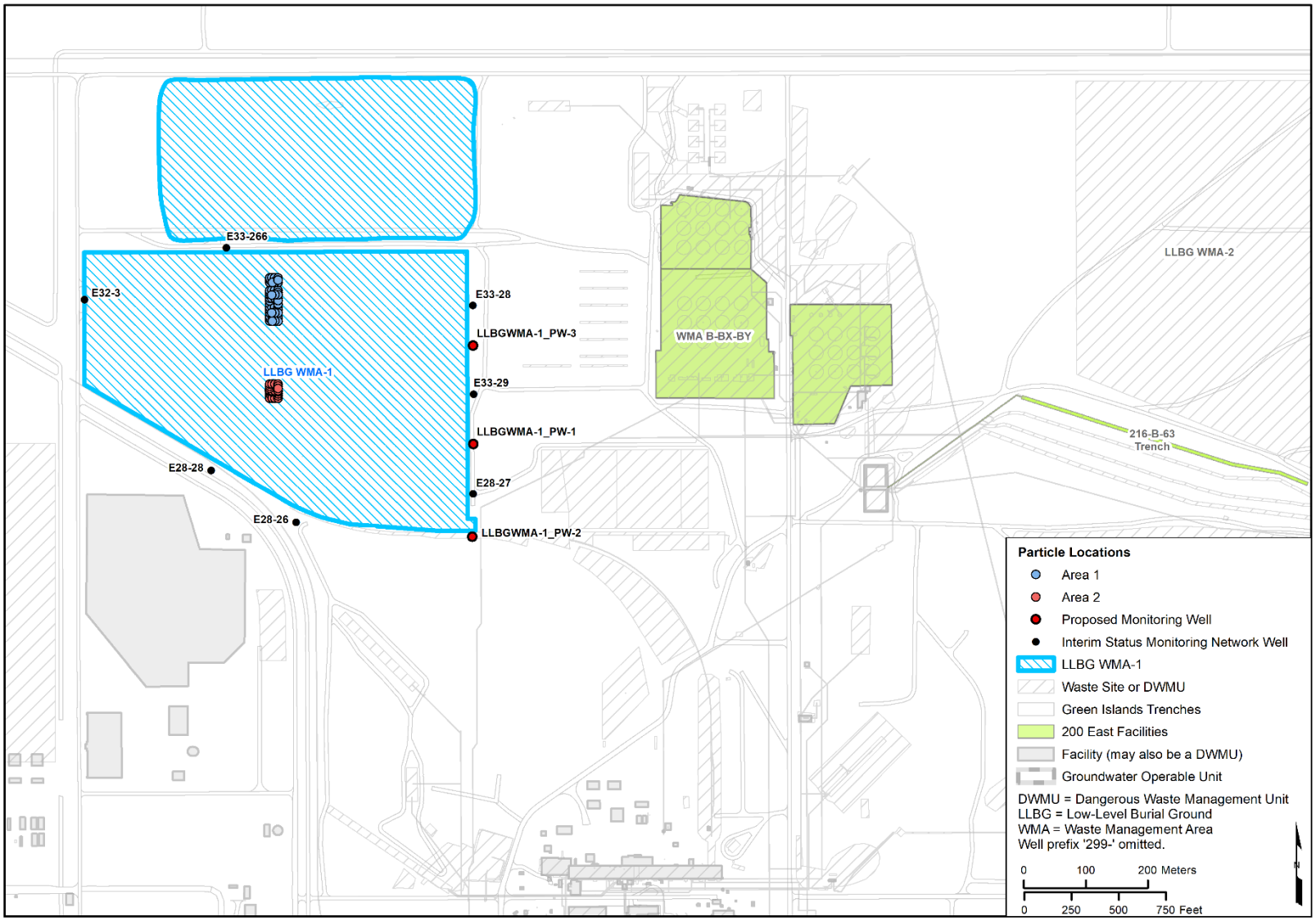

Figure I-21. Particle Release Locations and Areas of LLBG WMA-1

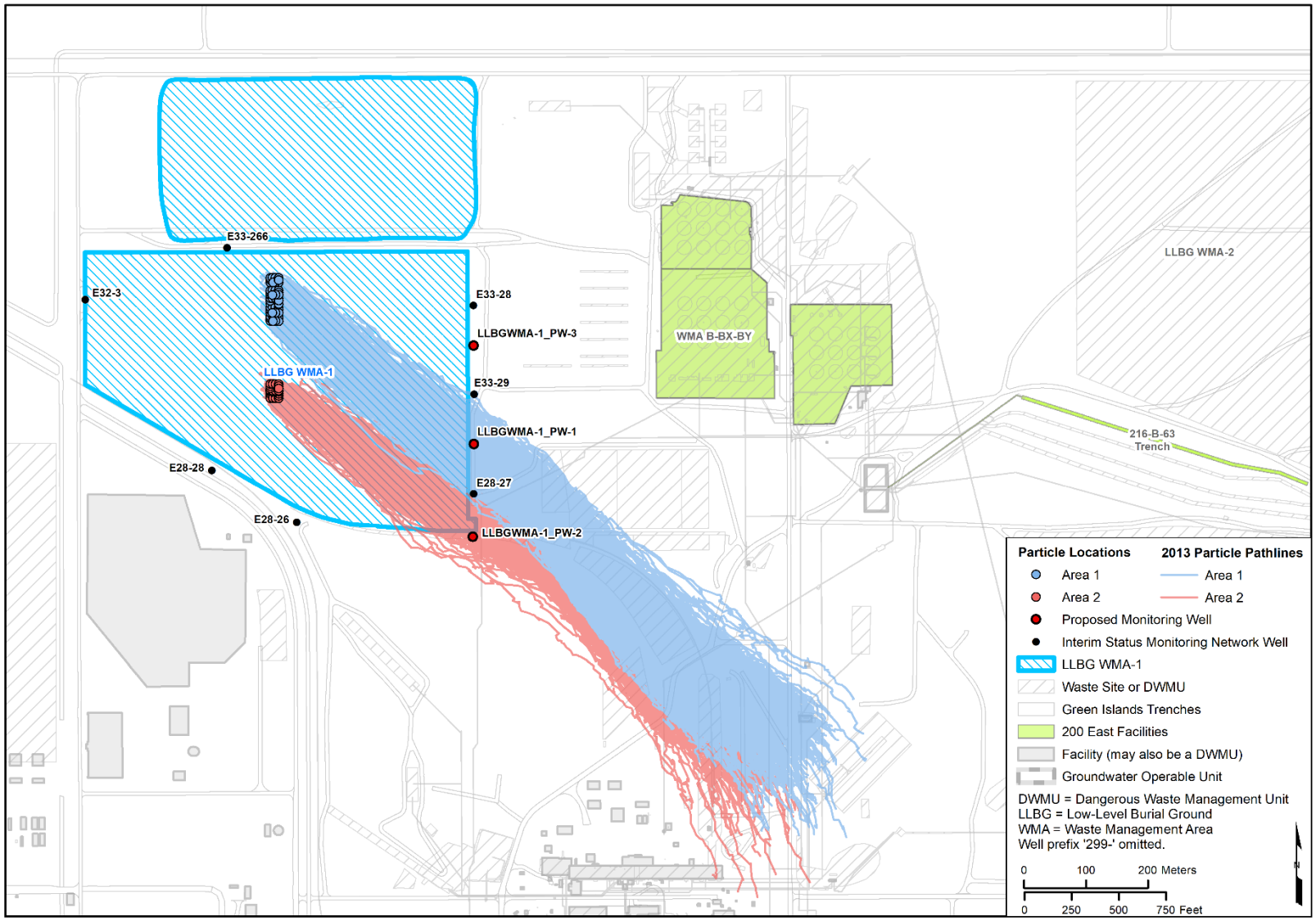

Figure I-22. CY 2013 Particle Pathlines per Area of LLBG WMA-1

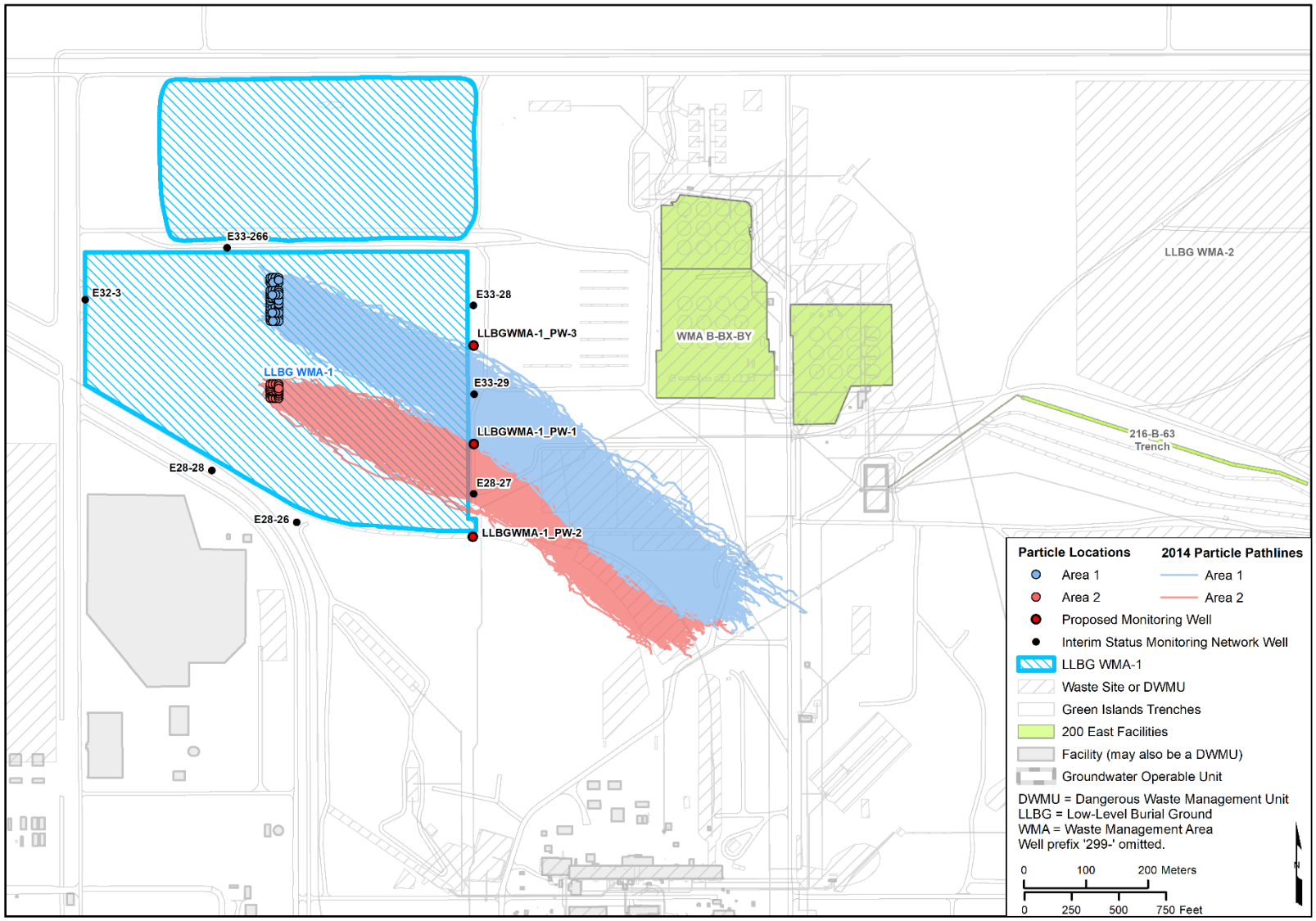

Figure I-23. CY 2014 Particle Pathlines per Area of LLBG WMA-1

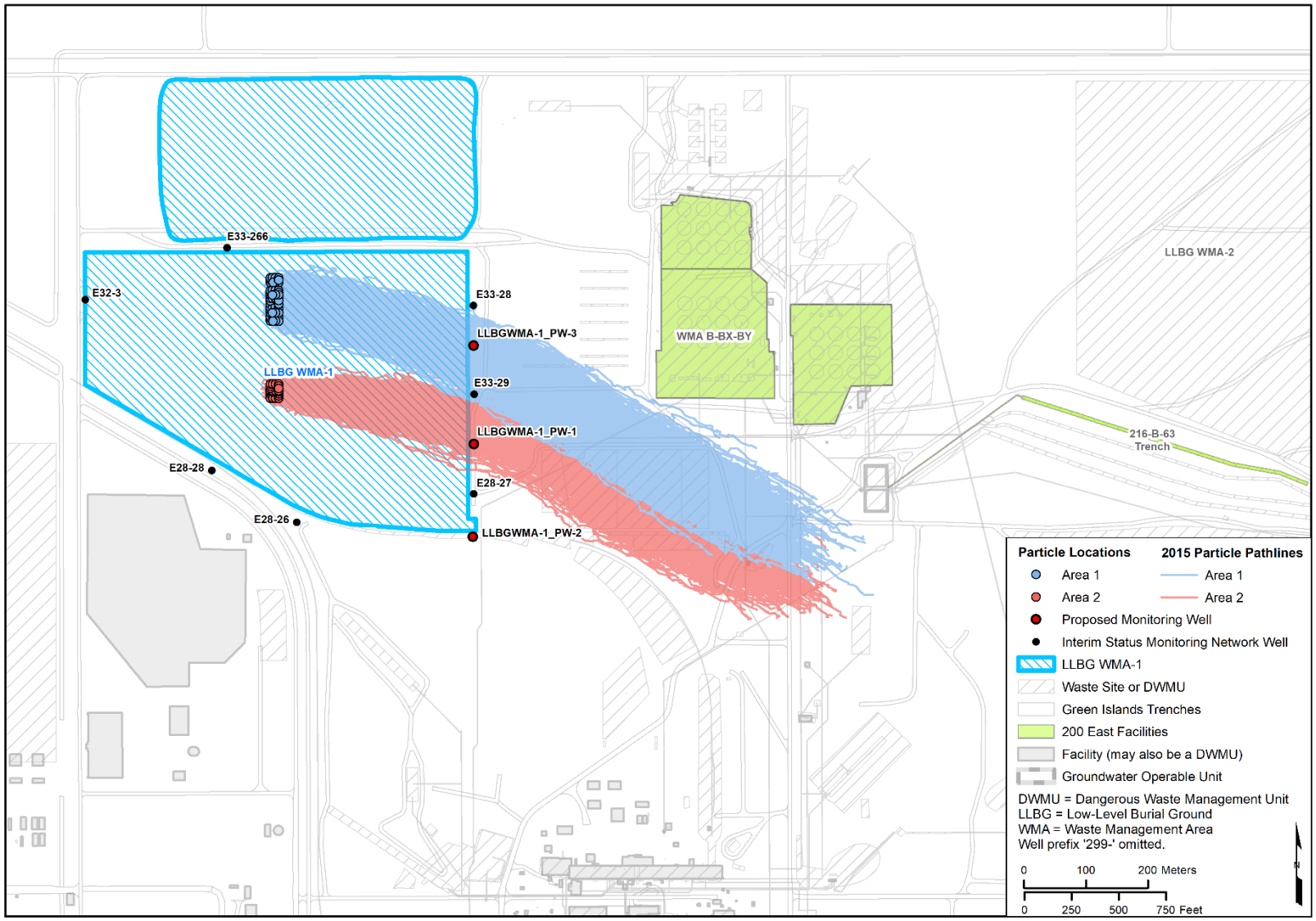

Figure I-24. CY 2015 Particle Pathlines per Area of LLBG WMA-1

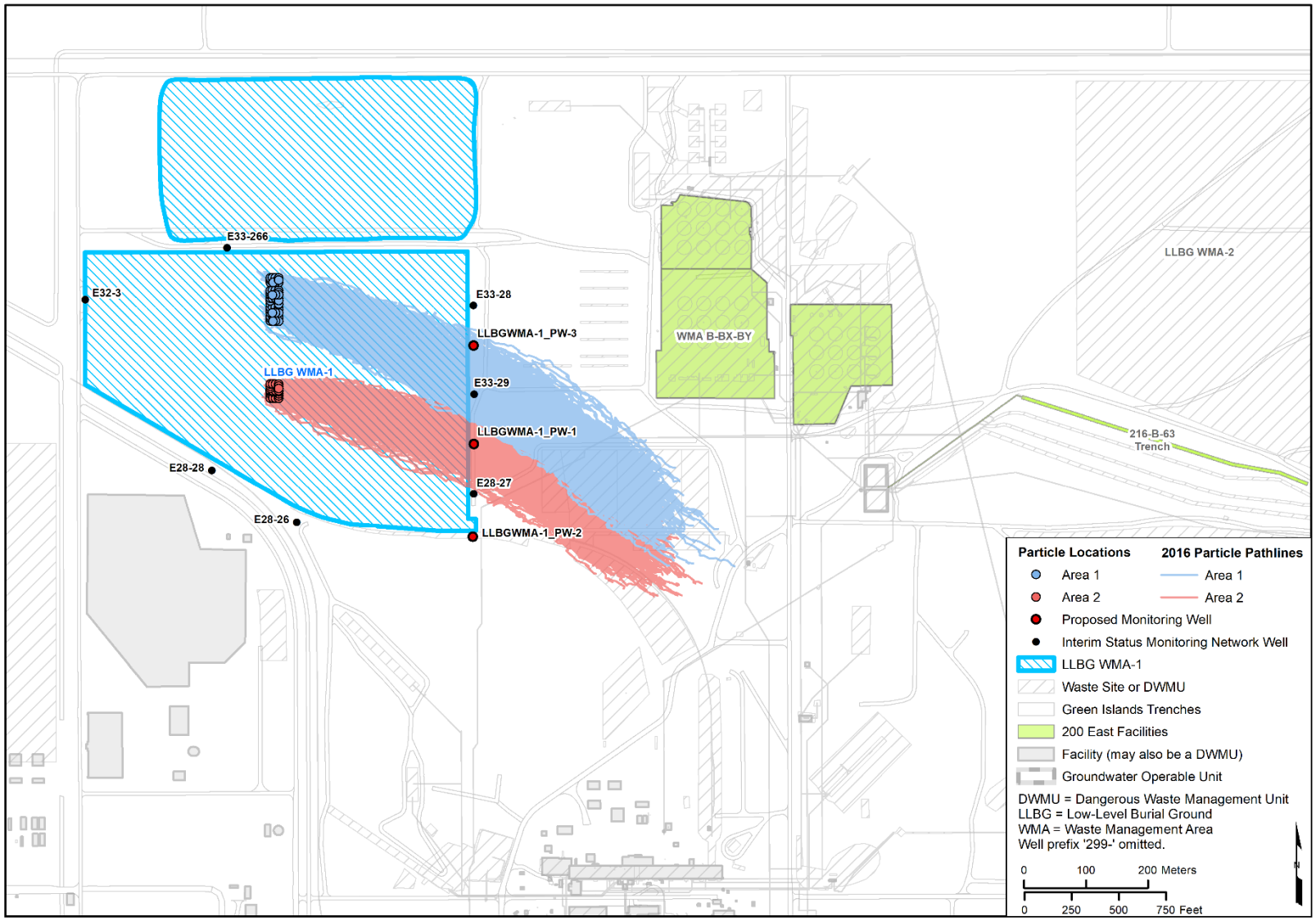

Figure I-25. CY 2016 Particle Pathlines per Area of LLBG WMA-1

Figure I-26. Particle Breakthrough Curves per Area at Monitoring Well LLBGWMA-1_PW-1

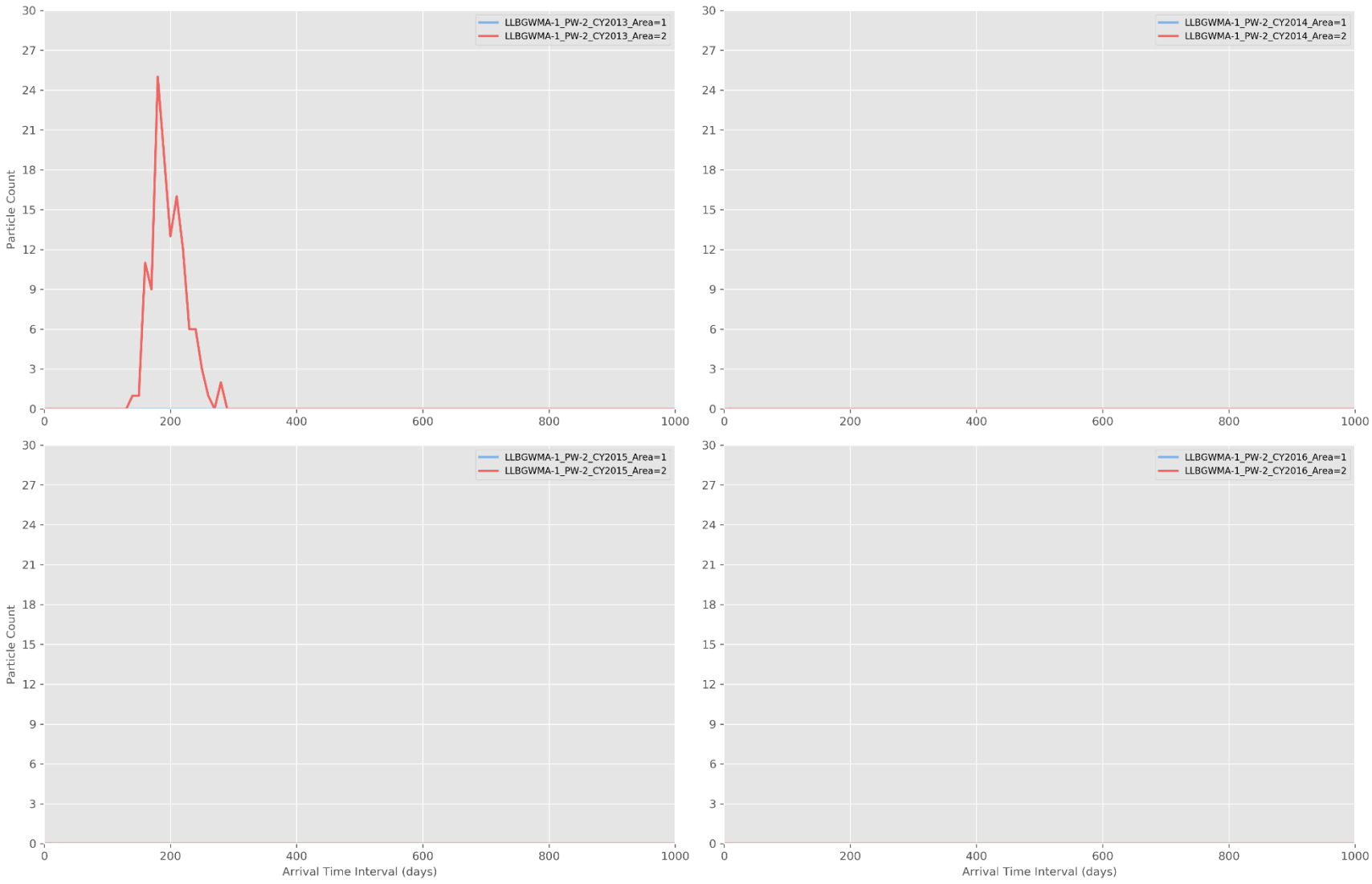

Figure I-27. Particle Breakthrough Curves per Area at Monitoring Well LLBGWMA-1_PW-2

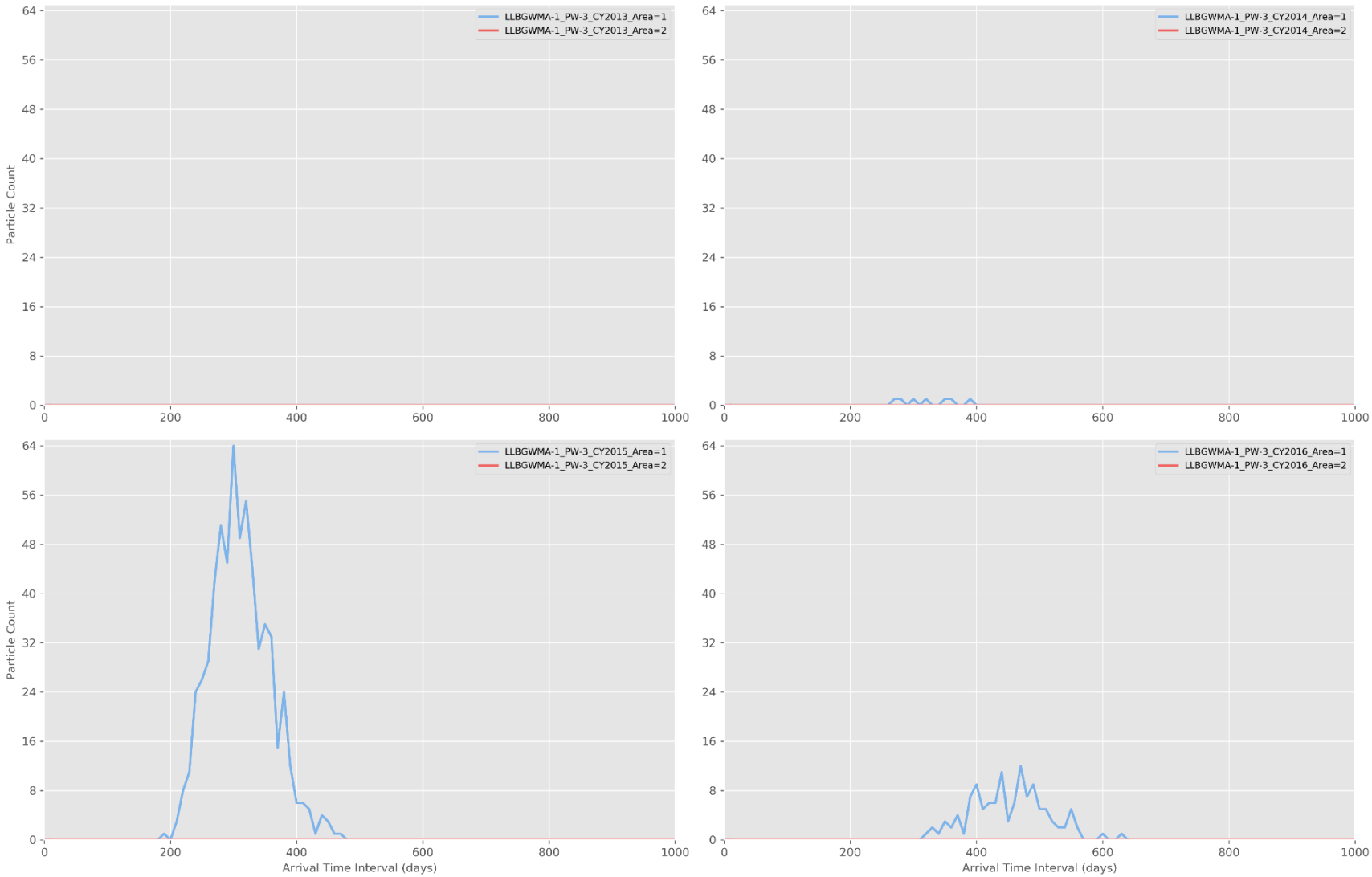

Figure I-28. Particle Breakthrough Curves per Area at Monitoring Well LLBGWMA-1_PW-3

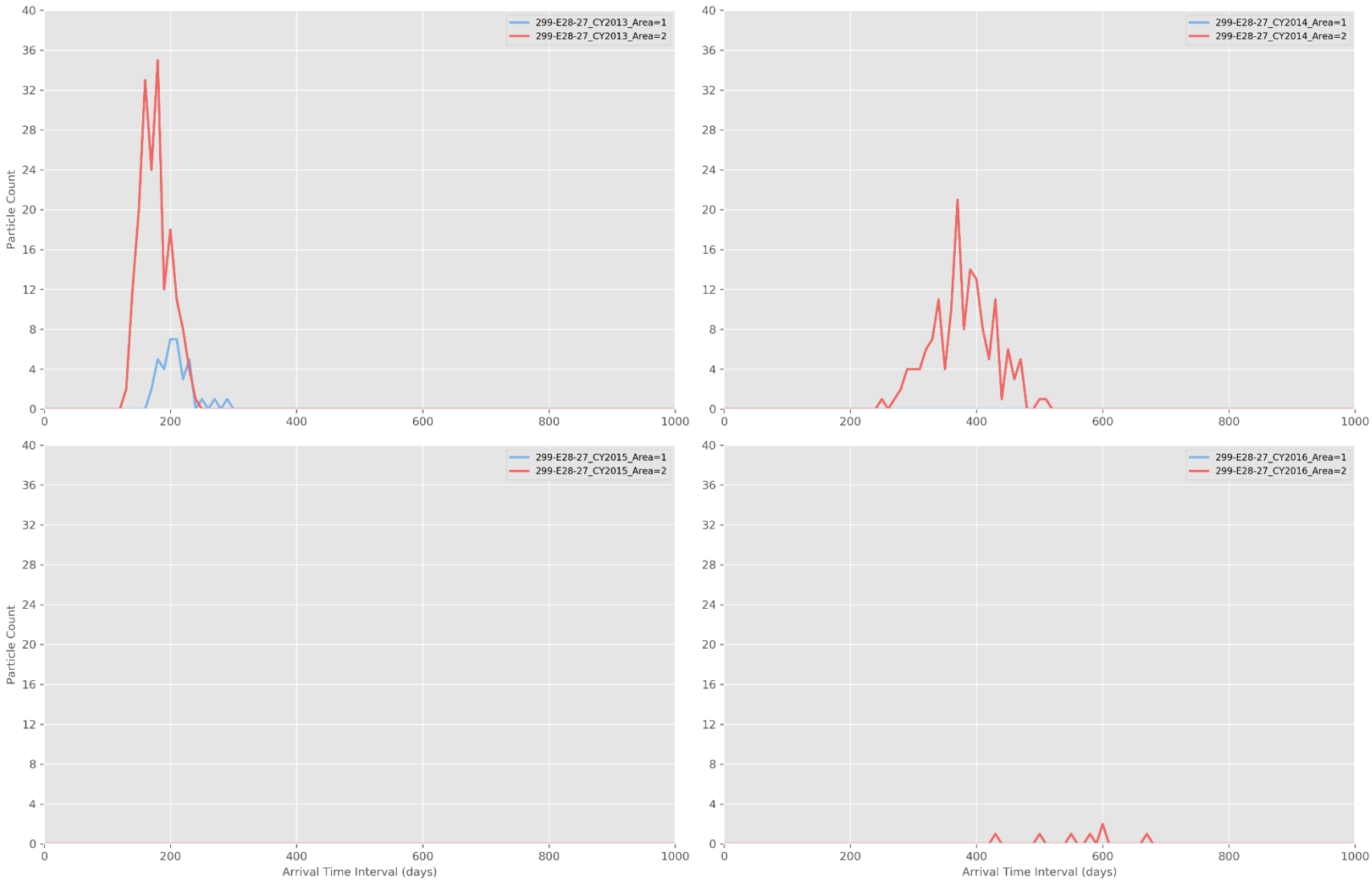

Figure I-29. Particle Breakthrough Curves per Area at Monitoring Well 299-E28-27

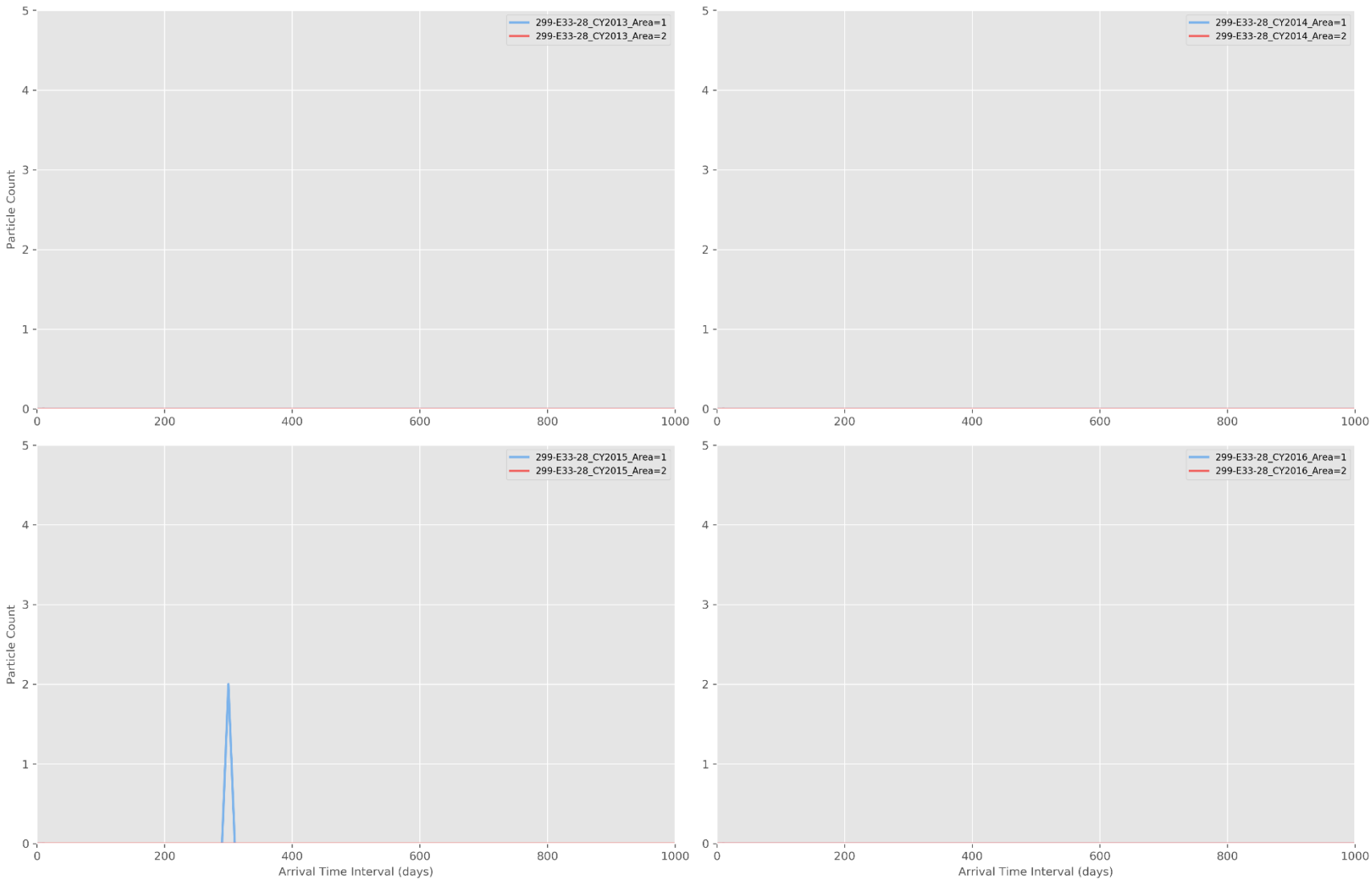

Figure I-30. Particle Breakthrough Curves per Area at Monitoring Well 299-E33-28

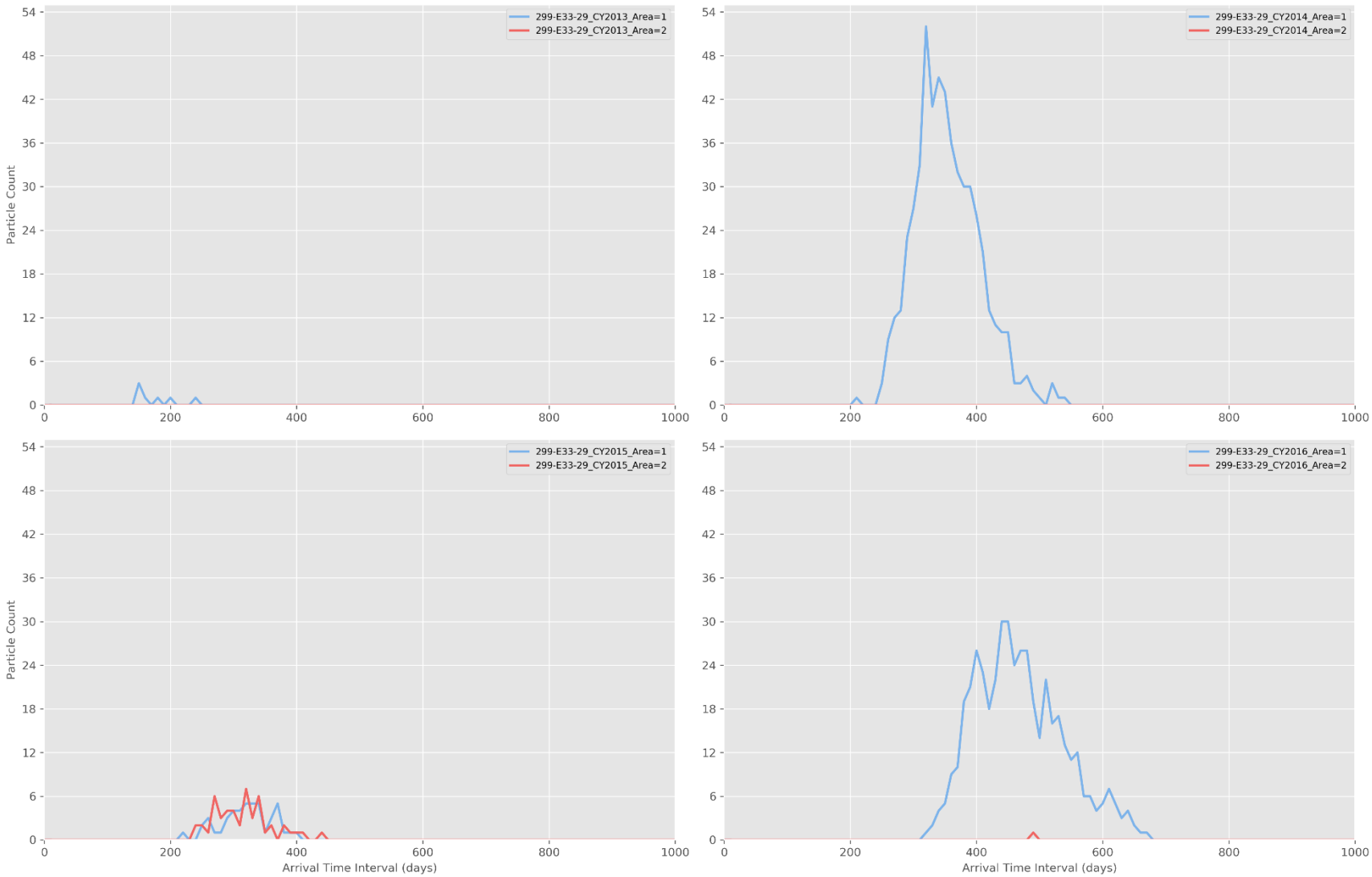

Figure I-31. Particle Breakthrough Curves per Area at Monitoring Well 299-E33-29

I3.6 Vertical Migration Potential

As described in Section 3.3 of the main text of this ECF, the American Petroleum Institute (API) plume diving calculation was used to estimate the likely rate of vertical migration of dissolved constituents downward under the influence of recharge at the water table. At each well the slope of the plume dive was multiplied by the distance from the particle starting location to the well location to estimate the depth to which the dissolved constituents may be anticipated to have migrated by the time they reach the monitoring well location.

This estimated depth of the plume was then compared to the depth from the water table to the bottom of the monitoring well screen. If the depth of the plume is below the bottom of the monitoring well screen, then the dissolved constituents may be anticipated to pass beneath the well screen. If it falls within the interval between the top of the water table and the bottom of the well screen, then the well depth is appropriate for detection of releases at LLBG WMA-1.

For each downgradient monitoring well at LLBG WMA-1, the distance from the centroid of the facility to each well was used in the calculation. The hydraulic conductivity used in the calculation for LLBG WMA-1, 15,000 m/d (49,213 ft/d), is the calibrated value of the Hanford formation from the CPGWM. The value is the hydraulic conductivity for the Hanford formation, which underlies part of the facility. The facility is also underlain by the Cold Creek unit, but the CPGWM hydraulic conductivity value for the Cold Creek unit was not used for this calculation because its higher value would result in a lower calculated vertical migration estimate, which is a less conservative estimate. The results of the API plume diving calculation for the downgradient wells for LLBG WMA-1 are shown in Table I-7.

Table I-7. Summary of Well Screen Interval Evaluation for Downgradient Wells

Monitoring Well	Existing or Proposed Well?	Distance, D, (m)[a]	Recharge, *i*, (m/yr)[b]	Slope, S, of Plume Dive[c]	Estimated Depth of Plume Below Water Table (m)[d]	Depth from Water Table to Bottom of Well Screen (m)[e]	Is Plume Depth Above Bottom of the Screen? (Yes/No/N/A)
299-E28-26	Existing	369.0	2.60E-03	1.48E-04	5.46E-02	3.00	Yes
299-E28-27	Existing	421.2	2.60E-03	1.48E-04	6.23E-02	2.20	Yes
299-E28-28	Existing	322.4	2.60E-03	1.48E-04	4.77E-02	2.10	Yes
299-E33-28	Existing	270.9	2.60E-03	1.48E-04	4.0E-02	2.70	Yes
299-E33-29	Existing	316.2	2.60E-03	1.48E-04	4.7E-02	4.10	Yes
LLBGWMA-1_PW-1	Proposed	363.6	2.60E-03	1.48E-04	5.38E-02	N/A	N/A
LLBGWMA-1_PW-2	Proposed	475.8	2.60E-03	1.48E-04	7.04E-02	N/A	N/A
LLBGWMA-1_PW-3	Proposed	283.4	2.60E-03	1.48E-04	4.19E-02	N/A	N/A

a. Distance of the well from centroid of dangerous waste management unit.

b. A representative number from the CPGWM. The recharge values represent fluxes from surface water discharge due to historical operations at the Hanford Site and are summarized in EMDT-BC-0002, *Vadose Zone Attenuated Recharge, Electronic Modeling Data Transmittal – Boundary Condition (Artificial Recharge)*-0002. The anthropogenic flux is added to the natural recharge component in order to establish the final total recharge flux used in the simulations. Discharges included in EMDT-BC-0002 have been attenuated to account for travel through the vadose zone.

Table I-7. Summary of Well Screen Interval Evaluation for Downgradient Wells

Monitoring Well	Existing or Proposed Well?	Distance, D, (m)[a]	Recharge, *i*, (m/yr)[b]	Slope, S, of Plume Dive[c]	Estimated Depth of Plume Below Water Table (m)[d]	Depth from Water Table to Bottom of Well Screen (m)[e]	Is Plume Depth Above Bottom of the Screen? (Yes/No/N/A)

c. Slope of the plume dive computed using the American Petroleum Institute plume diving calculation as detailed in the main text of this ECF. The migration parameters for LLBG WMA-1 used in the calculation of slope are as follows:

Hydraulic conductivity: 15,000 m/d (49,213 ft/d) (a calibrated value from the CPGWM)

Hydraulic gradient: 3.21E-06 (determined from 2016 water-level maps produced using TRIM)

d. Plume depth at monitoring well location computed from distance, D, times the slope, S.

e. Depths obtained from Table 2-38 in DOE/RL-2016-66, *Hanford Site RCRA Groundwater Monitoring Report for 2016*.

CPGWM = Central Plateau Groundwater Model

ECF = environmental calculation file

N/A = not applicable

TRIM = Tikhonov Regularized Inverse Method

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Appendix J

Facility-Specific Results for Waste Management Area A-AX

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Terms

API	American Petroleum Institute
CPGWM	Central Plateau Groundwater Model
CY	calendar year
ECF	environmental calculation file
SST	single-shell tank
TRIM	Tikhonov Regularized Inverse Method
WMA	waste management area

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J1 Purpose and Background

The primary purpose of the calculations presented here is to estimate directions of potential migration to assess the efficacy of the geographical distribution of wells in the proposed monitoring well network for the subject facility. The calculations described within the main text of this environmental calculation file (ECF) were performed for each of the 200 East Facilities. This appendix presents results developed from the calculations that are specific to Waste Management Area (WMA) A-AX.

Centrally located in the 200 East Area (Figure J-1), WMA A-AX contains 10 single-shell tanks (SSTs), 5 french drains, and various other liquid handling structures. This equipment was used to manage tank waste from the Plutonium-Uranium Extraction Plant and B Plant between 1956 and 1980. Two of the tanks are known, or are suspected, to have leaked (Chapter 1 in DOE/RL-2015-49, *Interim-Status Groundwater Quality Assessment Plan for the Single-Shell Tank Waste Management Area A-AX*).

The groundwater near WMA A-AX is monitored under an interim status groundwater quality assessment plan (DOE/RL-2015-49) in accordance with 40 CFR 265, Subpart F, "Interim Status Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities," "Ground-Water Monitoring." The monitoring began as an indicator evaluation program in 1989 and has undergone various modifications in the intervening years. In 2005, groundwater monitoring changed to a groundwater quality assessment program due to elevated concentrations of specific conductance in a downgradient well. The interim status groundwater monitoring well network generally has expanded with additional wells since inception (Chapter 1 in DOE/RL-2015-49).

The WMA A-AX monitoring network (Figure J-1), which is described in Section 3.1 in DOE/RL-2016-66, *Hanford Site RCRA Groundwater Monitoring Report for 2016*, consists of three upgradient wells (299-E24-20, 299-E24-22, and 299-E24-33) and six downgradient wells (299-E25-2, 299-E25-40, 299-E25-41, 299-E25-93, 299-E25-94, and 299-E25-237). The wells are screened at the top of the unconfined aquifer (Section 3.1 in DOE/RL-2016-66). This ECF presents calculations that evaluate the efficacy of the groundwater monitoring network for detecting hypothetical releases from WMA A-AX at existing and potential new monitoring well locations.

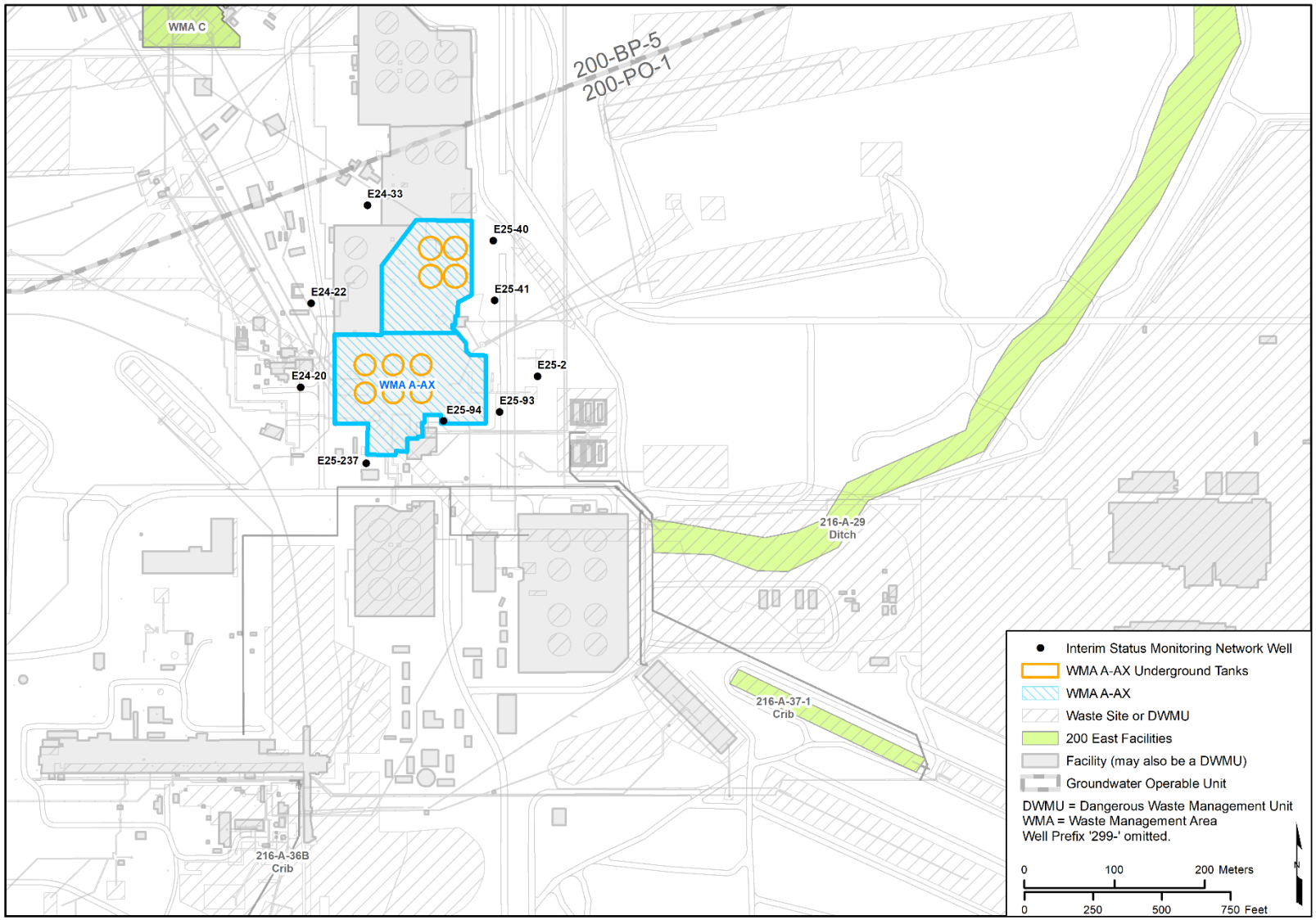

Figure J-1. Locations of Interim Status Groundwater Monitoring Wells at WMA A-AX

J2 Facility-Specific Input for WMA A-AX

Inputs used in the calculations that were specific to WMA A-AX are described in this chapter.

J2.1 Particle Count Grid and Release Locations

To prepare particle count maps, a distribution of facility-specific starting locations is required. The starting locations for the particle-tracking calculations represent the area over which a potential release from a given facility would impact the underlying water table. The particle releases were located at plausible release sites throughout the facility. For WMA A-AX, 20 release locations were specified around the circumference of each of the 10 SSTs (Figure J-2). Twenty particles were released and tracked from each release location to provide the density of particles in space and time required for the detailed facility-specific calculations, randomizing the seed values for the dispersion calculations. Thus, 4,000 (4,000 = 10 [tanks] × 20 [release locations] × 20 [releases]) particles were tracked for each of the four simulations.

Contour maps of particle counts were generated by counting the number of particles that pass through a pre-defined uniform calculational grid (Figure J-2). The grid used to develop the relative particle density maps is defined by 10 by 10 m (33 by 33 ft) cells. The grid is oriented to be parallel to the predominant groundwater flow direction at WMA A-AX.

J2.2 Migration Parameters

Parameters specific to the groundwater flow conditions at WMA A-AX are reported throughout the various documents for the facility. The parameters used in the calculations performed herein to represent nonreactive dissolved contaminant migration are mobile (or effective) porosity and hydraulic conductivity. The parameters used in these calculations are representative of local conditions for a conservative (i.e., nonreactive) solute dissolved within groundwater.

There is a range of hydraulic conductivity values reported in site literature for WMA A-AX. Values range from 1,981 m/d (6,499 ft/d) (Table 2 in ECF-Hanford-16-0013, *Hydraulic Gradient and Velocity Calculations for RCRA Sites in 2015*) to 17,000 m/d (55,774 ft/d) (Table 1 in ECF-Hanford-17-0241, *Hydraulic Gradient and Velocity Calculations for RCRA Sites in 2017*). As described in Section 4.2.1.1 of the main text of this ECF, the hydraulic conductivity used in the work performed herein corresponds to the calibrated values from the Central Plateau Groundwater Model (CPGWM) (CP-47631, *Model Package Report: Central Plateau Groundwater Model, Version 8.4.5*). Figure 3-2 in the main text of this ECF indicates WMA A-AX is located in the hydrostratigraphic unit zone corresponding to the Cold Creek unit. The value used for the hydraulic conductivity for WMA A-AX is 18,200 m/d (59,711 ft/d), which corresponds to the Cold Creek unit as shown in Table 4-1 in the main text of this ECF. The mobile (effective) porosity defined for the Cold Creek unit, which underlies WMA A-AX, is specified at 0.25.

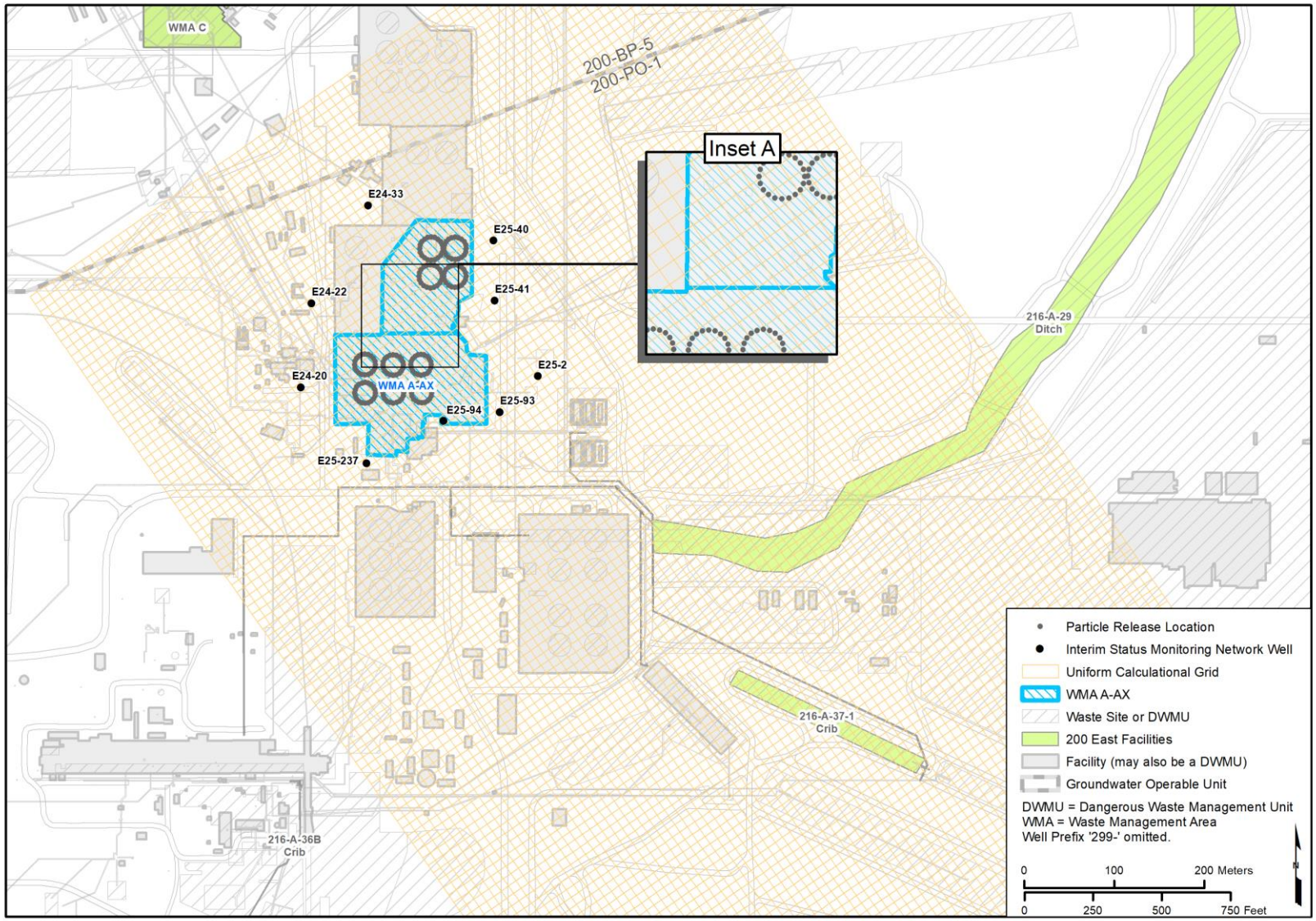

Figure J-2. Uniform Calculational Grid and Release Locations at WMA A-AX

J3 Facility-Specific Results for WMA A-AX

The groundwater elevation contours prepared in the vicinity of WMA A-AX using the Tikhonov Regularized Inverse Method (TRIM) are presented in this chapter. In addition, the outputs of the particle tracking and particle count calculations are presented, including the following:

- Maps of calculated particle pathlines for the flow conditions determined for each of the four years (2013, 2014, 2015, and 2016). These are presented at the facility-specific scale considering advective and dispersive migration.
- Time-series plots, referred to as particle breakthrough curves, of the relative arrival, peak, and decline in particle counts at each interim status groundwater monitoring well location and each proposed monitoring location, where applicable.
- Tabulation of relative particle counts for each interim status groundwater monitoring well location and each proposed monitoring location, where applicable.
- Maps of particle counts downgradient of each facility based on the flow conditions determined for each of the four years.

The results of calculations of potential vertical migration of contaminants at the monitoring well locations are also presented.

J3.1 Groundwater Elevation Contours

Figures J-3 through J-6 show the results of the groundwater elevation analysis completed using TRIM in the vicinity of WMA A-AX. The figures depict general patterns of groundwater elevations and hydraulic gradients for conditions represented by calendar years (CYs) 2013, 2014, 2015, and 2016. These groundwater elevation contours and associated hydraulic gradients form the basis for the facility-specific calculations performed for this ECF.

J3.2 Particle Tracking

Once the groundwater elevation contour maps and underlying piecewise continuous elevation grids were prepared using TRIM, particle tracking was implemented using both advection and dispersion.
The particle pathlines that were produced depict the patterns of spreading that might accompany the migration of contaminants near the waste management area for the flow conditions calculated for CYs 2013, 2014, 2015, and 2016. Figures J-7 through J-10 depict the particle pathlines developed based on the groundwater elevations prepared throughout the 200 East Area using TRIM. The resulting maps were prepared based on the release of 20 particles from each starting location to provide the high density of particles in space and time required for these detailed facility-specific calculations. Figures J-7 through J-10 depict the particle pathlines calculated after 500 days of travel, by which time it was determined that most of the particles would have arrived at or passed by the interim status groundwater monitoring wells. Figures J-7 through J-10 depict an instantaneous release to the water table from the release locations in WMA A-AX to illustrate the adequacy of the well network for monitoring the entire facility.

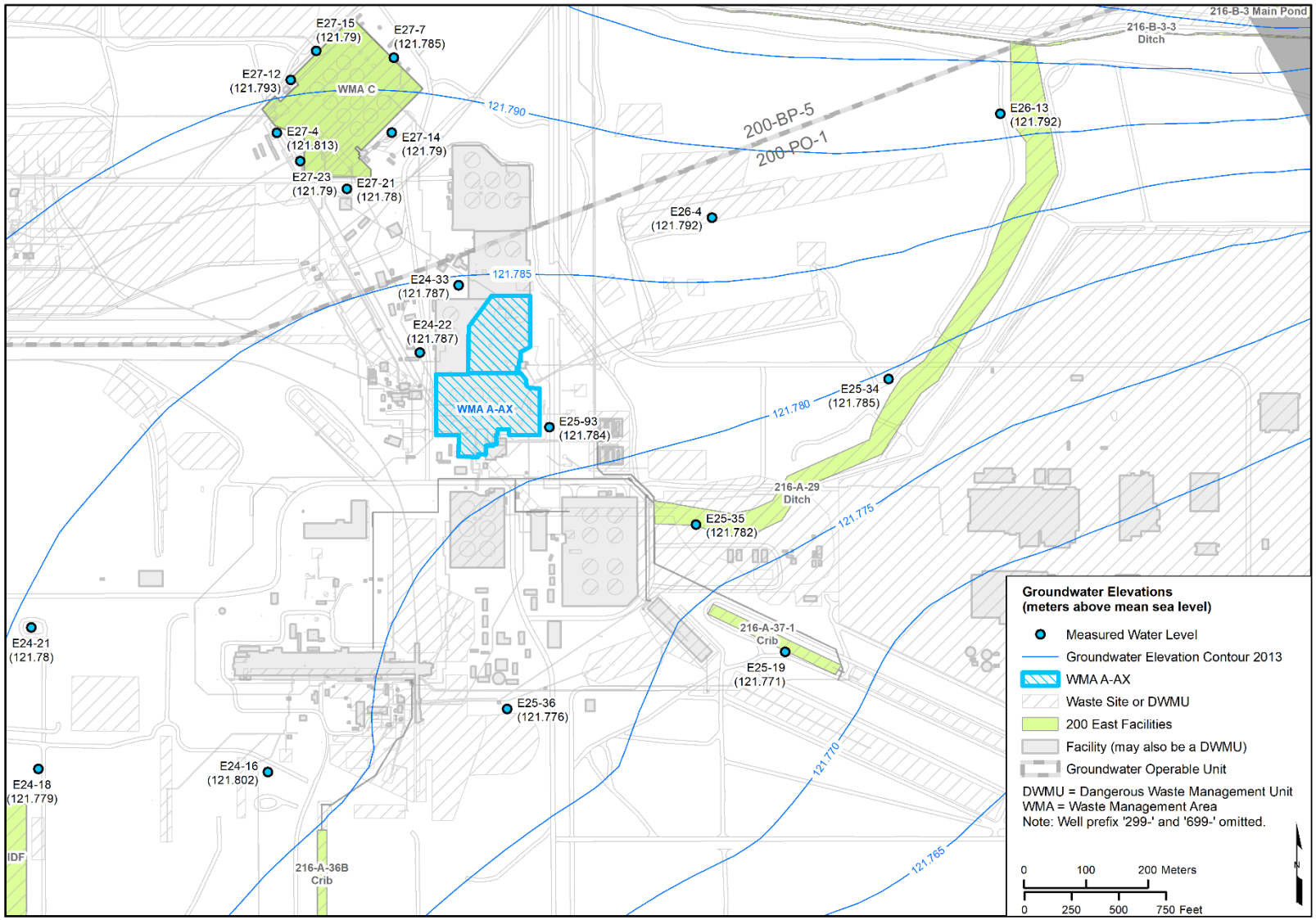

Figure J-3. Water-Level Elevation Map for WMA A-AX, 2013

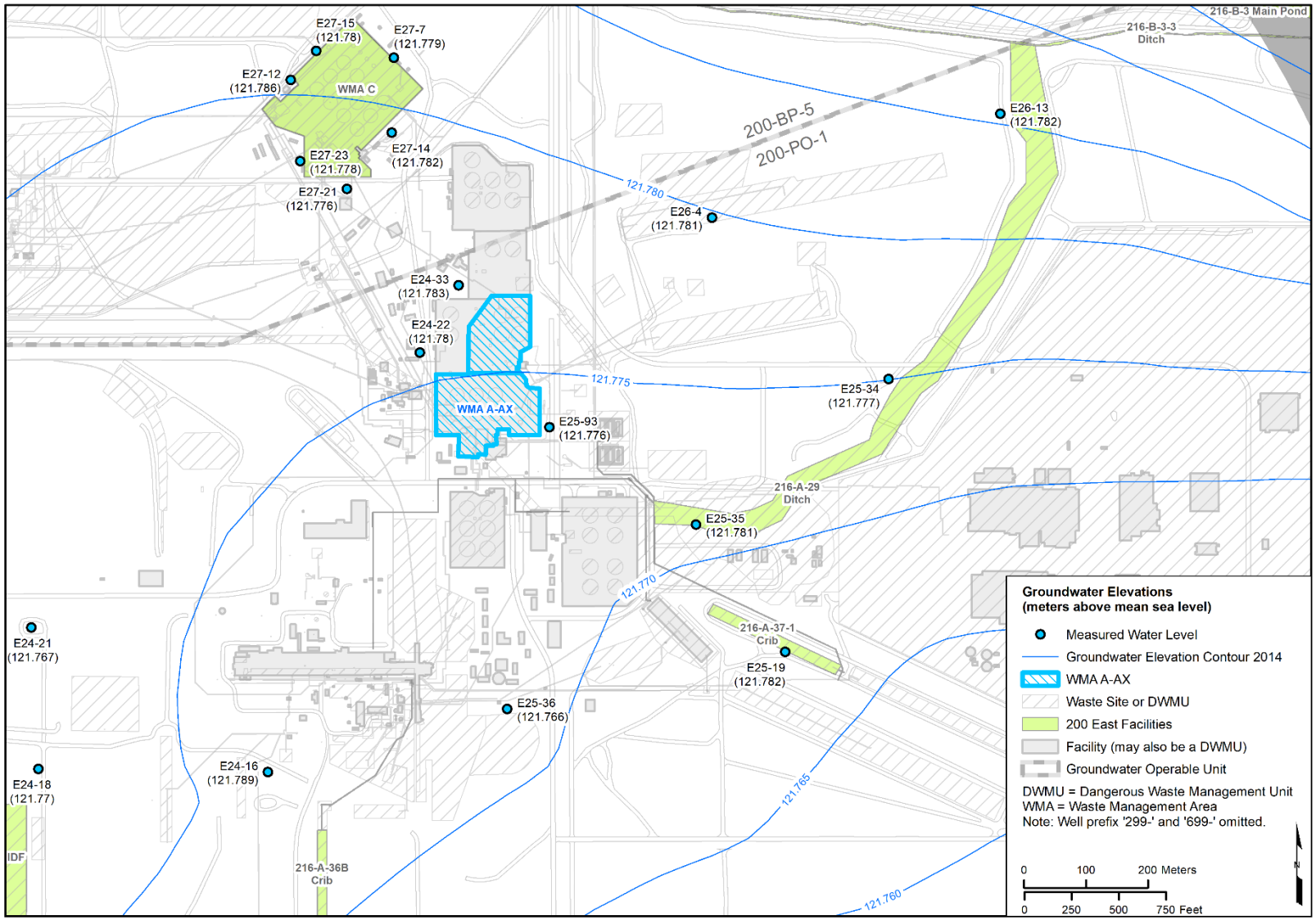

Figure J-4. Water-Level Elevation Map for WMA A-AX, 2014

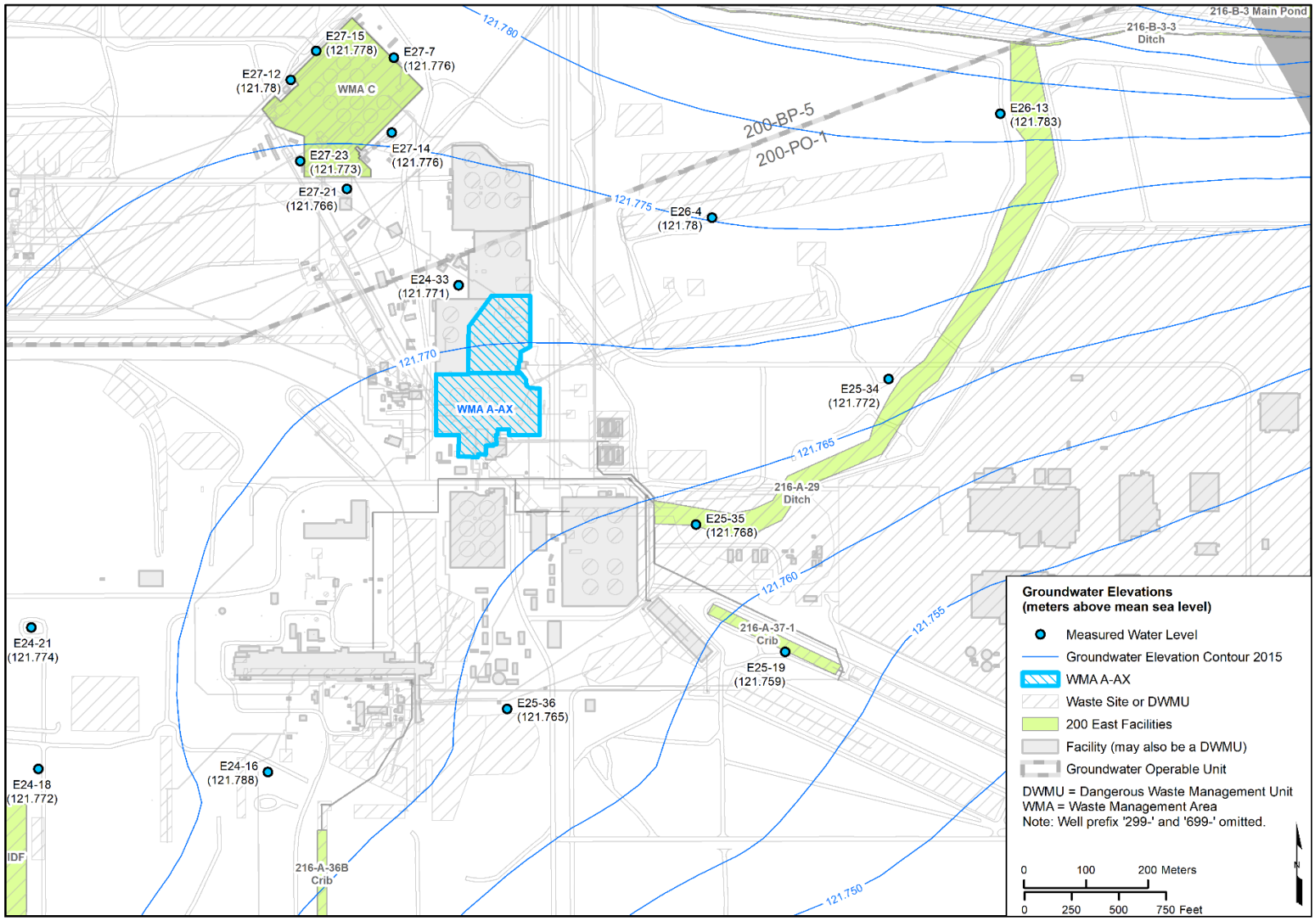

Figure J-5. Water-Level Elevation Map for WMA A-AX, 2015

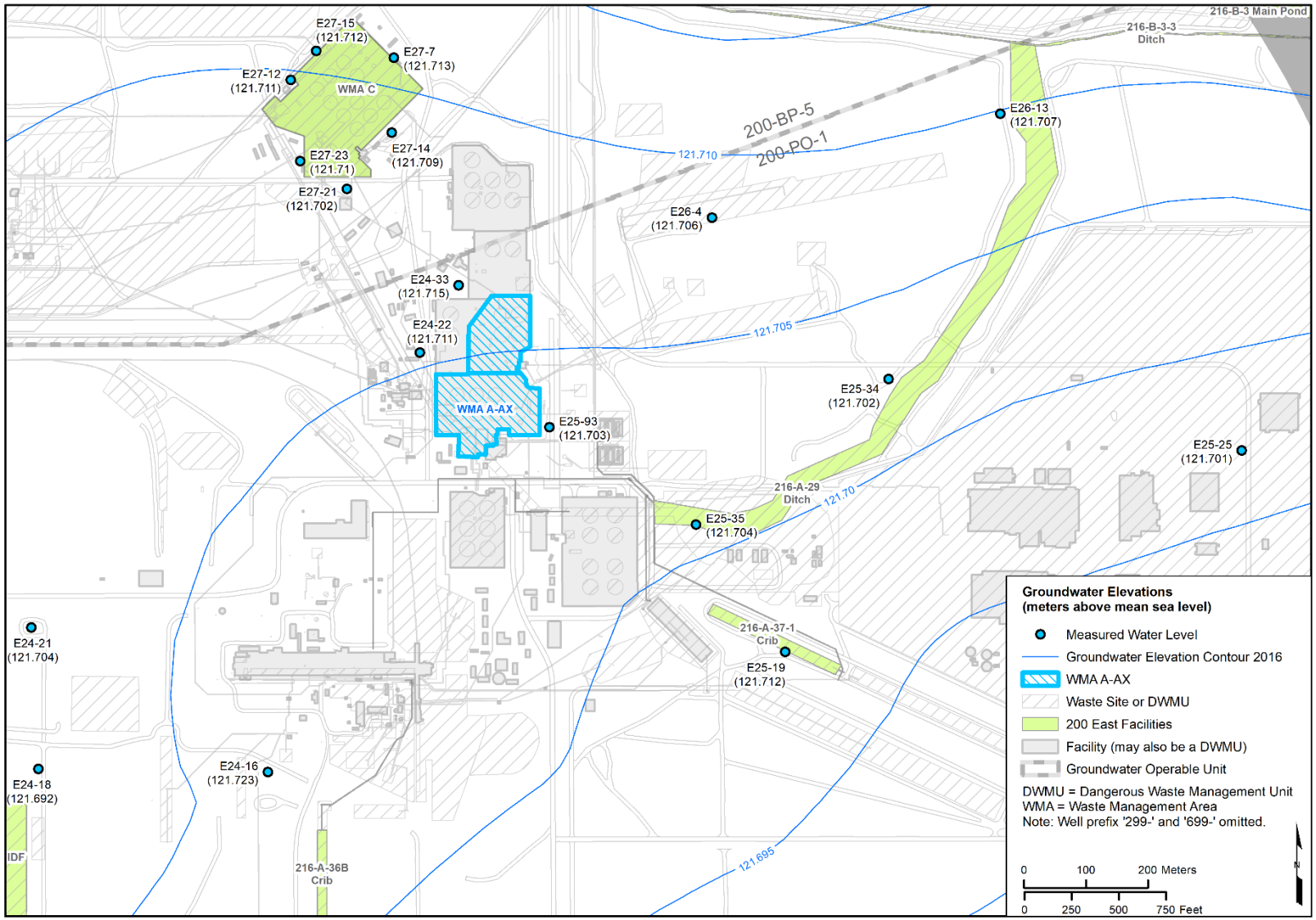

Figure J-6. Water-Level Elevation Map for WMA A-AX, 2016

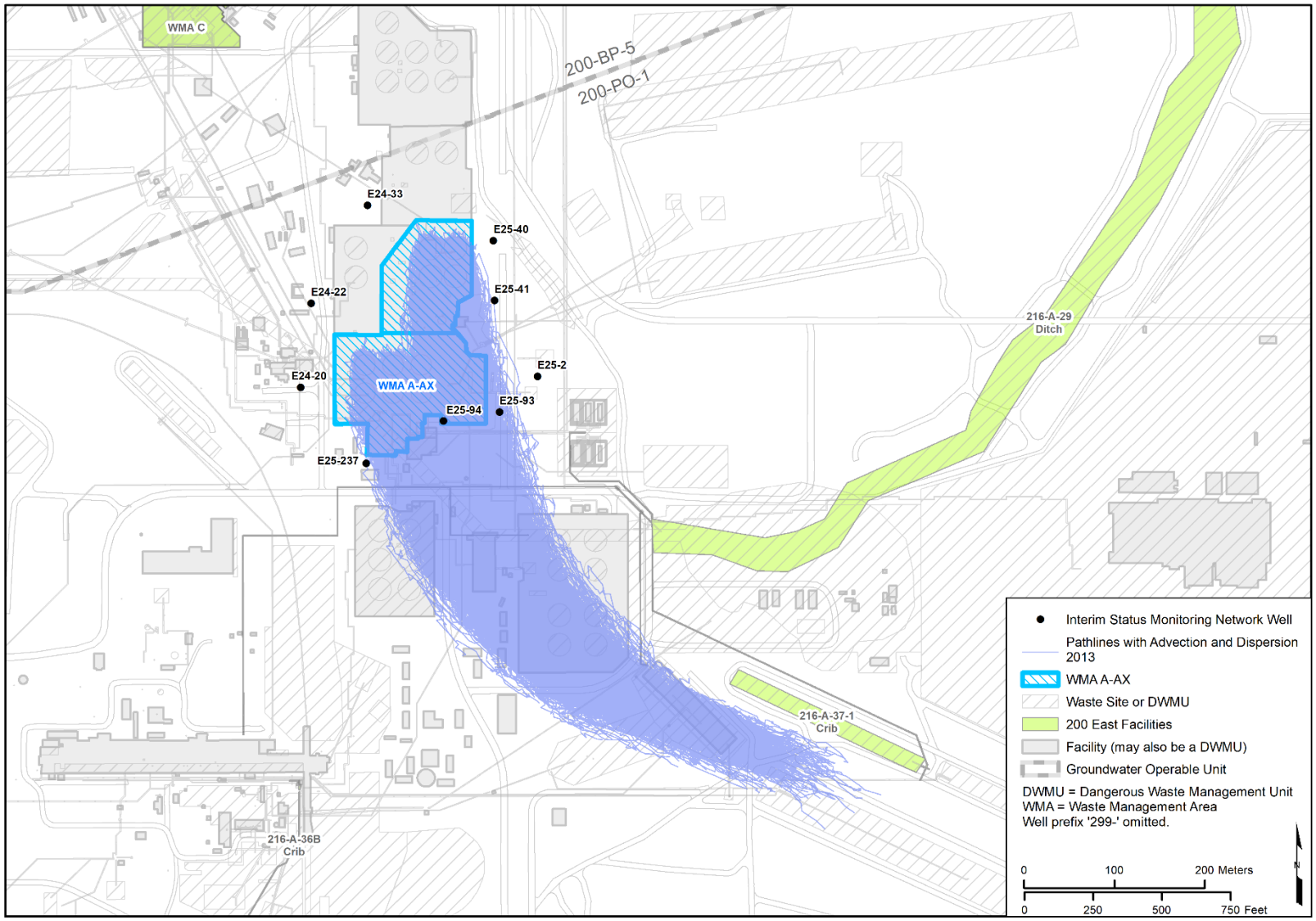

Figure J-7. Local-Scale Particle Pathlines, Advection and Dispersion – WMA A-AX, 2013

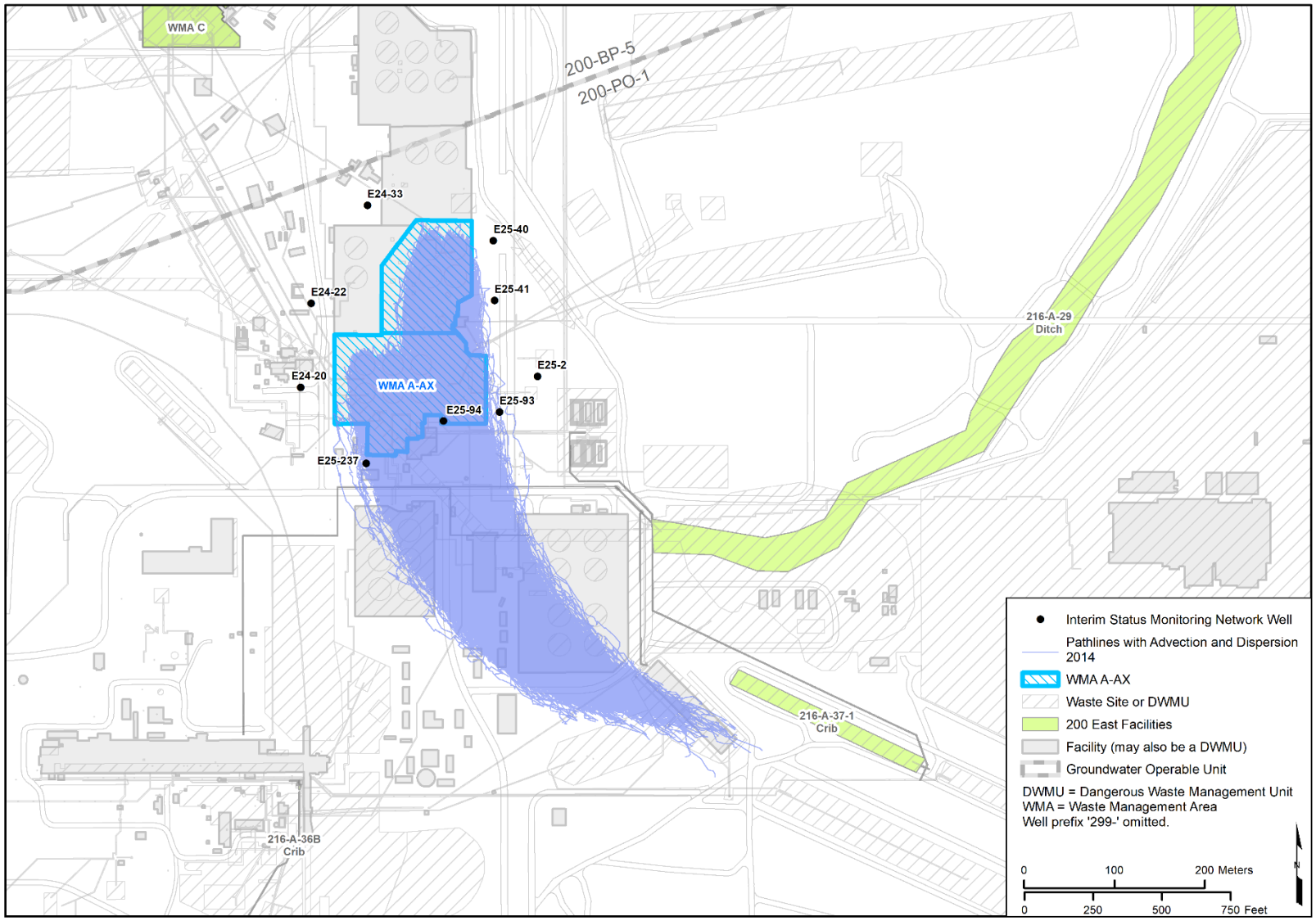

Figure J-8. Local-Scale Particle Pathlines, Advection and Dispersion – WMA A-AX, 2014

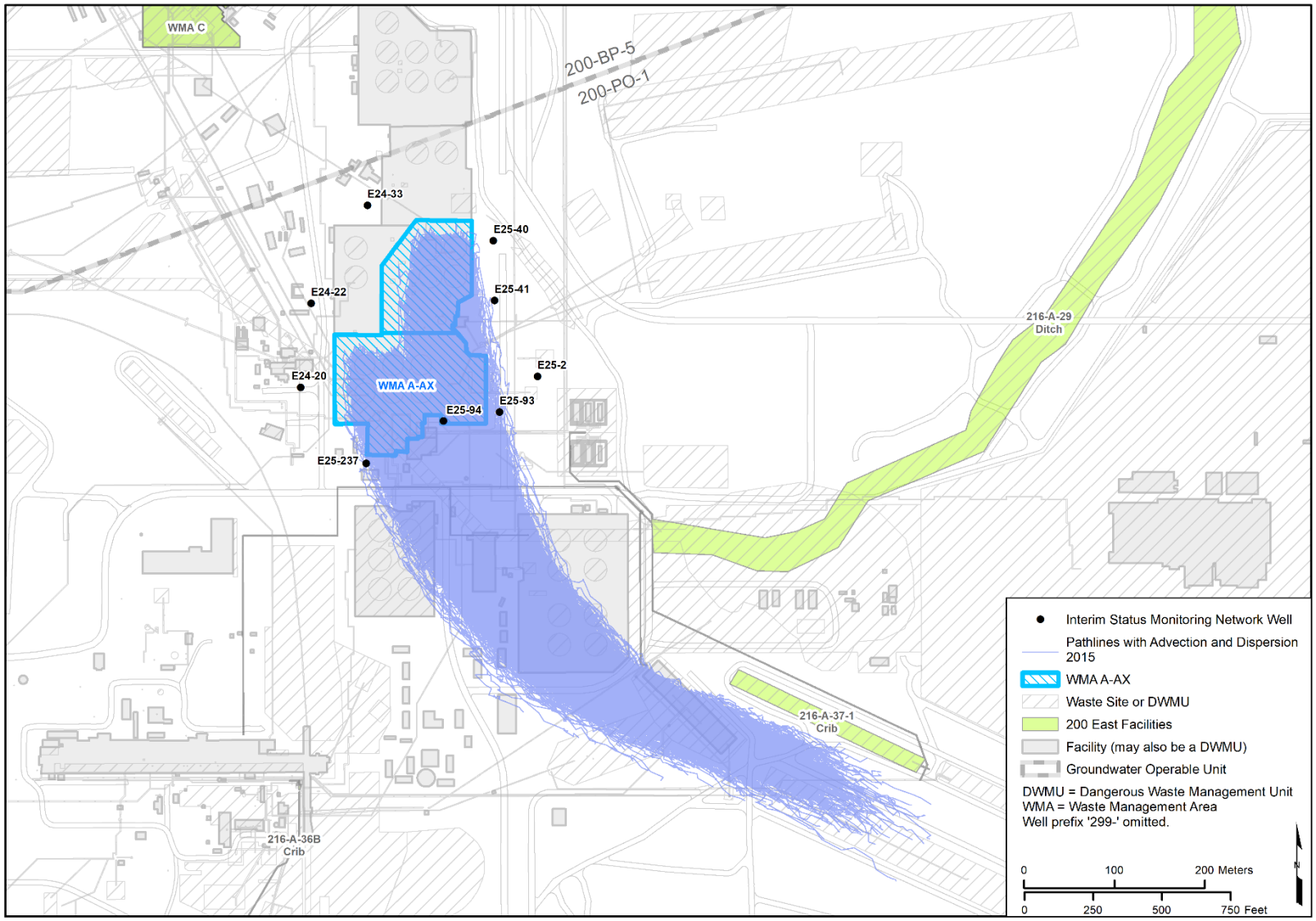

Figure J-9. Local-Scale Particle Pathlines, Advection and Dispersion – WMA A-AX, 2015

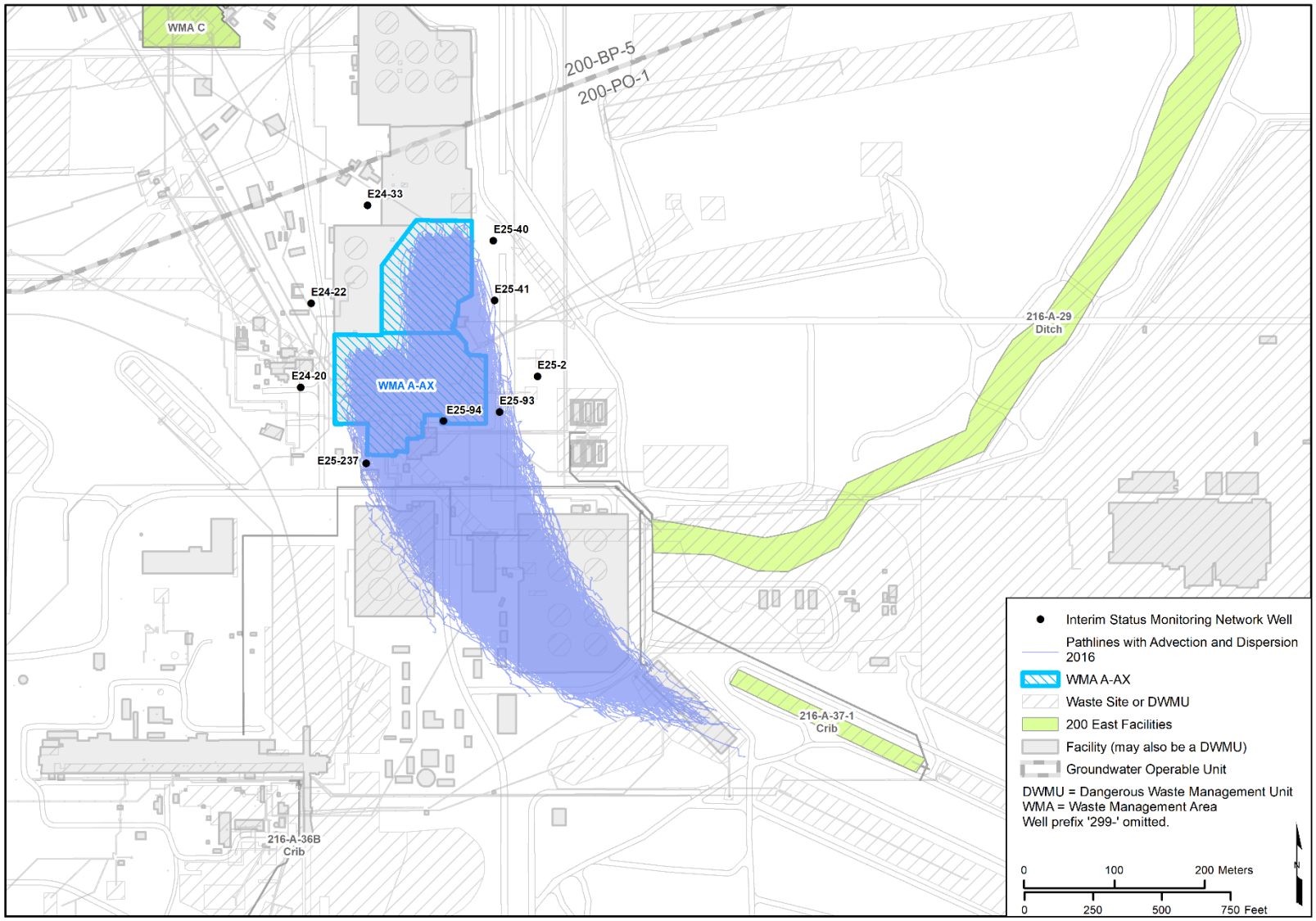

Figure J-10. Local-Scale Particle Pathlines, Advection and Dispersion – WMA A-AX, 2016

J3.3 Particle Counts

To compare the relative timing and density of the particles that pass by each monitoring well location, particle counts were calculated as described in Section 6.3 of the main text of this ECF. The particle counts were tabulated, particle breakthrough curves were created, and particle count maps were generated. While the particles were run for 500 days, the particle count tables are truncated to 403 days by which time the particles had passed the vicinity of the wells.

J3.3.1 Relative Particle Counts at Interim Status Groundwater Monitoring Wells

Tables J-1 through J-4 present the computed particle counts over time, binned into periods of 31 days, for each of the downgradient monitoring wells. Particle count tables are not included for downgradient well 299-E25-2 because no particles passed through the vicinity of the well under the simulated flow conditions. The tables present four entries (one for each year) for each well. At the bottom of the column for each mapped event is the total number of particles that passed through the vicinity of the well, regardless of time, and the average of the totals for the four mapped years rounded to the nearest integer. Each table provides an indication of the relative timing of the expected detections at each well and the relative potential that each well would detect a release at the facility for the flow conditions calculated for CYs 2013, 2014, 2015, and 2016.

Table J-1. Particle Density (Count) Monitoring Well 299-E25-41

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
31	37	14	17	29	
62	0	3	1	5	
93	0	0	0	0	
124	0	0	0	0	
155	0	0	0	0	
186	0	0	0	0	
217	0	0	0	0	
248	0	0	0	0	
279	0	0	0	0	
310	0	0	0	0	
341	0	0	0	0	
372	0	0	0	0	
403	0	0	0	0	Average
Total	37	17	18	34	**27**

Table J-2. Particle Density (Count) Monitoring Well 299-E25-93

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	**2014**	**2015**	**2016**	
31	1	0	0	0	
62	100	3	50	6	
93	159	10	93	93	
124	42	16	11	86	
155	5	6	0	37	
186	1	1	0	8	
217	0	1	1	2	
248	0	0	0	0	
279	0	0	0	0	
310	0	0	0	0	
341	0	0	0	0	
372	0	0	0	0	
403	0	0	0	0	Average
Total	308	37	155	232	**183**

Table J-3. Particle Density (Count) Monitoring Well 299-E25-94

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	**2014**	**2015**	**2016**	
31	531	369	542	394	
62	499	503	617	365	
93	204	576	221	391	
124	17	145	28	162	
155	4	13	4	30	
186	0	4	0	11	
217	0	0	0	2	
248	0	0	0	0	
279	0	0	0	0	
310	0	0	0	0	
341	0	0	0	0	
372	0	0	0	0	
403	0	0	0	0	Average
Total	1255	1610	1412	1355	**1408**

Table J-4. Particle Density (Count) Monitoring Well 299-E25-237

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
31	22	13	28	3	
62	67	123	77	46	
93	14	69	16	48	
124	8	19	4	21	
155	1	1	1	10	
186	0	0	0	2	
217	0	0	0	0	
248	0	0	0	0	
279	0	0	0	0	
310	0	0	0	0	
341	0	0	0	0	
372	0	0	0	0	
403	0	0	0	0	Average
Total	112	225	126	130	**148**

The average values depicted at the base of each table can be used to assess the relative potential for each well to detect a release at the facility. These averages are summarized as follows:

- 299-E25-41 – Average = 27
- 299-E25-93 – Average = 183
- 299-E25-94 – Average = 1408
- 299-E25-237 – Average = 148

J3.3.2 Relative Arrival Times at Interim Status Groundwater Monitoring Wells

Figures J-11 through J-14 depict plots of particle counts over time (particle breakthrough curves) for each downgradient well location. The underlying data plotted in Figures J-11 through J-15 are the same as the data in Tables J-1 through J-5, but the time interval over which particles are summed is not necessarily the same. Particle breakthrough curves show the relative timing and particle density for the arrival, peak, and decline in particle counts at each interim status monitoring location resulting from the hypothetical instantaneous release at the facility. The plots depict the relative potential at each well for detecting a release from the facility that reaches the water table for the flow conditions calculated for CYs 2013, 2014, 2015, and 2016. There is one figure for each well, with four lines shown on each plot (one for each year). Breakthrough curves are not included for downgradient well 299-E25-2 because no particles passed through the vicinity of the well under the simulated flow conditions.

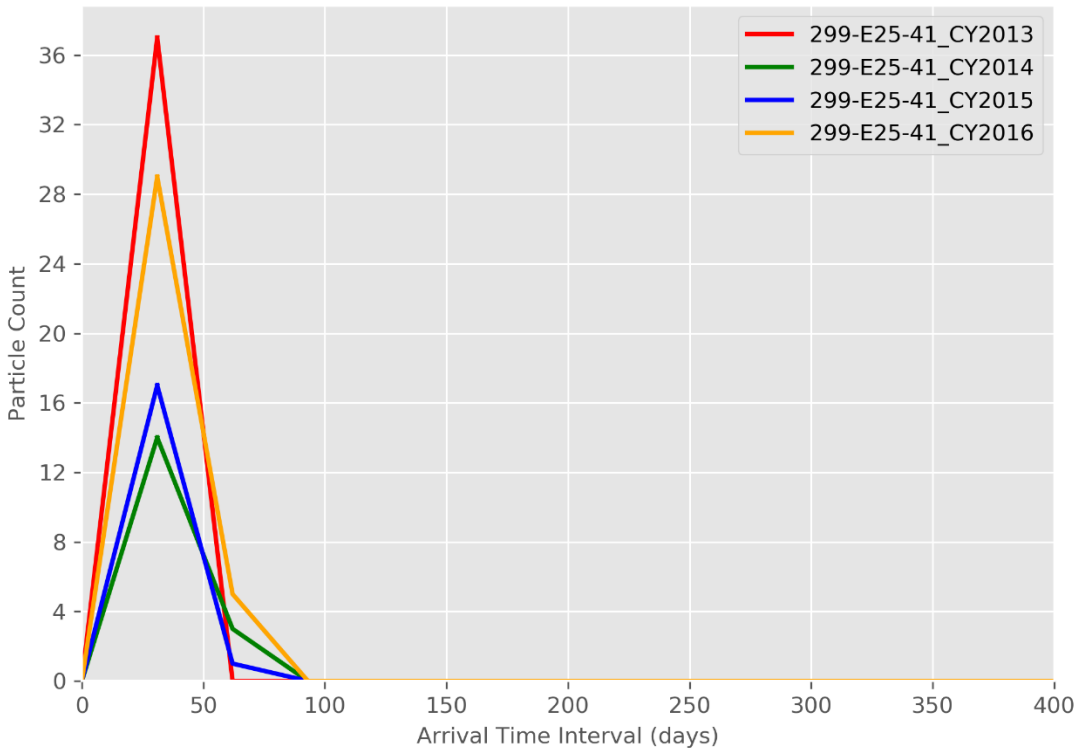

Figure J-11. Particle Breakthrough Curve at Monitoring Well 299-E25-41

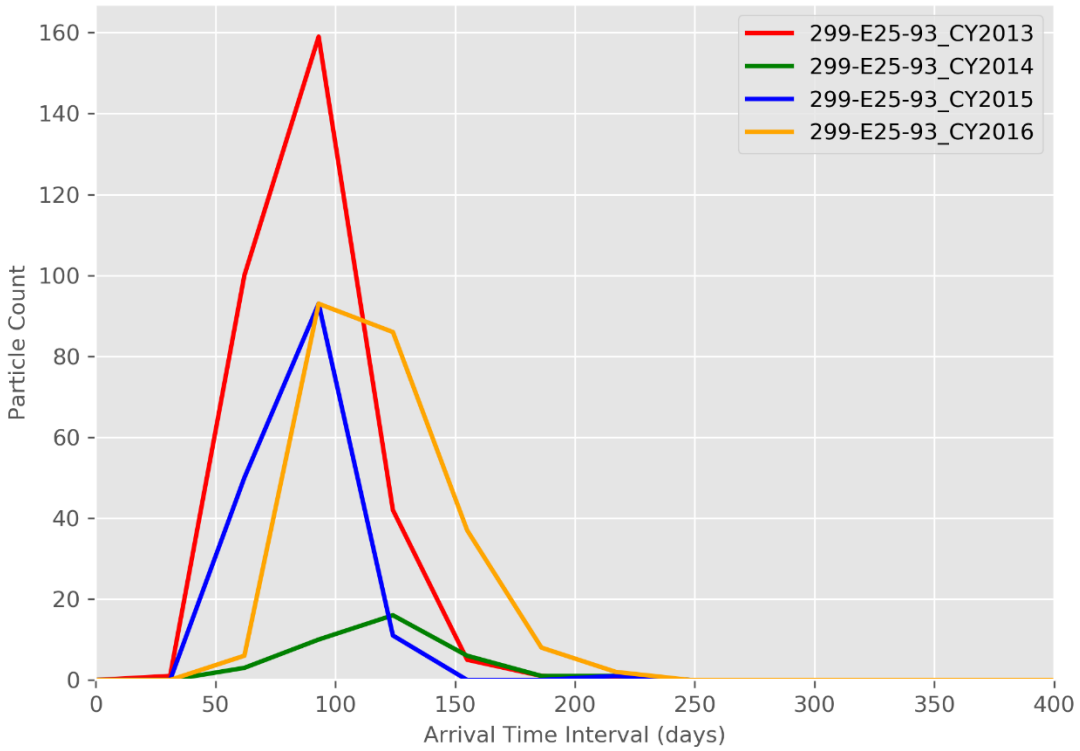

Figure J-12. Particle Breakthrough Curve at Monitoring Well 299-E25-93

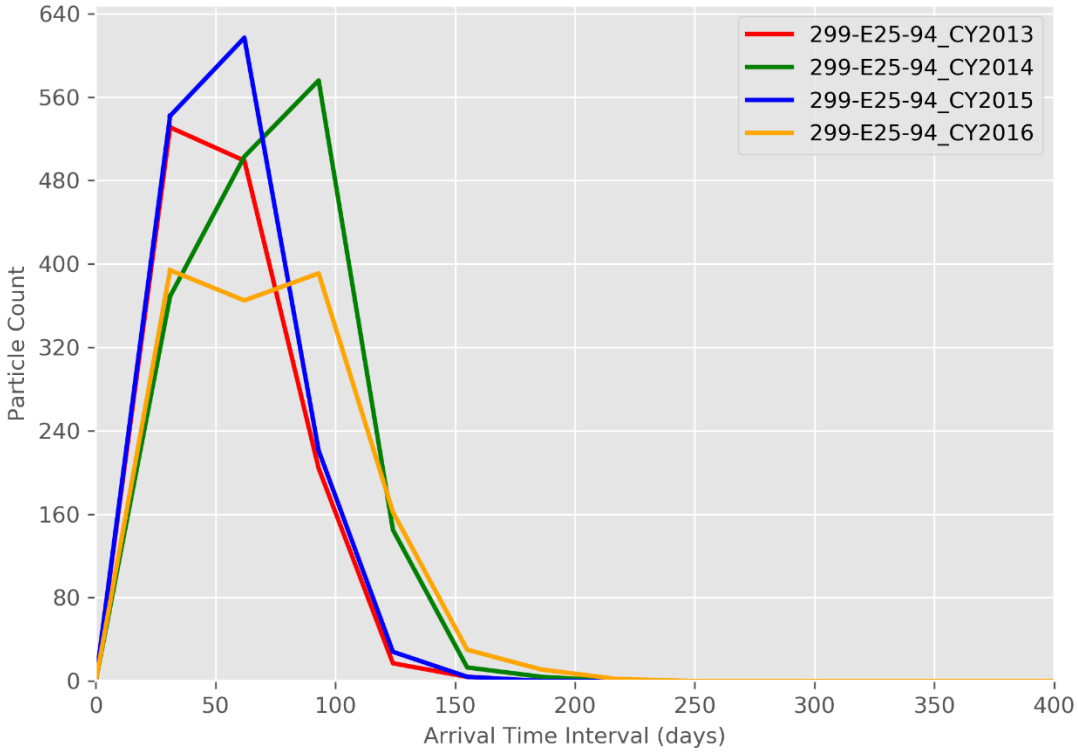

Figure J-13. Particle Breakthrough Curve at Monitoring Well 299-E25-94

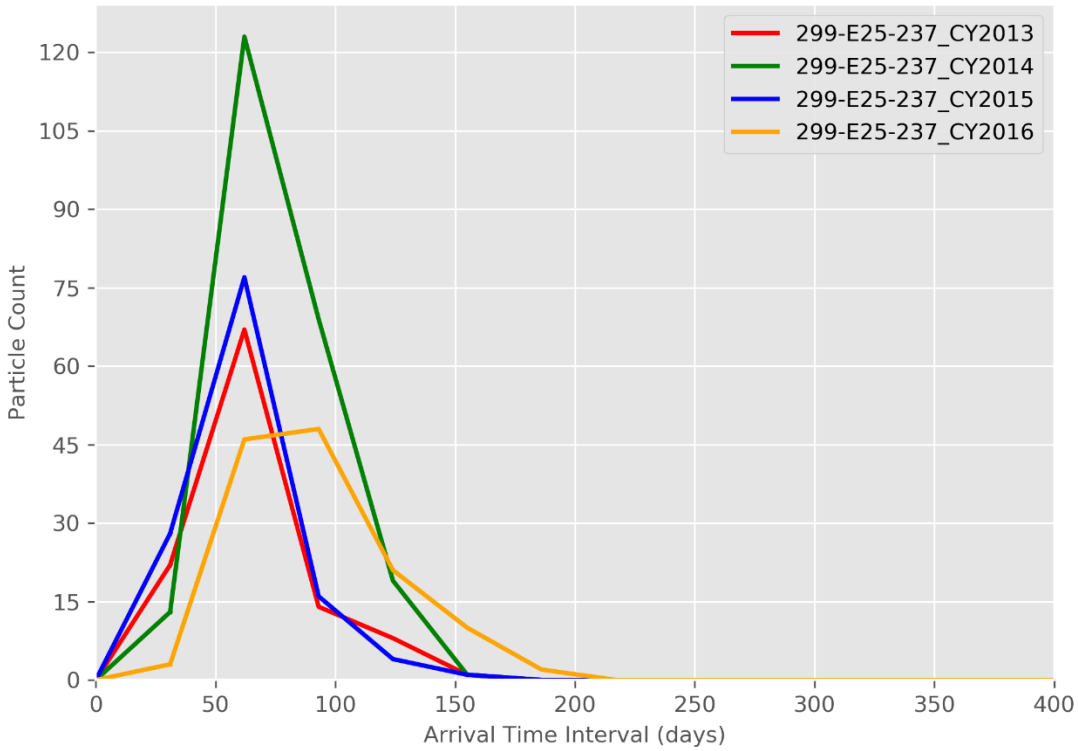

Figure J-14. Particle Breakthrough Curve at Monitoring Well 299-E25-237

J3.3.3 Particle Count Maps

Figures J-15 through J-18 depict the particle count maps developed based on the instantaneous release of a large number of particles at the facility. The particle count maps depict areas of relatively higher and lower potential impact from a release at the facility that reaches the water table for conditions represented by CYs 2013, 2014, 2015, and 2016. Figures J-15 through J-18 depict the particle density after 500 days of calculated travel, by which time it was determined that all particles would have arrived at or passed by the interim status groundwater monitoring wells (see entries in Tables J-1 through J-4).

The goal of well placement is for the well locations to span the range of particle pathline distribution as released from WMA A-AX. The particle count maps show that under the evaluated range of conditions, there are areas of high particle counts where there is no corresponding monitoring well. In addition, due to its age, well 299-E25-2 is not compliant with WAC 173-160, “Minimum Standards for Construction and Maintenance of Wells,” but a new well in a location near 299-E25-2 would be favorable for detection of releases. These factors indicate the need for additional monitoring wells. The location of the two proposed wells (WMA_A-AX_PW-1 and WMA_A-AX_PW-2) are shown in Figures J-15 through J-18.

J3.4 Proposed Monitoring Wells

The locations of the proposed monitoring wells are shown in Figures J-15 through J-18. The particle counts tabulated for these locations (Tables J-5 and J-6) indicate the relative timing of expected detections at the wells and the relative potential of the wells for detecting a release at the facility. The particle breakthrough curves (Figures J-19 and J-20) show the relative timing and particle density at the proposed monitoring well locations for the arrival, peak, and decline in particle counts resulting from the hypothetical instantaneous release to the water table beneath the facility.

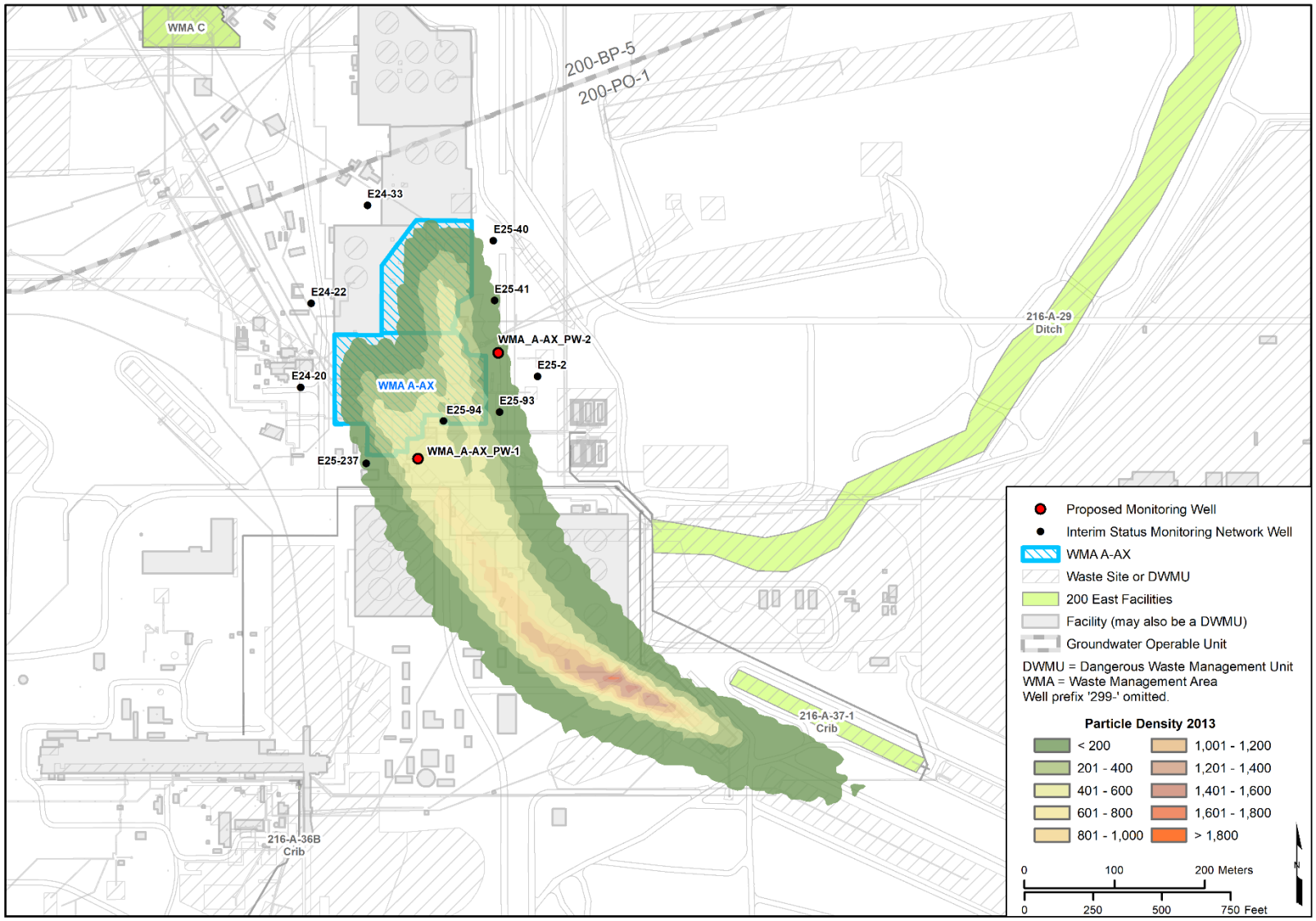

Figure J-15. Particle Count Map – WMA A-AX, 2013

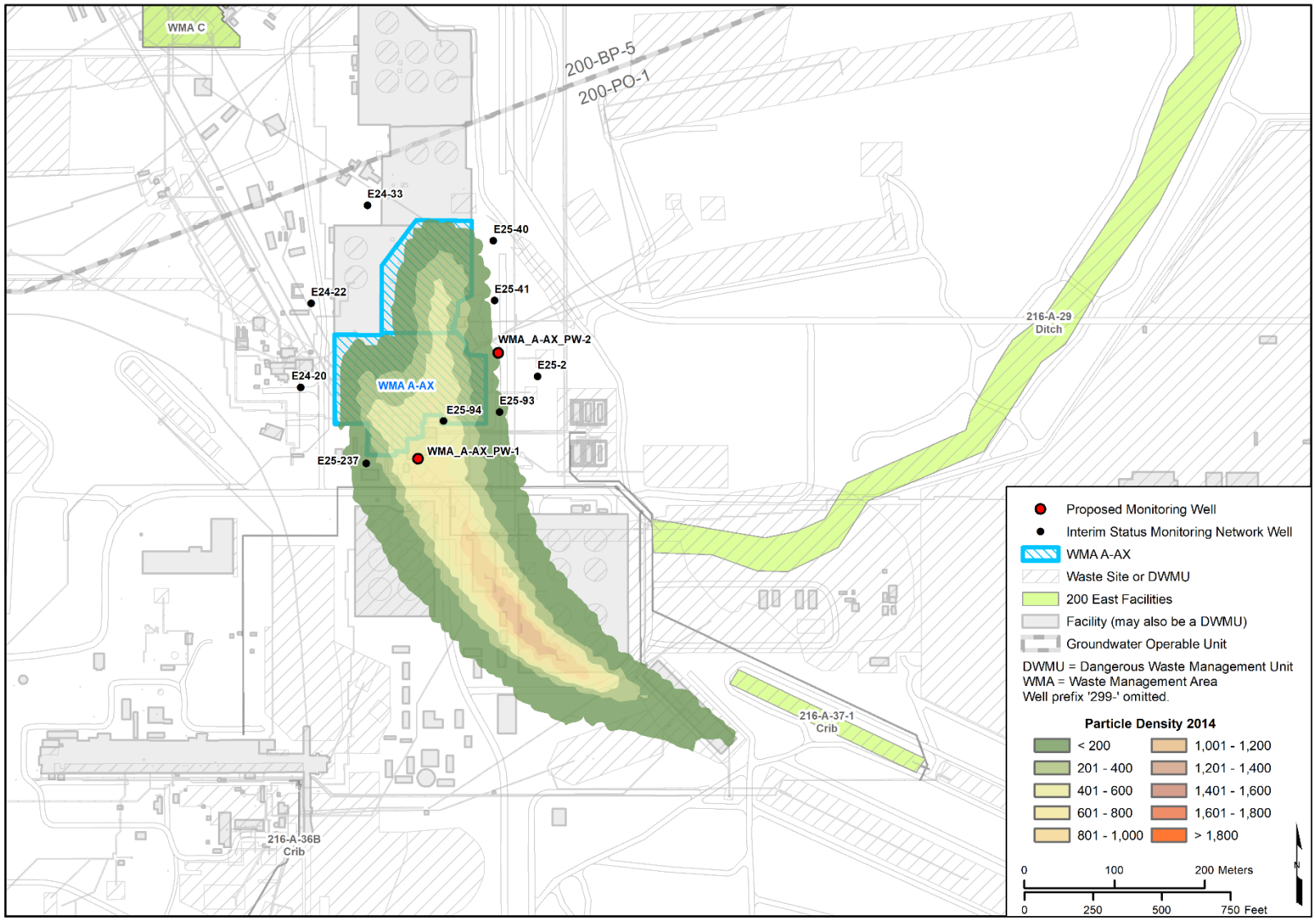

Figure J-16. Particle Count Map – WMA A-AX, 2014

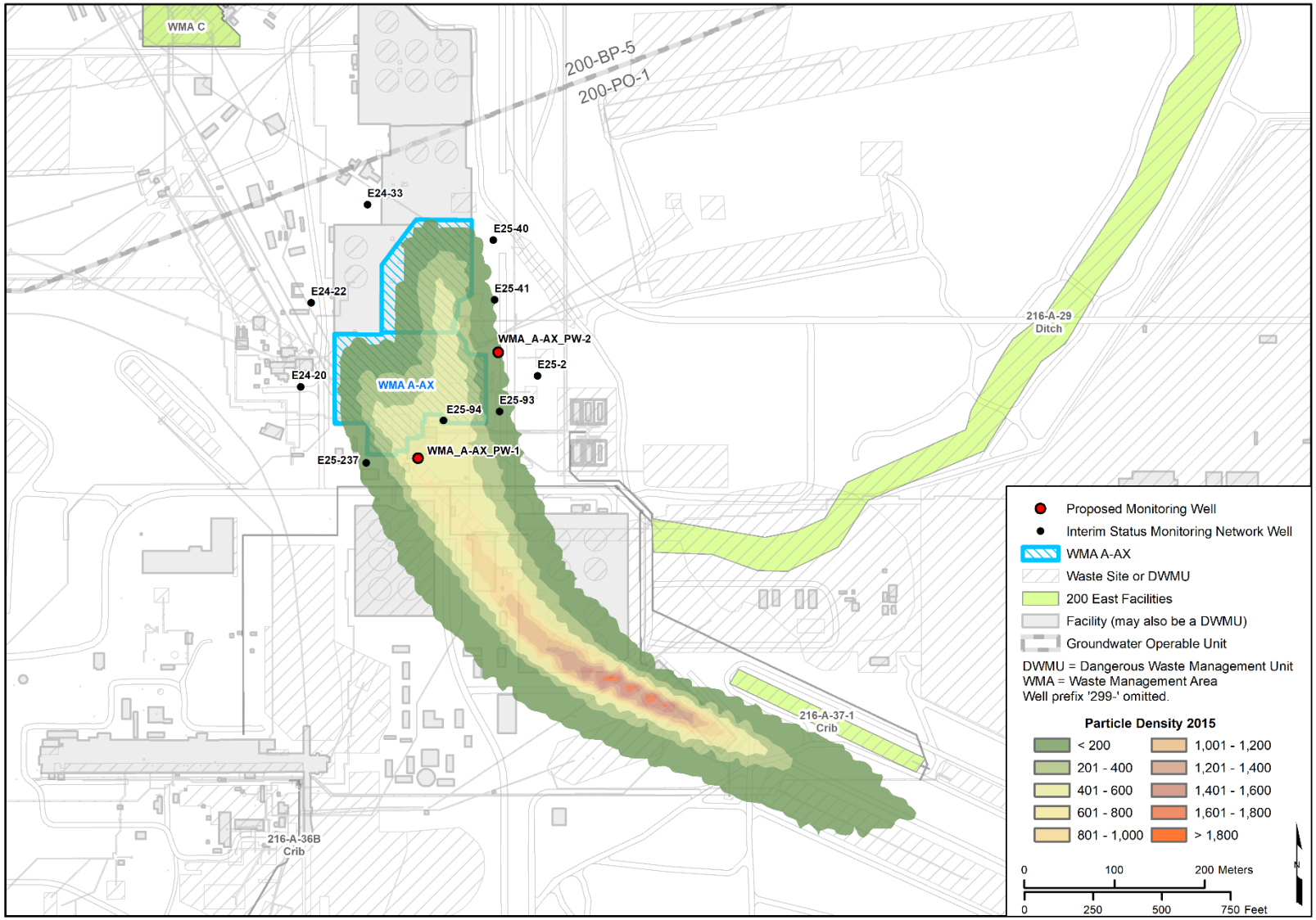

Figure J-17. Particle Count Map – WMA A-AX, 2015

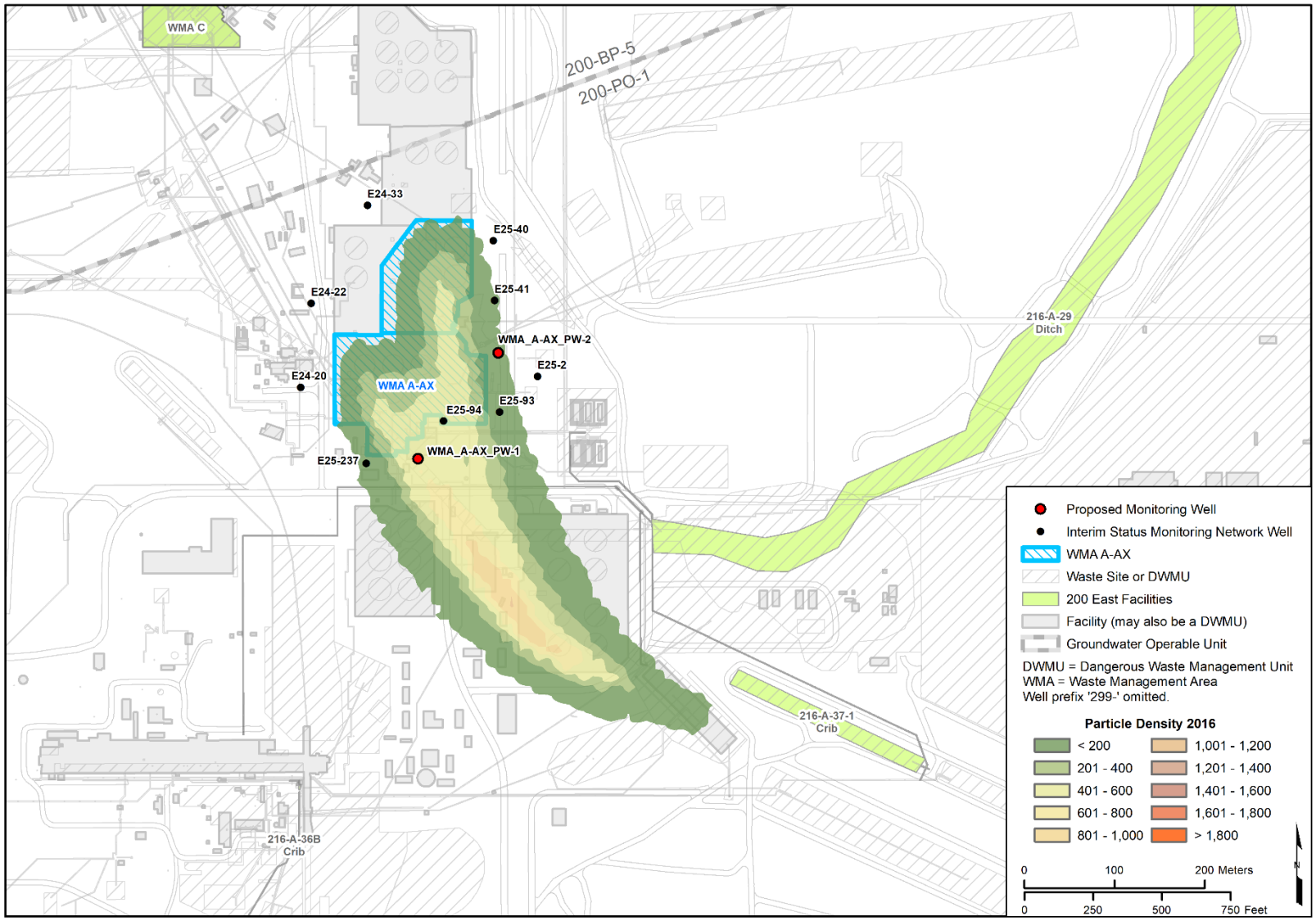

Figure J-18. Particle Count Map – WMA A-AX, 2016

Table J-5. Particle Density (Count) Proposed Monitoring Well WMA_A-AX_PW-1

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
31	328	146	410	102	
62	908	781	940	722	
93	306	516	283	494	
124	59	231	62	231	
155	10	88	7	57	
186	2	27	1	28	
217	0	8	0	6	
248	0	2	0	1	
279	0	0	0	0	
310	0	0	0	1	
341	0	0	0	0	
372	0	0	0	0	
403	0	0	0	0	Average
Total	1613	1799	1703	1642	**1689**

Table J-6. Particle Density (Count) Proposed Monitoring Well WMA_A-AX_PW-2

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
31	45	2	17	22	
62	41	11	19	55	
93	0	0	0	5	
124	0	0	0	0	
155	0	0	0	0	
186	0	0	0	0	
217	0	0	0	0	
248	0	0	0	0	
279	0	0	0	0	
310	0	0	0	0	
341	0	0	0	0	
372	0	0	0	0	
403	0	0	0	0	Average
Total	86	13	36	82	**54**

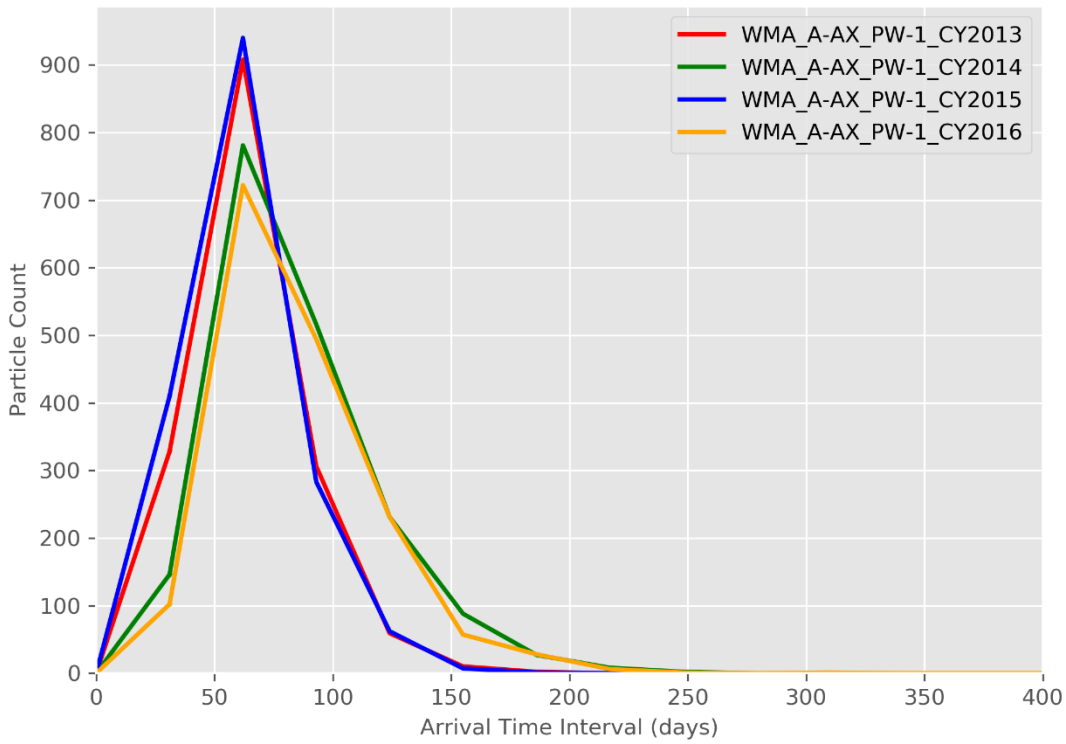

Figure J-19. Particle Breakthrough Curve at Monitoring Well WMA_A-AX_PW-1

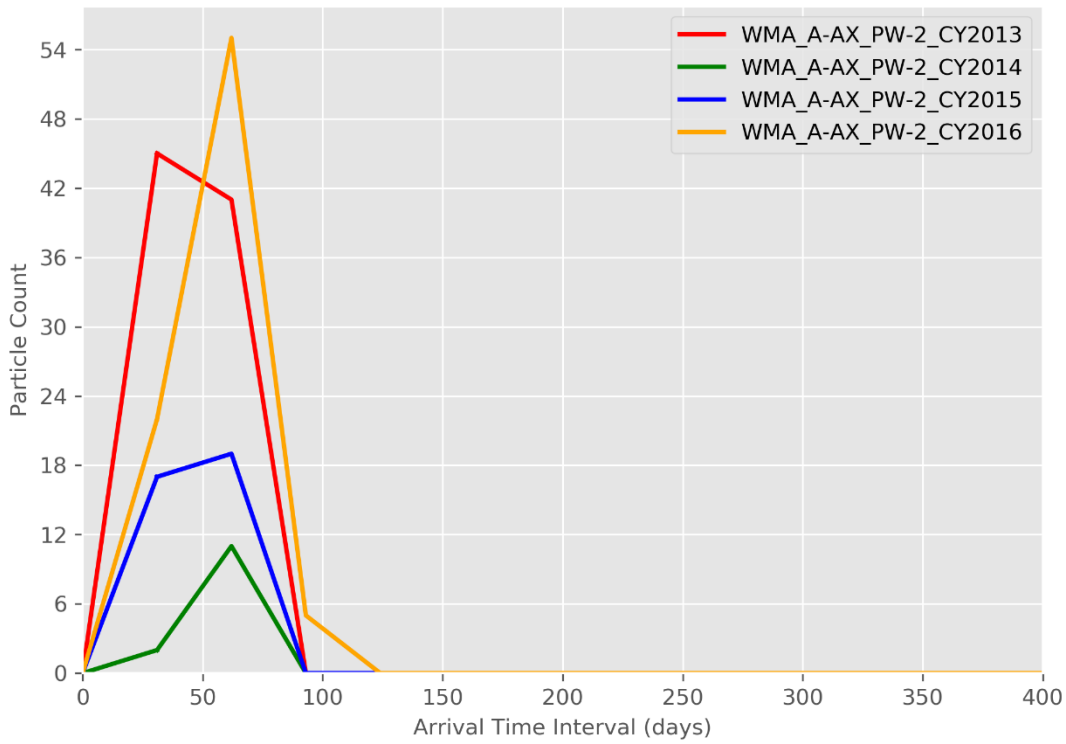

Figure J-20. Particle Breakthrough Curve at Monitoring Well WMA_A-AX_PW-2

J3.5 Analyses of Particle Pathlines for Each Area of WMA A-AX

Particle pathline maps shown in Section J3.2 depict an instantaneous release to the water table from the release locations in WMA A-AX. Particle tracking also was performed for smaller regions of the facility to evaluate well locations for detecting releases from various regions of WMA A-AX. This section contains the results of analyses performed to examine how releases from the various areas of WMA A-AX that reach the groundwater beneath those release areas relate to each individual monitoring well. A series of figures and tables are provided to illustrate the fate of releases originating from three different areas of the waste management area. For these analyses, the particle release points presented in Figure J-2 are grouped into one of five areas based on their spatial location. Those areas are depicted in Figure J-21. Figures J-22 through J-25 illustrate the particle pathlines originating from each of the areas for CYs 2013 through 2016.

Figures J-26 through J-31 illustrate the particle count time series for each existing and proposed monitoring well from CY 2013 through CY 2016. Each figure has four panels, each of which depicts the particle counts for one CY (2013 through 2016). Additionally, each panel shows a separate breakthrough curve for particles emanating from each area. For example, Figure J-26 depicts the particle counts at well WMA_A-AX_PW-1, which receives particles from areas 1 through 5 in 2014. In the figure, within the panel for 2014 (top row, right), the particle breakthrough curves from areas 1 through 5 are depicted with blue, red, purple, green, and yellow lines, respectively.

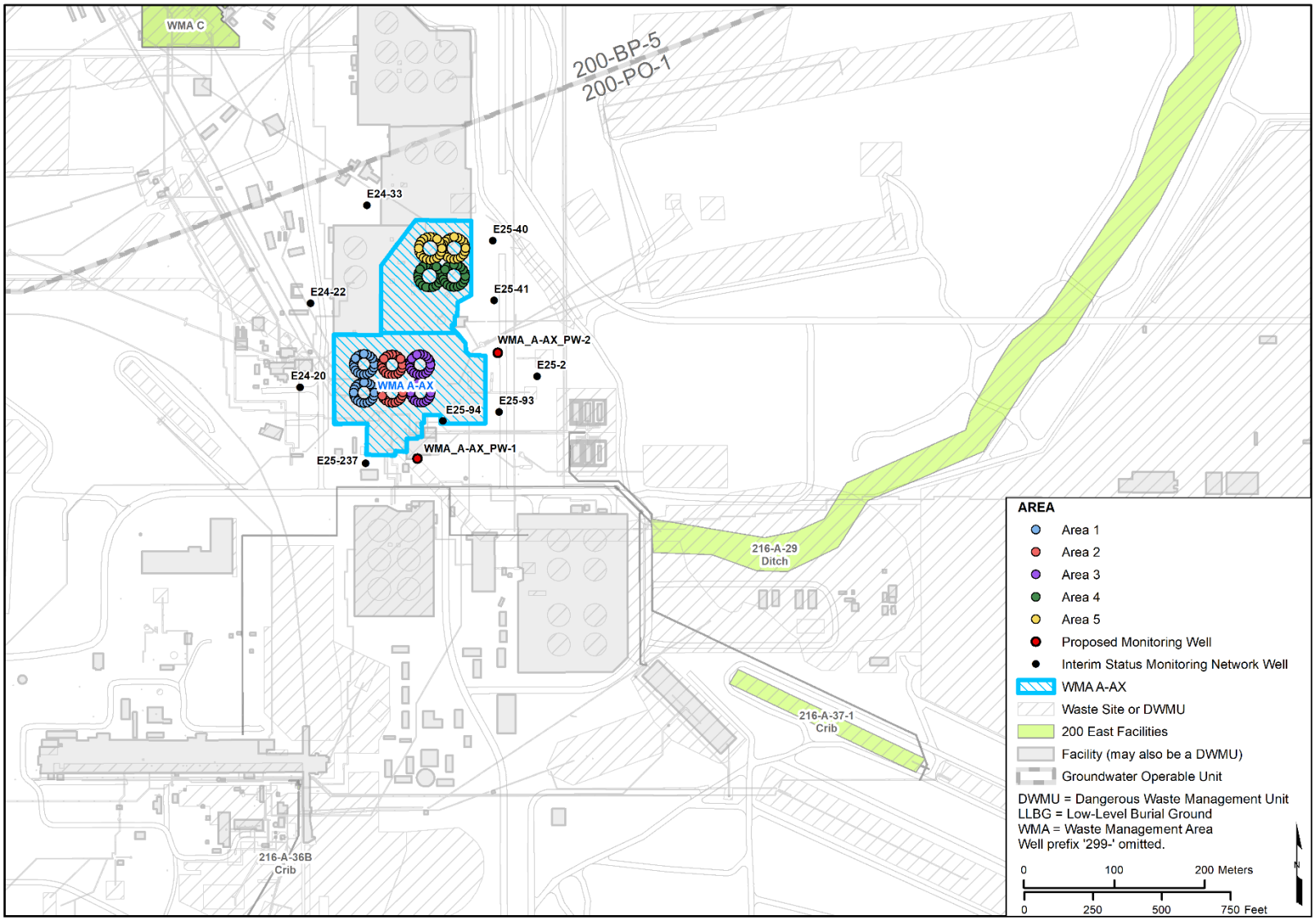

Figure J-21. Particle Release Locations and Areas of WMA A-AX

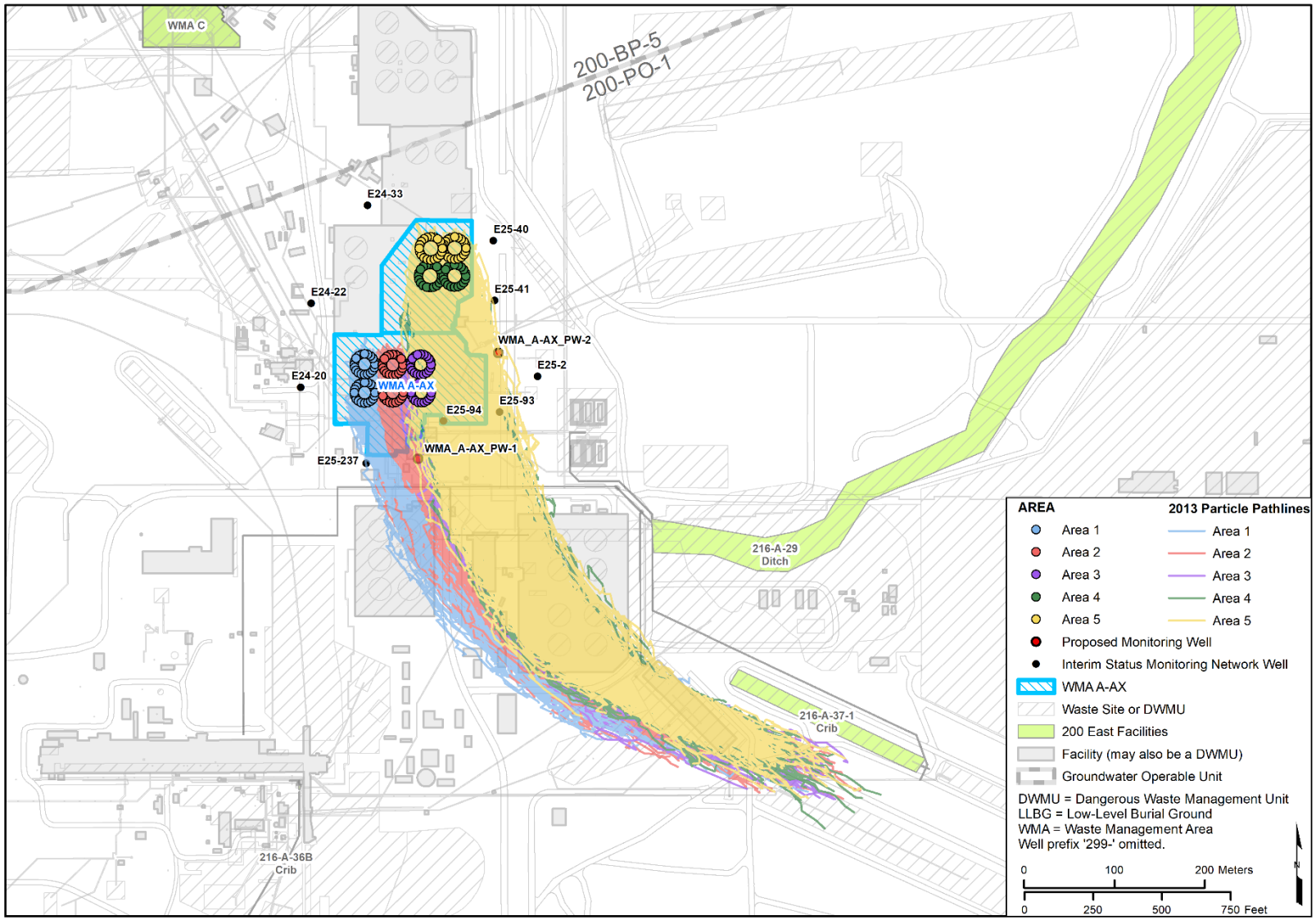

Figure J-22. CY 2013 Particle Pathlines per Area of WMA A-AX

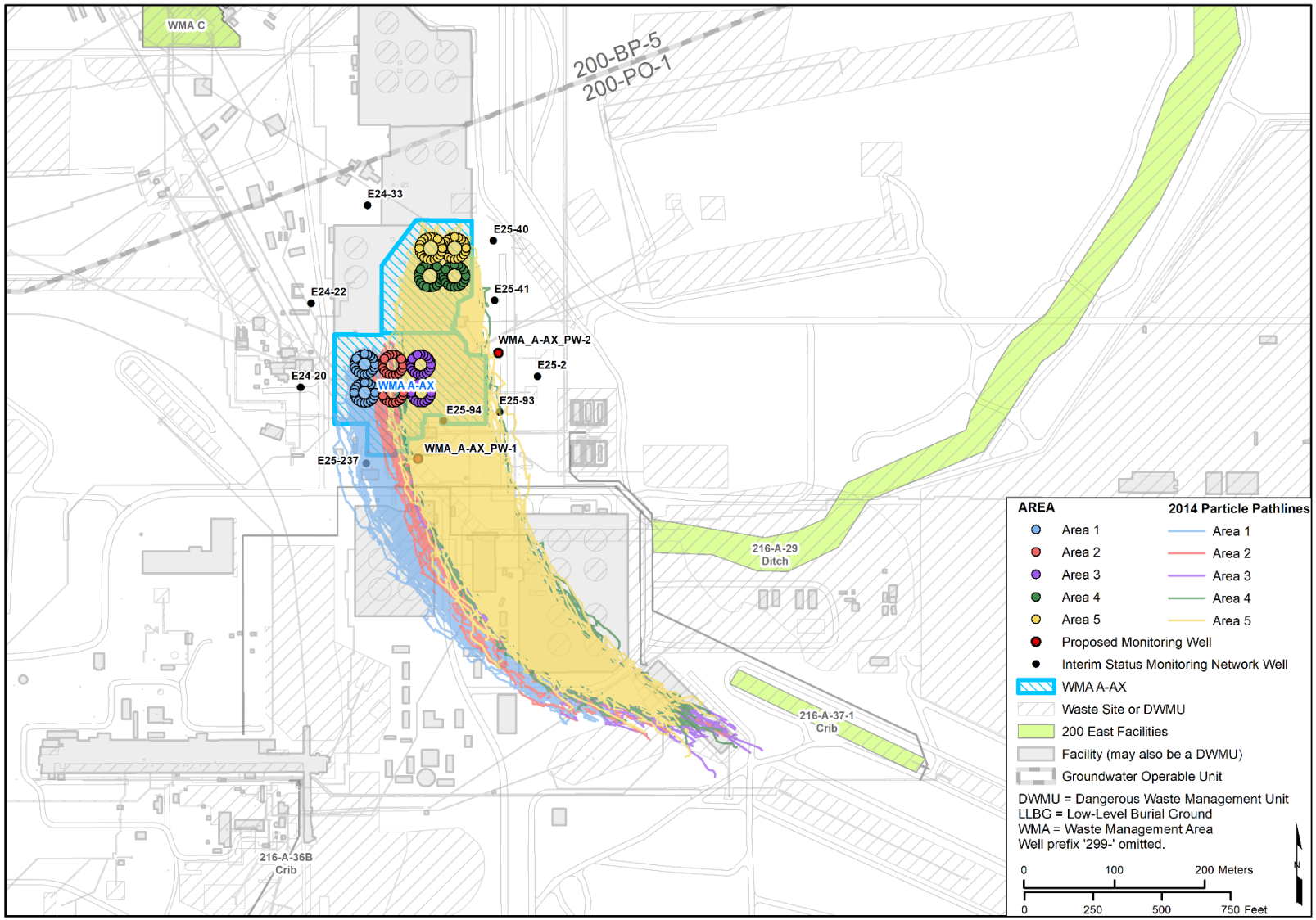

Figure J-23. CY 2014 Particle Pathlines per Area of WMA A-AX

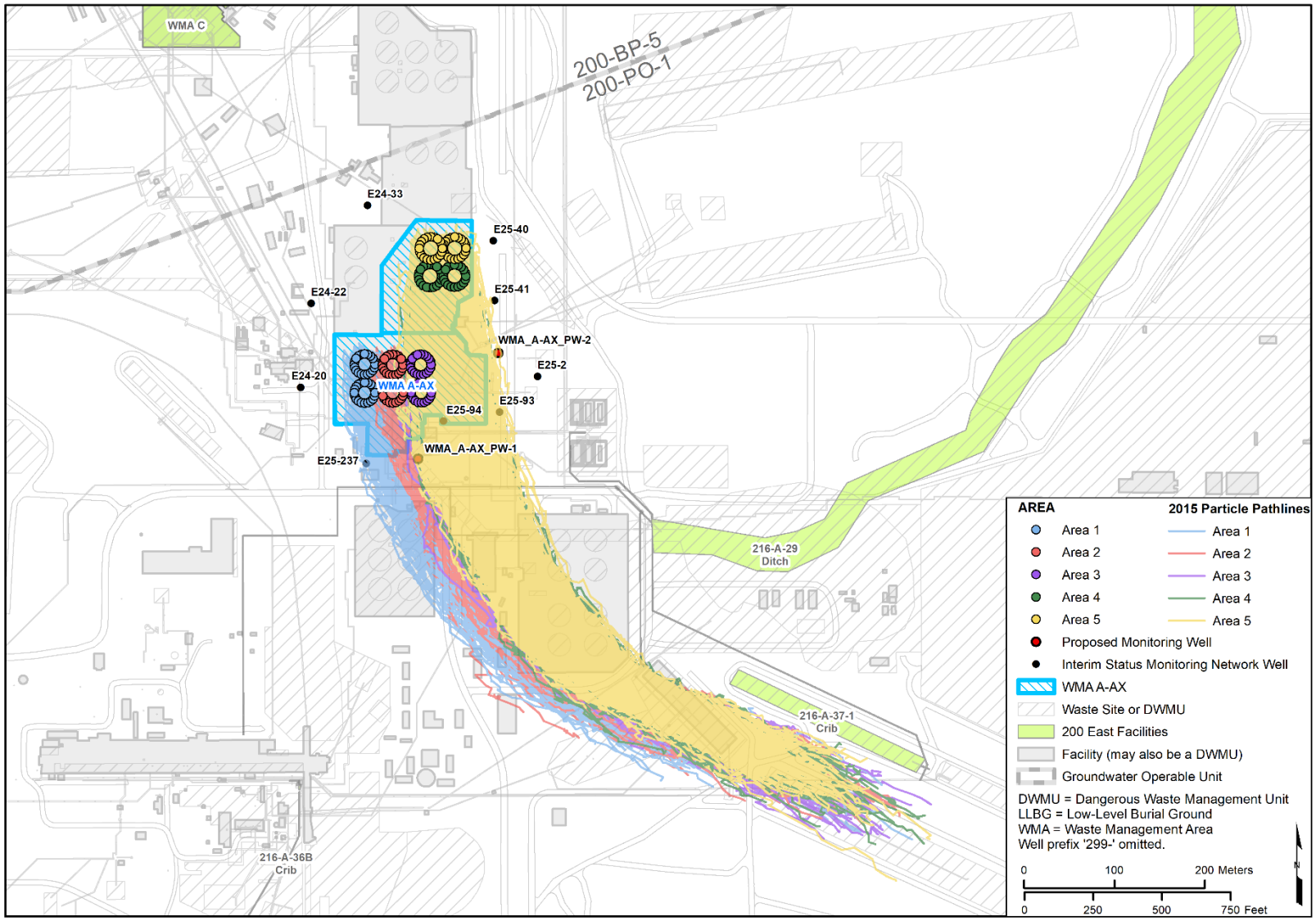

Figure J-24. CY 2015 Particle Pathlines per Area of WMA A-AX

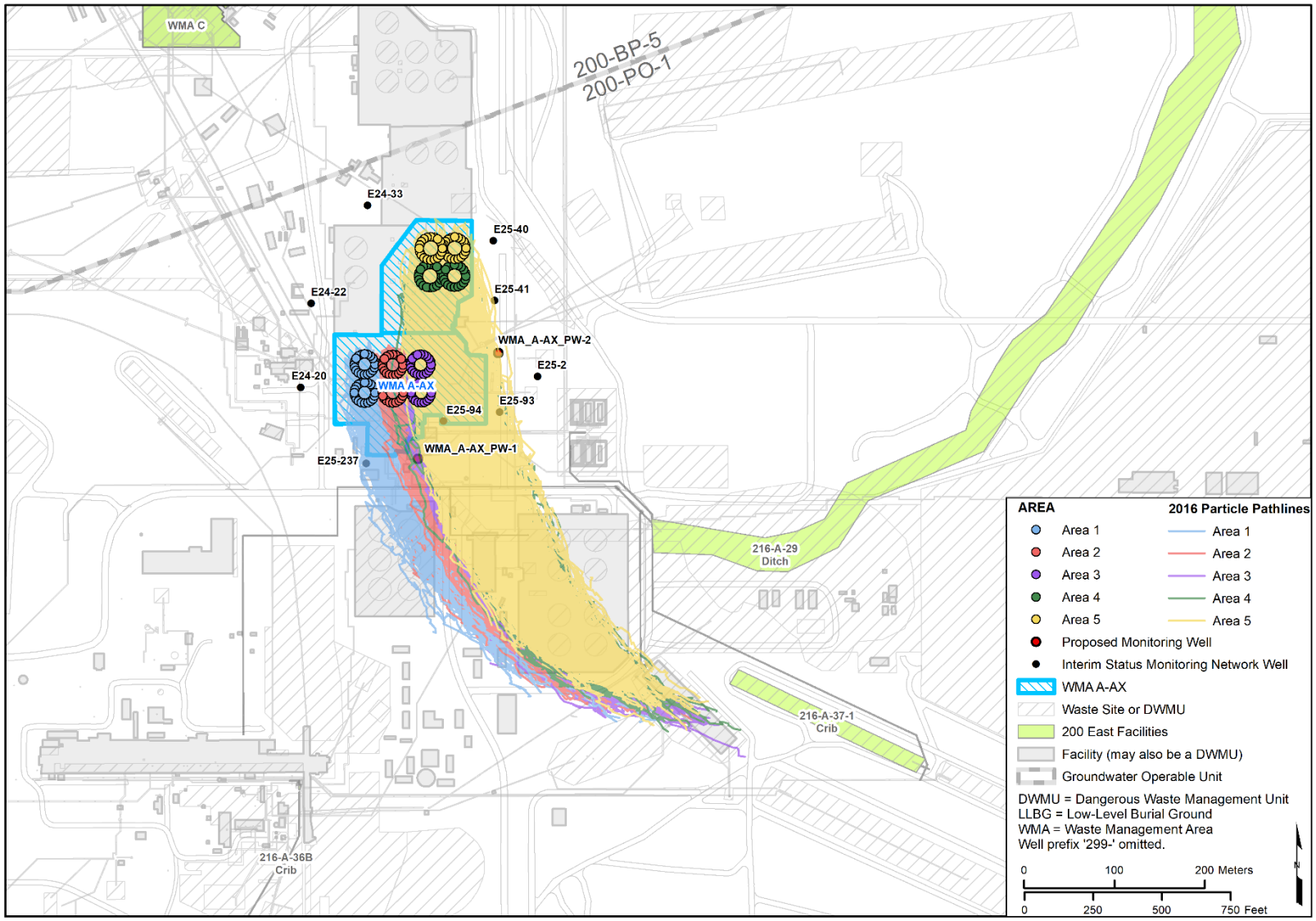

Figure J-25. CY 2016 Particle Pathlines per Area of WMA A-AX

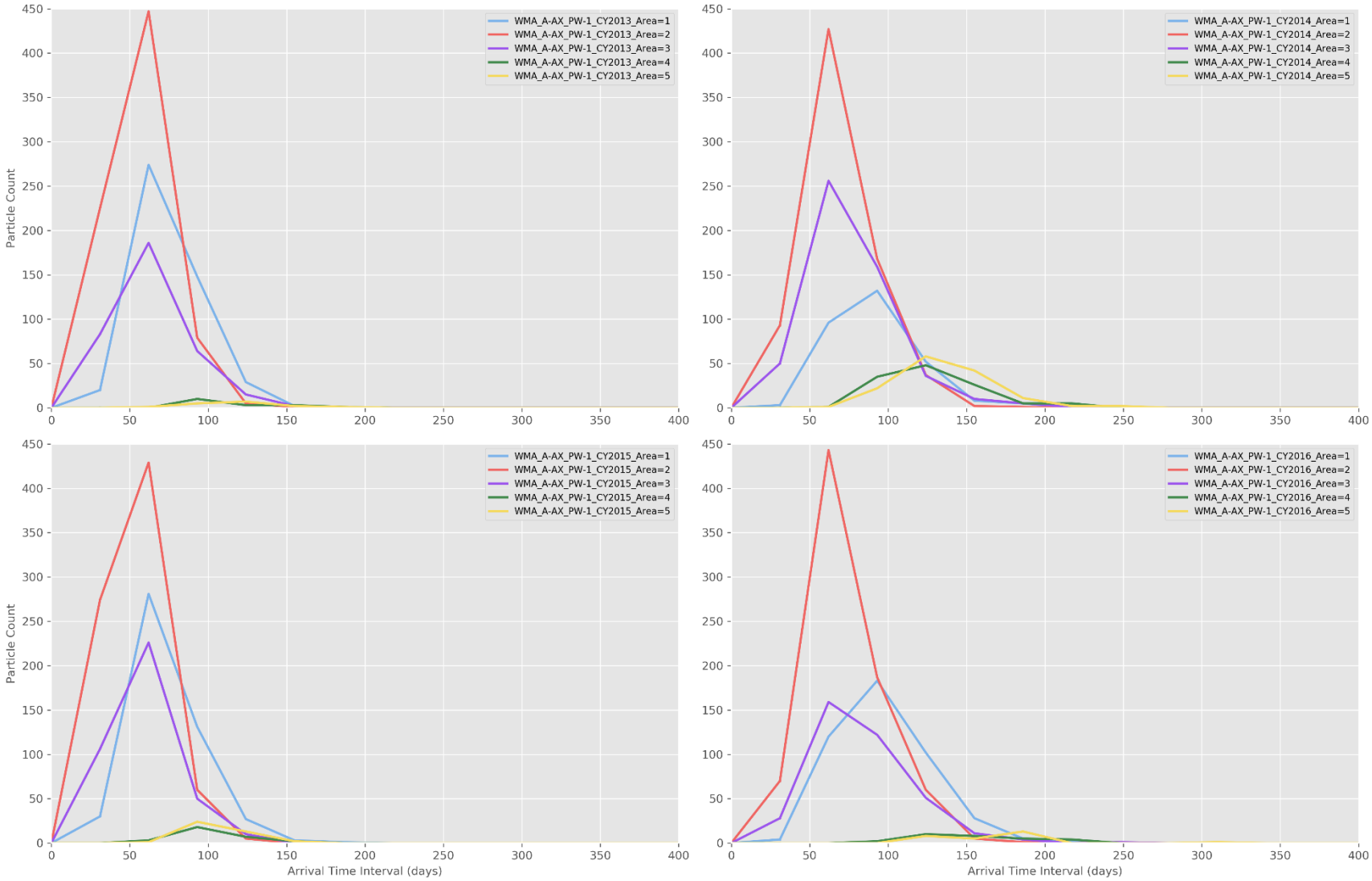

Figure J-26. Particle Breakthrough Curves per Area at Monitoring Well WMA_A-AX_PW-1

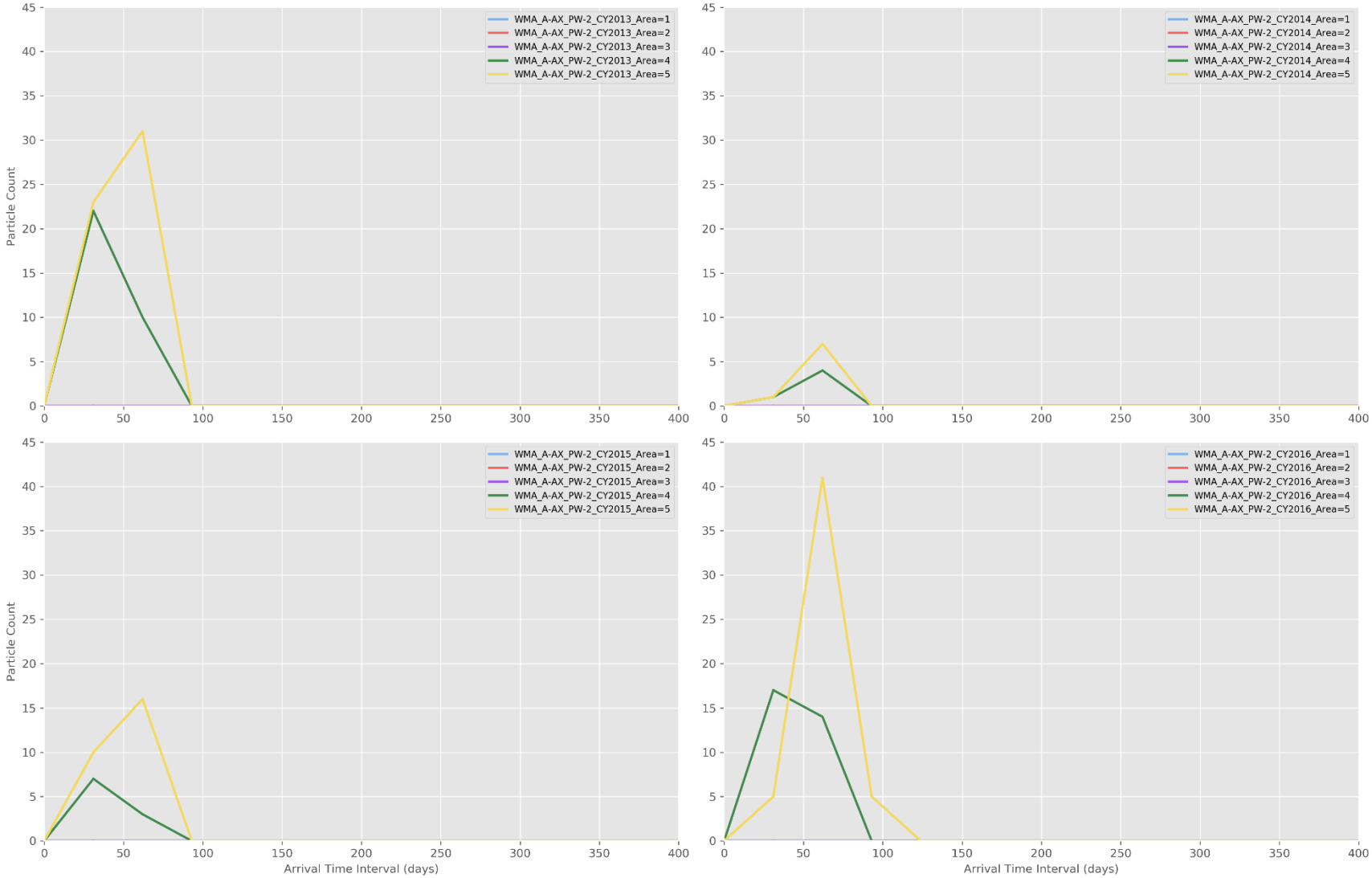

Figure J-27. Particle Breakthrough Curves per Area at Monitoring Well WMA_A-AX_PW-2

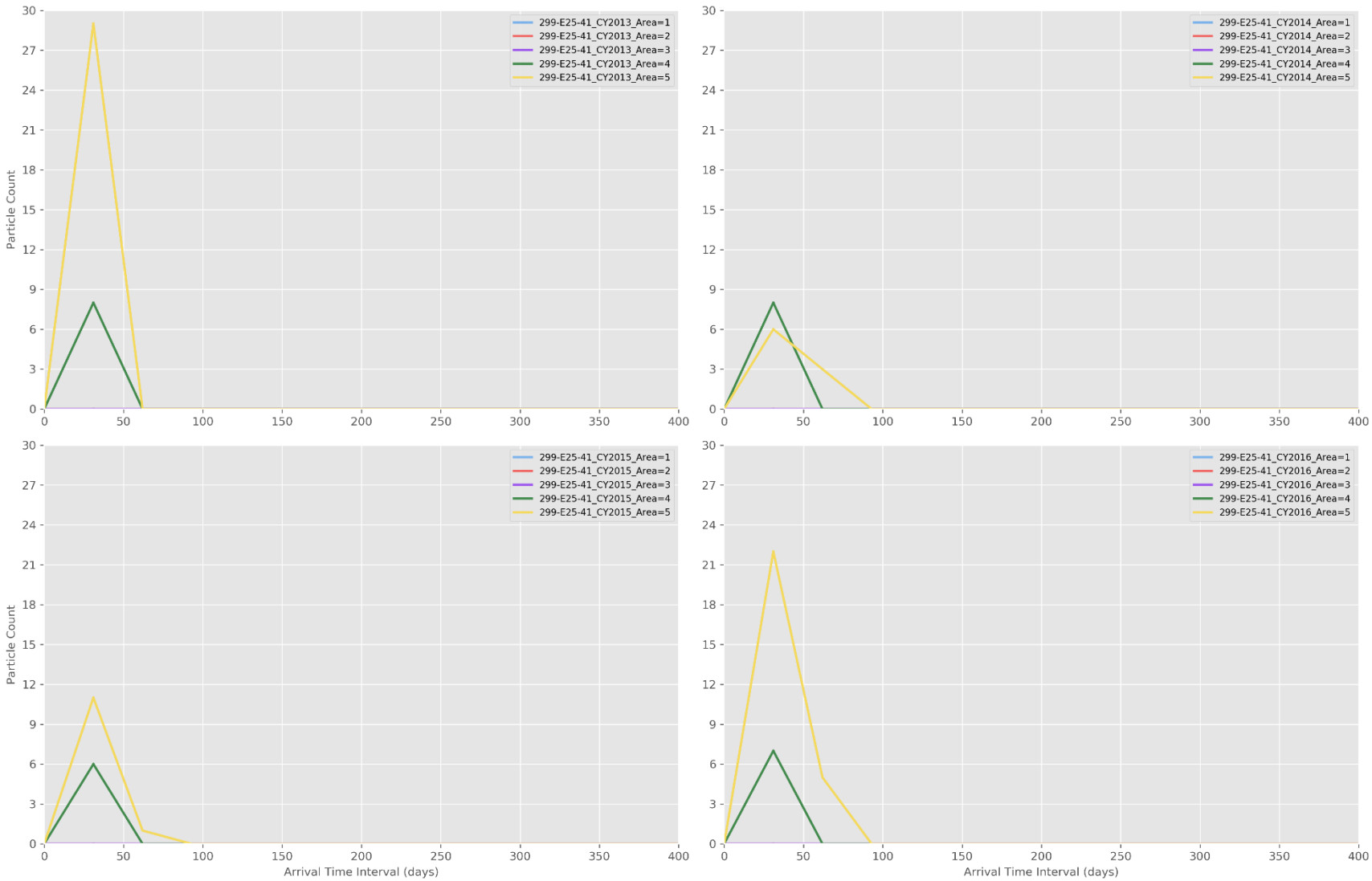

Figure J-28. Particle Breakthrough Curves per Area at Monitoring Well 299-E25-41

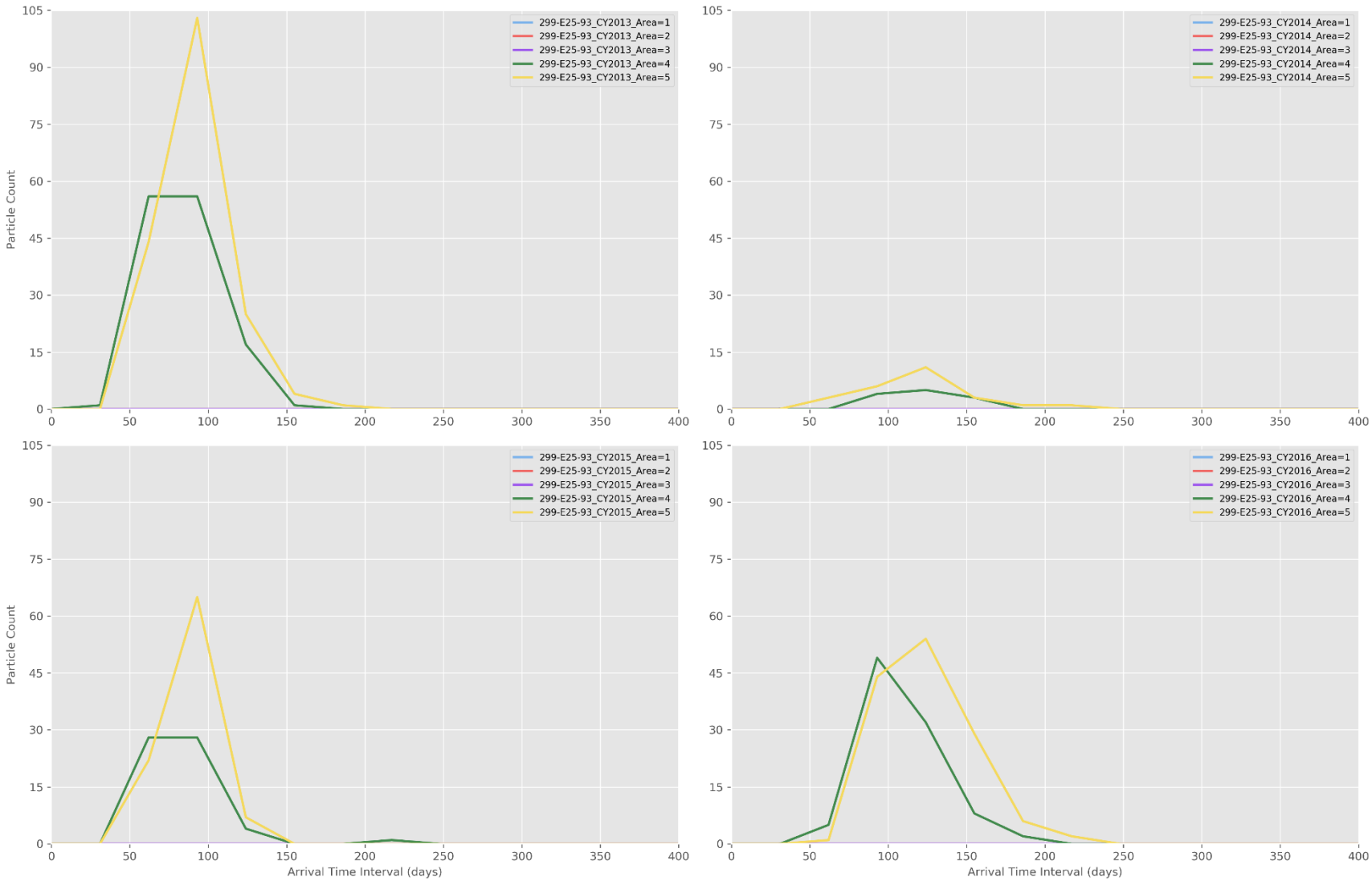

Figure J-29. Particle Breakthrough Curves per Area at Monitoring Well 299-E25-93

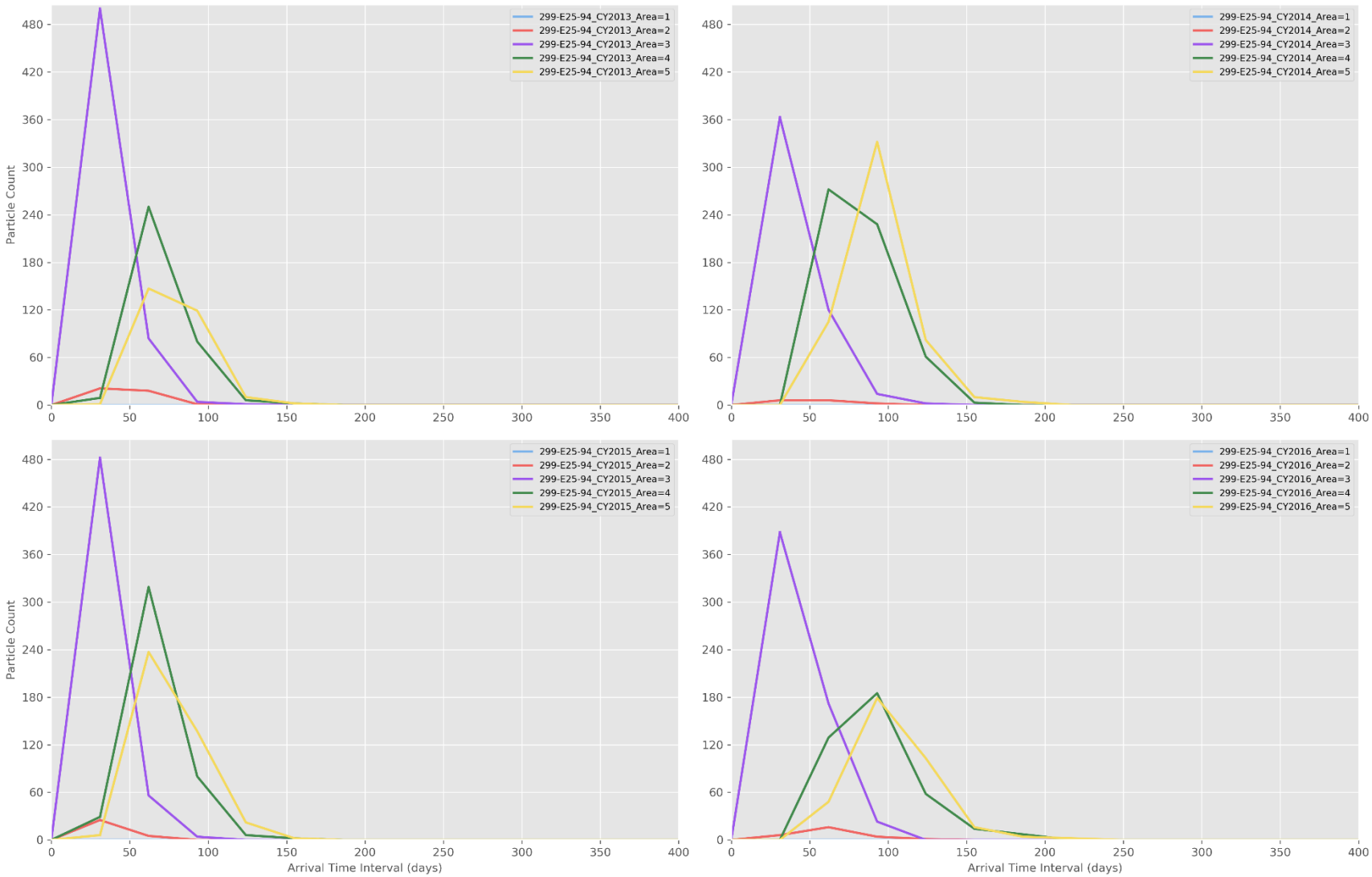

Figure J-30. Particle Breakthrough Curves per Area at Monitoring Well 299-E25-94

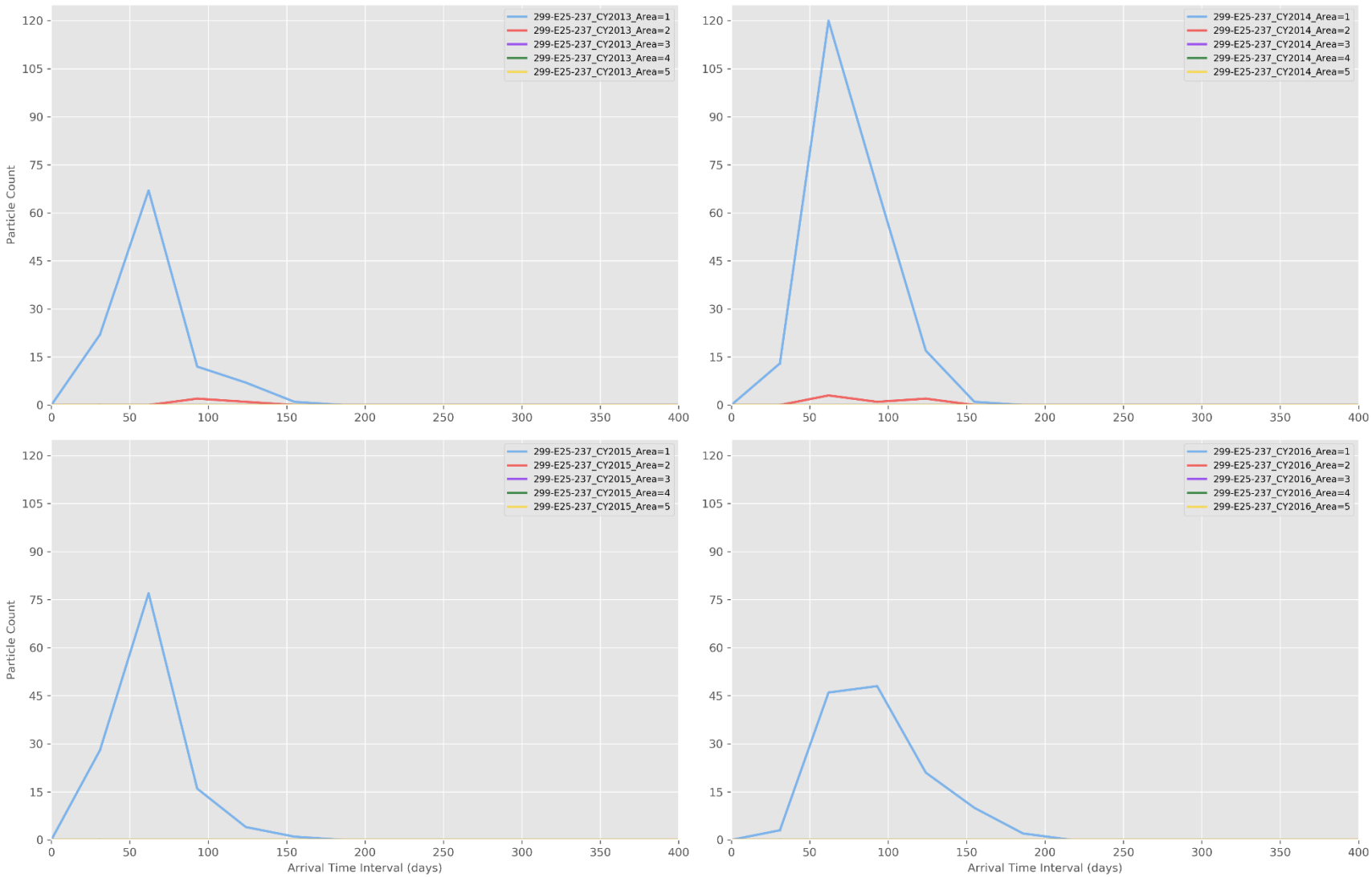

Figure J-31. Particle Breakthrough Curves per Area at Monitoring Well 299-E25-237

J3.6 Vertical Migration Potential

As described in Section 3.3 of the main text of this ECF, the American Petroleum Institute (API) plume diving calculation was used to estimate the likely rate of vertical migration of dissolved constituents downward under the influence of recharge at the water table. At each well the slope of the plume dive was multiplied by the distance from the particle starting location to the well location to estimate the depth to which the dissolved constituents may be anticipated to have migrated by the time they reach the monitoring well location.

This estimated depth of the plume was then compared to the depth from the water table to the bottom of the monitoring well screen. If the depth of the plume is below the bottom of the monitoring well screen, then the dissolved constituents may be anticipated to pass beneath the well screen. If it falls within the interval between the top of the water table and the bottom of the well screen, then the well depth is appropriate for detection of releases at WMA A-AX.

For each downgradient monitoring well at WMA A-AX, the distance from the centroid of the facility to each well was used in the calculation. The hydraulic conductivity used in the calculation for WMA A-AX, 18,200 m/d (59,711 ft/d), is the calibrated hydraulic conductivity from the CPGWM for the Cold Creek unit, which underlies the facility. The results of the API plume diving calculation for the downgradient wells for WMA A-AX are shown in Table J-7.

Table J-7. Summary of Well Screen Interval Evaluation for Downgradient Wells

Monitoring Well	Existing or Proposed Well?	Distance, D, (m)[a]	Recharge, *i*, (m/yr)[b]	Slope, S, of Plume Dive[c]	Estimated Depth of Plume Below Water Table (m)[d]	Depth from Water Table to Bottom of Well Screen (m)[e]	Is Plume Depth Above Bottom of the Screen? (Yes/No/N/A)
299-E25-2	Existing	141.3	8.62E-03	1.21E-04	1.71E-02	11.80	Yes
299-E25-40	Existing	144.8	8.62E-03	1.21E-04	1.76E-02	1.80	Yes
299-E25-41	Existing	101.7	8.62E-03	1.21E-04	1.23E-02	1.20	Yes
299-E25-93	Existing	120.8	8.62E-03	1.21E-04	1.46E-02	9.90	Yes
299-E25-94	Existing	90.7	8.62E-03	1.21E-04	1.10E-02	11.00	Yes
299-E25-237	Existing	142.1	8.62E-03	1.21E-04	1.72E-02	9.10	Yes
WMA_A-AX _PW-1	Proposed	126.9	8.62E-03	1.21E-04	1.54E-02	N/A	N/A
WMA_A-AX _PW-2	Proposed	93.5	8.62E-03	1.21E-04	1.13E-02	N/A	N/A

a. Distance of the well from centroid of dangerous waste management unit.

b. A representative number from the CPGWM. The recharge values represent fluxes from surface water discharge due to historical operations at the Hanford Site and are summarized in EMDT-BC-0002, *Vadose Zone Attenuated Recharge, Electronic Modeling Data Transmittal – Boundary Condition (Artificial Recharge)*-0002. The anthropogenic flux is added to the natural recharge component in order to establish the final total recharge flux used in the simulations. Discharges included in EMDT-BC-0002 have been attenuated to account for travel through the vadose zone.

c. Slope of the plume dive computed using the American Petroleum Institute plume diving calculation as detailed in the main text of this ECF. The migration parameters for WMA A-AX used in the calculation of slope are as follows:

Hydraulic conductivity: 18,200 m/d (59,711 ft/d) (a calibrated value from the CPGWM)

Hydraulic gradient: 1.07E-05 (determined from 2016 water-level maps produced using TRIM)

Table J-7. Summary of Well Screen Interval Evaluation for Downgradient Wells

Monitoring Well	Existing or Proposed Well?	Distance, D, (m)[a]	Recharge, *i*, (m/yr)[b]	Slope, S, of Plume Dive[c]	Estimated Depth of Plume Below Water Table (m)[d]	Depth from Water Table to Bottom of Well Screen (m)[e]	Is Plume Depth Above Bottom of the Screen? (Yes/No/N/A)

d. Plume depth at monitoring well location computed from distance, D, times the slope, S.

e. Depths obtained from Table 3-1 in DOE/RL-2016-66, *Hanford Site RCRA Groundwater Monitoring Report for 2016*.

CPGWM = Central Plateau Groundwater Model
ECF = environmental calculation file
N/A = not applicable
TRIM = Tikhonov Regularized Inverse Method
WMA = waste management area

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Appendix K

Facility-Specific Results for Waste Management Area B-BX-BY

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Terms

API	American Petroleum Institute
CY	calendar year
CPGWM	Central Plateau Groundwater Model
ECF	environmental calculation file
SST	single-shell tank
TRIM	Tikhonov Regularized Inverse Method
WMA	waste management area

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K1 Purpose and Background

The primary purpose of the calculations presented here is to estimate directions of potential migration to assess the efficacy of the geographical distribution of wells in the proposed monitoring well network for the subject facility. The calculations described within the main text of this environmental calculation file (ECF) were performed for each of the 200 East Facilities. This appendix presents results developed from the calculations that are specific to the Waste Management Unit (WMA) B-BX-BY.

WMA B-BX-BY, located in the northwestern part of the 200 East Area, consists of three tank farms: the 241-B Tank Farm, the 241-BX Tank Farm, and the 241-BY Tank Farm. Together, the tank farms comprise 40 single-shell tanks (SSTs) and ancillary liquid-handling equipment, including diversion boxes, piping, sluice and valve pits, pump pits, and a waste transfer vault. The 241-BX Tank Farm contains 12 large SSTs; the 241-BY Tank Farm contains 12 large SSTs; and the 241-B Tank Farm contains 12 large SSTs and 4 small SSTs. The WMA B-BX-BY area was used to store waste from every separation process performed at the Hanford Site; radioactive mixed waste was sent from the Plutonium-Uranium Extraction or Reduction-Oxidation plants to WMA B-BX-BY. Many of the tanks are confirmed or assumed to have leaked. Most drainable liquid was removed from the SSTs in the 241-B, 241-BX, and 241-BY Tank Farms and pumped to double-shell tanks to reduce the likelihood and severity of future leaks (Section 2.1.2 in DOE/RL-2012-53, *Groundwater Quality Assessment Plan for the Single-Shell Tank Waste Management Area B-BX-BY*).

Perched water is present in the deep vadose zone beneath WMA B-BX-BY and is estimated to extend from the central portion of the 241-BX Tank Farm northeast to the 216-B-8 Crib, encompassing the northwest corner of the 241-B Tank Farm. The simulations performed herein do not address this perched water zone. Instead, they are focused on the groundwater conditions in the underlying unconfined aquifer.

A groundwater quality assessment program for WMA B-BX-BY was put in place in 1996 (later revised) as required by WAC 173-303-400, “Dangerous Waste Regulations,” “Interim Status Facility Standards,” due to elevated specific conductance detected in one upgradient monitoring well. During the groundwater quality assessment, groundwater in two downgradient wells was found to have elevated chromium and nickel concentrations that were determined to be caused by well degradation (Section 2.1.3 in DOE/RL-2012-53). Nitrate and iron were found to exceed the drinking water standard and secondary drinking water standard, respectively. Additionally, the dangerous waste constituent cyanide was present in excess of the cleanup level in monitoring wells. The BY Cribs, the 241-BX Tank Farm, and the 241-BY Tank Farm were identified as possible sources (Section 3.2 of DOE/RL-2016-66, *Hanford Site RCRA Groundwater Monitoring Report for 2016*). Groundwater monitoring is ongoing at WMA B-BX-BY to assess the extent of dangerous waste that has entered the groundwater. The interim status groundwater monitoring well network has expanded since inception.

The WMA B-BX-BY interim status monitoring network (Figure K-1) consists of six upgradient wells (299-E33-20, 299-E33-32, 299-E33-38, 299-E33-42, 299-E33-44, and 299-E33-334) and nine downgradient wells (299-E33-31, 299-E33-41, 299-E33-47, 299-E33-48, 299-E33-49, 299-E33-335, 299-E33-337, 299-E33-338, and 299-E33-339) (Table 3-5 in DOE/RL-2016-66), most of which are screened across the entire unconfined aquifer to the underlying basalt surface (Section 3.2 in DOE/RL-2016-66). This ECF presents calculations that evaluate the efficacy of the groundwater monitoring network for detecting hypothetical releases from WMA B-BX-BY at existing and potential new monitoring well locations.

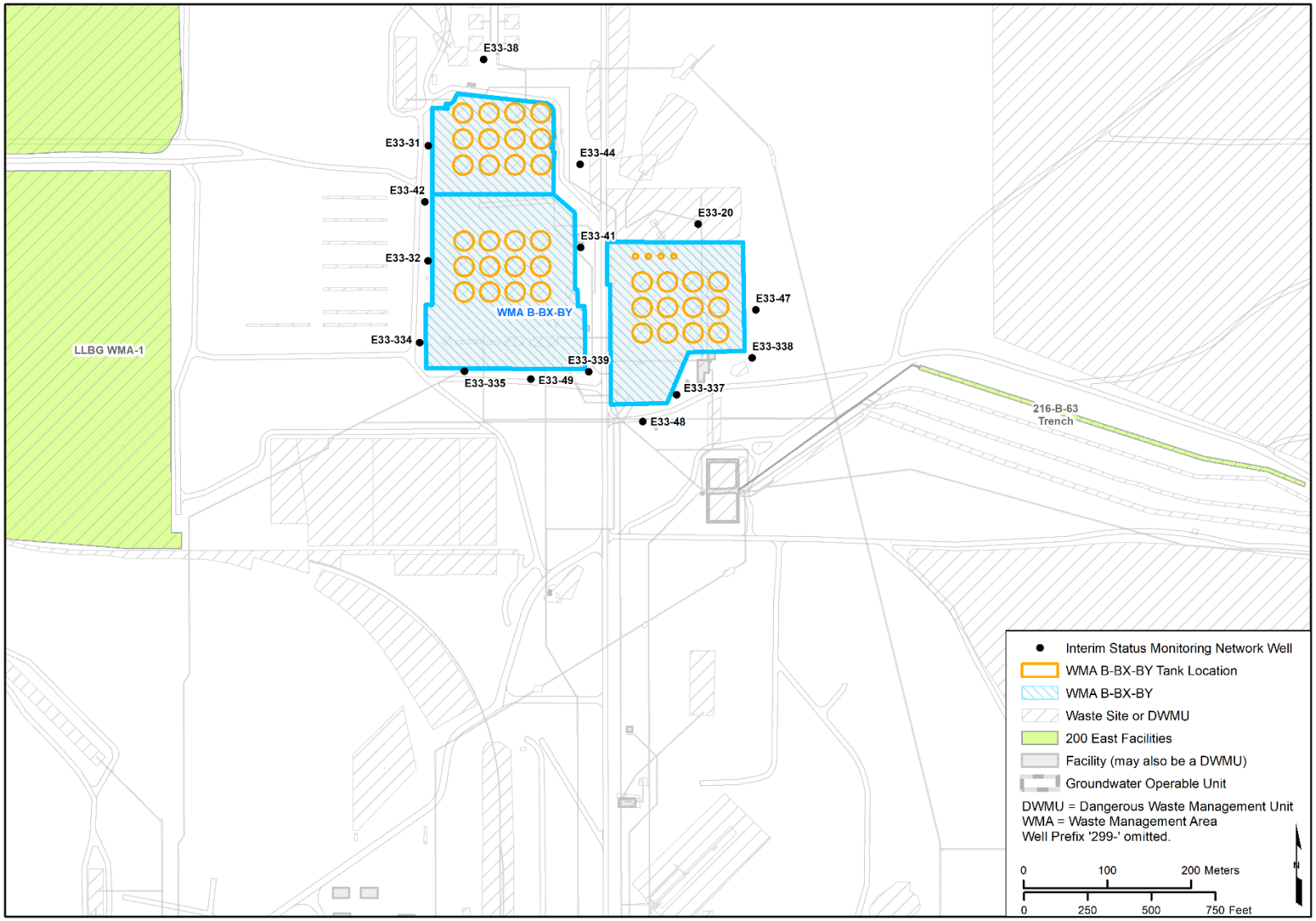

Figure K-1. Locations of Interim Status Groundwater Monitoring Wells at WMA B-BX-BY

K2 Facility-Specific Input for WMA B-BX-BY

Inputs used in the calculations that were specific to WMA B-BX-BY are described in this chapter.

K2.1 Particle Count Grid and Release Locations

To prepare particle count maps, a distribution of facility-specific starting locations is required. The starting locations for the particle-tracking calculations represent the area over which a potential release from a given facility would impact the underlying water table. The particle releases were located at plausible release sites throughout the facility. For WMA B-BX-BY, 20 release locations were specified around the circumference of each of the 36 large SSTs and 10 release locations were specified around the circumference of each of the small SSTs resulting in 760 release locations within the waste management area (Figure K-2). Twenty particles were released and tracked from each release location to provide the density of particles in space and time required for the detailed facility-specific calculations, randomizing the seed values for the dispersion calculations. Thus, 15,200 [15,200 = 36 (large tanks) × 20 (release locations) × 20 (releases) + 4 (small tanks) × 10 (release locations) × 20 (releases)] particles were tracked for each of the four simulations.

Contour maps of particle counts were generated by counting the number of particles that pass through a pre-defined uniform calculational grid (Figure K-2). The grid used to develop the relative particle density maps is defined by 10 by 10 m (33 by 33 ft) cells. The grid is oriented to be parallel to the predominant groundwater flow direction at WMA B-BX-BY.

K2.2 Migration Parameters

Parameters specific to the groundwater flow conditions at WMA B-BX-BY are reported throughout the various documents for the facility. The parameters used in the calculations performed herein to represent nonreactive dissolved contaminant migration are mobile (or effective) porosity and hydraulic conductivity. The parameters used in these calculations are representative of local conditions for a conservative (i.e., nonreactive) solute dissolved within groundwater.

There is a range of hydraulic conductivity values reported in site literature for WMA B-BX-BY. Values range from 15,100 m/d (49,541 ft/d) to 21,100 m/d (69,226 ft/d) for the Cold Creek unit (paleochannel) (Section 3.1.4 of DOE/RL-2015-75, *Aquifer Treatability Test Report for the 200-BP-5 Groundwater Operable Unit*). As described in Section 4.2.1.1 of the main text of this ECF, the hydraulic conductivity used in the work performed herein corresponds to the calibrated values from the Central Plateau Groundwater Model (CPGWM) (CP-47631, *Model Package Report: Central Plateau Groundwater Model, Version 8.4.5*). Figure 3-2 in the main text of this ECF indicates that WMA B-BX-BY is located in the hydrostratigraphic unit zone corresponding to the Cold Creek unit. The value used for the hydraulic conductivity for WMA B-BX-BY is 18,200 m/d (59,711 ft/d), which corresponds to the Cold Creek unit as shown in Table 4-1 in the main text of this ECF. The mobile (effective) porosity defined for the Cold Creek unit, which underlies WMA B-BX-BY, is specified at 0.25.

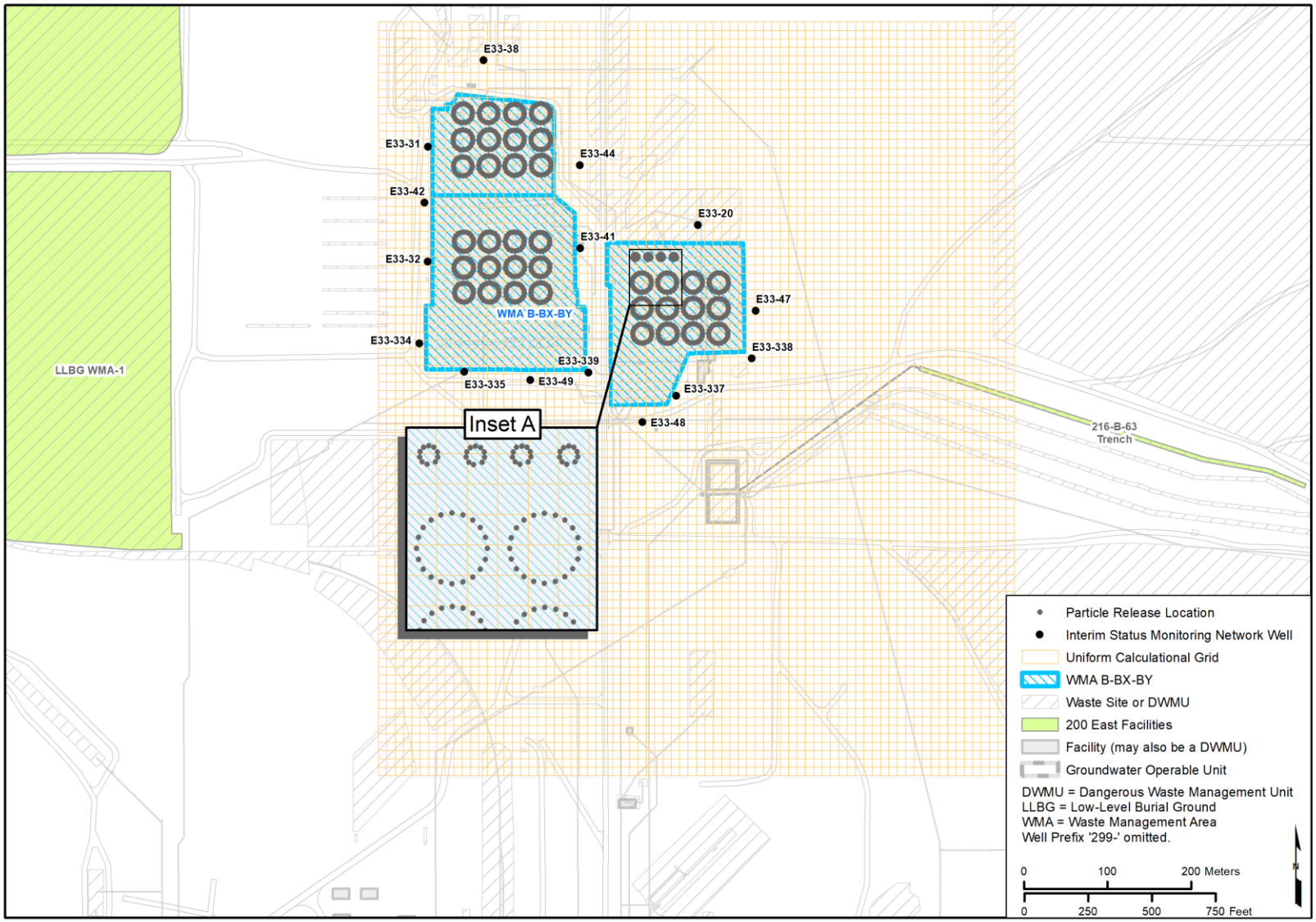

Figure K-2. Uniform Calculational Grid and Release Locations at WMA B-BX-BY

K3 Facility-Specific Results for WMA B-BX-BY

The groundwater elevation contours prepared in the vicinity of WMA B-BX-BY using the Tikhonov Regularized Inverse Method (TRIM) are presented in this section. In addition, the outputs of the particle tracking and particle count calculations are presented, including the following:

- Maps of calculated particle pathlines for the flow conditions determined for each of the four years (2013, 2014, 2015, and 2016). These are presented at the facility-specific scale considering advective and dispersive migration.
- Time-series plots, referred to as particle breakthrough curves, of the relative arrival, peak, and decline in particle counts at each interim status groundwater monitoring well location and each proposed monitoring location, where applicable.
- Tabulation of relative particle counts for each interim status groundwater monitoring well location and each proposed monitoring location, where applicable.
- Maps of particle counts downgradient of each facility based on the flow conditions determined for each of the four years.

The results of calculations of potential vertical migration of contaminants at the monitoring well locations are also presented.

K3.1 Groundwater Elevation Contours

Figures K-3 through K-6 show the results of the groundwater elevation analysis completed using TRIM in the vicinity of WMA B-BX-BY. The figures depict general patterns of groundwater elevations and hydraulic gradients for conditions represented by calendar years (CYs) 2013, 2014, 2015, and 2016. These groundwater elevation contours and associated hydraulic gradients form the basis for the facility-specific calculations performed for this ECF.

K3.2 Particle Tracking

Once the groundwater elevation contour maps and underlying piecewise continuous elevation grids were prepared using TRIM, particle tracking was implemented using both advection and dispersion.
The particle pathlines that were produced depict the patterns of spreading that might accompany the migration of contaminants near the waste management area for the flow conditions calculated for CYs 2013, 2014, 2015, and 2016. Figures K-7 through K-10 depict the particle pathlines developed based on the groundwater elevations prepared throughout the 200 East Area using TRIM. The resulting maps were prepared based on the release of 20 particles from each starting location to provide the high density of particles in space and time required for these detailed facility-specific calculations. Figures K-7 through K-10 depict the particle pathlines calculated after 4 years of travel, by which time it was determined that most of the particles would have arrived at or passed by the interim status groundwater monitoring wells. Figures K-7 through K-10 depict an instantaneous release to the water table from the release locations in WMA B-BX-BY to illustrate the adequacy of the well network for monitoring the entire facility.

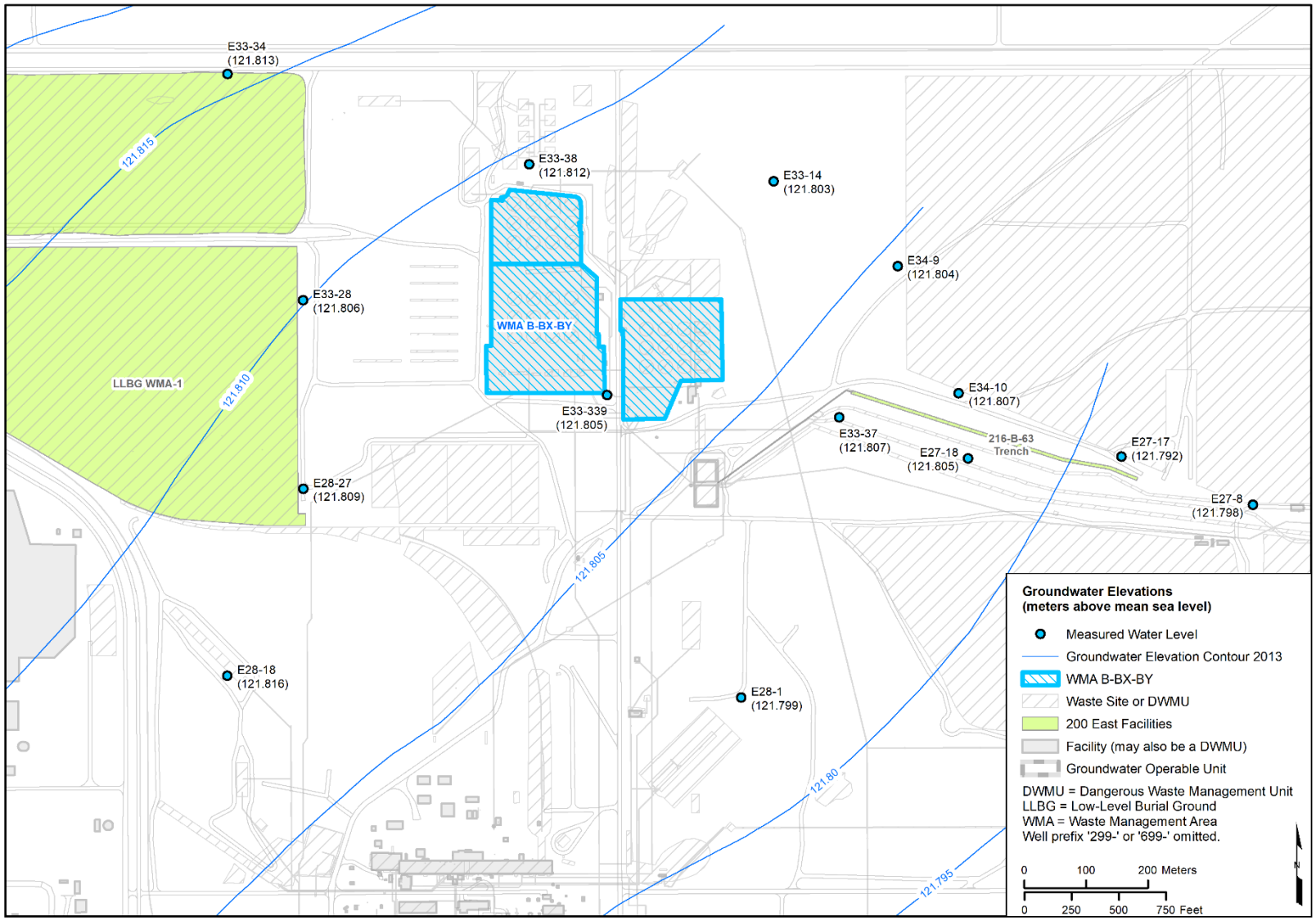

Figure K-3. Water-Level Elevation Map for WMA B-BX-BY, 2013

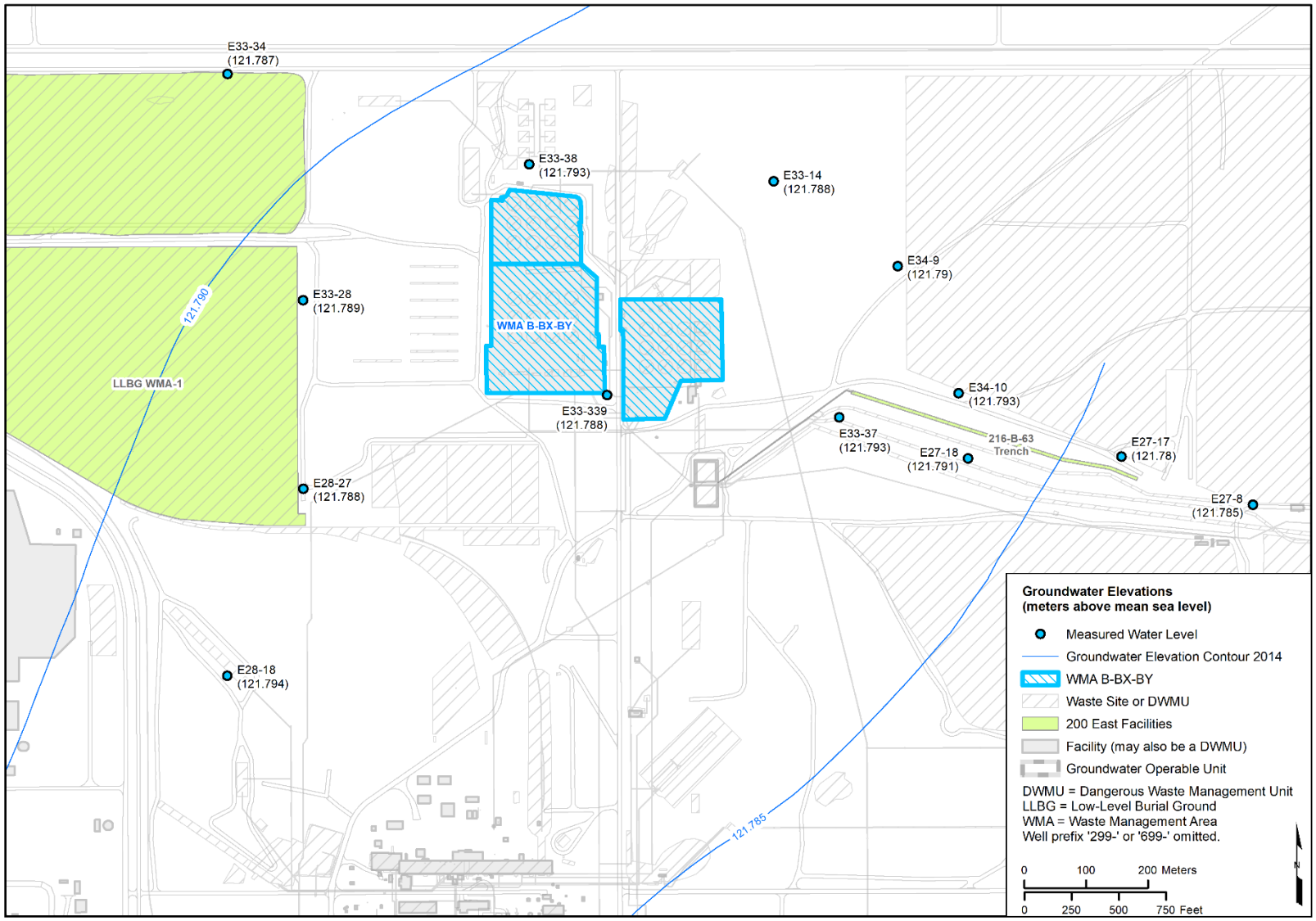

Figure K-4. Water-Level Elevation Map for WMA B-BX-BY, 2014

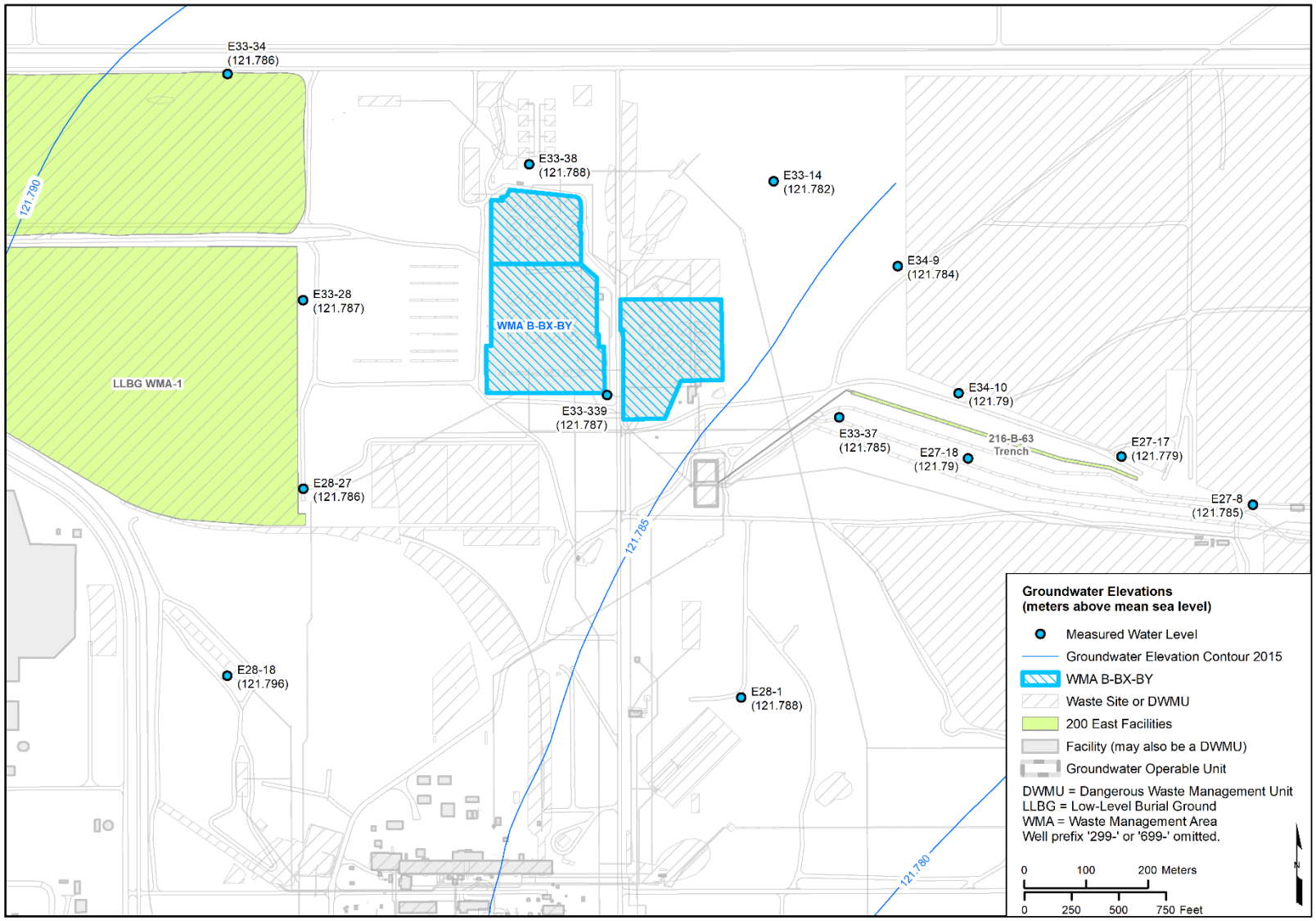

Figure K-5. Water-Level Elevation Map for WMA B-BX-BY, 2015

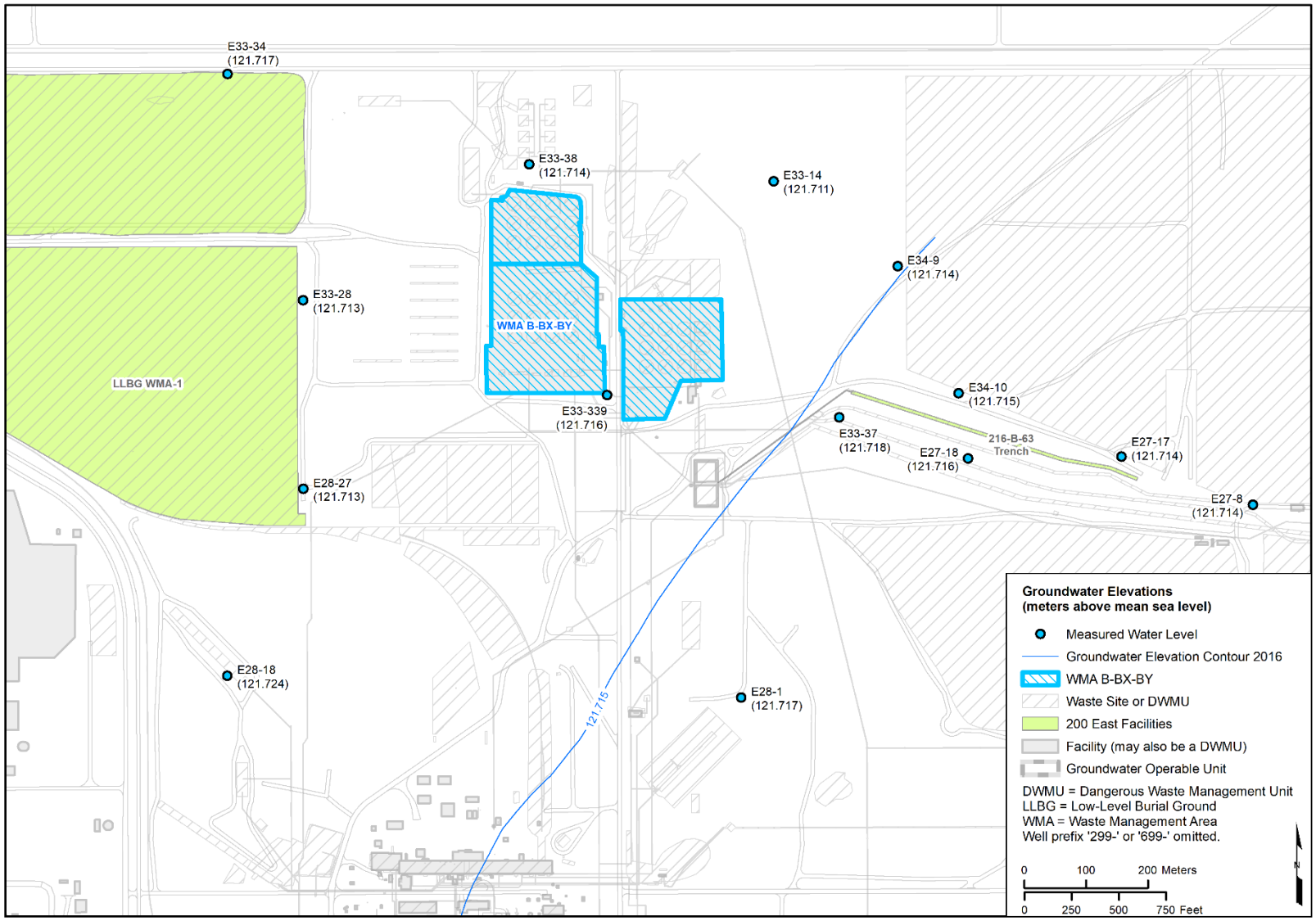

Figure K-6. Water-Level Elevation Map for WMA B-BX-BY, 2016

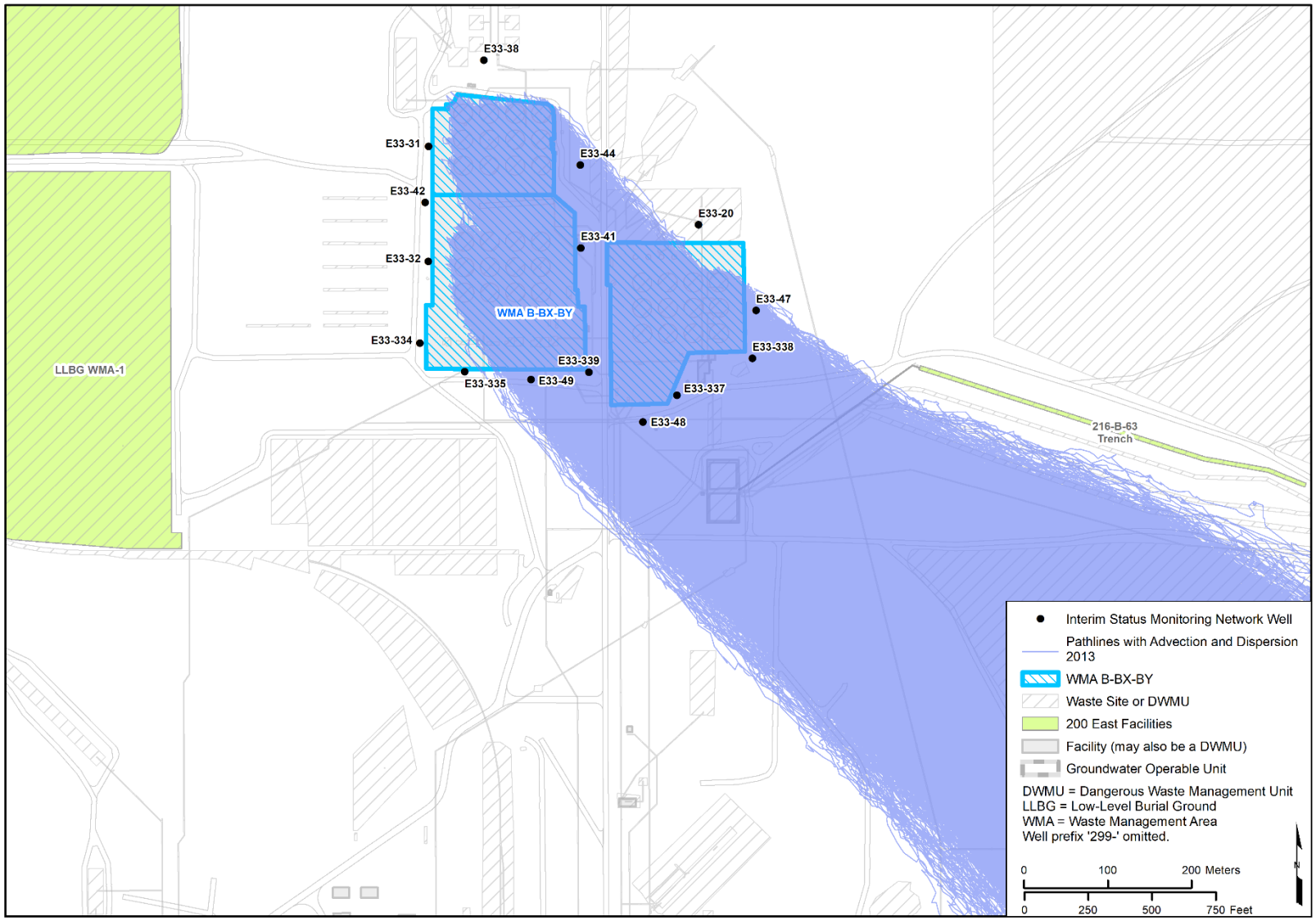

Figure K-7. Local-Scale Particle Pathlines, Advection and Dispersion – WMA B-BX-BY, 2013

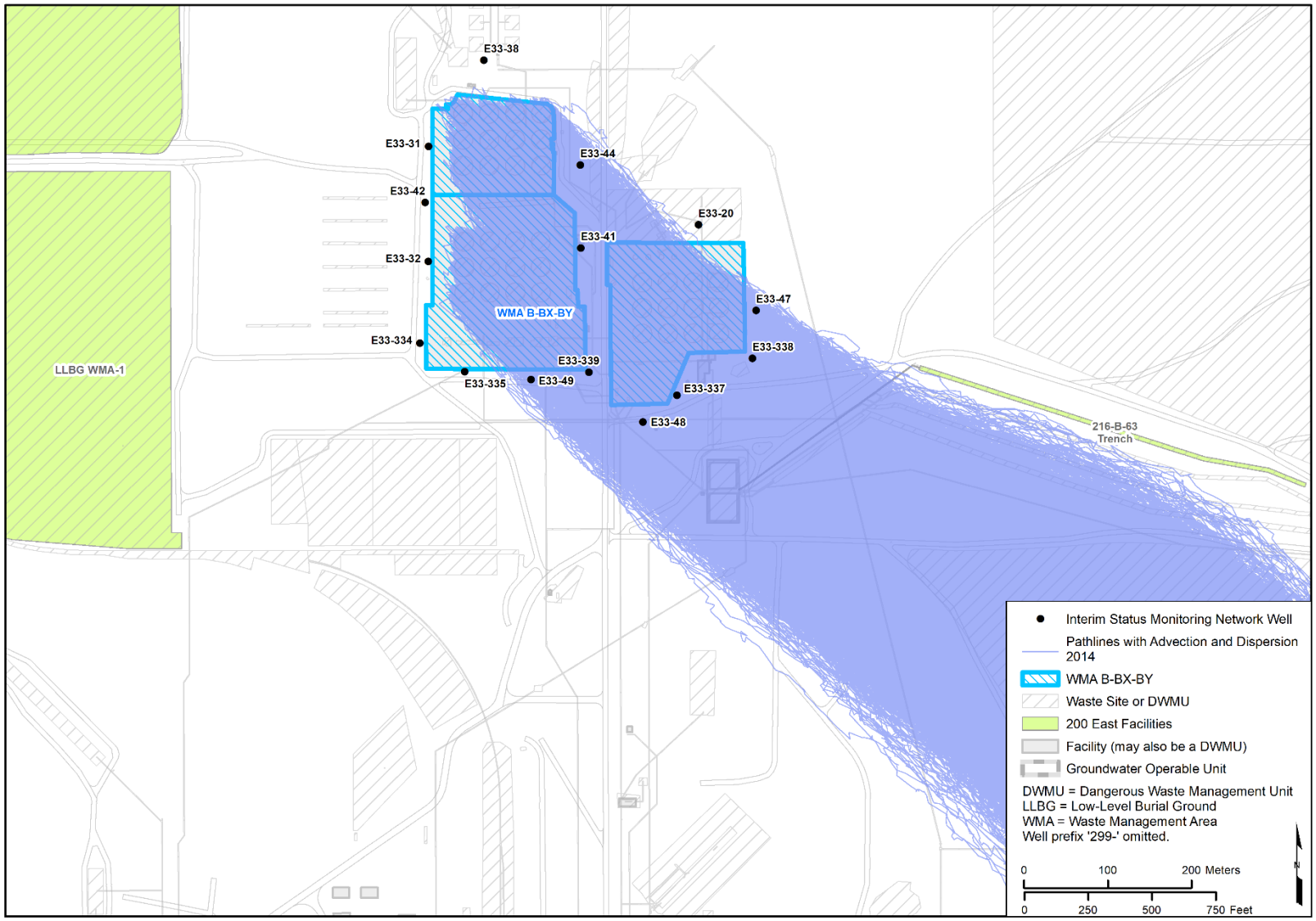

Figure K-8. Local-Scale Particle Pathlines, Advection and Dispersion – WMA B-BX-BY, 2014

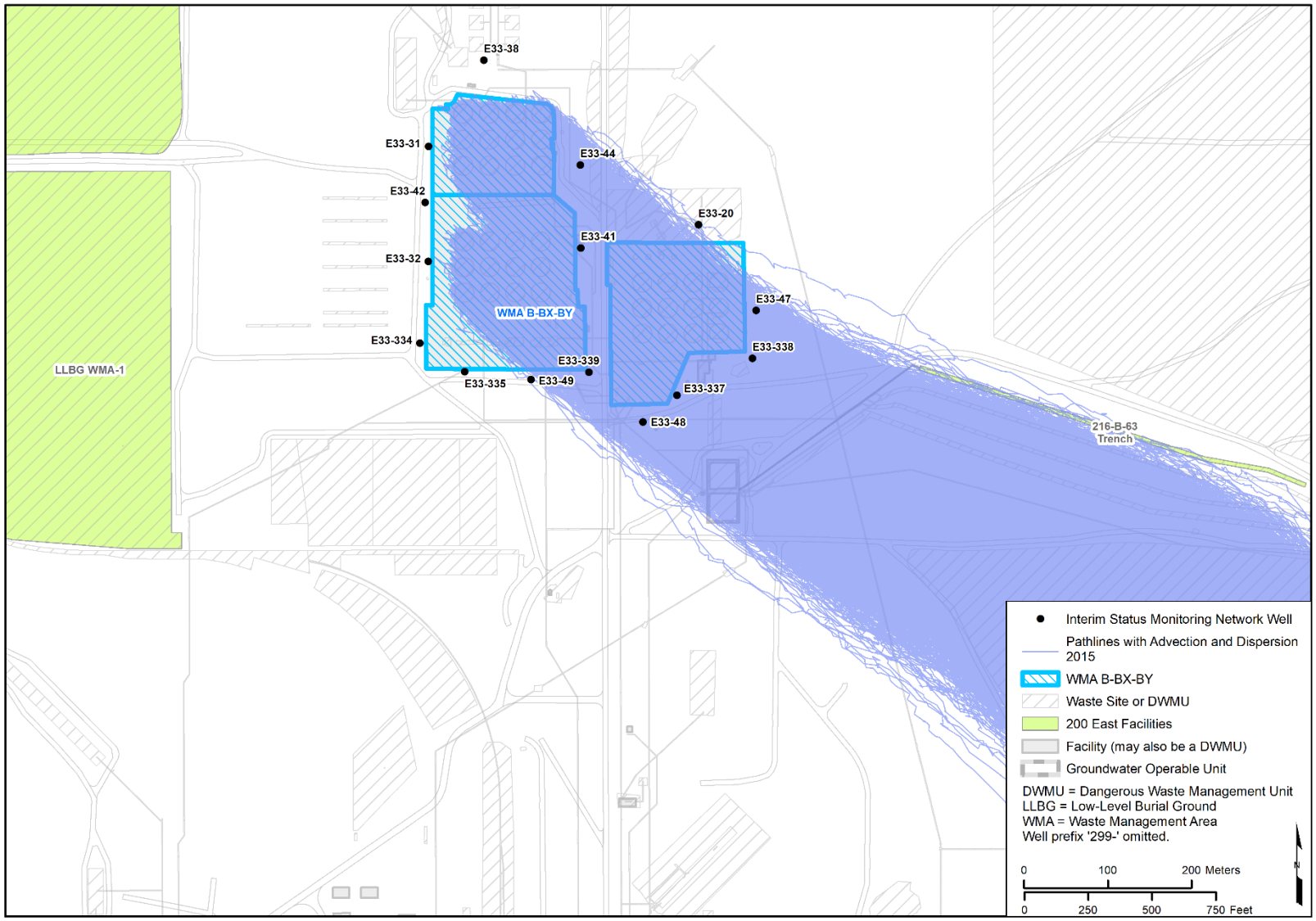

Figure K-9. Local-Scale Particle Pathlines, Advection and Dispersion – WMA B-BX-BY, 2015

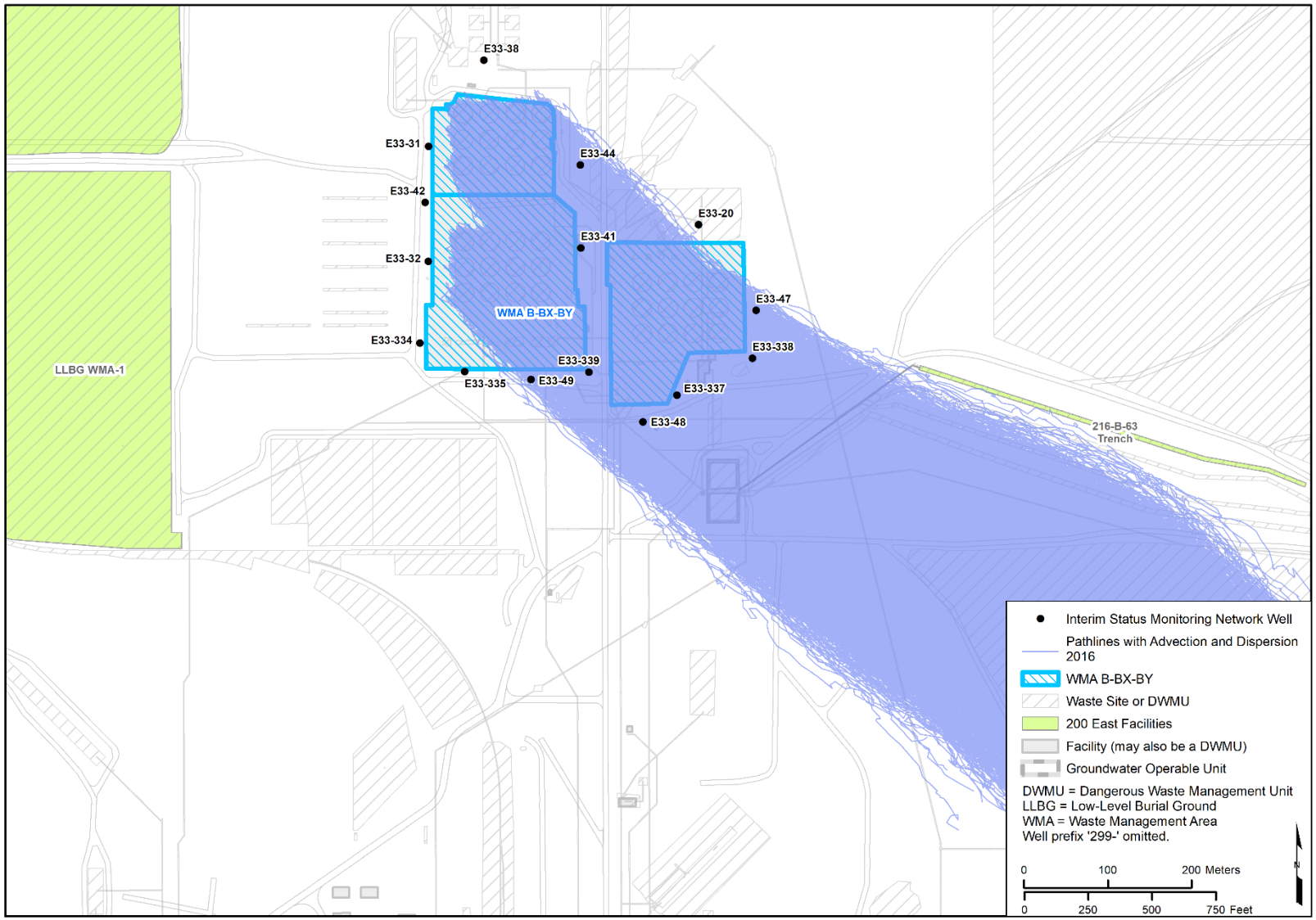

Figure K-10. Local-Scale Particle Pathlines, Advection and Dispersion – WMA B-BX-BY, 2016

K3.3 Particle Counts

To compare the relative timing and density of the particles that pass by each monitoring well location, particle counts were calculated as described in Section 6.3 of the main text of this ECF. The particle counts were tabulated, particle breakthrough curves were created, and particle count maps were generated.

K3.3.1 Relative Particle Counts at Interim Status Groundwater Monitoring Wells

Tables K-1 through K-10 present the computed particle counts over time, binned into periods of 125 days, for each of the downgradient monitoring wells. No particle count table is included for well 299-E33-31, which is classified as a downgradient well but it is upgradient in the flow conditions evaluated. Wells 299-E33-20 and 299-E33-44 are upgradient wells but their locations are downgradient from some of the release locations in the northwestern section of WMA B-BX-BY. Because particles pass in the vicinity of the wells, tables were included for wells 299-E33-20 and 299-E33-44. The tables present four entries (one for each year) for each well. At the bottom of the column for each mapped event is the total number of particles that passed through the vicinity of the well, regardless of time, and the average of the totals for the four mapped years rounded to the nearest integer. Each table provides an indication of the relative timing of the expected detections at each well and the relative potential that each well would detect a release at the facility for the flow conditions calculated for CYs 2013, 2014, 2015, and 2016.

Table K-1. Particle Density (Count) Monitoring Well 299-E33-20

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
125	0	0	0	0	
250	0	0	7	0	
375	0	1	13	3	
500	0	0	2	2	
625	0	0	0	1	
750	0	0	0	0	
875	0	0	0	0	
1000	0	0	0	0	
1125	0	0	0	0	
1250	0	0	0	0	
1375	0	0	0	0	
1500	0	0	0	0	Average
Total	0	1	22	6	**7.25**

Table K-2. Particle Density (Count) Monitoring Well 299-E33-41

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
125	2090	409	258	150	
250	20	1467	1317	915	
375	0	243	363	918	
500	0	1	13	149	
625	0	0	0	8	
750	0	0	0	0	
875	0	0	0	0	
1000	0	0	0	0	
1125	0	0	0	0	
1250	0	0	0	0	
1375	0	0	0	0	
1500	0	0	0	0	Average
Total	2110	2120	1951	2140	**2080**

Table K-3. Particle Density (Count) Monitoring Well 299-E33-44

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
125	619	723	910	596	
250	0	47	141	234	
375	0	0	1	7	
500	0	0	0	0	
625	0	0	0	0	
750	0	0	0	0	
875	0	0	0	0	
1000	0	0	0	0	
1125	0	0	0	0	
1250	0	0	0	0	
1375	0	0	0	0	
1500	0	0	0	0	Average
Total	619	770	1052	837	**820**

Table K-4. Particle Density (Count) Monitoring Well 299-E33-47

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
125	415	445	567	409	
250	6	61	166	128	
375	1	7	56	35	
500	0	25	245	10	
625	0	11	110	24	
750	0	1	7	26	
875	0	0	0	17	
1000	0	0	0	0	
1125	0	0	0	0	
1250	0	0	0	0	
1375	0	0	0	0	
1500	0	0	0	0	Average
Total	422	550	1151	649	**693**

Table K-5. Particle Density (Count) Monitoring Well 299-E33-48

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
125	669	0	0	0	
250	1647	202	76	5	
375	27	1208	689	276	
500	0	616	409	891	
625	0	89	26	583	
750	0	5	0	160	
875	0	0	0	18	
1000	0	0	0	1	
1125	0	0	0	0	
1250	0	0	0	0	
1375	0	0	0	0	
1500	0	0	0	0	Average
Total	2343	2120	1200	1934	**1899**

Table K-6. Particle Density (Count) Monitoring Well 299-E33-49

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
125	651	38	3	3	
250	10	252	43	114	
375	0	18	2	75	
500	0	0	0	12	
625	0	0	0	0	
750	0	0	0	1	
875	0	0	0	0	
1000	0	0	0	0	
1125	0	0	0	0	
1250	0	0	0	0	
1375	0	0	0	0	
1500	0	0	0	0	Average
Total	661	308	48	205	**306**

Table K-7. Particle Density (Count) Monitoring Well 299-E33-335

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
125	2	0	0	0	
250	0	0	0	0	
375	0	0	0	0	
500	0	0	0	0	
625	0	0	0	0	
750	0	0	0	0	
875	0	0	0	0	
1000	0	0	0	0	
1125	0	0	0	0	
1250	0	0	0	0	
1375	0	0	0	0	
1500	0	0	0	0	Average
Total	2	0	0	0	**1**

Table K-8. Particle Density (Count) Monitoring Well 299-E33-337

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
125	660	154	86	67	
250	2208	239	268	133	
375	83	1006	1426	344	
500	0	983	773	800	
625	0	422	124	617	
750	0	44	16	401	
875	0	1	0	127	
1000	0	0	0	23	
1125	0	0	0	2	
1250	0	0	0	0	
1375	0	0	0	0	
1500	0	0	0	0	Average
Total	2951	2849	2693	2514	**2752**

Table K-9. Particle Density (Count) Monitoring Well 299-E33-338

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
125	2241	1095	1100	701	
250	375	1182	1391	1056	
375	17	232	298	622	
500	0	505	898	139	
625	0	325	1040	294	
750	0	60	221	514	
875	0	1	14	261	
1000	0	0	0	58	
1125	0	0	0	8	
1250	0	0	0	2	
1375	0	0	0	0	
1500	0	0	0	0	Average
Total	2633	3400	4962	3655	**3663**

Table K-10. Particle Density (Count) Monitoring Well 299-E33-339

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	**2014**	**2015**	**2016**	
125	1929	135	64	15	
250	307	1373	1051	587	
375	0	550	453	1007	
500	0	39	10	350	
625	0	2	0	47	
750	0	0	0	3	
875	0	0	0	0	
1000	0	0	0	0	
1125	0	0	0	0	
1250	0	0	0	0	
1375	0	0	0	0	
1500	0	0	0	0	Average
Total	2236	2099	1578	2009	**1981**

The average values depicted at the base of each table can be used to assess the relative potential for each well to detect a release at the facility. These averages are summarized as follows:

- 299-E33-20 – Average = 7
- 299-E33-41 – Average = 2080
- 299-E33-44 – Average = 820
- 299-E33-47 – Average = 693
- 299-E33-48 – Average = 1899
- 299-E33-49 – Average = 306
- 299-E33-335 – Average = 1
- 299-E33-337 – Average = 2752
- 299-E33-338 – Average = 3663
- 299-E33-339 – Average = 1981

K3.3.2 Relative Arrival Times at Interim Status Groundwater Monitoring Wells

Figures K-11 through K-20 depict plots of particle counts over time (particle breakthrough curves) for each downgradient well location. The underlying data plotted in Figures K-11 through K-20 are the same as the data in Tables K-1 through K-10, but the time interval over which particles are summed is not necessarily the same. No breakthrough curve is included for well 299-E33-31, which is classified as a downgradient well but it is upgradient in the flow conditions evaluated. Wells 299-E33-20 and 299-E33-44 are upgradient wells but their locations are downgradient from some of the release locations in the northwestern section of WMA B-BX-BY. Because particles pass in the vicinity of the wells, breakthrough curves were included for wells 299-E33-20 and 299-E33-44. Particle breakthrough curves show the relative timing and particle density for the arrival, peak, and decline in particle counts at each interim status monitoring location resulting from the hypothetical instantaneous release at the facility. The plots depict the relative potential at each well for detecting a release from the facility that reaches the water table for the flow conditions calculated for CYs 2013, 2014, 2015, and 2016. There is one figure for each well, with four lines shown on each plot (one for each year).

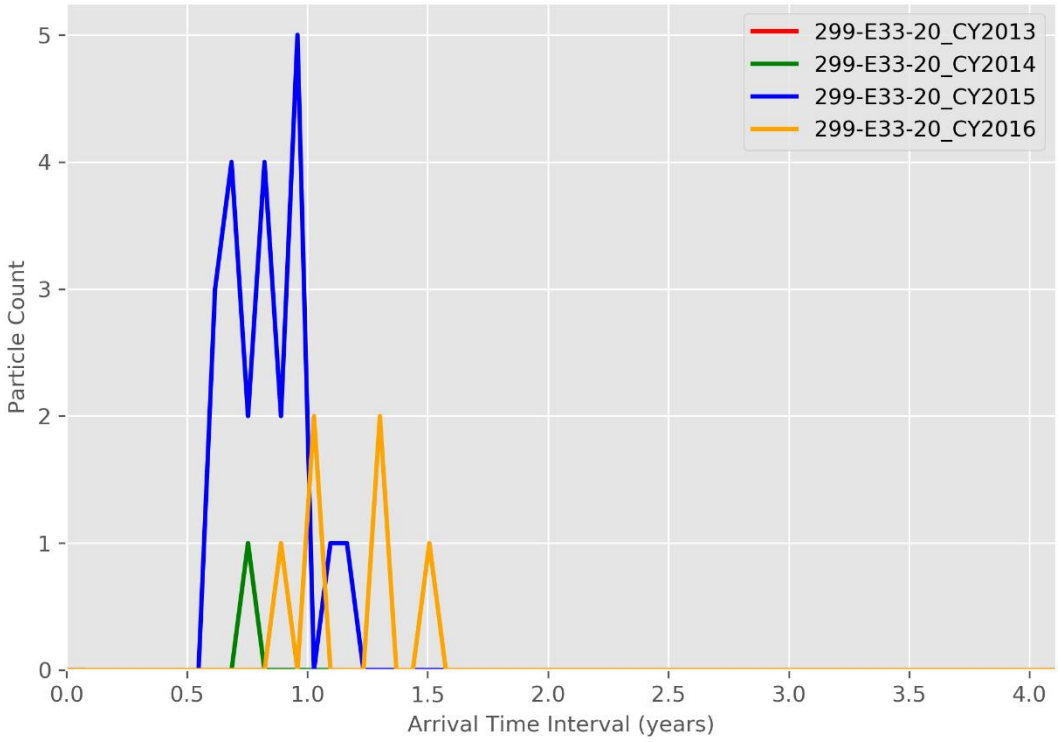

Figure K-11. Particle Breakthrough Curve at Monitoring Well 299-E33-20

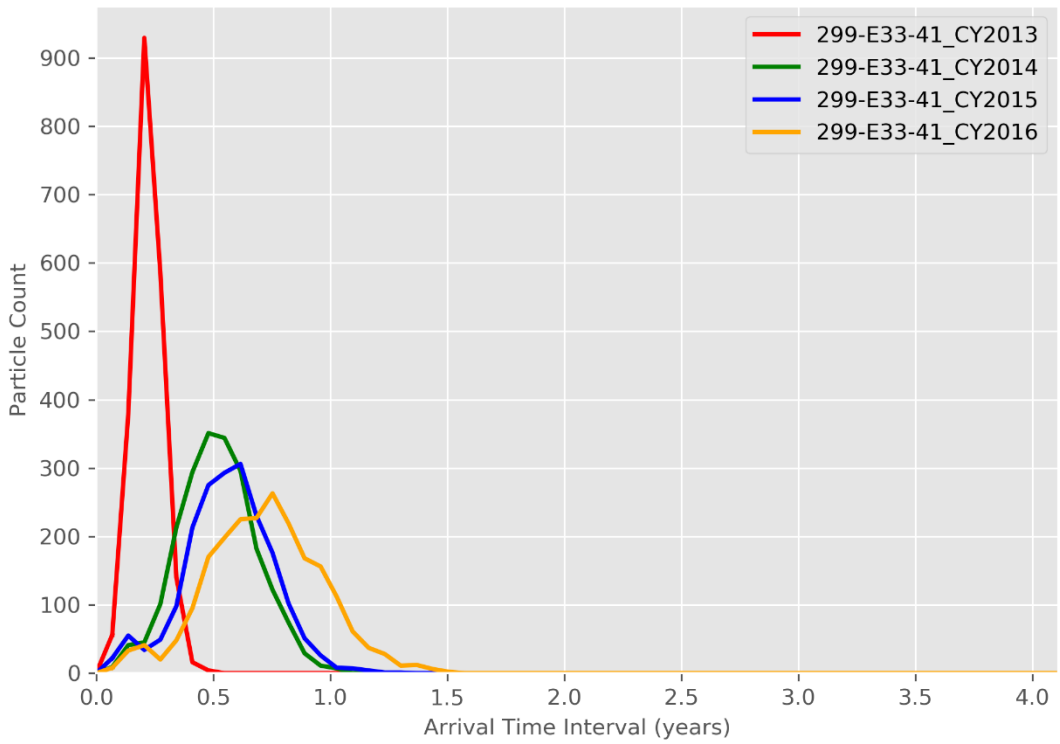

Figure K-12. Particle Breakthrough Curve at Monitoring Well 299-E33-41

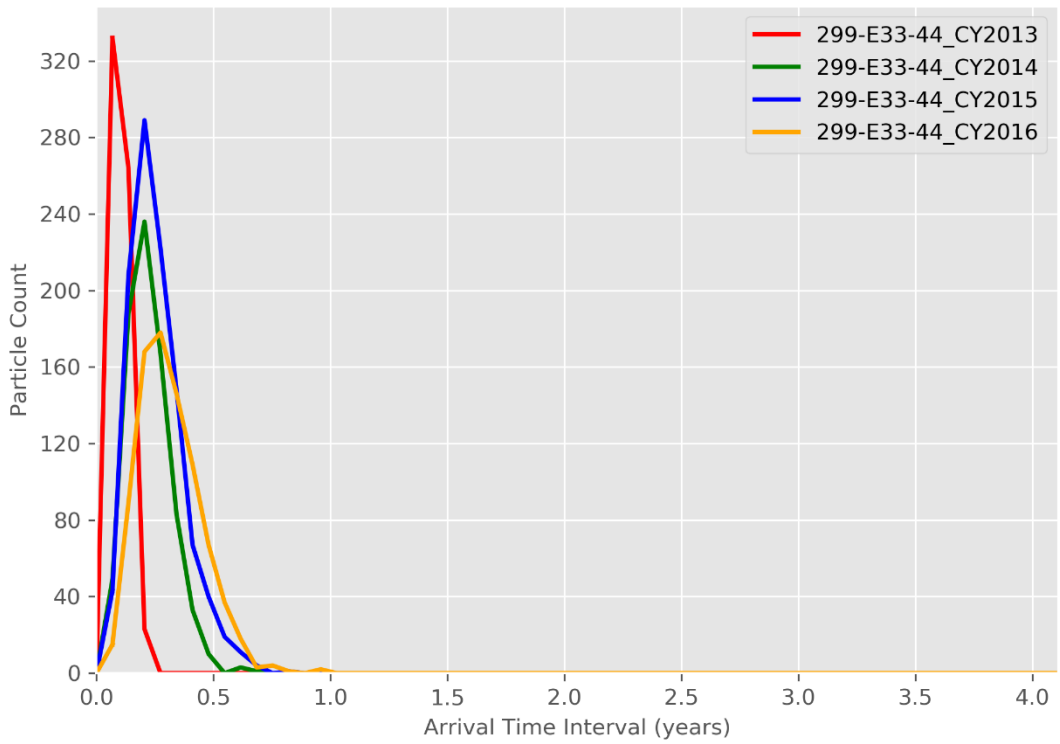

Figure K-13. Particle Breakthrough Curve at Monitoring Well 299-E33-44

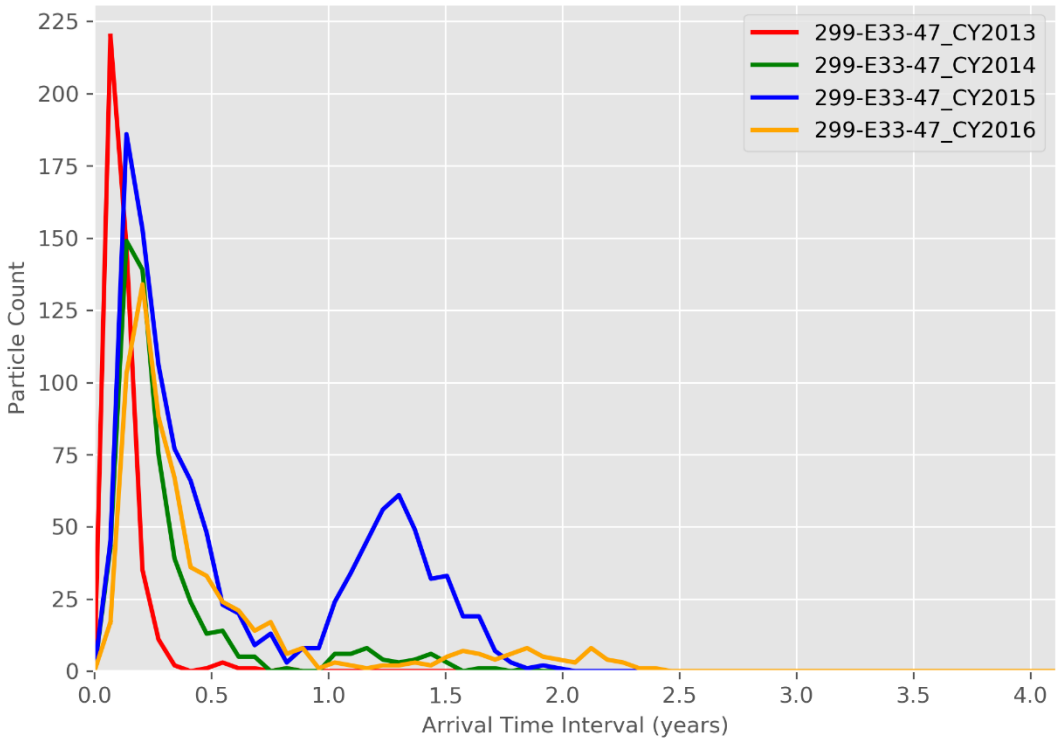

Figure K-14. Particle Breakthrough Curve at Monitoring Well 299-E33-47

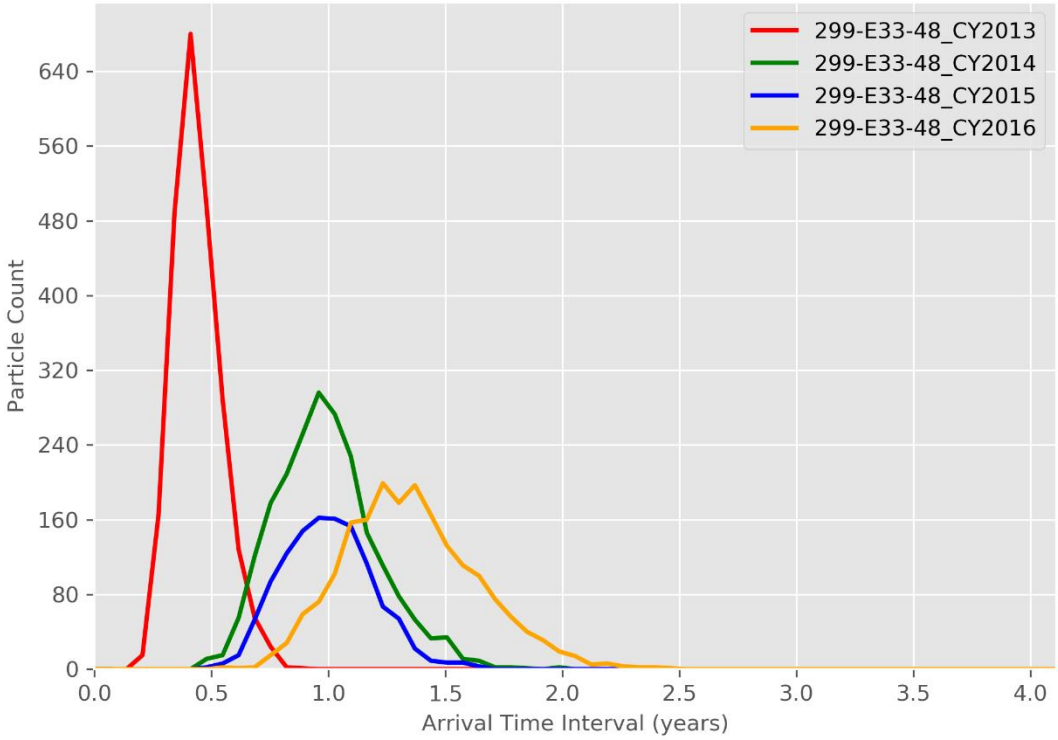

Figure K-15. Particle Breakthrough Curve at Monitoring Well 299-E33-48

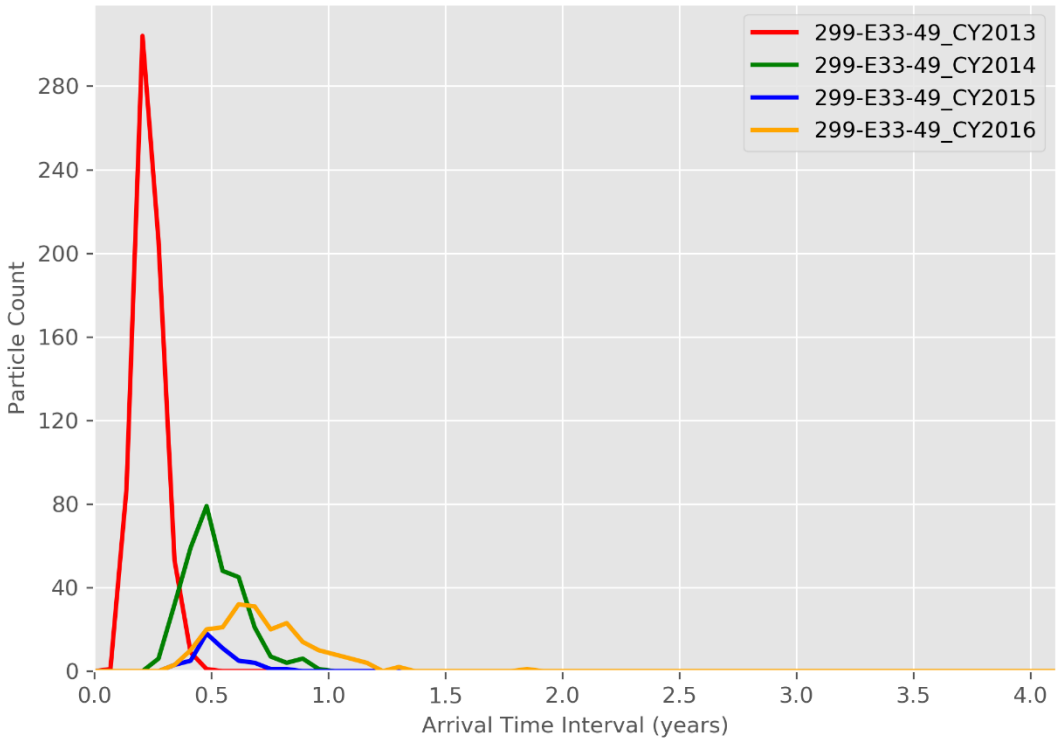

Figure K-16. Particle Breakthrough Curve at Monitoring Well 299-E33-49

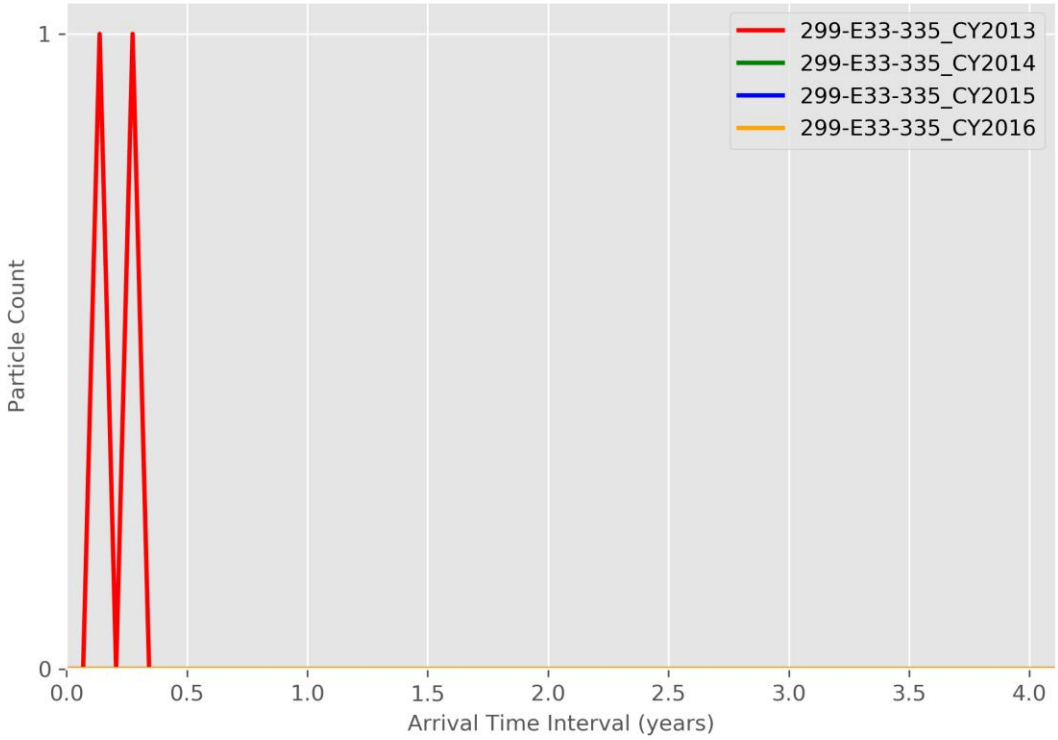

Figure K-17. Particle Breakthrough Curve at Monitoring Well 299-E33-335

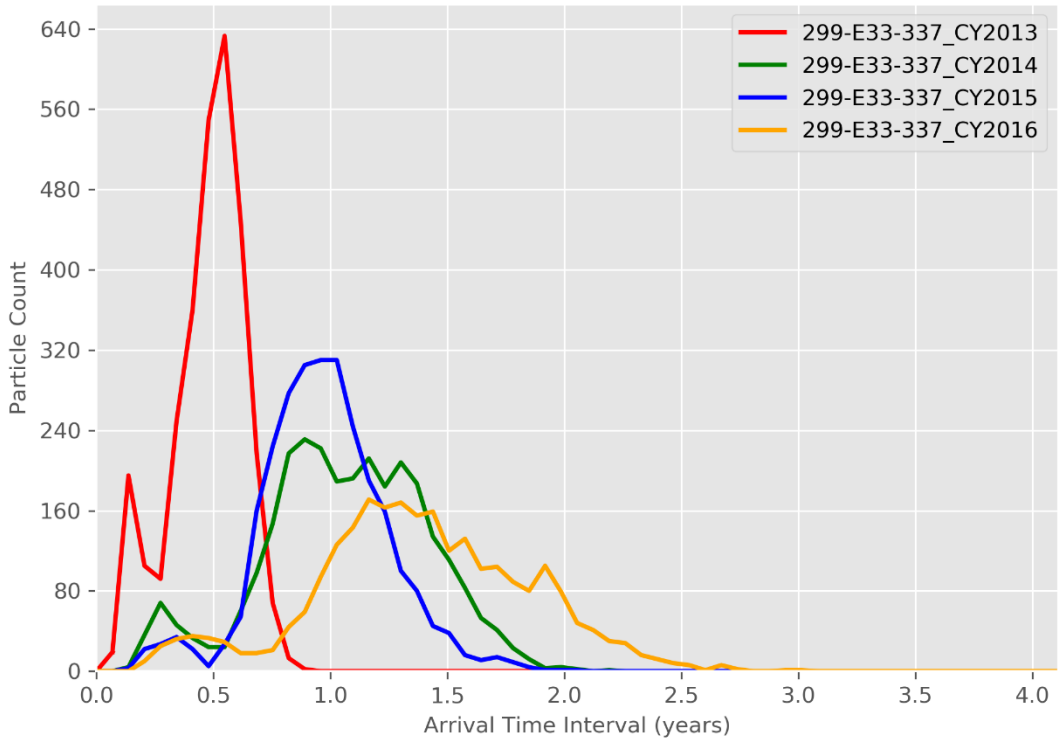

Figure K-18. Particle Breakthrough Curve at Monitoring Well 299-E33-337

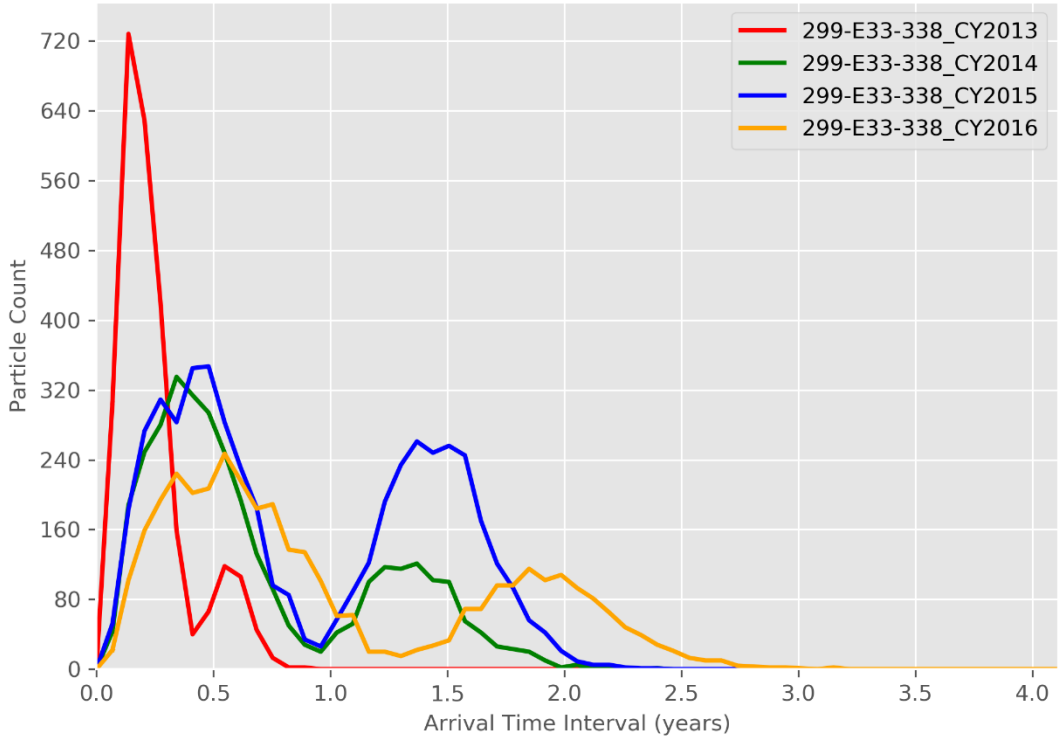

Figure K-19. Particle Breakthrough Curve at Monitoring Well 299-E33-338

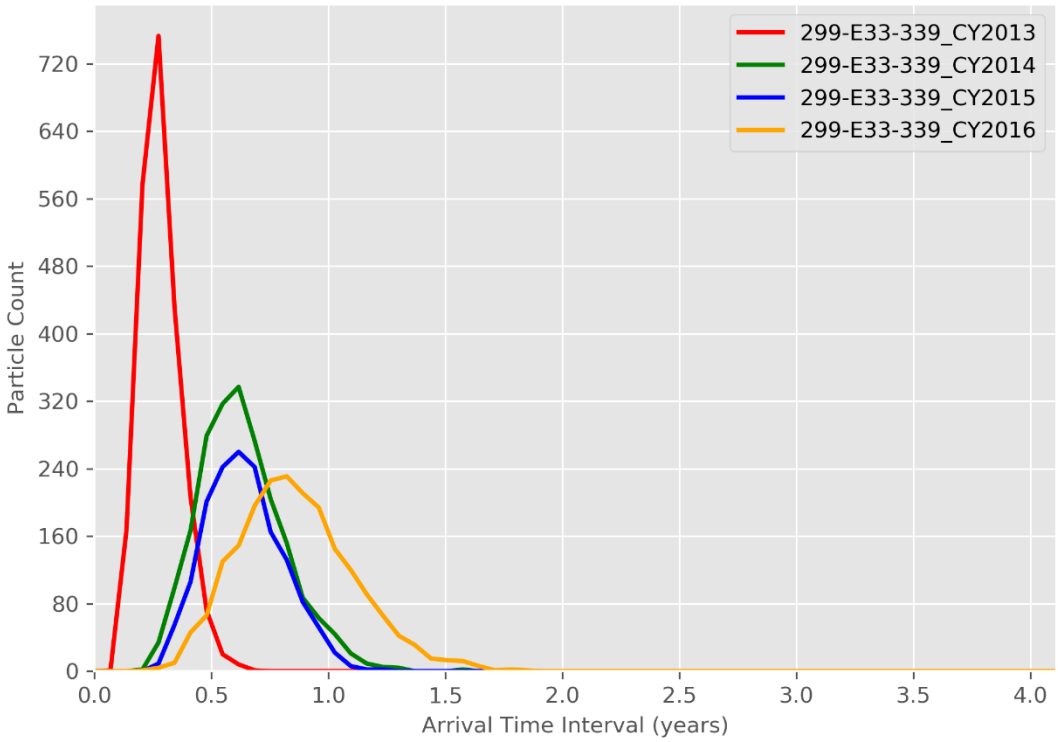

Figure K-20. Particle Breakthrough Curve at Monitoring Well 299-E33-339

K3.3.3 Particle Count Maps

Figures K-21 through K-24 depict the particle count maps developed based on the instantaneous release of a large number of particles at the facility. The particle count maps depict areas of relatively higher and lower potential impact from a release at the facility that reaches the water table for conditions represented by CYs 2013, 2014, 2015, and 2016. Figures K-21 through K-24 depict the particle density after 4 years of calculated travel, by which time it was determined that all particles would have arrived at or passed by the interim status groundwater monitoring wells (see entries in Tables K-1 through K-10).

The goal of well placement is for the well locations to span the range of particle pathline distribution as released from WMA B-BX-BY. The particle count maps show that under the evaluated range of conditions, there are areas of high particle counts where there are no corresponding monitoring wells, indicating the need for an additional monitoring well. The location of the one proposed well (WMA_B-BX-BY_PW-1) is shown in Figures K-21 through K-24.

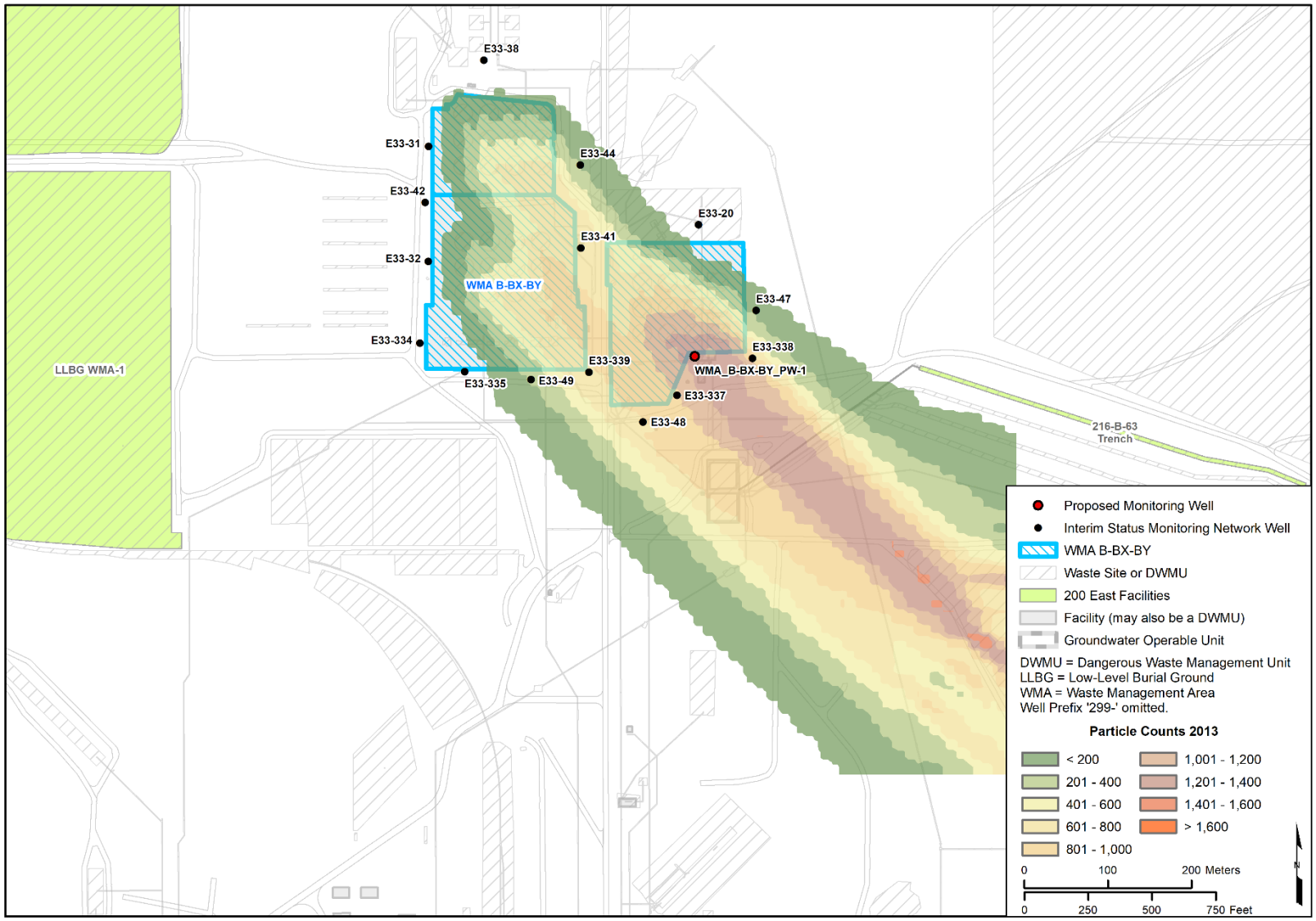

Figure K-21. Particle Count Map – WMA B-BX-BY, 2013

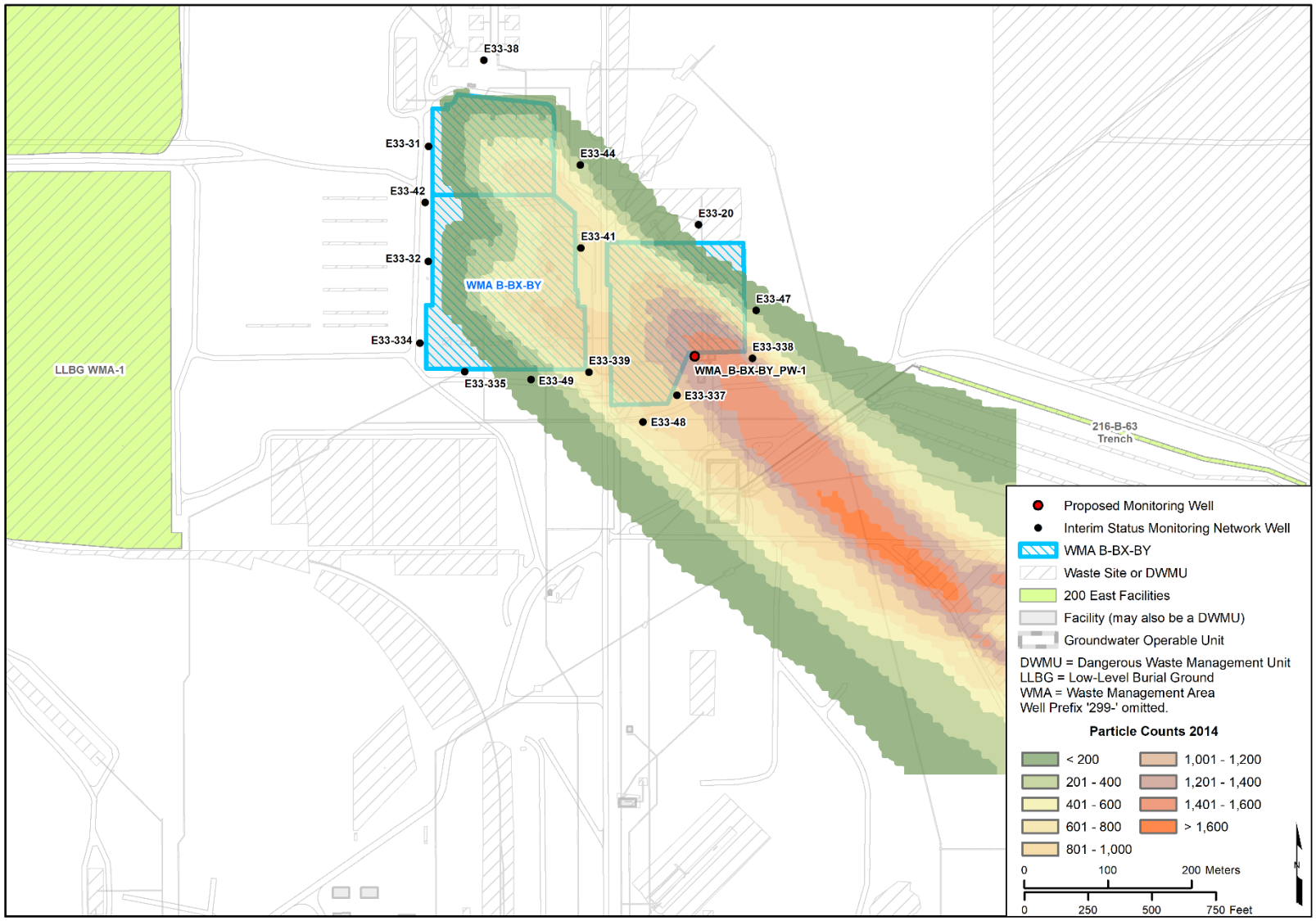

Figure K-22. Particle Count Map – WMA B-BX-BY, 2014

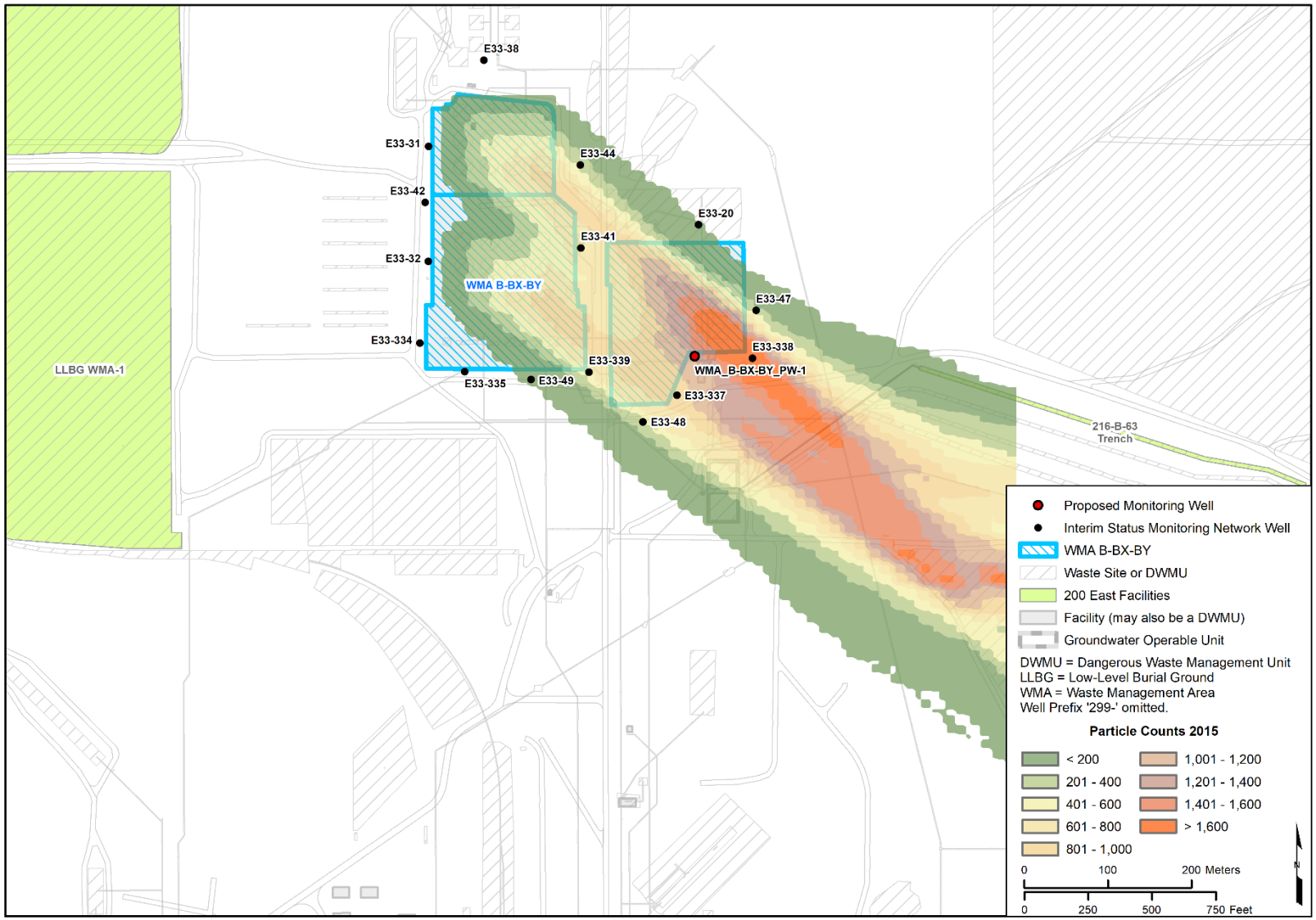

Figure K-23. Particle Count Map – WMA B-BX-BY, 2015

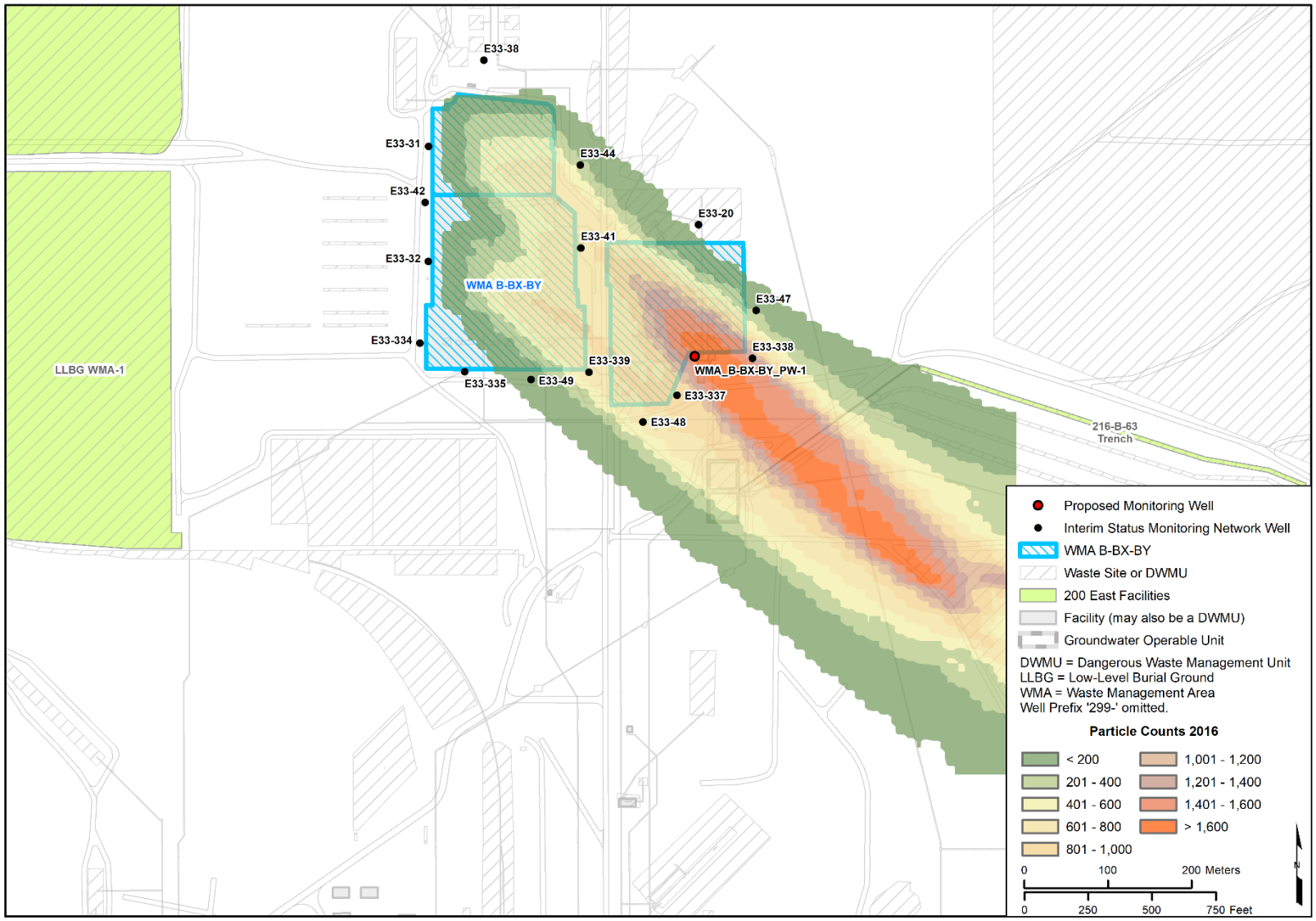

Figure K-24. Particle Count Map – WMA B-BX-BY, 2016

K3.4 Proposed Monitoring Wells

The location of the proposed monitoring well is shown in Figures K-21 through K-24. The particle counts tabulated for this location (Table K-11) indicate the relative timing of expected detections at the well and the relative potential of the well for detecting a release at the facility. The particle breakthrough curve (Figure K-25) shows the relative timing and particle density at the proposed monitoring well locations for the arrival, peak, and decline in particle counts resulting from the hypothetical instantaneous release to the water table beneath the facility.

Table K-11. Particle Density (Count) Monitoring Well WMA_B-BX-BY_PW-1

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
125	1996	1410	1344	1131	
250	1625	391	285	612	
375	18	535	521	164	
500	0	1207	1049	458	
625	0	391	474	1037	
750	0	33	44	869	
875	0	1	2	243	
1000	0	0	0	38	
1125	0	0	0	3	
1250	0	0	0	0	
1375	0	0	0	0	
1500	0	0	0	0	Average
Total	3639	3968	3719	4555	**3970**

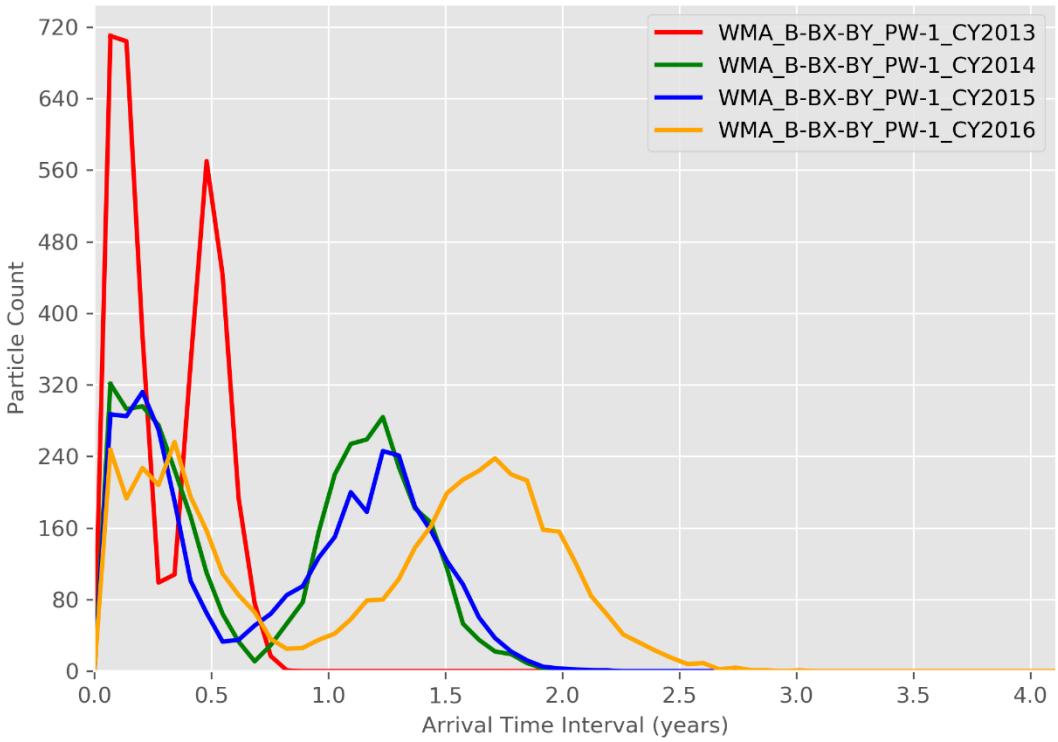

Figure K-25. Particle Breakthrough Curve at Monitoring Well WMA_B-BX-BY_PW-1

K3.5 Analyses of Particle Pathlines for Each Area of WMA B-BX-BY

Particle pathline maps shown in Section K3.2 depict an instantaneous release to the water table from the release locations in WMA B-BX-BY. Particle tracking also was performed for smaller regions of the facility to evaluate well locations for detecting releases from various regions of WMA B-BX-BY. This section contains the results of analyses performed to examine how releases from the various areas of WMA B-BX-BY that reach the groundwater beneath those release areas relate to each individual monitoring well. A series of figures and tables are provided to illustrate the fate of releases originating from three different areas of the waste management area. For these analyses, the particle release points presented in Figure K-2 are grouped into one of seven areas based on their spatial location. Those areas are depicted in Figure K-26. Figures K-27 through K-30 illustrate the particle pathlines originating from each of the areas for CYs 2013 through 2016.

Figures K-31 through K-41 illustrate the particle count time series for each existing and proposed downgradient monitoring well from CY 2013 through CY 2016. No plots are included for well 299-E33-31, which is classified as a downgradient well but it is upgradient in the flow conditions evaluated. Wells 299-E33-20 and 299-E33-44 are upgradient wells but their locations are downgradient from some of the release locations in the northwestern section of WMA B-BX-BY. Because particles pass in the vicinity of the wells, breakthrough curves were included for wells 299-E33-20 and 299-E33-44. Each figure has four panels, each of which depicts the particle counts for one CY (2013 through 2016). Additionally, each panel shows a separate breakthrough curve for particles emanating from each area. For example, Figure K-32 depicts the particle counts at well 299-E33-41, which receives particles from areas 2, 6, and 7 in 2015. In the figure, within the panel for 2015 (bottom row, left), the particle breakthrough curve from area 2 is depicted with a red line, area 6 with a pink line, and area 7 with a light green line.

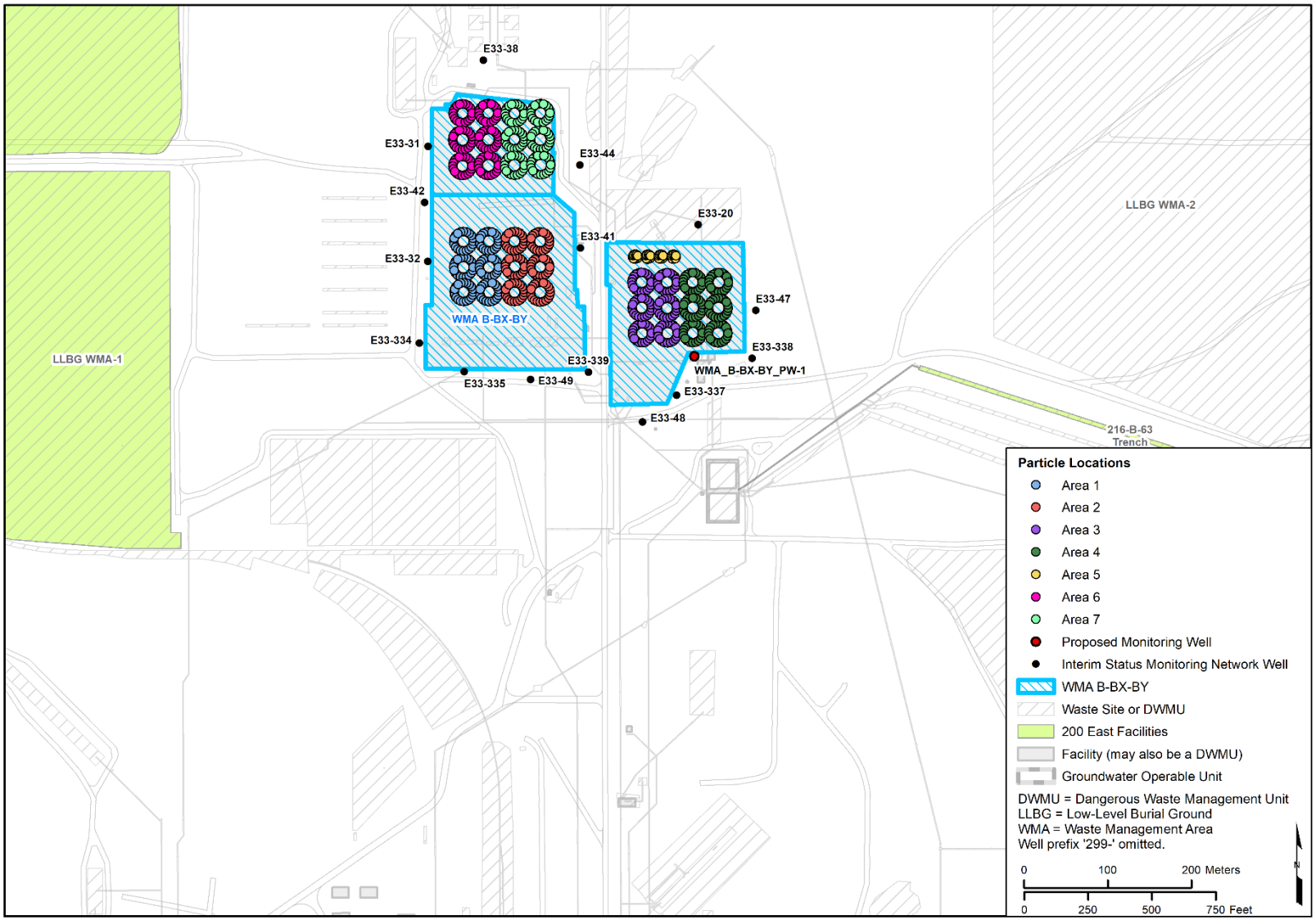

Figure K-26. Particle Release Locations and Areas of WMA B-BX-BY

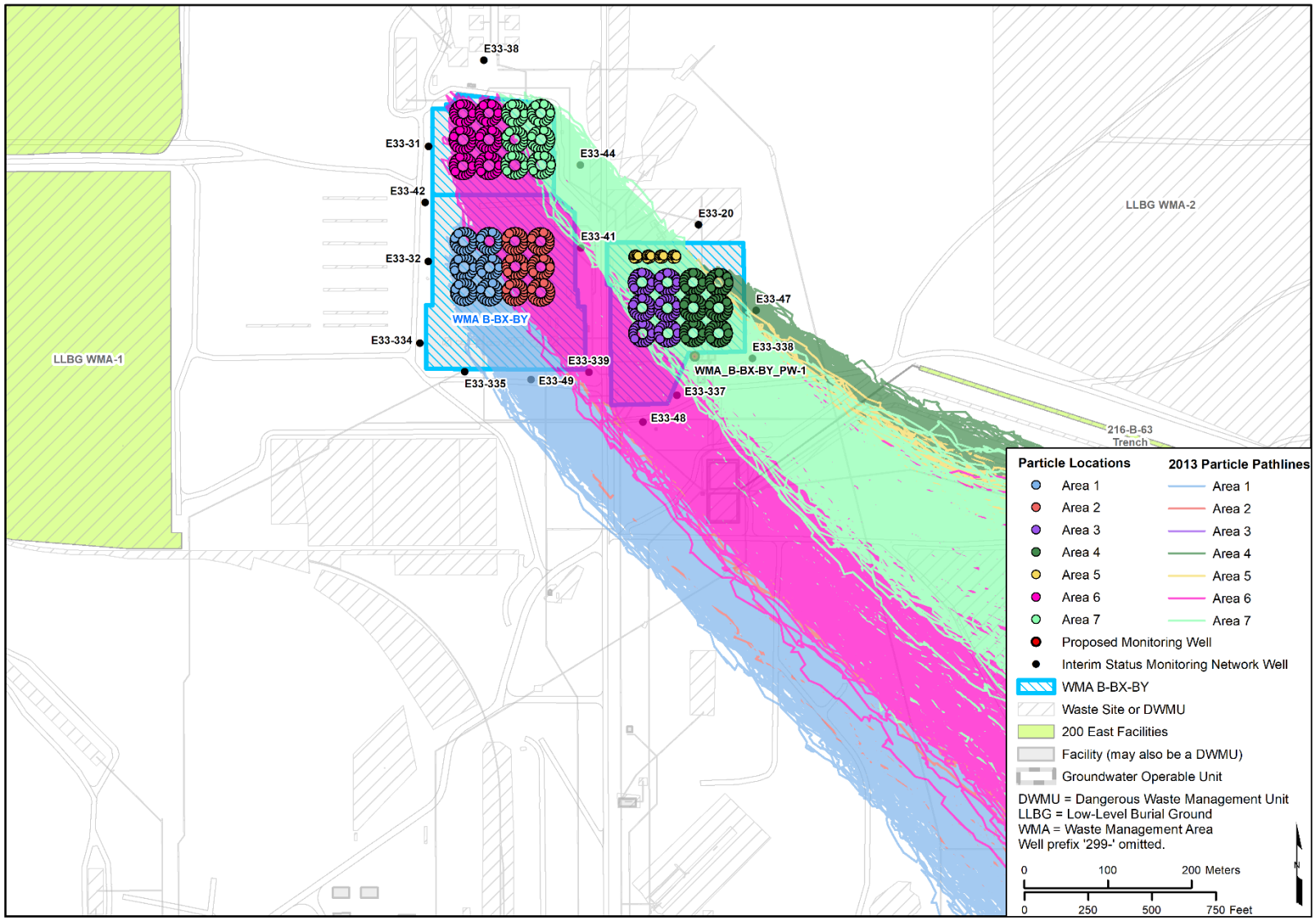

Figure K-27. CY 2013 Particle Pathlines per Area of WMA B-BX-BY

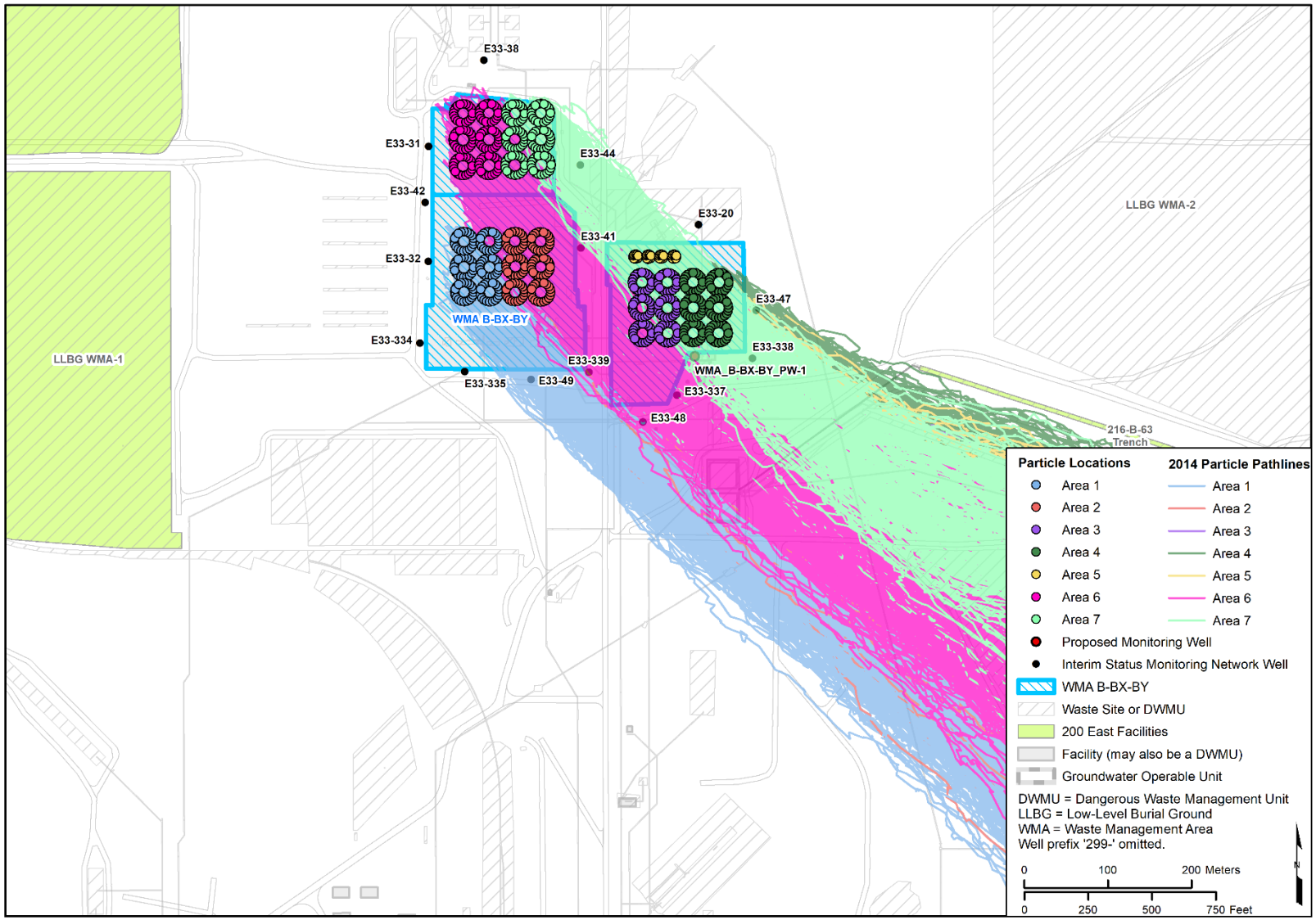

Figure K-28. CY 2014 Particle Pathlines per Area of WMA B-BX-BY

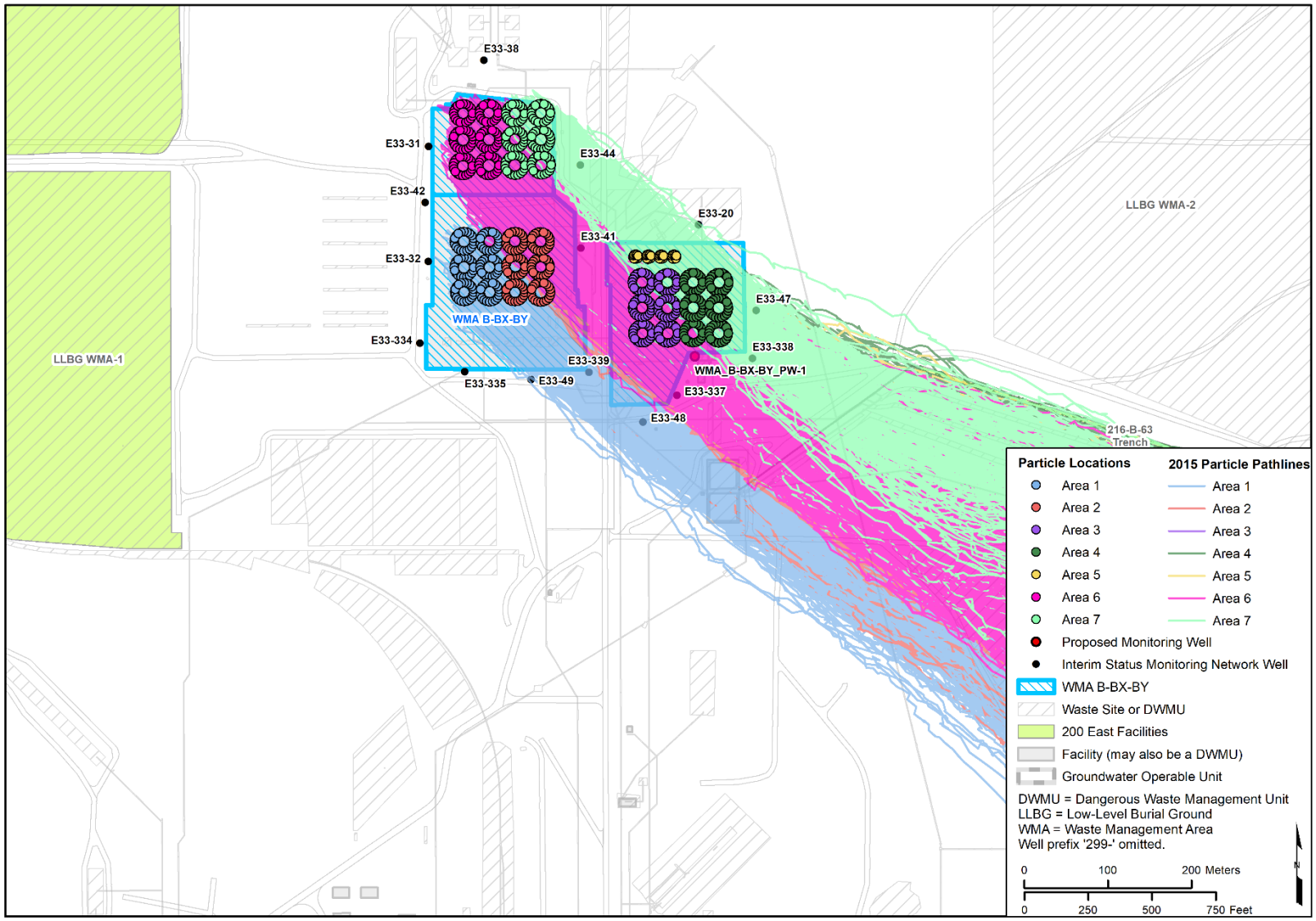

Figure K-29. CY 2015 Particle Pathlines per Area of WMA B-BX-BY

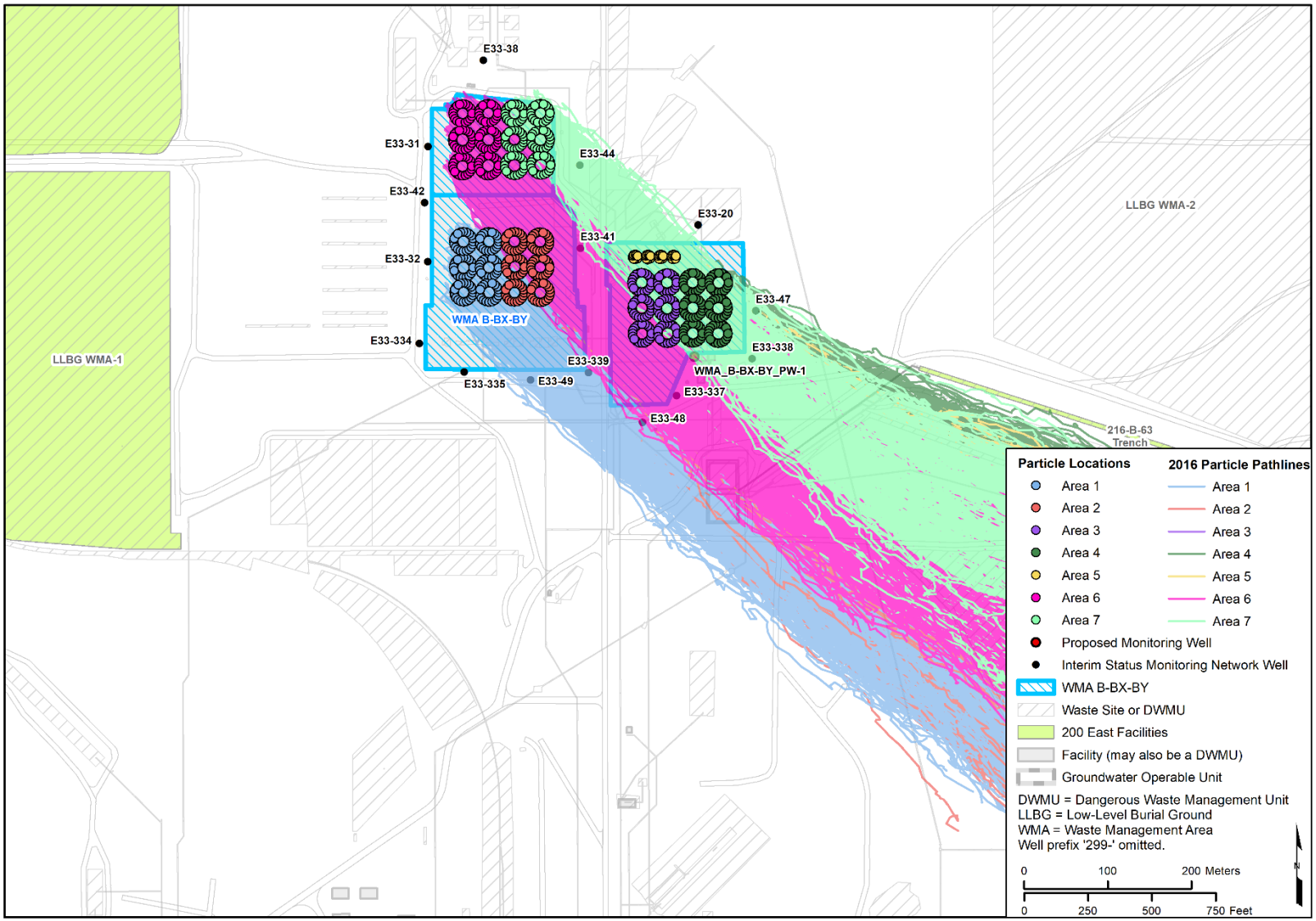

Figure K-30. CY 2016 Particle Pathlines per Area of WMA B-BX-BY

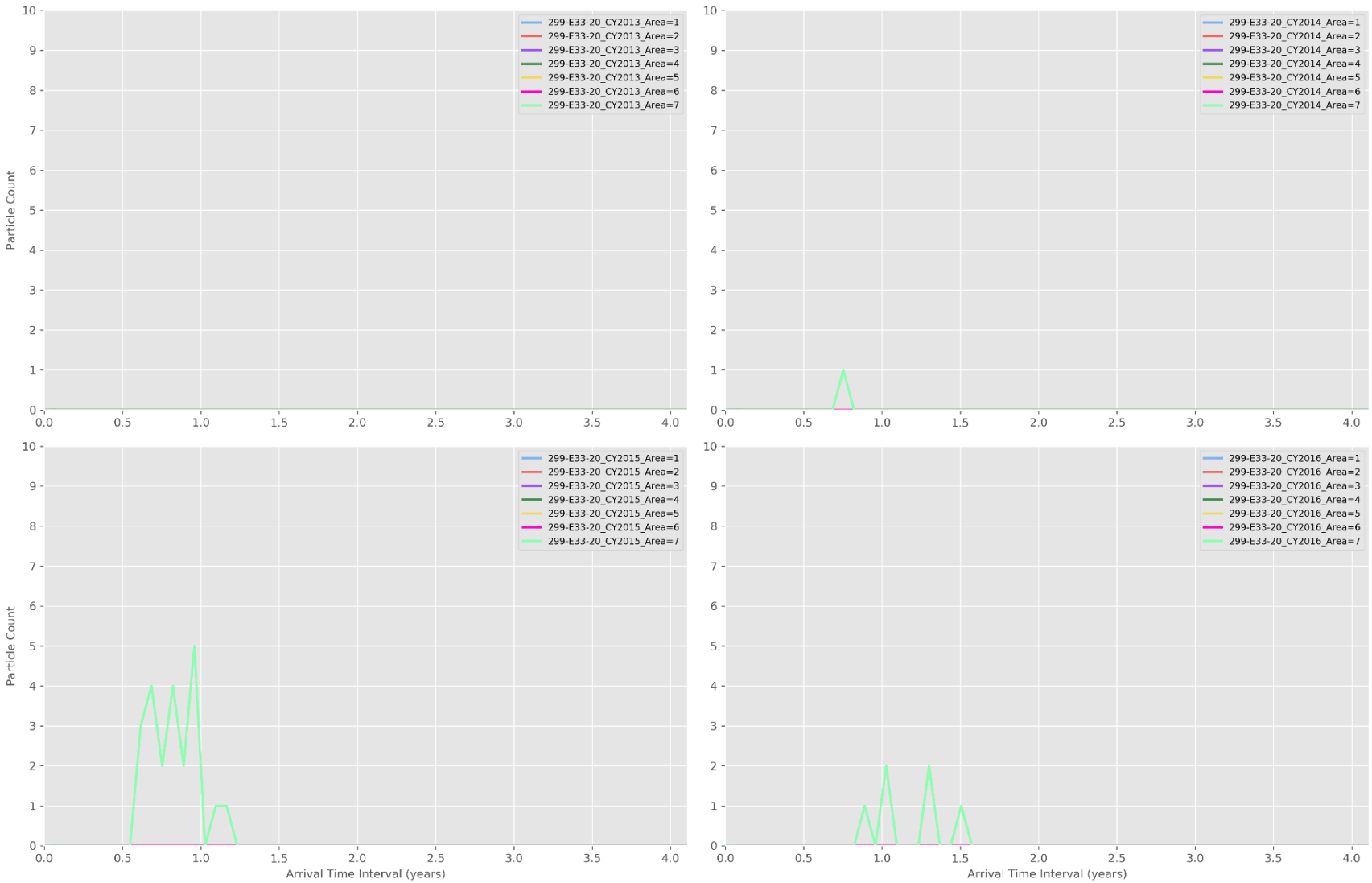

Figure K-31. Particle Breakthrough Curves per Area at Monitoring Well 299-E33-20

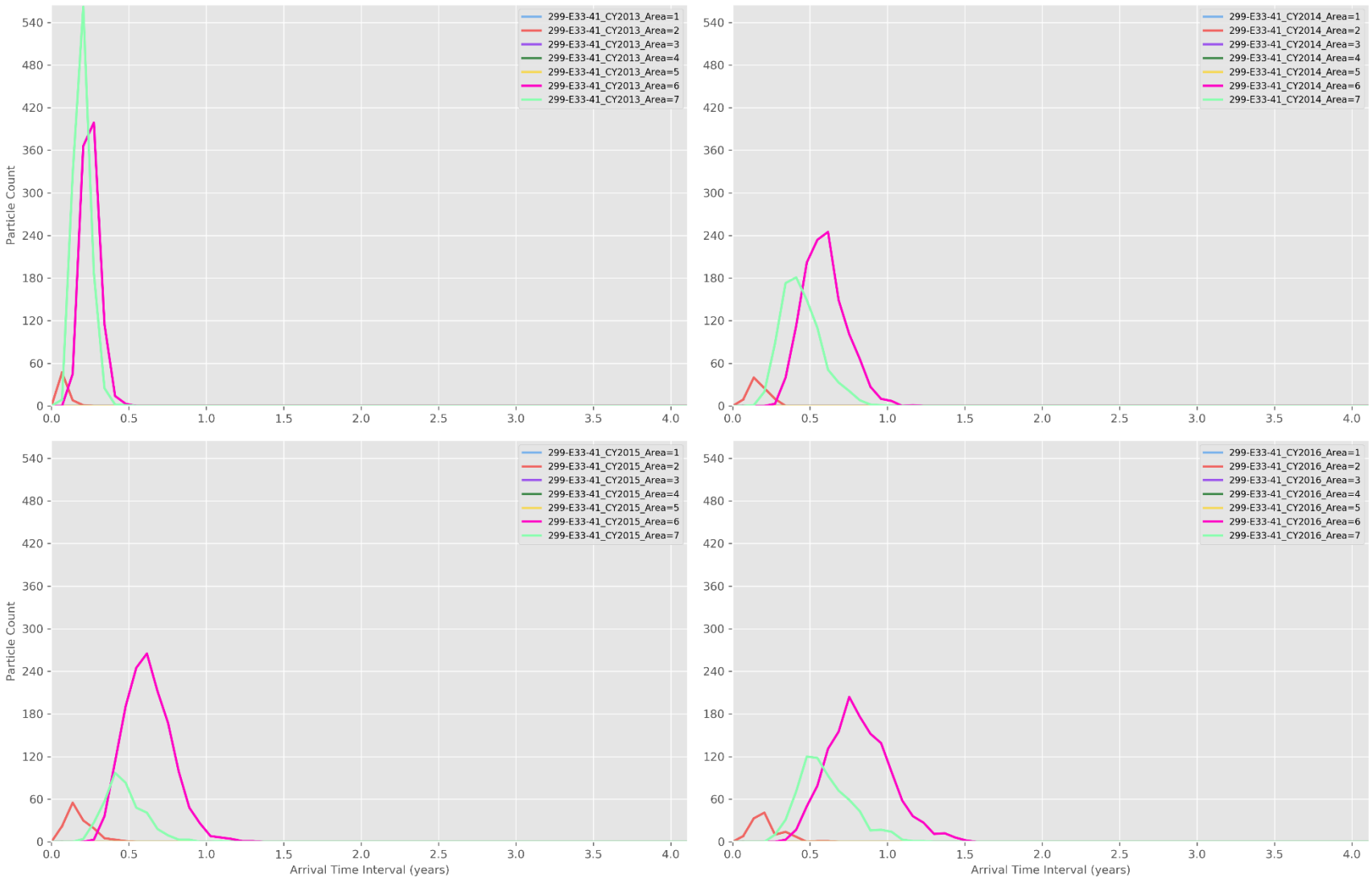

Figure K-32. Particle Breakthrough Curves per Area at Monitoring Well 299-E33-41

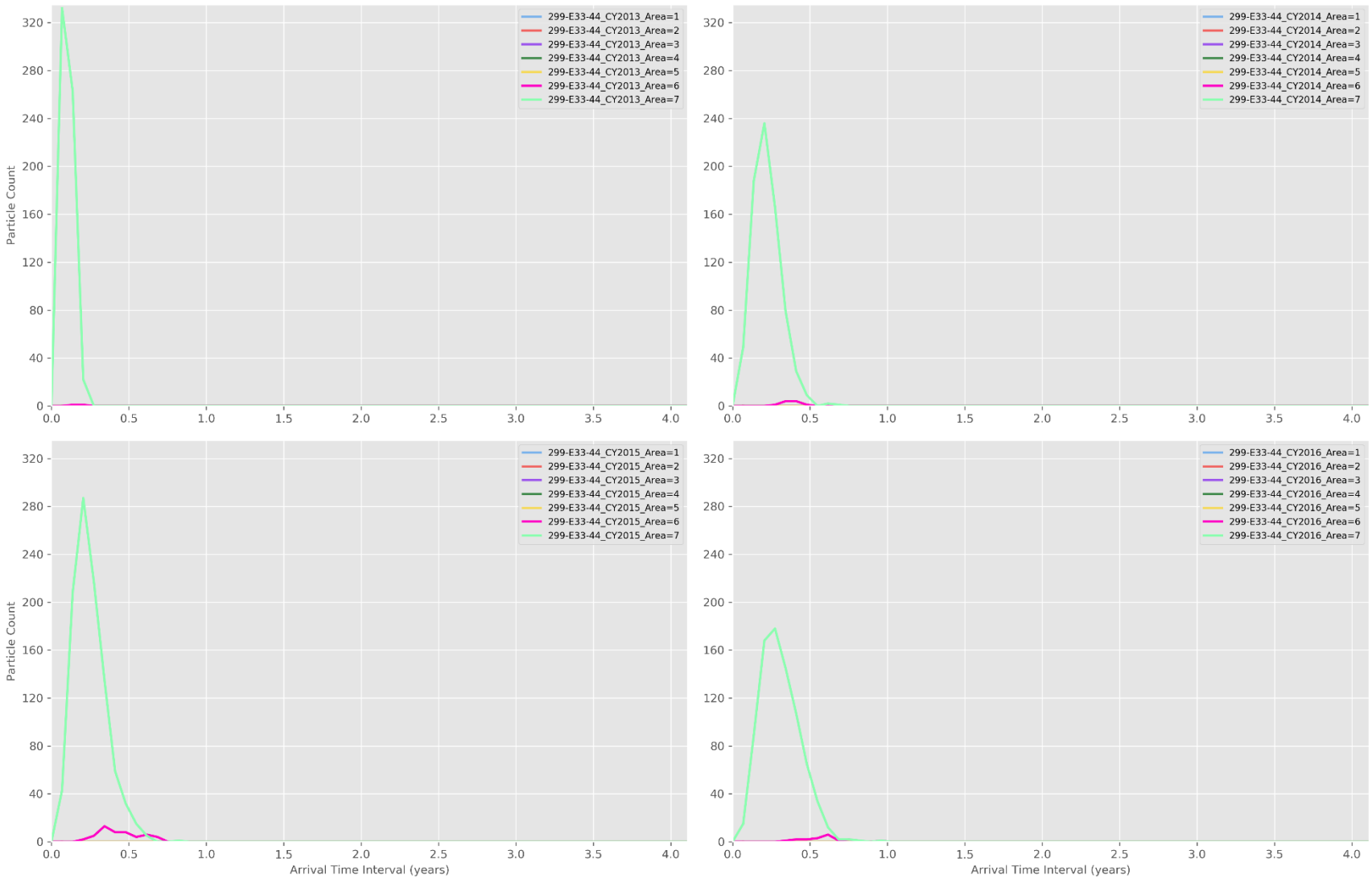

Figure K-33. Particle Breakthrough Curves per Area at Monitoring Well 299-E33-44

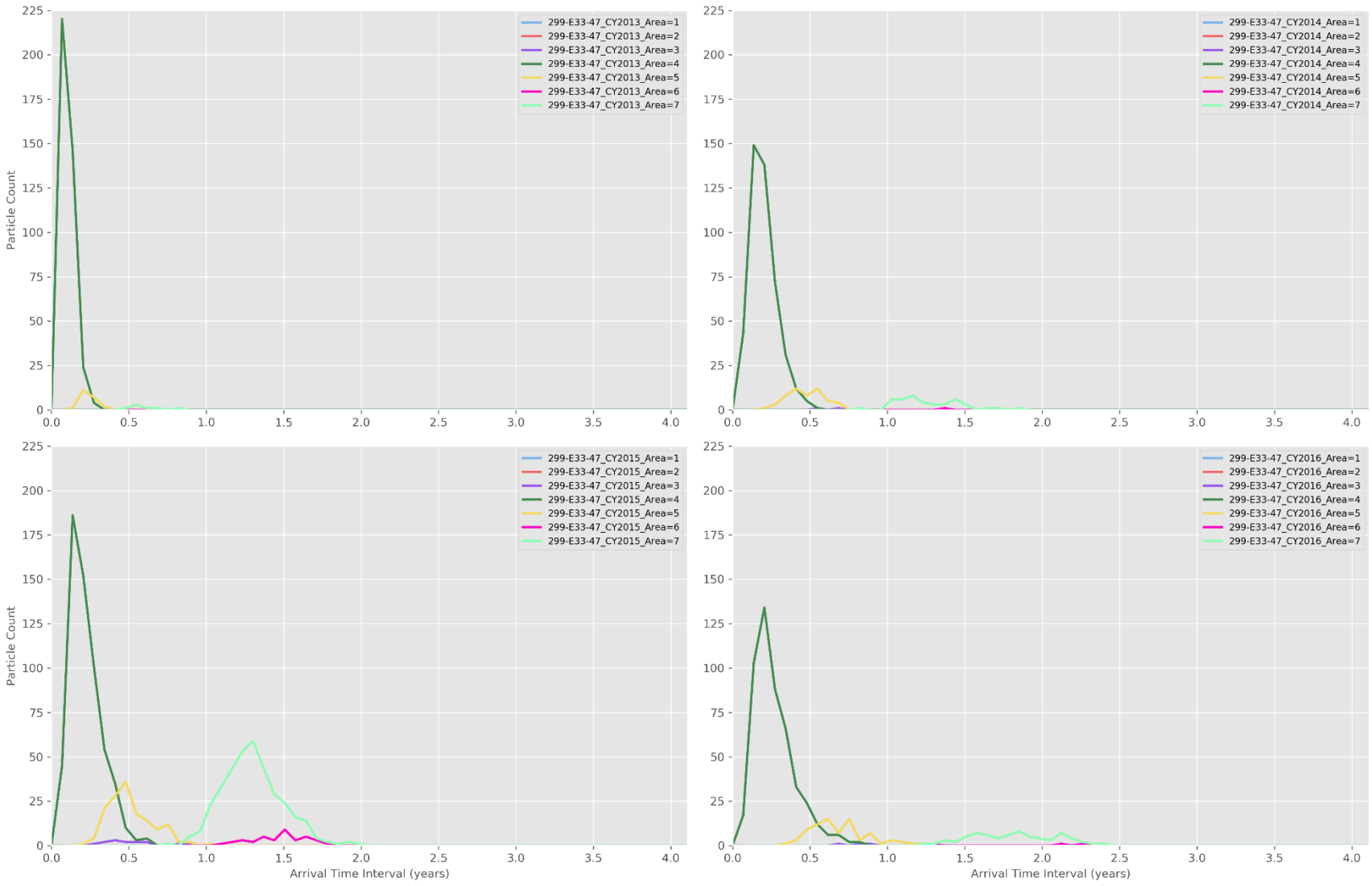

Figure K-34. Particle Breakthrough Curves per Area at Monitoring Well 299-E33-47

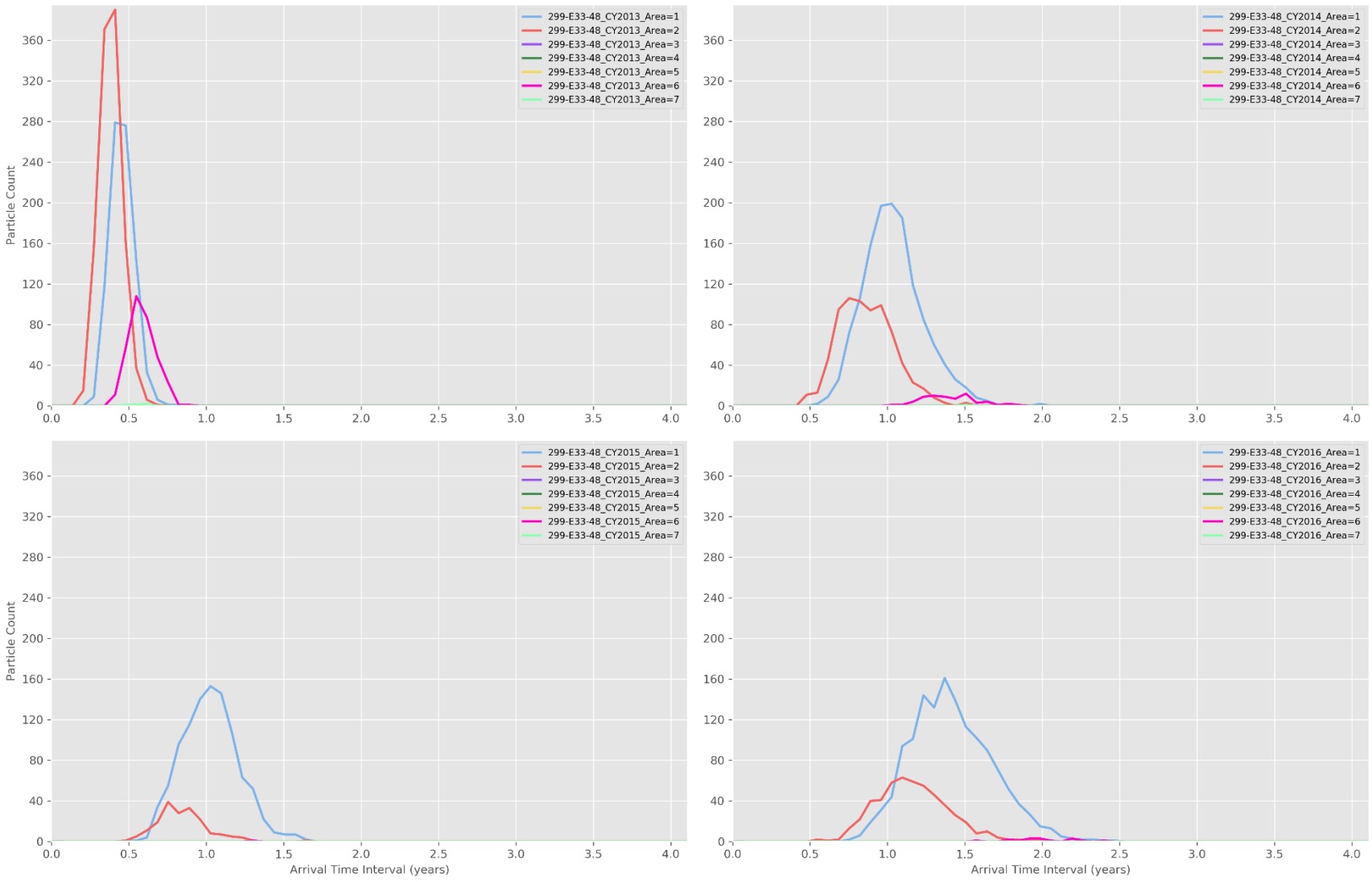

Figure K-35. Particle Breakthrough Curves per Area at Monitoring Well 299-E33-48

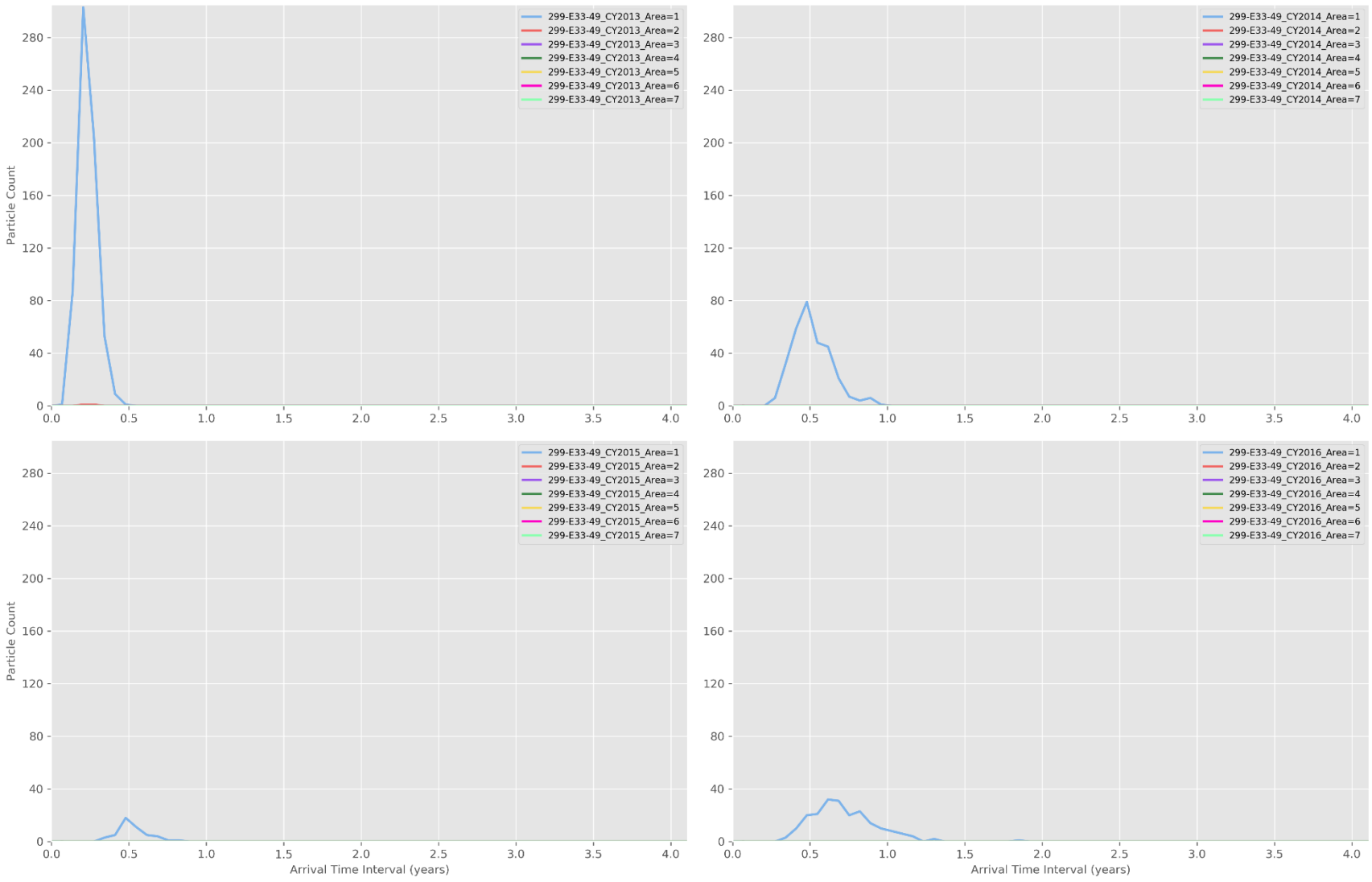

Figure K-36. Particle Breakthrough Curves per Area at Monitoring Well 299-E33-49

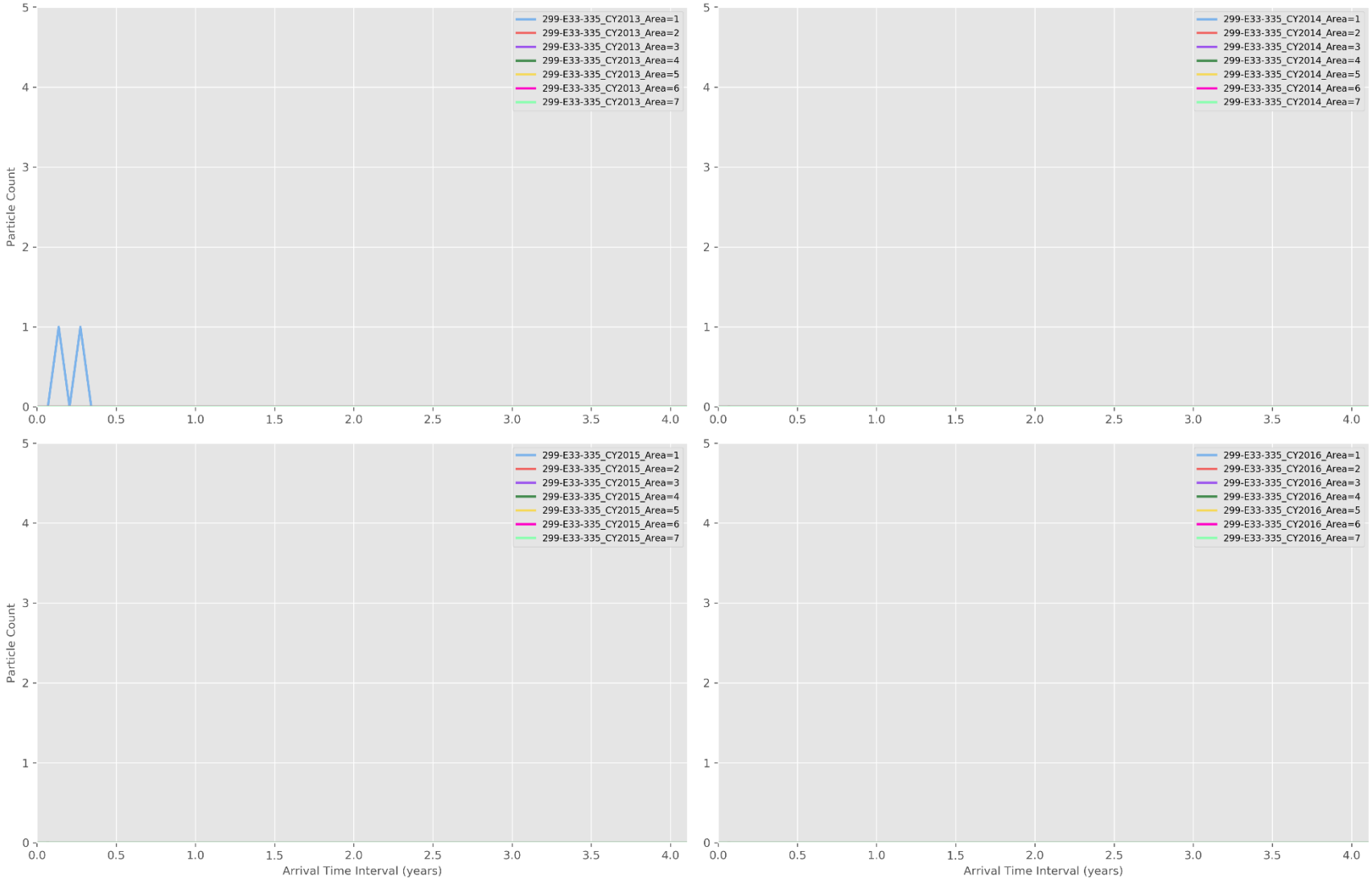

Figure K-37. Particle Breakthrough Curves per Area at Monitoring Well 299-E33-335

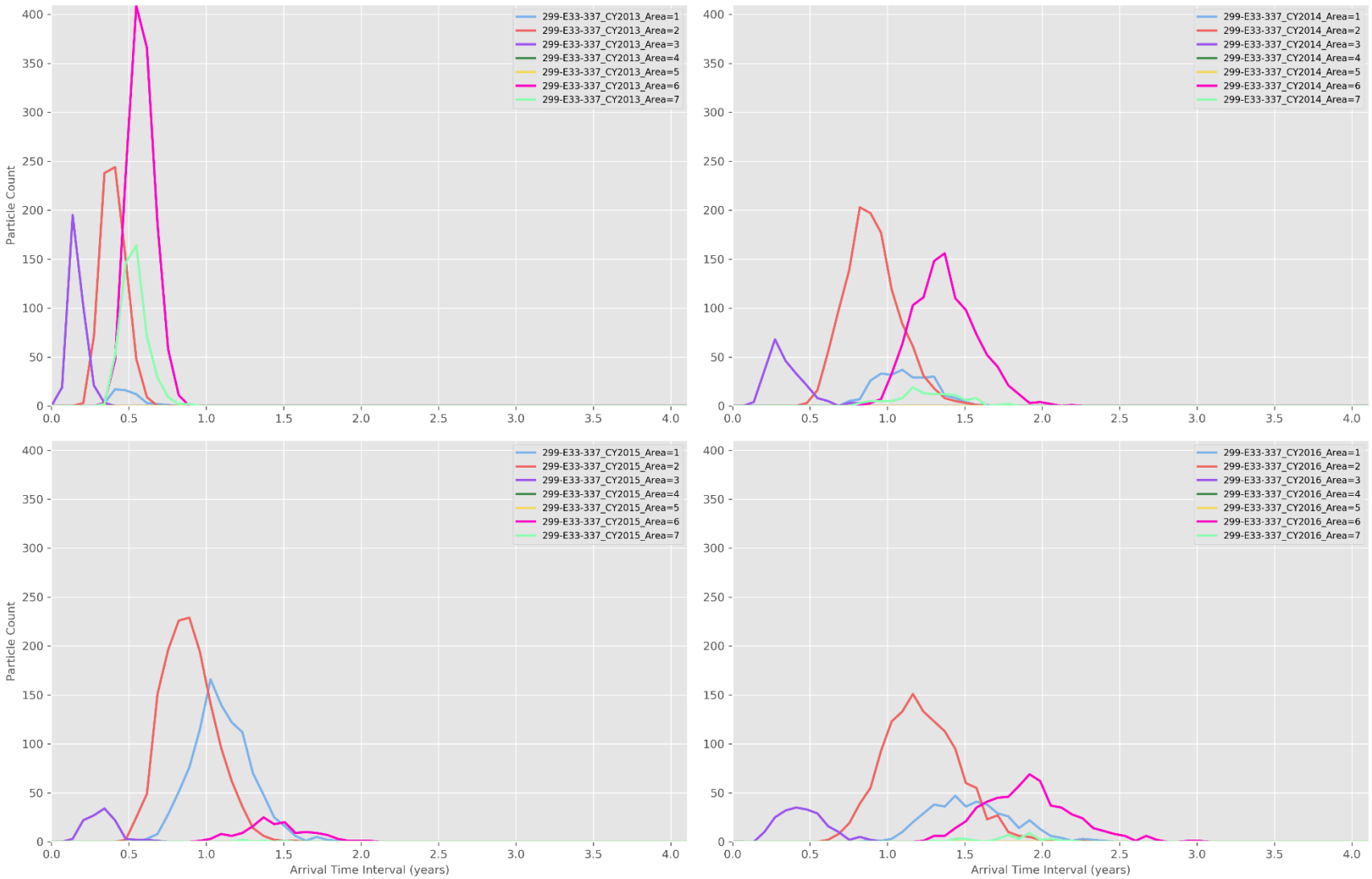

Figure K-38. Particle Breakthrough Curves per Area at Monitoring Well 299-E33-337

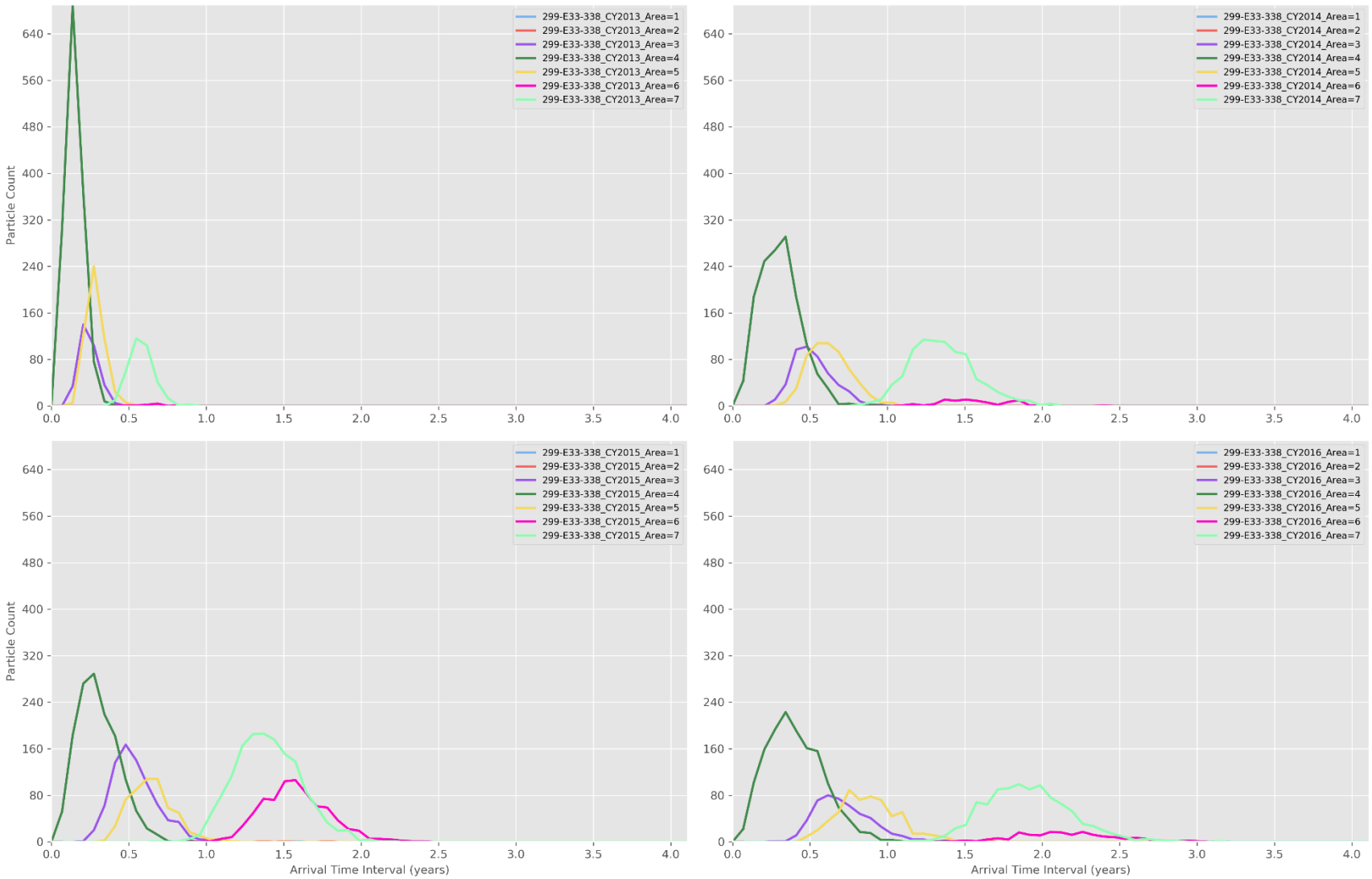

Figure K-39. Particle Breakthrough Curves per Area at Monitoring Well 299-E33-338

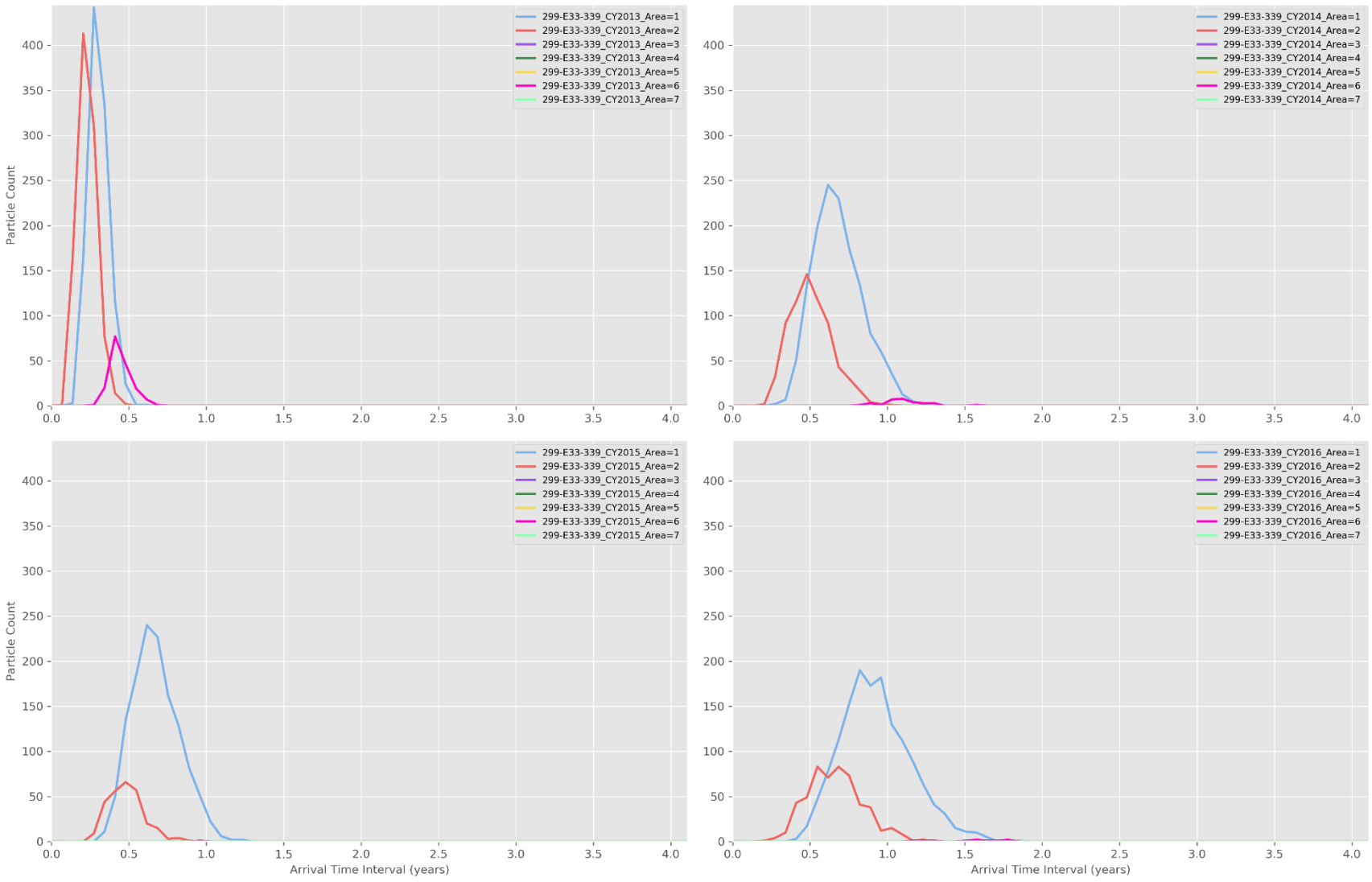

Figure K-40. Particle Breakthrough Curves per Area at Monitoring Well 299-E33-339

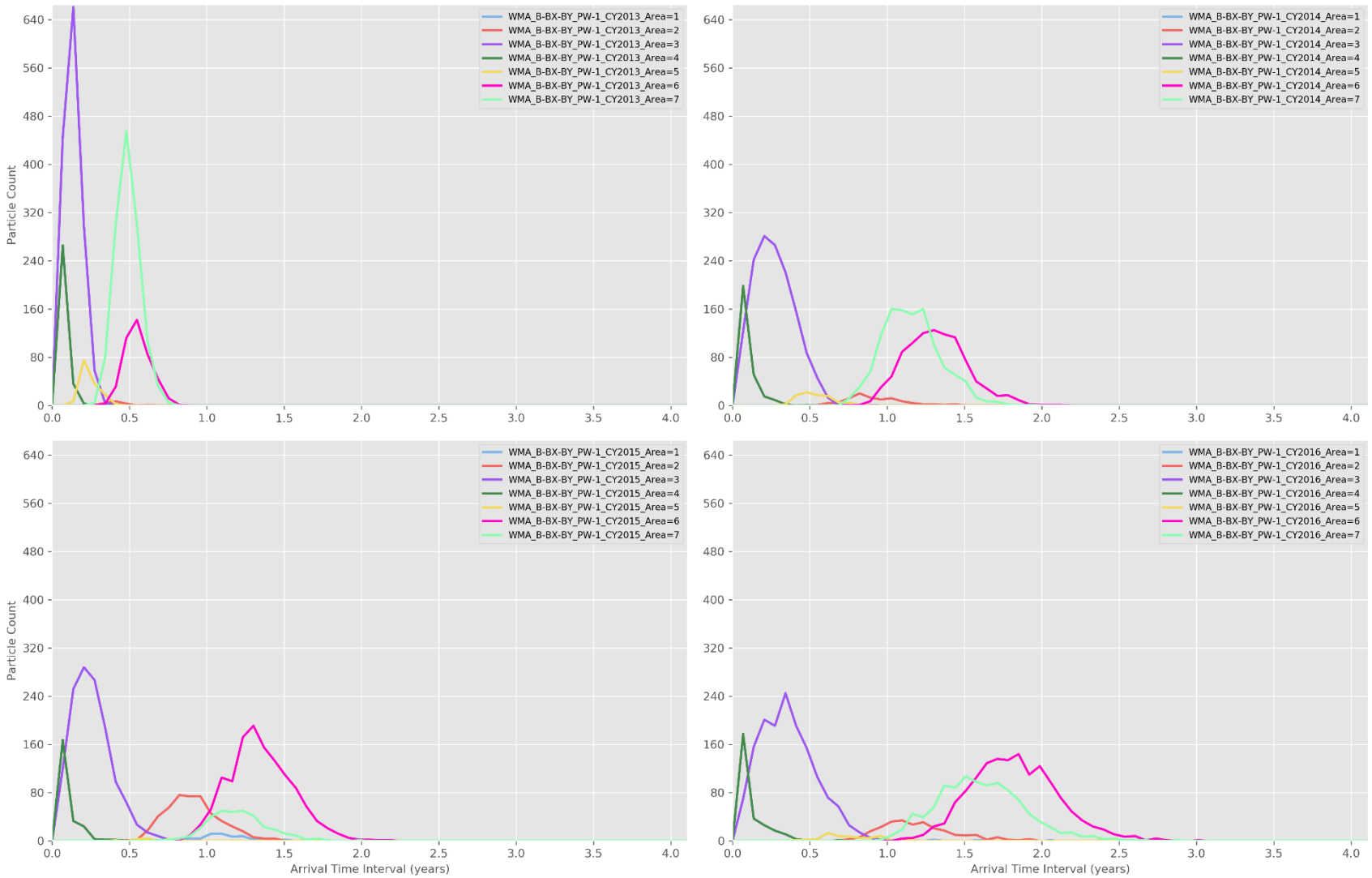

Figure K-41. Particle Breakthrough Curves per Area at Monitoring Well WMA_B-BX-BY_PW-1

K3.6 Vertical Migration Potential

As described in Section 3.3 of the main text of this ECF, the American Petroleum Institute (API) plume diving calculation was used to estimate the likely rate of vertical migration of dissolved constituents downward under the influence of recharge at the water table. At each well the slope of the plume dive was multiplied by the distance from the particle starting location to the well location to estimate the depth to which the dissolved constituents may be anticipated to have migrated by the time they reach the monitoring well location.

This estimated depth of the plume was then compared to the depth from the water table to the bottom of the monitoring well screen. If the depth of the plume is below the bottom of the monitoring well screen, then the dissolved constituents may be anticipated to pass beneath the well screen. If it falls within the interval between the top of the water table and the bottom of the well screen, then the well depth is appropriate for detection of releases at WMA B-BX-BY.

For each downgradient monitoring well at WMA B-BX-BY, the distance from the centroid of the facility to each well was used in the calculation. The hydraulic conductivity used in the calculation for WMA B-BX-BY, 18,200 m/d (59,711 ft/d), is the calibrated hydraulic conductivity from the CPGWM for the Cold Creek unit, which underlies the facility. The results of the API plume diving calculation for the downgradient wells for WMA B-BX-BY are shown in Table K-12. Well 299-E33-31 is not evaluated for vertical migration. Although the well is classified as a downgradient well, it is upgradient in the flow conditions evaluated. Wells 299-E33-20 and 299-E33-44 are classified as upgradient wells, but their locations are downgradient from some of the release locations in the northwestern section of WMA B-B-BY. Because of this, the wells are included in the vertical migration calculation.

Table K-12. Summary of Well Screen Interval Evaluation for Downgradient Wells

Monitoring Well	Existing or Proposed Well?	Distance, D, (m)[a]	Recharge, *i*, (m/yr)[b]	Slope, S, of Plume Dive[c]	Estimated Depth of Plume Below Water Table (m)[d]	Depth from Water Table to Bottom of Well Screen (m)[e]	Is Plume Depth Above Bottom of the Screen? (Yes/No/N/A)
299-E33-20	Existing	176.5	2.60E-03	1.64E-04	2.90E-02	0.90	Yes
299-E33-41	Existing	36.0	2.60E-03	1.64E-04	5.92E-03	1.60	Yes
299-E33-44	Existing	123.8	2.60E-03	1.64E-04	2.03E-02	2.80	Yes
299-E33-47	Existing	244.2	2.60E-03	1.64E-04	4.01E-02	4.40	Yes
299-E33-48	Existing	213.3	2.60E-03	1.64E-04	3.51E-02	6.00	Yes
299-E33-49	Existing	139.3	2.60E-03	1.64E-04	2.29E-02	4.90	Yes
299-E33-335	Existing	167.4	2.60E-03	1.64E-04	2.75E-02	3.60	Yes
299-E33-337	Existing	211.2	2.60E-03	1.64E-04	3.47E-02	5.20	Yes
299-E33-338	Existing	258.7	2.60E-03	1.64E-04	4.25E-02	4.00	Yes
299-E33-339	Existing	132.9	2.60E-03	1.64E-04	2.18E-02	4.50	Yes
WMA_B-BX-BY_PW-1	Proposed	197.3	2.60E-03	1.64E-04	3.24E-02	N/A	N/A

Table K-12. Summary of Well Screen Interval Evaluation for Downgradient Wells

Monitoring Well	Existing or Proposed Well?	Distance, D, (m)[a]	Recharge, *i*, (m/yr)[b]	Slope, S, of Plume Dive[c]	Estimated Depth of Plume Below Water Table (m)[d]	Depth from Water Table to Bottom of Well Screen (m)[e]	Is Plume Depth Above Bottom of the Screen? (Yes/No/N/A)

a. Distance of the well from centroid of dangerous waste management unit.

b. A representative number from the CPGWM. The recharge values represent fluxes from surface water discharge due to historical operations at the Hanford Site and are summarized in EMDT-BC-0002, *Vadose Zone Attenuated Recharge, Electronic Modeling Data Transmittal – Boundary Condition (Artificial Recharge)*-0002. The anthropogenic flux is added to the natural recharge component in order to establish the final total recharge flux used in the simulations. Discharges included in EMDT-BC-0002 have been attenuated to account for travel through the vadose zone.

c. Slope of the plume dive computed using the American Petroleum Institute plume diving calculation as detailed in the main text of this ECF. The migration parameters for WMA B-BX-BY used in the calculation of slope are as follows:

Hydraulic conductivity: 18,200 m/d (59,711 ft/d) (a calibrated value from the CPGWM)

Hydraulic gradient: 2.38E-06 (determined from 2016 water-level maps produced using TRIM)

d. Plume depth at monitoring well location computed from distance, D, times the slope, S.

e. Depths obtained from Table 3-5 in DOE/RL-2016-66, *Hanford Site RCRA Groundwater Monitoring Report for 2016*.

CPGWM = Central Plateau Groundwater Model

ECF = environmental calculation file

N/A = not applicable

TRIM = Tikhonov Regularized Inverse Method

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Appendix L

Facility-Specific Results for Waste Management Area C

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Terms

API	American Petroleum Institute
CPGWM	Central Plateau Groundwater Model
CY	calendar year
ECF	environmental calculation file
SST	single-shell tank
TRIM	Tikhonov Regularized Inverse Method
WMA	waste management area

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L1 Purpose and Background

The primary purpose of the calculations presented here is to estimate directions of potential migration to assess the efficacy of the geographical distribution of wells in the proposed monitoring well network for the subject facility. The calculations described within the main text of this environmental calculation file (ECF) were performed for each of the 200 East Facilities. This appendix presents results developed from the calculations that are specific to Waste Management Area (WMA) C.

Located in the east-central part of the 200 East Area, WMA C consists of the 241-C Tank Farm. The tank farm is composed of 16 single-shell tanks (SSTs) and ancillary liquid handling equipment including diversion boxes, a vault, a catch tank, a french drain, dry wells, and piping. The 241-C Tank Farm contains 16 SSTs, 4 of which have smaller capacities. WMA C was used to store radioactive mixed waste from the bismuth phosphate, Plutonium Uranium extraction, and uranium extraction processes. The tanks at WMA C have undergone interim stabilization. During interim stabilization, the supernatant liquid and salt cake were removed at the 241-C Tank Farm. Thus, the tanks' total remaining waste volume is primarily sludge, with generally a small percentage (i.e., less than 10%) of drainable liquid remaining (Section 2.1.2 in DOE/RL-2009-77, *Groundwater Quality Assessment Plan for the Single-Shell Tank Waste Management Area C*).

A groundwater quality assessment program for WMA C was put in place in 2009 due to elevated specific conductance detected in one downgradient monitoring well. During the groundwater quality assessment, groundwater was found to have the dangerous waste constituent cyanide. In 2016, the average cyanide concentrations in four wells were above the cleanup level (Section 3.3 of DOE/RL-2016-66, *Hanford Site RCRA Groundwater Monitoring Report for 2016*). Groundwater monitoring is ongoing at WMA C to assess the extent of dangerous waste that has entered the groundwater.

The interim status groundwater monitoring well network has grown with additional wells since inception. Groundwater flow direction at WMA C is south-southeast (Section 3.3 in DOE/RL-2016-66).

The WMA C interim status monitoring network (Figure L-1) consists of three upgradient wells (299-E27-12, 299-E27-15, and 299-E27-22), seven downgradient wells (299-E27-4, 299-E27-7, 299-E27-13, 299-E27-14, 299-E27-21, 299-E27-23, and 299-E27-24), and two crossgradient wells (299-E27-25 and 299-E27-155). These wells, with the exception of 299-E27-24 and 299-E27-155, are screened across the top of the aquifer (Section 4.1 in SGW-60442, *WMA C April through June 2016 Quarterly Groundwater Monitoring Report*). As of 2016, monitoring well 299-E27-4 was scheduled to be decommissioned and monitoring well 299-E27-7 was to be replaced with monitoring well 299-E27-26 (Section 3.3 in DOE/RL-2016-66), which is also shown in Figure L-1.

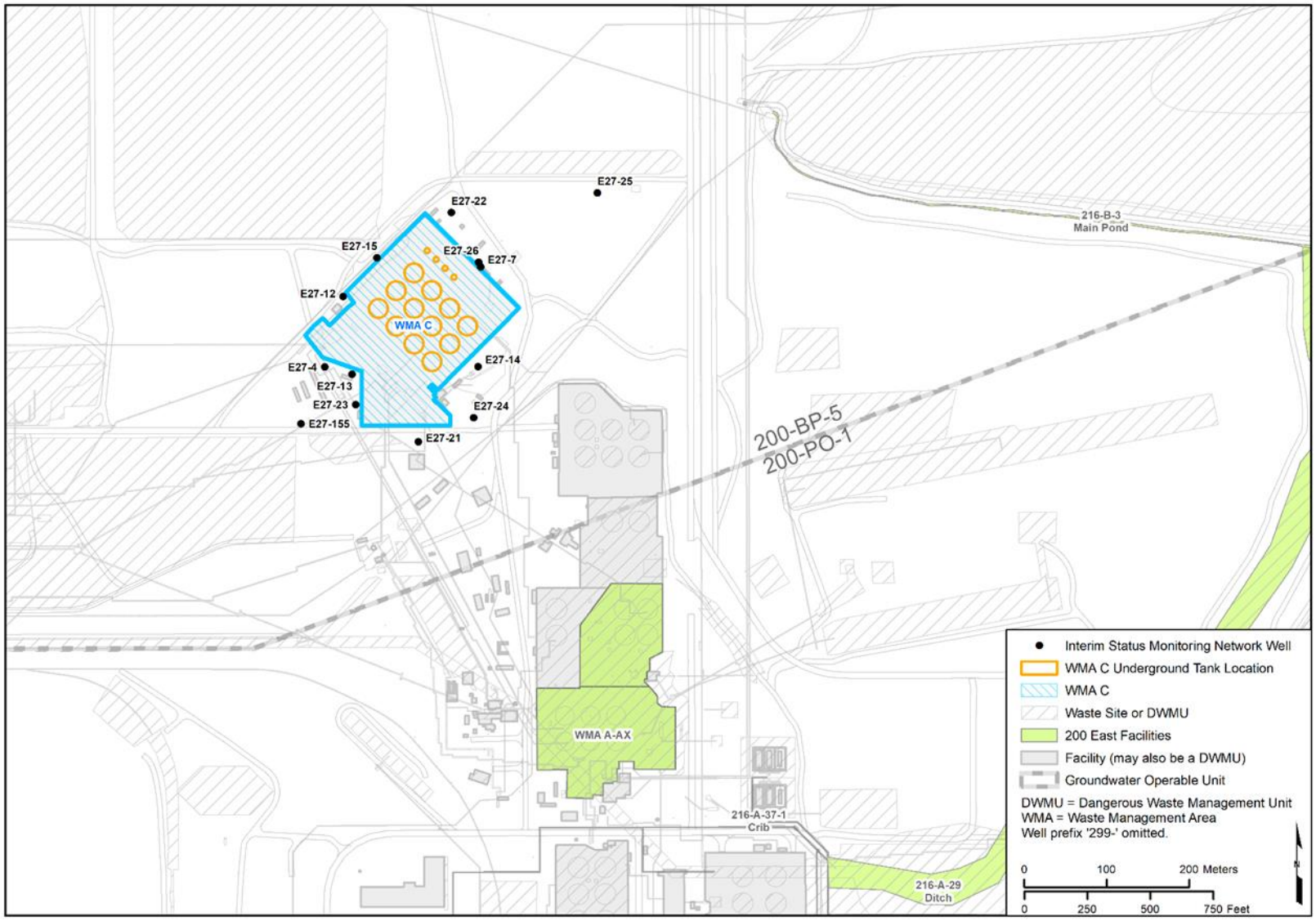

Figure L-1. Locations of Interim Status Groundwater Monitoring Wells at WMA C

L2 Facility-Specific Input for WMA C

Inputs used in the calculations that were specific to WMA C are described in this chapter.

L2.1 Particle Count Grid and Release Locations

To prepare particle count maps, a distribution of facility-specific starting locations is required. The starting locations for the particle-tracking calculations represent the area over which a potential release from a given facility would impact the underlying water table. The particle releases were located at plausible release sites throughout the facility. For WMA C, 20 release locations were specified around the circumference of each of the 12 large SSTs and 8 release locations were specified around the circumference of each of the 4 small SSTs (Figure L-2). Twenty particles were released and tracked from each release location to provide the density of particles in space and time required for the detailed facility-specific calculations, randomizing the seed values for the dispersion calculations. Thus, 5,440 [5,440 = 12 (large tanks) × 20 (release locations) × 20 (releases) + 4 (small tanks) × 8 (release locations) × 20 (releases)] particles were tracked for each of the four simulations.

Contour maps of particle counts were generated by counting the number of particles that pass through a pre-defined uniform calculational grid (Figure L-2). The grid used to develop the relative particle density maps is defined by 10 by 10 m (33 by 33 ft) cells. The grid is oriented to be parallel to the predominant groundwater flow direction at WMA C.

L2.2 Migration Parameters

Parameters specific to the groundwater flow conditions at WMA C are reported throughout the various documents for the facility. The parameters used in the calculations performed herein to represent nonreactive dissolved contaminant migration are mobile (or effective) porosity and hydraulic conductivity. The parameters used in these calculations are representative of local conditions for a conservative (i.e., nonreactive) solute dissolved within groundwater.

The hydraulic conductivity value reported in site literature for WMA C is 17,000 m/d (55,774 ft/d) (Table 1 in ECF-Hanford-17-0241, *Hydraulic Gradient and Velocity Calculations for RCRA Sites in 2017*). As described in Section 4.2.1.1 of the main text of this ECF, the hydraulic conductivity used in the work performed herein corresponds to the calibrated values from the Central Plateau Groundwater Model (CPGWM) (CP-47631, *Model Package Report: Central Plateau Groundwater Model, Version 8.4.5*). Figure 3-2 in the main text of this ECF indicates WMA C is located in the hydrostratigraphic unit zone corresponding to the Hanford formation. The value used for the hydraulic conductivity for WMA C is 15,000 m/d (49,213 ft/d), which corresponds to the Hanford formation as shown in Table 4-1 in the main text of this ECF. The mobile (effective) porosity defined for the Hanford formation, which underlies WMA C, is specified at 0.25.

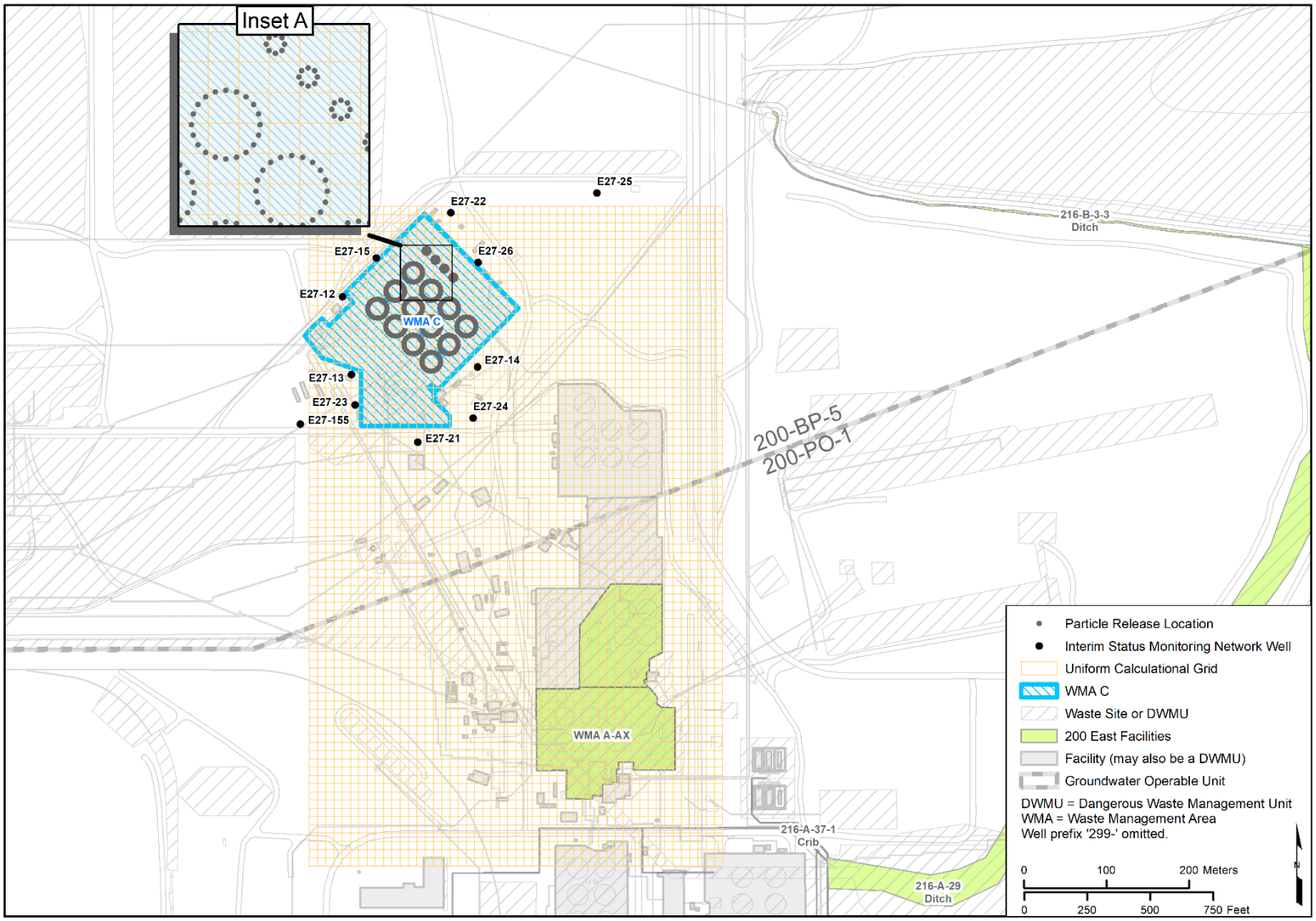

Figure L-2. Uniform Calculational Grid and Release Locations at WMA C

L3 Facility-Specific Results for WMA C

The groundwater elevation contours prepared in the vicinity of WMA C using the Tikhonov Regularized Inverse Method (TRIM) are presented in this chapter. In addition, the outputs of the particle tracking and particle count calculations are presented, including the following:

- Maps of calculated particle pathlines for the flow conditions determined for each of the four years (2013, 2014, 2015, and 2016). These are presented at the facility-specific scale considering advective and dispersive migration.
- Time-series plots, referred to as particle breakthrough curves, of the relative arrival, peak, and decline in particle counts at each interim status groundwater monitoring well location and each proposed monitoring location, where applicable.
- Tabulation of relative particle counts for each interim status groundwater monitoring well location and each proposed monitoring location, where applicable.
- Maps of particle counts downgradient of each facility based on the flow conditions determined for each of the four years.

The results of calculations of potential vertical migration of contaminants at the monitoring well locations are also presented.

L3.1 Groundwater Elevation Contours

Figures L-3 through L-6 show the results of the groundwater elevation analysis completed using TRIM in the vicinity of WMA C. The figures depict general patterns of groundwater elevations and hydraulic gradients for conditions represented by calendar years (CYs) 2013, 2014, 2015, and 2016. These groundwater elevation contours and associated hydraulic gradients form the basis for the facility-specific calculations performed for this ECF.

L3.2 Particle Tracking

Once the groundwater elevation contour maps and underlying piecewise continuous elevation grids were prepared using TRIM, particle tracking was implemented using both advection and dispersion.
The particle pathlines that were produced depict the patterns of spreading that might accompany the migration of contaminants near WMA C for the flow conditions calculated for CYs 2013, 2014, 2015, and 2016. Figures L-7 through L-10 depict the particle pathlines developed based on the groundwater elevations prepared throughout the 200 East Area using TRIM. The resulting maps were prepared based on the release of 20 particles from each starting location to provide the high density of particles in space and time required for these detailed facility-specific calculations. Figures L-7 through L-10 depict the particle pathlines calculated after 200 days of travel, by which time it was determined that most of the particles would have arrived at or passed by the interim status groundwater monitoring wells. Figures L-7 through L-10 depict an instantaneous release to the water table from the release locations in WMA C to illustrate the adequacy of the well network for monitoring the entire facility.

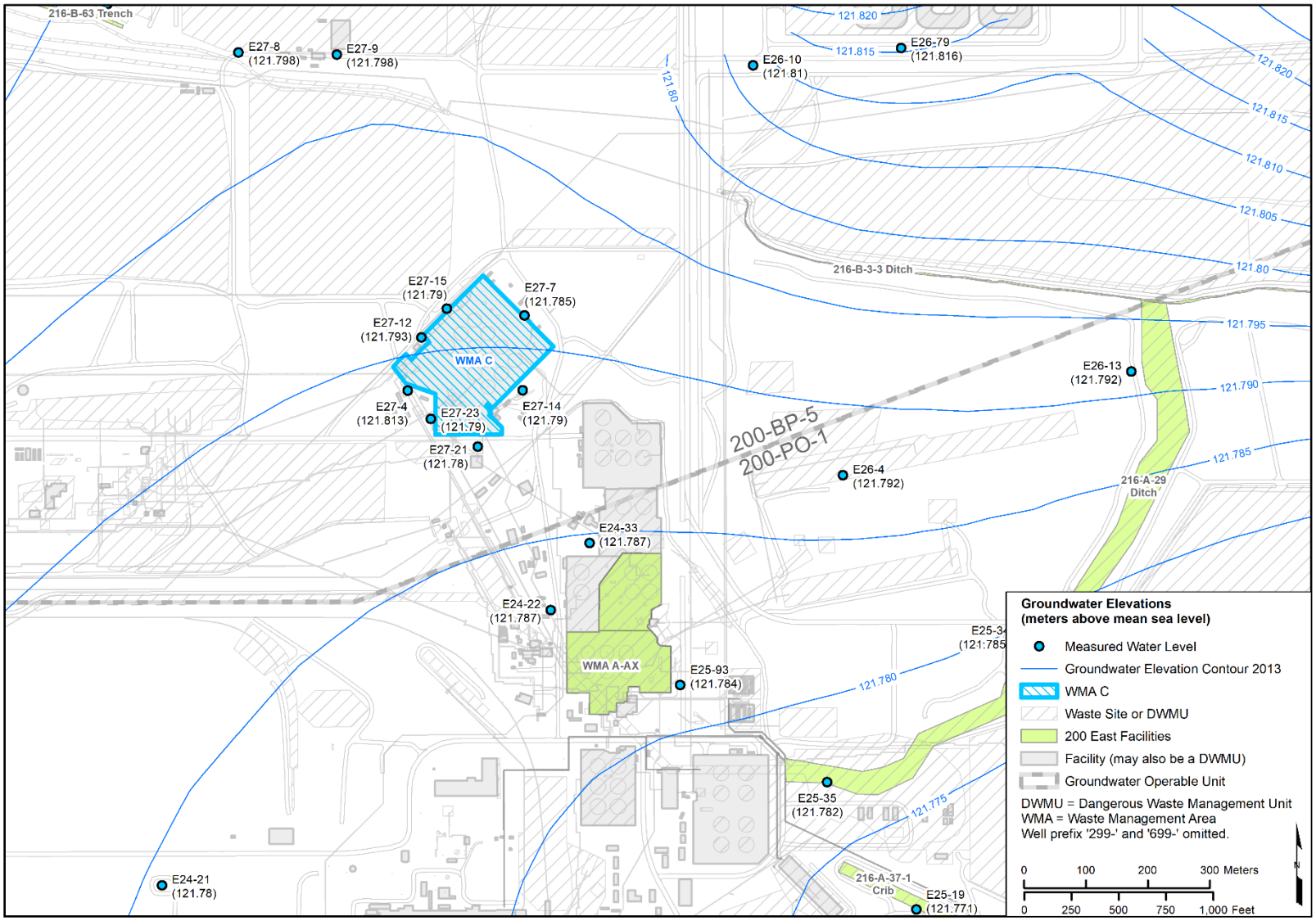

Figure L-3. Water-Level Elevation Map for WMA C, 2013

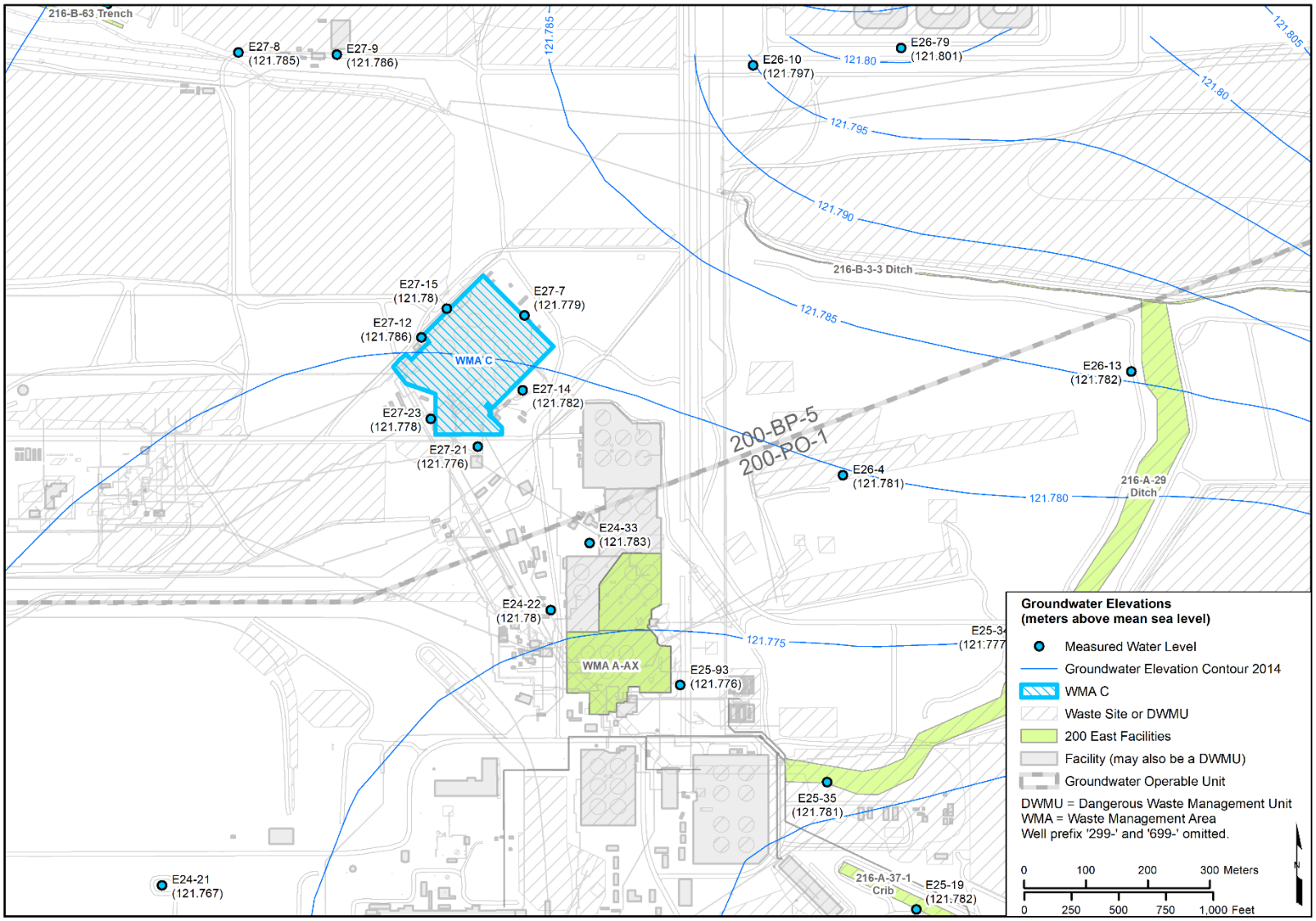

Figure L-4. Water-Level Elevation Map for WMA C, 2014

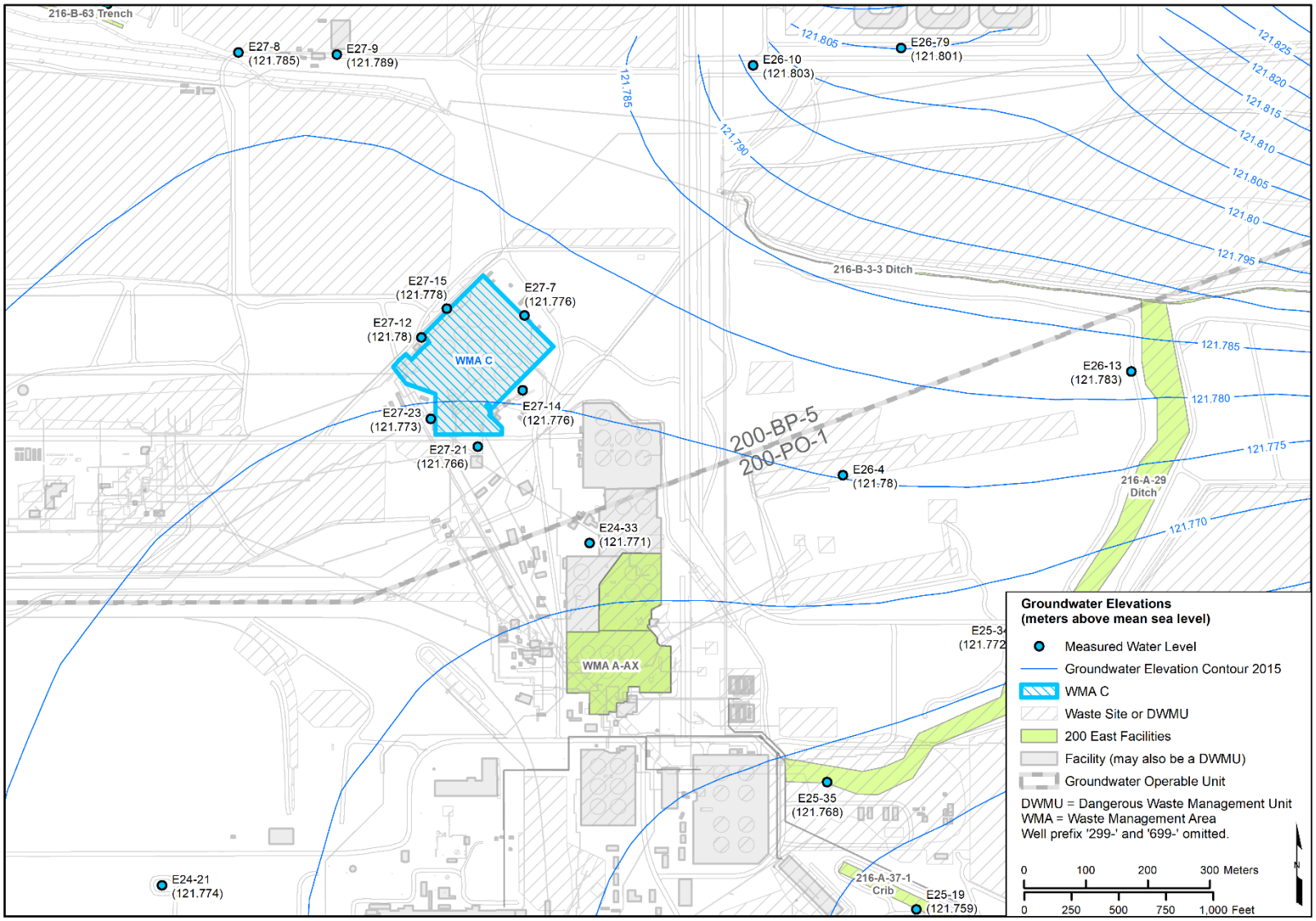

Figure L-5. Water-Level Elevation Map for WMA C, 2015

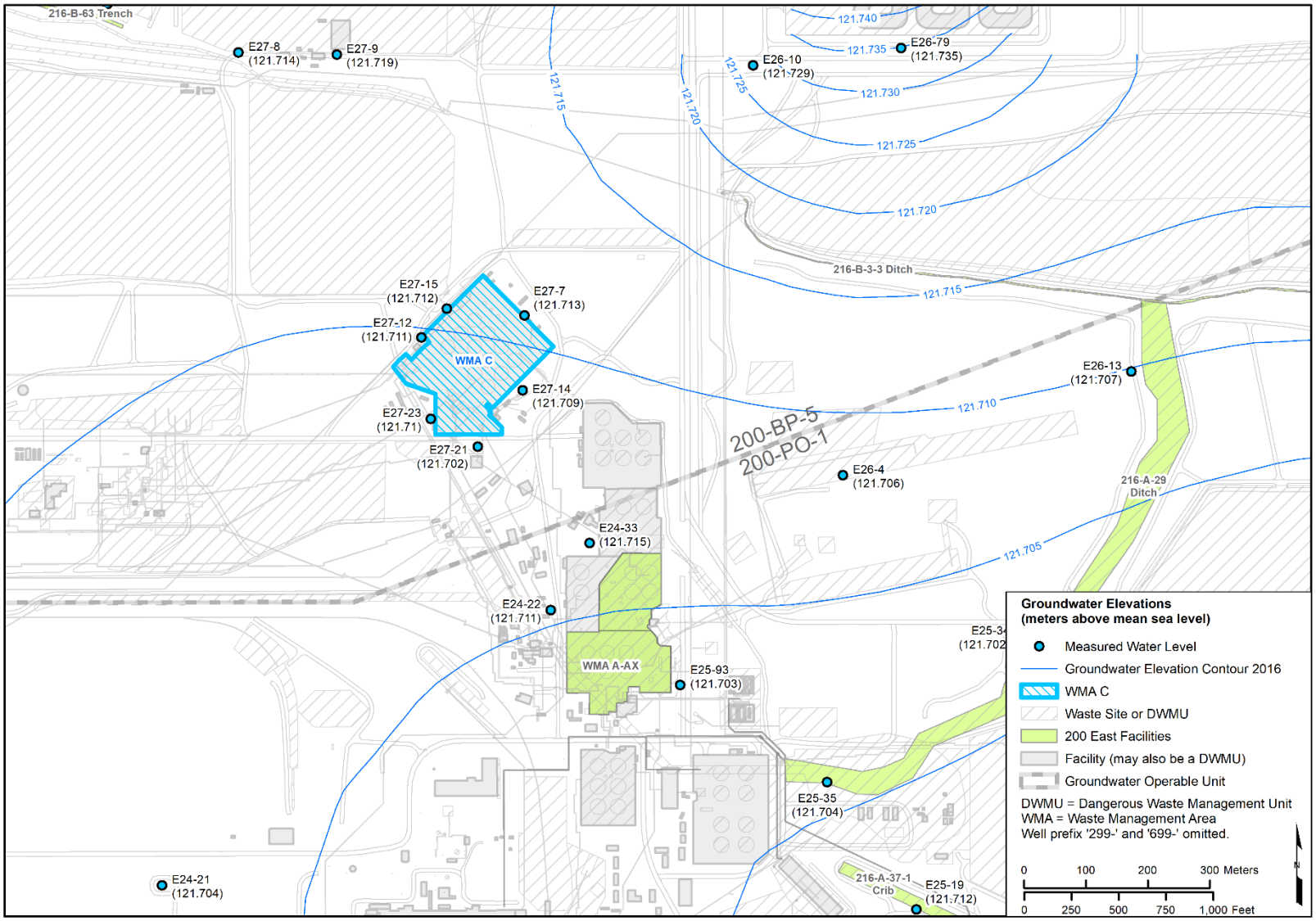

Figure L-6. Water-Level Elevation Map for WMA C, 2016

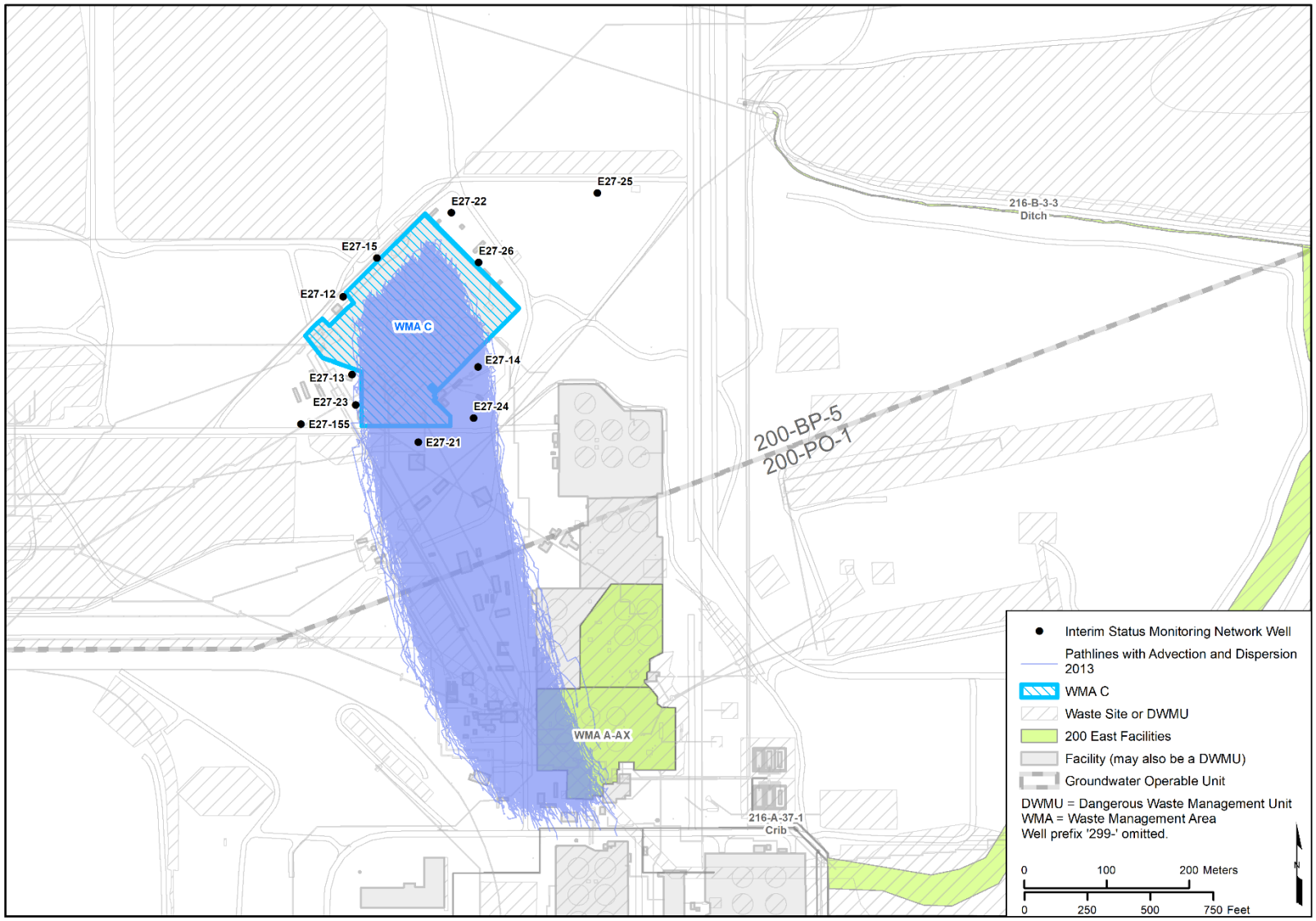

Figure L-7. Local-Scale Particle Pathlines, Advection and Dispersion – WMA C, 2013

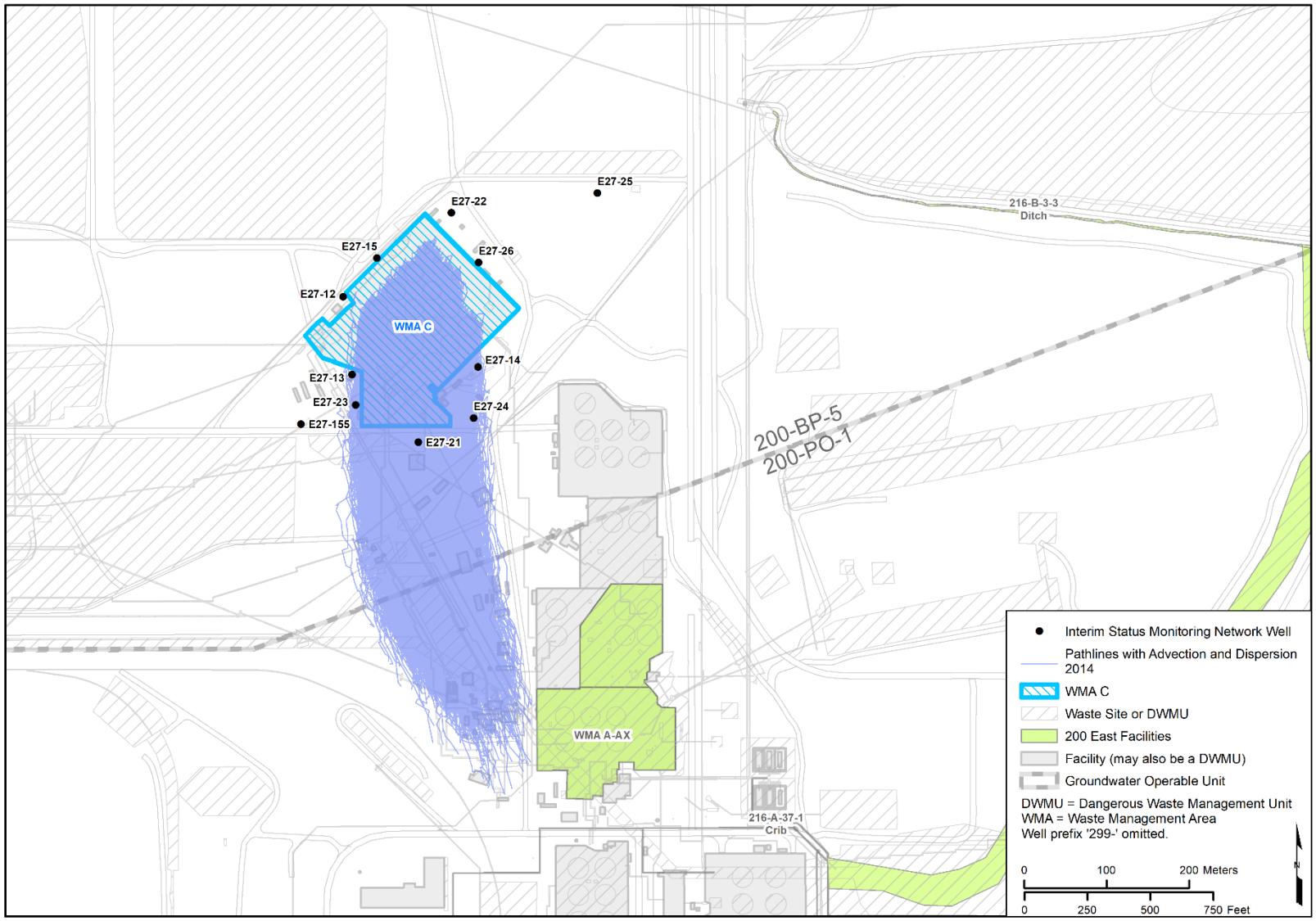

Figure L-8. Local-Scale Particle Pathlines, Advection and Dispersion – WMA C, 2014

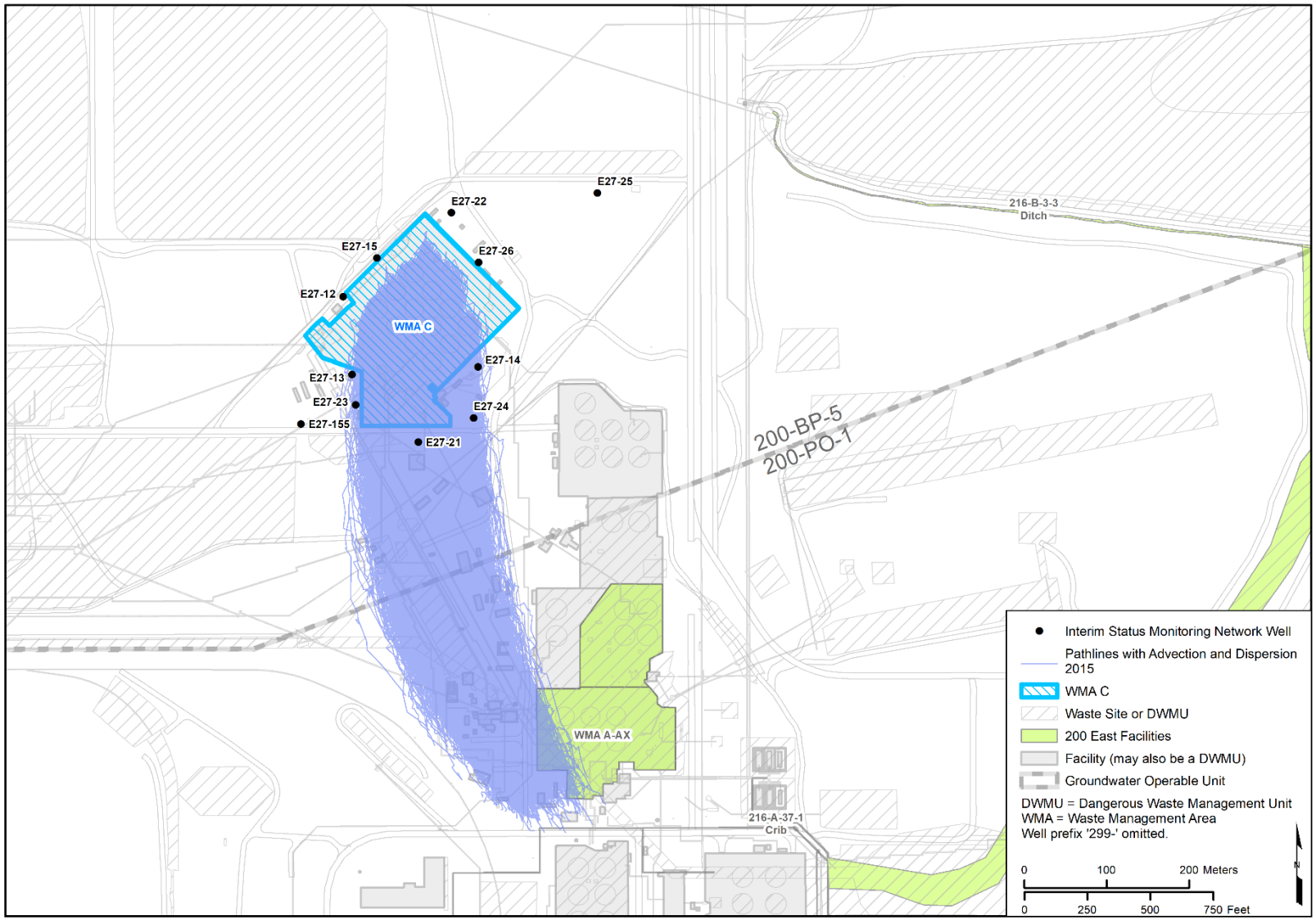

Figure L-9. Local-Scale Particle Pathlines, Advection and Dispersion – WMA C, 2015

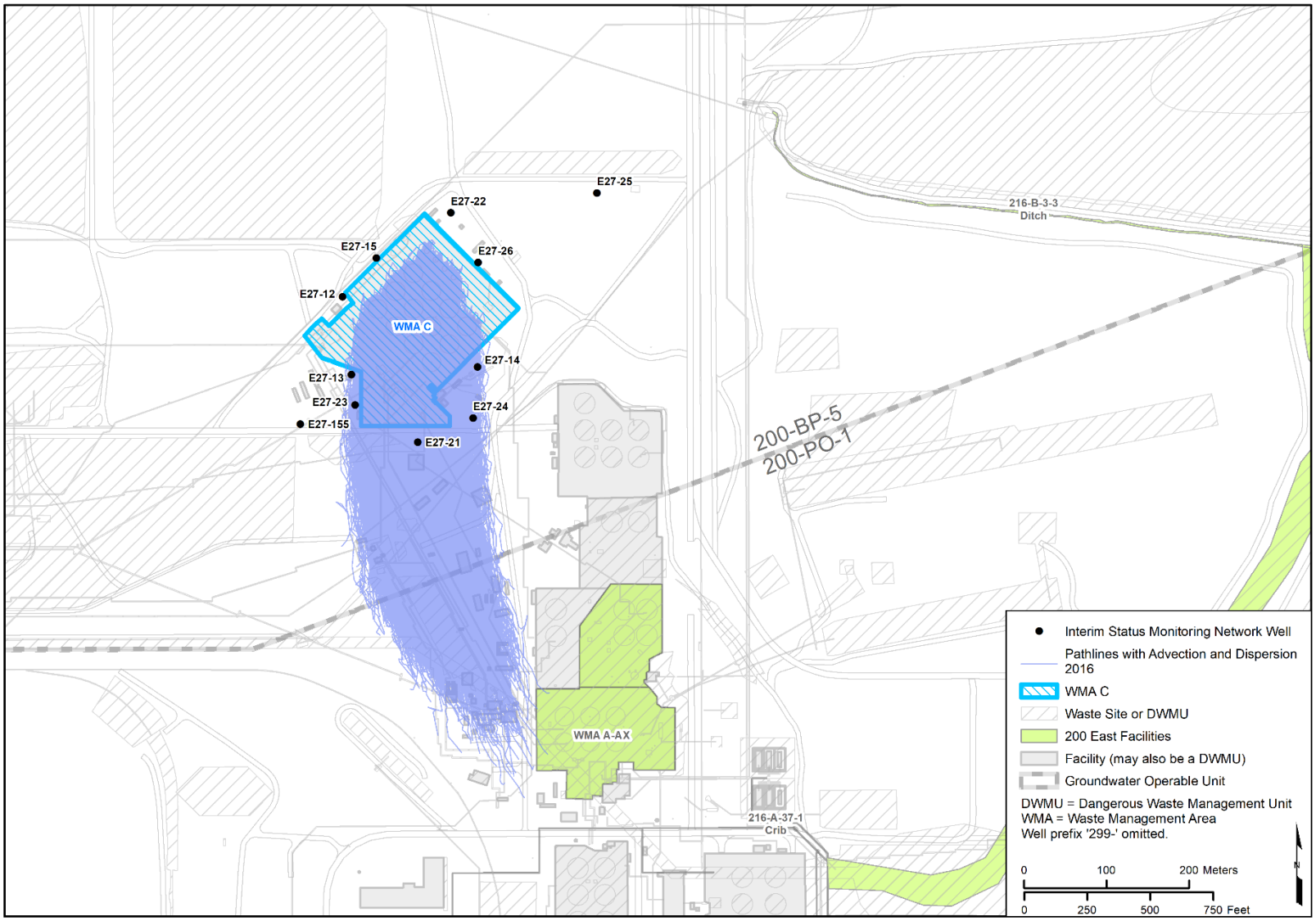

Figure L-10. Local-Scale Particle Pathlines, Advection and Dispersion – WMA C, 2016

L3.3 Particle Counts

To compare the relative timing and density of the particles that pass by each monitoring well location, particle counts were calculated as described in Section 6.3 of the main text of this ECF. The particle counts were tabulated, particle breakthrough curves were created, and particle count maps were generated.

L3.3.1 Relative Particle Counts at Interim Status Groundwater Monitoring Wells

Tables L-1 through L-6 present the computed particle counts over time, binned into periods of 20 days, for each of the downgradient monitoring wells. Particle count tables are not included for cross-gradient wells 299-E27-25 and 299-E27-155 because no particle passed through the vicinity of these wells under the simulated flow conditions. Because monitoring well 299-E27-7 was replaced with well 299 E27-26 (Section 3.3 in DOE/RL-2016-66), particle counts were only tabulated for the replacement well 299-E27-26. In addition, no particle count table is included for well 299-E27-4, which was scheduled to be decommissioned. The tables present four entries (one for each year) for each well. At the bottom of the column for each mapped event is the total number of particles that passed through the vicinity of the well, regardless of time, and the average of the totals for the four mapped years rounded to the nearest integer. Each table provides an indication of the relative timing of the expected detections at each well and the relative potential that each well would detect a release at the facility for the flow conditions calculated for CYs 2013, 2014, 2015, and 2016.

Table L-1. Particle Density (Count) Monitoring Well 299-E27-13

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
20	6	10	27	7	
40	27	91	80	104	
60	0	33	13	44	
80	0	10	0	15	
100	0	2	1	2	
120	0	0	0	0	
140	0	0	0	0	
160	0	0	0	0	
180	0	0	0	0	
200	0	0	0	0	Average
Total	33	146	121	172	**118**

Table L-2. Particle Density (Count) Monitoring Well 299-E27-14

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
20	335	149	209	168	
40	86	51	27	42	
60	7	3	8	2	
80	1	1	0	0	
100	0	0	0	0	
120	0	0	0	0	
140	0	0	0	0	
160	0	0	0	0	
180	0	0	0	0	
200	0	0	0	0	Average
Total	429	204	244	212	**272**

Table L-3. Particle Density (Count) Monitoring Well 299-E27-21

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
20	44	10	64	7	
40	745	365	772	334	
60	1118	848	1256	815	
80	481	838	667	847	
100	85	519	158	530	
120	5	198	13	173	
140	0	57	0	43	
160	0	4	0	7	
180	0	1	0	0	
200	0	0	0	0	Average
Total	2478	2840	2930	2756	**2751**

Table L-4. Particle Density (Count) Monitoring Well 299-E27-23

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
20	0	2	0	0	
40	25	40	85	42	
60	10	132	87	150	
80	0	53	9	83	
100	0	16	1	26	
120	0	1	0	2	
140	0	0	0	0	
160	0	0	0	0	
180	0	0	0	0	
200	0	0	0	0	Average
Total	35	244	182	303	**191**

Table L-5. Particle Density (Count) Monitoring Well 299-E27-24

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
20	81	1	32	1	
40	482	103	212	124	
60	210	98	57	116	
80	38	28	6	17	
100	2	10	0	4	
120	0	0	0	2	
140	0	0	0	0	
160	0	0	0	0	
180	0	0	0	0	
200	0	0	0	0	Average
Total	813	240	307	264	**406**

Table L-6. Particle Density (Count) Monitoring Well 299-E27-26

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
20	0	0	0	1	
40	0	0	0	0	
60	0	0	0	0	
80	0	0	0	0	
100	0	0	0	0	
120	0	0	0	0	
140	0	0	0	0	
160	0	0	0	0	
180	0	0	0	0	
200	0	0	0	0	Average
Total	0	0	0	1	**0**

The average values depicted at the base of each table can be used to assess the relative potential for each well to detect a release at the facility. These averages are summarized as follows:

- 299-E27-13 – Average = 118
- 299-E27-14 – Average = 272
- 299-E27-21 – Average = 2751
- 299-E27-23 – Average = 191
- 299-E27-24 – Average = 406
- 299-E27-26 – Average = 0

L3.3.2 Relative Arrival Times at Interim Status Groundwater Monitoring Wells

Figures L-11 through L-16 depict plots of particle counts over time (particle breakthrough curves) for each downgradient well location. The underlying data plotted in Figures L-11 through L-16 are the same as the data in Tables L-1 through L-6, but the time interval over which particles are summed is not necessarily the same. Breakthrough curves are not included for cross-gradient wells 299-E27-25 and 299-E27-155 because no particle passed through the vicinity of these wells under the simulated flow conditions. Because monitoring well 299-E27-7 was replaced with well 299 E27-26 (Section 3.3 in DOE/RL-2016-66), particle counts were only plotted for the replacement well 299-E27-26. In addition, no breakthrough curve is included for well 299-E27-4, which was scheduled to be decommissioned. Particle breakthrough curves show the relative timing and particle density for the arrival, peak, and decline in particle counts at each interim status monitoring location resulting from the hypothetical instantaneous release at the facility. The plots depict the relative potential at each well for detecting a release from the facility that reaches the water table for the flow conditions calculated for CYs 2013, 2014, 2015, and 2016. There is one figure for each well, with four lines shown on each plot (one for each year).

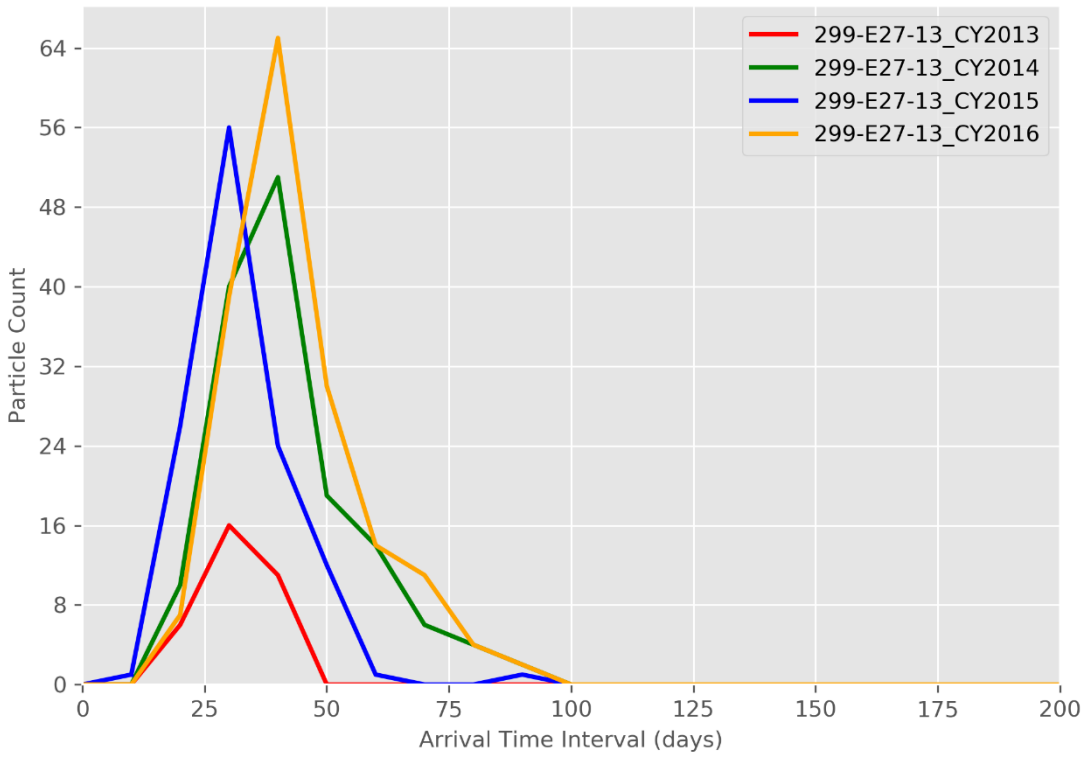

Figure L-11. Particle Breakthrough Curve at Monitoring Well 299-E27-13

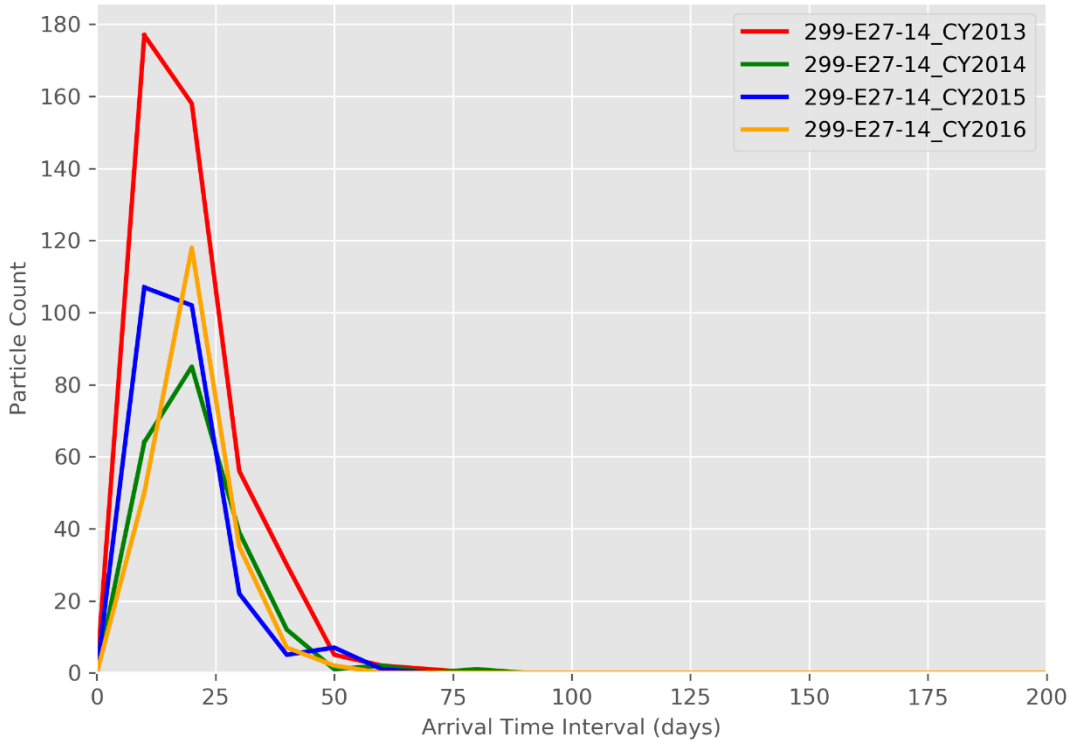

Figure L-12. Particle Breakthrough Curve at Monitoring Well 299-E27-14

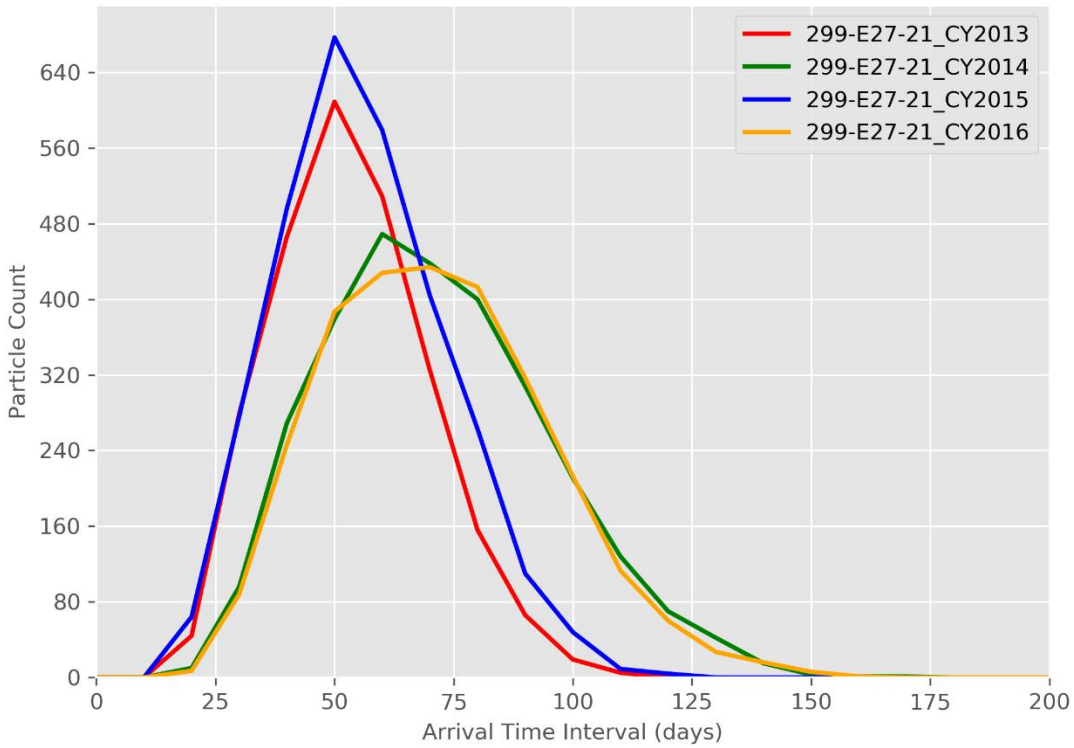

Figure L-13. Particle Breakthrough Curve at Monitoring Well 299-E27-21

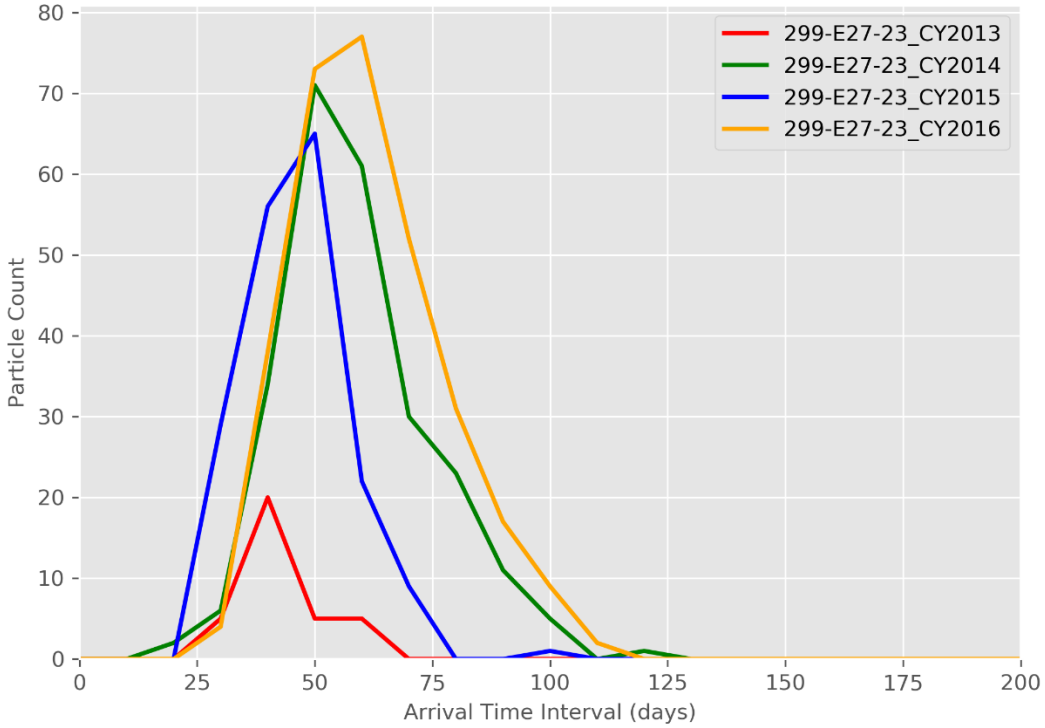

Figure L-14. Particle Breakthrough Curve at Monitoring Well 299-E27-23

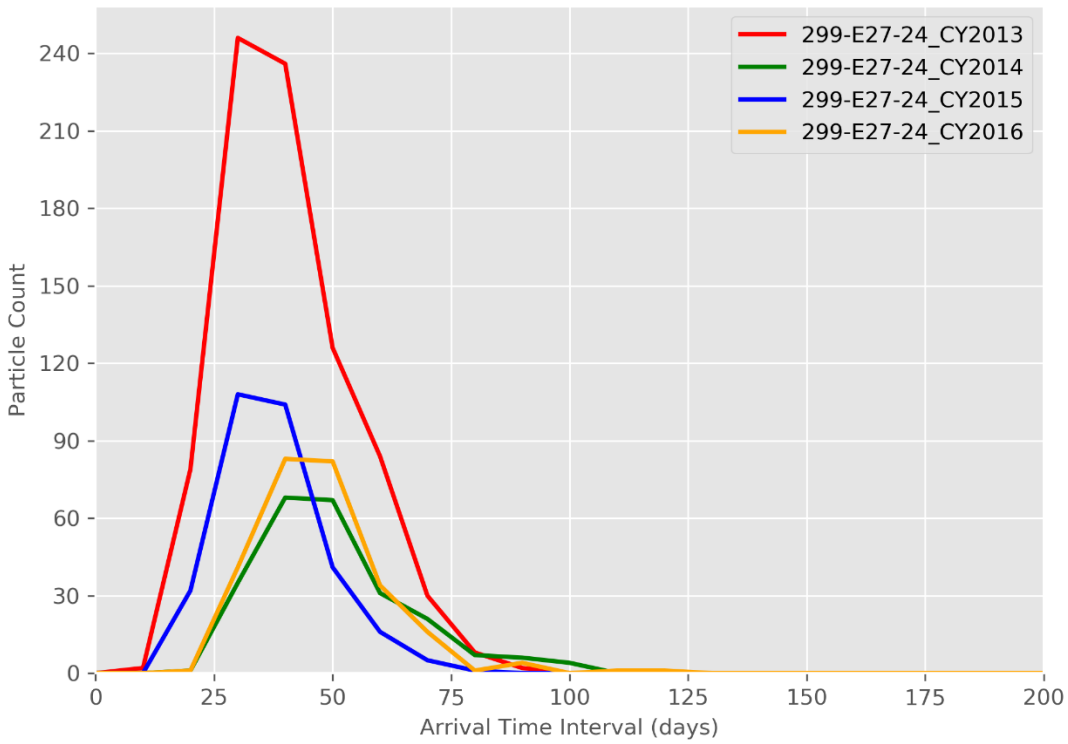

Figure L-15. Particle Breakthrough Curve at Monitoring Well 299-E27-24

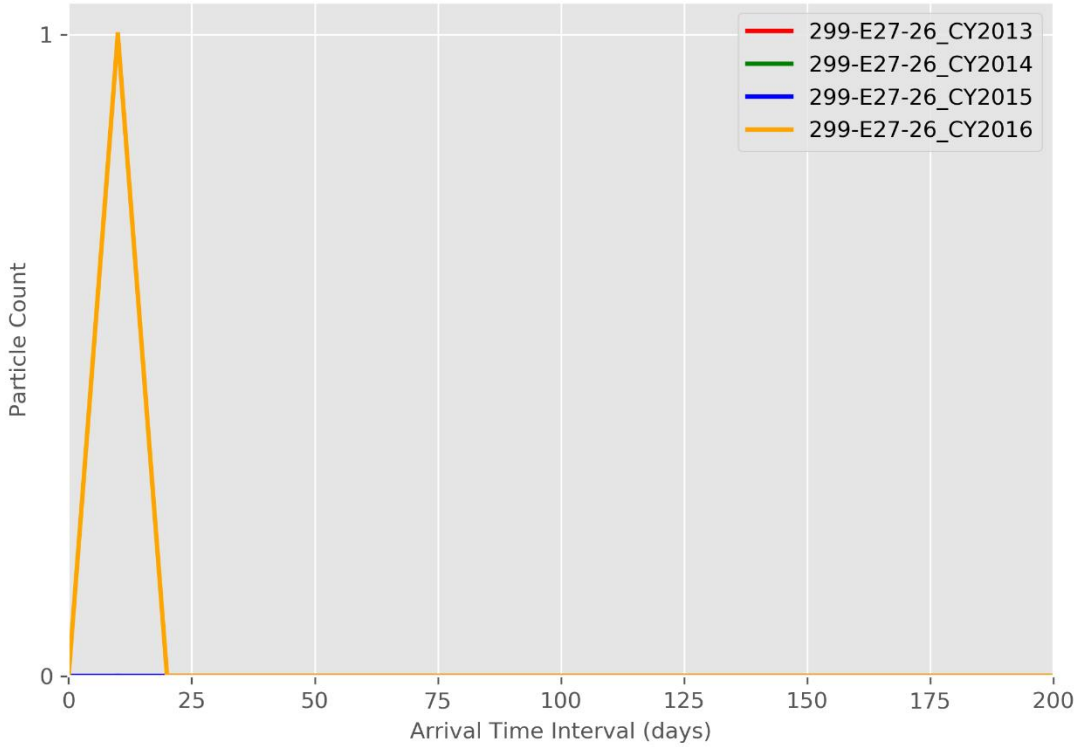

Figure L-16. Particle Breakthrough Curve at Monitoring Well 299-E27-26

L3.3.3 Particle Count Maps

Figures L-17 through L-20 depict the particle count maps developed based on the instantaneous release of a large number of particles at the facility. The particle count maps depict areas of relatively higher and lower potential impact from a release at the facility that reaches the water table, for conditions represented by CYs 2013, 2014, 2015, and 2016. Figures L-17 through L-20 depict the particle density after 200 days of calculated travel, by which time it was determined that all particles would have arrived at or passed by the interim status groundwater monitoring wells (see entries in Tables L-1 through L-6).

The goal of well placement is for the well locations to span the range of particle pathline distribution as released from WMA C. The particle count maps show that under the evaluated range of conditions, there are areas of high particle counts where there is no corresponding monitoring well, indicating the need for an additional monitoring well. In addition, well 299-27-24 is not screened across the water table, but its location is favorable for detection of releases, indicating the need for a well screened across the water table to be installed in the vicinity of well 299-27-24. The locations of the two proposed wells (WMA_C_PW-1, and WMA_C_PW-2) are shown in Figures L-17 through L-20.

L3.4 Proposed Monitoring Wells

The locations of the proposed monitoring wells are shown in Figures L-17 through L-20. The particle counts tabulated for these locations (Tables L-7 and L-8) indicate the relative timing of expected detections at the wells and the relative potential of the wells for detecting a release at the facility.
The particle breakthrough curves (Figures L-21 and L-22) show the relative timing and particle density at the proposed monitoring well locations for the arrival, peak, and decline in particle counts resulting from the hypothetical instantaneous release to the water table beneath the facility.

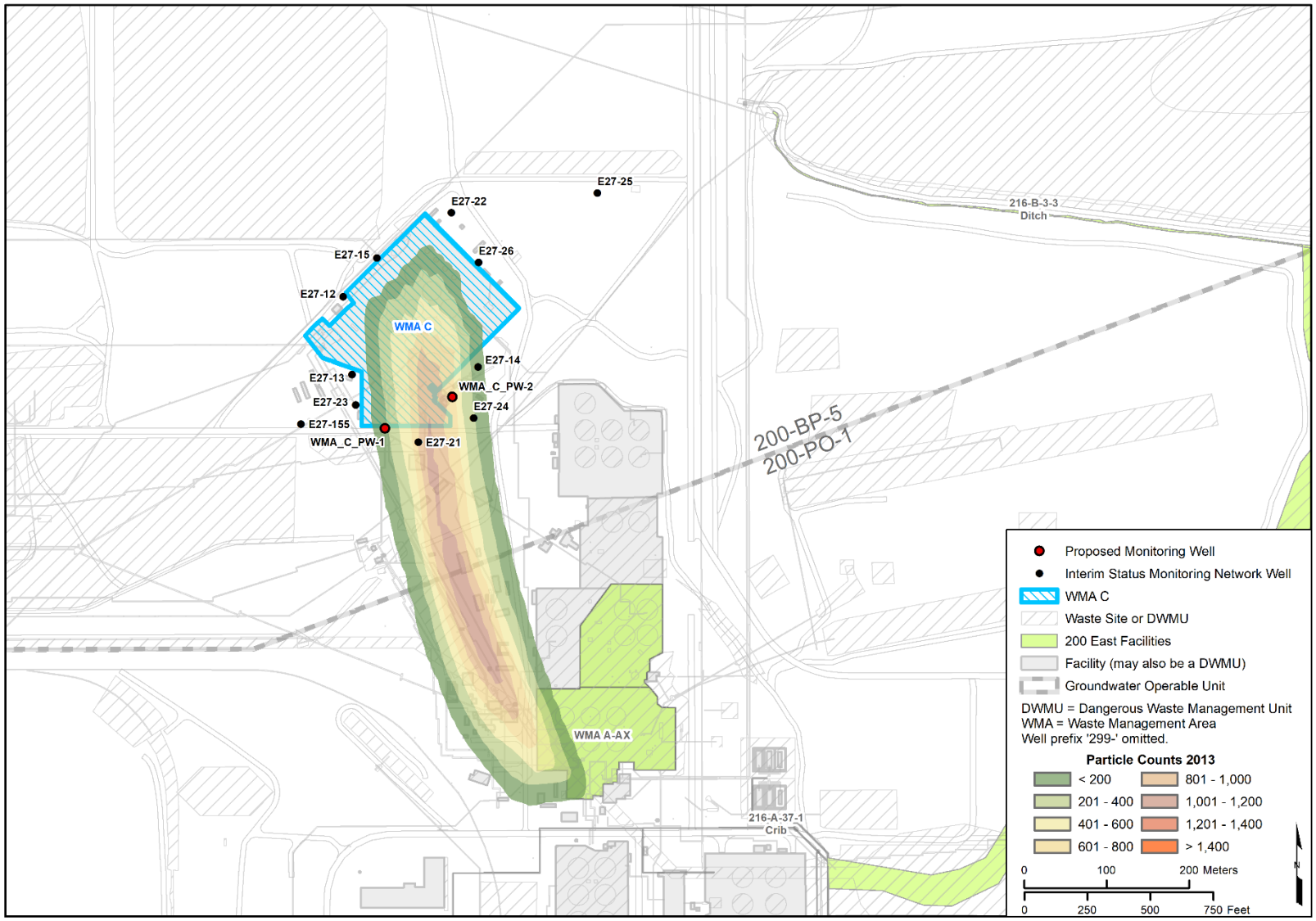

Figure L-17. Particle Count Map – WMA C, 2013

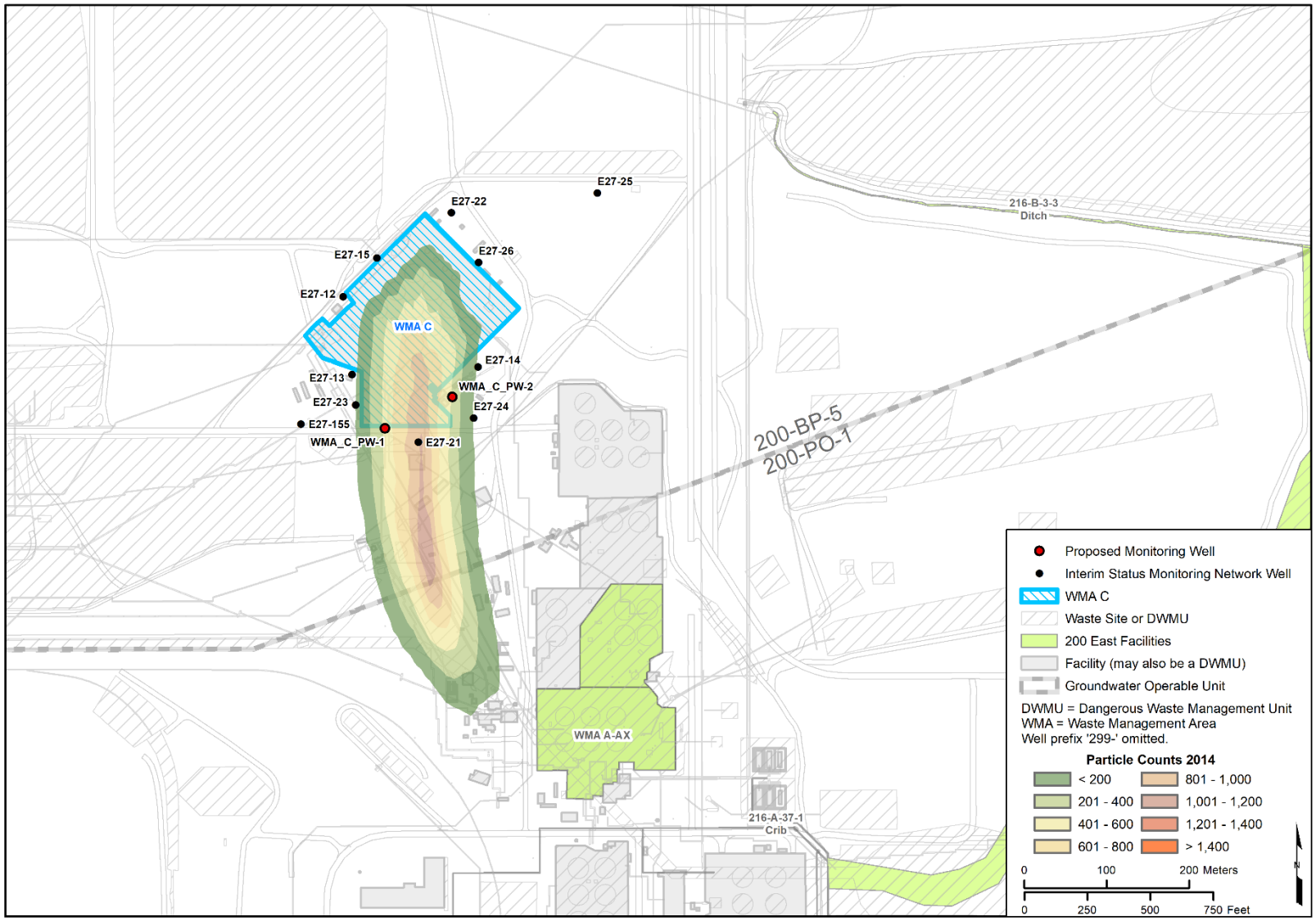

Figure L-18. Particle Count Map – WMA C, 2014

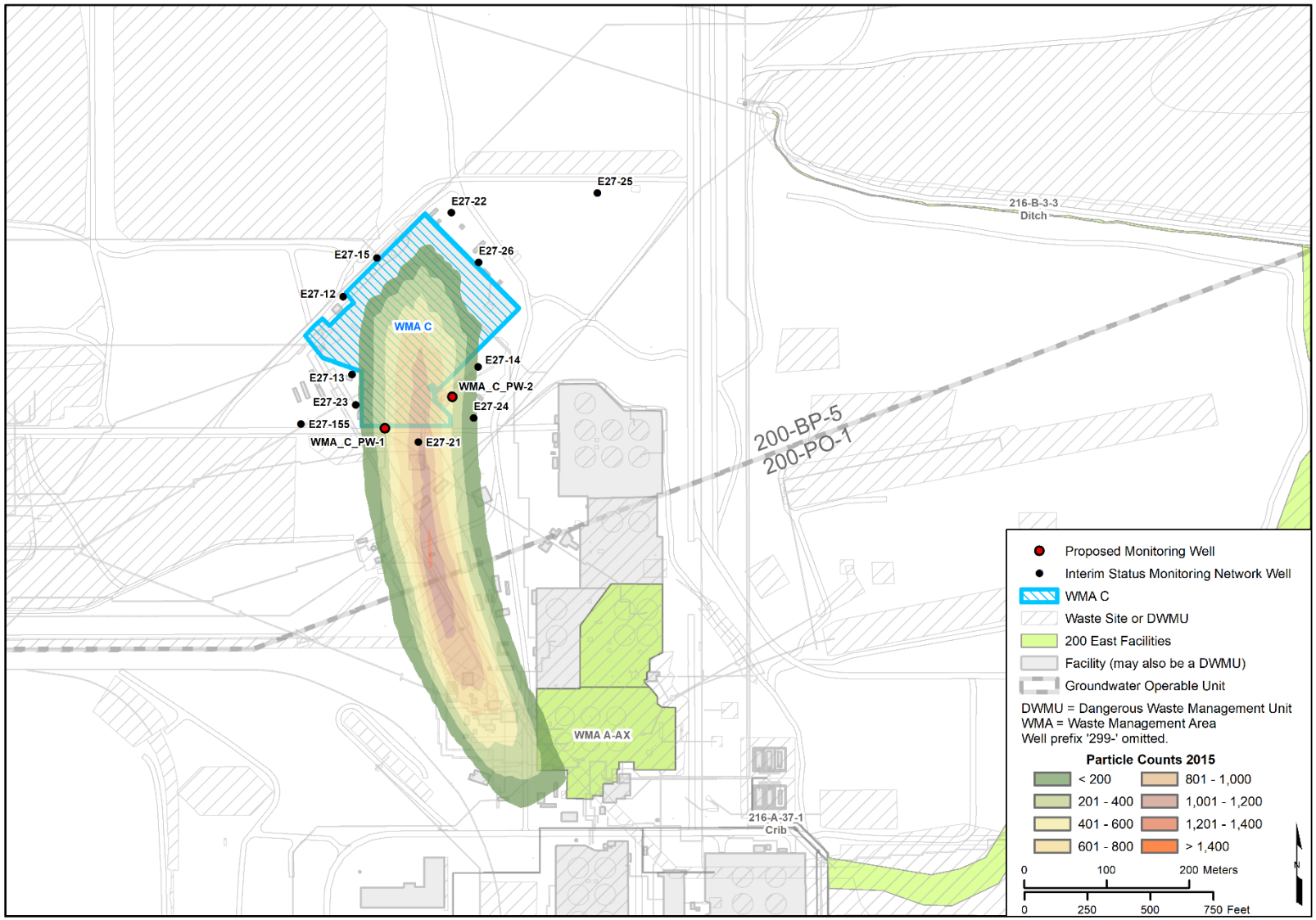

Figure L-19. Particle Count Map – WMA C, 2015

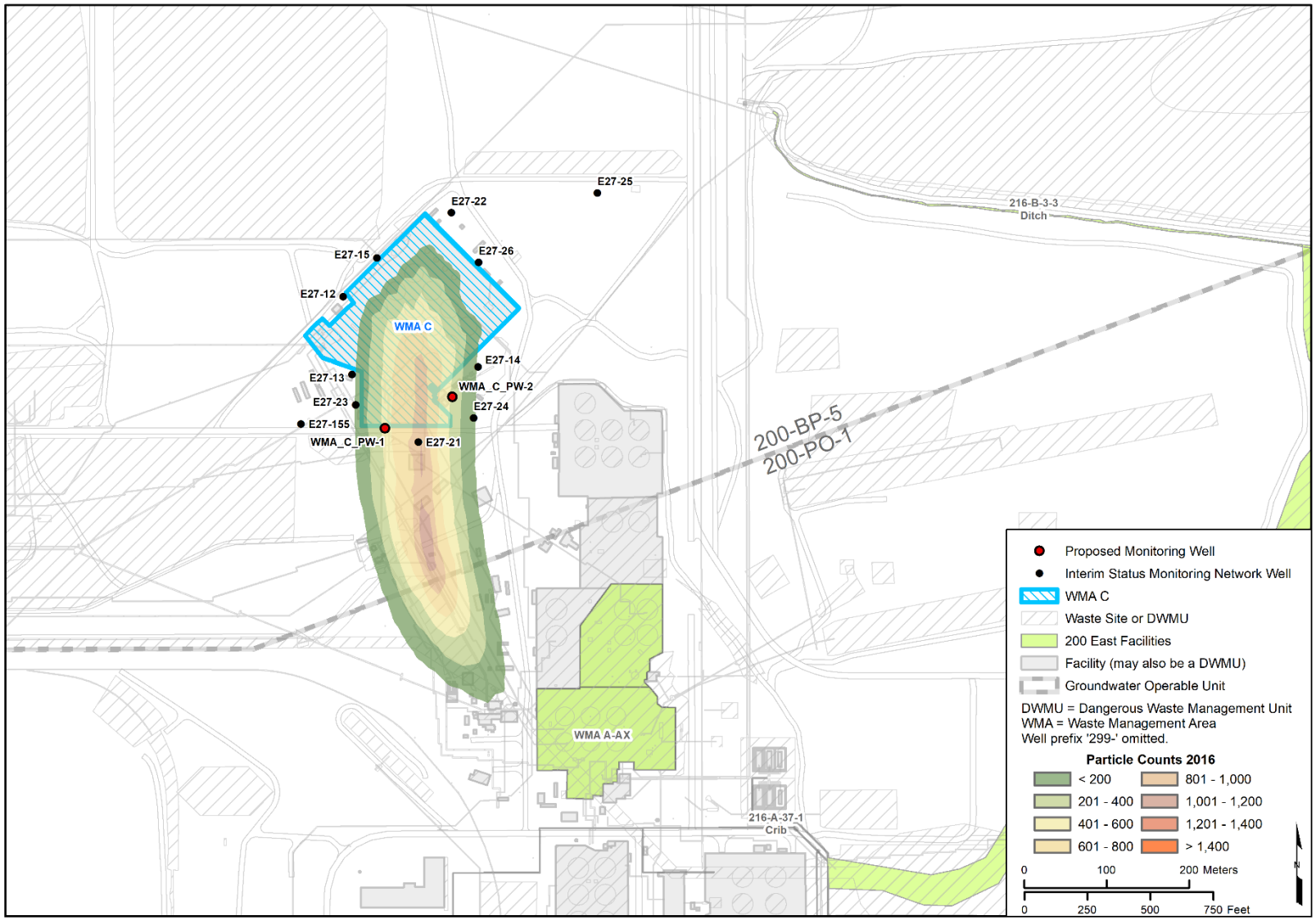

Figure L-20. Particle Count Map – WMA C, 2016

Table L-7. Particle Density (Count) Proposed Monitoring Well WMA_C_PW-1

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
20	3	0	3	2	
40	232	113	364	127	
60	303	531	650	535	
80	67	542	273	560	
100	2	255	34	274	
120	1	80	6	76	
140	0	11	0	18	
160	0	0	0	3	
180	0	1	0	0	
200	0	0	0	0	Average
Total	608	1533	1330	1595	**1267**

Table L-8. Particle Density (Count) Proposed Monitoring Well WMA_C_PW-2

Time Interval (days)	Relative Particle Density (Count) by Year				
	2013	2014	2015	2016	
20	687	300	557	305	
40	924	589	613	571	
60	384	255	167	260	
80	40	81	21	75	
100	1	14	0	13	
120	0	1	0	0	
140	0	0	0	0	
160	0	0	0	0	
180	0	0	0	0	
200	0	0	0	0	Average
Total	2036	1240	1358	1224	**1465**

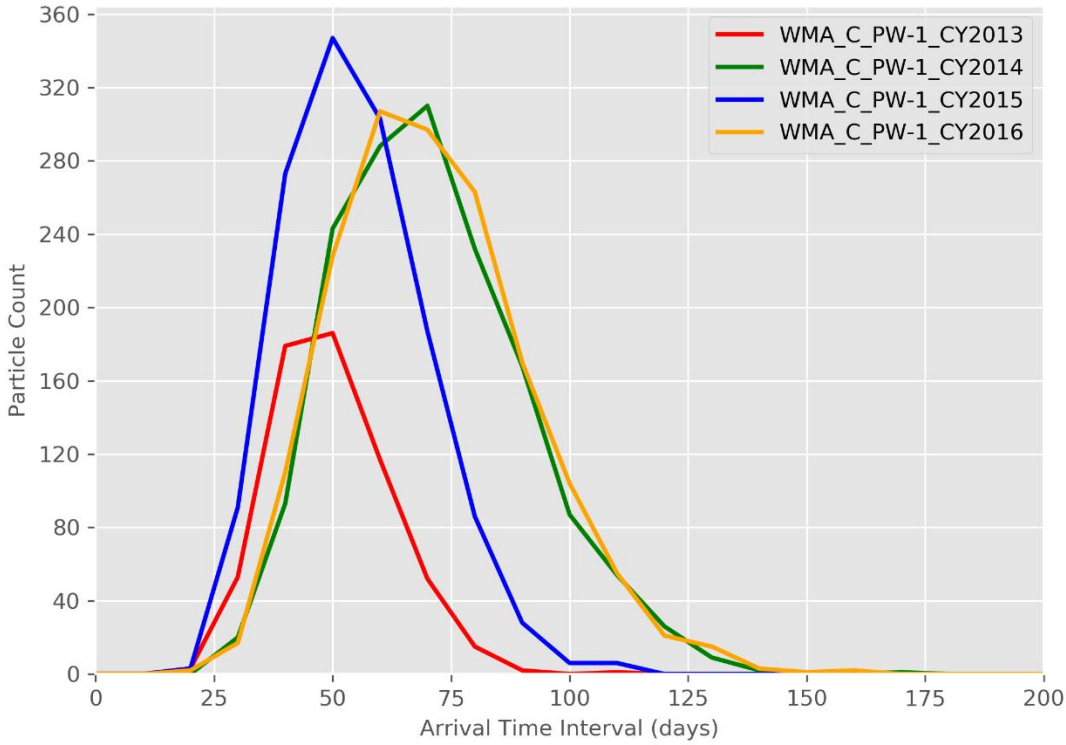

Figure L-21. Particle Breakthrough Curve at Monitoring Well WMA_C_PW-1

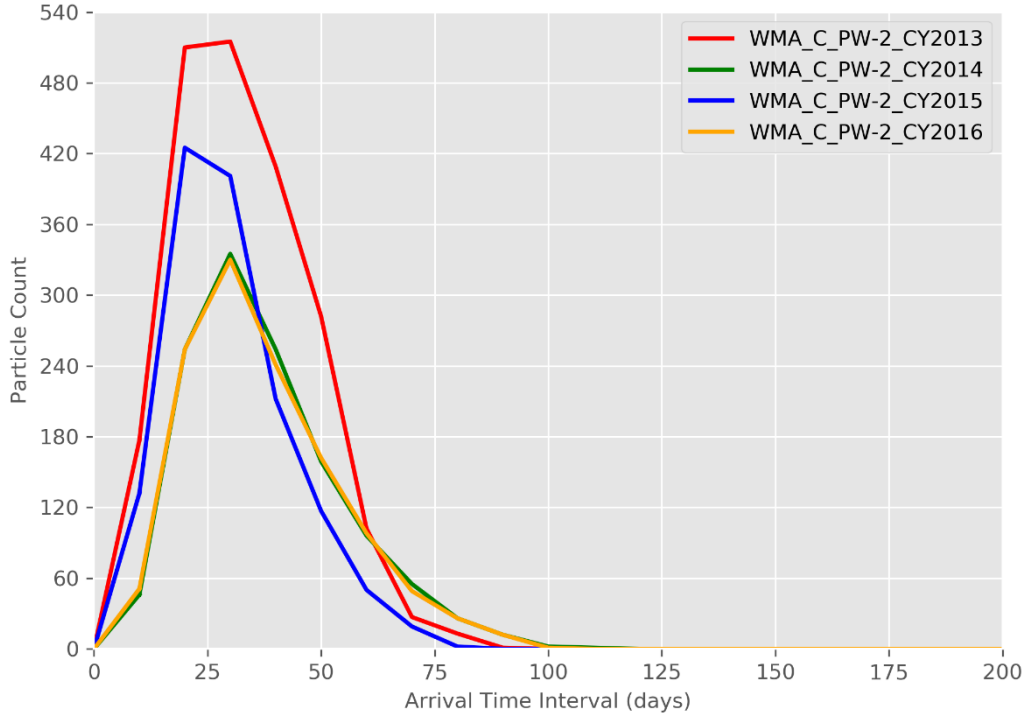

Figure L-22. Particle Breakthrough Curve at Monitoring Well WMA_C_PW-2

L3.5 Analyses of Particle Pathlines for Each Area of WMA C

Particle pathline maps shown in Section L3.2 depict an instantaneous release to the water table from the release locations in WMA C. Particle tracking also was performed for smaller regions of the facility to evaluate well locations for detecting releases from various regions of WMA C. This section contains the results of analyses performed to examine how releases from the various areas of WMA C that reach the groundwater beneath those release areas relate to each individual monitoring well. A series of figures and tables are provided to illustrate the fate of releases originating from three different areas of the waste management area. For these analyses, the particle release points presented in Figure L-2 are grouped into one of six areas based on their spatial location. Those areas are depicted in Figure L-23. Figures L-24 through L-27 illustrate the particle pathlines originating from each of the areas for CYs 2013 through 2016.

Figures L-28 through L-35 illustrate the particle count time series for each existing and proposed monitoring well from CY 2013 through CY 2016. Each figure has four panels, each of which depicts the particle counts for one CY (2013 through 2016). Additionally, each panel shows a separate breakthrough curve for particles emanating from each area. For example, Figure L-34 depicts the particle counts at well WMA_C_PW-1, which receives particles from areas 1, 2, and 3 in 2013. In the figure, within the panel for 2013 (top row, left), the particle breakthrough curve from area 1 is depicted with a blue line, area 2 with an orange line, and area 3 with a purple line.

L3.6 Vertical Migration Potential

As described in Section 3.3 of the main text of this ECF, the American Petroleum Institute (API) plume diving calculation was used to estimate the likely rate of vertical migration of dissolved constituents downward under the influence of recharge at the water table. At each well the slope of the plume dive was multiplied by the distance from the particle starting location to the well location to estimate the depth to which the dissolved constituents may be anticipated to have migrated by the time they reach the monitoring well location.

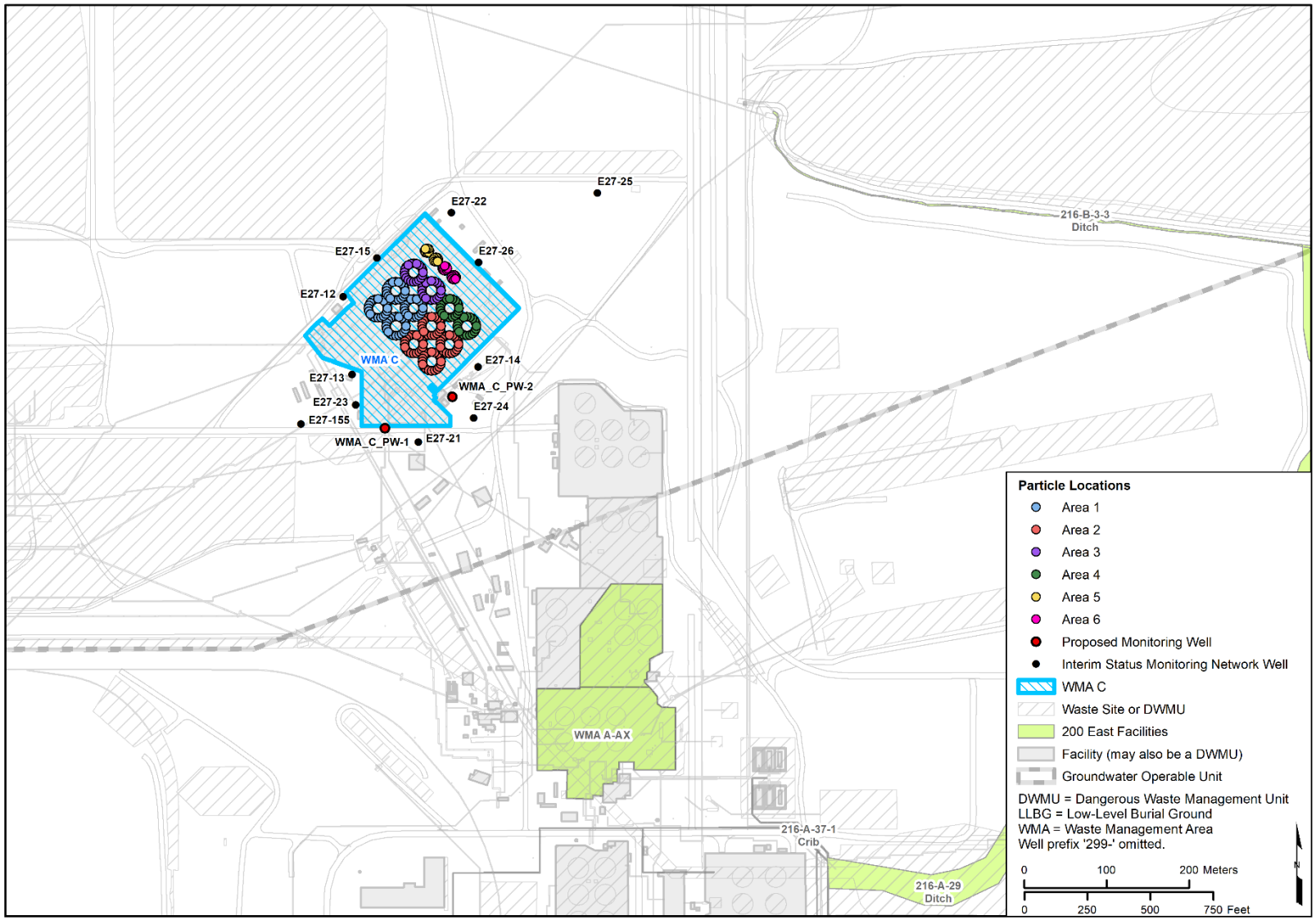

Figure L-23. Particle Release Locations and Areas of WMA C

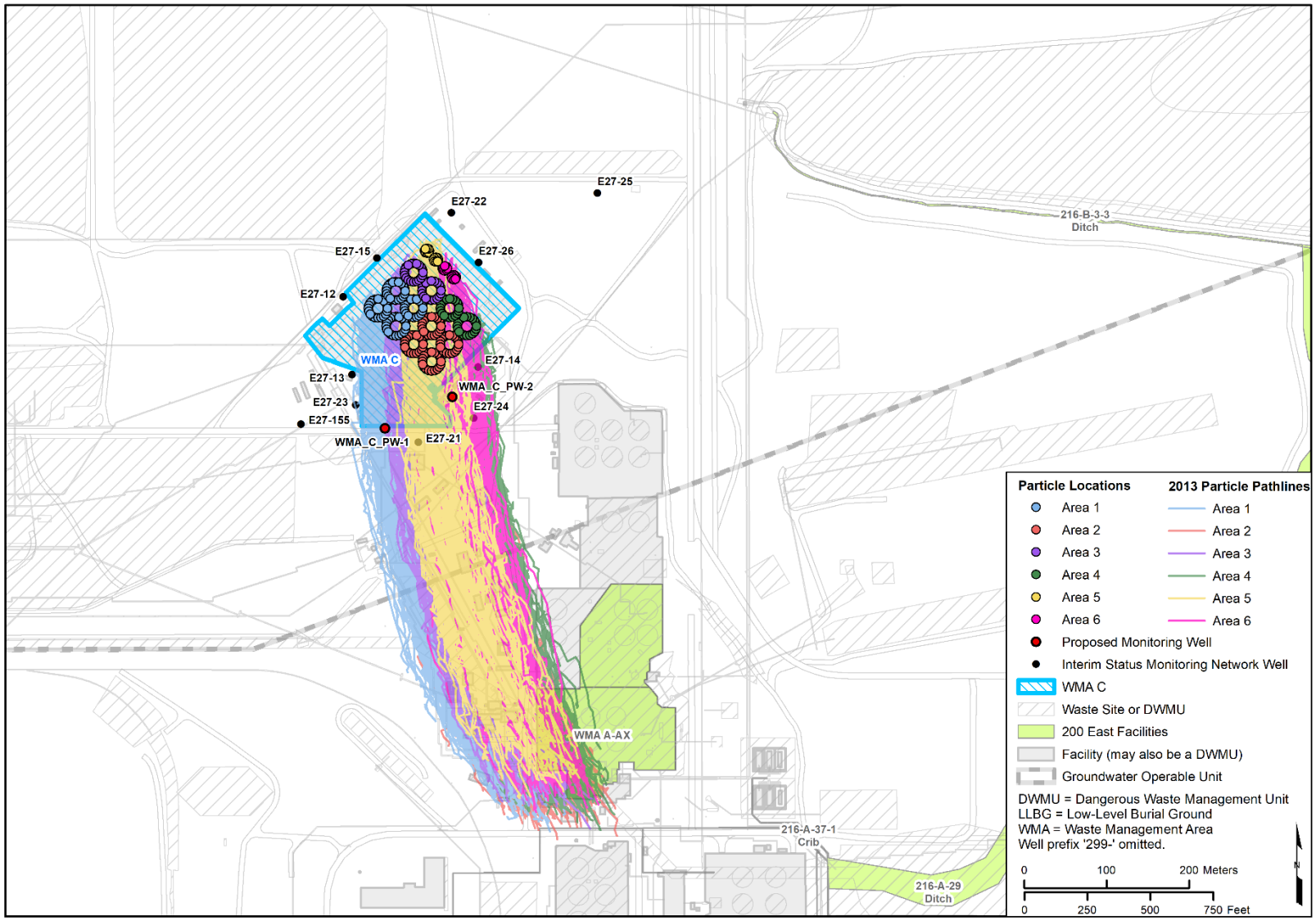

Figure L-24. CY 2013 Particle Pathlines per Area of WMA C

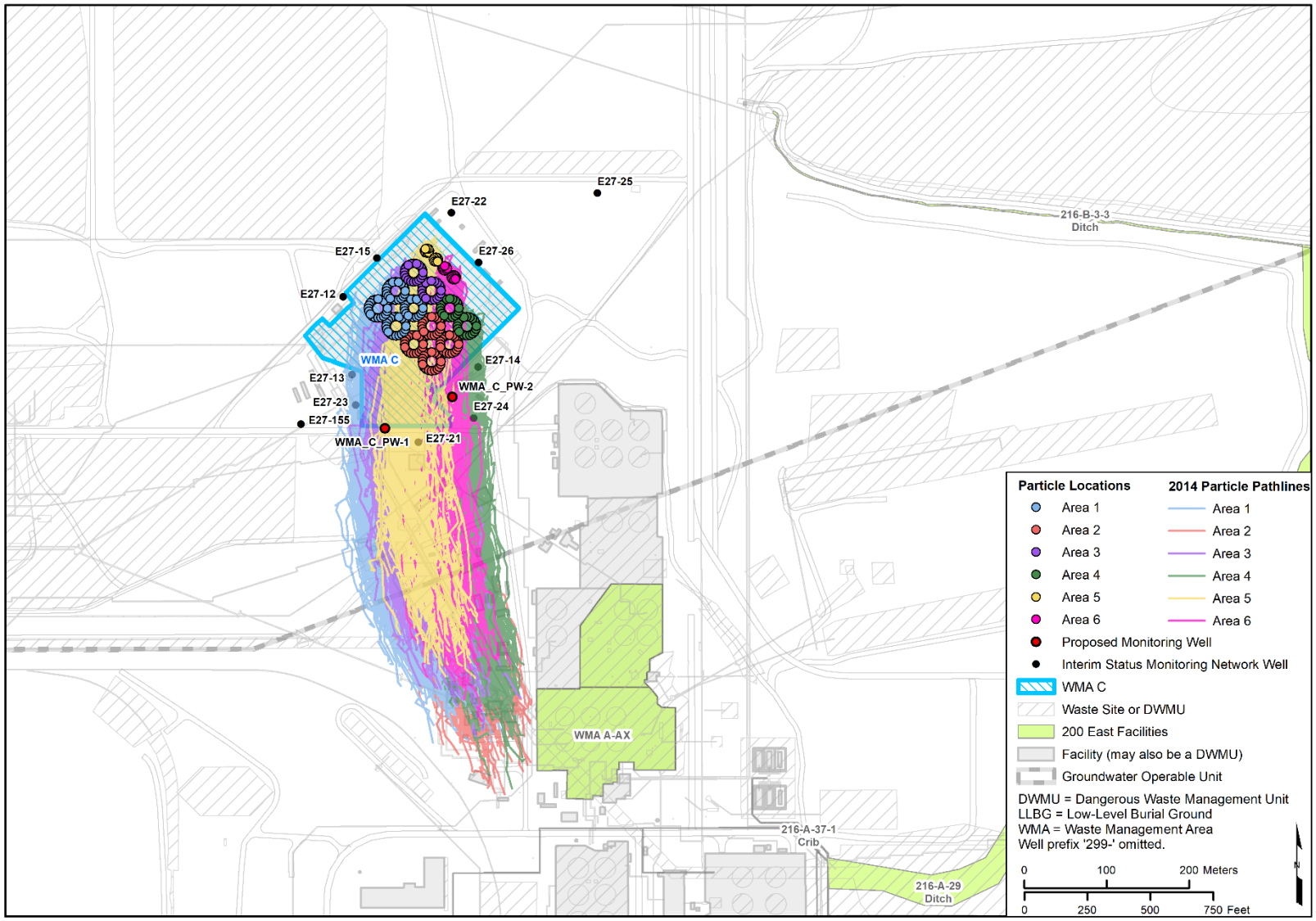

Figure L-25. CY 2014 Particle Pathlines per Area of WMA C

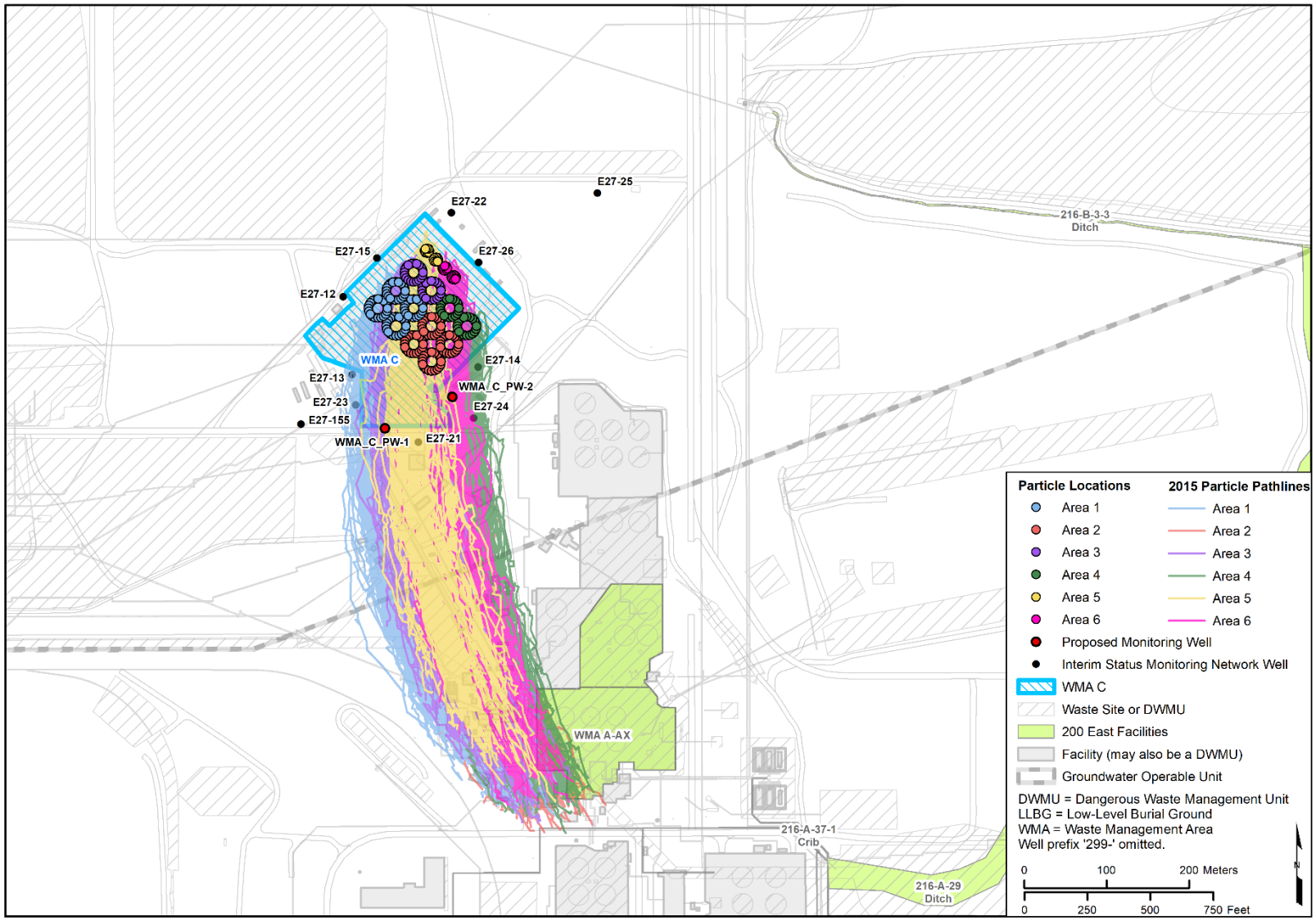

Figure L-26. CY 2015 Particle Pathlines per Area of WMA C

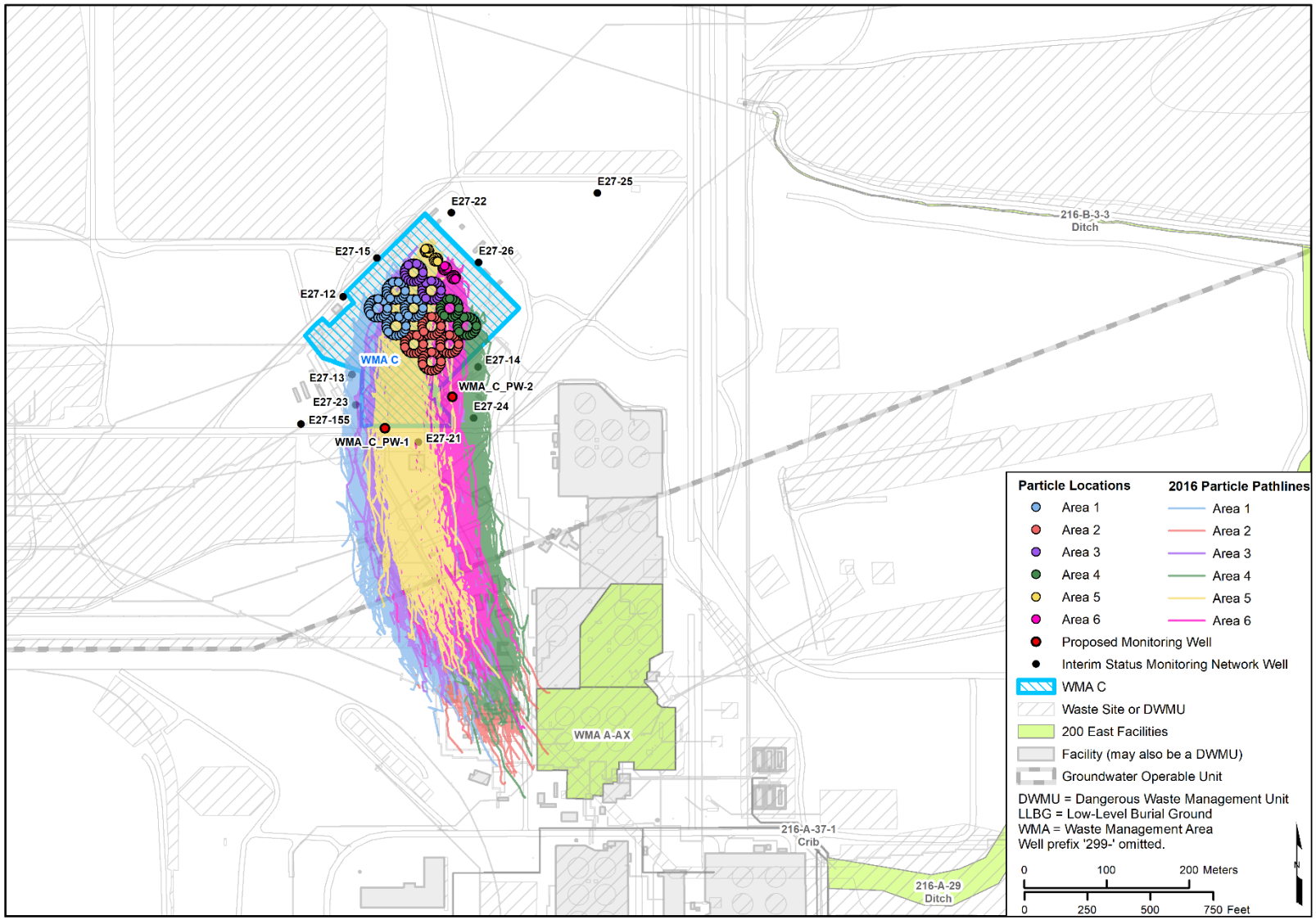

Figure L-27. CY 2016 Particle Pathlines per Area of WMA C

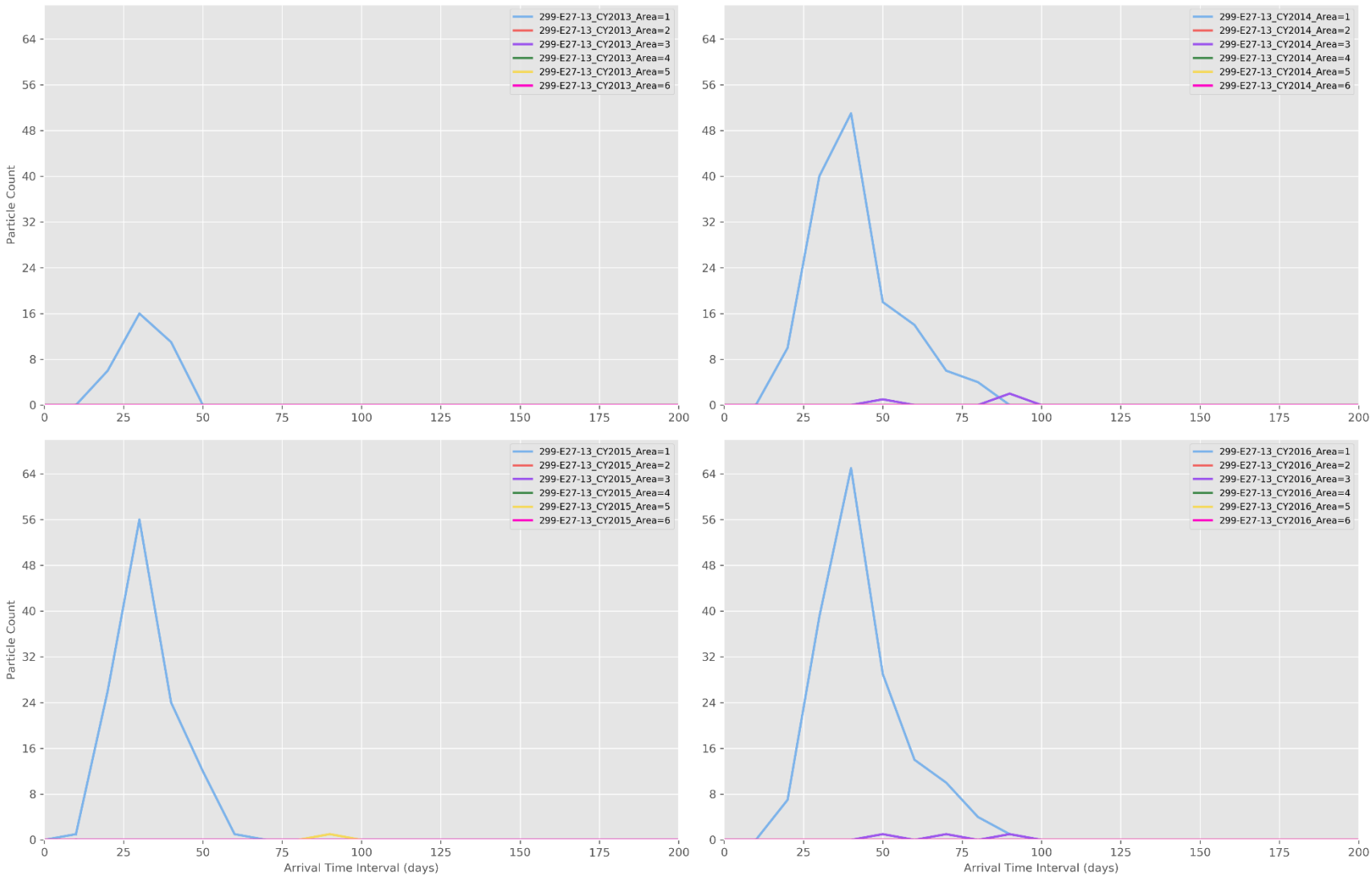

Figure L-28. Particle Breakthrough Curves per Area at Monitoring Well 299-E27-13

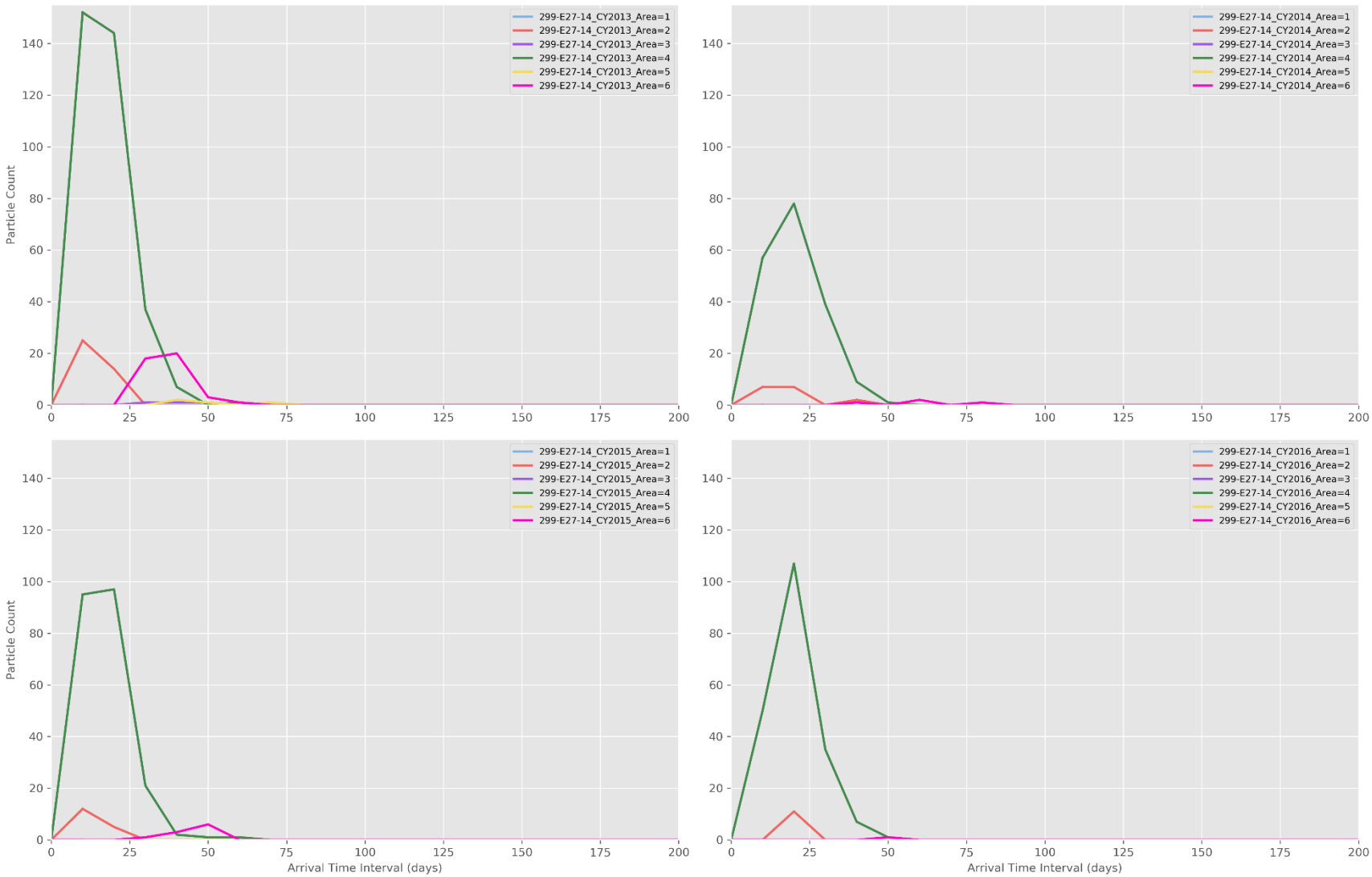

Figure L-29. Particle Breakthrough Curves per Area at Monitoring Well 299-E27-14

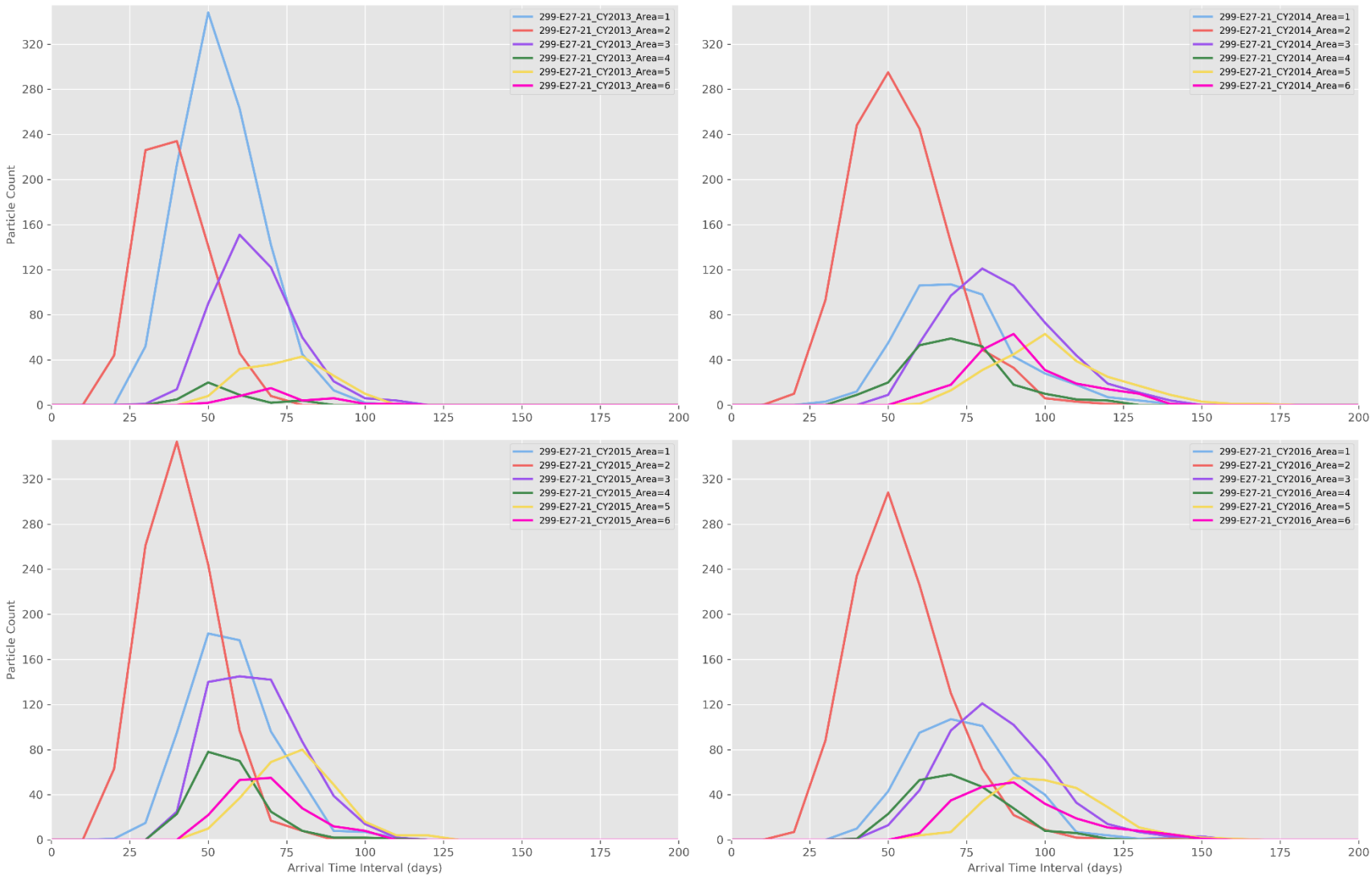

Figure L-30. Particle Breakthrough Curves per Area at Monitoring Well 299-E27-21

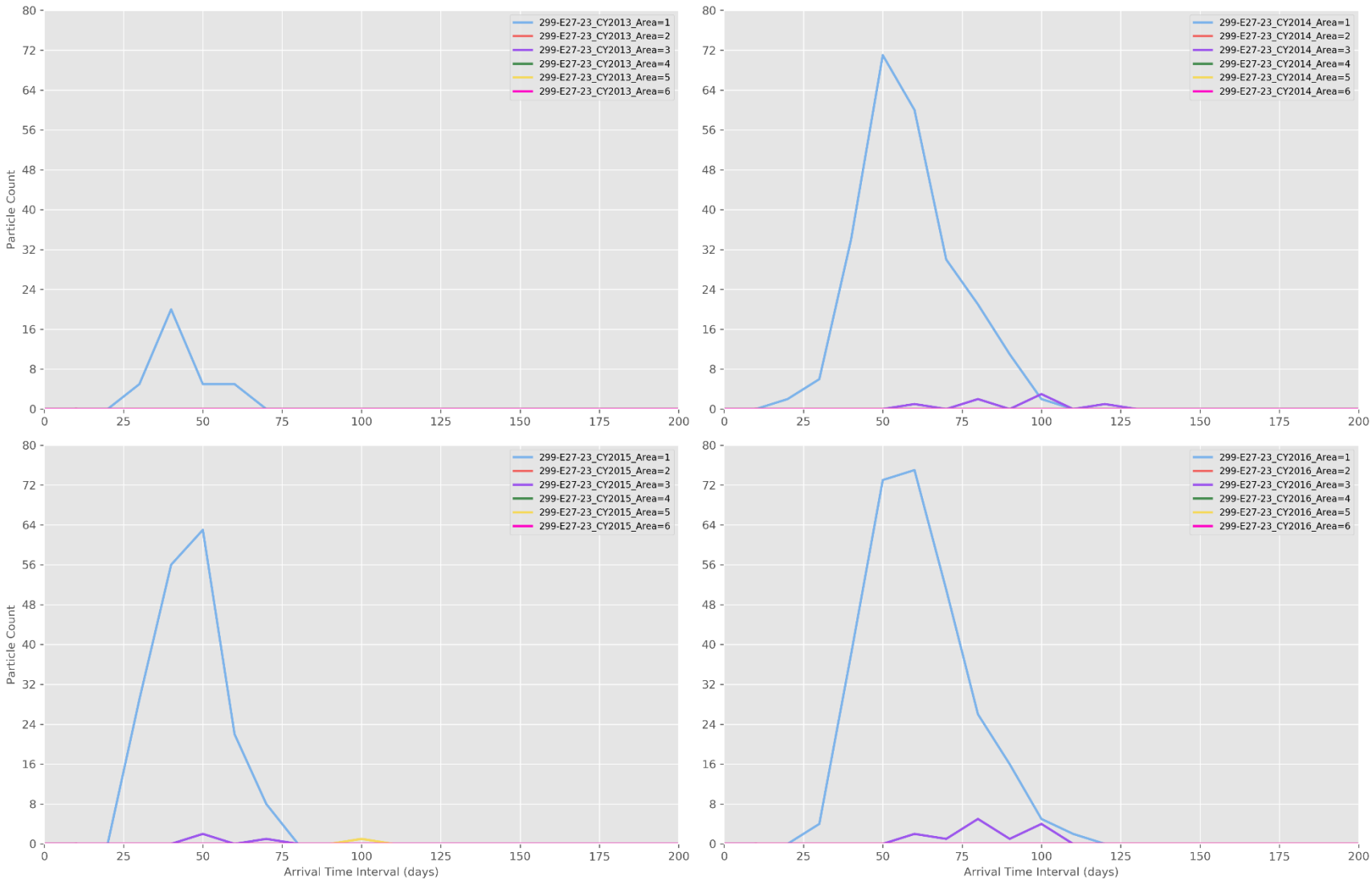

Figure L-31. Particle Breakthrough Curves per Area at Monitoring Well 299-E27-23

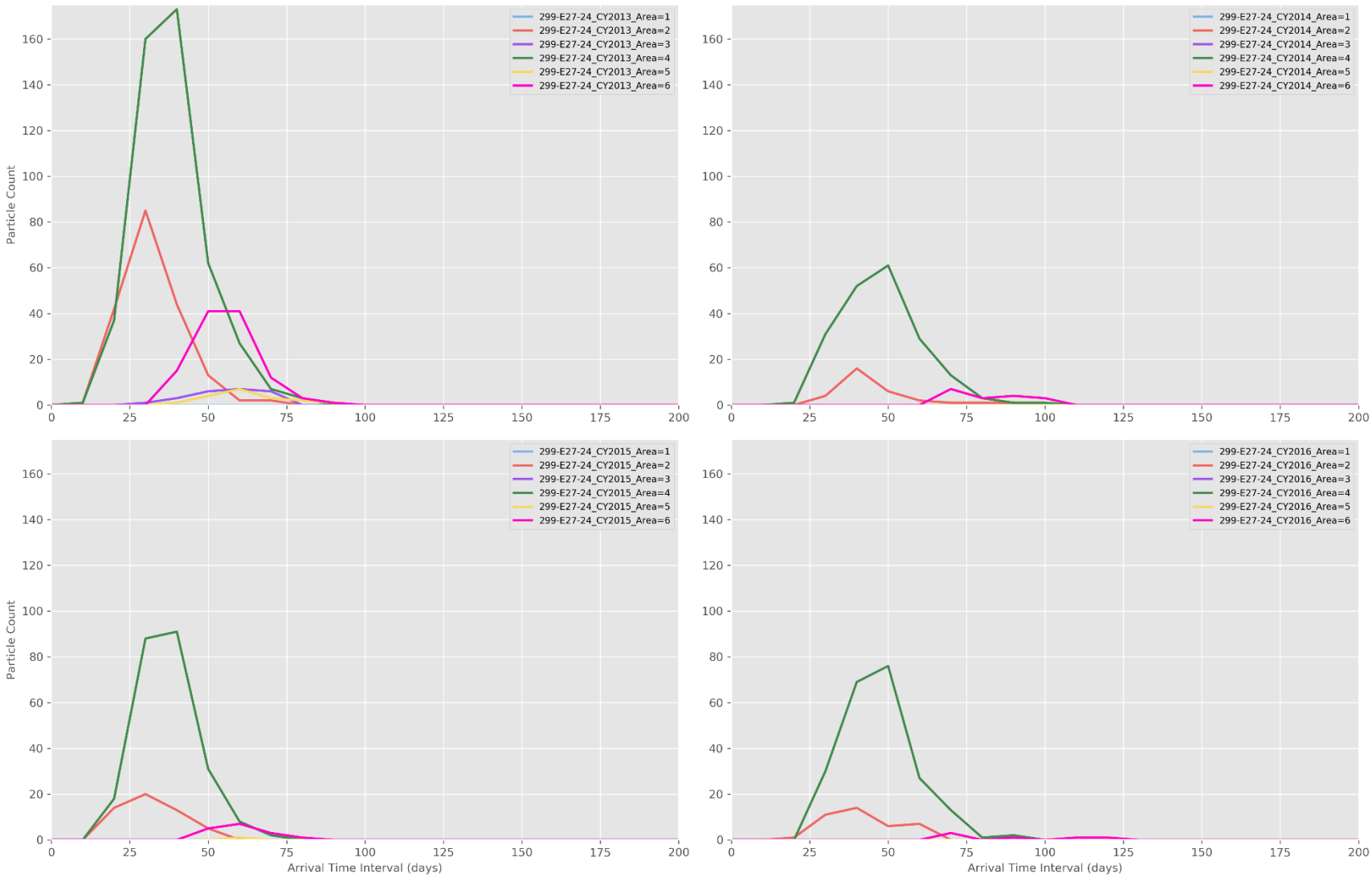

Figure L-32. Particle Breakthrough Curves per Area at Monitoring Well 299-E27-24

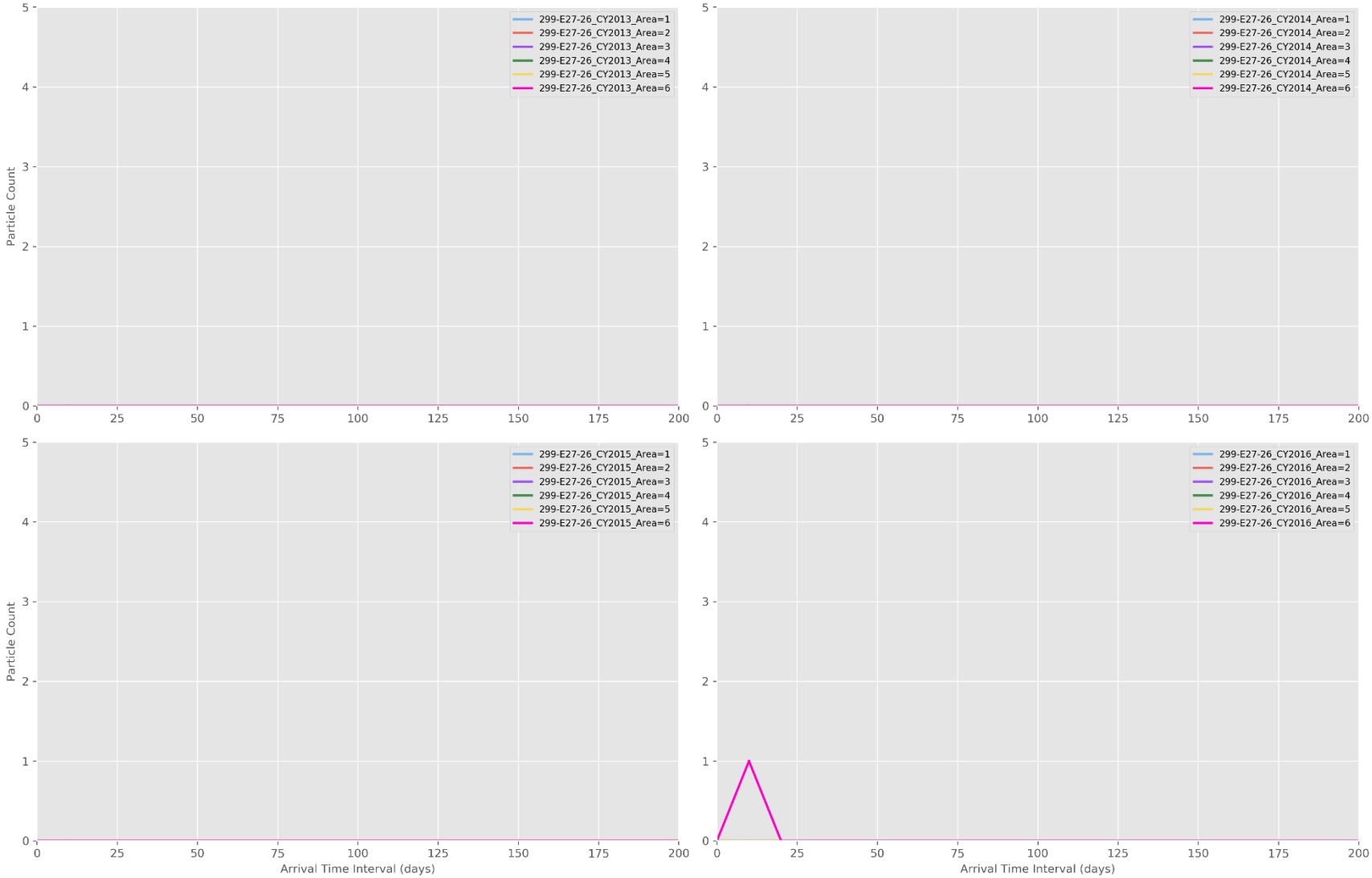

Figure L-33. Particle Breakthrough Curves per Area at Monitoring Well 299-E27-26

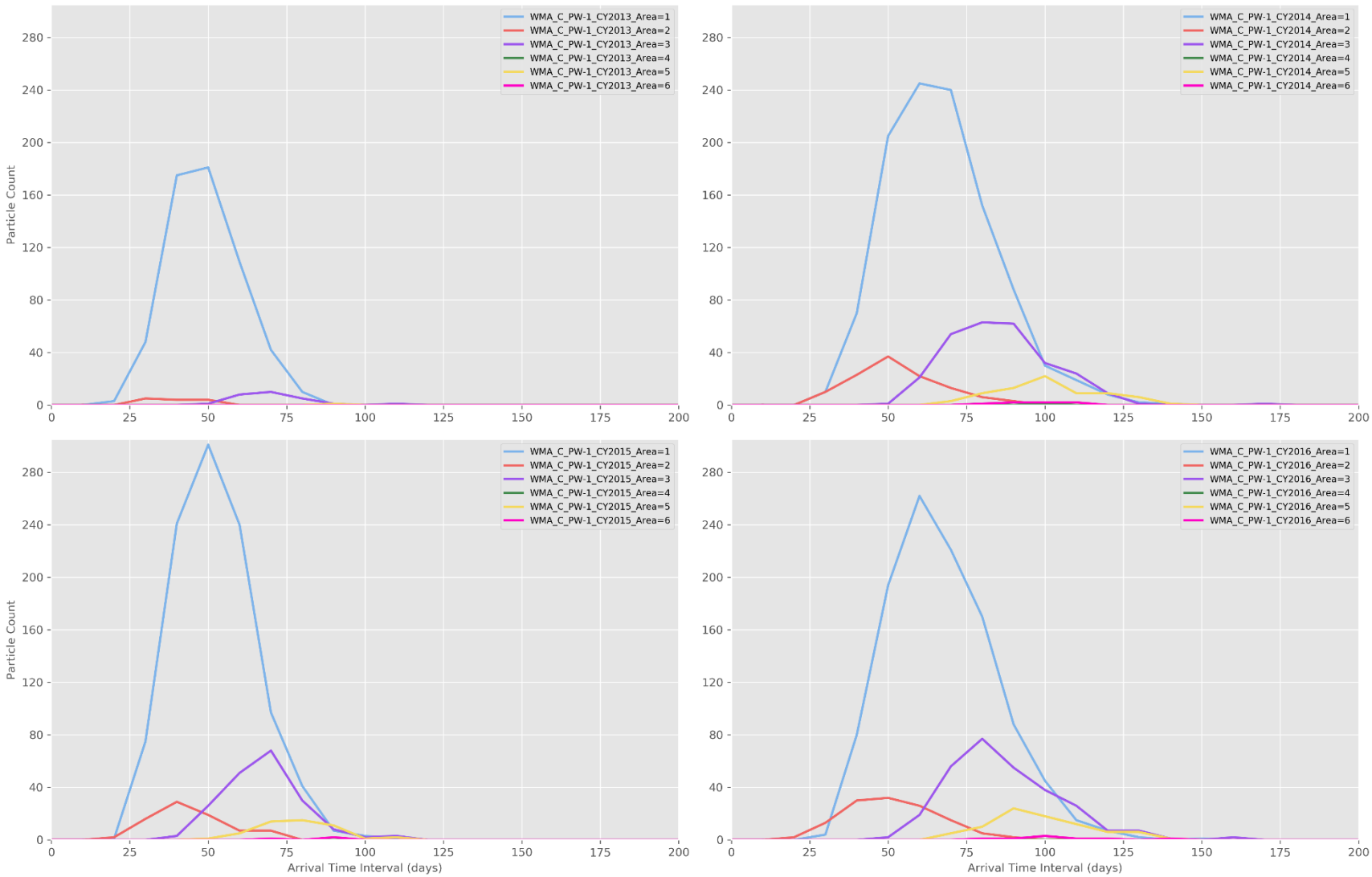

Figure L-34. Particle Breakthrough Curves per Area at Monitoring Well WMA_C_PW-1

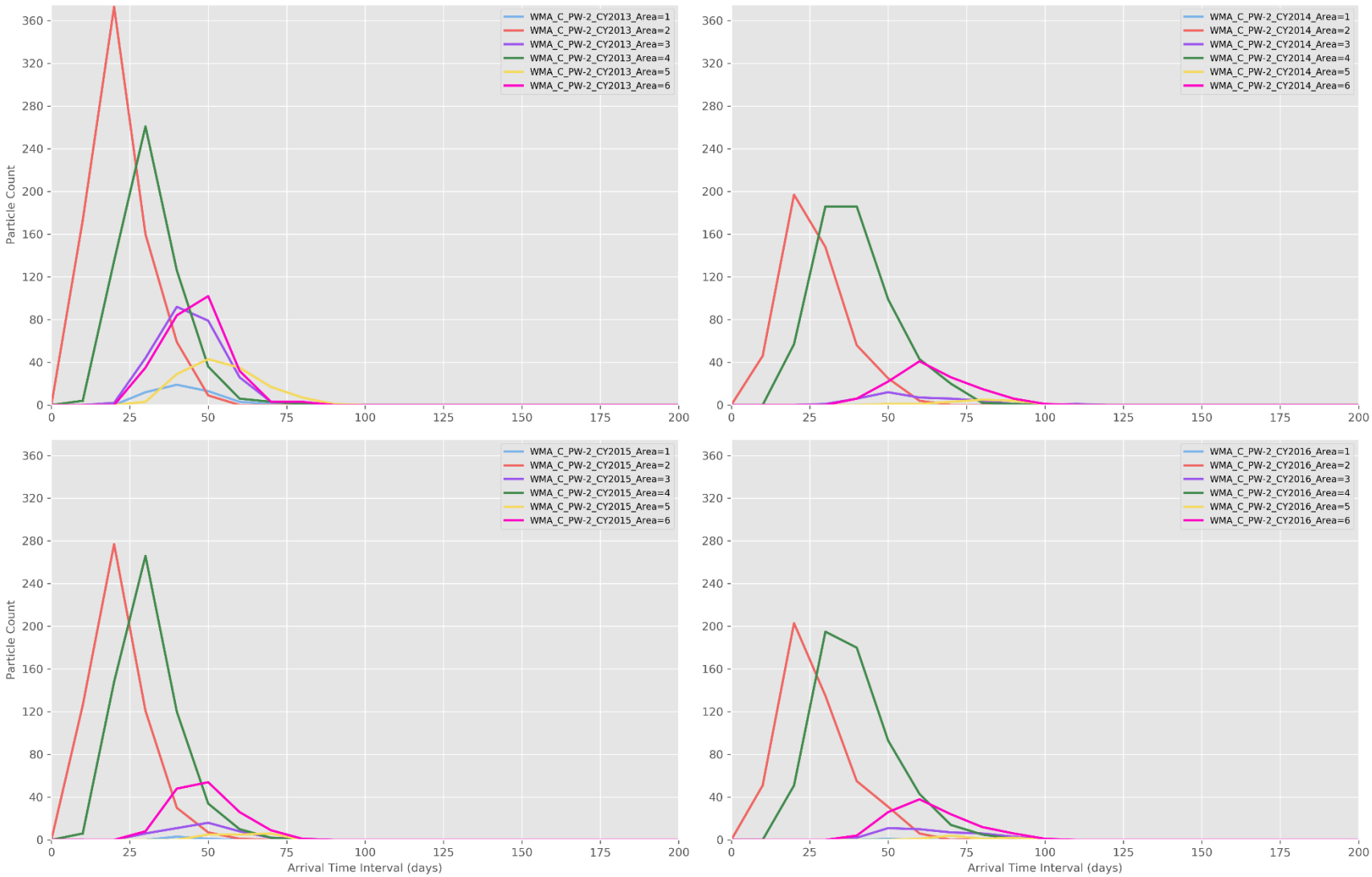

Figure L-35. Particle Breakthrough Curves per Area at Monitoring Well WMA_C_PW-2

This estimated depth of the plume was then compared to the depth from the water table to the bottom of the monitoring well screen. If the depth of the plume is below the bottom of the monitoring well screen, then the dissolved constituents may be anticipated to pass beneath the well screen. If it falls within the interval between the top of the water table and the bottom of the well screen, then the well depth is appropriate for detection of releases at WMA C.

For each downgradient monitoring well at WMA C, the distance used in the calculation was the distance from the centroid of the facility to each well location. The hydraulic conductivity used in the calculation for WMA C, 15,000 m/d (49,213 ft/d), is the calibrated hydraulic conductivity from the CPGWM for the Hanford formation, which underlies the facility. Wells 299-27-24 and 299-E27-155 were not evaluated because they are deep wells and not screened across the top of the aquifer. The results of the API plume diving calculation for the downgradient wells for WMA C are shown in Table L-9.

Table L-9. Summary of Well Screen Interval Evaluation for Downgradient Wells

Monitoring Well	Existing or Proposed Well?	Distance, D, (m)[a]	Recharge, *i*, (m/yr)[b]	Slope, S, of Plume Dive[c]	Estimated Depth of Plume Below Water Table (m)[d]	Depth from Water Table to Bottom of Well Screen (m)[e]	Is Plume Depth Above Bottom of the Screen? (Yes/No/N/A)
299-E27-4	Existing	117.9	8.26E-03	1.51E-04	1.78E-02	10.10	Yes
299-E27-13	Existing	94.2	8.26E-03	1.51E-04	1.43E-02	1.30	Yes
299-E27-14	Existing	92.5	8.26E-03	1.51E-04	1.40E-02	2.20	Yes
299-E27-21	Existing	140.4	8.26E-03	1.51E-04	2.12E-02	10.10	Yes
299-E27-23	Existing	117.9	8.26E-03	1.51E-04	1.78E-02	10.10	Yes
299-E27-25	Existing	275.5	8.26E-03	1.51E-04	4.17E-02	4.50	Yes
299-E27-26	Existing	110.6	8.26E-03	1.51E-04	1.67E-02	10.00	Yes
WMA_C_PW-1	Proposed	128.5	8.26E-03	1.51E-04	1.94E-02	N/A	N/A
WMA_C_PW-2	Proposed	97.8	8.26E-03	1.51E-04	1.48E-02	N/A	N/A

a. Distance of the well from centroid of dangerous waste management unit.

b. A representative number from the CPGWM. The recharge values represent fluxes from surface water discharge due to historical operations at the Hanford Site and are summarized in EMDT-BC-0002, *Vadose Zone Attenuated Recharge, Electronic Modeling Data Transmittal – Boundary Condition (Artificial Recharge)*–0002. The anthropogenic flux is added to the natural recharge component in order to establish the final total recharge flux used in the simulations. Discharges included in EMDT-BC-0002 have been attenuated to account for travel through the vadose zone.

c. Slope of the plume dive computed using the American Petroleum Institute plume diving calculation as detailed in the main text of this ECF. The migration parameters for WMA C used in the calculation of slope are as follows:

Hydraulic conductivity: 15,000 m/d (49,213 ft/d) (a calibrated value from the CPGWM)

Hydraulic gradient: 1.04E-05 (determined from 2016 water-level maps produced using TRIM)

d. Plume depth at monitoring well location computed from distance, D, times the slope, S.

e. Depths obtained from Table 3-8 in DOE/RL-2016-66, *Hanford Site RCRA Groundwater Monitoring Report for 2016*.

CPGWM = Central Plateau Groundwater Model

ECF = environmental calculation file

N/A = not applicable

TRIM = Tikhonov Regularized Inverse Method

WMA = waste management area

L4 References

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DOE/RL-2009-77, 2010, *Groundwater Quality Assessment Plan for the Single-Shell Tank Waste Management Area C*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0069394H.

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EMDT-BC-0002, 2009, *Vadose Zone Attenuated Recharge, Electronic Modeling Data Transmittal – Boundary Condition (Artificial Recharge)*-0002, Rev. 0, INTERA, Inc., Richland, Washington.

SGW-60442, 2016, *WMA C April through June 2016 Quarterly Groundwater Monitoring Report*, Rev. 0, CH2M Hill Plateau Remediation Company, Richland, Washington. Available at: https://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0072439H.

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