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SECTION

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Appendix E
Evaluation of Groundwater Protection

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Terms

2-D	two-dimensional
3-D	three-dimensional
ARAR	applicable or relevant and appropriate requirement
bgs	below ground surface
CT	carbon tetrachloride
CERCLA	<i>Comprehensive Environmental Response, Compensation, and Liability Act of 1980</i>
CFR	<i>Code of Federal Regulations</i>
COPC	contaminant of potential concern
DAF	dilution attenuation factor
DOD	Department of Defense
DOE	U.S. Department of Energy
DNAPL	dense, nonaqueous-phase liquid
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
ET	evapotranspiration
EVSDS	Effluent Volume to Soil Disposal Sites
FEP	feature, event, and process
HEIS	Hanford Environmental Information System
K_d	partitioning coefficient
LTRR	long-term recharge rates
MCL	maximum contaminant level
MDA	method detection activity
MDL	method detection limit
OU	operable unit
PCE	tetrachloroethylene
PNNL	Pacific Northwest National Laboratory
PoCal	point of calculation
PQL	practical quantitation limit

QA	quality assurance
QC	quality control
RI	remedial investigation
RIFAT	Remedial Investigation Report Full Analytical Tables
RISAT	Remedial Investigation Report Summary Analytical Tables
SSL	soil screening level
STOMP	Subsurface Transport Over Multiple Phases
SVE	soil vapor extraction
TCE	trichloroethylene
UCL	upper confidence limit
VOA	volatile organic analyte
VOC	volatile organic compound
WAC	<i>Washington Administrative Code</i>

E1.0 Introduction

This appendix provides an understanding of the potential contaminants of potential concern (COPCs) that may affect groundwater at the 200-PW-1, 200-PW-3, and 200-PW-6 (200-PW-1/3/6) operable unit (OU) sites.

E1.1 Background

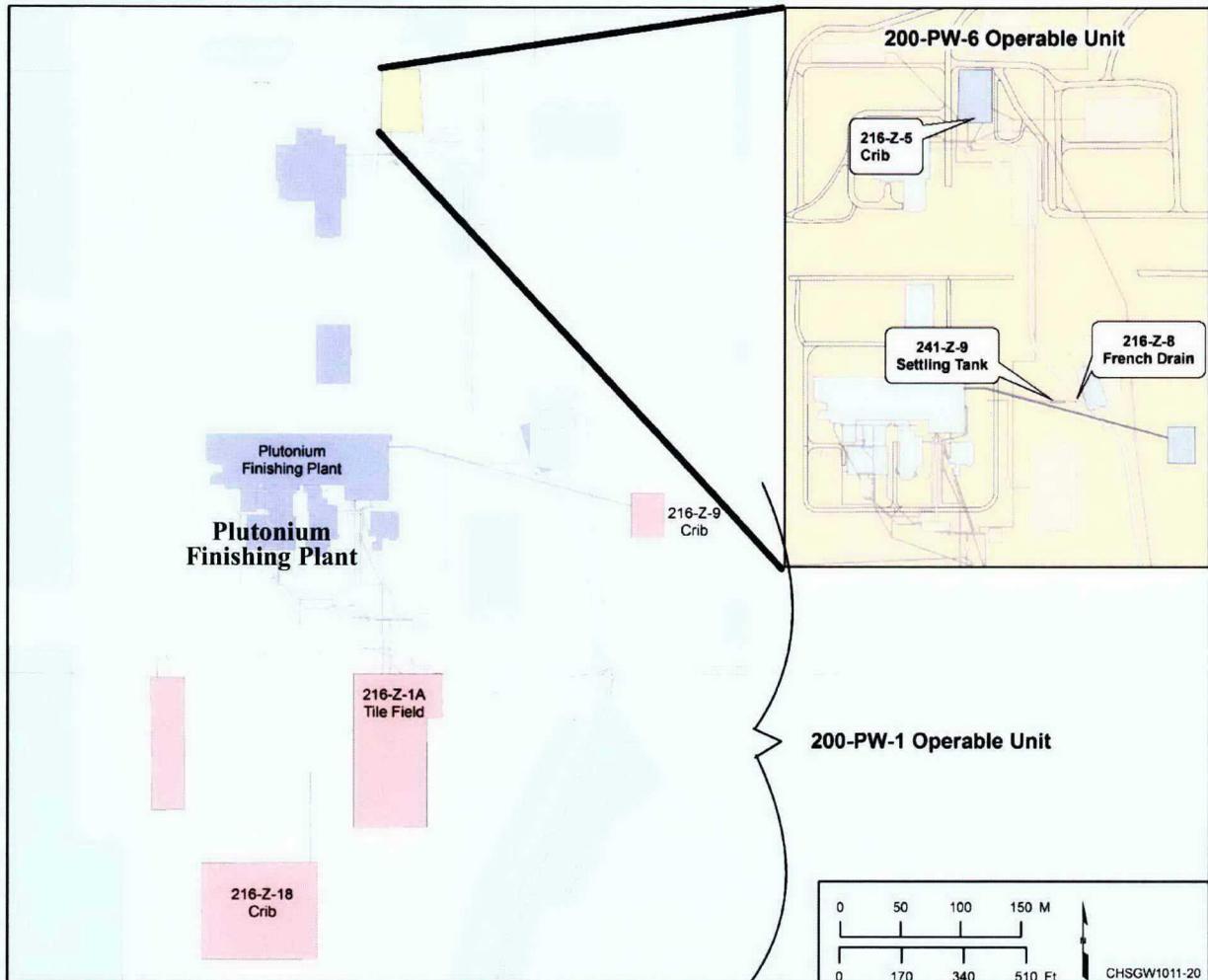
The “National Oil and Hazardous Substances Pollution Contingency Plan” (40 *Code of Federal Regulations* [CFR] 300, Subchapter J) requires that a baseline risk assessment be conducted to “characterize the current and potential threats to human health and the environment” [40 CFR 300.430(d)(4), “Remedial Investigation/Feasibility Study and Selection of Remedy”]. The environment is defined in 40 CFR 300 as:

the navigable waters, the waters of the contiguous zone and the ocean waters of which the natural resources are under the exclusive management authority of the United States under the *Magnusen-Stevens Fishery Conservation and Management Act* of 1966, (16 USC 1801, et seq.); and any other surface water, groundwater, drinking water supply, land surface or subsurface strata, or ambient air within the United States or under jurisdiction of the United States.

The baseline risk assessments performed for *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA) sites generally conform to EPA/540/1-89/002, *Risk Assessment Guidance for Superfund Volume I Human Health Evaluation Manual (Part A): Interim Final*, and 63 FR 26846, “Guidelines for Ecological Risk Assessment; Notice.” These guidance documents focus on the protection of human health and ecological receptors and do not specifically address protection of groundwater from potential future impacts from vadose zone sources. Currently, no CERCLA guidance document is available that specifically addresses risk assessment criteria and methods to assess the protection of groundwater from potential future impacts from vadose zone sources. Additionally, the U.S. Environmental Protection Agency (EPA) and the Washington State Department of Ecology (Ecology) expect that remedial actions will be protective of groundwater and that the U.S. Department of Energy (DOE) will take steps necessary to prevent further degradation of groundwater (DOE/RL-2002-59, *Hanford Site Groundwater Strategy: Protection, Monitoring, and Remediation*).

E1.2 Screening and Evaluation of Groundwater Protection Contaminants of Potential Concern

A summary of human health risks from direct contact with the COPCs identified for the 200-PW-1/3/6 OUs in DOE/RL-2006-51, *Remedial Investigation Report for the Plutonium/Organic-Rich Process Condensate/Process Waste Group Operable Unit: Includes the 200-PW-1, 200-PW-3, and 200-PW-6 Operable Units* (RI Report), is presented in Section E3.2 of this report. To evaluate potential future human health concerns in groundwater from the 200-PW-1/3/6 OUs contaminants, soil contaminant data from boreholes proximal to the waste sites considered representative for the evaluation of groundwater protection at the 200-PW-1/3/6 OUs were evaluated. These representative waste sites include the 216-Z-9 Trench/Crib, the 216-Z-1A Tile Field/Crib, the 216-Z-18 Crib, the 216-Z-8 French Drain, and 216-A-8 Crib. Figure E1-1 shows the locations of the Z-Area waste sites in the 200-PW-1 and 200-PW-6 OUs. Figure E1-2 shows the location of the 216-A-8 waste site in the 200-PW-3 OU. Section E2.1.1 describes the borehole data sources of the soil data.

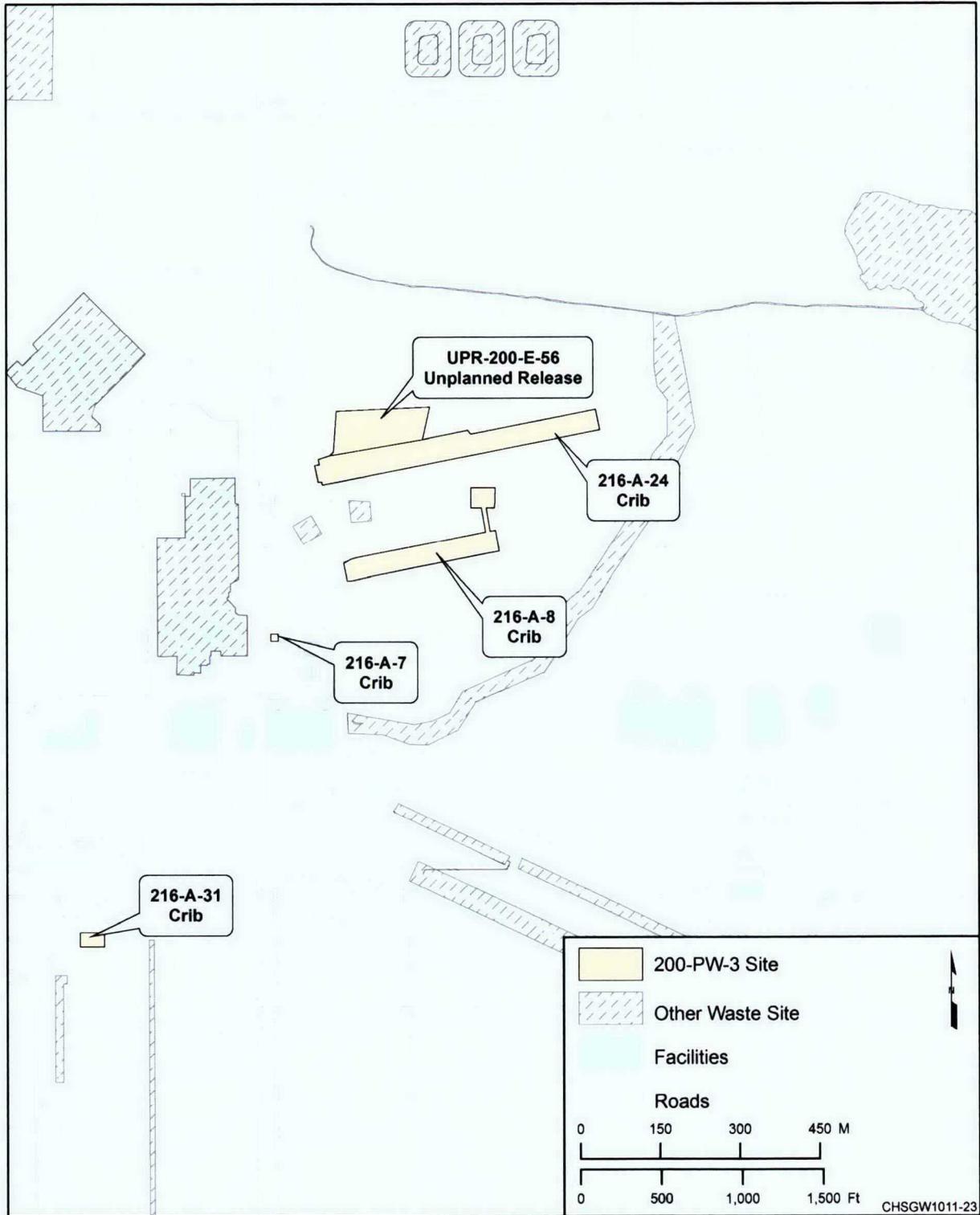


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2 **Figure E1-1. Locations of the 200-PW-1 and 200-PW-6 Waste Sites in the 200 West Area**

3 The COPC selection process used for groundwater protection differs somewhat from the COPC selection
4 process used to evaluate the direct contact exposure pathway for a number of reasons:

- 5 • The data represent single or duplicate analyses of contaminants in discrete geologic host materials in
6 the subsurface vertically, at specified depth intervals.
- 7 • The data represent stratified and systematic random sample populations rather than strictly random
8 sample populations.
- 9 • Contaminant reduction in soils, especially deep vadose zone soils, by, e.g., surficial removal methods,
10 may not be practical or cost effective, thus requiring consideration of other remedial actions designed
11 to affect the fate and transport of contaminants to groundwater.
- 12 • There is typically no subsequent post-remedy verification sampling data available.
- 13 • The screened COPC data serve as the primary basis for defining the contaminant source term in risk
14 characterization using fate and transport modeling.

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Figure E1-2. Location of the 216-A-8 Crib in the 200-PW-3 Operable Unit Waste Sites of the 200 East Area

1 These distinctions are important because the determination of whether contamination exists in the
2 subsurface is generally evaluated only once for vadose zone soil data. The objectives of the evaluation of
3 vadose zone COPCs involve assessing the existence of any contamination in the vadose zone soils, and
4 minimizing the uncertainty associated with identifying the presence or absence of contamination in this
5 one and only evaluation. This objective differs from that of traditional EPA soil screening, which is
6 intended to serve as a streamlined evaluation tool to help site managers expedite the elimination of areas,
7 pathways, and/or contaminants of concern, thereby enabling the identification of areas needing further
8 investigation (EPA 540/R-96/018, *Soil Screening Guidance: Users Guide*). The EPA soil screening level
9 (SSL) methodology was designed for use during the early stages of a site evaluation when information
10 about subsurface conditions may be limited, is based on conservative, simplifying assumptions
11 (EPA 540/R-96/018). This process is, therefore, more aptly regarded as a COPC “evaluation” process vs.
12 a traditional COPC “screening” process, which typically involves the application of more complete
13 evaluation measure in subsequent evaluation efforts (e.g., verification sampling). Thus, more complete
14 and robust measures to minimize uncertainties associated with identifying the presence or absence of
15 contamination in the context of Type I and Type II errors are warranted for the process of contaminant
16 identification in vadose zone soil data for groundwater protection. Therefore, the measures utilized in the
17 COPC evaluation process for vadose zone soils include greater levels of scrutiny and rigor in the
18 evaluation of data in the context of, for example, detection, if it is quantifiable (e.g., practical quantitation
19 limits [PQLs]), outliers/exceedances, the use of site data in lieu of default values, and/or other measures
20 that may extend beyond those used in traditional soil screening.

21 It is also important that robust measures in the COPC “evaluation” of vadose zone soil data be employed
22 prior to the fate and transport modeling phase. Less rigor in the identification of COPCs not only passes
23 reducible uncertainties to the risk characterization evaluation, but also exacerbates those uncertainties by
24 creating unnecessary confusion and challenges for the evaluation of model results when reducible
25 uncertainties are incorporated in the contaminant source term, and attempt to be interpreted in the context of
26 model results for groundwater impacts. Thus, all appropriate measures for minimizing reducible
27 uncertainties in the identification of vadose zone contamination are most appropriately employed prior to
28 the fate and transport modeling phase of the COPC evaluation process. Therefore, the identification COPC
29 evaluation process for vadose zone soils must involve a process that is more rigorous, complete, and even
30 less conservative than the soil screening processes intended to be accompanied by verification sampling
31 following remedial actions. Thus, all measures to reduce uncertainties associated with correctly identifying
32 subsurface soil contamination must be employed in this COPC evaluation process.

33 The process used in the COPC soil evaluation from boreholes proximal to the 200-PW-1/3/6 waste sites
34 for groundwater protection involved three phases of evaluation, which are described in the following
35 section. The following sections describe the process used in the identification of COPC in soil samples
36 from boreholes near the 200-PW-1/3/6 waste sites selected for the evaluation of groundwater protection.
37 Chapter E4.0 describes the results of the evaluation process, the methodology used to calculate soil source
38 term concentrations for each COPC evaluated in the fate and transport modeling phase of the protection
39 of groundwater COPC evaluation process.

40

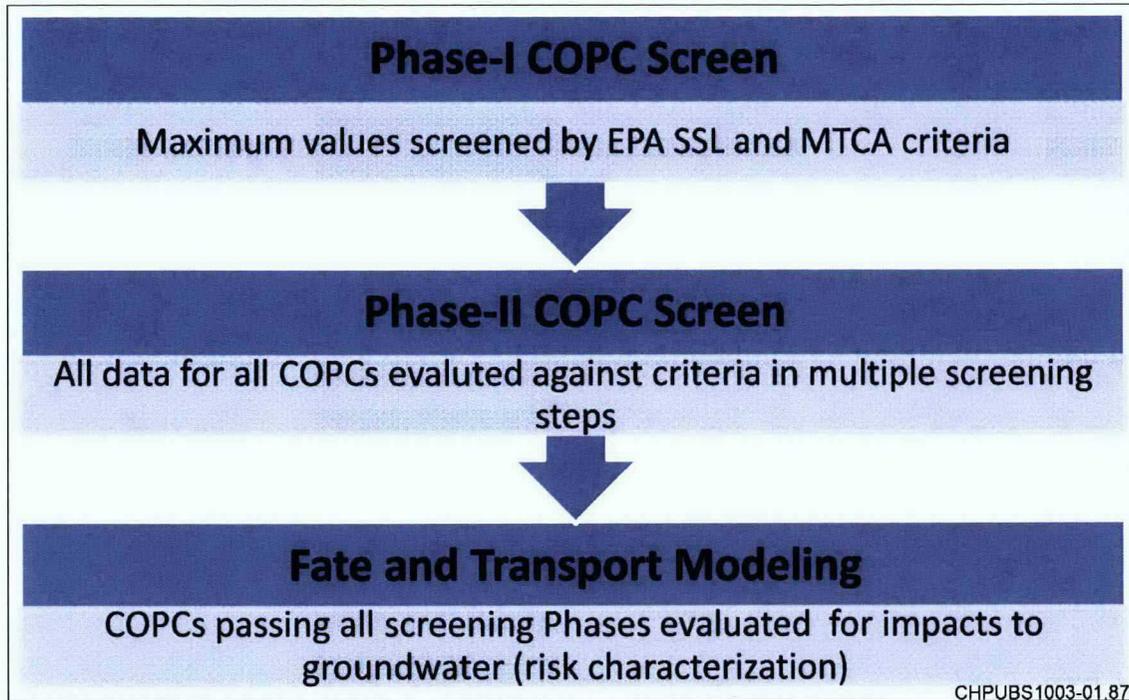
E2.0 COPC Screening and Evaluation Processes

All analytes reported in the analyses of soil samples from all boreholes proximal to the 200-PW-1/3/6 waste sites selected for evaluating groundwater protection were evaluated as COPCs. These analytes included non-radioactive metal, volatile organic compounds (VOCs), semi-volatile compounds, anionic species (e.g., nitrate), and radionuclides. The waste sites included in the evaluation were those considered to have the potential to affect groundwater based on the operations, waste disposal practices, and waste streams. Although the 216-Z-1A is regarded as a waste site, the 216-Z-18 Crib was included in the evaluation because it appeared that there were some COPCs in the subsurface soils associated with this waste site that were not identified in the soils for the 216-Z-1A Crib; therefore, the 216-Z-18 Crib was included in the evaluation for completeness.

The COPC screening and evaluation process involved two main phases of contaminant data screening to identify contaminants in the vadose zone soils to be evaluated in vadose zone fate and transport modeling for risk characterization. Phase I involved an initial screening comparing the maximum detected concentrations of all analytes in the borehole samples from each waste site to the lower of the EPA SSLs (EPA/540/R-95/128), or the soil concentrations for groundwater protection, based on the Fixed Parameter three-phase partitioning model (*Washington Administrative Code* [WAC] 173-340-747[3][a], "Model Toxics Control Act—Cleanup," "Deriving Soil Concentrations for Ground Water Protection," Equation 747-1). Phase II involved screening all data for each COPC remaining from the Phase I screen in a succession of steps that included the following criteria:

1. Laboratory code
2. Background (as appropriate), and/or a soil screening level for groundwater protection based on the EPA Soil-Water partition equation (EPA/540/R-95/128, *Soil Screening Guidance: Technical Background Document*), and use of the parameters in the Ecology Fixed Parameter three-phase partitioning equation (WAC 173-340-747, Equation 747-1)
3. Background (as appropriate), and/or a soil screening level for groundwater protection based on the EPA Soil-Water partition equation (EPA/540/R-95/128), and use of the parameters in the Ecology Fixed Parameter three-phase partitioning equation (WAC-173-340-747, Equation 747-1)
4. Quantitation limit and pathway considerations
5. Evaluation of data anomalies (quality assurance/quality control [QA/QC] check), and other considerations
6. Contaminant transport time to groundwater and consideration of radionuclide decay time (as appropriate)

Data for COPCs passing all screening phases were then used to calculate source term concentrations of contaminated soil volumes evaluated for risk characterization evaluations using vadose zone fate and transport modeling. Figure E2-1 illustrates a schematic summary of this sequence of screening and evaluation phases and steps, which is described in ECF-200PW1/3/6-10-0346, *200-PW-1/3/6 COPC Screening and Evaluation Phases*. Chapter E3.0 reports the progressive results of each phase of the screening evaluation process are. Chapter E4.0 summarizes the modeling results and associated candidate COCs for each waste site. Chapter E5.0 presents the uncertainty analysis and evaluation of the model results. Figures E2-1, E2-2, and E2-3 illustrate schematic summaries of this sequence of screening and evaluation phases and steps.



1
2 **Figure E2-1. Schematic Sequence of the Overall Process of COPC Screening and**
3 **Evaluation and Model Based Risk Characterization for Groundwater Protection**

4 **E2.1 Borehole Data Sources and Analytical Data Processing**

5 Analytical data sets for each borehole or boring were extracted from the Hanford Environment
6 Information System (HEIS) database and the Remedial Investigation Report Full Analytical Tables
7 (RIFAT) and Remedial Investigation Report Summary Analytical Tables (RISAT) reports generated for
8 each waste site as documented in ECF-200PW1/3/6-10-0360, *Identification of Contaminants of Potential*
9 *Concern for the 200-PW-1/3/6 Operable Unit*.

10 All soil samples from soil borings for a waste site are combined to evaluate the groundwater protection
11 pathway. The deep zone (or vadose zone) soil, where the soil surface is 0 m (0 ft) below ground surface
12 (bgs) to the water table, is used to evaluate the potential impacts to groundwater beneath the site from
13 vadose zone contaminants. Table E2-1 identifies boreholes, borings, and other sources of soil data used in
14 the COPC selection process by waste site. Only waste sites with COPCs passing the initial screening
15 phase are listed. The boreholes and borings serving as the source of soil data for COPCs at the 216-Z-1A,
16 216-Z-18, and 216-Z-9 waste sites identified in Table E2-1 are shown in the context of the waste site
17 locations in Figures E2-4 and E2-5a and b.

18 Forty-one (41) boreholes within 50 m (164 ft) of the 216-Z-9 waste site with data on chemical and/or
19 radiological analytes were evaluated for inclusion in the COPC screening process. These boreholes
20 represent subsurface sampling and analysis efforts that range in time from 1992 to 2006. The data from
21 six of these boreholes (299-W15-216, -217, -218, -219, -220, and -223) were collected in 1992 to 1993.
22 The data from one borehole (299-W15-46) was collected in 2004. The data from two of the boreholes
23 (299-W-15-84 and 299-15-95) were collected in 2001. All other data from the remaining
24 31 boreholes/subsurface borings at 216-Z-9 were collected in 2006.

25

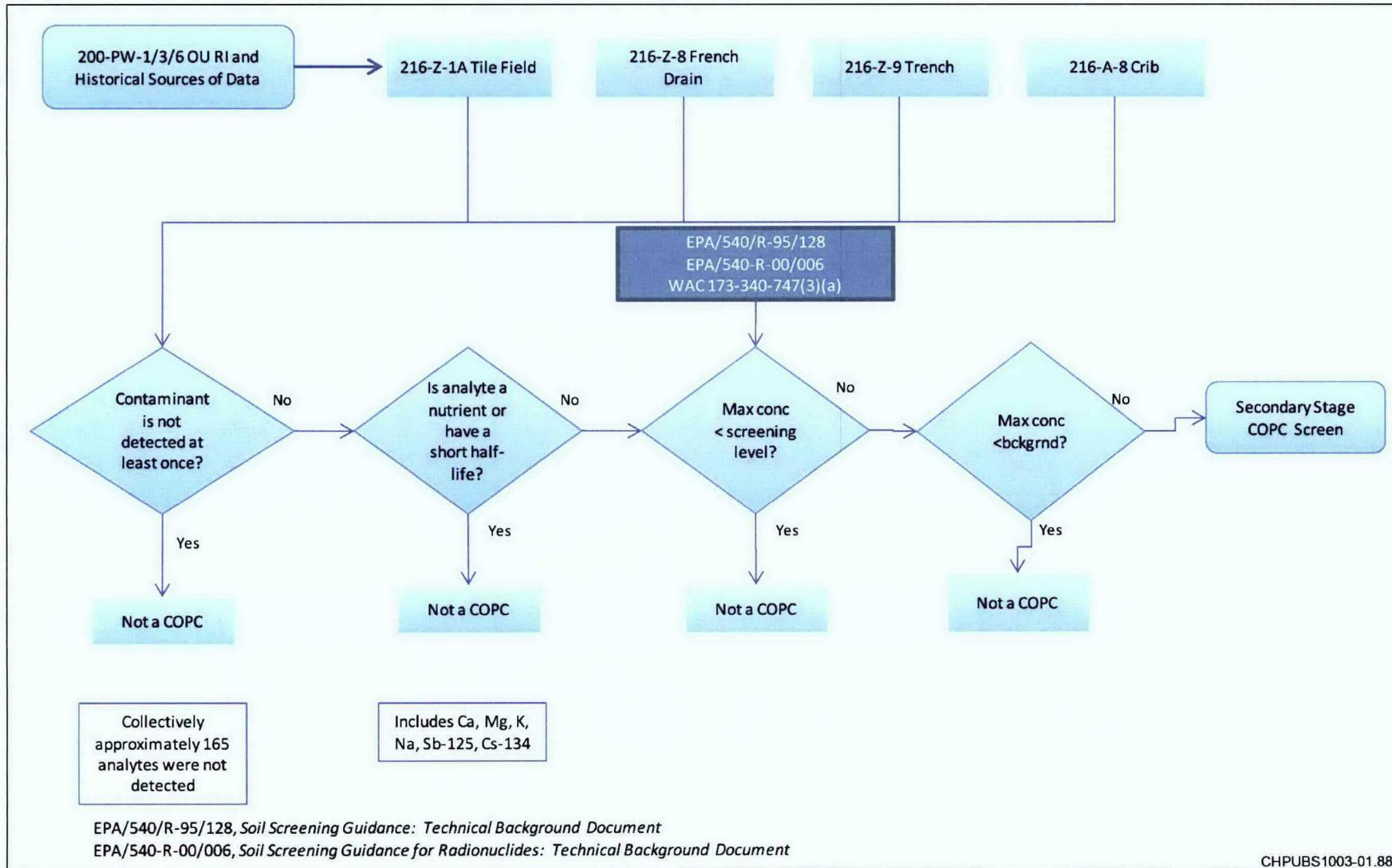
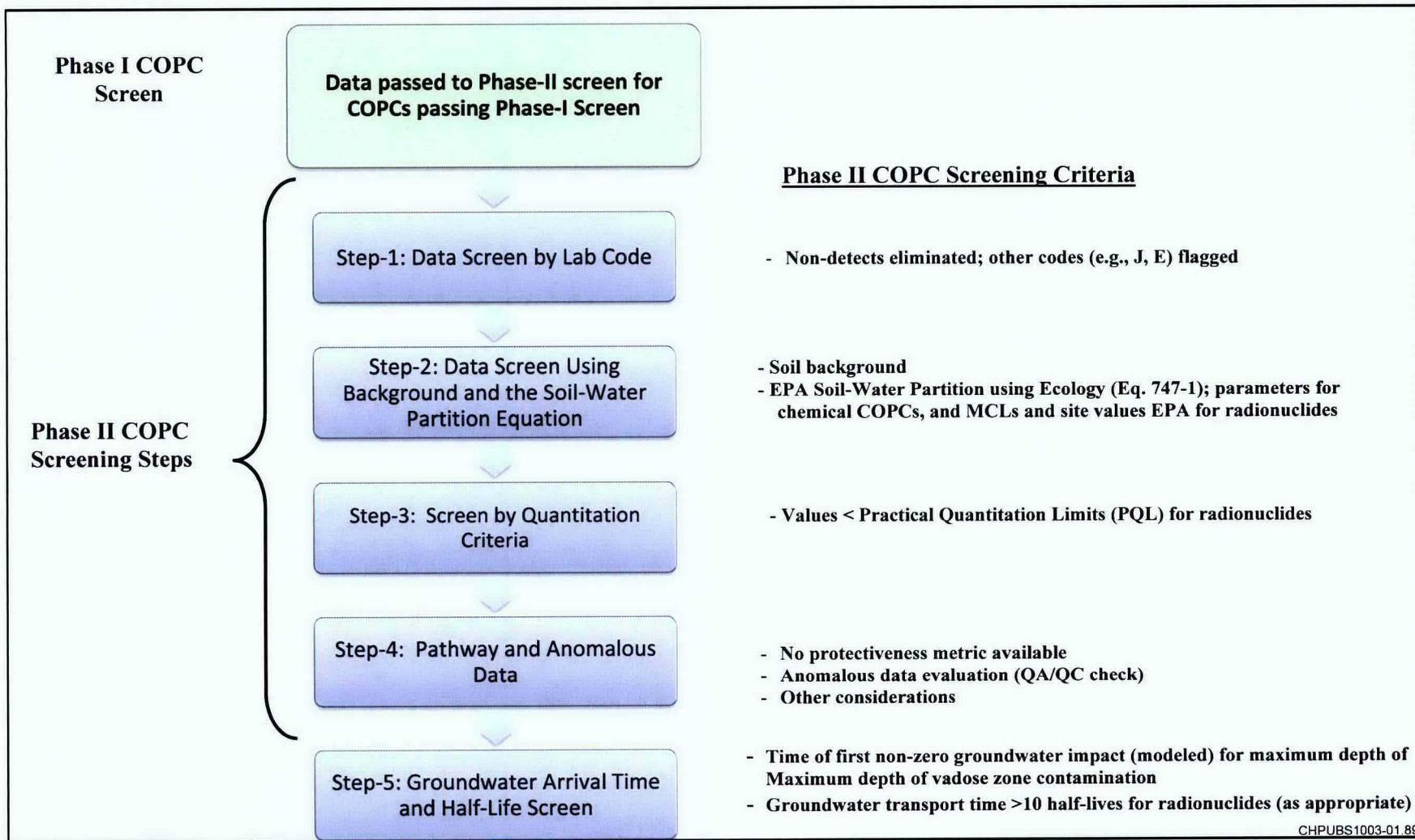


Figure E2-2. Flow Diagram of the Initial Phase (Phase I) of the COPC Screening Process for Groundwater Protection

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Figure E2-3. Flow Diagram for the Screening Steps and Criteria Associated with Data Screening in the Phase II COPC Screening Process

Table E2-1. Boreholes, Boring, and Other Sources of Soil Samples and Data Used in the COPC Screening Process

Waste Site	Boreholes				
216-Z-1A Tile Fields	299-W18-174	299-W18-246	299-W18-248		299-W18-252 ^a
	299-W18-85	299-W18-86	299-W18-87	299-W18-88	299-W18-149
216-Z-1A Tile Fields (plutonium and americium) ^b	299-W18-150	299-W18-158	299-W18-159	299-W18-163	299-W18-164
	299-W18-165	299-W18-166	299-W18-167	299-W18-168	299-W18-169
	299-W18-171	299-W18-172	299-W18-173	299-W18-174	299-W18-175
216-Z-8 French Drain	216-W15-202				
	299-W15-216	299-W15-95	C5225	C5239	C5336
	299-W15-217	C5198	C5226	C5240	C5337
	299-W15-218	C5199	C5227	C5241	C5338
	299-W15-219	C5200	C5228	C5242	C5339
216-Z-9 Trench	299-W15-220	C5201	C5229	C5327	CPT-16
	299-W15-223	C5202	C5231	C5328	
	299-W15-46	C5203	C5236	C5329	
	299-W15-48	C5206	C5237	C5332	
	299-W15-84	C5223	C5238	C5335	
216-A-8 Crib	C4545				
216-Z-18 Crib	299-W18-247	299-W18-96		299-W18-249	
216-Z-361 Settling Tank	NA				
216-Z-10 Injection / Reverse Well	NA				

Notes:

Only waste sites with COPCs passing the initial screening phase are listed.

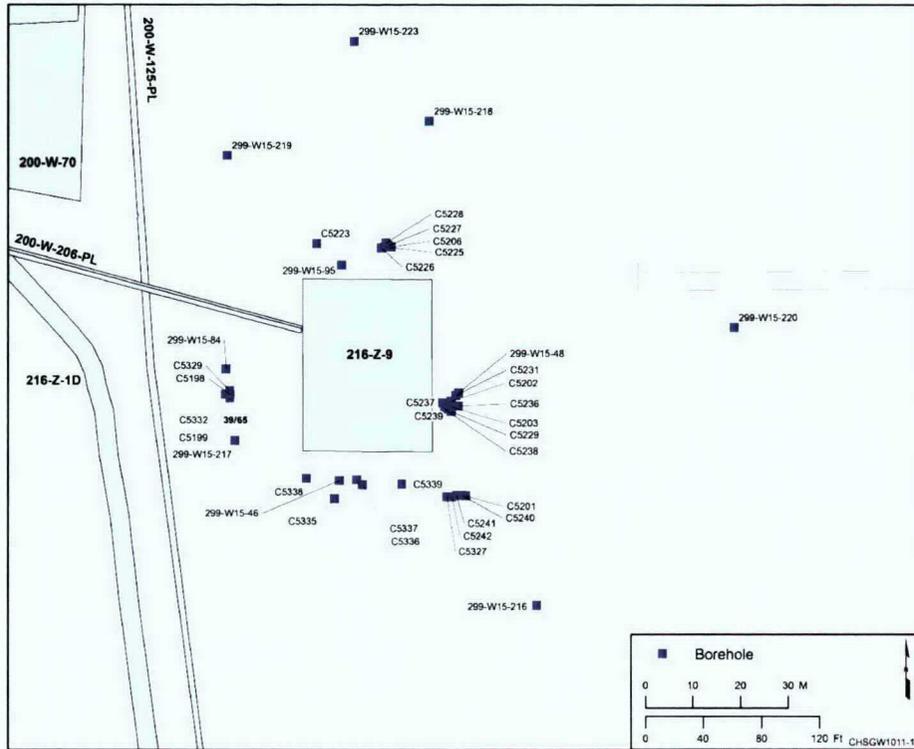
a. Borehole used for Phase I of COPC screening, but regarded as too distant (>50m) from 216-Z-1A Crib for consideration in Phase II COPC screening (see Table E3-2).

b. Plutonium and americium data only (RHO-ST-17, *Distribution of Plutonium and Americium Beneath the 216-Z-1A Crib: A Status Report*)

NA = Not applicable. The 216-Z-361 Settling Tank had no detected COPCs; the Injection/Reverse Well did not have any samples.

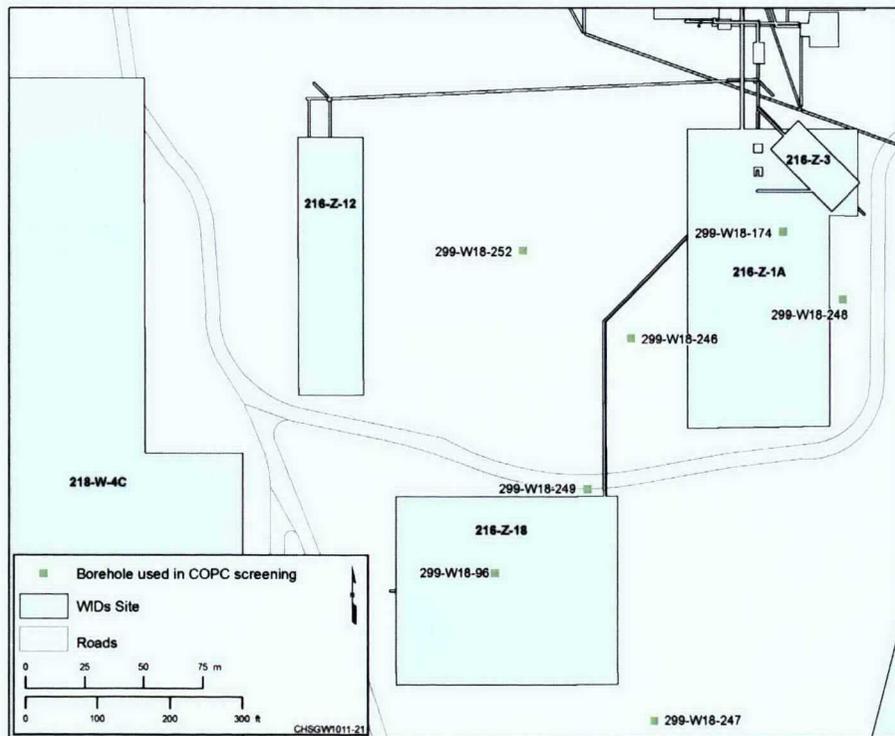
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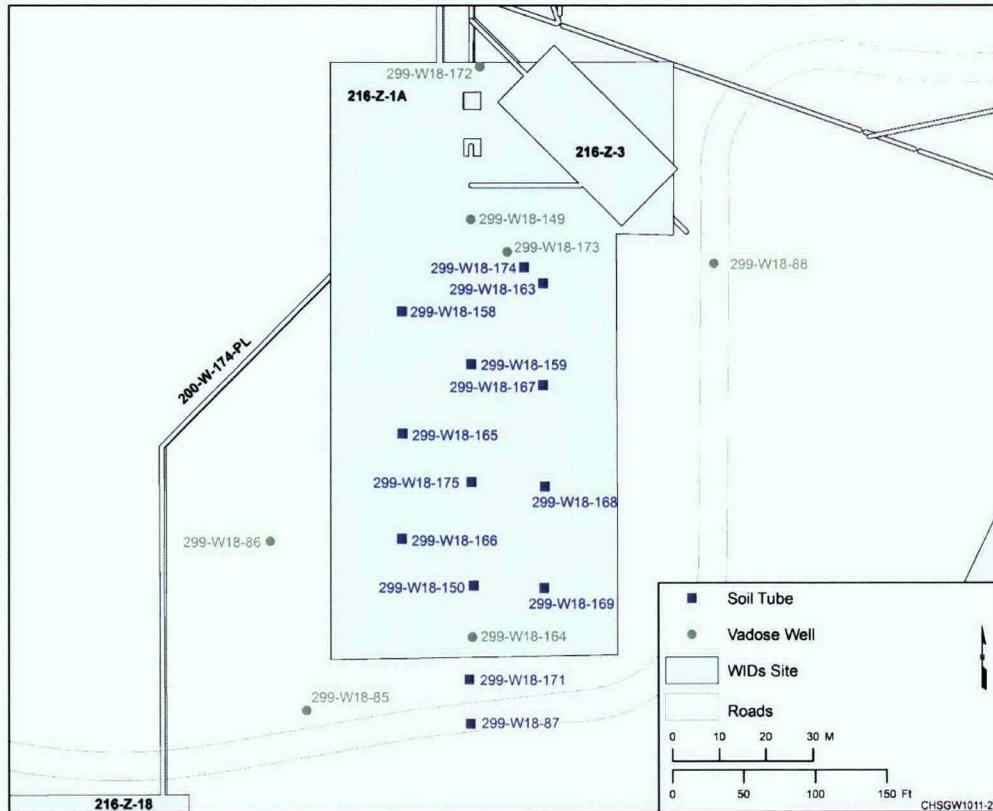
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Figure E2-4. Borehole and Boring Locations Serving as the Sources of Samples and Data for 216-Z-9



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Figure E2-5a. Locations of Boreholes Serving as the Sources of Non-Radiological Samples and Data near the 216-Z-1A and 216-Z-18 Cribs



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 2 **Figure E2-5b. Locations of Boreholes Serving as the Sources of Plutonium and**
 3 **Americium Samples and Data near the 216-Z-1A Crib**

4 These sampling efforts constitute distinct timeframe intervals, beginning in 1992 to 1993 just prior to the
 5 initiation of the soil vapor extraction (SVE) system, to 2006, after about 13 years of SVE operation. The
 6 levels of VOCs have decreased over time during the course of SVE operation. Thus, the data for the
 7 volatile organic analytes (VOAs) are not directly comparable, because they span the timeframe of the
 8 SVE operation. Although the VOA data of different timeframes provide a basis for evaluating the changes
 9 in the VOA soil concentrations over time, the VOA data from the 1992 to 1993 timeframe were not
 10 included in the Phase II COPC data screening because the more recent data (2004 to 2006) were
 11 considered more representative data. The data from all of the 216-Z-9 boreholes were used for
 12 non-VOA COPCs.

13 Five boreholes within about 75 m (246 ft) of the 216-Z-1A with relevant soil data were evaluated for
 14 inclusion in the COPC screening process. Data from the four boreholes most representative of providing
 15 information on the extent of non-radionuclide contamination at the waste site were identified for Phase I
 16 COPC screening. Plutonium-239/240 (Pu-239/240) and americium-241 (Am-241) data are from the
 17 analytical results documented in RHO-ST-17, *Distribution of Plutonium and Americium Beneath the*
 18 *216-Z-1A Crib: A Status Report*, which documents the work performed to characterize the distribution of
 19 plutonium and americium in sediments beneath the crib.

20 The borehole 299-W18-249 was excluded from the Phase I COPC screening for 216-Z-1A because it was
 21 located 50 meters from 216-Z-1A; however, this borehole is located directly adjacent to the 216-Z-18
 22 waste site (Figure E2-5a) and was included in the Phase I COPC screening for 216-Z-18. Data from the
 23 299-W18-252 borehole was included in the initial Phase I COPC screening and transect evaluation

1 (Section E4.3), but was not included in the Phase II data screening because its distance from the waste site
2 was regarded as too great (>70 m [230 ft]), for the data to be considered representative for modeling of
3 the 216-Z-1A Crib.

4 Data from only one borehole C4545 were available for COPC screening at 216-A-8. Sample data from
5 borehole 216-W15-202 were used for evaluation of the 216-Z-8 French Drain (RHO-RE-EV-46 P).

6 **E2.2 Phase I COPC Screen: Initial Screening of Maximum Values Using EPA SSL and** 7 ***Model Toxics Control Act Criteria***

8 The initial COPC screening step has two parts: (1) the available sampling data and site information are
9 reviewed to select data applicable to evaluate groundwater impacts and, (2) analyte concentrations within
10 the data set are evaluated to identify analytes and affected environmental media (i.e., soil) that have the
11 potential to affect groundwater requiring a more detailed assessment.

12 **E2.2.1 Identify Soil Screening Levels for Protection of Groundwater**

13 Screening levels are obtained from several different sources to evaluate the vadose zone soils for the
14 protection of groundwater. The EPA methodology for developing SSLs to identify contaminants in soil
15 that have the potential to adversely affect groundwater is described for chemicals in EPA/540/R-95/128,
16 *Soil Screening Guidance: Technical Background Document*, and for radionuclides in EPA/540-R-00-006,
17 *Soil Screening Guidance for Radionuclides: Technical Background Document*. Soil concentrations
18 protective of groundwater are back calculated from an acceptable groundwater concentration (i.e., a
19 maximum contaminant level [MCL; radionuclides or chemicals] or a risk-based groundwater
20 concentration [chemicals]). First, the acceptable groundwater concentration is multiplied by a dilution
21 attenuation factor (DAF) to arrive at an acceptable soil leachate concentration, and then linear equilibrium
22 soil/water partitioning equations are used to calculate a soil concentration corresponding to the target
23 leachate or groundwater concentration. The EPA equations include the following assumptions for the
24 migration-to-groundwater calculations:

- 25 • The contamination source is infinite
- 26 • Contaminants are uniformly distributed throughout the zone of contamination
- 27 • Soil contamination extends from the contaminated zone to the water table
- 28 • There is no chemical or biological degradation in the unsaturated zone
- 29 • Soil/water partitioning in the contaminated zone is in equilibrium and is instantaneous and linear
- 30 • The receptor well is screened within the groundwater plume
- 31 • There is no dilution of contaminants in groundwater from upgradient recharge
- 32 • Aquifer properties are homogeneous and isotropic

33 The SSLs for chemicals are available at the *Regional Screening Levels for Chemical Contaminants at*
34 *Superfund Sites* (EPA, 2009) screening level/ preliminary remediation goal website.

35 Additionally, the State of Washington within the *Washington Administrative Code* (WAC) 173-340-747
36 prescribes specific methods that may be used to evaluate the protection of groundwater pathway.
37 Screening levels for the protection of groundwater are calculated using the fixed parameter three-phase
38 partitioning model as described in WAC 173-340-747(3)(a). For purposes of this evaluation, the lower of
39 the EPA SSL or the WAC 173-340-747(3)(a) was selected.

40 For radionuclides, EPA/540-R-00-006 provides generic soil screening levels. The soil screening levels for
41 the migration to groundwater pathway were developed using a DAF of 20 to account for natural processes

1 that reduce contaminant concentrations in the subsurface. Table E2-2 contains soil background levels,
 2 EPA screening levels, and EPA soil-water partitioning coefficient (K_d) values. These values are used in
 3 the COPC selection process.

Table E2-2. Summary of Phase I Parameter Screening Values

Analyte Name	Values Used in Screening		
	Soil Background ($\mu\text{g}/\text{kg}$ or pCi/g)	Soil Screening Levels ($\mu\text{g}/\text{kg}$ or pCi/g)	EPA K_d Value (cm^3/g)
Radionuclides			
Americium-241	--	2.52	8.2
Carbon-14	--	40	0.8
Cesium-137	--	40.8	--
Europium-152	--	--	--
Europium-154	--	--	--
Europium-155	--	--	--
Gross alpha	--	--	--
Gross beta	--	--	--
Neptunium-237	--	0.09	0.1
Nickel-63	--	34.2	34
Plutonium-238	--	1.56	5
Plutonium-239/240	--	1.56	5
Potassium-40	16.6	--	--
Protactinium-231	--	--	--
Radium-226	0.815	0.32	3
Radium-228	--	0.32	3
Strontium-90	--	0.192	1
Technetium-99	--	3.73	0.007
Thorium-230	--	6.06	20
Total beta radiostrontium	--	0.192	--
Uranium-233	--	0.24 ^a	0.4
Uranium-234	1.1	0.24 ^a	0.4
Uranium-235	0.109	0.24 ^a	0.4
Uranium-236	--	0.24 ^a	0.4
Uranium-238	1.06	0.24 ^a	0.4
Metals			
Antimony	5,000	270	45
Arsenic	6,470	1.3	29
Barium	132,000	82,000	41
Beryllium	1,510	3,200	790

Table E2-2. Summary of Phase I Parameter Screening Values

Analyte Name	Values Used in Screening		
	Soil Background ($\mu\text{g}/\text{kg}$ or pCi/g)	Soil Screening Levels ($\mu\text{g}/\text{kg}$ or pCi/g)	EPA K_d Value (cm^3/g)
Cadmium	1,000	380	75
Cobalt	15,700	490	45
Copper	22,000	46,000	35
Hexavalent chromium ^b	--	192	0
Iron	32,600,000	640,000	25
Lead	10,200	14,000	900
Manganese	512,000	57,000	65
Mercury	330	30	52
Nickel	19,100	48,000	65
Phosphorus	--	2.7	35
Selenium	--	260	5
Silver	730	1,600	8.3
Thallium	--	140	150,000
Vanadium	85,100	2,600	1,000
Semi-Volatile Organic Compounds			
Aroclor-1254	--	8.8	260
Aroclor-1248	--	5.2	150
Benzo(a)anthracene	--	10	350
Benzo(a)pyrene	--	3.5	1,200
Benzo(b)fluoranthene	--	35	1,200
Bis(2-ethylhexyl) phthalate	--	1,100	240
Naphthalene	--	0.47	3.1
Pentachlorophenol	--	5.7	9.9
Phenyl sulfone	--	71	2.2
Tributyl phosphate	--	36	4.7
Volatile Organic Compounds			
1,1,1-Trichloroethane	--	70	0.088
1,1,1,2-Tetrachloroethane	--	0.026	0.19
1,1,2-Trichloroethane	--	0.078	0.12
1,1-Dichloroethane	--	0.69	0.064
1,1-Dichloroethene	--	2.5	0.064
1-Butanol	--	760	0.0069
2-Butanone	--	1,500	0.0090
Acetic acid, methyl ester	--	7,500	0.0061

Table E2-2. Summary of Phase I Parameter Screening Values

Analyte Name	Values Used in Screening		
	Soil Background ($\mu\text{g}/\text{kg}$ or pCi/g)	Soil Screening Levels ($\mu\text{g}/\text{kg}$ or pCi/g)	EPA K_d Value (cm^3/g)
Acetonitrile	--	26	0.0093
Benzene	--	0.21	0.29
Bromodichloromethane	--	0.032	0.064
Bromoform	--	2.3	0.064
Bromomethane	--	2.2	0.026
Carbon tetrachloride	--	0.077	0.088
Chloroform	--	0.053	0.064
Chloromethane	--	49	0.026
cis-1,2-Dichloroethylene	--	21	0.079
Ethylbenzene	--	1.7	0.89
Hexachloroethane	--	2.9	0.39
Methylene chloride	--	1.2	0.043
Nitromethane	--	0.12	0.021
Tetrachloroethene	--	0.049	0.19
Toluene	--	690	0.47
trans-1,2-Dichloroethylene	--	29	0.079
Trichloroethene	--	0.72	0.12
Wet Chemistry Parameters			
Nitrate ^b	52,000	102,400	--
Nitrite	--	6,400	--
Phosphate	785	--	--
Sulfate	--	--	--

Notes:

Hexachloroethane and Naphthalene were analyzed using two analytical methods: EPA Method 8270 and EPA Method 8260.

DOE/RL-92-24, *Hanford Site Background: Part 1, Soil Background for Nonradioactive Analytes*

DOE/RL-96-12, *Hanford Site Background: Part 2, Soil Background for Radionuclides*

EPA/540/R-96/018, *Soil Screening Guidance: User's Guide*, Publication 9355.4-23

EPA/540-R-00-007, *Soil Screening Guidance for Radionuclides: User's Guide*, OSWER 9355.4-16A

a. SSL calculated based on proposed MCL of 20 pCi/L (activity) for uranium.

b. WAC 173-340-747, "Model Toxics Control Act—Cleanup," "Deriving Soil Concentrations for Ground Water Protection."

-- = No value

1 E2.2.2 Initial COPC Selection Process

- 2 Typically, not all contaminants present at a site pose a threat to groundwater or contribute significantly to
3 overall site risks. The EPA guidelines (EPA 540/1-89/002) recommend focusing on a group of COPCs

1 based on inherent toxicity, site concentration, and the behavior of the constituents in the environment. To
2 identify these COPCs, groundwater protection screening levels (listed in Table E2-2) are compared to site
3 concentrations of analytes in soil.

4 The steps of the selection process for identifying initial soil COPCs for the evaluation of groundwater
5 protection are as follows.

- 6 1. **Identify Non-Detected Analytes:** Analytes that have been collected from appropriate locations, have
7 adequate detection limits, and that have not been detected at least once in deep zone samples are
8 eliminated as COPCs. All analytes detected at least once are carried forward to the next step of the
9 process.
- 10 2. **Essential Nutrients:** Essential nutrients are those analytes considered essential for human nutrition
11 and are not associated with toxicity to humans. Essential nutrients (calcium, magnesium, potassium,
12 and sodium) were measured in soil and are not considered for inclusion as COPCs.
- 13 3. **Radionuclides with Half-Lives of Less than 3 Years:** Radioisotopes with half-lives less than or
14 equal to 3 years are eliminated from further consideration because only a small fraction of activity
15 remains after 30 years of decay. Antimony-125 and cesium-134 were measured in soil but were not
16 detected and are not considered for inclusion as COPCs.
- 17 4. **Comparison of Maximum Detected Contaminant Concentrations to Soil Screening Levels:** The
18 soil screening levels listed in Table E2-2 were used as the groundwater protection screening values.
19 For nonradionuclides, the maximum detected concentrations in soil from each of the soil borings were
20 compared to SSLs for migration to groundwater, and EPA's generic SSLs for migration to
21 groundwater using a dilution attenuation factor of 20 were used for radionuclides
22 (EPA/540-R-00-006). If contaminant concentrations were above screening values, they were carried
23 forward into the next step of the process.
- 24 5. **Comparison of Maximum Detected Contaminant Concentrations to Background:** The maximum
25 concentrations of inorganics and radionuclides were compared to the Hanford Site-specific
26 90th percentile background values shown in Table E2-2. Inorganics and radionuclides were
27 eliminated as COPCs based on these background levels if their maximum concentrations did not
28 exceed background.

29 **E2.3 Phase II Screening Steps**

30 Phase II of the COPC screening process for groundwater protection involved five main steps of evaluation.
31 The approach for this phase of screening differed from that in Phase I, in that all data for all COPCs from all
32 boreholes near each waste site were evaluated. The screening was limited to data for subsurface samples
33 from depths above the water table, i.e., within the vadose zone. The following water table depths were used
34 to define the depth threshold of vadose zone samples included in the screening: 216-A-8, 80 m
35 (256.7 ft) bgs; 216-Z-1A and 216-Z-18, 73.5 m (235.8 ft) bgs; 216-Z-9 is 59 m (221 ft) bgs.

36 As in other screening analyses, fewer data were evaluated in the successive steps of the process as data
37 were screened out according to the criteria associated with each screening step. The criteria and
38 evaluation process associated with each of the five main steps in the Phase II COPC evaluation process
39 are described in Sections E2.2.1 to E2.2.5. A summary of the values used for these screening criteria in
40 the Phase II COPC data screening are summarized in Table E2-3.

Table E2-3. Values Used for the Phase II Screening Steps in the 200-PW-1/3/6 COPC Screening Process

Groundwater Protection COPC	Values Used in Screening				K _d Reference
	Soil Background ^a	EPA Soil-Water Partitioning Eq.; Ecology Eq. 747-1 Parameters	K _d Value for Groundwater Arrival Time Screen	K _d Value for COC Modeling	
Metals and Other Inorganics	mg/kg	mg/kg	mL/g	mL/g	
Aluminum	11,800	1500	1,500		ORNL, 2009; EPA, 2009
Antimony ^b	5.2	5.42	45		Ecology, 2009
Arsenic	6.47	0.0341	29		Ecology, 2009
Barium	132	1648	25		Hanford Site-specific K _d value: PNL-7660
Beryllium	1.51	63	790		Ecology, 2009
Cadmium ^c	0.93	0.69	30		Hanford Site-specific K _d value: PNL-7660
Hexavalent chromium ^d	---	0.192	0	0	Hanford Site-specific K _d value: PNL-7660
Cobalt	15.8	4.35	50		Hanford Site-specific K _d value: PNL-7660
Copper	21.6	284	22		Ecology, 2009
Iron	33,050	152	25		EPA, 2009; ORNL, 2009
Lead	10.3	3000	30		Hanford Site-specific K _d value: PNL-7660
Manganese	506	65.3	50		Hanford Site-specific K _d value: PNL-7660
Mercury	0.35	2.09	30		Hanford Site-specific K _d value: PNL-7660
Nickel	19.1	130	65		Hanford Site-specific K _d value: PNL-7660
Selenium ^e	0.78	5.2	5		Ecology, 2009
Silver	1.38	13.6	8.3		Ecology, 2009
Thallium ^f	3.7	1.48	71		Ecology, 2009
Vanadium	85	2240	1,000		Ecology, 2009
Nitrogen in nitrate and nitrite ^g	12.2	40	0	0	Hanford Site-specific K _d value: PNNL-13895
Phosphate	0.668	0.00064	0		Ecology, 2009
Sulfate	264	1030	0.00612		ORNL, 2009

Table E2-3. Values Used for the Phase II Screening Steps in the 200-PW-1/3/6 COPC Screening Process

Groundwater Protection COPC	Values Used in Screening				K _d Reference
	Soil Background ^a	EPA Soil-Water Partitioning Eq.; Ecology Eq. 747-1 Parameters	K _d Value for Groundwater Arrival Time Screen	K _d Value for COC Modeling	
Organic Compounds	mg/kg	mg/kg	mL/g	mL/g	
Acetonitrile					ORNL, 2009
Aroclor-1248		0.0386	43.9		EPA, 2009; ORNL, 2009 (Using K _d = K _{oc} /1000)
Aroclor-1254		0.0663	75.6		EPA, 2009; ORNL, 2009 (Using K _d = K _{oc} /1000)
Acetic acid, methyl ester		32.6	0.0033		EPA, 2009; ORNL, 2009 (Using K _d = K _{oc} /1000)
Benzene		0.00448	0.062	0.05	Ecology, 2009 (Using K _d = K _{oc} /1000)
Benzo(a)anthracene		0.856	360		Ecology, 2009 (Using K _d = K _{oc} /1000)
Benzo(a) pyrene		0.232	970		Ecology, 2009 (Using K _d = K _{oc} /1000)
Benzo(b)fluoranthene		2.95	1230		Ecology, 2009 (Using K _d = K _{oc} /1000)
Bis(2-ethylhexyl) phthalate		13.4	111.1		Ecology, 2009 (Using K _d = K _{oc} /1000)
Bromodichloromethane		0.00368	0.055	0.05	Ecology, 2009 (Using K _d = K _{oc} /1000)
Bromoform		0.0363	0.126	0.1	Ecology, 2009 (Using K _d = K _{oc} /1000)
Bromomethane		0.0518	0.009		Ecology, 2009 (Using K _d = K _{oc} /1000)
1-Butanol		3.31	0.0069	0.01	Ecology, 2009 (Using K _d = K _{oc} /1000)
2-Butanone		21.8	0.027		ORNL, 2009
Carbon tetrachloride		0.0315 ^h	0.152	0.15	Ecology, 2009 (Using K _d = K _{oc} /1000)
Chloroform		0.00751	0.053	0.05	Ecology, 2009 (Using K _d = K _{oc} /1000)
Chloromethane					
1,2-Dibromo-3-chloropropane		0.000362	0.13		ORNL, 2009
1,1-Dichloroethane		0.0419	0.053	0.05	Ecology, 2009 (Using K _d = K _{oc} /1000)

Table E2-3. Values Used for the Phase II Screening Steps in the 200-PW-1/3/6 COPC Screening Process

Groundwater Protection COPC	Values Used in Screening				K _d Reference
	Soil Background ^a	EPA Soil-Water Partitioning Eq.; Ecology Eq. 747-1 Parameters	K _d Value for Groundwater Arrival Time Screen	K _d Value for COC Modeling	
1,1-Dichloroethene		0.0501	0.065		Ecology, 2009 (Using K _d = K _{oc} /1000)
cis-1,2-dichloroethylene		0.350	0.0355		Ecology, 2009 (Using K _d = K _{oc} /1000)
trans-1,2-dichloroethylene		0.543	0.038		Ecology, 2009 (Using K _d = K _{oc} /1000)
Ethylbenzene		0.0344	0.204	0.2	Ecology, 2009 (Using K _d = K _{oc} /1000)
Hexachloroethane		0.125	1.78		Ecology, 2009 (Using K _d = K _{oc} /1000)
Methylene Chloride		0.0218	0.01	0.01	Ecology, 2009 (Using K _d = K _{oc} /1000)
Naphthalene		10.2	1.19		Ecology, 2009 (Using K _d = K _{oc} /1000)
Nitromethane					
Pentachlorophenol		0.0116	0.592	0.6	Ecology, 2009 (Using K _d = K _{oc} /1000)
Phenyl sulfone					
1,1,2,2-Tetrachloroethane		0.00123	0.079	0.05	Ecology, 2009 (Using K _d = K _{oc} /1000)
Tetrachloroethene		0.000859	0.265	0.25	Ecology, 2009 (Using K _d = K _{oc} /1000)
Toluene		4.65	0.14		Ecology, 2009 (Using K _d = K _{oc} /1000)
Tributyl phosphate		0.398	43.9		ORNL, 2009 (Using K _d = K _{oc} /1000)
1,1,1-Trichloroethane		1.584	0.14		Ecology, 2009 (Using K _d = K _{oc} /1000)
1,1,2-Trichloroethane		0.004	0.075	0.05	Ecology, 2009 (Using K _d = K _{oc} /1000)
Trichloroethylene		0.0223	0.094	0.1	Ecology, 2009 (Using K _d = K _{oc} /1000)

Table E2-3. Values Used for the Phase II Screening Steps in the 200-PW-1/3/6 COPC Screening Process

Groundwater Protection COPC	Values Used in Screening				K _d Reference
	Soil Background ^a	EPA Soil-Water Partitioning Eq.; Ecology Eq. 747-1 Parameters	K _d Value for Groundwater Arrival Time Screen	K _d Value for COC Modeling	
Radionuclides	pCi/g	pCi/g	mL/g	mL/g	
Americium-241			200		Hanford Site-specific K _d value: PNL-7660
Carbon-14		8.0	0	0	Hanford Site-specific K _d value: PNNL-13895; RPP-13310
Cesium-137 + Daughters			25		Hanford Site-specific K _d value: PNNL-13895; RPP-13310
Europium-152			200		Hanford Site-specific K _d value: PNL-7660
Gadolinium-152 ⁱ			240		EDF-ER-275
Europium-154			200		Hanford Site-specific K _d value: PNL-7660
Europium-155			200		Hanford Site-specific K _d value: PNL-7660
Neptunium-237			15		Hanford Site-specific K _d value: PNNL-11800
Nickel-63			30		Hanford Site-specific K _d value: PNL-7660
Plutonium-238			200		Hanford Site-specific K _d value: PNL-7297
Plutonium-239/240			200		Hanford Site-specific K _d value: PNL-7660
Potassium-40	16.6		5.5		Hanford Site-specific K _d value: PNNL-11800
Protactinium-231			550		EDF-ER-275
Radium-226	0.815	0.036	3		ORNL, 2009
Radium-228		0.012	3		ORNL, 2009
Strontium-90			25		Hanford Site-specific K _d value: PNL-7660
Total beta radiostrontium			25		Hanford Site-specific K _d value: PNL-7660
Gross beta	22.96				

Table E2-3. Values Used for the Phase II Screening Steps in the 200-PW-1/3/6 COPC Screening Process

Groundwater Protection COPC	Values Used in Screening			K _d Reference	
	Soil Background ^a	EPA Soil-Water Partitioning Eq.; Ecology Eq. 747-1 Parameters	K _d Value for Groundwater Arrival Time Screen		K _d Value for COC Modeling
Technetium-99		3.6		0	Hanford Site-specific K _d value: PNL-7297
Thorium-230			200		Hanford Site-specific K _d value: EPA/520/6-78-007A
Thorium-232	1.32		200		Hanford Site-specific K _d value: EPA/520/6-78-007A
Uranium	3.21				
Uranium-234	1.098				
Uranium-235	0.109				
Uranium-236					
Uranium-238	1.059				

Notes:

Values used in Step 2 of the Phase II screening process and are the larger of the soil background and the EPA Soil-Water Partitioning values.

Values used in Step 5 of the Phase II screening process (groundwater arrival time and/or fate and transport modeling activities).

a. 90th percentile soil background values for non-radionuclides from DOE/RL-92-24, *Hanford Site Background: Part 1, Soil Background for Nonradioactive Analytes*, except where noted.

b. Antimony background = 90th percentile of Statewide soil background data (Ecology Publication 94-115, *Natural Background Soil Metals Concentrations in Washington State*, p. 11-134).

c. Cadmium background = 90th percentile of State soil background data for the Yakima Basin (Ecology Publication 94-115, p. 11-42).

d. A K_d value of zero was used in the calculation of the Chromium VI screening value from the EPA Soil-Water partition equation, rather than the K_d value of 19 listed in the Ecology CLARC Table (Ecology, 2009).

e. Selenium background = 90th percentile of Statewide soil background data (Ecology Publication 94-115, p. 11-135).

f. All Thallium background analyses reported in DOE/RL-92-24 and Ecology Publication 94-115 were below detection limits. The background screening level was, therefore, based on the limit of detection (LOD) of 3.7 mg/kg reported in DOE/RL-92-24, which is lower than the detection limit of value 5 mg/kg for Thallium reported by Ecology Publication 94-115.

g. Values are for nitrate and nitrite re-calculated as Nitrogen; i.e., Nitrogen in nitrate+nitrite.

h. Carbon tetrachloride screening value calculated from the EPA Soil-Water partition equation used a groundwater protection level of 3.4 µg/L, per

Table E2-3. Values Used for the Phase II Screening Steps in the 200-PW-1/3/6 COPC Screening Process

Groundwater Protection COPC	Values Used in Screening				K _d Reference
	Soil Background ^a	EPA Soil-Water Partitioning Eq.; Ecology Eq. 747-1 Parameters	K _d Value for Groundwater Arrival Time Screen	K _d Value for COC Modeling	
EPA et al., 2008, <i>Record of Decision Hanford 200 Area 200-ZP-1 Superfund Site Benton County, Washington</i> .					
i. Gadolinium-152 is listed because it is a long-lived decay product of the parent isotope, Europium-152, which is a COPC, and a half-life of 13.5 years.					
Ecology, 2009, Cleanup Levels and Risk Calculations (CLARC) database					
EDF-ER-275, <i>Fate and Transport Modeling Results and Summary Report</i>					
EPA, 2009, "Regional Screening Levels for Chemical Contaminants at Superfund Sites"					
EPA/520/6-78-007A, <i>Radionuclide Interactions with Soil and Rock Media, Volume I: Processes Influencing Radionuclide Mobility and Retention, Element Chemistry and Geochemistry, Conclusions and Evaluation</i>					
ORNL, 2009, Risk Assessment Information System					
PNL-7297, <i>Hanford Waste-Form Release and Sediment Interaction: A Status Report with Rationale and Recommendations for Additional Studies</i>					
PNL-7660, <i>Compilation of Data to Estimate Groundwater Migration Potential for Constituents in Active Liquid Discharges at the Hanford Site</i>					
PNNL-11800, <i>Composite Analysis for Low-Level Waste Disposal in the 200 Area Plateau of the Hanford Site</i>					
PNNL-13895, <i>Hanford Contaminant Distribution Coefficient Database and Users Guide</i>					
RPP-13310, <i>Modeling Data Package for an Initial Assessment of Closure for C Tank Farm</i>					
COC = contaminant of concern					
Eq. = equation					
K _{oc} = soil organic carbon water partition coefficient					

1 The soil concentration data for the 200-PW-1, 200-PW-3, and 200-PW-6 waste site boreholes reported in
2 units of $\mu\text{g}/\text{kg}$ in the RIFAT and RISAT data reports (ECF-200PW136-10-0337) were converted to units
3 of mg/kg for comparison to soil background and WAC 173-340, "Model Toxics Control Act – Cleanup,"
4 EPA SSLs, and EPA Soil Water Partition equation values. Data reported for a COPC by multiple
5 analytical methods for the same sample (depth), the data sets were combined where there were not
6 multiple data values reported for a sample (depth); i.e., only one value reported overall for the combined
7 data set. Where there were multiple values reported by different methods for a single sample, the largest
8 values were used to represent the sample.

9 Data for nitrate, nitrite, and total nitrogen in nitrate and nitrite were reported separately in units of $\mu\text{g}/\text{kg}$
10 in the RIFAT data reports, which were also converted to units of mg/kg . The total nitrogen for the nitrate
11 and nitrite data values of each sample were then calculated from the mass fraction (ratio) of nitrogen in
12 nitrate (fraction of nitrogen in nitrate [by weight] = 0.226^1), nitrogen and nitrite (fraction of nitrogen in
13 nitrite [by weight] = 0.304^2) for comparison to the total nitrogen data and also because the groundwater
14 protection metrics are typically in units of nitrogen in nitrate+nitrite. The nitrogen values for nitrate and
15 nitrite were then added, and compared to the values reported for total nitrogen, where they were also
16 reported. Where there was more than one value for total nitrogen in nitrate+nitrite per sample, the larger
17 values was used to represent the sample.

18 **E2.3.1 Step 1: Data Screen by Lab Code**

19 The first step in this phase of the evaluation was to screen all data records by lab code, screening out all
20 "non-detect" data having a "U" lab code, and to flag data with other lab codes (e.g., "J," "E," "B," and
21 "C" codes)³ that denote data that may be questionable (estimated data, lab contamination, etc.), or that
22 otherwise indicate data concerns in terms of detection and/or whether the data are sufficiently quantifiable
23 for risk characterization applications. Samples with "B" codes, denoting analyte contamination in the
24 laboratory "blank" were also omitted from the screening as unrepresentative of soil contamination.

25 **E2.3.2 Step 2: Data Screen Using Background and the Soil-Water Partition Equation**

26 All non-radionuclide COPC data above detection were then screened against soil background and/or the
27 soil concentration levels based on the EPA Soil-Water Partition Equation for Migration to Groundwater
28 Pathway (EPA/540/R-95/128, Equation 22, Section 2.5.1) using the parameter values identified in
29 WAC 173-340-747 for the Fixed Parameter three-phase partitioning equation (WAC-173-340-747,
30 Equation 747-1). Screening using the EPA Soil-Water Partition Equation and/or Equation 747-1 is a
31 conservative screen involving the determination of soil (source term) concentrations that are below
32 groundwater protection levels (e.g., MCLs) assuming, e.g., no vadose zone, and an infinite source, as
33 described in Section E2.1.2.

34 Detected COPC data were also compared to the 90th percentile soil background values for naturally
35 occurring non-radioactive analytes (e.g., DOE/RL-92-24, *Hanford Site Background: Part 1, Soil*
36 *Background for Nonradioactive Analytes*) and for naturally-occurring radionuclides in the Hanford Site
37 vadose zone (DOE/RL-96-12, *Hanford Site Background: Part 2, Soil Background for Radionuclides*) to
38 determine which of the data could be regarded as belonging to the population of naturally occurring soil
39 background values. All data less than the 90th percentile values of the background population were
40 screened out as indistinguishable from background, and were, therefore, considered to posing no
41 additional risk above background levels.

¹ Fraction of nitrogen in nitrate = MW of N / MW of NO_3^- that = $(14\text{g}/\text{mol}) / (62\text{g}/\text{mol}) = 0.226$.

² Fraction of nitrogen in nitrite = MW of N / MW of NO_2^- that = $(14\text{g}/\text{mol}) / (46\text{g}/\text{mol}) = 0.304$.

³ Laboratory Qualifier Codes are defined in Section 3.2.8 of CP-15383, *Common Requirements of the Format for Electronic Analytical Data (FEAD)*.

1 **E2.3.3 Step 3: Quantitation Considerations**

2 The COPC data that passed the previous steps of the Phase II screening were then evaluated in Step 3
3 against criteria relevant to whether the remaining data are credibly quantifiably above detection.

4 The PQL screening in Step 3 involved the determination as to whether the data above detection limits are
5 credibly/reasonably quantifiable for the intended use (risk-based screening and evaluation).

6 WAC 173-340, "Model Toxics Control Act – Cleanup," defines PQLs as:

7 *...the lowest concentration that can be reliably measured within specified limits of*
8 *precision, accuracy, representativeness, completeness, and comparability during*
9 *routine laboratory operating conditions, using department approved methods.*

10 Data above detection limits, may or may not be quantifiable for purpose of the application, and/or may be
11 identified as "estimated" as indicated by the laboratory code. The issue of defining and utilizing PQLs
12 and/or other quantitation limits is addressed in both state and federal guidelines, as well as in the technical
13 literature as follows:

- 14 • Currie, 1968, "Limits for Qualitative Detection and Quantitative Determination: Application to
15 Radiochemistry"
- 16 • Ecology, 1993, "Guidance for the Use of Tables: Practical Quantitation Limits (PQLs), Method
17 Detection Limits (MDLs), and PQL Comparisons to Method B Cleanup Levels"
- 18 • EPA 540-R-01-003, *Guidance for Comparing Background and Chemical Concentrations in Soil for*
19 *CERCLA Sites*
- 20 • EPA, 2006, MDL Factsheet, "IDL-MDL-PQL: What the 'L' is going on? What does all this alphabet
21 soup really mean?"
- 22 • WAC 173-340-700, "Overview of Cleanup Standards"
- 23 • WAC 173-340-709, "Methods for Defining Background Concentrations"

24 Most technical definitions of PQL are based on parameters such as the method detection limit (MDL) for
25 non-radionuclides MDL, the method detection activity (MDA) for non-radionuclides, and/or associated or
26 the standard deviations.

27 Non-radionuclide data was not subjected to PQL screening due to the absence information on the MDL,
28 particularly for much of the older legacy data, and also because the contract-required detection limit
29 information alone was deemed inadequate for PQL screening. However, a decision rule for PQL
30 screening of radionuclide data was adopted by establishing a PQL threshold of three times the MDA
31 value associated with the radionuclide measurements, i.e., data values \leq three times the MDA were
32 considered as not sufficiently quantifiable to carry forward as COPC data.

33 **E2.3.4 Step 4: Pathway and Anomalous Data Evaluation**

34 Step 4 of COPC evaluation involved the evaluation of pathway criteria and anomalous data. The pathway
35 aspect of Step 4 in the screening evaluation involves the elimination of groundwater protection COPCs
36 that are not regulated, not subject to the ingestion pathway, or which have no quantifiable or appropriate
37 basis for evaluation as groundwater protection COPCs (e.g., no groundwater protectiveness metric).

38 The evaluation of anomalous data involved further scrutiny of data in instances where a COPC appeared
39 to be unusual or anomalous. In some cases, this phase of the evaluation involved the re-evaluation of

1 sampling and analysis records and QA/QC reports. The identification of data regarded as anomalous were
2 based on criteria that included the following:

- 3 • Anomalous concentrations (e.g., singular concentration anomalies)
- 4 • Spatial occurrences (e.g., depth) inconsistent with the conceptual model
- 5 • Anomalous patterns and/or correlations in COPC behavior

6 This phase of the COPC evaluation was performed primarily to ensure that COPC data passing the
7 previous screening phases were not artifacts of e.g., transcription errors, laboratory contamination,
8 borehole contamination, or other reasons, before including the data in the fate and transport modeling
9 evaluation.

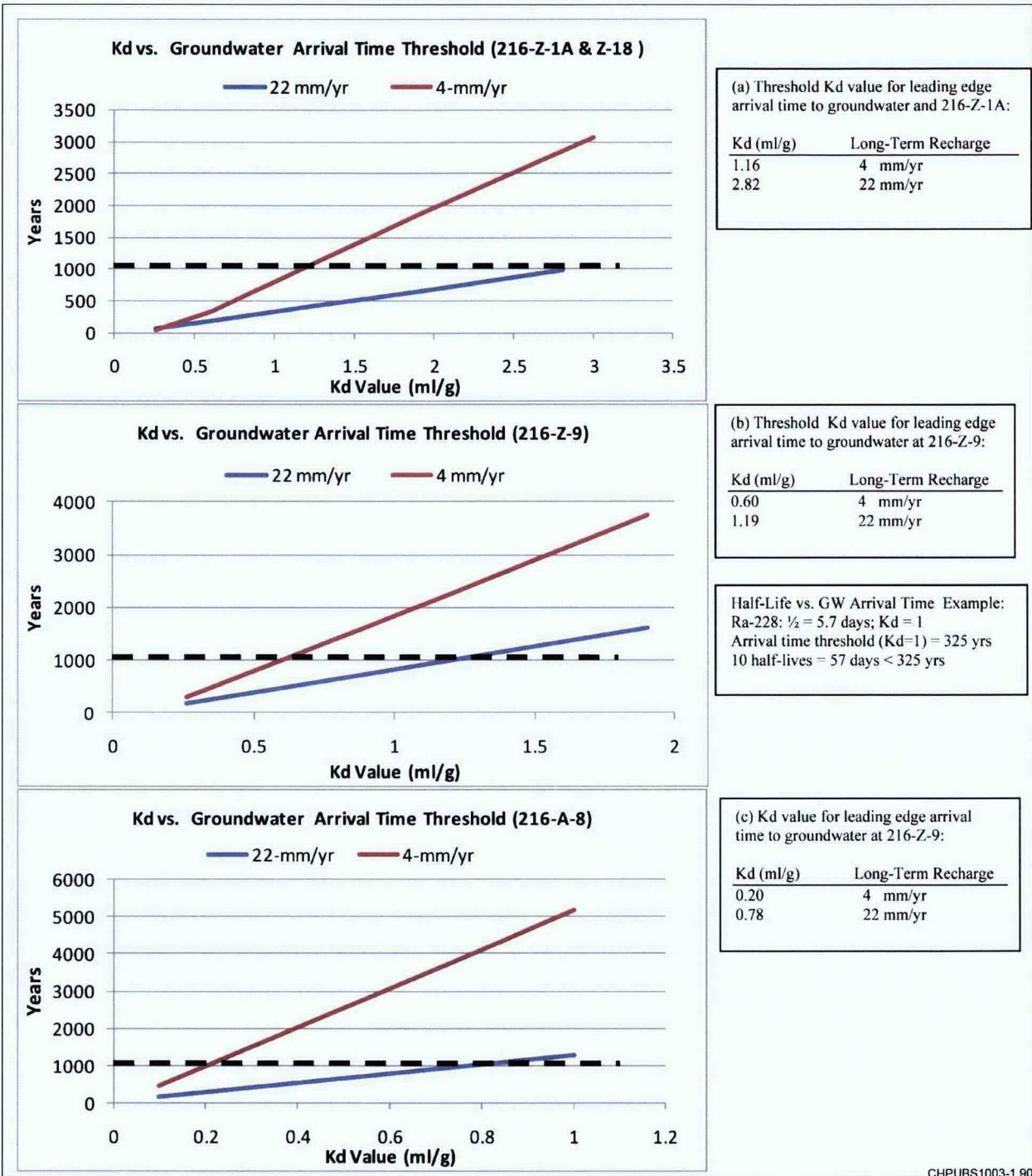
10 **E2.3.5 Step 5: Groundwater Arrival Time and Half-Life Screen**

11 The remaining COPCs were then evaluated in the context of their ability to affect groundwater within a
12 specified timeframe based on a 1,000-year timeframe of compliance. The timeframe for compliance
13 regarding the assessment of protectiveness for groundwater is related to the CERCLA consideration of
14 long-term effectiveness in the analysis and performance of remedial actions (40 CFR 300.430), and
15 regulations and guidelines regarding the assessment of controls for radiological and hazardous
16 constituents. The basis for a compliance timeframe of at least 1,000 years is primarily derived from
17 DOE Order 435.1, *Radioactive Waste Management*, concerning the performance objectives and
18 performance assessment for low-level waste disposal, and EPA regulations concerning the effectiveness
19 of controls for residual radioactive materials from inactive uranium processing sites (40 CFR 192.02,
20 “Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings,” “Standards”;
21 DOE/RL-2007-35, *200-UW-1 Operable Unit Remedial Action Goals for Removal/Treatment/Disposal*
22 *Waste Sites*, Section 4.3).

23 This step in the Phase II screening process involved the elimination of COPCs that have no impact on
24 groundwater within a 1,000-year compliance timeframe, and radionuclides with half-lives causing them
25 effectively to decay to stable non-hazardous species before reaching groundwater. In this phase of the
26 COPC evaluation, the maximum vadose zone depth of the data passing the previous screening phases was
27 determined for each COPC at each waste site.

28 **E2.3.5.1 Groundwater Arrival Time Screen**

29 The time required for any non-zero impact to groundwater from COPC source terms at the maximum
30 depth of occurrence in the vadose zone were compared to a 1,000-year timeframe of compliance for each
31 COPC at each waste site. This temporal screening was based on vadose zone travel time results of
32 transport modeling described in ECF-200PW1/3/6-10-0326, *200-PW-1/3/6 Screening Process and*
33 *Contaminant Fate and Transport Model to Evaluate Impacts to Groundwater in Support of*
34 *DOE/RL-2007-27 Draft B*, in a manner consistent with the EPA Soil Screening Guidance
35 (EPA/540/R-95/128), using the COPC K_d values listed in Table E2-3. This step in the screening process is
36 effectively a K_d screen owing to the systematic (essentially linear) relationships between source term
37 depth, K_d , and travel time to groundwater as shown in Figure E2-6, based on the information described in
38 ECF-200PW1/3/6-10-0326, Tables 15-17. The decision rule for this phase of screening was to screen out
39 any COPC with K_d values that did not affect groundwater within the 1,000-year compliance timeframe,
40 i.e., that yielded no calculated groundwater concentration greater than zero, at the maximum depth of
41 occurrence.



CHPUBS1003-1.90

Figure E2-6. Groundwater Arrival Time as a Function of COPC K_d Values for (a) the 216-Z-1A and 216-Z-18 Cribs, (b) the 216-Z-9 Crib, and (c) the 216-A-8 Crib, Including an Example Calculation for the Comparison of the Travel Time to Groundwater to the Half-Life of Radium-228

1
2
3
4
5

1 K_d threshold values as a function of the first non-zero concentration impact to groundwater were
2 determined for long-term recharge rate of both 4 mm/yr and a 22 mm/yr (ECF-200PW1/3/6-10-0326).
3 The K_d threshold values based on the larger recharge rate of 22 mm/yr were used in the Step 5 screen for
4 conservatism in this step of the Phase II screening process. It is noted that the decision rule threshold is
5 based on any non-zero impact to groundwater. This is significant in the context of uncertainty and
6 conservatism, because this threshold represent the first indication of a groundwater impact, i.e., leading
7 edge of a groundwater impact arrival time curve, rather than, e.g., peak concentrations, which arrive later
8 than the leading edge. It is also noted that the groundwater arrival time screening criteria were applied
9 regardless of subsequent peak concentrations, and only focused on whether there was any non-zero
10 impact to groundwater within the timeframe of compliance.

11 The maximum depth of occurrence for each COPC passing the first three phases of screening and
12 evaluation was used as the source term reference depth for most of the groundwater arrival time
13 screening. For most COPCs in the Z-Area waste sites, the maximum depth of contamination was in, or
14 above, the Cold Creek unit. The groundwater arrival time screen was, therefore, primarily based on a
15 source term depth corresponding to the deepest part (i.e., bottom) of the Cold Creek unit as described in
16 ECF-200PW1/3/6-10-0326 and Table E4-1. Thus, the use of a reference depth for most of the
17 groundwater arrival time screening that is \geq to the maximum depth of screened COPC data was adequate
18 because contamination at shallower depths would have longer groundwater arrival times than that for the
19 reference conditions. Figures E2-7 and E2-8 illustrate the contaminant depths used for most of the
20 groundwater arrival time screening.

21 The lowest COPC K_d values yielding no impact on groundwater within the 1,000 year timeframe for
22 sources at the depth of lower Cold Creek unit, and a recharge rate of 22 mm/yr was determined to be
23 2.8 mL/g for the 216-Z-1A and 216-Z-18 Cribs, 1.19 mL/g for the 216-Z-9 Crib, and a K_d value of 0.52
24 for the 216-A-8 Crib (see ECF-200PW1/3/6-10-0326, Section 5 for details). Thus, any COPC with larger
25 K_d values were also screened out because larger K_d values result in longer travel time to groundwater. The
26 groundwater arrival time was also determined for individual instances on a case-by-case basis where
27 some screened COPC data occur below the reference depth at the bottom of the Cold Creek unit in the
28 Z-Area waste sites in 200-West Area.

29 **E2.3.5.2 Half-Life Screen**

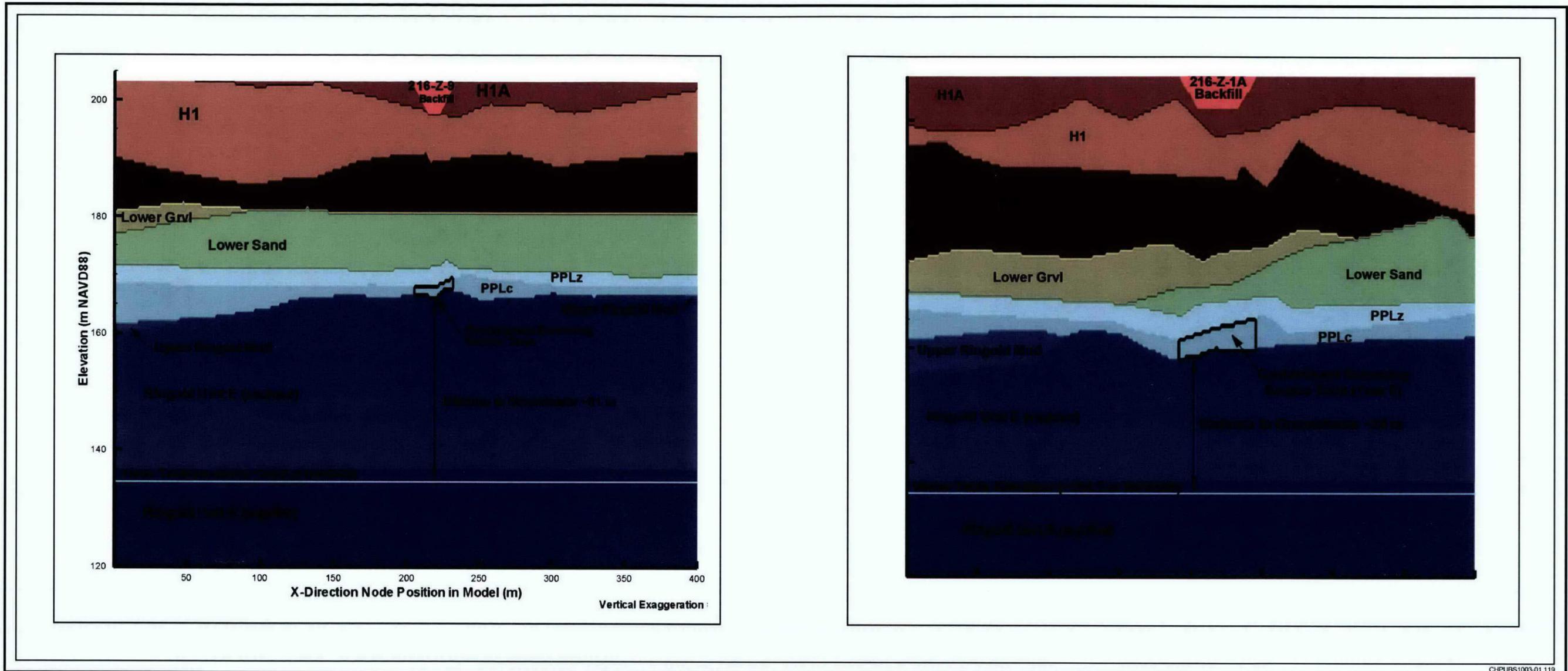
30 A half-live screen was applied to the remaining radionuclide COPCs and daughters, following the
31 groundwater arrival time screen. The decision logic for the half-life screen was to eliminate radionuclide
32 COPCs passing the groundwater arrival time screen, which would require ≥ 10 half-lives to reach
33 groundwater. This decision criterion is based on the rationale that 99.9 percent of the radionuclide activity
34 decays away for radionuclides requiring ≥ 10 half-lives to reach groundwater,⁴ and that ≤ 0.1 percent of
35 the remaining activity does not pose a threat to groundwater. In practice, radionuclides with the non-zero
36 groundwater impact arrival times greater than 1,000 years were screened out if 10 times the half-life of
37 the parent and/or daughters were less than the time required for the first non-zero impact on groundwater
38 concentration.

⁴ The fraction of radionuclide activity remaining after 10 half-lives is determined from the relationship between the number of half-lives (n), and the fraction of activity remaining (y), where: $y = 1/(2^n)$.

1 **E2.4 Screened COPCs**

2 The data for the COPCs passing all five steps of screening were then evaluated for impacts to
3 groundwater using calculated source term concentrations for each COPC in the vadose zone fate and
4 transport modeling. Chapter E4.0 describes the process used in the determination of the COPC source
5 term concentrations. Chapter E5.0 describes the fate and transport modeling, parameterization of the
6 model, assumptions, and uncertainties.

7



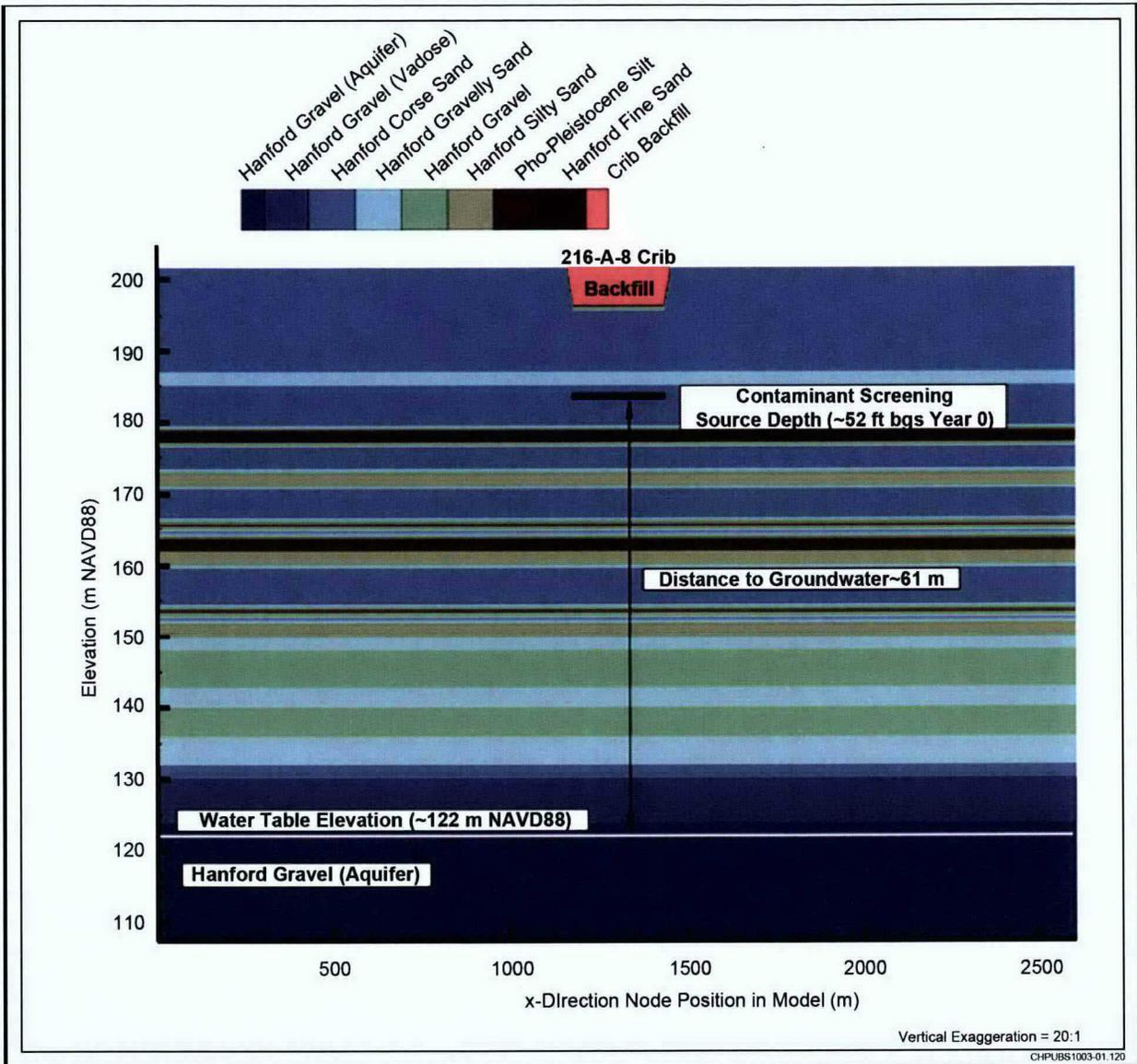
1
2
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4

Note: The source term is shown as the outlined region at the base of the Cold Creek unit.

Figure E2-7. Geometry and Depth of the Reference Source Term Used for Groundwater Arrival Time Screening Analysis for Contaminants with K_d Values Greater than Zero at the 216-Z-9 and 216-Z-1A Cribs

CHPUBS1003-01.119

1
2



1
2
3
4

Figure E2-8. Depth of the Reference Source Term Used for Groundwater Arrival Time Screening Analysis for Contaminants with K_d Values Greater than Zero at the 216-A-8 Crib

1 E3.0 Results of COPC Screening Evaluation

2 The results of the Phase I and Phase II COPC screening and evaluation for groundwater protection are
3 summarized in this Chapter for each of the waste sites evaluated (Table E3-1). The results of each phase
4 of screening, and of each of the successive steps in the Phase II screening process is also summarized in
5 Sections E3.1 and E3.2, respectively.

6 Only five of the seven waste sites identified in Table E2-1 had vadose zone soils containing groundwater
7 protection COPCs. No COPCs for the protection of groundwater were identified from two sites, the
8 216-Z-361 Settling Tank and the 216-Z-10 Injection/Reverse Well. The results of the successive phases
9 of the COPC screening and evaluation process are summarized in the following sections.

Table E3-1. Summary of the Results of the Phase I and Phase II COPC Screening Evaluation

Waste Site	Number of COPCs Passing Phase I Screen	Number of COPCs Passing Phase II Screen	COPCs Passing Phase II Screen for Fate and Transport Modeling
216-A-8	17	4	Hexavalent chromium, carbon-14, technetium-99, nitrogen in nitrate+nitrite
216-Z-8	3	0	None
216-Z-1A	14	7	1,1-Dichloroethane, carbon tetrachloride, chloroform, methylene chloride, tetrachloroethene, trichloroethylene, nitrogen in nitrate+nitrite
216-Z-18	19	7	Benzene, carbon tetrachloride, chloroform, ethylbenzene, methylene chloride, tetrachloroethene, nitrogen in nitrate+nitrite
216-Z-9	72*	15	Hexavalent chromium, nitrogen in nitrate+nitrite, 1-butanol, carbon tetrachloride, chloroform, methylene chloride, tetrachloroethene, trichloroethene, 1,1,2,2-tetrachloroethane, 1,1,2-trichloroethane, bromodichloromethane, bromoform, pentachlorophenol, technetium-99, uranium

* This number of COPCs from the Phase I screen is less than that reported in ECF-200PW1/3/6-10-0360 because nitrate and nitrite were combined with nitrogen in nitrate+nitrite for the Phase II screen.

10 E3.1 Results of the Phase I COPC Screen

11 The purpose of the initial phase of the COPC screening and evaluation process was to identify the COPCs
12 for each waste site that warranted screening of all data points.

13 Table E3-1 lists the results of the Phase I COPC selection process for each of the waste sites included the
14 200-PW-1/3/6 OU. A detailed description of the initial COPC selection process including the rationale for
15 selection or elimination of COPCs is described in a separate environmental calculation
16 (ECF-200PW1/3/6-10-0360). Table E3-2 summarizes the results of the screening process, identifying the
17 COPCs for each waste site.

Table E3-2. Contaminants of Potential Concern for Migration to Groundwater—Summary of the Results of the Phase I Screen of the 200-PW-1/3/6 COPC Screening Process for Groundwater Protection

Initial COPCs	Representative Sites				
	216-Z-1A Tile Field	216-Z-8 French Drain	216-Z-9 Trench	216-A-8 Crib	216-Z-18 Crib
Radionuclides					
Americium-241	√*	√	√		
Carbon-14				√	
Cesium-137				√	
Europium-152			√		
Europium-154			√		
Europium-155			√	√	
Gross alpha			√	√	
Gross beta			√	√	
Neptunium-237			√	√	
Nickel-63			√		
Plutonium-238		√	√		
Plutonium-239/240	√*	√	√	√	
Potassium-40			√	√	
Protactinium-231			√		
Radium-226			√		
Radium-228			√	√	
Strontium-90			√		
Technetium-99			√	√	
Thorium-230			√		
Total beta radiostrontium			√	√	
Uranium-233			√		
Uranium-234			√		
Uranium-235			√		
Uranium-236			√		
Uranium-238			√		
Metals					
Antimony			√		√
Arsenic			√		
Barium	√		√		√
Beryllium					√

Table E3-2. Contaminants of Potential Concern for Migration to Groundwater—Summary of the Results of the Phase I Screen of the 200-PW-1/3/6 COPC Screening Process for Groundwater Protection

Initial COPCs	Representative Sites				
	216-Z-1A Tile Field	216-Z-8 French Drain	216-Z-9 Trench	216-A-8 Crib	216-Z-18 Crib
Cadmium			√		
Cobalt			√		√
Copper			√		
Hexavalent chromium			√	√	
Iron			√		√
Lead			√		
Manganese	√		√		√
Mercury			√		
Nickel			√		√
Selenium			√	√	
Silver			√		
Thallium				√	
Vanadium			√		√
Semi-Volatile Organic Compounds					
Aroclor-1254				√	
Aroclor-1248			√		
Benzo(a)anthracene			√		
Benzo(a)pyrene			√		
Benzo(b)fluoranthene			√		
Bis(2-ethylhexyl) phthalate			√		
Naphthalene			√		
Pentachlorophenol			√		
Phenyl sulfone			√		
Tributyl phosphate			√		
Volatile Organic Compounds					
1,1,1-Trichloroethane					√
1,1,2,2-Tetrachloroethane			√		
1,1,2-Trichloroethane			√		
1,1-Dichloroethane	√		√		
1,1-Dichloroethene			√		
1-Butanol			√		

Table E3-2. Contaminants of Potential Concern for Migration to Groundwater—Summary of the Results of the Phase I Screen of the 200-PW-1/3/6 COPC Screening Process for Groundwater Protection

Initial COPCs	Representative Sites				
	216-Z-1A Tile Field	216-Z-8 French Drain	216-Z-9 Trench	216-A-8 Crib	216-Z-18 Crib
2-Butanone			√		
Acetic acid, methyl ester			√		
Acetonitrile			√		
Benzene			√		√
Bromodichloromethane			√		
Bromoform			√		
Bromomethane			√		
Carbon tetrachloride	√		√		√
Chloroform	√		√		√
Chloromethane			√		
cis-1,2-Dichloroethylene	√				
Ethylbenzene			√		√
Hexachloroethane			√		
Methylene chloride	√		√		√
Nitromethane			√		
Tetrachloroethene	√		√		√
Toluene			√		√
trans-1,2-Dichloroethylene	√				
Trichloroethene	√		√		√
Wet Chemistry Parameters					
Nitrate	√		√		√
Nitrite			√		
Nitrogen in Nitrate+Nitrite			√	√	
Phosphate	√		√	√	√
Sulfate			√		
* Am-241 and Pu-239/240 data for 216-Z-1A from RHO-ST-17 (1979) used in Phase II screen only; data not listed in HEIS.					
√ = Initial COPC					

1 E3.2 Results of the Phase II COPC Screening Steps

2 Tables E3-7, E3-8, and E3-9 summarize the results of COPC screening for the successive phases screening
3 at each of the waste sites having COPC data passing the Phase I screen (based on maximum values). The

1 first column of these tables lists the COPCs and the initial number of soil concentration data for each COPC
2 passing the Phase I screen. The tables list the number of data for each COPC in each successive screening
3 step. The screening step in which an analyte is eliminated as a COPC, i.e., all remaining data for a COPC
4 are screened out, is highlighted in red, and shaded in gray, thereafter.

5 **E3.2.1 Results for 216-A-8**

6 Tables E3-1 and E3-7a summarize the results of COPC screening for 216-A-8. The Phase I screen yielded
7 17 COPCs listed in the Table E3-2. A majority of these data for most of the remaining COPCs have
8 concentrations levels less than the detection limits, which were eliminated from consideration in Step 1 of
9 the Phase II screen. Aroclor 1254 and selenium were screened out as COPCs in Step 2, because all the
10 remaining data were below either background levels, or the EPA Soil Water Partitioning screening level.
11 Thallium was flagged as tentatively screened out in Step 2 because the remaining two of the three
12 thallium data values above the laboratory detection limits were less than the detection limit values for the
13 Hanford Site-wide soil background (3.7 mg/kg) and the statewide soil background measurements
14 (5 mg/kg) (see Table E3-2). However, thallium was carried forward in the screening process for
15 conservatism. Europium-155 (Eu-155), radium-228, and neptunium-237 were screened out in Step 3
16 because none of the detected data was above PQL values. Phosphate, potassium-40, gross alpha, and
17 gross beta were screened out as COPCs in Step 4. Phosphate was screened out because it is not regulated
18 for groundwater protection (Ecology, 2009). Potassium-40 was eliminated as a groundwater protection
19 COPC because this analyte is exclusively a naturally occurring radionuclide, and was not an
20 anthropogenic component of the operational waste stream. Gross alpha and gross beta were screened out
21 because they are not radionuclide-specific analytes, their contributions to the alpha and beta/photon
22 emitters MCL dose-rates are not known. Gross alpha and gross beta also have no K_d values, which are
23 necessary for modeling. Thallium, cesium-137, Pu-239/240, and total beta radiostrontium (Sr-90) were
24 screened out in the Step 5 groundwater arrival time screen. Table E3-3 summarizes the maximum depths
25 and K_d values used in this screening step for the 216-A-8 COPCs.

Table E3-3. Maximum Depths of Contamination and COPC K_d Values Used in the Groundwater Arrival Time Screen for the 216-A-8 COPCs Eliminated in the Step 5 Groundwater Arrival Time Screen

216-A-8 COPCs	Maximum Depth (m [ft] bgs)	K_d (mL/g)	K_d Threshold Value	Non-Zero Arrival in <1,000 Years?
Thallium	7.6 (25)	71	0.8	No
Cesium-137	15.7 (51.5)	25	0.8	No
Neptunium-237	7.6 (25)	15	0.8	No
Plutonium-239/240	6.5 (21.5)	200	0.8	No
Total beta radiostrontium (Sr-90)	15.7 (51.5)	25	0.8	No

26 Four COPCs passed all five screening steps: hexavalent chromium, nitrogen (in nitrate+nitrite),
27 carbon-14, and technetium-99 (Tc-99). It is notable that only one or two data points for each of these
28 COPCs passed the screen. Chapter E4.0 describes how these data were used in the determination of the
29 COPC source term concentrations.

30 **E3.2.2 Results for the 216-Z-8 French Drain**

31 Tables E3-1 and E3-7b summarize the results of COPC screening for 216-Z-8 French Drain for each of
32 the successive phases of screening. The Phase I screen yielded three COPCs listed in the first column of

1 Table E3-7b, which included Am-241, Pu-238, and Pu-239/240. All three of the transuranic COPCs were
 2 screened out in the Step 5 groundwater arrival time screen. The K_d values of 1.2 mL/g for a reference
 3 depth of 37 m (122 ft), determined for the 216-Z-9 Crib was used as a conservative threshold for the
 4 Step 5 groundwater arrival time screen at 216-Z-8, which is about 300 m (984 ft) northwest of the
 5 216-Z-9 Crib. Use of the 216-Z-9 groundwater arrival time calculations where the depth to groundwater is
 6 59 m (221 ft) bgs for the Step 5 screening at 216-Z-8 was considered to provide a conservative basis for
 7 assessing the groundwater arrival time for contaminants at 216-Z-8, where the maximum depth of
 8 contamination is only 10.6 m (35 ft) bgs, and the depth to groundwater is comparable (about 72 m
 9 [237 ft] bgs in 2007) (ECF-200PW1-3-6-10-0347, *Determination of Vadose Zone Contaminated Soil*
 10 *Volumes and Calculation of COPC Source Term Concentrations for 200-PW-1/3/6 Waste Sites*).
 11 Table E3-4 summarizes the maximum depths and K_d values used in this screening step for the 216-Z-8
 12 French Drain COPCs. It should be noted that no source term concentrations were calculated for the
 13 216-Z-8 French Drain since all COPCs were screened out.

**Table E3-4. Maximum Depths and K_d Values Used in the Groundwater Arrival Time screen for the
 216-Z-8 French Drain COPCs Eliminated in the Step 5 Groundwater Arrival Time Screen**

216-Z-8 French Drain COPCs	Maximum Depth (m [ft] bgs)	K_d (mL/g)	K_d Threshold Value	Non-Zero Arrival in <1,000 Years?
Americium-241	10.6 (35)	200	<1.2	No
Plutonium-238	10.6 (35)	200	<1.2	No
Plutonium-239/240	10.6 (35)	200	<1.2	No

14 E3.2.3 Results for 216-Z-1A

15 Tables E3-1 and E3-8a summarize the results of COPC screening for 216-Z-1A. The Phase I screen
 16 yielded 14 COPCs listed in Table E3-8a, seven of which passed all steps in the Phase II screen. Many of
 17 the data for these COPCs have concentrations levels less than the detection limits, which were eliminated
 18 from consideration in Step 1 of the Phase II screen. Three COPCs, 1,1,1-trichloroethane, benzene, and
 19 ethylbenzene were screened out as COPCs in Step 2 as having no data above detection limits. Three
 20 COPCs (barium, cis-1,2-dichloroethylene, and trans-1,2-dichloroethylene) were screened out as COPCs
 21 in Step 2 because all the remaining data were below either background levels or the EPA Soil Water
 22 Partitioning screening level (toluene, cis-1,2-dichloroethylene, trans-1,2-dichloroethylene). Phosphate
 23 was screened out in Step 4 as a COPC not regulated for groundwater protection (Ecology, 2009).
 24 Manganese, Am-241, and Pu-239/240 were screened out in the Step 5 groundwater arrival time screen.
 25 Table E3-5 summarizes the maximum depths and K_d values used in this screening step for the 216-Z-1A
 26 COPCs.

27 Seven COPCs passed all five screening steps: carbon tetrachloride (CT), chloroform, methylene chloride,
 28 1,1-dichloroethane, tetrachloroethene (PCE), trichloroethylene (TCE), and nitrogen (in nitrate+nitrite).
 29 Only one data point passed the screen for nitrogen (in nitrate+nitrite). Chapter E4.0 describes how these
 30 data were used in the determination of the COPC source term concentrations.

Table E3-5. Maximum Depths and K_d Values Used in the Groundwater Arrival Time Screen for the 216-Z-1A COPCs Eliminated in the Step 5 Groundwater Arrival Time Screen

216-Z-1A COPCs	Maximum Depth (m [ft] bgs)	K_d (mL/g)	K_d Threshold Value	Non-Zero Arrival in <1,000 Years?
Manganese	43 (140.5)	50	2.84	No
Americium-241	45.7 (150)	200	2.84	No
Plutonium-239/240	44 (145)	200	2.84	No

E3.2.4 Results for 216-Z-18

Tables E3-1 and E3-8b summarize the results of COPC screening for 216-Z-18. The Phase I screen yielded 19 COPCs listed in Tables 3-1 and 3-8b, seven of which passed all steps in the Phase II screen. The analytes 1,1,1-trichloroethane, trichloroethene, and toluene were screened out as COPCs in Step 2, because all the remaining data were below the EPA Soil Water Partitioning screening levels. Phosphate was screened out in Step 4 as a COPC not regulated for groundwater protection (Ecology, 2009). Antimony, barium, beryllium, cobalt, iron, manganese, nickel, and vanadium were screened out in the Step 5 groundwater arrival time screen. Table E3-6 summarizes the maximum depths and K_d values used in this screening step for the 216-Z-18 COPCs. The maximum depths of contamination for all of these COPCs are ≤ 50 m (160 ft) bgs reference depth used in the screen. All of the COPC K_d values are significantly larger than the 2.84 mL/g K_d threshold value for groundwater arrival time of $>1,000$ years. The depth to groundwater at 216-Z-18 is 73.5 m (235.8 ft) bgs.

Table E3-6. Maximum Depths and K_d Values Used in the Groundwater Arrival Time Screen for the 216-Z-18 COPCs Eliminated in the Step 5 Groundwater Arrival Time Screen

216-Z-18 COPCs	Maximum Depth (m [ft] bgs)	K_d (mL/g)	K_d Threshold Value	Non-Zero Arrival in <1,000 Years?
Antimony	44.6 (146.5)	45	2.84	No
Barium	41.4 (136)	25	2.84	No
Beryllium	10.2 (33.5)	790	2.84	No
Cobalt	18.1 (59.6)	50	2.84	No
Iron	18.1 (59.6)	25	2.84	No
Manganese	39.1 (128.3)	50	2.84	No
Nickel	39.7 (130.5)	65	2.84	No
Vanadium	18.1 (59.6)	1000	2.84	No

Seven COPCs passed all five screening steps: benzene, CT, chloroform, ethylbenzene, methylene chloride, PCE, and nitrogen (in nitrate+nitrite). Three of the COPCs have only one or two data points that passed the screen. Chapter E4.0 describes how these data were used in the determination of the COPC source term concentrations..

1 E3.2.5 Results for 216-Z-9

2 Tables E3-1 and E3-9 summarize the results of COPC screening for the 216-Z-9 Crib. The Phase I screen
3 yielded 72 COPCs (Table E3-9). This number of COPCs from the Phase I screen is less than that reported
4 in ECF-200PW1/3/6-10-0360 because nitrate and nitrite in that tally were combined with nitrogen in
5 nitrate+nitrite for the Phase II screen. Much of the data for many of the COPCs were non-detect values,
6 and were removed from consideration in the Step 4 screen.

7 Barium, lead, mercury, nickel, selenium, silver, vanadium, sulfate, 1,1-dichloroethane,
8 1,1-dichloroethene, 2-butanone, acetic acid-methyl ester, benzene, benzo(a)anthracene, benzo(a)pyrene,
9 benzo(b)fluoranthene, bis(2-ethylhexyl) phthalate, bromomethane, ethylbenzene, naphthalene, and
10 toluene were screened out as COPCs in Step 2, because all the remaining data were below either
11 background levels (antimony and barium), or the EPA Soil Water Partitioning screening level. The
12 radionuclides nickel-63 and protactinium-231 were eliminated in the Step 3 screen because the single
13 remaining data values for each COPC were less than the PQL value. Phosphate, acetonitrile,
14 chloromethane, nitromethane, phenyl sulfone, potassium-40, and the uranium isotopes (U-233, U-234,
15 U-235, U-236, and U-238) were screened out in Step 4. Chloromethane, nitromethane, phenyl sulfone,
16 gross alpha, and gross beta were eliminated as COPCs for groundwater protection as analytes that are
17 either not subject to the ingestion pathway (acetonitrile,⁵ chloromethane², or have no quantifiable or
18 appropriate basis for evaluation as groundwater protection COPCs (nitromethane,⁶ phenyl sulfone³, gross
19 alpha, gross beta). Phosphate was eliminated in the Step 4 screen because phosphate was also detected in
20 the laboratory blanks of the only two data points above the screening levels, and is not regulated for the
21 groundwater pathway. Potassium-40 was eliminated as a groundwater protection COPC in Step 4 because
22 this analyte is exclusively a naturally occurring radionuclide, and was not an anthropogenic component of
23 the operational waste stream.

24 A number of COPC concentrations for specified sample depths were further evaluated in the Step 4
25 screen as potential anomalies, especially where isolated occurrence of high K_d analytes were detected at
26 depths inconsistent with the K_d value. Anomalous data above detection limits were observed for cadmium
27 (56.8 m [186.5 ft] bgs), manganese (56.8 m [186.5 ft] bgs), and Am-241 (56.8 and 53.5 m [186.5 and
28 175.5 ft] bgs) in samples from the 299-W-15-46 borehole at the 216-Z-9 Crib. The concentrations of
29 metals and non-mobile radionuclides were not generally detected above the background or Soil-Water-
30 Partitioning screening levels (Table E2-3), except for these analytes at these depths. Based on the review
31 of boring log information combined with laboratory QA results used during data assessment, it is evident
32 that at certain depths the following anomalies exist due to the following sources of field and/or laboratory
33 cross-contamination in the samples:

- 34 • The 299-W-15-46 borehole is known to be internally contaminated, ostensibly on the inside of the
35 steel casing (DOE/RL-2006-51, Section 3.2.1.2).
- 36 • The stainless steel casing and/or lines, which may have been coated in cadmium, are potential sources of
37 anomalous cadmium and manganese, especially in the presence of the acidic waste discharged to the Crib.
- 38 • The laboratory blanks are documented to have been contaminated for samples B17N67 (53.8 m
39 [176.5 ft] bgs) and B17N70 (56.8 m [186.5 ft] bgs) from the 299-W-15-46 borehole.
- 40 • The data for anomalously deep occurrences of cadmium, manganese, and Am-241 are all associated
41 with samples B17N67 (53.8 m [176.5 ft] bgs) and B17N70 (56.8 m [186.5 ft] bgs) from the
42 299-W-15-46 borehole.

⁵ EPA rescinded ingestion reference doses for these analytes.

⁶ No groundwater protectiveness metric (e.g., MCL, or other cleanup level), or criteria (e.g., K_d value).

Table E3-7. Summary of the COPC Data Screening Results for Each Step in the Phase II COPC Screening Process for Groundwater Protection

Table E3-7a. Summary of Phase II Screening Results for the 216-A-8 Crib

Waste Site	COPCs at Beginning of Phase-II Screen		Phase-II COPC Screen; Step-1		Phase-II COPC Screen; Step-2		Phase-II COPC Screen; Step-3		Phase-II COPC Screen; Step-4		Phase-II COPC Screen; Step-5		Results of Phase-II COPC Screen	
	COPCs Remaining After Phase-I COPC Screen		COPCs Remaining After Lab Code Screen		COPC Remaining After Background & Soil-Water Partition Eq. Screen		COPCs Remaining After Quantitation Criteria Screen		COPCs Remaining After Pathway and Anomalous Data Evaluation Screen		COPCs Remaining After Contaminant Transport Time to Groundwater and Half-Life Screen		COPCs Remaining for Fate and Transport Modeling	
	#	COPC	#	COPC	#	COPC	#	COPC	#	COPC	#	COPC	#	COPC
216-A-8	9	Aroclor-1254	1	Aroclor-1254		Aroclor-1254		Aroclor-1254		Aroclor-1254		Aroclor-1254		Aroclor-1254
	9	Hexavalent Chromium	2	Hexavalent Chromium	2	Hexavalent Chromium	2	Hexavalent Chromium	2	Hexavalent Chromium	2	Hexavalent Chromium	2	Hexavalent Chromium
	7+2(C)	Selenium	3+2(C)	Selenium		Selenium		Selenium		Selenium		Selenium		Selenium
	3	Thallium	3	Thallium	2/0	Thallium	2/0	Thallium	2/0	Thallium		Thallium		Thallium
	7+2(B)	Phosphate	7+2(C)	Phosphate	7+2(B)	Phosphate	7+2(B)	Phosphate		Phosphate		Phosphate		Phosphate
	9	Nitrogen in Nitrite and Nitrate	10	Nitrogen in Nitrite + Nitrate	1	Nitrogen in Nitrite + Nitrate	1	Nitrogen in Nitrite + Nitrate	1	Nitrogen in Nitrite + Nitrate	1	Nitrogen in Nitrite + Nitrate	1	Nitrogen in Nitrite + Nitrate
	9	Carbon-14	3	Carbon-14		Carbon-14	1*	Carbon-14	1	Carbon-14	1	Carbon-14	1	Carbon-14
	9	Cesium-137	10	Cesium-137	10	Cesium-137	5	Cesium-137	5	Cesium-137		Cesium-137		Cesium-137
	9	Europium-155	1	Europium-155	1	Europium-155		Europium-155		Europium-155		Europium-155		Europium-155
	9	Radium-228	6	Radium-228	6	Radium-228		Radium-228		Radium-228		Radium-228		Radium-228
	4	Neptunium-237	2	Neptunium-237	2	Neptunium-237	0	Neptunium-237		Neptunium-237		Neptunium-237		Neptunium-237
	9	Plutonium-239/240	4	Plutonium-239/240	2	Plutonium-239/240	1	Plutonium-239/240	1	Plutonium-239/240		Plutonium-239/240		Plutonium-239/240
	9	Potassium-40	7	Potassium-40	1	Potassium-40	1	Potassium-40		Potassium-40		Potassium-40		Potassium-40
	8	Technetium-99	3	Technetium-99	3	Technetium-99	1	Technetium-99	1	Technetium-99	1	Technetium-99	1	Technetium-99
	2	Total beta radiostrontium	2	Total beta radiostrontium	2	Total beta radiostrontium	1	Total beta radiostrontium	1	Total beta radiostrontium		Total beta radiostrontium		Technetium-99
	2	Gross alpha	1	Gross alpha	2	Gross alpha	1	Gross alpha	1	Gross alpha		Gross alpha		Gross alpha
	2	Gross alpha	1	Gross alpha	1	Gross alpha	1	Gross alpha	1	Gross alpha		Gross alpha		Gross alpha

Table E3-7b. Summary of Phase II Screening Results for the 216-Z-8 French Drain

Waste Site	COPCs at Beginning of Phase-II Screen		Phase-II COPC Screen; Step-1		Phase-II COPC Screen; Step-2		Phase-II COPC Screen; Step-3		Phase-II COPC Screen; Step-4		Phase-II COPC Screen; Step-5		Results of Phase-II COPC Screen	
	COPCs Remaining After Phase-I COPC Screen		COPCs Remaining After Lab Code Screen		COPC Remaining After Background & Soil-Water Partition Eq. Screen		COPCs Remaining After Quantitation Criteria Screen		COPCs Remaining After Pathway and Anomalous Data Evaluation Screen		COPCs Remaining After Contaminant Transport Time to Groundwater and Half-Life Screen		COPCs Remaining for Fate and Transport Modeling	
	#	COPC	#	COPC	#	COPC	#	COPC	#	COPC	#	COPC	#	COPC
216-Z-8 French Drain	12	Americium-241	12	Americium-241	12	Americium-241	12	Americium-241	12	Americium-241		Americium-241		Americium-241
	12	Plutonium-238	12	Plutonium-238	12	Plutonium-238	12	Plutonium-238	12	Plutonium-238		Plutonium-238		Plutonium-238
	12	Plutonium-239/240	12	Plutonium-239/240	12	Plutonium-239/240	12	Plutonium-239/240	12	Plutonium-239/240		Plutonium-239/240		Plutonium-239/240

Notes:

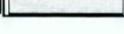
Columns labeled # = The number of data values remaining after applicable step in the screening process.

The color code is explained in the legend.

GC/MS = gas chromatograph/mass spectrometer

IDL = instrument detection limit

RDL = required detection limit

LEGEND		COPC not screened out
		Stage where COPC screened out
		Tentatively screened
		COPC Screened out

(J) Denotes estimated values \leq PQL or RDL, and \geq MDL, or estimated concentration for tentatively identified compounds
 (E) Estimated value due to interference (Inorganics); Concentration exceeds the calibration range of the GC/MS (Organics)
 (B) Detected at a value less than the RDL, but \leq the IDL/MDL (Inorganics); Detected in both the QC blank and the sample (Organics)
 (C) Detected in both the sample and the QC blank, and concentration $\leq 5 \times$ the blank concentration (Inorganics)

Table E3-8. Summary of the COPC Data Screening Results for Each Step in the Phase II COPC Screening Process for Groundwater Protection

Table E3-8a. Summary of Phase II Screening Results for the 216-Z-1A Crib

Waste Site	COPCs at Beginning of Phase-II Screen		Phase-II COPC Screen; Step-1		Phase-II COPC Screen; Step-2		Phase-II COPC Screen; Step-3		Phase-II COPC Screen; Step-4		Phase-II COPC Screen; Step-5		Results of Phase-II COPC Screen	
	COPCs Remaining After Phase-I COPC Screen		COPCs Remaining After Lab Code Screen		COPC Remaining After Background & Soil-Water Partition Eq. Screen		COPCs Remaining After Quantitation Criteria Screen		COPCs Remaining After Pathway and Anomalous Data Evaluation Screen		COPCs Remaining After Contaminant Transport Time to Groundwater and Half-Life Screen		COPCs Remaining for Fate and Transport Modeling	
	#	COPC	#	COPC	#	COPC	#	COPC	#	COPC	#	COPC	#	COPC
216-Z-1A	22	Barium	22	Barium	22	Barium	22	Barium	22	Barium	22	Barium	22	Barium
	22	Manganese	22	Manganese	1	Manganese	1	Manganese	1	Manganese	1	Manganese	1	Manganese
	26	Nitrogen in Nitrite and Nitrate	19	Nitrogen in Nitrite and Nitrate	1	Nitrogen in Nitrite and Nitrate	1	Nitrogen in Nitrite and Nitrate	1	Nitrogen in Nitrite and Nitrate	1	Nitrogen in Nitrite and Nitrate	1	Nitrogen in Nitrite and Nitrate
	1	Phosphate	1	Phosphate	1	Phosphate	1	Phosphate	1	Phosphate	1	Phosphate	1	Phosphate
	76	1,1-Dichloroethane	3	1,1-Dichloroethane	2(J)	1,1-Dichloroethane	2(J)	1,1-Dichloroethane	2(J)	1,1-Dichloroethane	2(J)	1,1-Dichloroethane	2(J)	1,1-Dichloroethane
	75	Carbon tetrachloride	75	Carbon tetrachloride	71	Carbon tetrachloride	71	Carbon tetrachloride	71	Carbon tetrachloride	71	Carbon tetrachloride	71	Carbon tetrachloride
	75	Chloroform	18	Chloroform	15	Chloroform	15	Chloroform	15	Chloroform	15	Chloroform	15	Chloroform
	76	cis-1,2-dichloroethylene	1	cis-1,2-dichloroethylene		cis-1,2-dichloroethylene		cis-1,2-dichloroethylene		cis-1,2-dichloroethylene		cis-1,2-dichloroethylene		cis-1,2-dichloroethylene
	75	trans-1,2-dichloroethylene	2	trans-1,2-dichloroethylene	2	trans-1,2-dichloroethylene		trans-1,2-dichloroethylene		trans-1,2-dichloroethylene		trans-1,2-dichloroethylene		trans-1,2-dichloroethylene
	71	Methylene chloride	13	Methylene chloride	13	Methylene chloride	13	Methylene chloride	13	Methylene chloride	13	Methylene chloride	13	Methylene chloride
	76	Tetrachloroethene	26	Tetrachloroethene	26	Tetrachloroethene	26	Tetrachloroethene	26	Tetrachloroethene	26	Tetrachloroethene	26	Tetrachloroethene
	76	Trichloroethylene	23	Trichloroethylene	23	Trichloroethylene	7	Trichloroethylene	7	Trichloroethylene	7	Trichloroethylene	7	Trichloroethylene
	459	Americium-241	280	Americium-241	280	Americium-241	280	Americium-241	280	Americium-241	280	Americium-241	280	Americium-241
	424	Plutonium-239/240	124	Plutonium-239/240	124	Plutonium-239/240	124	Plutonium-239/240	124	Plutonium-239/240	124	Plutonium-239/240	124	Plutonium-239/240

Table E3-8b. Summary of Phase II Screening Results for the 216-Z-8 Crib

Waste Site	COPCs at Beginning of Phase-II Screen		Phase-II COPC Screen; Step-1		Phase-II COPC Screen; Step-2		Phase-II COPC Screen; Step-3		Phase-II COPC Screen; Step-4		Phase-II COPC Screen; Step-5		Results of Phase-II COPC Screen	
	COPCs Remaining After Phase-I COPC Screen		COPCs Remaining After Lab Code Screen		COPC Remaining After Background & Soil-Water Partition Eq. Screen		COPCs Remaining After Quantitation Criteria Screen		COPCs Remaining After Pathway and Anomalous Data Evaluation Screen		COPCs Remaining After Contaminant Transport Time to Groundwater and Half-Life Screen		COPCs Remaining for Fate and Transport Modeling	
	#	COPC	#	COPC	#	COPC	#	COPC	#	COPC	#	COPC	#	COPC
216-Z-18	30	Antimony	3	Antimony	3	Antimony	3	Antimony	3	Antimony	3	Antimony	3	Antimony
	26	Barium	26	Barium	1	Barium	1	Barium	1	Barium	1	Barium	1	Barium
	29	Beryllium	21	Beryllium	1	Beryllium	1	Beryllium	1	Beryllium	1	Beryllium	1	Beryllium
	28	Cobalt	25	Cobalt	4	Cobalt	4	Cobalt	4	Cobalt	4	Cobalt	4	Cobalt
	27	Iron	19	Iron	4	Iron	4	Iron	4	Iron	4	Iron	4	Iron
	27	Manganese	26	Manganese	3	Manganese	3	Manganese	3	Manganese	3	Manganese	3	Manganese
	28	Nickel	25	Nickel	2	Nickel	2	Nickel	2	Nickel	2	Nickel	2	Nickel
	27	Vanadium	26	Vanadium	5	Vanadium	5	Vanadium	5	Vanadium	5	Vanadium	5	Vanadium
	20	Nitrogen in Nitrite and Nitrate	20	Nitrogen as Nitrate	2	Nitrogen as Nitrate	2	Nitrogen as Nitrate	2	Nitrogen as Nitrate	2	Nitrogen as Nitrate	2	Nitrogen as Nitrate
	2	Phosphate	2	Phosphate	2	Phosphate	2	Phosphate	2	Phosphate	2	Phosphate	2	Phosphate
	91	1,1,1-Trichloroethane	3	1,1,1-Trichloroethane		1,1,1-Trichloroethane		1,1,1-Trichloroethane		1,1,1-Trichloroethane		1,1,1-Trichloroethane		1,1,1-Trichloroethane
	87	Benzene	3	Benzene	1	Benzene	1	Benzene	1	Benzene	1	Benzene	1	Benzene
	87	Carbon tetrachloride	72+12(J)	Carbon tetrachloride	80+10(J)	Carbon tetrachloride	80+10(J)	Carbon tetrachloride	80+10(J)	Carbon tetrachloride	80+10(J)	Carbon tetrachloride	80+10(J)	Carbon tetrachloride
	87	Chloroform	9+11(J)	Chloroform	4+2(J)	Chloroform	4+2(J)	Chloroform	4+2(J)	Chloroform	4+2(J)	Chloroform	4+2(J)	Chloroform
	89	Ethylbenzene	7+1(J)	Ethylbenzene	1	Ethylbenzene	1	Ethylbenzene	PQL	Ethylbenzene	1	Ethylbenzene	1	Ethylbenzene
	84	Methylene chloride	24	Methylene chloride	23	Methylene chloride	23	Methylene chloride	23	Methylene chloride	23	Methylene chloride	23	Methylene chloride
	89	Tetrachloroethene	7	Tetrachloroethene	7	Tetrachloroethene	7	Tetrachloroethene	7	Tetrachloroethene	7	Tetrachloroethene	7	Tetrachloroethene
	88	Toluene	28	Toluene		Toluene		Toluene		Toluene		Toluene		Toluene
87	Trichloroethene	3	Trichloroethene		Trichloroethene		Trichloroethene		Trichloroethene		Trichloroethene		Trichloroethene	

Notes:

Columns labeled # = The number of data values remaining after applicable step in the screening process.

The color code is explained in the legend.

GC/MS = gas chromatograph/mass spectrometer

IDL = instrument detection limit

RDL = required detection limit

LEGEND		
		COPC not screened out
		Stage where COPC screened out
		Tentatively screened
		COPC Screened out

(J) Denotes estimated values \leq PQL or RDL, and \geq MDL, or estimated concentration for tentatively identified compounds
 (E) Estimated value due to interference (Inorganics); Concentration exceeds the calibration range of the GC/MS (Organics)
 (B) Detected at a value less than the RDL, but \leq the IDL/MDL (Inorganics); Detected in both the QC blank and the sample (Organics)
 (C) Detected in both the sample and the QC blank, and concentration $\leq 5 \times$ the blank concentration (Inorganics)

Table E3-9. Summary of the COPC Data Screening Results for Each Step in the Phase II COPC Screening Process for Groundwater Protection for the 216-Z-9 Crib

Waste Site	COPCs at Beginning of Phase-II Screen		Phase-II COPC Screen; Step-1		Phase-II COPC Screen; Step-2		Phase-II COPC Screen; Step-3		Phase-II COPC Screen; Step-4		Phase-II COPC Screen; Step-5		Results of Phase-II COPC Screen	
	COPCs Remaining After Phase-I COPC Screen		COPCs Remaining After Lab Code Screen		COPC Remaining After Background & Soil-Water Partition Eq. Screen		COPCs Remaining After Quantitation Criteria Screen		COPCs Remaining After Pathway and Anomalous Data Evaluation Screen		COPCs Remaining After Contaminant Transport Time to Groundwater and Half-Life Screen		COPCs Remaining for Fate and Transport Modeling	
	#	COPC	#	COPC	#	COPC	#	COPC	#	COPC	#	COPC	#	COPC
216-Z-9	53	Antimony	19	Antimony	1	Antimony	1	Antimony	1	Antimony	1	Antimony	1	Antimony
	22	Arsenic	18	Arsenic	3	Arsenic	3	Arsenic	3	Arsenic	3	Arsenic	3	Arsenic
	72	Barium	72	Barium		Barium		Barium		Barium		Barium		Barium
	48	Cadmium	34	Cadmium	16	Cadmium	16	Cadmium	16	Cadmium	16	Cadmium	16	Cadmium
	69	Cobalt	69	Cobalt	3	Cobalt	3	Cobalt	3	Cobalt	3	Cobalt	3	Cobalt
	72	Copper	72	Copper	1	Copper	1	Copper	1	Copper	1	Copper	1	Copper
	18	Hexavalent Chromium	3	Hexavalent Chromium	3	Hexavalent Chromium	3	Hexavalent Chromium	3	Hexavalent Chromium	3	Hexavalent Chromium	3	Hexavalent Chromium
	69	Iron	69	Iron	4	Iron	4	Iron	4	Iron	4	Iron	4	Iron
	24	Lead	24	Lead		Lead		Lead		Lead		Lead		Lead
	72	Manganese	72	Manganese	3	Manganese	3	Manganese	3	Manganese	3	Manganese	3	Manganese
	48	Mercury	21	Mercury		Mercury		Mercury		Mercury		Mercury		Mercury
	72	Nickel	72	Nickel		Nickel		Nickel		Nickel		Nickel		Nickel
	22	Selenium	10	Selenium		Selenium		Selenium		Selenium		Selenium		Selenium
	59	Silver	19	Silver		Silver		Silver		Silver		Silver		Silver
	69	Vanadium	69	Vanadium		Vanadium		Vanadium		Vanadium		Vanadium		Vanadium
	56	Nitrogen in Nitrite and Nitrate	55	Nitrogen in Nitrite and Nitrate	34	Nitrogen in Nitrite and Nitrate	34	Nitrogen in Nitrite and Nitrate	34	Nitrogen in Nitrite and Nitrate	34	Nitrogen in Nitrite and Nitrate	34	Nitrogen in Nitrite and Nitrate
	46	Phosphate	2	Phosphate	2	Phosphate		Phosphate		Phosphate		Phosphate		Phosphate
	30	Sulfate	28	Sulfate		Sulfate		Sulfate		Sulfate		Sulfate		Sulfate
	18	Aroclor-1248	4	Aroclor-1248	4	Aroclor-1248	4	Aroclor-1248	4	Aroclor-1248	4	Aroclor-1248	4	Aroclor-1248
	130	1,1,2,2-Tetrachloroethane	3(J)	1,1,2,2-Tetrachloroethane	2(J)	1,1,2,2-Tetrachloroethane	3(J)	1,1,2,2-Tetrachloroethane	3(J)	1,1,2,2-Tetrachloroethane	3(J)	1,1,2,2-Tetrachloroethane	3(J)	1,1,2,2-Tetrachloroethane
	129	1,1,2-Trichloroethane	2	1,1,2-Trichloroethane	1	1,1,2-Trichloroethane	1	1,1,2-Trichloroethane	1	1,1,2-Trichloroethane	1	1,1,2-Trichloroethane	1	1,1,2-Trichloroethane
	31	1,1-Dichloroethane	2	1,1-Dichloroethane		1,1-Dichloroethane		1,1-Dichloroethane		1,1-Dichloroethane		1,1-Dichloroethane		1,1-Dichloroethane
	138	1,1-Dichloroethene	1+1(J)	1,1-Dichloroethene		1,1-Dichloroethene		1,1-Dichloroethene		1,1-Dichloroethene		1,1-Dichloroethene		1,1-Dichloroethene
	53	1-Butanol	8+8(JE)	1-Butanol	7(JE)	1-Butanol	7(JE)	1-Butanol	7(JE)	1-Butanol	7(JE)	1-Butanol	7(JE)	1-Butanol
	138	2-Butanone	29+20(J)	2-Butanone	0	2-Butanone		2-Butanone		2-Butanone		2-Butanone		2-Butanone
	21	Acetic acid, methyl ester	2 (J)	Acetic acid, methyl ester	0	Acetic acid, methyl ester		Acetic acid, methyl ester		Acetic acid, methyl ester		Acetic acid, methyl ester		Acetic acid, methyl ester
	49	Acetonitrile	1+6(J)	Acetonitrile	1+6(J)	Acetonitrile	1+6(J)	Acetonitrile	1+6(J)	Acetonitrile	1+6(J)	Acetonitrile	1+6(J)	Acetonitrile
	169	Benzene	3+5(J)	Benzene		Benzene		Benzene		Benzene		Benzene		Benzene
	65	Benzo(a)anthracene	1(J)	Benzo(a)anthracene		Benzo(a)anthracene		Benzo(a)anthracene		Benzo(a)anthracene		Benzo(a)anthracene		Benzo(a)anthracene
	65	Benzo(a)pyrene	1(J)	Benzo(a)pyrene		Benzo(a)pyrene		Benzo(a)pyrene		Benzo(a)pyrene		Benzo(a)pyrene		Benzo(a)pyrene
	65	Benzo(b)fluoranthene	1(J)	Benzo(b)fluoranthene		Benzo(b)fluoranthene		Benzo(b)fluoranthene		Benzo(b)fluoranthene		Benzo(b)fluoranthene		Benzo(b)fluoranthene
	65	Bis(2-ethylhexyl) phthalate	10+15(J)	Bis(2-ethylhexyl) phthalate		Bis(2-ethylhexyl) phthalate		Bis(2-ethylhexyl) phthalate		Bis(2-ethylhexyl) phthalate		Bis(2-ethylhexyl) phthalate		Bis(2-ethylhexyl) phthalate
	132	Bromodichloromethane	2	Bromodichloromethane	1	Bromodichloromethane	1	Bromodichloromethane	1	Bromodichloromethane	1	Bromodichloromethane	1	Bromodichloromethane
132	Bromoform	2	Bromoform	1	Bromoform	1	Bromoform	1	Bromoform	1	Bromoform	1	Bromoform	
129	Bromomethane	1+1(J)	Bromomethane		Bromomethane		Bromomethane		Bromomethane		Bromomethane		Bromomethane	
393	Carbon tetrachloride	227+39(JE)	Carbon tetrachloride	179+33(JE)	Carbon tetrachloride	179+33(JE)	Carbon tetrachloride	179+33(JE)	Carbon tetrachloride	179+33(JE)	Carbon tetrachloride	179+33(JE)	Carbon tetrachloride	
393	Chloroform	243+39(JE)	Chloroform	67+14(JE)	Chloroform	67+14(JE)	Chloroform	67+14(JE)	Chloroform	67+14(JE)	Chloroform	67+14(JE)	Chloroform	
138	Chloromethane	1+1(J)	Chloromethane	1+1(J)	Chloromethane	1+1(J)	Chloromethane	1+1(J)	Chloromethane	1+1(J)	Chloromethane	1+1(J)	Chloromethane	

Notes:

Columns labeled # = The number of data values remaining after applicable step in the screening process.

The color code is explained in the legend.

7 GC/MS = gas chromatograph/mass spectrometer

8 IDL = instrument detection limit

9 RDL = required detection limit

10

11

LEGEND	
	COPC not screened out
	Stage where COPC screened out
	Tentatively screened
	COPC Screened out

(J) Denotes estimated values \leq PQL or RDL, and \geq MDL, or estimated concentration for tentatively identified compounds
 (E) Estimated value due to interference (Inorganics); Concentration exceeds the calibration range of the GC/MS (Organics)
 (B) Detected at a value less than the RDL, but \leq the IDL/MDL (Inorganics); Detected in both the QC blank and the sample (Organics)
 (C) Detected in both the sample and the QC blank, and concentration $\leq 5 \times$ the blank concentration (Inorganics)

Table E3-9. Summary of the COPC Data Screening Results for Each Step in the Phase II COPC Screening Process for Groundwater Protection for the 216-Z-9 Crib

Waste Site	COPCs at Beginning of Phase-II Screen		Phase-II COPC Screen; Step-1		Phase-II COPC Screen; Step-2		Phase-II COPC Screen; Step-3		Phase-II COPC Screen; Step-4		Phase-II COPC Screen; Step-5		Results of Phase-II COPC Screen	
	COPCs Remaining After Phase-I COPC Screen		COPCs Remaining After Lab Code Screen		COPC Remaining After Background & Soil-Water Partition Eq. Screen		COPCs Remaining After Quantitation Criteria Screen		COPCs Remaining After Pathway and Anomalous Data Evaluation Screen		COPCs Remaining After Contaminant Transport Time to Groundwater and Half-Life Screen		COPCs Remaining for Fate and Transport Modeling	
	#	COPC	#	COPC	#	COPC	#	COPC	#	COPC	#	COPC	#	COPC
216-Z-9	169	Ethylbenzene	1+3(J)	Ethylbenzene		Ethylbenzene		Ethylbenzene		Ethylbenzene		Ethylbenzene		Ethylbenzene
	70	Hexachloroethane	8+1(J)	Hexachloroethane	6	Hexachloroethane	6	Hexachloroethane	6	Hexachloroethane		Hexachloroethane		Hexachloroethane
	170	Methylene chloride	58+11(J)	Methylene chloride	13+1(J)	Methylene chloride	13+1(J)	Methylene chloride	13+1(J)	Methylene chloride	2	Methylene chloride	2	Methylene chloride
	71	Naphthalene	1(J)	Naphthalene		Naphthalene		Naphthalene		Naphthalene		Naphthalene		Naphthalene
	1	Nitromethane	1	Nitromethane	1	Nitromethane	1	Nitromethane		Nitromethane		Nitromethane		Nitromethane
	74	Pentachlorophenol	1(J)	Pentachlorophenol	1	Pentachlorophenol	1	Pentachlorophenol	1	Pentachlorophenol	1	Pentachlorophenol	1	Pentachlorophenol
	1(J)	Phenyl sulfone	1(J)	Phenyl sulfone	1(J)	Phenyl sulfone	1(J)	Phenyl sulfone		Phenyl sulfone		Phenyl sulfone		Phenyl sulfone
	169	Tetrachloroethene	41+12(J)	Tetrachloroethene	29+11(J)	Tetrachloroethene	29+11(J)	Tetrachloroethene	29+11(J)	Tetrachloroethene	29+11(J)	Tetrachloroethene	29+11(J)	Tetrachloroethene
	169	Toluene	27	Toluene		Toluene		Toluene		Toluene		Toluene		Toluene
	86	Tributyl phosphate	12+7(J)	Tributyl phosphate	12	Tributyl phosphate	12	Tributyl phosphate	12	Tributyl phosphate		Tributyl phosphate		Tributyl phosphate
	395	Trichloroethylene	4+9(J)	Trichloroethylene	1	Trichloroethylene	1	Trichloroethylene	1	Trichloroethylene	1	Trichloroethylene	1	Trichloroethylene
	159	Americium-241	71	Americium-241	71	Americium-241	64	Americium-241	64	Americium-241		Americium-241		Americium-241
	59	Europium-152	3	Europium-152	2	Europium-152	2	Europium-152	2	Europium-152		Europium-152+D		Europium-152
	59	(Gadolinium-152 as Eu-152 D)	3	Gadolinium-152 as Eu-152 D)	2	Gadolinium-152 (Eu-152 D)	2	Gadolinium-152 (Eu-152 D)	2	Gadolinium-152 (Eu-152 D)		Gadolinium-152 (Eu-152 D)		Gadolinium-152 (Eu-152 D)
	59	Europium-154	1	Europium-154	1	Europium-154	1	Europium-154	1	Europium-154		Europium-154+D		Europium-154
	59	Europium-155	3	Europium-155	3	Europium-155	1	Europium-155	1	Europium-155		Europium-155		Europium-155
	9	Gross alpha	9	Gross alpha	9	Gross alpha	9	Gross alpha		Gross alpha		Gross alpha		Gross alpha
	9	Gross beta	9	Gross beta	9	Gross beta	9	Gross beta		Gross beta		Gross beta		Gross beta
	23	Neptunium-237	5	Neptunium-237	5	Neptunium-237	4	Neptunium-237	4	Neptunium-237		Neptunium-237		Neptunium-237
	4	Nickel-63	1	Nickel-63	1	Nickel-63		Nickel-63		Nickel-63		Nickel-63		Nickel-63
	116	Plutonium-238	22	Plutonium-238	22	Plutonium-238	10	Plutonium-238	10	Plutonium-238		Plutonium-238		Plutonium-238
	55	Plutonium-239/240	24	Plutonium-239/240	24	Plutonium-239/240	22	Plutonium-239/240	22	Plutonium-239/240		Plutonium-239/240		Plutonium-239/240
	46	Potassium-40	41	Potassium-40	15	Potassium-40	14	Potassium-40		Potassium-40		Potassium-40		Potassium-40
	4	Protactinium-231	1	Protactinium-231	1	Protactinium-231		Protactinium-231		Protactinium-231		Protactinium-231		Protactinium-231
	47	Radium-226	38	Radium-226	12	Radium-226	10	Radium-226	10	Radium-226		Radium-226+D		Radium-226+D
	47	Radium-228	37	Radium-228	37	Radium-228	33	Radium-228	33	Radium-228		Radium-228+D		Radium-228
	3	Strontium-90	2	Strontium-90	2	Strontium-90	2	Strontium-90	2	Strontium-90		Strontium-90		Strontium-90
	43	Total beta radiostrontium	2+2(J)	Total beta radiostrontium	2	Total beta radiostrontium	1	Total beta radiostrontium	1	Total beta radiostrontium		Total beta radiostrontium		Total beta radiostrontium
	16	Technetium-99	5	Technetium-99	4	Technetium-99	3	Technetium-99	3	Technetium-99	3	Technetium-99	3	Technetium-99
14	Thorium-230	2+2(B)	Thorium-230	2+2(B)	Thorium-230	1+2(B)	Thorium-230	1+2(B)	Thorium-230		Thorium-230		Thorium-230	
5	Uranium-233	1	Uranium-233	1	Uranium-233	1	Uranium-233		Uranium-233		Uranium-233		Uranium-233	
67	Uranium-234	61	Uranium-234	16	Uranium-234	13	Uranium-234		Uranium-234		Uranium-234		Uranium-234	
129	Uranium-235	24+3(J)	Uranium-235	6+1(J)	Uranium-235	1	Uranium-235		Uranium-235		Uranium-235		Uranium-235	
5	Uranium-236	3	Uranium-236	3	Uranium-236	3	Uranium-236		Uranium-236		Uranium-236		Uranium-236	
85	Uranium-238	69	Uranium-238	2	Uranium-238	2	Uranium-238		Uranium-238		Uranium-238		Uranium-238	
291	Uranium (combined)	165	Uranium (combined)	28	Uranium (combined)	19	Uranium (combined)	2	Uranium (combined)	2	Uranium (combined)	2	Uranium (combined)	

Notes:

Columns labeled # = The number of data values remaining after applicable step in the screening process.

The color code is explained in the legend.

GC/MS = gas chromatograph/mass spectrometer

IDL = instrument detection limit

RDL = required detection limit

9

LEGEND

	COPC not screened out
	Stage where COPC screened out
	Tentatively screened
	COPC Screened out

- (J) Denotes estimated values \leq PQL or RDL, and \geq MDL, or estimated concentration for tentatively identified compounds
- (E) Estimated value due to interference (Inorganics); Concentration exceeds the calibration range of the GC/MS (Organics)
- (B) Detected at a value less than the RDL, but \leq the IDL/MDL (Inorganics); Detected in both the QC blank and the sample (Organics)
- (C) Detected in both the sample and the QC blank, and concentration $\leq 5 \times$ the blank concentration (Inorganics)

1 Based on this information, the data for these analytes at these depths were interpreted to be anomalous,
2 and were omitted from further evaluation in the screening process. The maximum depths of
3 contamination for the remaining data for all of the COPCs, except for manganese, are \leq the 37.2 m
4 (122 ft) reference depth used for most of the groundwater arrival time screen in Step 5. It is notable that
5 only one manganese value above the screening level remained for samples deeper than 31.8 m (104.5 ft).
6 Although this manganese data point (520 mg/kg), at 48.3 m (158.4 ft) bgs, was carried forward to the
7 Step 5 screen, it is the value is only about 3 percent larger than the background screening level, and
8 significantly less than the State background level for eastern Washington (Ecology Publication 94-115,
9 *Natural Background Soil Metals Concentrations in Washington State*).

10 The evaluation of the uranium isotopes and uranium as an inorganic analyte were reassigned to the
11 combination of all uranium isotopes because EPA regulates uranium impacts to groundwater as total
12 uranium (40 CFR 141.25[a], "National Primary Drinking Water Regulations," "Analytical Methods for
13 Radioactivity"). Only the uranium isotopic data were evaluated in the COPC screening beyond Step 2,
14 because all of the uranium metal data were below background levels. The uranium isotopic data
15 remaining at Step 4 of the COPC screening process were then evaluated in the following manner. The
16 uranium isotopic activities for each sample were added, converted from activity unity (pCi/g) to
17 concentration units (mg/kg) using the specific activities of each isotope. The total uranium concentrations
18 were then compared to the 90th percentile of the soil background population. This process yielded only
19 two samples with concentrations that exceeded the uranium background screening metric. The data for
20 these two samples were then carried forward to the subsequent stages of the COPC screening process as
21 uranium (combined).

22 Twenty-one (21) COPCs (7 inorganic analytes, 3 organic compounds, and 11 radionuclides) were
23 screened out in the Step 5 groundwater arrival time/half-life screen. Table E3-10 summarizes the
24 maximum depths and K_d values used in this screening step for the 216-Z-1A COPCs.

25 Three of the radionuclides (Eu-152, Eu-154, and radium-228 [Ra-228]) were screened out by half-life.
26 Tables E3-11 and E3-12 summarize the information used in the half-life screening step. As indicated in
27 these tables, the time required for any non-zero impact to groundwater is significantly greater than
28 10 half-lives of the parent and/or decay products for these COPCs. Thus, these radionuclides are
29 eliminated as groundwater protection COPCs because they have decayed to one or more stable
30 non-hazardous isotopes by the time they reach groundwater. It is also indicated from the information in
31 these tables that Eu-152 ($K_d = 1.0$ mL/g) is not screened out by groundwater arrival time (K_d threshold
32 values for $>1,000$ year arrival time = 1.2 mL/g), and cannot be screened out by half-life alone (13.5 yrs)
33 because it has a long-lived daughter isotope (gadolinium-152 [Gd-152]; 10^{14} yrs). Due to the combination
34 of the short half-life of the Eu-152 parent, and the very large K_d value (240 mL/g) of the long-lived
35 daughter isotope, this COPC can be screened out indirectly by groundwater arrival because the Gd-152
36 daughter isotope requires $> 1,000$ years to reach groundwater.

37 Fifteen (15) COPCs had some data that passed all five screening steps: hexavalent chromium, nitrogen
38 (in nitrate+nitrite), 1,1,2,2-tetrachloroethane, 1-butanol, CT, chloroform, methylene chloride,
39 1,1-dichloroethane, PCE, TCE, 1,1,2-trichloroethane, bromodichloromethane, bromoform,
40 pentachlorophenol, Tc-99, and uranium (combined). It is notable that there were only 1 to 3 data points
41 passing the screen for 10 of the 15 COPCs nitrogen (in nitrate+nitrite). Chapter E4.0 describes how these
42 data were used in the determination of the COPC source term concentrations.

Table E3-10. Maximum Depths, K_d Values, and K_d Threshold Values Used in the Step 5 Groundwater Arrival Time Screen for the 216-Z-9 COPCs

216-Z-9 COPCs	Maximum Depth (m [ft] bgs)	K_d (mL/g)	K_d Threshold Value	Non-Zero Arrival in <1000 Years?
Antimony	149	45	8.5	No
Arsenic	34.4 (113)	29	1.2	No
Cadmium	37.2 (122)	30	12	No
Cobalt	37.2 (122)	30	1.2	No
Copper	31.8 (104.5)	22	1.2	No
Iron	37.2 (122)	25	1.2	No
Manganese	48.2 (158.4)	50	8.5	No
Aroclor-1248	21.9 (72)	44	1.2	No
Hexachloroethane	22.8 (75)	1.8	1.2	No
Tributyl phosphate	33.2 (109)	1.9	1.2	No
Americium-241	37.2 (122)	200	1.2	No
Europium-152+D	34.3 (112.5)	1	1.2	Yes
Europium-154+D	34.3 (112.5)	1	1.2	Yes
Europium-155	34.3 (112.5)	1	1.2	Yes
Neptunium-237	37.9 (124.5)	15	1.2	No
Nickel-63	35.8 (117.5)	30	1.2	No
Plutonium-238	37.2 (122)	200	1.2	No
Plutonium-239/240	37.2 (122)	200	1.2	No
Protactinium-231	35.8 (117.5)	550	1.2	No
Radium-226+D	38.2 (125.4)	3	1.2	No
Radium-228+D	59.4 (195)	3	15	Yes
Strontium-90	34.3 (112.5)	25	1.2	No
Total beta radiostrontium	34.3 (112.5)	225	1.2	No
Thorium-230	36.3 (119)	200	1.2	No

Notes:

The maximum depths of contamination for most COPCs are less than, and/or sufficiently close to, the 37.2 m (122 ft) reference depth for which the K_d threshold value is 1.2 mL/g. The K_d threshold values for the COPCs with a maximum depth of contamination deeper than the approximately 37 m (121 ft) reference depth are also listed. The COPCs with K_d values greater than the threshold K_d values; i.e., non-zero groundwater arrival time >1,000 years, were screened out in Step 5. The depth to groundwater at 216-Z-9 is 59 m (221 ft) bgs.

Table E3-11. Half-Lives of Selected Radionuclide COPC Parents, and Decay Products

Parent Isotope	Half-Life	Decay Mode	Decay Product	Half-life	Decay Mode	Decay Product	Half-Life	Decay Mode	Decay Product	Half-Life	Decay Product(s)	Ten Half-Lives
Eu-152	13.5 yrs	ec	Sm-152	Stable								135 yrs
		β-	Gd-152	10 ¹⁴ yrs		Other long- lived daughters						>1,000 Years
Eu-154	8.6 yrs	ec	Sm-144	Stable								86 Years
		β-	Gd-154	Stable								
Eu-155	4.8 yrs	β-	Gd-155	Stable								48 yrs
Ra-226	1,026 yrs	α	Rn-222									>1,000 Years
Ra-228	5.75 yrs	β-	Ac-228	6.15 hrs	β-	Th-228	1.92 yrs	α	Ra-224	3.6 days	To stable Pb-208 with other decays with half-lives <1 min	58 Years

Notes:

Determinant half-life values (longest in the of the parent or decay product) used to define the 10X half-life metric for comparison to K_d-based groundwater arrival time used in the screening.

Ac-228 = actinium-228
 Eu-152 = europium-152
 Eu-154 = europium-154
 Eu-155 = europium-155
 Gd-152 = gadolinium-152
 Gd-154 = gadolinium-154
 Gd-155 = gadolinium-155
 Pb-208 = lead-208

Ra-224 = radium-224
 Ra-226 = radium-226
 Ra-228 = radium-228
 Rn-222 = radon-222
 Sm-144 = samarium-144
 Sm-152 = samarium-152
 Th-228 = thorium-228

Table E3-12 Comparison of the Groundwater Arrival Time for the First Non-Zero Impact to Groundwater from Radionuclide COPCs

Isotope	Maximum Depth (m [ft] bgs)	K_d (mL/g)	Time to First Non-Zero Impact to Groundwater	Ten Half-Lives	Ten Half-Lives < Time to Groundwater Impact (Screened Out)	Non-Zero Arrival in >1000 Years (Screened Out)
Gadolinium-152 (from europium-152)	34.3 (112.5)	240	>1,000 years*	NA		Yes
Europium -154	34.3 (112.5)	1	> 900 years	86 Years	Yes	---
Europium -155	34.3 (112.5)	1	> 900 years	48 Years	Yes	---
Radium-226	38.1 (125)	3	> 1,000 years*	NA		Yes
Radium-228	59.4 (195)	3	120 years	58 Years	Yes	---

Notes:

Comparison is at the maximum depth of contamination beneath the 216-Z-9 Crib, to the radionuclide 10^x half-life metric used in the Step 5 COPC screen.

* Contaminants at ≤38 m (125 ft) bgs, with K_d > 1.2 have groundwater arrival time >1,000 years.

NA = not applicable

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E4.0 Determination of Contaminated Soil Volumes and Source Term Concentrations for the 200-PW-1/3/6 Waste Sites

This chapter describes the process used to estimate a) the contaminated soil volumes in the vadose zone beneath the 200-PW-1/3/6 waste sites, and b) the source term concentrations for the contaminated soil volumes at the waste sites. Fate and transport modeling for the evaluation of potential impacts to groundwater from vadose zone contamination beneath the 200-PW-1/3/6 OU waste sites requires reasonable estimates of the contaminated soil volumes and representative concentrations within the soil volumes. Fate and transport modeling was used to evaluate the groundwater impacts for the screened COPCs for the 216-Z-9, 216-Z-1A, 216-Z-18, and the 216-A-8 waste sites.

E4.1 Background: The Use of Contaminated Soil Volume and Concentration Data in Fate and Transport Modeling

The source term used in forward fate and transport modeling requires assignment of: (a) one or more contaminated soil volumes, and (b) a COPC soil concentration for the calculation of contaminant mass in the model. Equation E4-1 summarizes the relationships between the source term mass, concentration, and the contaminated soil volume given by the thickness (depth interval) and lateral dimensions (length and width of the volume).

Equation E4-1

$$\text{Mass}_C = \text{Conc}_C \times \text{Bulk density}_S \times \text{Volume}_S$$

$$\text{In units of: } \text{kg}_C = (\text{mg}_C/\text{kg}_S) \times (\text{kg}_S/\text{m}^3) \times \text{m}^3 \times (1\text{E-}06 \text{ Kg}_C/\text{mg}_C)$$

where:

Volume_S = Volume of the contaminated soil (S) volume

Volume = length (L) × width (W) × height (H)

Mass_C = contaminant (C) mass

Conc_C = contaminant source term concentration

The source term mass calculated in two-dimensional (2-D) vadose zone modeling is based on the use of a contaminated source term volume. This is represented by the lateral dimension of the contaminated soil volume parallel to the direction of groundwater flow (length [L]), and the thickness of the soil volume (H), for each 1 m (3.3-ft) wide soil volume (W) (see Section E5.4). The COPC soil concentration used in the calculation is intended to be a value that represents the overall concentration within the entire contaminated soil volume for the purpose of calculating and/or conservatively estimating the source term COPC mass (or activity).

Thus, the determination of both the contaminated soil volume and the soil concentration requires a rationale and technical basis for the manner in which they are determined. The determination of contaminated soil volume(s) and concentration(s) for use in modeling can be simplistic, e.g. a single volume and concentration, or more sophisticated, e.g., multiple volumes each with a representative concentration. The approach used here involved the determination of multiple volumes and concentrations for each waste site. The following sections describe the rationale and process used in the determination of contaminated soil volumes, and in the determination of the COPC soil concentration values for the soil volumes at each of the waste sites for which vadose zone fate and transport modeling was performed.

E4.2 Determination of Contaminated Soil Volumes

The following steps were used in the process for the determination of the contaminated soil volumes and calculation of the source term concentrations for the 216-Z-9, 216-Z-1A, and 216-Z-18, and 216-A-8 waste sites:

1. Determination of the depth intervals and thicknesses of the contaminated soil volumes in the vadose zone beneath each of the waste sites based on the stratigraphic units, thicknesses, and depths in which contaminants preferentially occur
2. Binning of the data for each of the COPCs within the contaminated depth interval identified for the waste sites
3. Calculation of summary statistical values for the COPC data within each of the contaminated soil volumes, at each waste site, as appropriate
4. Determination of reasonable bounding dimensions of the lateral extent of contaminated soil volumes to be used in the modeling based on evaluation of the following:
 - COPC concentration patterns in north-south (N-S), and east-west (E-W) transects across the waste sites constructed from borehole data
 - Soil concentration isopleths (contours) constructed from the soil data
 - Evaluation of three-dimensional (3-D) plumes constructed for representative COPCs at the 216-Z-9 waste site
5. Comparative evaluation of the weight of evidence for constraining the lateral dimensions of the contaminated soil volumes at the waste sites
6. Comparison of methods for estimating representative COPC concentrations for the soil volumes
7. Consideration of the uncertainties, assumptions, and biases associated with estimated contaminant source term concentrations

The source term concentrations and dimensions of the contaminated soil volumes are then provided as input parameters for the vadose zone fate and transport modeling. The modeling is the tool by which potential impacts to groundwater are evaluated, and by which the risk for this pathway is characterized.

E4.2.1 Identification of the Stratigraphic Units, Thicknesses and Depths of Contamination

The identification of the geology and stratigraphic units in the vadose zone beneath the waste sites is a prerequisite to the determination of the depth intervals and thicknesses of the contaminated soil volumes. Section 2.2.3 of the feasibility study describes the general geologic relationships for the 200-PW-1/3/6 OU. The detailed stratigraphy for each of the representative waste sites was based on the information from the original driller logs and/or the stratigraphic sections prepared from them archived in the Well Information and Document Lookup database, as well as the 3-D geologic relationships developed from a composite of all boreholes in the vicinities of the waste sites (PNNL-16198, *Carbon Tetrachloride Flow and Transport in the Subsurface of the 216-Z-18 Crib and 216-Z-1A Tile Field at the Hanford Site: Multifluid Flow Simulations and Conceptual Model Update*, and Figure 2.4 in PNNL-15914, *Carbon Tetrachloride Flow and Transport in the Subsurface of the 216-Z-9 Trench at the Hanford Site: Heterogeneous Model Development and Soil Vapor Extraction Modeling*).

1 The geologic information for the reference boreholes identified in Figure E4-1 was used to describe the
2 detailed stratigraphy for the waste sites.

3 A summary of the detailed stratigraphic relationships for specific boreholes from the three representative
4 waste sites (216-Z-9, 216-Z-1A & 216-Z-18, and 216-A-8) are illustrated in Figure E4-1. The
5 stratigraphic relationships for the 216-Z-1A Crib were also used for the 216-Z-18 Crib approximately
6 50 m (164 ft) southwest of the 216-Z-1A Crib.

7 Identification of the lateral dimensions and specific depths and depth intervals of vadose zone
8 contamination is important for fate and transport modeling for the following reasons:

- 9 • The contamination in the vadose zone is not spatially uniform.
- 10 • The contamination occurs primarily within specific sediment types and over specific depth intervals (H).
- 11 • Calculated estimates of the amounts of contamination (source term mass; $Mass_c$) in the vadose zone
12 are based on the dimensions of the contaminated soil volumes.

13 The identification of discrete contamination depth intervals within the stratigraphic sequence is also an
14 important basis for the calculation of contaminated soil volumes because it represents a refinement from
15 the practice of more arbitrary and/or less representative methods of estimating depth intervals and soil
16 volumes. This refinement also serves to reduce the uncertainty associated with the estimation of
17 contaminated soil volume, source term (contaminant) masses, and resulting groundwater impacts
18 compared to those determined by more arbitrary methods that tend to be unrepresentative and larger.

19 **E4.2.2 Waste Site Stratigraphy, Contaminant Depth Profiles, and Depth Intervals of Contamination**

20 Depth profiles for the contaminants passing the COPC screening and evaluation process at each of the
21 waste sites were compared to the detailed stratigraphic subdivision depths to evaluate correlations
22 between lithologies and preferentially contaminated depth intervals. Detailed descriptions of the
23 representative vadose zone stratigraphies for the waste sites were prepared from driller logs and/or the
24 stratigraphic sections prepared from them (PNNL-16198; PNNL-15914). The detailed stratigraphic
25 information was utilized in several ways that include the following:

- 26 • Elucidation of the actual geology and stratigraphy of the vadose zone beneath the waste sites prior to
27 simplification; e.g., modeling
- 28 • A basis for understanding the less detailed simplification of the actual stratigraphy used in the
29 modeling
- 30 • Comparison of depth profiles for COPCs to lithologies in the actual vs. simplified stratigraphies to
31 evaluate depth concentration correlations

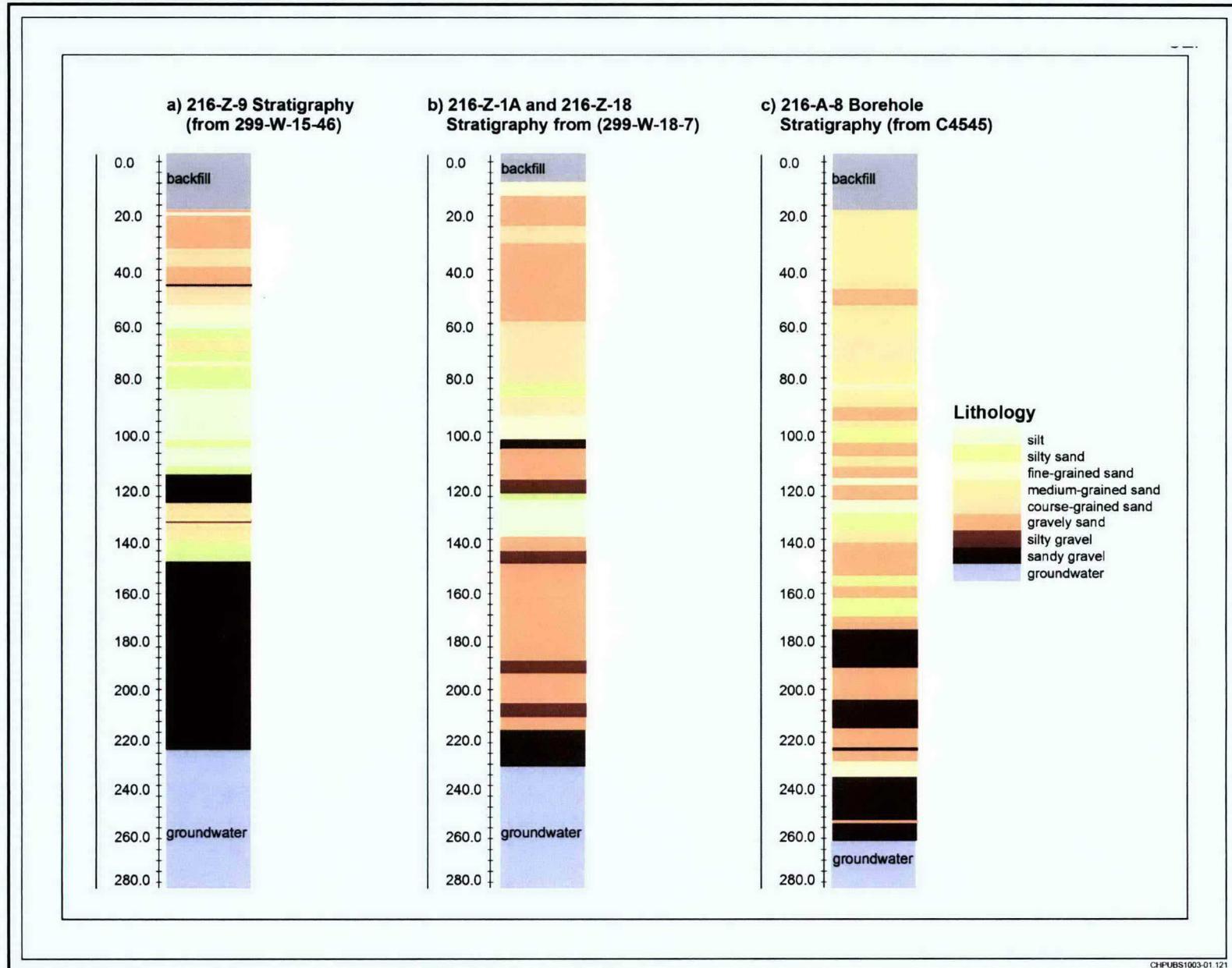


Figure E4-1. Detailed Stratigraphy in the Vadose Zone Beneath (a) the 216-Z-9 Waste Site, (b) 216-Z-1A and 216-Z-18 Waste Sites, and (c) the 216-A-8 Waste Site

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1 The depth intervals, over which most of the vadose zone contamination occurs, appear to be correlated
2 with specific lithologies and facies in the stratigraphic sequences that at all four waste sites tend to be
3 units containing finer-grained sediments and/or some calcareous components, with less contamination in
4 the coarser-grained sediments. This general pattern of contaminant behavior is apparent from borehole to
5 borehole for all of the waste sites evaluated, corroborating similar observations from previous
6 investigations of these waste sites, as cited in the following documents:

- 7 • DOE/RL-2006-51, *Remedial Investigation Report for the Plutonium/Organic-Rich Process*
8 *Condensate/Process Waste Group Operable Unit: Includes the 200-PW-1, 200-PW-3, and 200-PW-6*
9 *Operable Units*
- 10 • DOE/RL-2006-58, *Carbon Tetrachloride Dense Non-Aqueous Phase Liquid (DNAPL) Source Term*
11 *Interim Characterization Report*
- 12 • PNNL-14895, *Three-Dimensional Modeling of DNAPL in the Subsurface of the 216-Z-9 Trench at*
13 *the Hanford Site*
- 14 • PNNL-15914, *Carbon Tetrachloride Flow and Transport in the Subsurface of the 216-Z-9 Trench at*
15 *the Hanford Site: Heterogeneous Model Development and Soil Vapor Extraction Modeling*
- 16 • PNNL-16198, *Carbon Tetrachloride Flow and Transport in the Subsurface of the 216-Z-18 Crib and*
17 *216-Z-1A Tile Field at the Hanford Site: Multifluid Flow Simulations and Conceptual Model Update*

18 Thus, this aspect of the contaminant behavior conceptual model is an important factor in the
19 understanding of the nature and extent of contamination in the vadose zone and thus, also important for
20 the determination of the depth intervals of contaminated soil volumes used as source terms in the
21 modeling.

22 Examples of the correlation between COPC soil concentration and stratigraphy are illustrated in
23 Figures E4-2 and E4-3, which show concentration depth profiles for selected COPCs in the context of the
24 vadose zone stratigraphy beneath the 216-A-8, 216-Z-1A⁷ and 216-Z-9 cribs. The depth intervals within
25 which screened COPC data occur were, therefore, determined and grouped primarily based on
26 stratigraphy and lithology to establish the specific intervals for use in the fate and transport modeling.
27 Thus, the contaminated soils in the Hanford formation (+/- the Ringold Formation) can best be described
28 as occurring in discrete lithologic layers within the geologic units or formations, e.g., discrete layers
29 within a main subdivision (H1, H2, or H3 units) of the Hanford formation. Based on the general
30 stratigraphic relationships, most of the units and layers can be reasonably regarded as continuous tabular
31 units within the modeling domain for vadose zone modeling.

32 **E4.2.3 Merging Z-Area Contaminated Depth Intervals Within a 3-D Geologic Framework**

33 The geologic framework for the fate and transport modeling utilized the 3-D stratigraphy developed for
34 the entire domain of the Z-Area waste sites based on the compilation and evaluation of geologic data from
35 215 boreholes and a comprehensive effort to correlate units and define the main geologic contacts
36 (PNNL-14895; PNNL-15914; PNNL-16198). Thus, the domain-wide stratigraphy (Figure E4-4) was used
37 for the modeling as best representing the main generalized geologic subdivisions in the vadose zone
38 beneath the 216-Z-1A, 216-Z-18, and 216-Z-9 waste sites for assigning hydrogeologic properties in the
39 modeling and depth intervals, particularly for the Cold Creek units.

40

⁷ The stratigraphic relationships and contaminant depth intervals for the 216-Z-1A crib were also used for the
216-Z-18 Crib approximately 50 m (164 ft) southwest of the 216-Z-1A Crib.

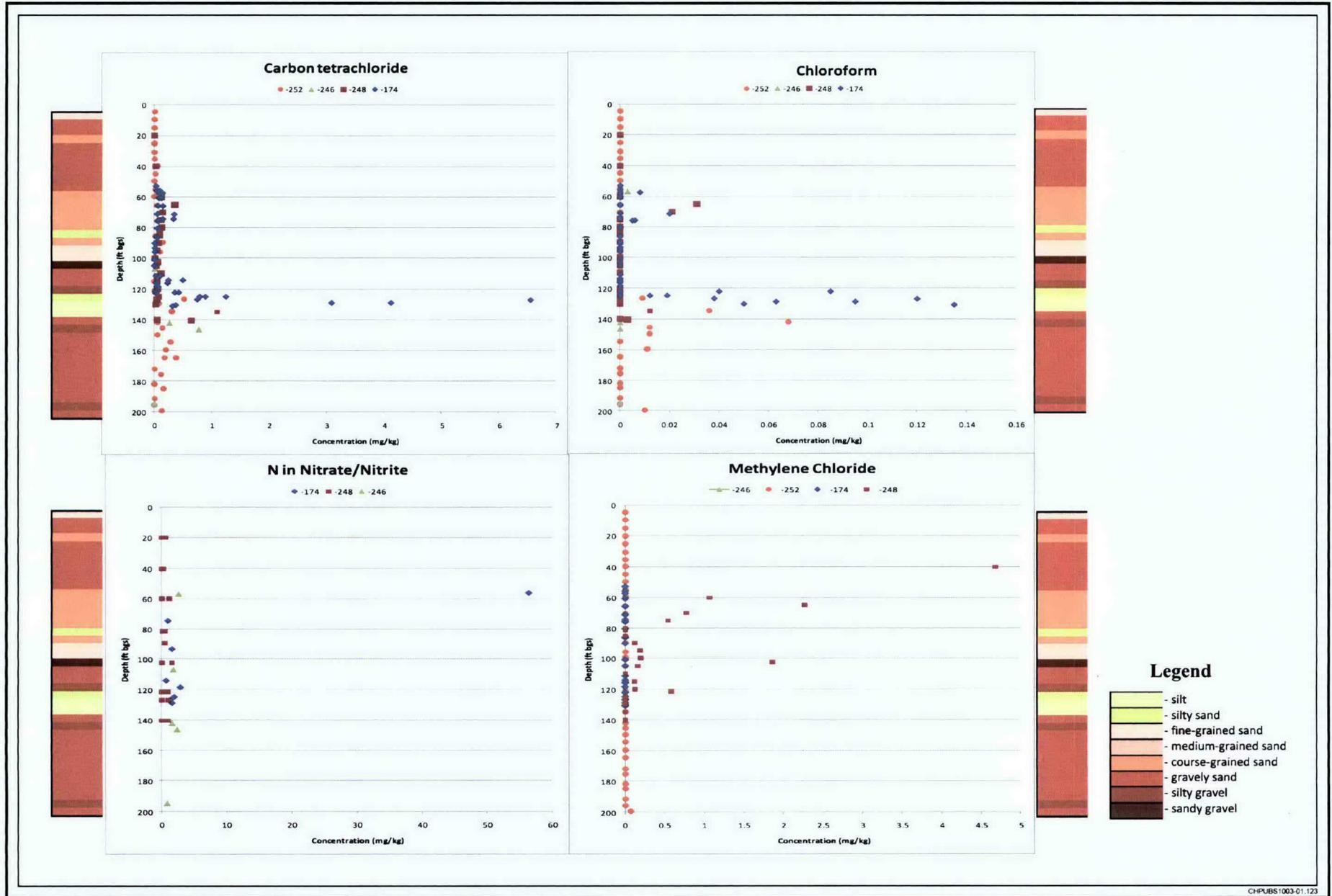
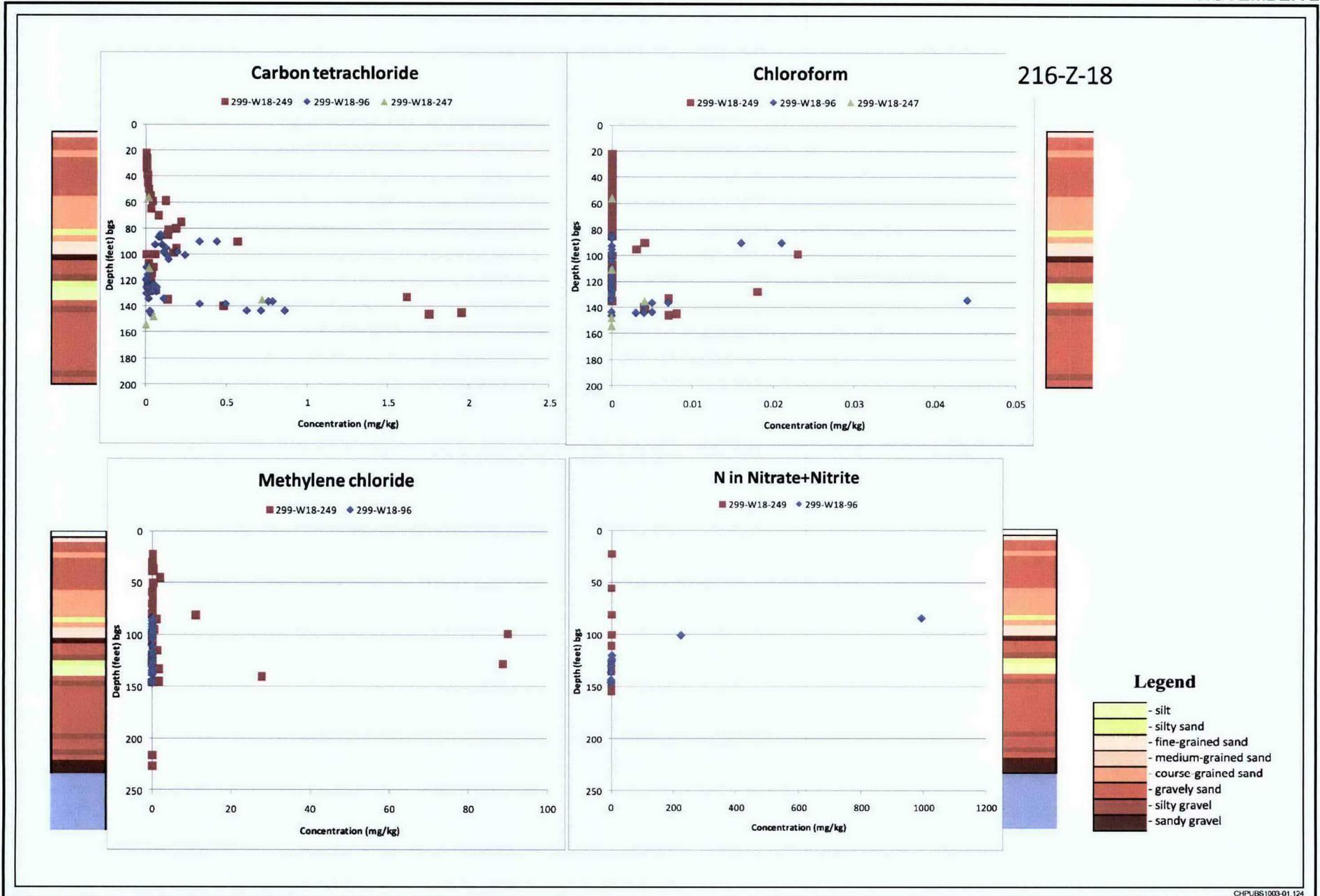


Figure E4-2b. Concentration-Depth Profiles for 216-Z-1A; Based on Stratigraphy from Borehole 299-W18-7

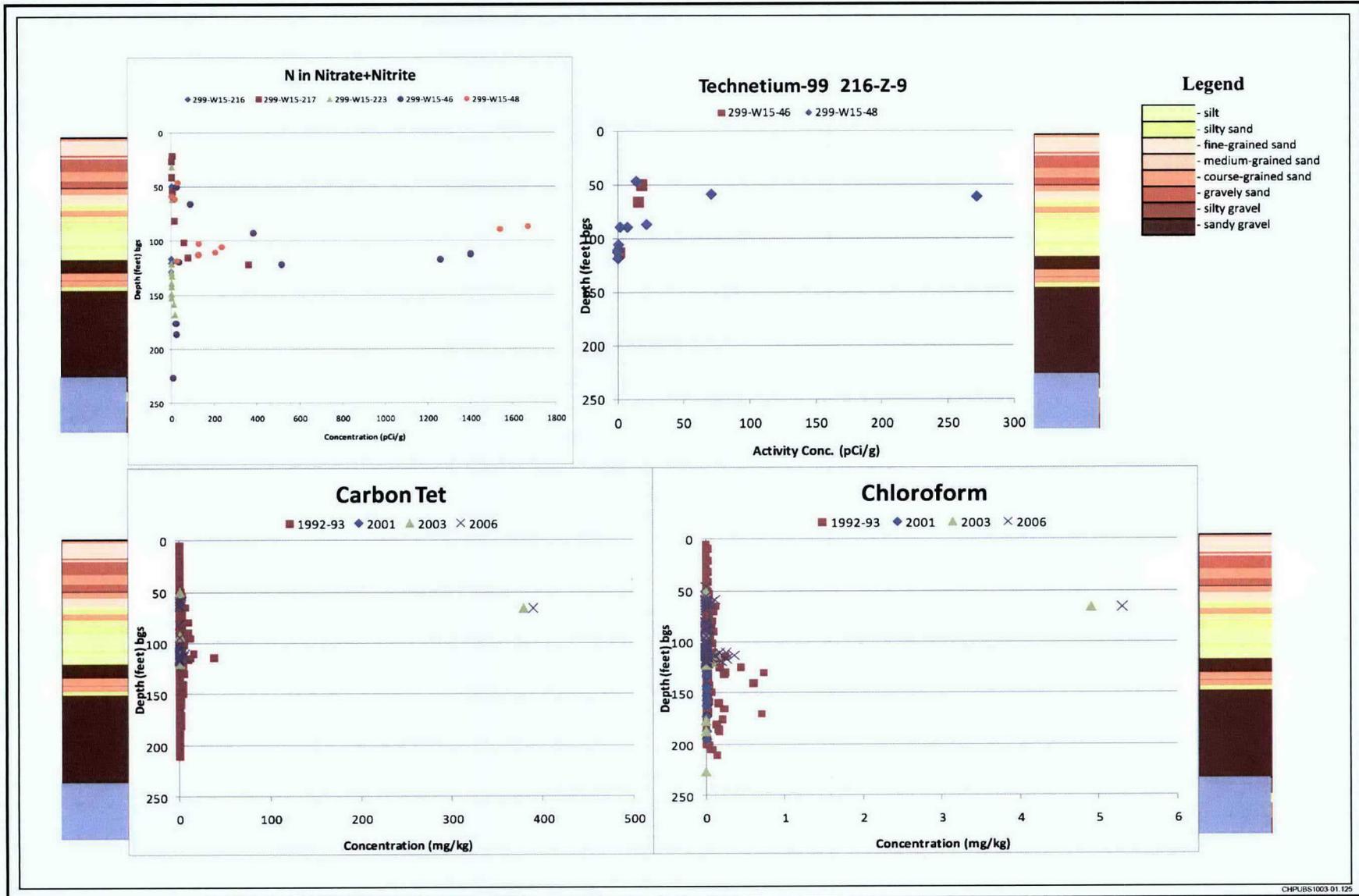
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Figure E4-2c. Concentration-Depth Profiles for 216-Z-18; Based on Stratigraphy from Borehole 299-W18-7



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Figure E4-2d. Concentration-Depth Profiles for 216-Z-9; Based on Stratigraphy from Borehole 299-W15-46

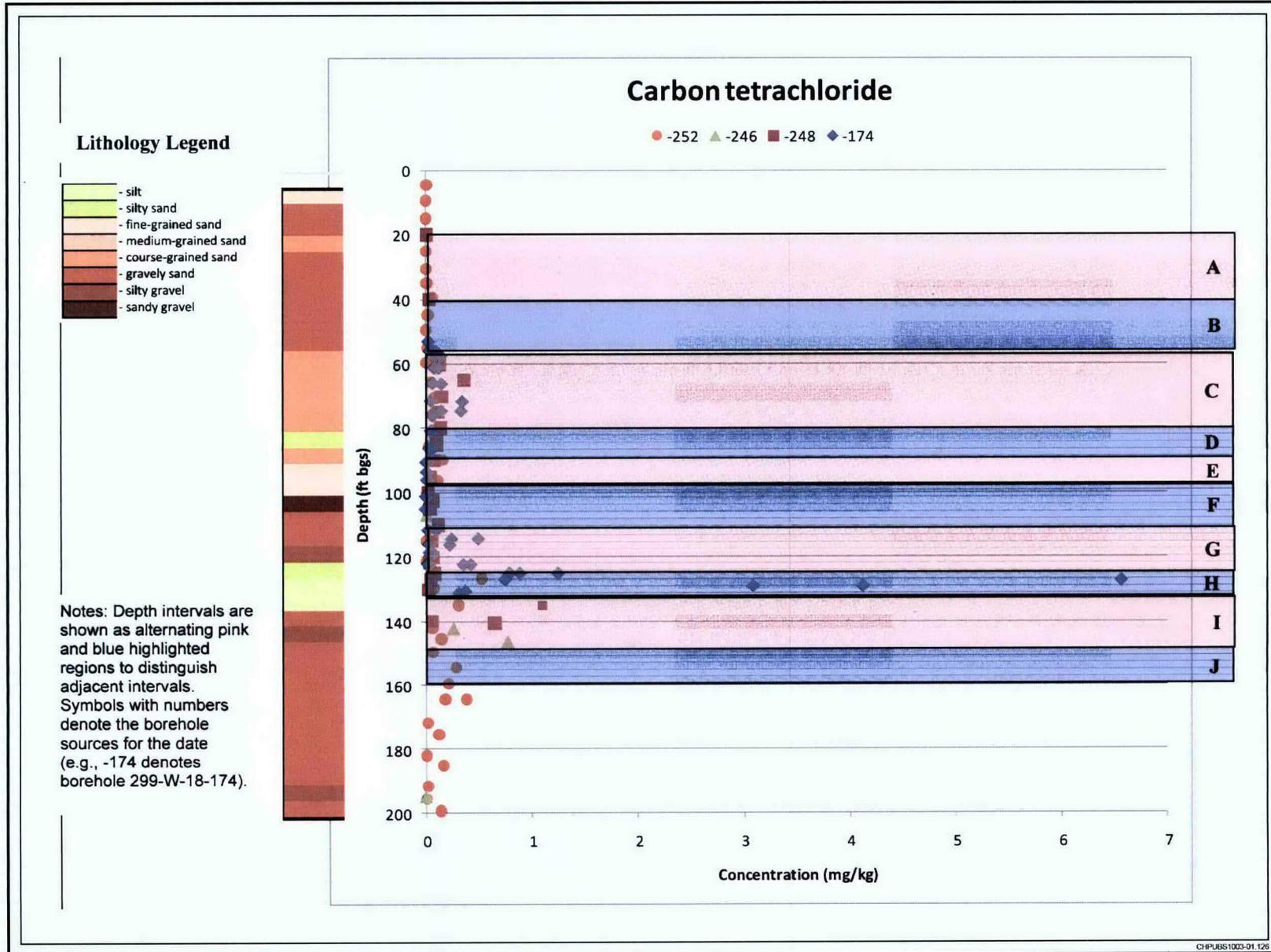
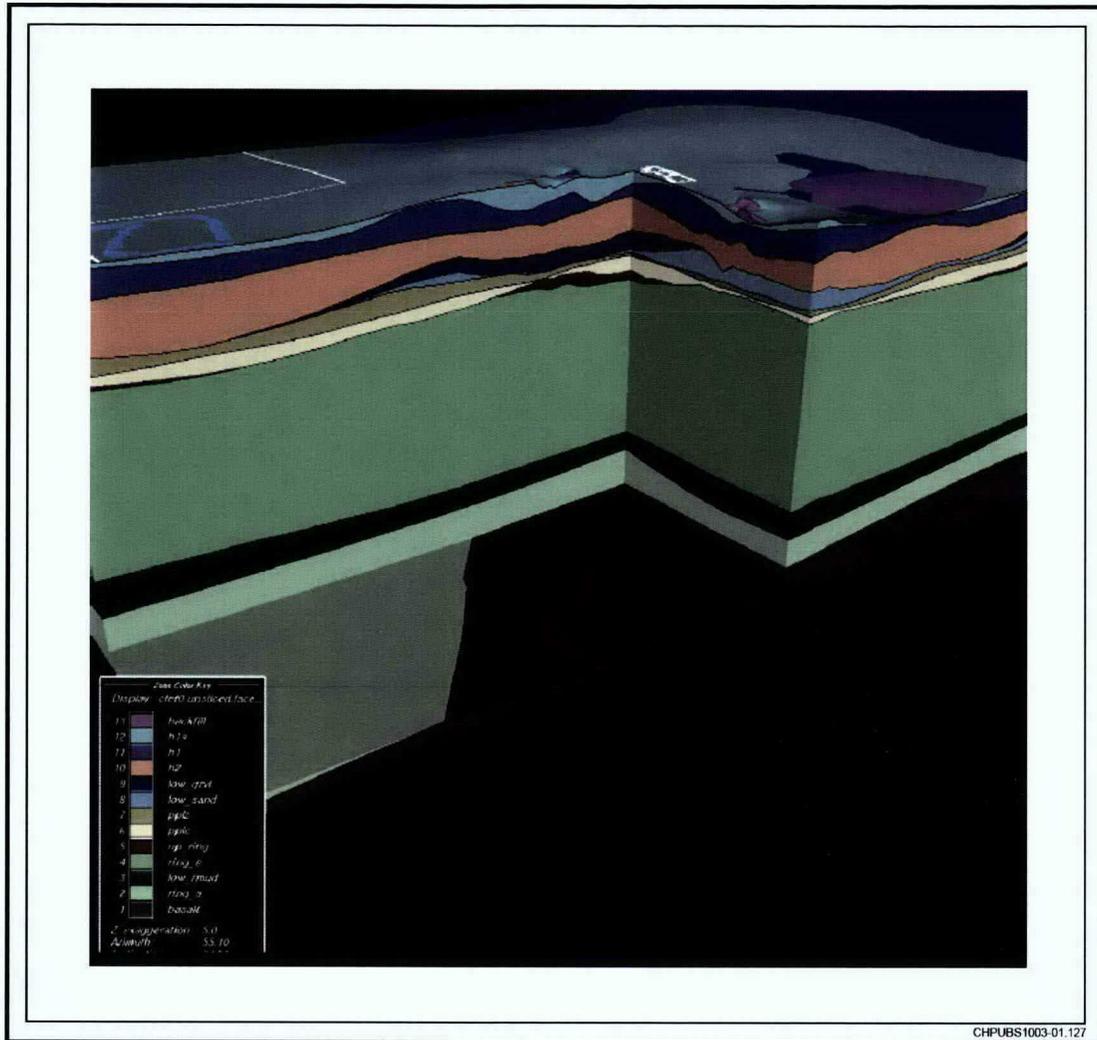


Figure E4-3. Illustration of the Depth Intervals Identified for 216-Z-1A Based on Comparison of the Detailed Stratigraphy and Concentration-Depth Profile for CT

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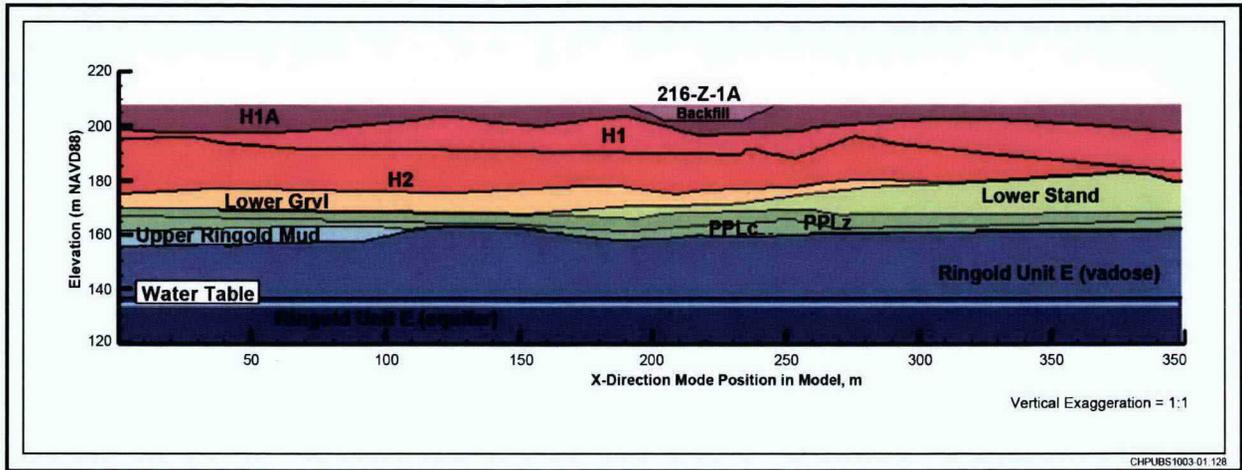
Source: PNNL-14895, *Three-Dimensional Modeling of DNAPL in the Subsurface of the 216-Z-9 Trench at the Hanford Site*. Note: for additional information, see PNNL-14895.

Figure E4-4. Three-Dimensional Geologic Model with a Cut-Out Beneath the 216-Z-9 and 216-Z-1A Cribs

The specific stratigraphy used for the vadose zone fate and transport modeling for the 216-Z-9, 216-Z-1A, and 216-Z-18 waste sites shown in Figures E4-5 and Figure E4-6, was based on W-E cross-sections across the domain of each waste site, because the direction of groundwater flow in the unconfined aquifer is primarily west to east in this area. Further description of the stratigraphic units, thicknesses, and hydrogeologic parameters used for these units is provided in ECF-200PW1-3-6-10-0326.

E4.2.4 Defining Depth Intervals for Contaminated Soil Volumes

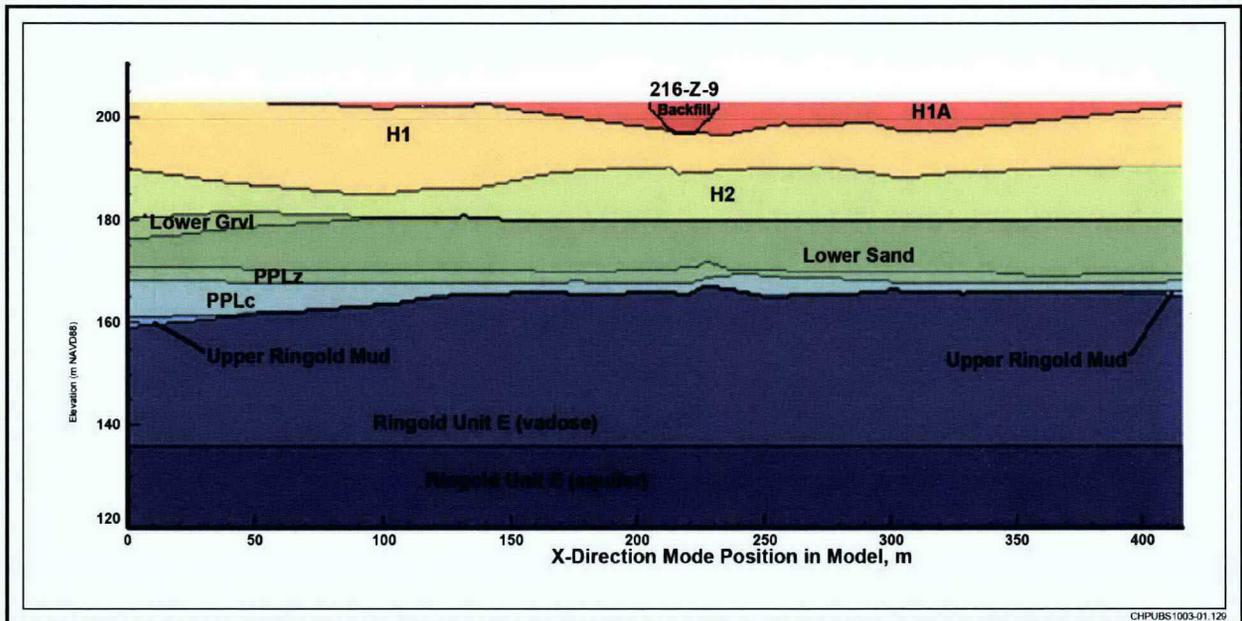
Most of the contaminated soil volume assignments for the vadose zone modeling at each of the waste sites can be defined as discrete rectangular-shaped volumes based on the discrete depth intervals identified for the contaminated soil volumes in Section E4.2.2, and appropriate estimates of, or scenarios for, the lateral extent of the contaminated soil volume. However, it was determined that some of the contaminated soil volumes for the waste sites were more appropriately defined differently.



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Figure E4-5a



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Figure E4-5b

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Figure E4-5. E-W Cross-Sections of the Stratigraphy Used in Fate and Transport Modeling of Potential Impacts to Groundwater from Vadose Zone Contaminants at 216-Z-1A and 216-Z-18

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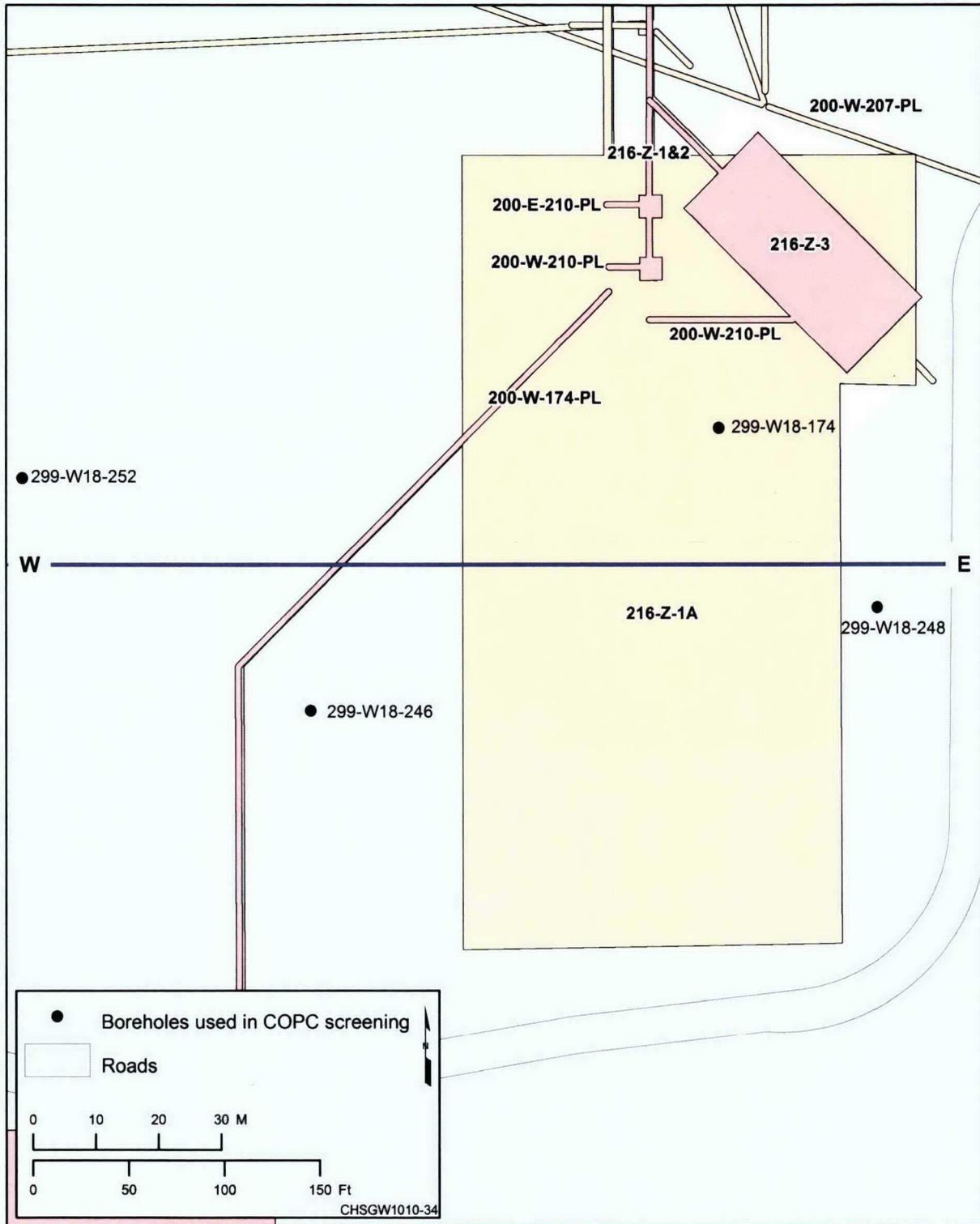


Figure E4-6. Locations of Boreholes and W-E Transect Plane for the 216-Z-1A Crib

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1 Thus, three approaches to defining contaminant source term volumes were used to best represent the
2 vertical distribution of contaminants in the vadose zone in the context of the stratigraphic and lithologic
3 relationships:

- 4 1. Contamination volumes defined as a rectangular-shaped volume for a specific depth interval
- 5 2. Contamination volumes defined by generally tabular-shaped volumes with variable thicknesses where
6 contamination occurs throughout a geologic unit
- 7 3. Contaminated source terms described as unit-thickness volumes, referred to as point source volumes

8 The first approach for defining contaminated soil volumes is most applicable to contamination residing in
9 lithologic units or intervals that are largely horizontal, which are the conditions for most of the Hanford
10 Site vadose zone sediments. The second approach for defining contaminated soil volumes for modeling is
11 specific to contamination within the Cold Creek unit. Based on evaluation of the COPC concentration
12 depth profiles for the Z-Area waste sites in the 200-West Area shown in Figure E4-2, it is indicated that
13 contamination may largely pervasive throughout much or most of the Cold Creek unit, where the highest
14 levels of contamination also tend to occur. The Cold Creek unit is geologically distinct from the overlying
15 Hanford formation sediments and the underlying Ringold sediments in that it consists of very fine-grained
16 calcareous silty/sandy sediment, calcium-carbonate cemented layers, +/- multi-lithic material in the
17 lowermost part. Although the contamination within the Cold Creek unit is consistent with the contaminant
18 behavior conceptual model, in that contamination tends to occur preferentially in lithologies containing
19 finer-grained and/or calcareous sedimentary material, a different definition of the geometry of the
20 contaminated soil volume represented by the Cold Creek unit was deemed to be appropriate. Therefore,
21 the contaminated soil volumes for the upper and lower facies of the Cold Creek formation in the vadose
22 zone beneath the 216-Z-9, 216-Z-1A, and 216-Z-18 Cribs were determined using the variable thickness of
23 the Cold Creek unit based on the detailed description of the Cold Creek unit in the geologic framework
24 determined in the studies by Pacific Northwest National Laboratory (PNNL) (PNNL-14895;
25 PNNL-15914; PNNL-16198).

26 Contaminated soil volumes defined as point source (1 m [3 ft] thickness) volumes were determined to be
27 warranted where the sampling results indicated that the contamination occurred essentially at an isolated
28 depth, where there are one or more data points at given depth, not part of a data series related to a
29 lithologic layer or unit. Therefore, point source volumes were defined based on an assumed thickness of
30 1 m (3.2 ft). Depth intervals of 1 m (3.2 ft) were used for the 216-A-8 waste site, and for the uppermost
31 source term (<7.5 m [<24.5 ft] bgs) at 216-Z-9 where there were only one or three data points at a specific
32 depths for multiple COPCs. Thus, the entire source term was assumed to reside in a 1 m (3.2 ft) thick
33 layer at each of the depths specified in Table E4-1. The depth of the top or bottom of a contaminated soil
34 thickness interval was adjusted slightly in some cases to accommodate the modeling grid spacing.
35 Table E4-1 summarizes the specific depth intervals of contaminated soils identified for the 216-A-8,
36 216-Z-1A, 216-Z-18, and 216-Z-9 waste sites. An example of the depth intervals used 216-Z-1A are
37 shown together with the concentration-depth profile for CT and the stratigraphic relationships in
38 Figure E4-3 to illustrate the manner in which data were grouped for the depth intervals. These depth
39 intervals for the waste sites are also illustrate in Figure E4-6 together with the lateral dimensions for the
40 modeling base case.

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Table E4-1. Summary of the Depth Intervals of Contaminated Soils for the 216-Z-1A, 216-Z-18, 216-Z-9, and 216-A-8 Waste Sites

216-Z-1A & 216-Z-18 Contaminated Soil Depth Interval; Top to Bottom					216-Z-9 Contaminated Soil Depth Interval; Top to Bottom					216-A-8 Contaminated Soil Depth Interval; Top to Bottom				
Interval ID	Depth bgs		Thickness		Interval ID	Depth bgs		Thickness		Interval ID	Depth bgs		Thickness	
	(ft)	(m)	(ft)	(m)		(ft)	(m)	(ft)	(m)		(ft)	m	(ft)	(m)
A	20-40	6-12.2	20	7	1	<24.5	<7.5		1	A	19-21.5	5.8-6.4	2.5	1
B	40.5-56	12.3-17.1	15.5	5	2	31-45	9.5-13.7	4	1	B	22.5-25	6.8-7.6	2.5	1
C	57-80	17.3-24.4	23	6	3	46-50	14-15.2	4	1	C	27.5-30	8.4-9.1	2.5	1
D	80.5-90	24.5-27.4	9.5	3	4	54-60	16.5-18.3	6	2	D	104-106.5	31.7-32.5	2.5	1
E	90.1-96	27.5-29.3	5.6	2	5	61-67	18.6-20.4	6	2					
F	98-111.5	29.9-34	12	4	6	67-82	20.4-25	15	5					
G	111.5-122.5	34-37.3	12	4	7	87-93	26.5-28.3	6	2					
H	123-130.5	37.5-39.8	5.5	2	8	94-102	28.6-31	6	2					
I	131-146	39.9-44.5	PPLz	3.5-5	9	102-106	31-32.3	4	1					
J	146.1-160	44.5-48.7	PPLc	2-5.5	10	111-118	33.8-36	PPLz	1-3.5					
					11	118-123	36-37.5	PPLc	1-4					
					12	123-130	37.5-39.6	7	2					
					13	133-140	40.5-42.7	7	2					
					14	177-186	54-56.7	6	2					
					15	190-195	58-59.4	5	2					

1 **E4.3 Estimation of the Lateral Extent of Contaminated Soil Volumes**

2 The contaminated soil volumes that together with representative COPC concentrations serve as the basis
3 for defining the source term masses in fate and transport modeling used in the assessment of impacts to
4 groundwater. The volume estimates depend on a determination of representative, and/or upper bound
5 limits for the lateral extent of contamination in the vadose zone beneath the 200-PW-1/3/6 waste sites
6 parallel to the direction of groundwater flow. Evaluations of the lateral extent of contamination at the
7 216-Z-1A and 216-Z-9 waste sites were primarily based on the following lines of evidence:

- 8 1. Contaminant concentration patterns observed for transects across the waste sites, extending beyond
9 the waste site boundaries
- 10 2. Evaluation of isopleth (contours) depictions of COPC soil concentrations beneath the waste sites
- 11 3. Three-dimensional depictions of the lateral and vertical extent contamination at the waste sites
- 12 4. A comparison and contrast of these lines of evidence with 3-D modeling of CT behavior in the vadose
13 zone
- 14 5. Consideration of other relevant information

15 The types of other relevant information considered in this evaluation include the following:

- 16 1. Site data and model results on the lateral extent of CT dense, nonaqueous-phase liquid (DNAPL)
17 contamination
- 18 2. The physical and chemical properties of the COPCs at the 216-Z-1A and 216-Z-9 waste sites
- 19 3. Comparison of COPC data and subsurface concentration contours before and after implementation of
20 the SVE system in 1992 to 1993
- 21 4. The nature and extent of plutonium (transuranic) contamination in the vadose zone
- 22 5. The spatial distribution of contamination observed at other Hanford waste sites with
23 comparable/analogous liquid disposal volume histories

24 Selected COPC data from boreholes within, and/or extending outward from the 216-Z-1A and 216-Z-9
25 waste sites boundaries were evaluated in these various ways to determine the lateral extent to which
26 contamination in the subsurface extends outward from the vicinity of the waste sites. These data enabled
27 the lateral extent of the overall contamination to be evaluated, and enabled the lateral extent of
28 contamination within discrete geologic intervals to be evaluated as a function of depth and over time. The
29 data associated with the 216-Z-1A and 216-Z-9 waste sites are especially conducive to these types of
30 methods to evaluate the lateral extent of contamination because of the number, locations, and chronology
31 of borehole data in and around the waste sites (see Figures E4-6 and E4-8). The nature and extent of
32 contamination associated with these waste sites is considered to be representative for the 200-PW-1/6
33 waste sites in the Z-Area. The extent of contamination at these waste sites is also likely to serve as an
34 analogue and/or bounding example for contaminant behavior at other Hanford wastes sites in the context
35 of the type and magnitude of liquid discharges received. These cases are also considered here to be
36 representative and/or bounding for the 216-Z-18 and 216-A-8 waste sites where less characterization
37 borehole and subsurface data are available.

1 **E4.3.1 Contaminant Profile Transects**

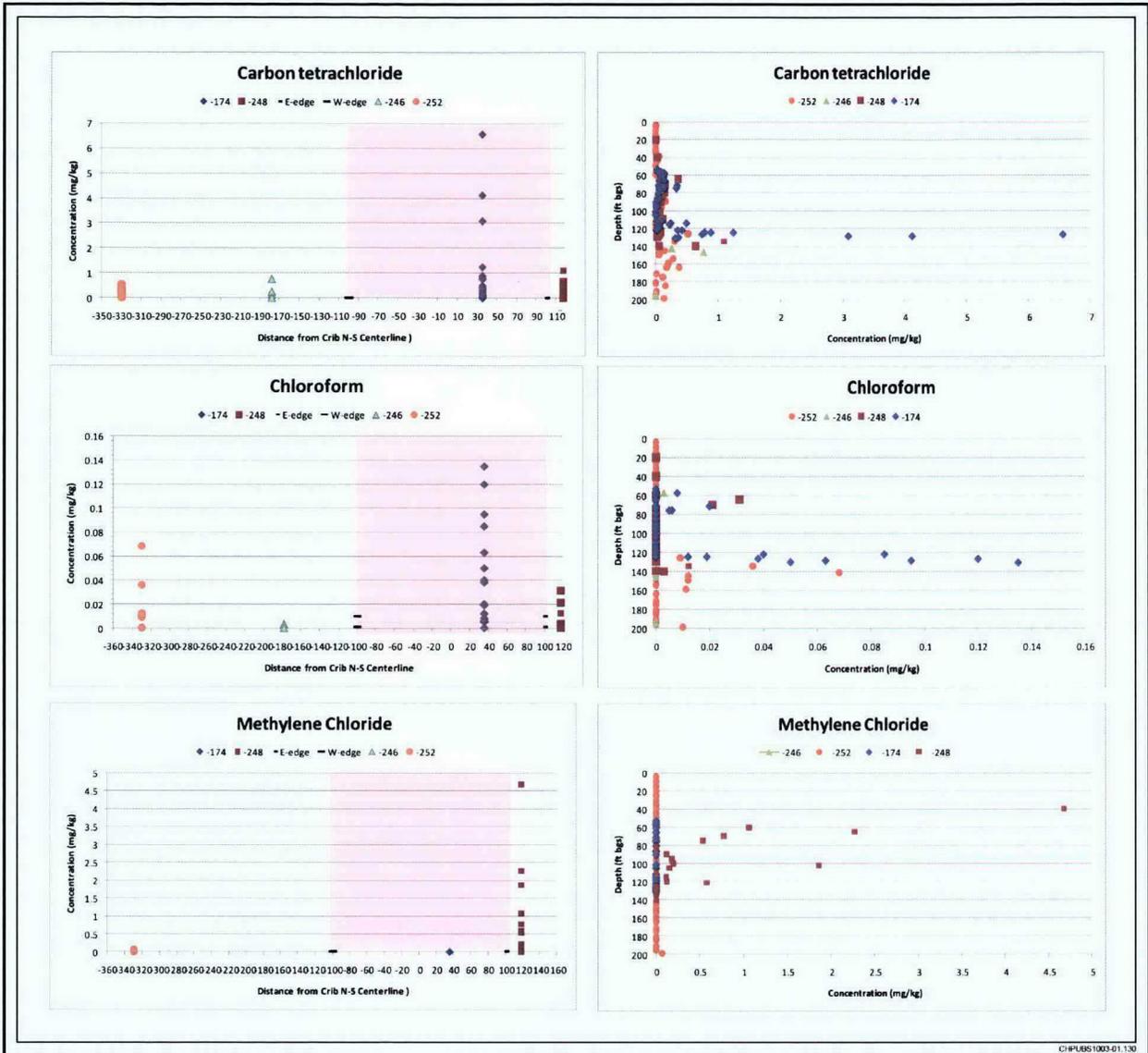
2 The contaminant profile transects were constructed by plotting the soil concentrations of selected COPCs
3 (y-axis) against the distance from the centerline of the crib, as projected onto a vertical plane (transect)
4 extending through the crib in a west-east (W-E) direction (the direction of groundwater flow), and the
5 length dimension used in the fate and transport modeling (as shown in the following sections). These
6 transects were also evaluated in the context of the COPC concentration depth profiles to show the depths
7 at which the highest concentrations occur in the context of the waste site footprint. Additional transects
8 were also evaluated for the data from the 216-Z-9 crib, which included transects in an N-S direction
9 through the crib, and lateral W-to-E transects at the north and south edges of the crib.

10 **E4.3.2 216-Z-1A Transect and Depth Profiles**

11 Representative data for the most frequently detected COPC analytes measured in each of four boreholes
12 transecting the 216-Z-1A waste site in an E-W direction shown in Figures E4-7a and E4-7b, were
13 evaluated in the context of: (a) overall concentrations in the E-W transect, and (b) depth profiles for each
14 borehole. The COPC analytes chosen for evaluation in the contaminant profile transects were COPCs
15 passing all screening steps, and which were measured in each of the boreholes. These analytes include
16 CT, chloroform, methylene chloride, tetrachloroethene, trichloroethene, and nitrogen (nitrate+nitrite). All
17 of the data for the representative COPCS are plotted in Figures E4-7a and E4-7b, by distance from the
18 centerline of the crib. The relative location of the crib in the transects are shown in Figures E4-7a
19 and E4-7b as the highlighted (pink) regions in the transect Figures.

20 It is indicated from the comparison of the representative COPC data in the W-E transects across the
21 216-Z-1A waste site, that for all but one of the COPCs (methylene chloride), the maximum contamination
22 levels are largest beneath the waste site footprint, and decrease sharply to significantly smaller levels
23 outside the footprint of the waste site. The lateral and vertical distribution for all of the volatile organic
24 COPCs, except for methylene chloride, follows the same pattern, and appears to be strongly correlated.
25 The levels of nitrogen in nitrate+nitrite in all but one sample are below natural background levels. The
26 one sample with an elevated nitrogen level (approximately 58 mg/kg) occurs beneath the waste site
27 footprint at a depth of about 18 m (60 ft) bgs. The following is a summary of the most notable subsurface
28 spatial patterns of COPC soil concentrations resulting from the evaluation of the transects and depth-
29 concentration profiles:

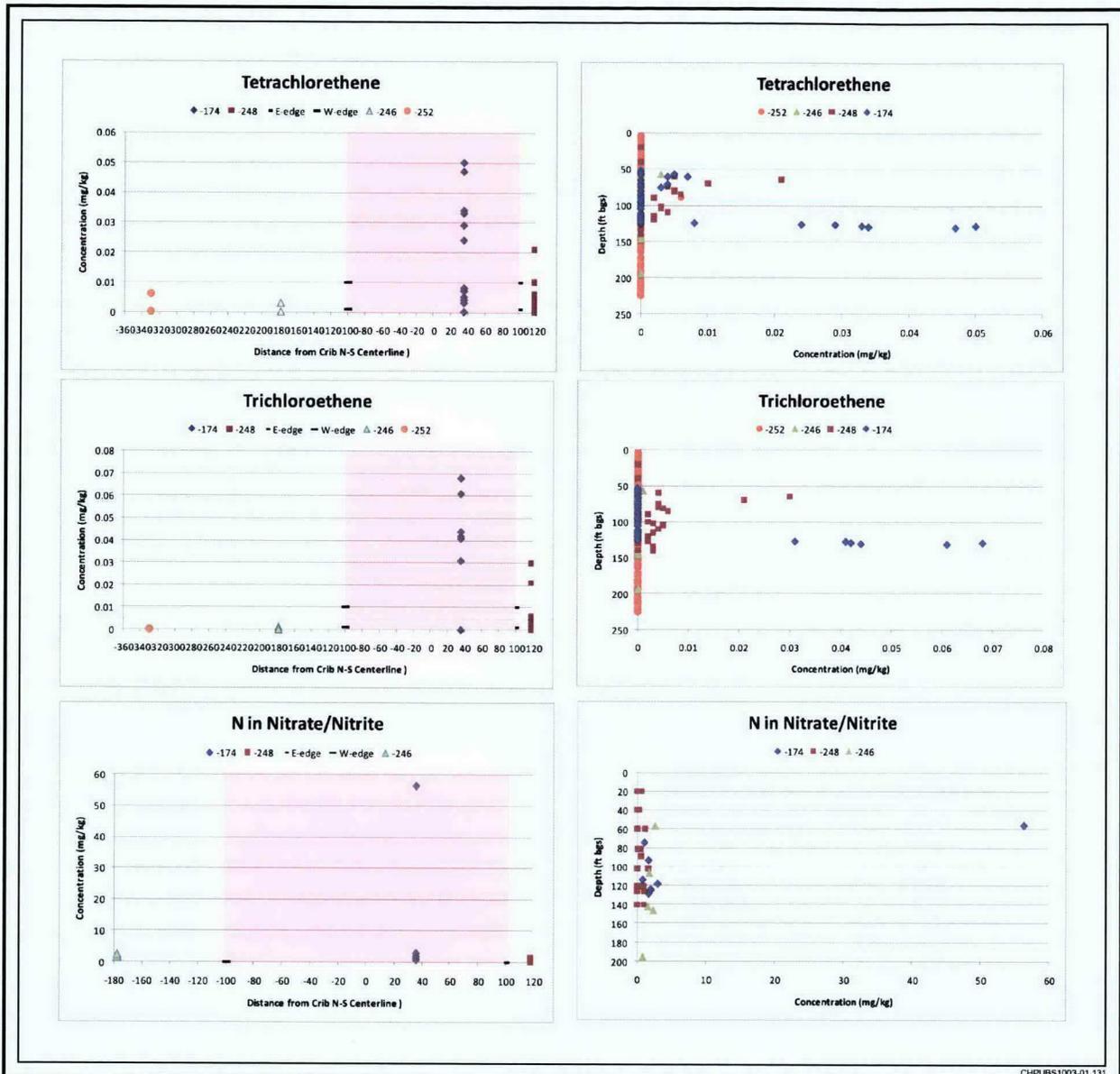
- 30 1. There are relatively few data with very high levels of contamination.
- 31 2. The highest levels of contamination are generally beneath the footprint of the waste site and do not
32 extend laterally beyond the E-W margins of the waste site (footprint).
- 33 3. The highest levels of contamination beneath the waste site, and on the flanks, occur in the Cold Creek
34 sediments (approximately 32 to 38 m [105 to 125 ft] bgs) and/or in the contaminated interval from
35 about 18 to 24 m (60 to 80 ft) bgs.
- 36 4. Intermediate levels of contamination in the Cold Creek formation, and/or, within the contaminated
37 interval from about 18 to 24 m (60 to 80 ft) bgs do extend beyond the east and west boundaries of the
38 waste site for VOA COPCs.



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Notes: The location of the Crib footprint in the transects is depicted as the pink shaded areas. Vertical trends in the soil concentrations with depth are also shown in the corresponding depth profiles for each COPC.

Figure E4-7a. Lateral Patterns of Soil Concentrations for CT, Chloroform, and Methylene Chloride with Respect to Distance from the 216-Z-1A Crib Footprint in a W-E Transect Through the Waste Site



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Notes: The location of the Crib footprint in the transects is depicted as the shaded (pink) areas. Vertical trends in the soil concentrations with depth are also shown in the corresponding depth profiles for each COPC.

Figure E4-7b. Lateral Patterns of Soil Concentrations for Tetrachloroethane, Trichloroethene, and Nitrogen in Nitrate+Nitrite with Respect to Distance from the 216-Z-1A Crib Footprint in a W-E Transect Through the Waste Site

7 The only exception to these patterns of contaminant behavior are the levels of methylene chloride in
 8 samples from borehole 299-W18-248 which appear to be spurious, rather than representative of the actual
 9 nature and extend of the contamination in the vadose zone. These data appear to be spurious because the
 10 largest levels occur in samples from the borehole east of the crib, rather than beneath the crib and,
 11 therefore, do not correlate with any of the behavior of any of the other volatile COPCs seen at other waste
 12 sites. The absence of any measurable methylene chloride from the vadose zone soils directly beneath the
 13 waste site where the maximum values of all other COPCs is also indicative of spurious data. This
 14 hypothesis is consistent with the occurrence of methylene chloride as a common laboratory contaminant
 15 in the reagents used in laboratory glassware cleaning.

1 All of the COPC data evaluated for the 216-Z-1A and the 216-Z-18 waste sites were collected in 1992 to
2 1993, prior to, or just following startup of the SVE system that has been in operation since 1992 to 1993.
3 The vintage of these data are important because the levels of the VOAs in the vadose zone soils have been
4 significantly reduced, as indicated from the data obtained from 216-Z-9 (Sections E4.3.1 to E4.3.3).
5 Although these are the only data available from the 216-Z-1A waste site, these data are regarded as
6 conservatively biased, as discussed in the sections on modeling results and uncertainties (Section E4.4).

7 **E4.3.3 216-Z-9 Transect and Soil Concentration Depth Profiles**

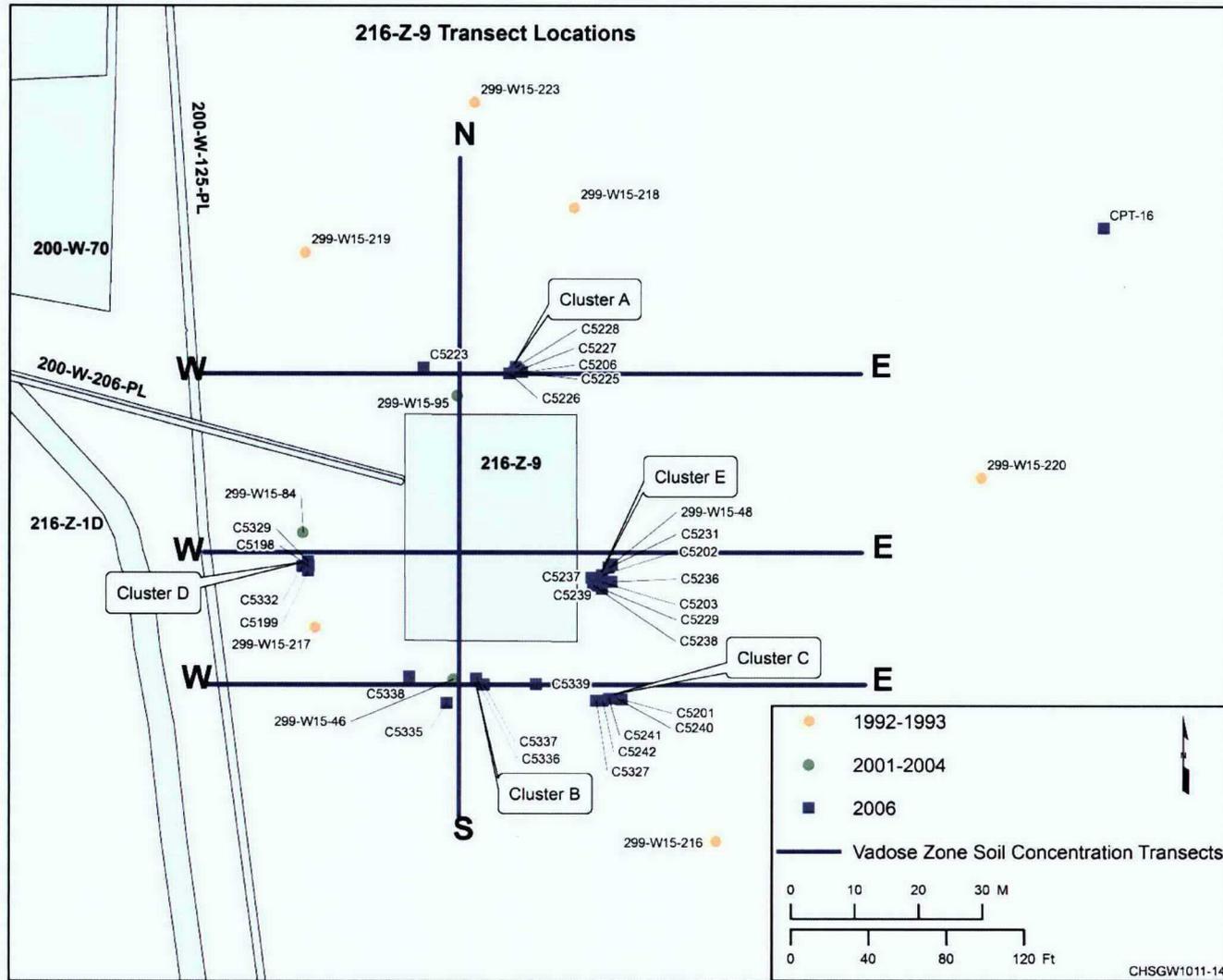
8 Transects and depth profiles for the 216-Z-9 Crib were evaluated based on data for representative COPCs
9 from 41 boreholes and/or subsurface sampling locations surrounding the 216-Z-9 waste site.

10 Four transects and associated COPC depth profiles were used to determine and constrain the extent of the
11 contamination laterally and vertically in the vadose zone beneath the 216-Z-9 waste site (Figures E4-9a
12 through E4-9f). Data for CT, chloroform, methylene chloride, tetrachloroethene, hexachloroethane, and
13 nitrogen in nitrate+nitrite were evaluated in the 216-Z-9 transects and depth profiles.

14 Data from six boreholes were evaluated in the construction of an N-S transect across the waste site
15 (Figure E4-8). Three W-E transects were also evaluated; one through the center of the waste site, one
16 approximately 10 m (33 ft) from the north edge of the waste site, and a third, approximately 10 m (33 ft)
17 from the south edge of the waste site. Data from two boreholes, a clusters of five borings, and a second
18 cluster of eight boring were evaluated in the E-W transect through the center of the waste site
19 (Figure E4-9). Data from eight boreholes or borings were used in the construction of the W-E transect at
20 the north end of the 216-Z-9 crib (Figure E4-10). A total of 3 boreholes and 12 borings (two clusters of
21 5 and 7 borings, respectively) were used in the construction of the W-E transect at the south end of the
22 216-Z-9 crib (Figure E4-10). The transect data are shown in Figures E4-9 to E4-10, by distance from
23 specified reference locations, e.g., the N-S centerline for W-E transect, and the W-E centerline for the
24 N-S transect. The relative positions of the crib footprint boundaries are also shown as highlighted
25 rectangles in the Figures. Depth profiles, i.e., COPC concentration with depth, for each transect data set
26 are also shown in these Figures. The transect data together with the depth profile data provide a basis for
27 evaluating the lateral and vertical extent of subsurface contamination at the 216-Z-9 Crib.

28 The COPC concentrations were also evaluated in the context of the chronology of the sample data. The
29 data from the 41 boreholes near the 216-Z-9 crib represent four time intervals: data collected in 1992 to
30 1993, 2001, 2004, and 2006. The dates of the data are important because a majority of the COPCs passing
31 all phases of the screening and evaluation are VOCs that would be affected by the operation of the SVE
32 system initiated in 1992 to 1993. Thus, the data from 1992 to 1993 represent the soil concentrations at the
33 beginning of the SVE operation; the data from 2001, represent concentrations after about 7 to 8 years of
34 SVE operation; and the data from 2006, represent concentrations after about 14 years of SVE operation.
35 The trends of COPC concentrations for these periods are also shown in the transects and depth profile
36 data discussed and shown in Section E4.3.2 (Figures E4-9 and E4-10). The COPC data used in the
37 construction of the transects for the VOA COPCs omitted the older 1992 to 1993 data as less
38 representative of the current contaminant conditions than the more recent data collected from 2001 to
39 2006. However, all data were used in the construction of the transects and depth profiles for nitrogen in
40 nitrate+nitrite because this COPC is not expected to be affected by the SVE operation. Thus, all of the
41 nitrate/nitrite data can be used to delineate the spatial extent of contamination.

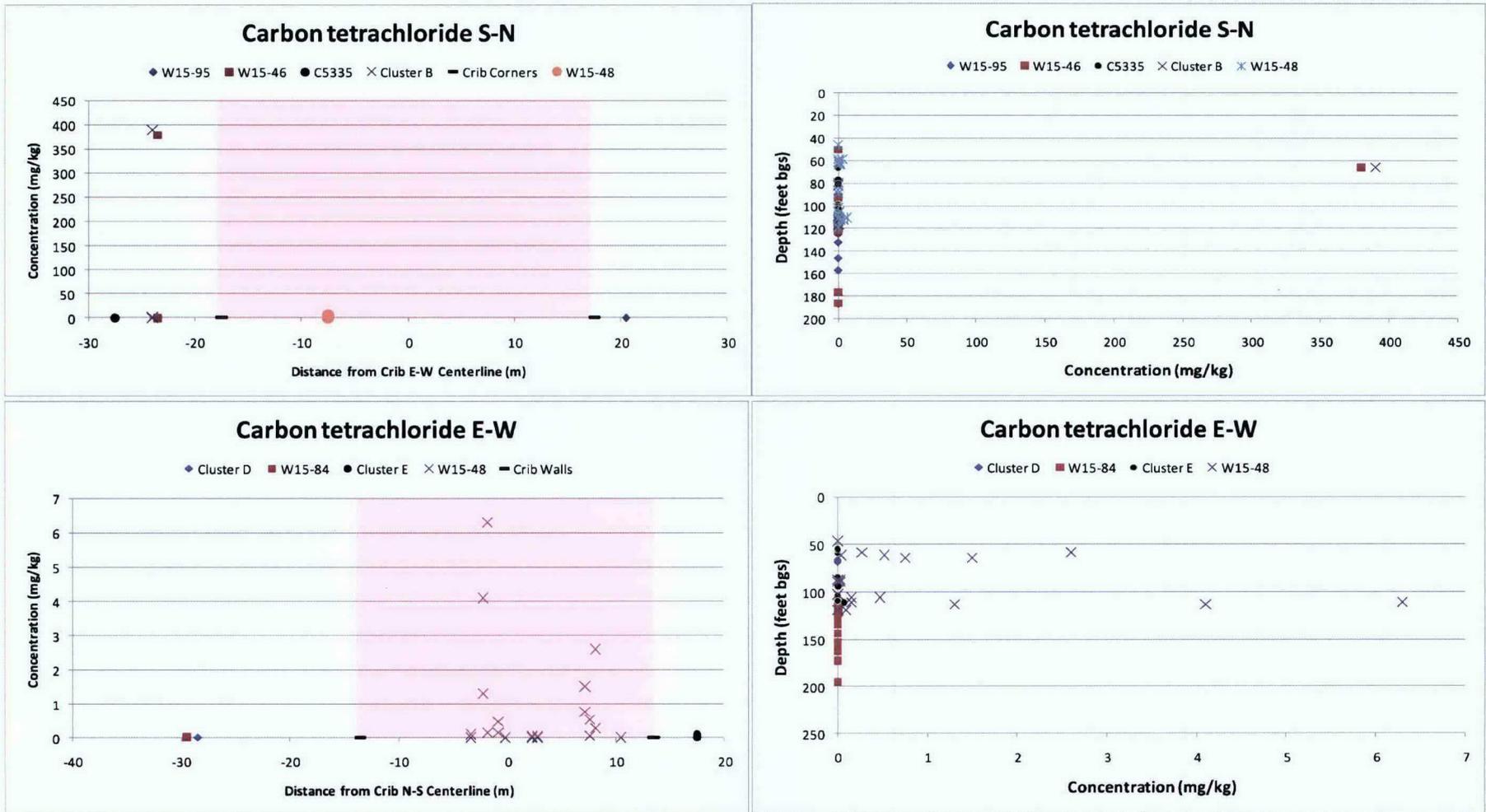
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Notes: The data for the N-S and E-W transects across the waste site are labeled as N-S and E-W, respectively, in Figure E4-9. The data for the W-E transects adjacent to the north and south boundaries of the Crib are labeled as N E-W and S E-W, respectively, in Figure E4-10.

Figure E4-8. Locations of Vadose Zone Soil Concentration Transects Across and Adjacent to the 216-Z-9 Crib

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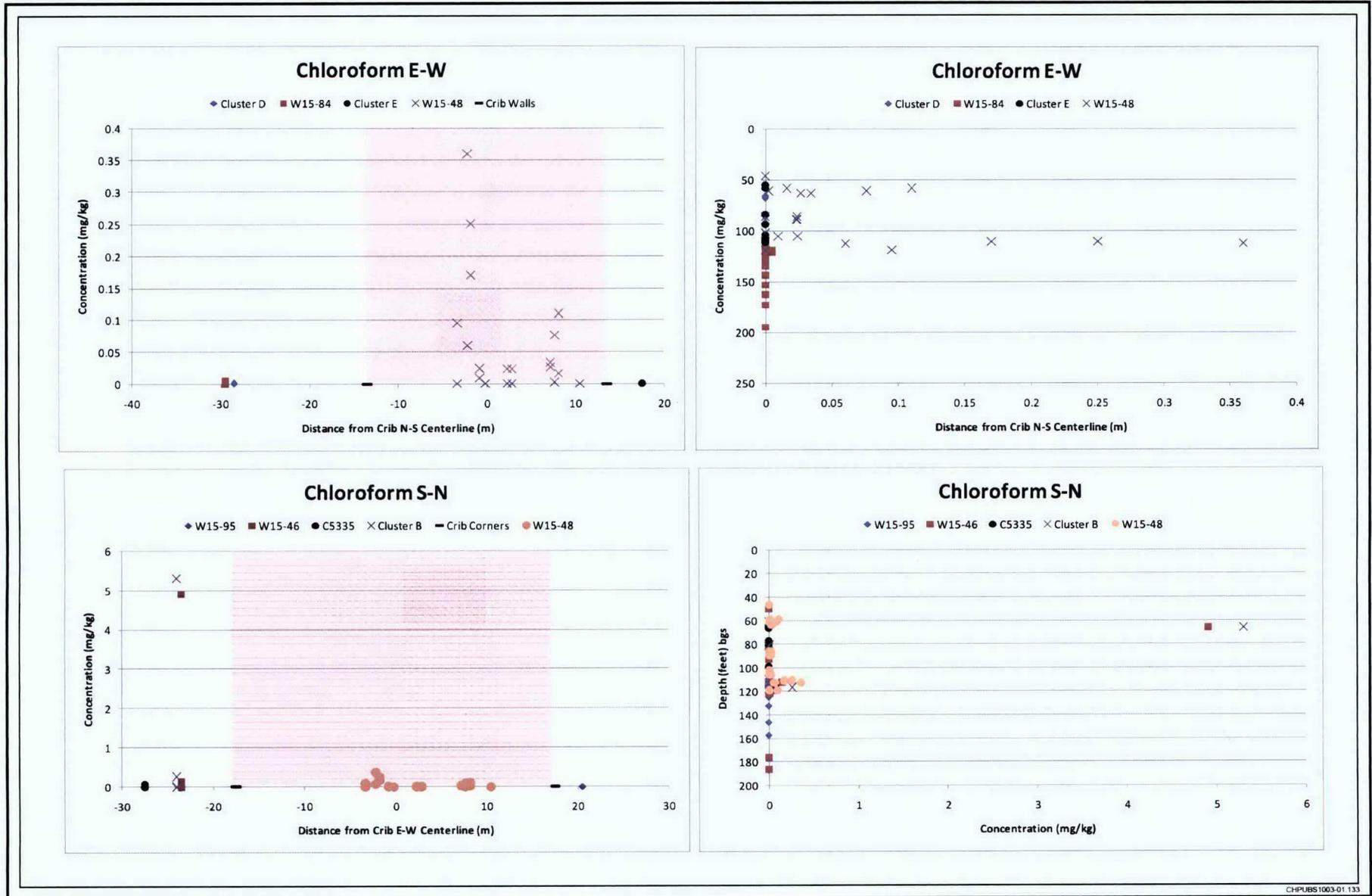


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Note: The location of the Crib footprint in the transects is depicted by the pink highlighted areas. Vertical trends in the soil concentrations with depth are also shown in the corresponding depth profiles for each COPC.

Figure E4-9a. Lateral Patterns of Vadose Zone Soil Concentrations for CT with Respect to Distance from the 216-Z-9 Crib Footprint in W-E and N-S Transects Through the Waste Site

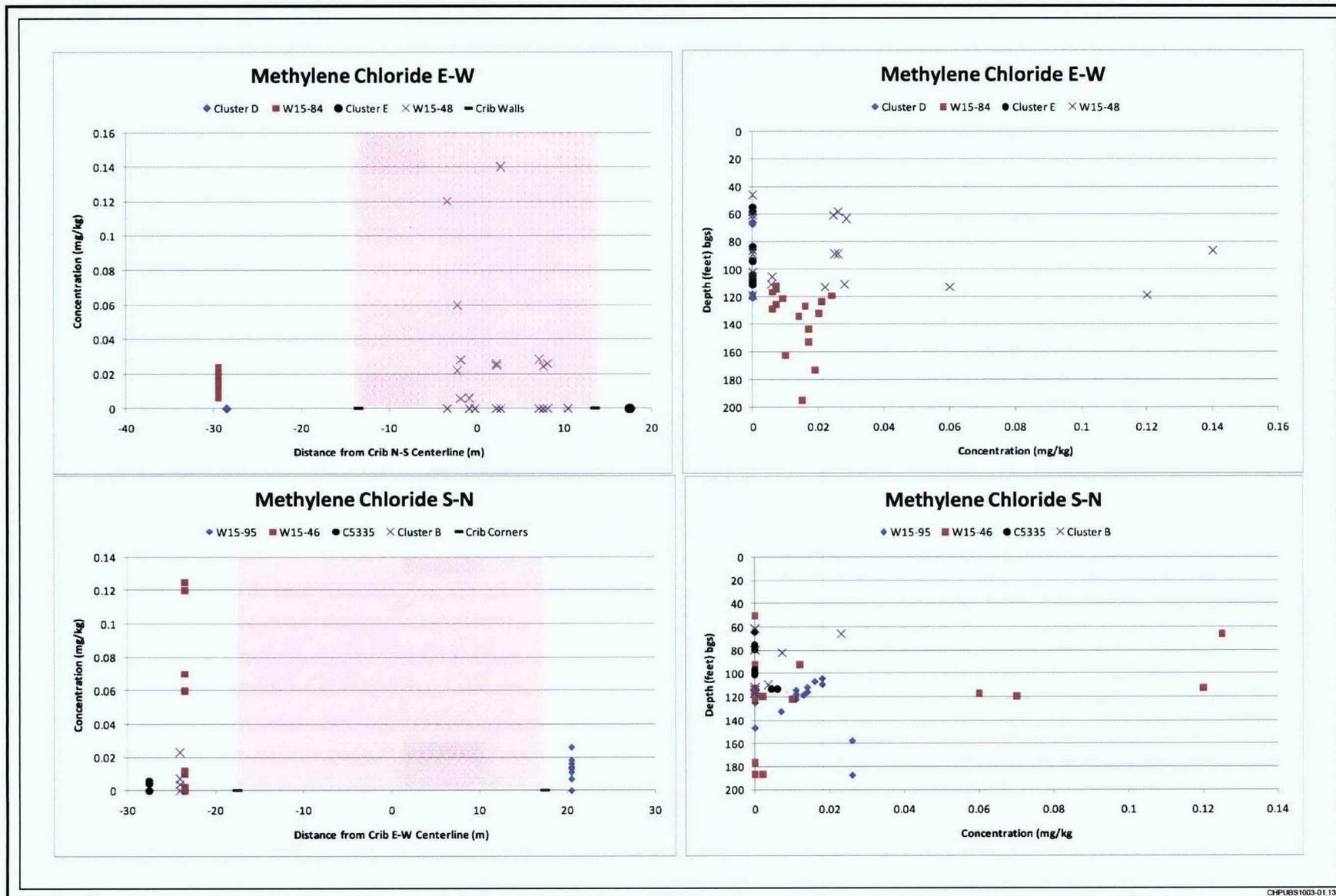


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Note: The location of the Crib footprint in the transects is depicted by the pink highlighted areas. Vertical trends in the soil concentrations with depth are also shown in the corresponding depth profiles for each COPC.

Figure E4-9b. Lateral Patterns of Vadose Zone Soil Concentrations for Chloroform with Respect to Distance from the 216-Z-9 Crib Footprint in W-E and N-S Transects Through the Waste Site

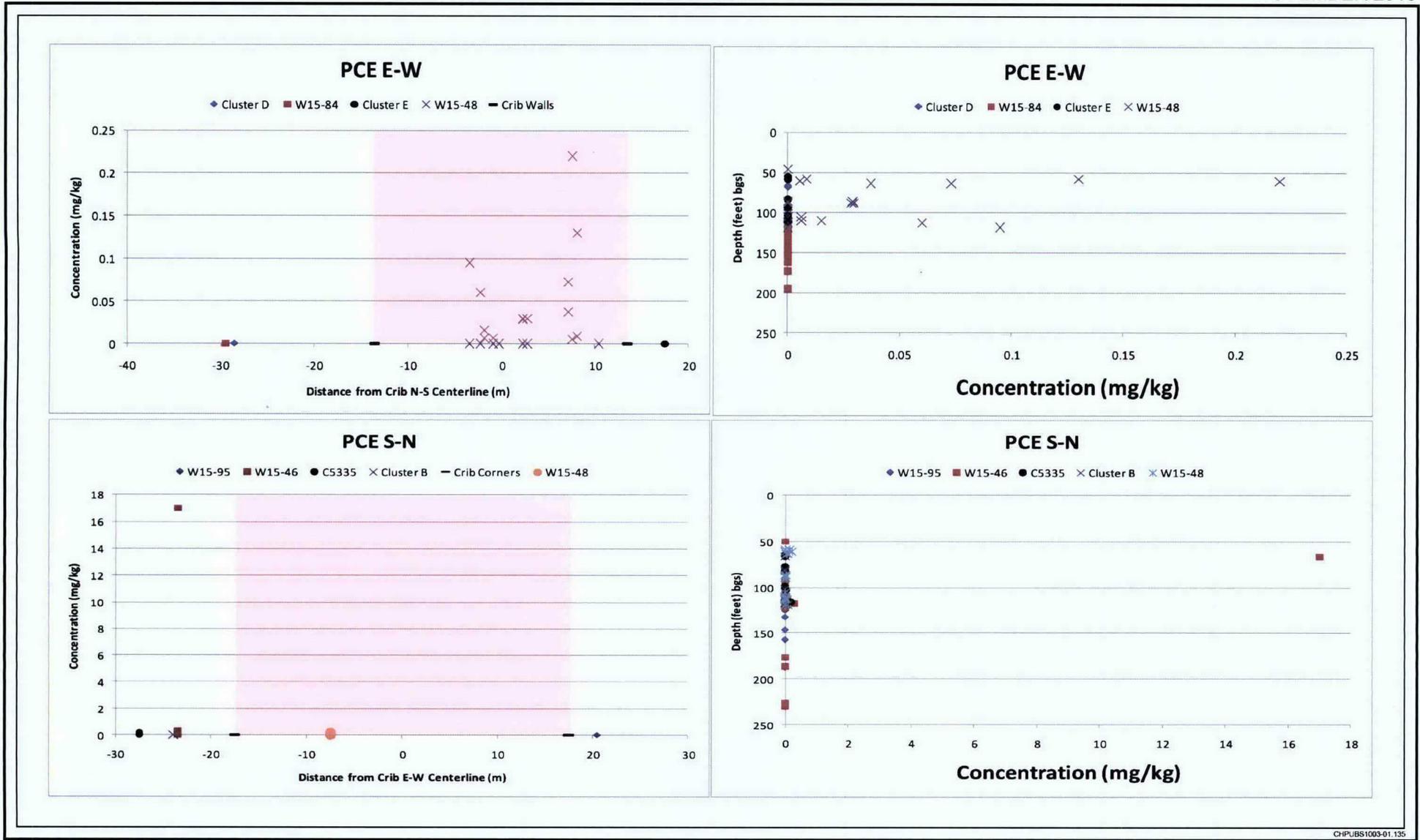


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Note: The location of the Crib footprint in the transects is depicted by the pink highlighted areas. Vertical trends in the soil concentrations with depth are also shown in the corresponding depth profiles for each COPC.

Figure E4-9c. Lateral Patterns of Vadose Zone Soil Concentrations for Methylene Chloride with Respect to Distance from the 216-Z-9 Crib Footprint in W-E and N-S Transects Through the Waste Site

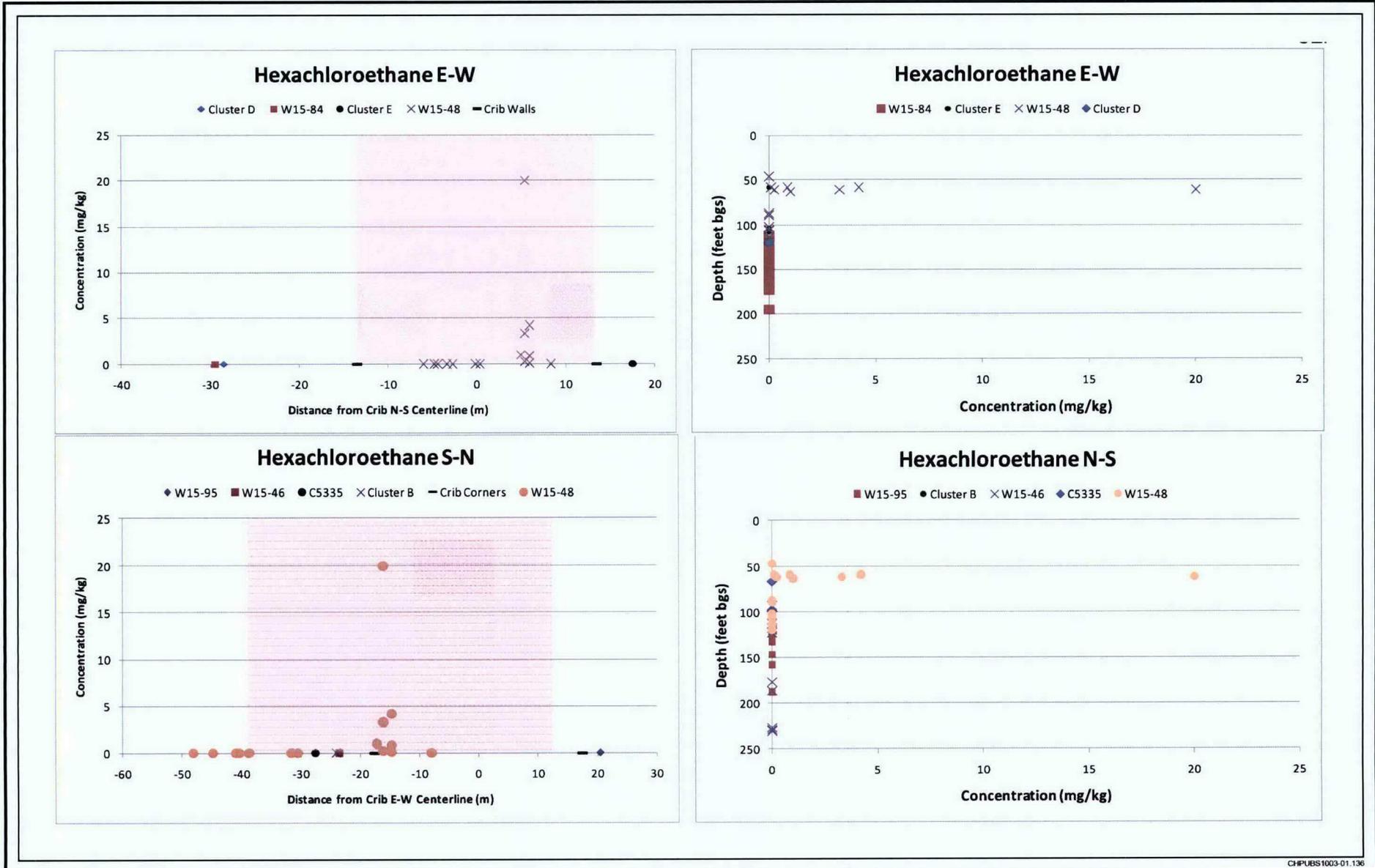


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Note: The location of the Crib footprint in the transects is depicted by the pink highlighted areas. Vertical trends in the soil concentrations with depth are also shown in the corresponding depth profiles for each COPC.

Figure E4-9d. Lateral Patterns of Vadose Zone Soil Concentrations for Tetrachloroethene with Respect to Distance from the 216-Z-9 Crib Footprint in W-E and N-S Transects Through the Waste Site

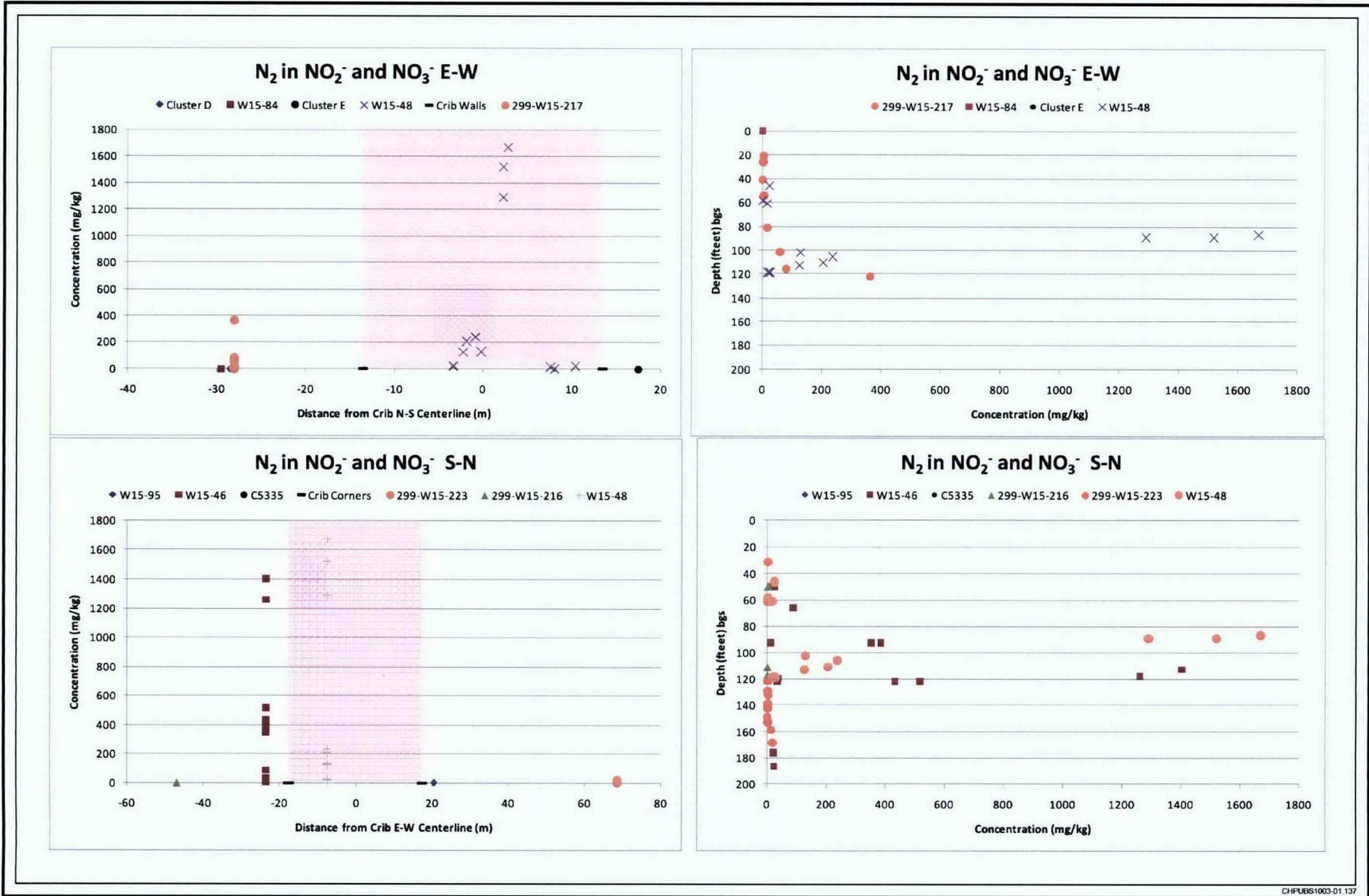


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Note: The location of the Crib footprint in the transects is depicted by the pink highlighted areas. Vertical trends in the soil concentrations with depth are also shown in the corresponding depth profiles for each COPC.

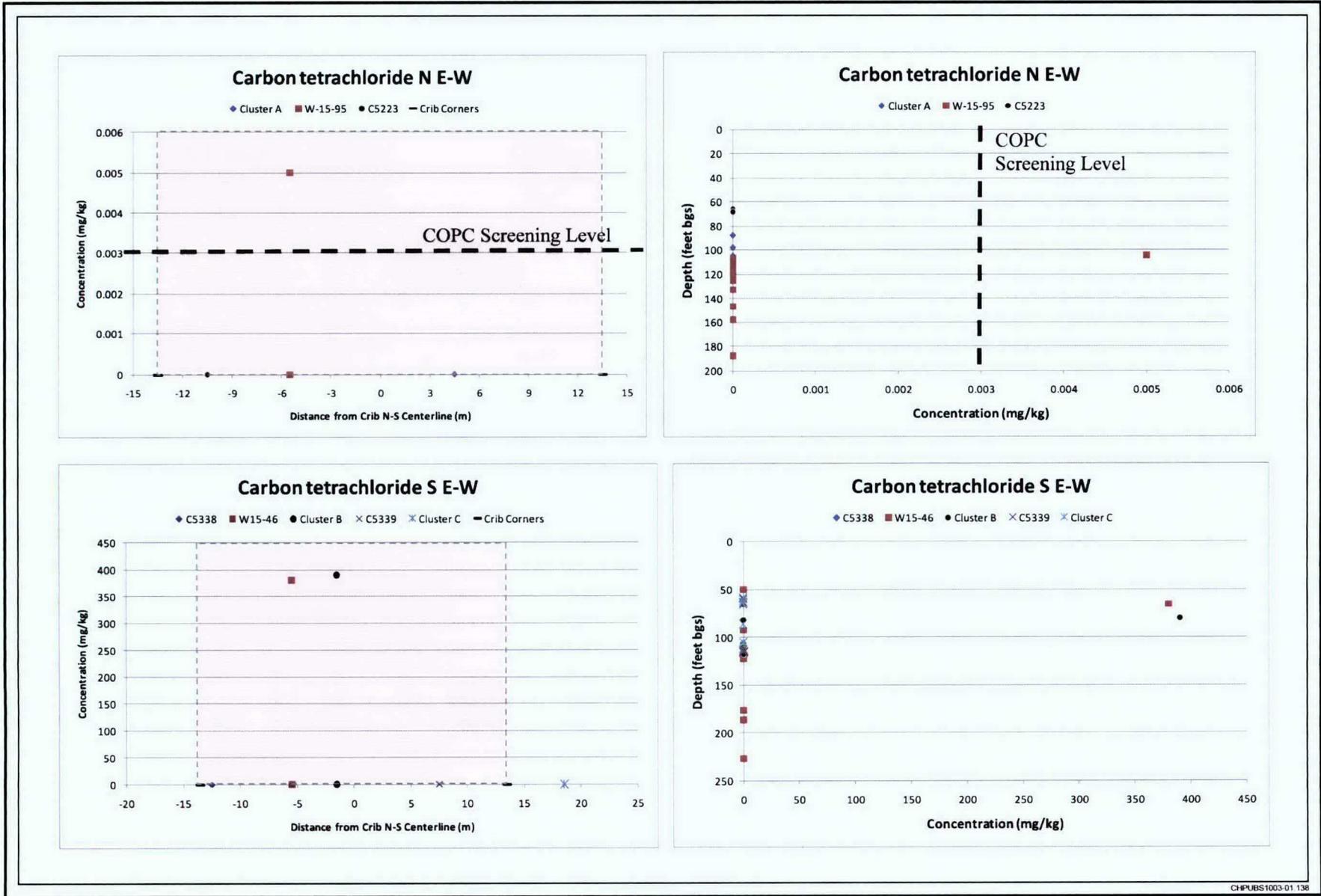
Figure E4-9e. Lateral Patterns of Vadose Zone Soil Concentrations for Hexachloroethane with Respect to Distance from the 216-Z-9 Crib Footprint in W-E and N-S Transects Through the Waste Site



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Note: The location of the Crib footprint in the transects is depicted by the pink highlighted areas. Vertical trends in the soil concentrations with depth are also shown in the corresponding depth profiles for each COPC.

Figure E4-9f. Lateral Patterns of Vadose Zone Soil Concentrations for Nitrogen in Nitrate+Nitrite with Respect to Distance from the 216-Z-9 Crib Footprint in W-E and N-S Transects Through the Waste Site

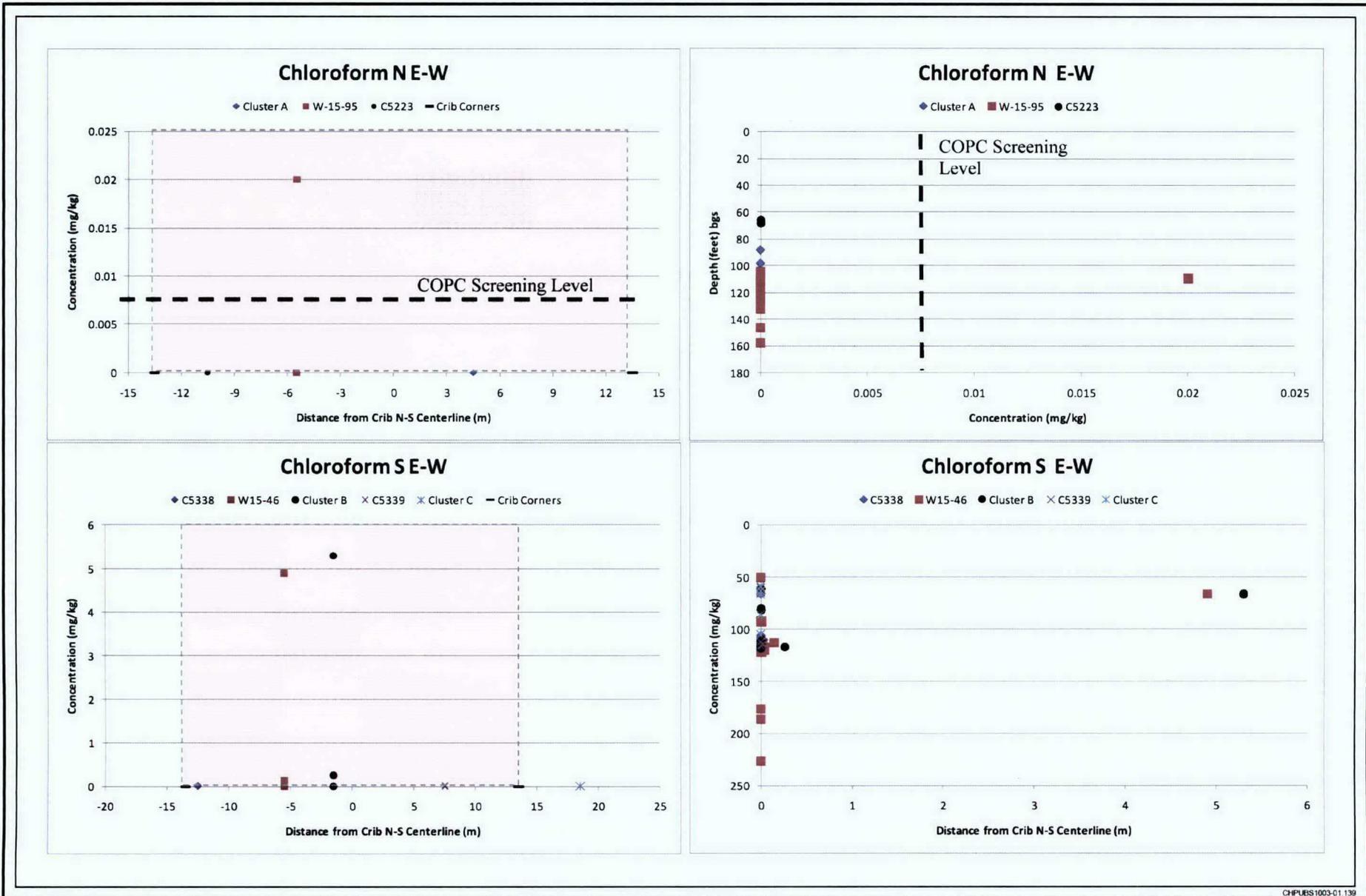


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Note: The location of the Crib footprint in the transects is depicted by the pink highlighted areas. The data for the W-E transects adjacent to the north and south boundaries of the Crib are labeled as N E-W and S E-W, respectively.

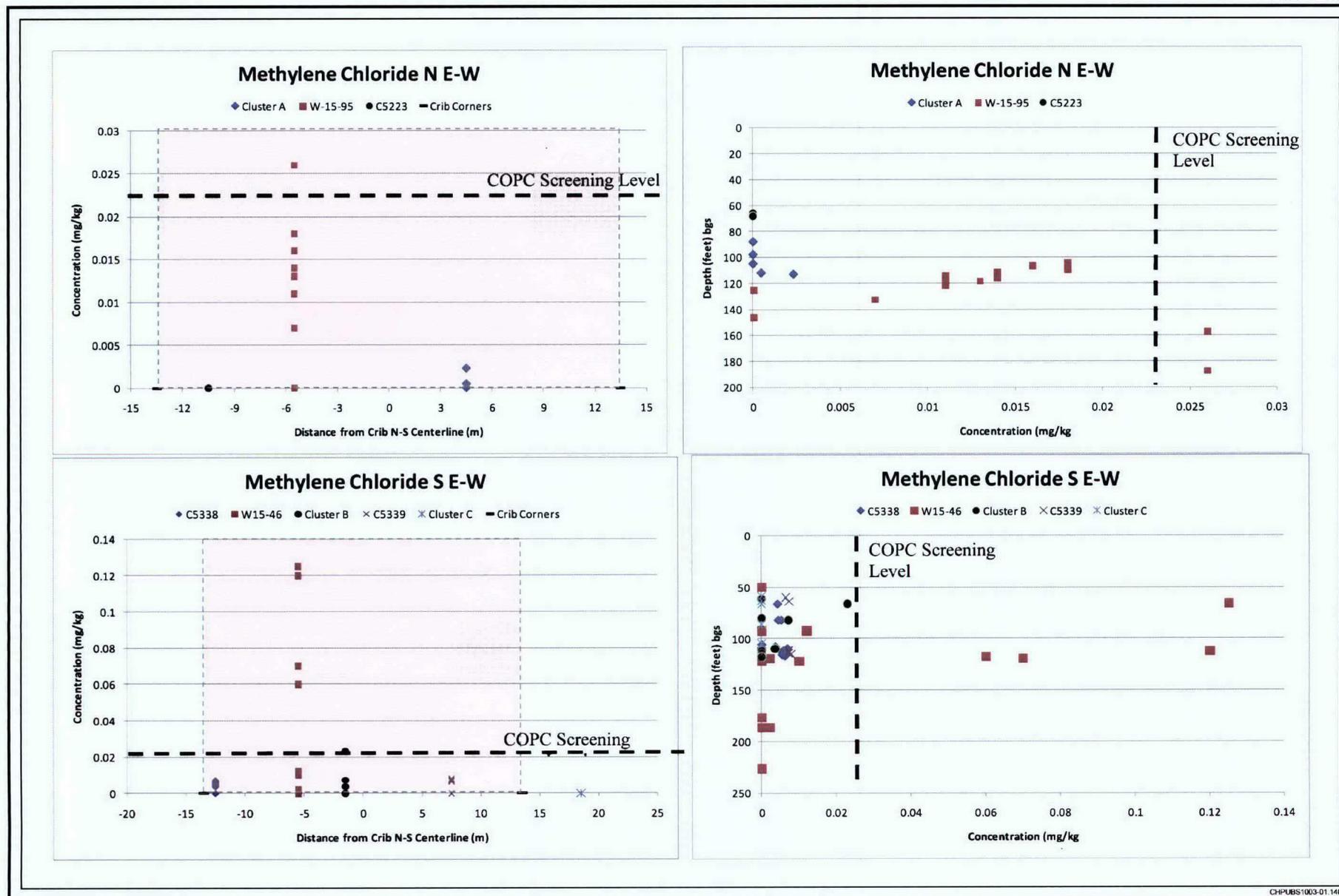
Figure E4-10a. W-E COPC Transects and Concentration Depth Profiles Adjacent to the North End and South Boundaries of the 216-Z-9 Crib



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Note: The location of the Crib footprint in the transects is depicted by the pink highlighted areas. The data for the west-east transects adjacent to the north and south boundaries of the Crib are labeled as N E-W and S E-W, respectively.

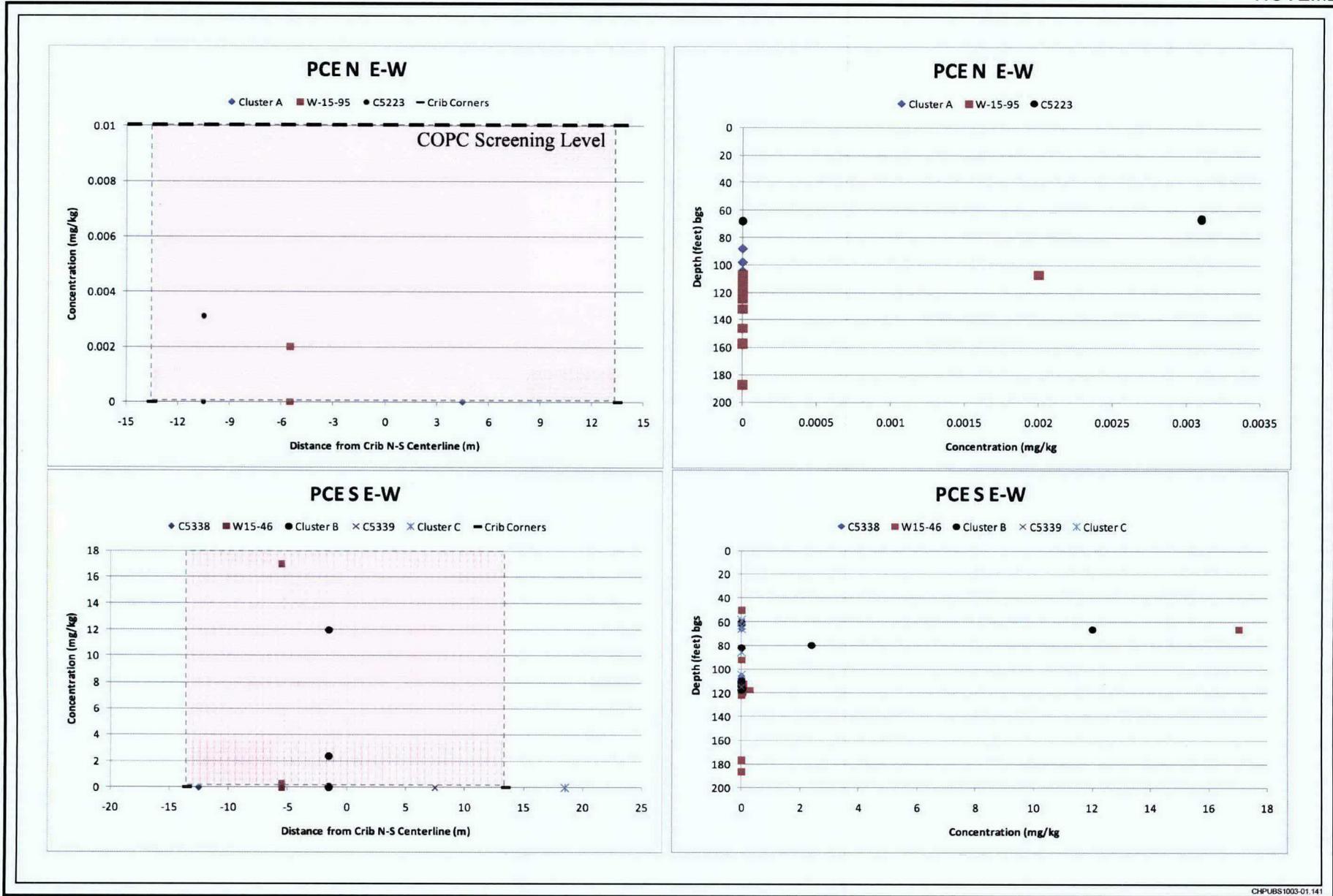
Figure E4-10b. W-E COPC Transects and Concentration Depth Profiles Adjacent to the North End and South Boundaries of the 216-Z-9 Crib



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 2 Note: The location of the Crib footprint in the transects is depicted by the pink highlighted areas. The data for the W-E transects adjacent to the north and south boundaries of the
 3 Crib are labeled as N E-W and S E-W, respectively.

4 **Figure E4-10c. W-E COPC Transects and Concentration Depth Profiles Adjacent to the North End and South Boundaries of the 216-Z-9 Crib**

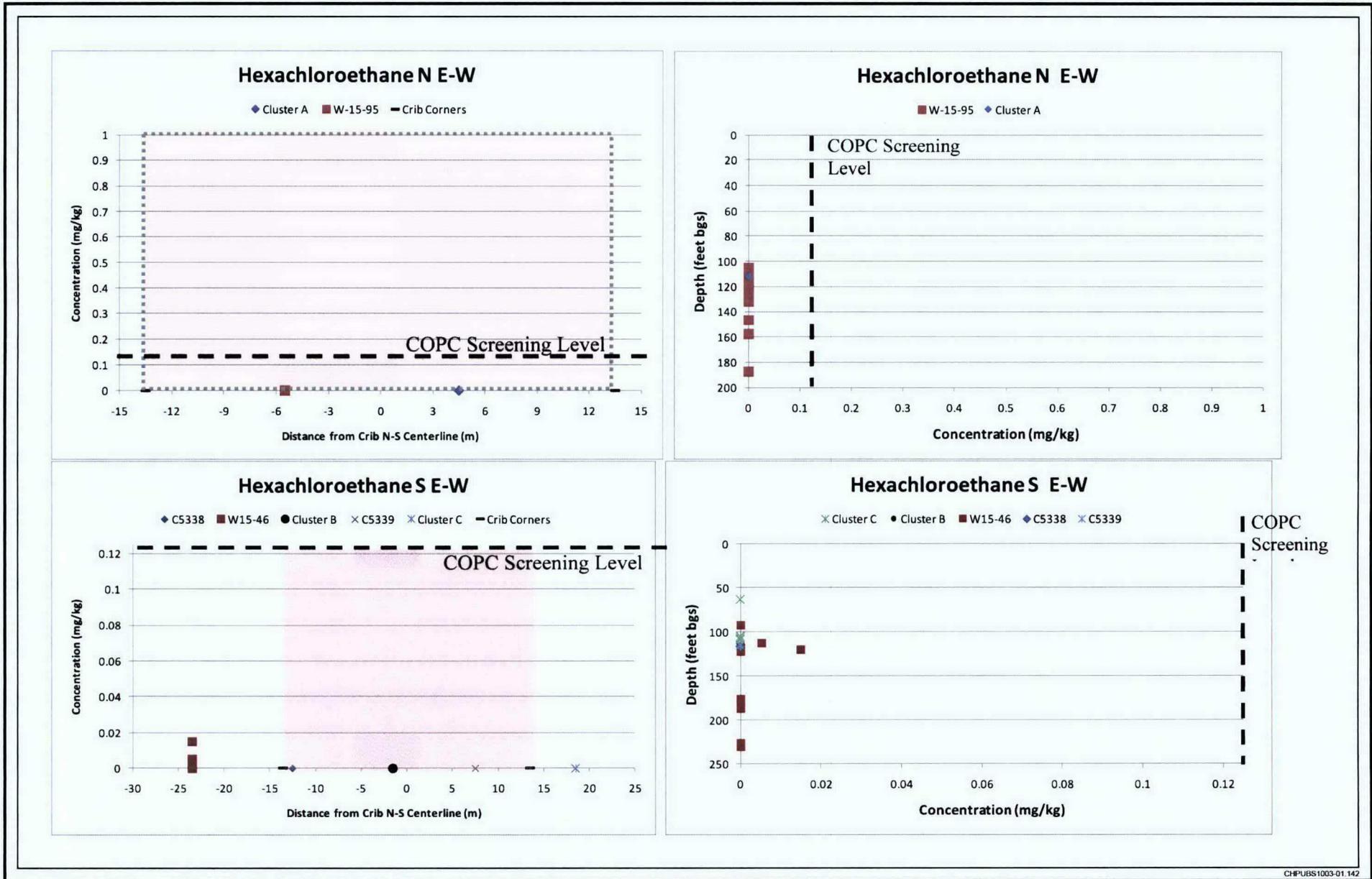


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Note: The location of the Crib footprint in the transects is depicted by the pink highlighted areas. The data for the W-E transects adjacent to the north and south boundaries of the Crib are labeled as N E-W and S E-W, respectively.

Figure E4-10d. W-E COPC Transects and Concentration Depth Profiles Adjacent to the North End and South Boundaries of the 216-Z-9 Crib



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1
 2 Note: The location of the Crib footprint in the transects is depicted by the highlighted (pink) areas. The data for the W-E transects adjacent to the north and south boundaries of the
 3 Crib are labeled as N E-W and S E-W, respectively.

4 **Figure E4-10e. W-E COPC Transects and Concentration Depth Profiles Adjacent to the North End and South Boundaries of the 216-Z-9 Crib**

1 Distinct patterns of COPC soil concentrations can be seen from evaluation of the data in the 216-Z-9
2 transects and associated soil concentration depth profiles. These evaluations included the comparison of
3 the patterns of COPC concentrations in the N-to-S and W-to-E transects, and assessment of the lateral and
4 vertical locations of where the elevated levels of contamination in the vadose zone occur. The following
5 is a summary of the patterns of COPC soil concentrations resulting from these evaluations:

- 6 1. The highest levels of contamination for all COPCs occur, and appear to be limited to zones beneath
7 the footprint of the waste site in the 299-W-15-48 slant borehole, and/or subsurface soils within about
8 10 m (33 ft) of the southern edge of the waste site (the 299-W15-46, and Cluster B).
- 9 2. Very high levels of contamination do not appear to extend laterally outward beyond the northern,
10 eastern, or western margins of the waste site (footprint), or beyond 10 m (33 ft) of the southern margin.
- 11 3. The highest levels of contamination beneath the footprint and the southern edge of the waste site
12 appear to be largely confined vertically to two main depth intervals: a) a contaminated depth interval
13 from about 18 to 24 m (60 to 80 ft) bgs, and b) the Cold Creek sediments (approximately 32 to 38 m
14 [105 to 125 ft] bgs) that are correlated to specific (finer-grained) lithologies.
- 15 4. There is a strong correlation in the spatial and concentration patterns of all VOAs evaluated.
- 16 5. There are very few data (e.g., ≤ 4) with highly elevated levels of contamination for any of the
17 evaluated COPCs, and for most COPCs, there are also few values above screening levels.

18 These spatial patterns of COPC soil concentrations in the vadose zone beneath the 216-Z-9 Crib are
19 similar to those observed beneath the 216-Z-1A Crib, but are better defined due to more abundant and
20 spatially diverse data at 216-Z-9. Although meaningful transects could not be constructed for some key
21 COPCs such as Tc-99 and hexavalent chromium, they appear to follow same spatial and concentration
22 patterns observed for other COPCs e.g., (1), (2), and (3), and (5) in the aforementioned section. It would,
23 therefore, appear that the general patterns observed for the COPCs evaluated in the transects and
24 concentration depth profiles apply to all or most organic and non-organic relatively mobile COPCs
25 (e.g., having low K_d values < 0.3 mL/g. The patterns observed for nitrogen (nitrate+nitrite) probably best
26 represent the nature of spatial soil concentration patterns for other mobile inorganic analytes such as
27 Tc-99 and hexavalent chromium.

28 **E4.3.4 COPC Concentration Isopleth Maps for the 216-Z-9 Crib**

29 Concentration isopleth "maps," i.e., equal concentration contours, for selected COPCs were constructed
30 from the 216-Z-9 borehole data in an attempt to evaluate the lateral extent of contamination and the
31 magnitude of the concentration gradients laterally. This evaluation of borehole data in this manner is
32 limited to cases where there is adequate data for the construction of meaningful two-dimensional contours
33 of COPC soil concentration. The construction of such isopleth maps is possible for the 216-Z-9 Crib due
34 to the density and areal coverage of COPC subsurface sampling and analysis for selected COPCs is
35 extensive (i.e., 41 boreholes/borings surrounding the waste site on all sides).

36 The data used in the construction of the isopleth maps for the 216-Z-9 Crib were primarily limited to
37 select VOAs because these were the COPC data measured in every borehole/boring sample. Isopleth
38 maps were constructed for the soil concentrations of selected VOAs representing the range of the majority
39 of COPCs at the 216-Z-9 Crib that passed screening. Isopleth maps also provide a weight of evidence for
40 evaluating patterns of contaminant behavior spatially and temporally. Nitrogen in nitrate+nitrite was the
41 only non-VOA COPCs evaluated because it was the only significant non-organic COPC with sufficient
42 data for the evaluation. The following are the COPCs for which concentration isopleth figures were
43 constructed:

- 1 • Carbon tetrachloride (CT)
- 2 • Methylene chloride
- 3 • Tetrachloroethene (PCE)
- 4 • 1-Butanol
- 5 • Nitrogen in nitrate+nitrite

6 This evaluation is also conducive to the assessment of the changes in the spatial patterns of COPC soil
7 concentrations of the VOAs over time based on data from three periods: 1992 to 1992, 2001 to 2004, and
8 2006. The soil concentrations of the VOAs are observed to have changed over time due to the operation
9 of the SVE system since 1992 to 1993.⁸

10 Figure E4-11 shows the trend of average CT soil concentrations beneath the 216-Z-9 Crib over a period
11 of 13 years since 1993. The isopleth maps shown in Figure E4-12 were constructed by calculating the
12 average COPC concentration for the COPC data within the depth interval 15 to 37 m (50 to 120 ft) bgs,
13 for the period of interest. The isopleths for nitrogen in nitrate+nitrite were based the data for this depth
14 interval for all periods, because the soil concentrations for this COPC are not expected to vary over time
15 due to volatilization or operation of the SVE system. The depth interval was selected to represent the
16 vertical portions of the vadose zone over which most of the contamination is observed to occur, and to
17 also allow larger amounts of data to be used in estimating average COPC concentrations. Average
18 concentrations were used in the construction of the isopleth maps as the most representative metric of
19 contaminant source term mass. All isopleths were constructed by hand, using the data shown in the
20 figures, judgment in the interpolation of concentration contours, and the spatial patterns of soil
21 concentration determined from other COPCs.

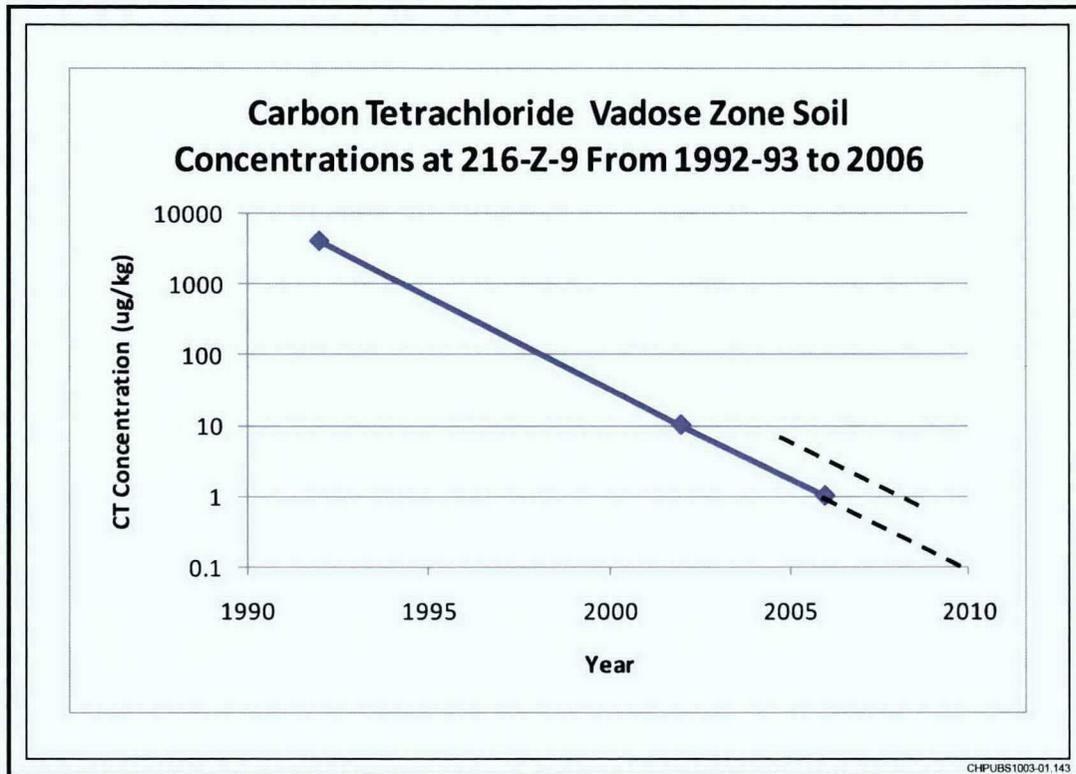
22 Sufficient data were available to evaluate the spatial patterns of soil concentrations over time for CT
23 (Figure E4-12) and for methylene chloride. Figure E4-12 illustrates the spatial trends in soil CT
24 concentrations, showing concentration isopleths for the periods 1992 to 1993, 2001 to 2004, and 2006.
25 The temporal patterns for methylene chloride (not shown) were similar. The temporal trends in the size
26 and levels of VOA soil concentrations were also evaluated by constructing isopleths (mg/kg) for the sum
27 of all VOA analytes for the three periods as an indicator for the general trends in VOAs over time.

28 The following are the main conclusions drawn from the evaluation of the isopleth maps and figures:

- 29 • The levels of contamination and the lateral extent of VOA soil contamination in the vicinity of the
30 216-Z-9 Crib have decreased significantly since 1992 to 1993.
- 31 • The present spatial pattern of soil contamination for the VOAs is generally symmetrical with respect
32 to the E-W dimensions of the footprint of the 216-Z-9 Crib, but asymmetrical N-S, with the highest
33 levels of contaminated centered at the south edge of the waste site.
- 34 • The maximum dimensions of the subsurface contaminant plume greater than the soil screening levels
35 are similar to the footprint dimensions of the waste site.
- 36 • The concentration gradients for the VOAs at the southern edge of the 216-Z-9 Crib appear to have
37 become steeper over time.

⁸ The soil concentrations for the VOAs represent only adsorbed +/- interstitial components of contamination, which may dissolved aqueous components, but not vapor components. It is also noted that the concentrations of soil, aqueous, and vapor at equilibrium are related by the physiochemical partitioning relationships between the solid, liquid (free product), aqueous, and vapor phases described by aqueous solubility, vapor pressure, solid-liquid partitioning (e.g., soil-water K_d partition).

- 1 • The spatial and temporal trends in the VOA soil concentrations and the geometry of the contaminant
2 plumes in 2006 are strongly correlated.
- 3 • The subsurface plume for nitrogen appears to be laterally more extensive than that for the VOAs in
4 2006, symmetrically elongated in an N-direction, with the highest concentrations centered at the south
5 edge of the waste site.
- 6 • The lateral extent of the nitrogen plume above background levels may be as much as two to three
7 times the footprint dimensions of the waste site.

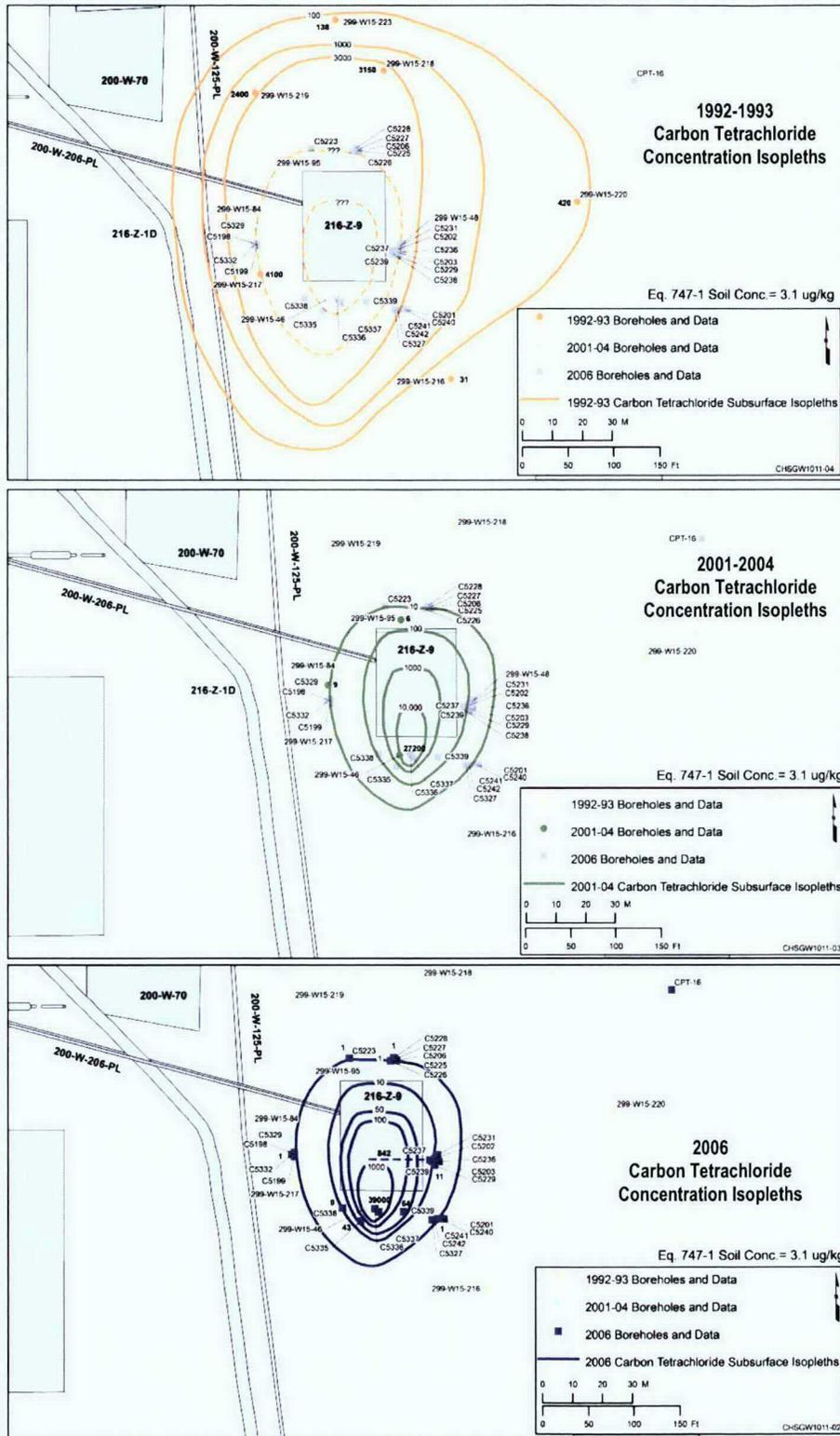


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Note: Concentrations at reference locations around the crib (see Figures E4-12) appear to decrease logarithmically over time (note logarithmic scale for the concentration axis).

Figure E4-11. Trend of Average CT Soil Concentrations near the 216-Z-9 Crib from 1992 to 1993 to 2006, for the Depth Interval from 15 to 37 m (50 to 120 ft) bgs

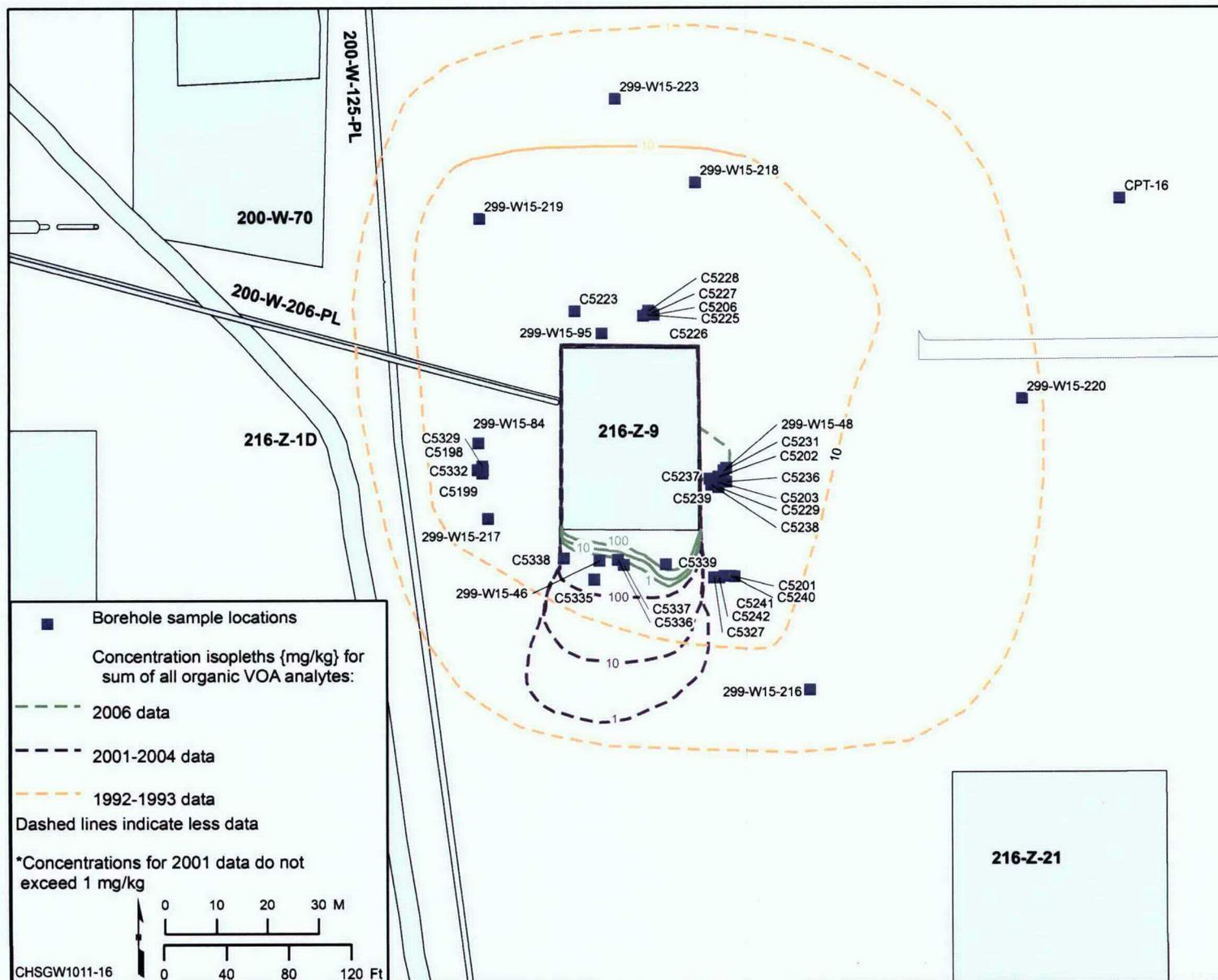
Detailed evaluation of the temporal trends in the decrease of CT soil concentrations over time indicate that the concentrations have decreased logarithmically from 1992 to 1993 to 2006, by over three orders of magnitude (e.g., decrease of up to 4,000 times), ostensibly due to the operation of the SVE system (Figure E4-11). The pattern and magnitude of reduction in concentration over time for most, if not all, VOAs, appear to follow the same general pattern as CT (see Figure E4-12). The isopleths for the sum of the soil concentrations for all VOA analytes in Figure E4-13 show the same general pattern of decrease in the lateral dimensions of the contaminant plume and concentrations over time, and steeper concentration gradients at the southern edge of the waste site. Although isopleth plots for the sum of concentrations for all VOA analytes in Figure E4-13 have been shown to be useful in CERCLA or RCRA compliance work in the U.S. Department of Defense (DOD) complex these relationships alone are not necessarily compelling. This is because they can incorporate sampling bias, e.g., due to the frequency of measurement locations and depths, which can also differ by COPC, and sampling date. However, these



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Note: Average COPC borehole concentrations and isopleths ($\mu\text{g}/\text{kg}$) are for the depth interval 15 to 37 m (50 to 120 ft) bgs.

Figure E4-12. Carbon Tetrachloride Subsurface Isoleths—1992-2006 with Respect to the 216-Z-9 Footprint



Note: Concentration isopleths (mg/kg) are for the sum of all VOAs.

Figure E4-13. 216-Z-9 Temporal Trends of the Total VOA Soil Contamination Footprint in the Context of the 216-Z-9 Footprint

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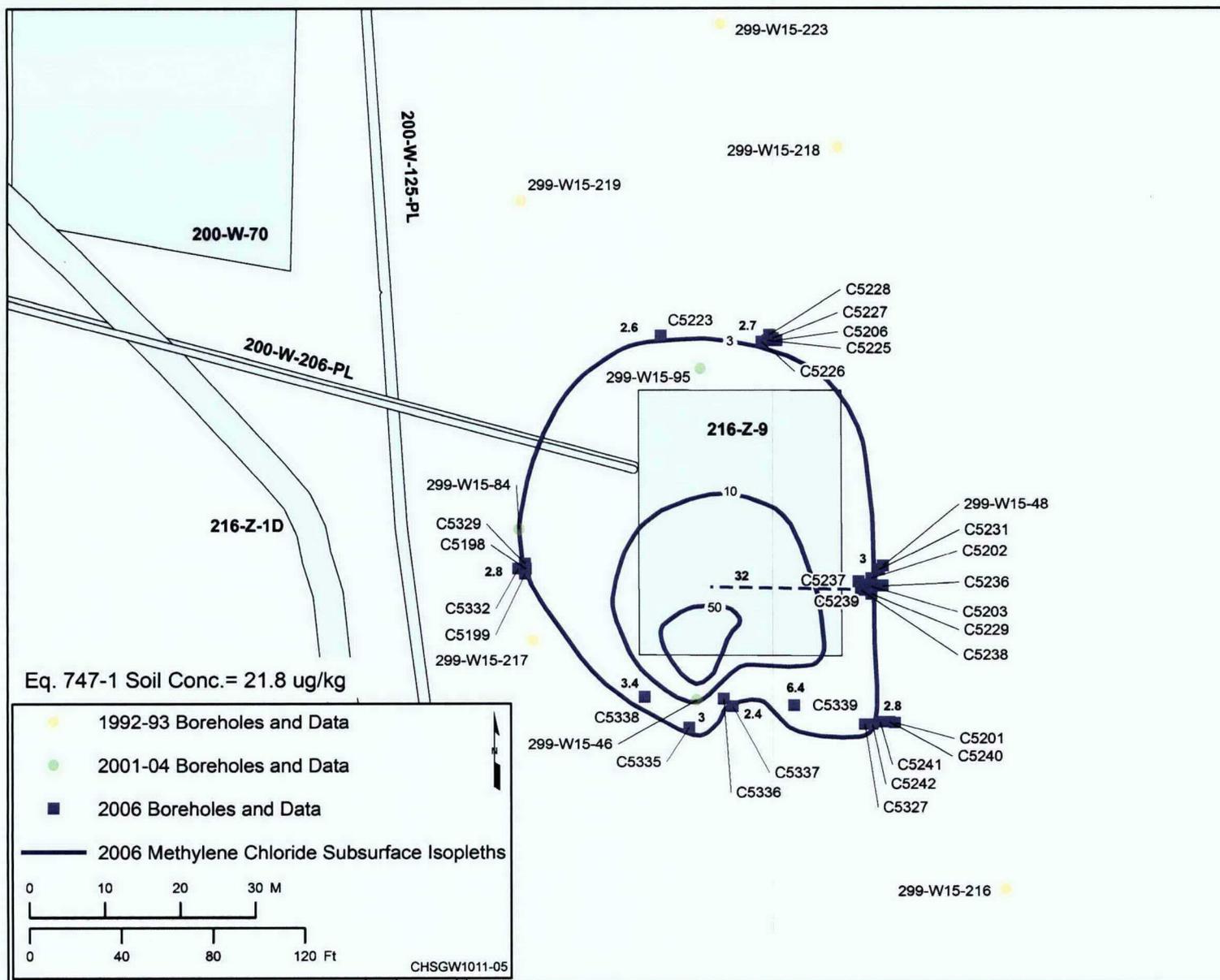
1 relationships coupled with the patterns of VOA behavior seen in isopleth Figures E-14 to E-16, which are
2 analyte-, depth-, and time-specific, provide a compelling weight of evidence for these COPC patterns of
3 behavior.

4 It is also inferred from this evaluation that the present (Year 2010) VOA concentrations in soil should be
5 even lower than those observed in 2006, possibly by as much as an order of magnitude, based on an
6 additional four years of SVE operation, and extrapolation of the concentration trend shown in
7 Figure E4-11; however, extrapolated trends are dependent on the point at which the efficiency of the SVE
8 reaches the point of diminishing return; i.e., flattening trend of concentration reduction with time. It can
9 also be inferred that the lateral extent and spatial patterns of subsurface soil concentrations (e.g., lateral
10 gradients) for nitrate in the beneath the 216-Z-9 waste site and concentration patterns applicable to other
11 mobile inorganic COPC, e.g., Tc-99. Analogous behavior of e.g., Tc-99 to nitrate is expected from the
12 contaminant behavior conceptual model, because both COPCs are mobile COPCs with assumed K_d values
13 of 0 mL/g, and which are expected to have spatial patterns of contamination that largely followed the
14 water plume associated with the liquid discharges at the waste site.

15 It is also reasonable to assume that the patterns of COPC behavior, and insight gained on the nature and
16 extent of contamination at the 216-Z-9 Crib where there is a nearly unprecedented wealth of data,
17 logically have implications and applications for other Hanford waste sites where fewer data are available.
18 The extrapolation of the deductions and conclusions pertaining to the nature and contamination extent at
19 the 216-Z-9 waste site, for example, are most applicable to waste sites with similar or comparable waste
20 streams and/or waste discharge/disposal histories. Thus, the conclusions should be directly applicable to
21 the other 200-PW-1/6 waste sites (i.e., 216-Z-1A and 216-Z-18). These findings may also serve as a case
22 study and basis for establishing or bounding the lateral extent of selected COPCs in the vadose zone.

23 The relationships shown for the COPCs in these isopleth maps are only as valid as the data from which
24 they were constructed, and the assumptions associated with their construction. For example, although the
25 isopleths are the average COPC concentrations for the data collected over the depth interval from 15 to
26 37 m (50 to 120 ft) bgs, this does not necessarily mean that these average concentrations accurately
27 represent the weighted average of concentrations throughout the plume. This is because the average
28 concentration determined in this manner incorporates the collective biases associated with, e.g., sample
29 location bias, in terms of both lateral coverage, and depth, and frequency of analysis. The lateral extent of
30 contamination portrayed by the isopleths, for example, incorporate a bias due to a greater frequency of
31 data in most contaminated regions of the vadose zone, which are typically preferentially sampled. At the
32 216-Z-9 Crib, there appears to be some preferential sampling of the depth intervals just above and within
33 the Cold Creek unit, where the concentrations of COPCs are typically highest for most COPCs, and also
34 where the extent of lateral spreading is known or expected to be the greatest. It is, therefore, important to
35 understand the limitations of such constructs, in terms of what they do, and do not to represent. The
36 lateral extent of the 2-D isopleths shown in Figures E4-12 and E4-14 to E4-17, are effectively the average
37 lateral extent of contamination over the depth interval from 15 to 37 m (50 to 120 ft) bgs. Thus, they do
38 not provide information to distinguish whether the lateral extent of contamination varies with depth in the
39 vadose zone. Therefore, the lateral extent of the contamination plume for many, if not all, COPCs may be
40 smaller in the shallower parts of the vadose zone than in the Cold Creek unit, or as depicted by the 2-D
41 isopleths. This depends on the extent to which the lateral extent of contamination in the shallower parts of
42 the vadose zone differs from that deeper in vadose zone in the vicinity of the Cold Creek unit, as well as
43 on the extent to which the data represent preferential sampling over one or more depth intervals. This is
44 an important issue for understanding the uncertainties and biases associated with the input parameters for
45 fate and transport modeling.

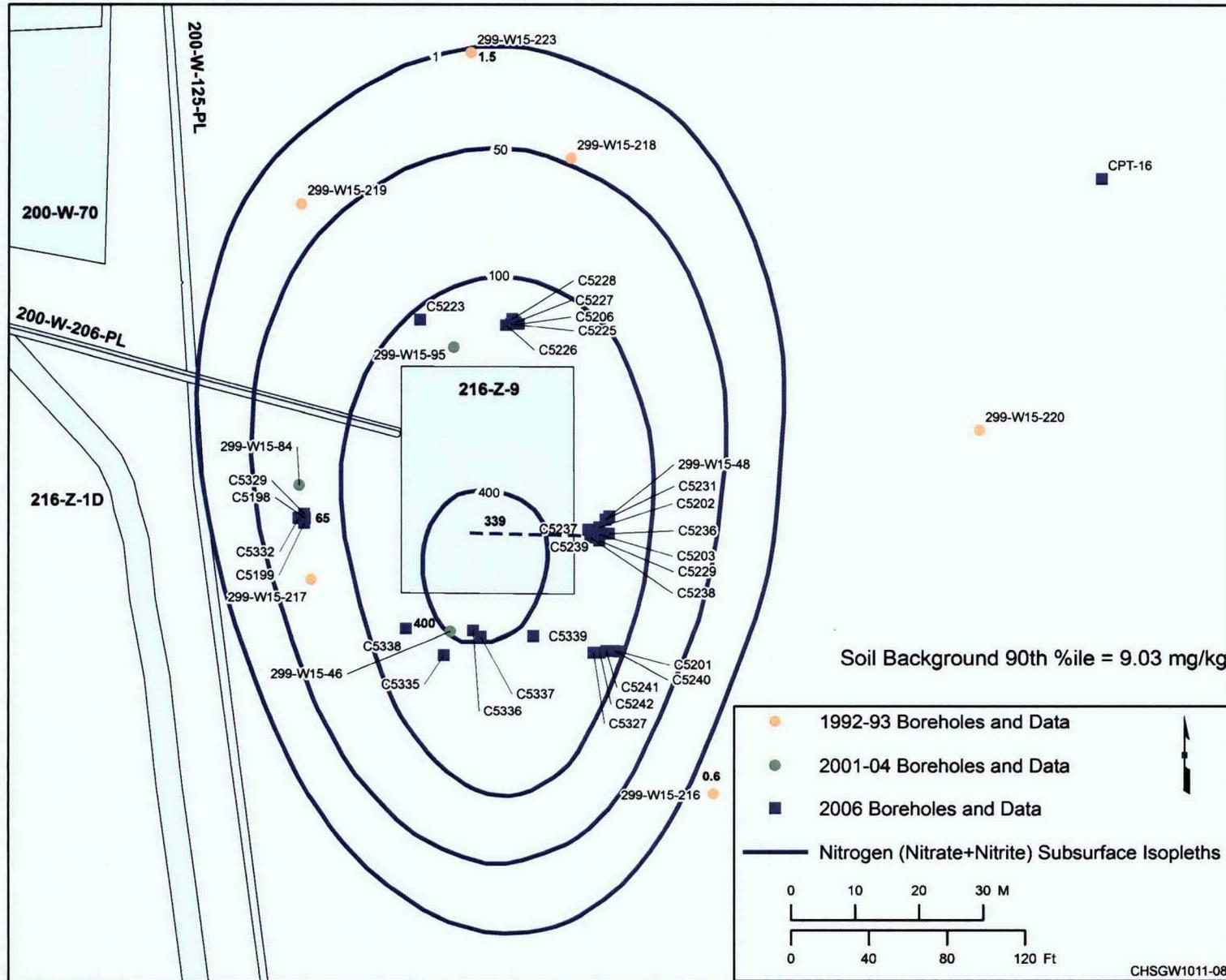
46



Notes: 2006 data. Average COPC borehole concentrations and isopleths ($\mu\text{g}/\text{kg}$) are for the depth interval 15 to 37 m (50 to 120 ft) bgs.

Figure E4-14. 216-Z-9 Methylene Chloride Subsurface Isoleths with Respect to the 216-Z-9 Footprint

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Note: 2006 Data. Average COPC borehole concentrations and isopleths ($\mu\text{g}/\text{kg}$) are for the depth interval 15 to 37 m (50 to 120 ft) bgs.

Figure E4-17. Nitrogen (Nitrate+Nitrite) Subsurface Isoleths with Respect to the 216-Z-9 Footprint

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1 **E4.3.5 Three-Dimensional COPC Plumes for 216-Z-9**

2 The COPC soil data from the boreholes and borings in the area surrounding the 216-Z-9 Crib were also
3 used to construct 3-D depictions of the contaminant plume for CT and for nitrogen (in nitrate+nitrite).
4 These two contaminants were selected as the COPCs best representing the spatial patterns of the VOA
5 COPCs (CT), and the mobile non-organic COPCs (nitrogen). The 3-D depictions of the subsurface
6 contamination provide a method for evaluating the spatial distribution of the soil contaminants that
7 integrates the entire array of borehole data, and minimizes the effects of sampling, and measurement
8 frequency biases in the construction of subsurface soil plume geometry. Figures E4-18 through E4-21
9 show a north-looking W-E cross-sectional view and a plan view of the 3-D plumes for both contaminants.
10 These show the relationship of the crib dimensions and location to that of the contaminant plumes.

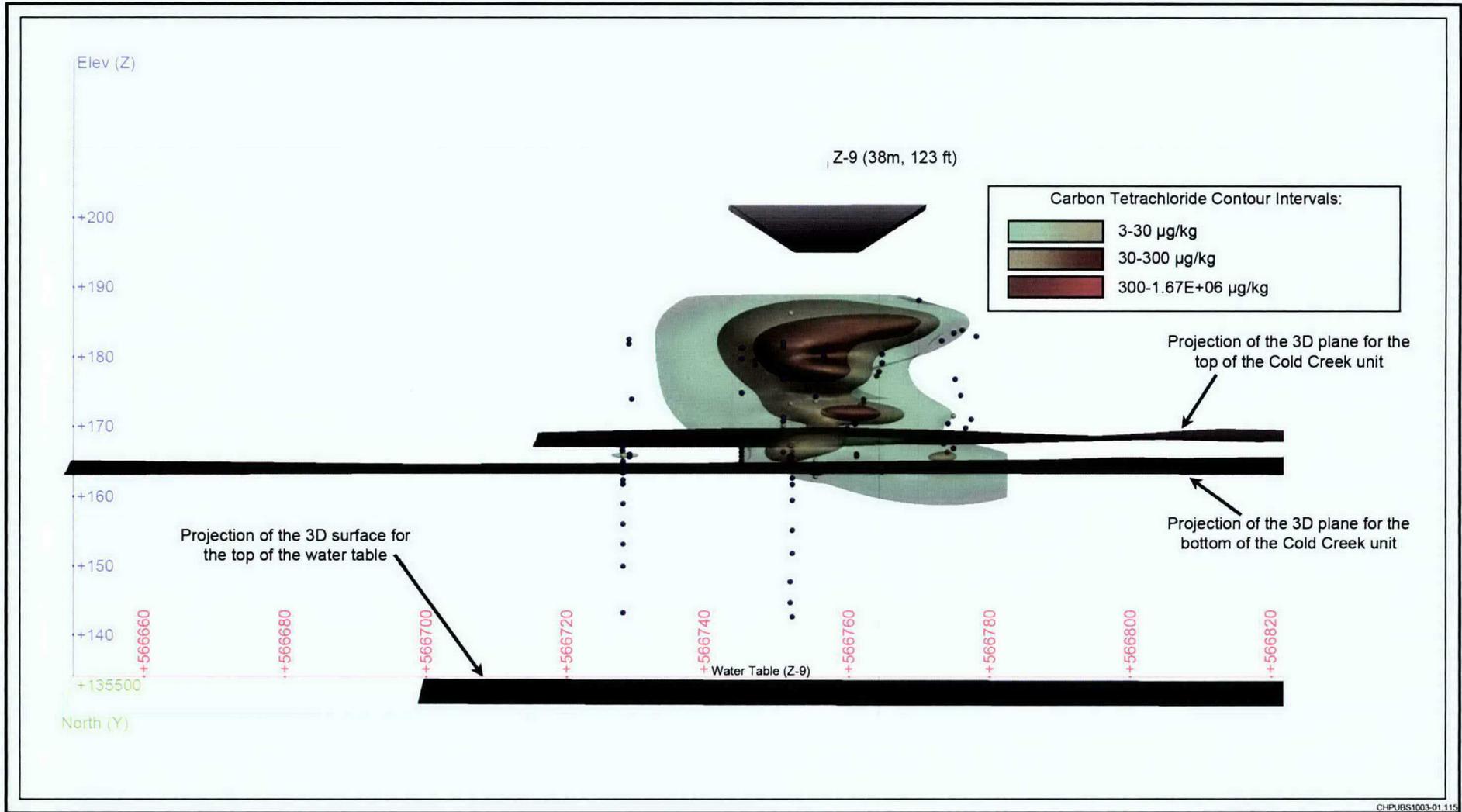
11 The evaluation of the CT and nitrogen spatial distribution and soil concentration gradients based on the
12 3-D depiction of the contaminant plumes corroborate the conclusions and inferences from the evaluation
13 of, and comparison to, the soil concentration isopleths for the 216-Z-9 Crib and the transects across the
14 216-Z-1A and 216-Z-9 waste sites. However, the 3-D plumes provide perspective, detail, and insight
15 regarding the extent and geometry of the plumes that could not otherwise be recognized. These 3-D
16 depictions also provide the most representative perspective on the spatial extent of contamination and
17 contamination gradients both laterally and vertically; thus, this manner of evaluation of the subsurface
18 contaminant plumes truly provide a new dimension to the manner in which subsurface contamination can
19 be evaluated, as well as additional perspective and refinements to the evaluation of the nature and extent
20 of subsurface contamination.

21 As inferred from comparing the lateral trends of COPC soil contaminations across the 216-Z-1A and
22 216-Z-9 Crib, and COPC isopleths beneath the 216-Z-9 Crib, the information and insight gained from
23 evaluating the contaminant plumes for these two COPCs can serve as reference cases for understanding
24 and defining the spatial behavior of other contaminant at other waste sites. Perhaps one of the most
25 valuable applications associated with the use of the 3-D plume information concerns the calculation of
26 representative soil concentrations. The ability to evaluate the soil concentration throughout various parts
27 of the contaminant plume provides insight into the manner in which COPC soil concentrations are
28 determined, that serve as the source terms for vadose zone fate and transport modeling. Section E4.4.4
29 describes and discusses this insight pertaining to the calculation of representative COPC concentrations
30 for specified soil volumes.

31 **E4.3.6 Other Factors Pertaining to the Contaminant Source Term Conceptual Model**

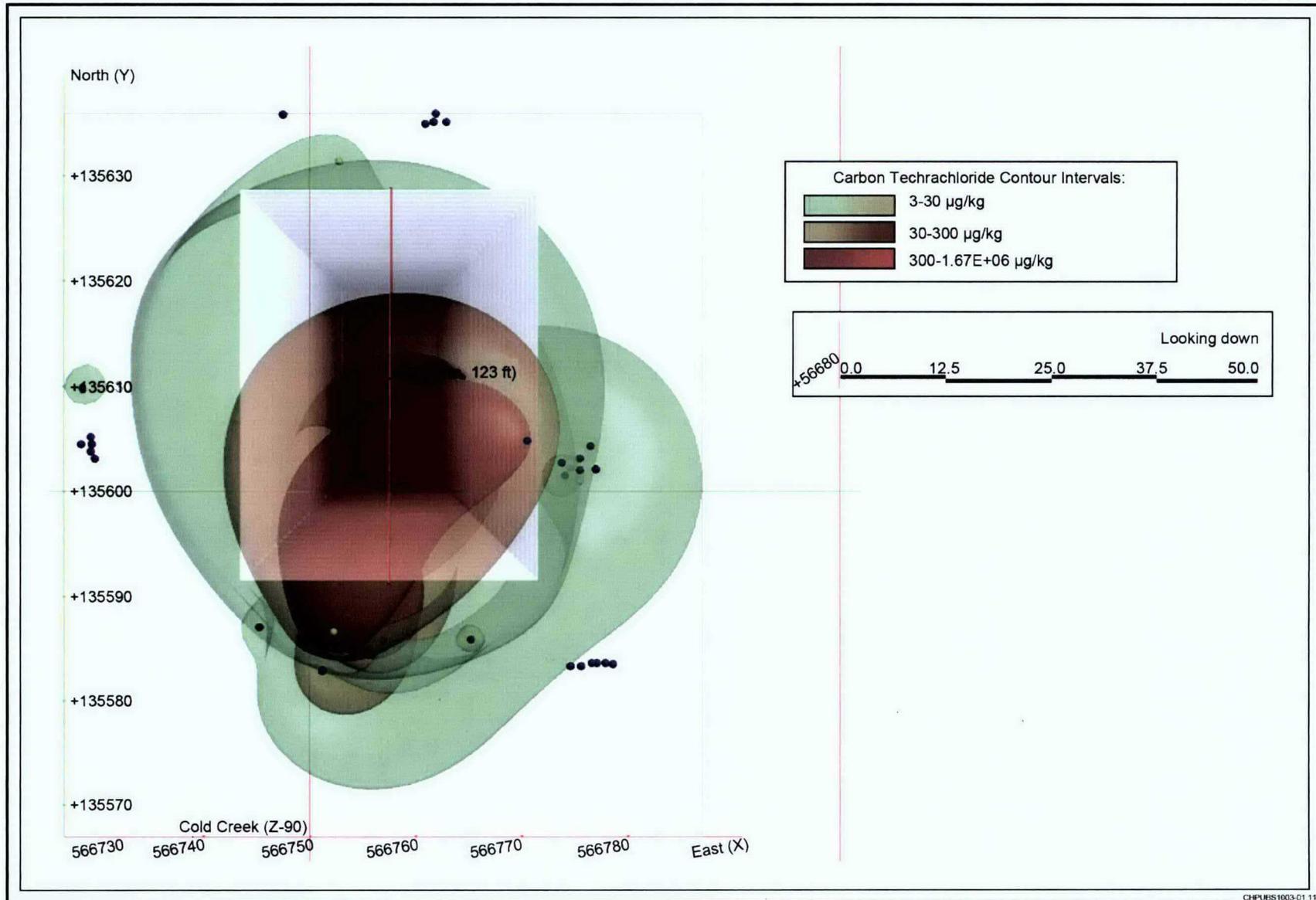
32 Other factors that are important for understanding the spatial distribution and concentrations of the VOAs
33 in the 200-PW-1 vadose zone are the physical and chemical properties that control their geochemical
34 behavior and the tendency for their concentrations and spatial extent to be affected (reduced) by the SVE
35 system. This section discusses the rationale for similarities and/or differences in the contaminant behavior
36 conceptual of the VOA COPCs beneath the 200-PW-1 (Z-Area) waste sites as a basis for assumptions
37 concerning analogous behavior among VOA COPCs, including the relative dimensions of contaminant
38 soil volumes.

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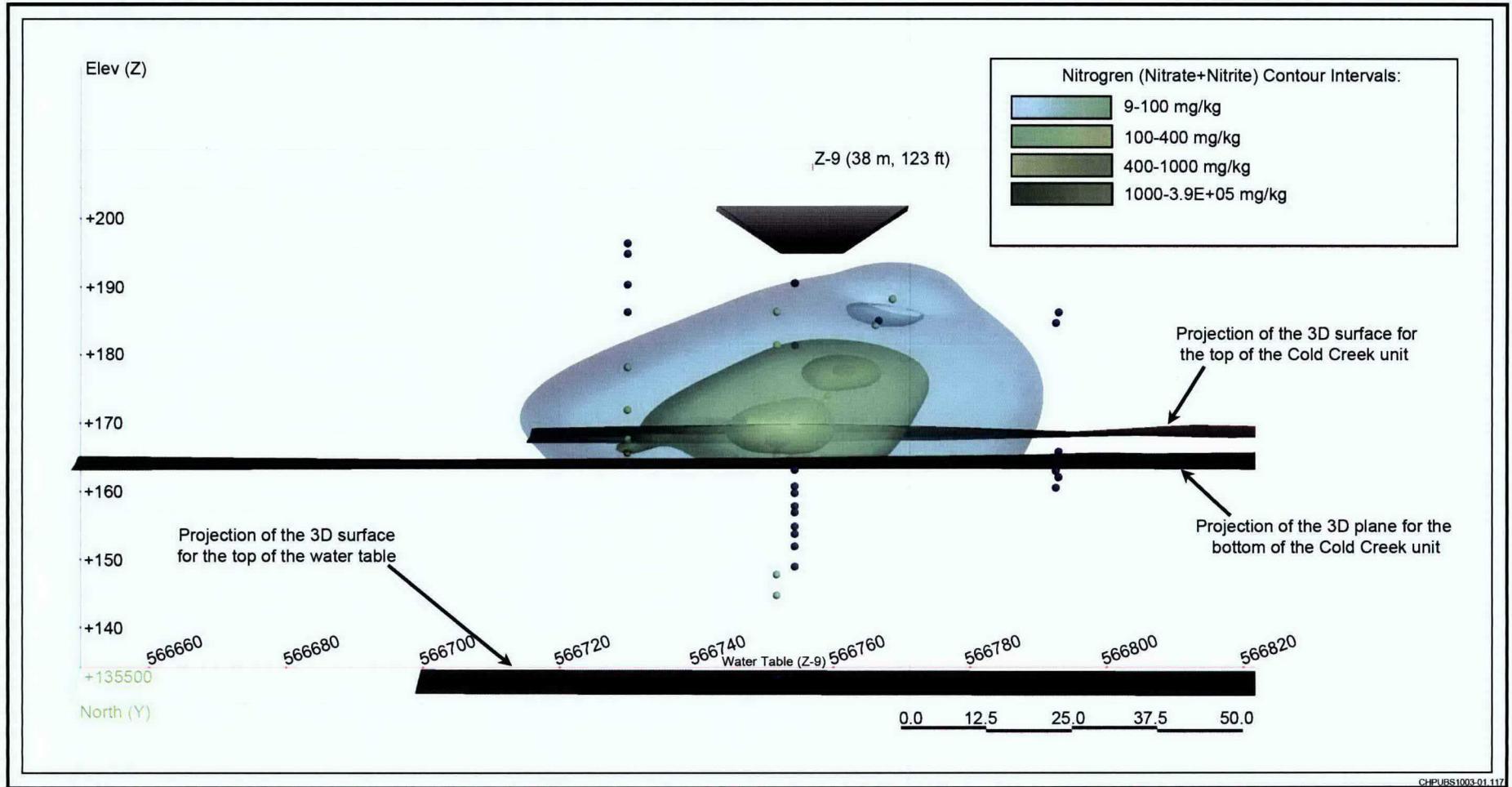
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Figure E4-18. North-Looking, W-E Cross-Section Showing a 3-D Portrayal of the CT Contaminant Plume in the Vadose Zone Beneath the 216-Z-9 Crib and the Relationship of the Crib Cross-Section to the Contaminant Plume

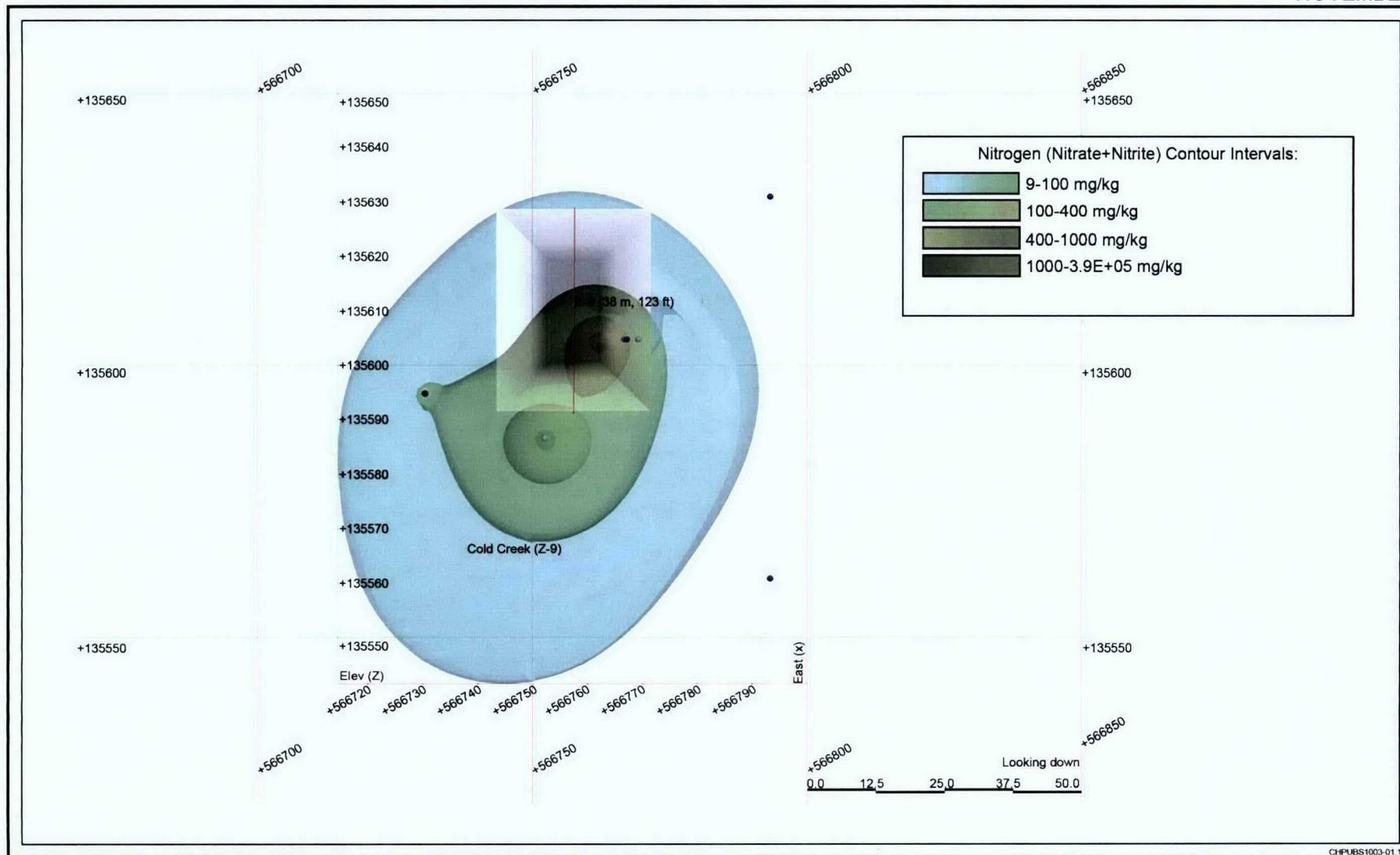


Note: The outermost plume boundary (green) denotes the 0.00351 mg/kg screening level contour, the outermost part of two brown-colored zones denote the 0.030 mg/kg, and the 0.300 mg/kg contours.

Figure E4-19. Plan View of a 3-D Portrayal of the CT Contaminant Plume in the Vadose Zone Beneath the 216-Z-9 Crib Showing the Relationship of the Crib Footprint to the Plume



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Note: The outermost plume boundary (blue) denotes the 9 mg/kg background screening level contour, the outermost part of three green-colored zones denote the 100 mg/kg, the 400 mg/kg contours, and the 1,000 mg/kg contour for the small innermost core zone of the plume.

Figure E4-21. Plan View of a 3-D Portrayal of the CT Contaminant Plume in the Vadose Zone Beneath the 216-Z-9 Crib Showing the Relationship of the Crib Footprint to the Plume

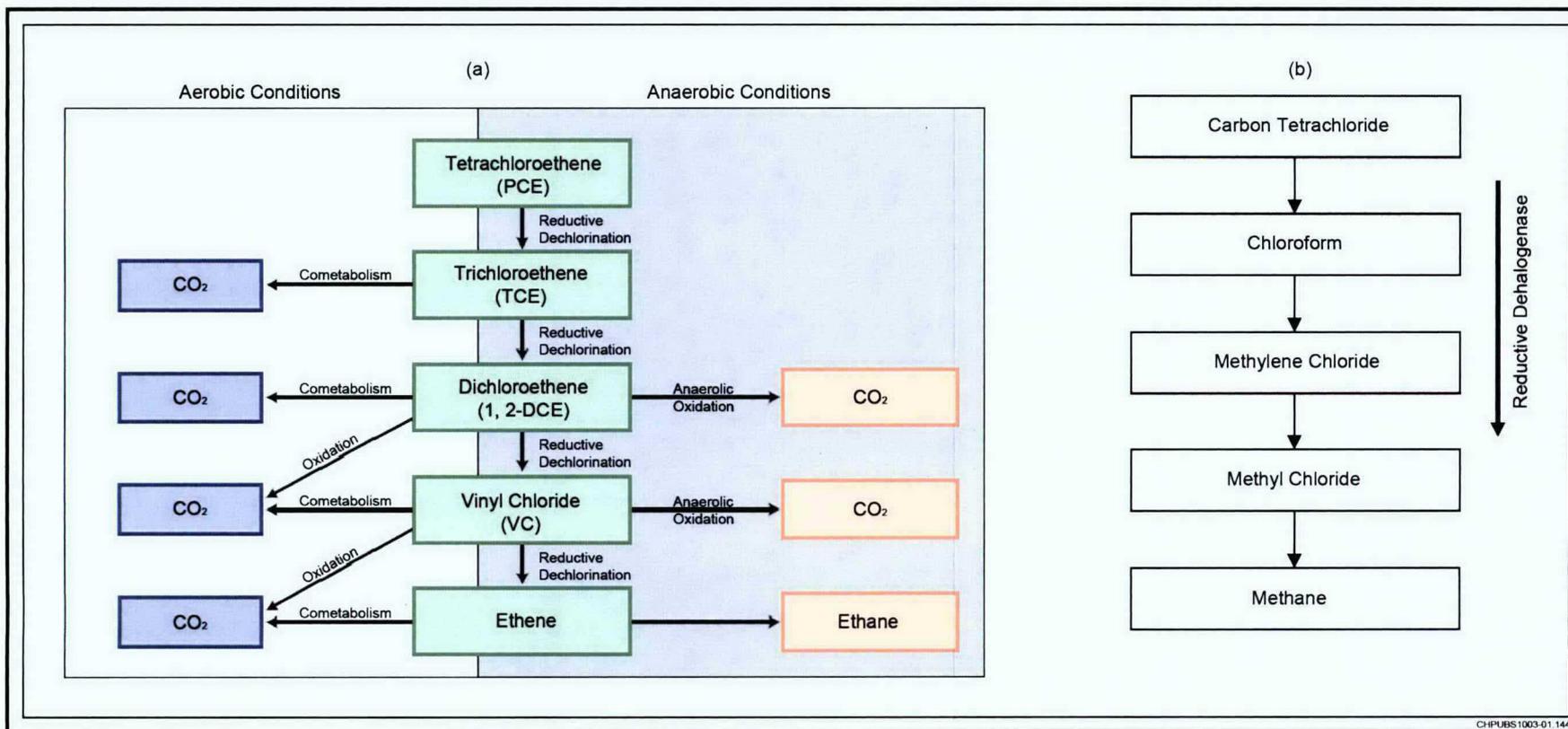
1 Some of the main physical and chemical properties that control the geochemical behavior of the VOA
 2 COPCs include the specific gravity, vapor pressure, water solubility and phase partitioning (e.g., water
 3 solubility, Henry's Law behavior) as identified in Table E4-2. These properties are important
 4 characteristics of the VOAs because they define the manner in which the VOAs are effectively partitioned
 5 between the free product (liquid) phase, vapor phase, aqueous phase, and sorbed phases as indicated in
 6 Table E4-2. The concentrations of soil, aqueous, and vapor at equilibrium are related by the
 7 physiochemical partitioning relationships between the solid, liquid (free product), aqueous, and vapor
 8 phases described by aqueous solubility, vapor pressure, solid-liquid partitioning (e.g., soil-water K_d
 9 partition). The soil concentrations for the VOAs represent only adsorbed +/- interstitial components of
 10 contamination that may dissolved aqueous components, but not soil vapor components.

Table E4-2. Comparison of Key Physical and Chemical Phase Partitioning Properties of Some Groundwater Protection VOA COPCs in the Vadose Zone at the 200-PW-1 Waste Sites

COPC	Specific Gravity (g/cm ³)	Water Solubility (Ksp) g/100 mL	Vapor Pressure (mm Hg at 25 °C)	Henry's Law Constant (atm·m ³ /mole)	Soil-Water Partition Coefficient (adsorption K_d ; mL/g)
Phase partitioning	--	Water-Liquid (Free Product)	Gas-Liquid (Free Product)	Gas-Water	Soil (Sorbed)-Water
Carbon tetrachloride	1.59	0.08	91.3	2.9E-02	0.15
Chloroform	1.48	0.8	160	3.7E-03	0.05
Dichloromethane (methylene chloride)	1.33	1.3	400	2.57E-03	0.01
Tetrachloroethene (PCE)	1.62	0.015	18.5	1.8E-02	0.25
Trichloroethene (TCE)	1.46	0.13	58	1.1E-02	0.1
1,1-Dichloroethane	1.2	0.6	230	1.8E-02	0.05
1-Butanol	0.81	7.7	7.0	8.81E-06	0.01

11 Many of the COPCs passing the screening steps are halogenated hydrocarbons that have similar physical
 12 and chemical properties, similar geochemical behavior and are, therefore, expected to have similarities in
 13 the nature and extent of the subsurface contaminant plumes. As seen in Table 4-2, all but one of the
 14 COPCs (1-butanol) are chlorinated hydrocarbons that are denser than water (DNAPL), relatively volatile,
 15 with a range of water solubilities, and not strongly retarded by sorption during aqueous transport. The
 16 nature and distribution of many of these COPCs are also expected to be similar because they are related in
 17 terms of their chemical structures. Four of the COPCs in Table E4-2 are related by the degradation
 18 (breakdown products) of CT (chloroform, dichloroethane, methylene chloride) as shown in
 19 Figure E4-22(a). Two others, tetrachloroethene and trichloroethene, are similarly related to one another as
 20 illustrated in Figure E4-22(b).

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Note: Adopted from Hazardous Substance Research Centers, 2005. www.hsrb.org/prague/major

Figure E4-22. Degradation Pathways for (a) PCE/TCE, and (b) CT

1 Although 1-butanol is not a halogenated hydrocarbon, and has some properties that differ significantly
2 from those of the halogenated hydrocarbons (e.g., specific gravity, water solubility, Henry's Law
3 constant), it has a large enough vapor pressure to also be subject to source term removal by the SVE
4 system. It is also notable that two of the VOAs listed in Table 4-2 (methylene chloride and 1-butanol) are
5 relatively soluble in water, and may, therefore, be expected to have contaminated soil volumes that tend
6 to follow the water plume more closely than other VOAs.

7 **E4.3.7 PNNL 3-D Modeling and Conceptual model**

8 The results and conclusions of the PNNL studies of CT migration through the vadose zone beneath the
9 216-Z-9 and 216-Z-1A trenches are also relevant to the assessment of the nature and extent of the
10 contaminated soil volumes in the vadose zone at the 200-PW-1 OU (PNNL-14895; PNNL-15914; and
11 PNNL-16198). These studies were conducted using 3-D fate and transport simulations to enhance the
12 conceptual model of CT distribution in the vertical and lateral direction beneath the 216-Z-9 trench, and
13 to investigate the effect of SVE on the distribution of CT in the subsurface. The simulations targeted
14 migration of CT and co-disposed organics in the subsurface beneath the 216-Z-9 trench as a function of
15 the properties and distribution of subsurface sediments and of the properties and disposal history of the
16 waste. The results and conclusions of these studies provide additional insight on the spatial and temporal
17 behavior of the contaminants in the 200-PW-1 vadose zone and the contaminant source term conceptual
18 model. The studies also provide an independent basis for comparing and contrasting the data-based lines
19 of evidence for the lateral extent of contamination in the vadose zone (i.e., transects, isopleths, 3-D plume
20 depictions). The main conclusions resulting from these studies include the following:⁹

- 21 • The CT accumulates in the finer-grain sediments of the vadose zone but does not appear to pool on
22 top of these layers.
- 23 • Migration of CT tends to be preferentially vertically downward below the disposal area, with the
24 center of mass typically directly beneath the disposal area and within the Cold Creek unit.
- 25 • Considerable lateral movement of CT is not likely; however, significant lateral migration of vapor CT
26 occurs.
- 27 • Lateral spreading of CT, defined as the distance between the 1 percent saturation contour planes west
28 and east or south and north of the 216-Z-9 trench, is estimated to initially be on the order of 40 m
29 (131 ft) in the Hanford formation, 45 m (148 ft) in the Cold Creek unit, and 60 m (197 ft) in the
30 Ringold formation, with the expectation that CT residuals would be located in the fine-grained
31 sediment features within this region of the vadose zone.
- 32 • Because the migration of CT is primarily in the vertical direction, CT in the groundwater would be
33 most likely expected in a zone distributed around the centerline of the disposal area.
- 34 • Pronounced decreases occur over all CT phases (gaseous, sorbed, and aqueous phase) with SVE, and
35 a more gradual decrease in CT DNAPL.
- 36 • Measured vadose zone soil data show low CT concentrations at distances greater than 30 m (98 ft) from
37 the disposal areas, compared to the much higher CT concentrations vertically beneath the disposal areas.
- 38 • The spatial extent of the contaminated soil volumes for the volatile organic COPCs is smallest for the
39 DNAPL (free product) plumes, and largest for the vapor (gas) phase plumes (e.g., Figure E4-23), and
40 intermediate for sorbed and aqueous phase contamination SVE can effectively removes CT from the

⁹ Most conclusions focus on the CT DNAPL, but are also relevant for the vapor and aqueous phase of CT.

1 permeable layers of the vadose zone. SVE previously applied in the 216-Z-9 trench area has likely
2 removed a large portion of CT initially present in the permeable layers within the large radius of
3 influence of the extraction wells.

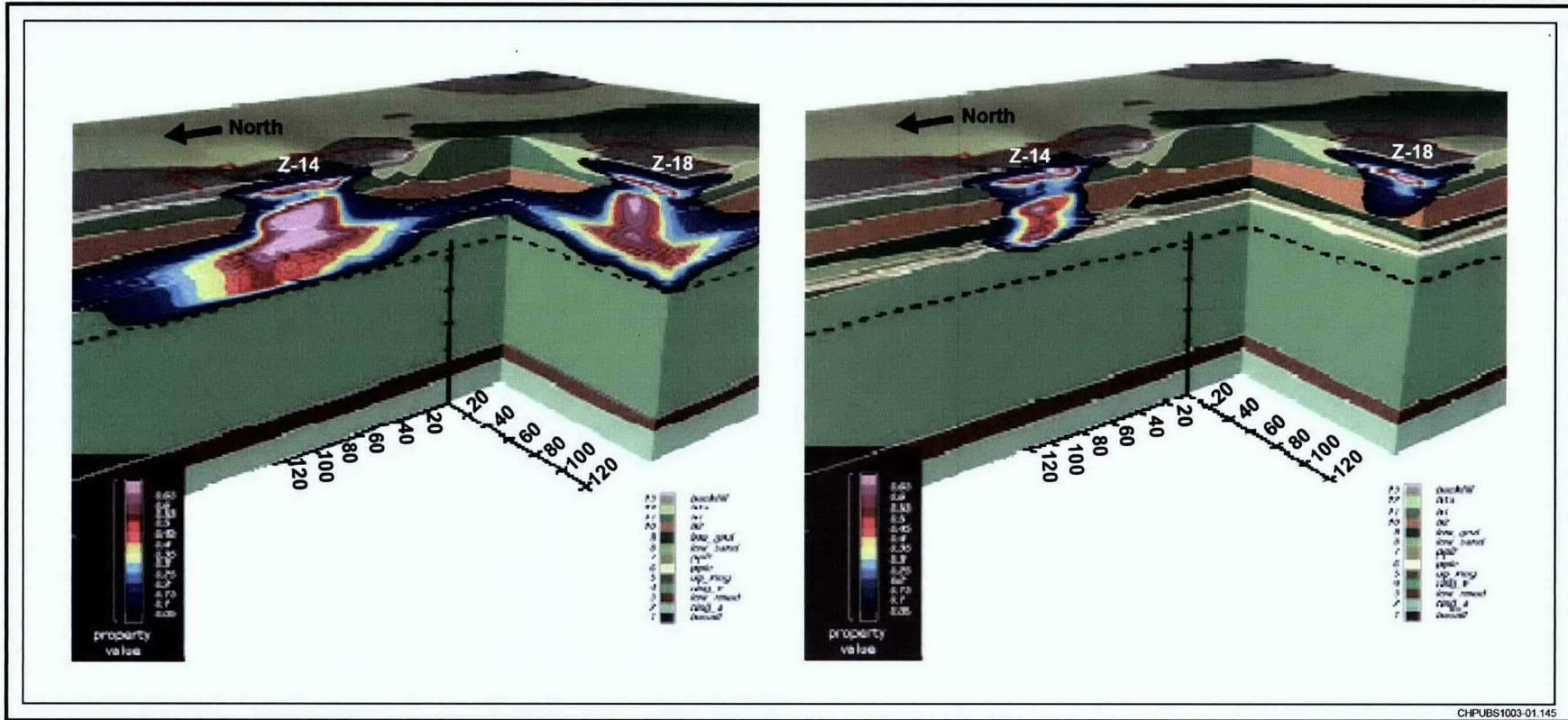
- 4 • Finer grain layers with more moisture content are less affected by SVE and contain the CT remaining
5 in the vadose zone.

6 Figures E4-23 to E4-25 illustrate many of these conclusions. Figures E4-23 and E4-24 illustrate the
7 predicted nature and extent of the CT vapor phase plumes and the CT water plume concentrations in the
8 vadose zone beneath the 216-Z-9 and 216-Z-1A Cribs over time, respectively. Figure E4-23 also shows
9 the extent of the vapor phase CT plume with and without the SVE system. The most significant features
10 and information in these figures pertaining to the nature and extent of the contaminated soil volumes in
11 the 200-PW-1 vadose zone include the following:

- 12 1. Both the vapor and aqueous (dissolved) phase plumes for CT, and by analogy, other VOA COPCs,
13 are predicted to be significantly larger than the footprint of the waste site without, and prior to,
14 operation of an SVE system, especially near the Cold Creek unit.
- 15 2. The SVE system is predicted to significantly reduce the size and concentrations of both the CT vapor
16 and aqueous phase plumes to dimensions comparable to the footprint of the waste site.
- 17 3. The residual levels of CT (and other VOAs) are predicted to be concentrated in the Cold Creek sediments.

18 These features are consistent with the other data-based lines of evidence on the spatial dimensions of the
19 contaminant plumes for the VOA COPCs previously described in Section E4.3 (i.e., transect data, COPC
20 isopleths, and 3-D plume graphics). The most significant factor is that the spatial extent of vadose zone
21 contamination and the contaminant mass for the VOAs have been reduced by the SVE system based on
22 the temporal trends in soil concentrations of CT at 216-Z-9 shown in Figure E4-12, and plotted in
23 Figure E4-11. Figure E4-26 presents a summary of the predicted versus the observed reduction in CT
24 mass for the CT phases with the operation of the SVE from 1993 to 2006. It is notable that the observed
25 reductions in CT soil concentrations at 216-Z-9 closely follow the temporal trends of total mass and
26 sorbed CT predicted in the PNNL studies. Although the focus of the PNNL studies was on CT, it is
27 logical to presume that essentially all VOAs with comparable physical and chemical properties to CT, as
28 discussed in Section E4.3.4, would be similarly affected by the SVE system, and, therefore, have
29 contaminated soil volumes with spatial and temporal patterns similar to that of CT. This appears to be
30 corroborated by the isopleths data shown for methylene chloride, tetrachloroethene, and 1-butanol in
31 Section E4.3.2, and lateral dimensions of the contaminated soil volumes of the VOA COPCs since 2006
32 as comparable to those of the waste site footprint. It is also likely that the contaminated vadose zone soil
33 plume dimensions are presently (year 2010) even smaller due to the additional time of SVE operation
34 since the last soil sampling efforts in 2006.

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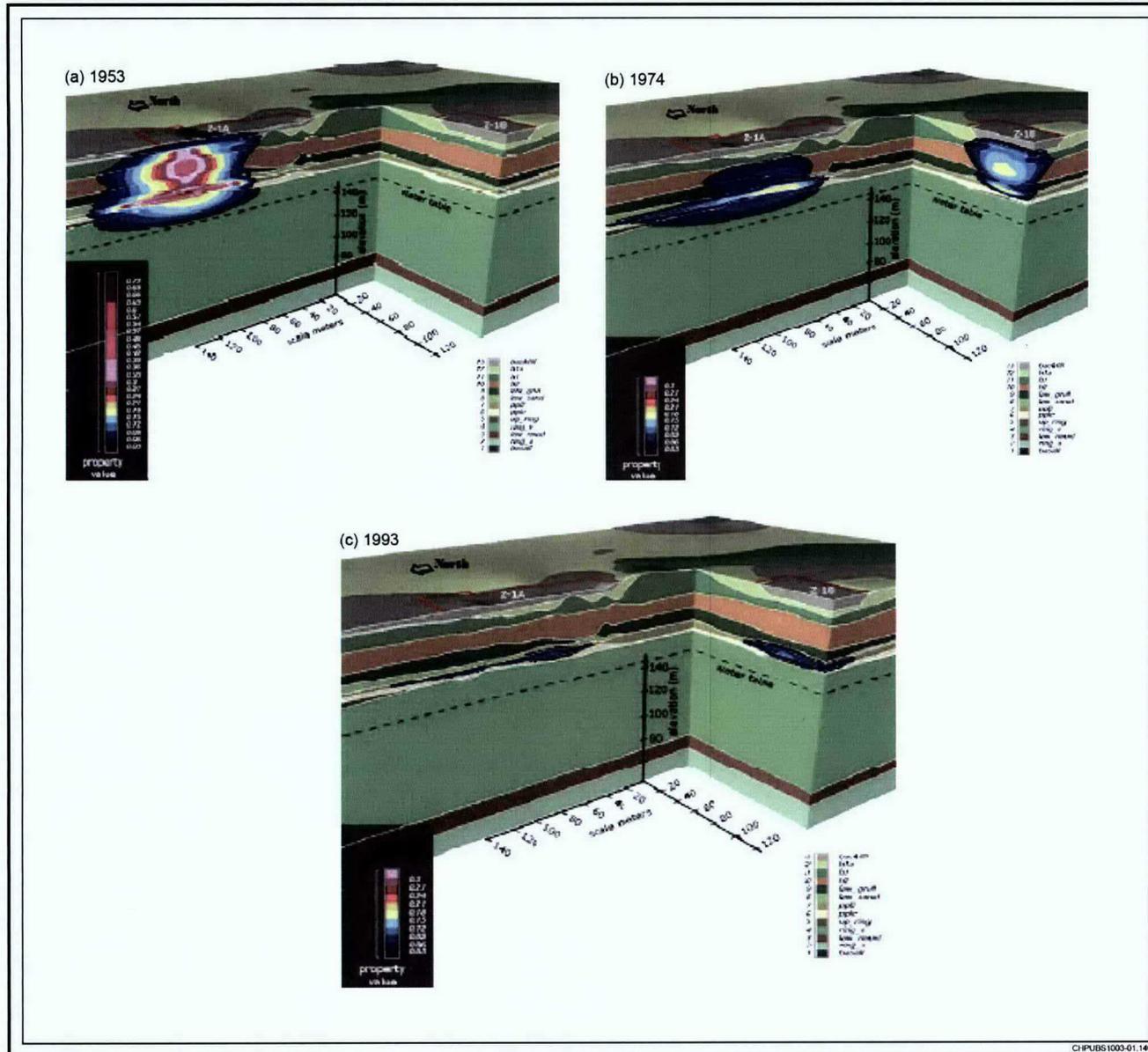
a) CT Gas Concentrations (g/L) at 1995 (Base Case)*

b) CT Gas Concentrations (g/L) at Year 2000 (Base Case with SVE)*

*0.1 g/L is equivalent to 12,000 ppmv at standard temperature and pressure. Higher CT concentrations shown in red, lower concentrations shown in dark blue

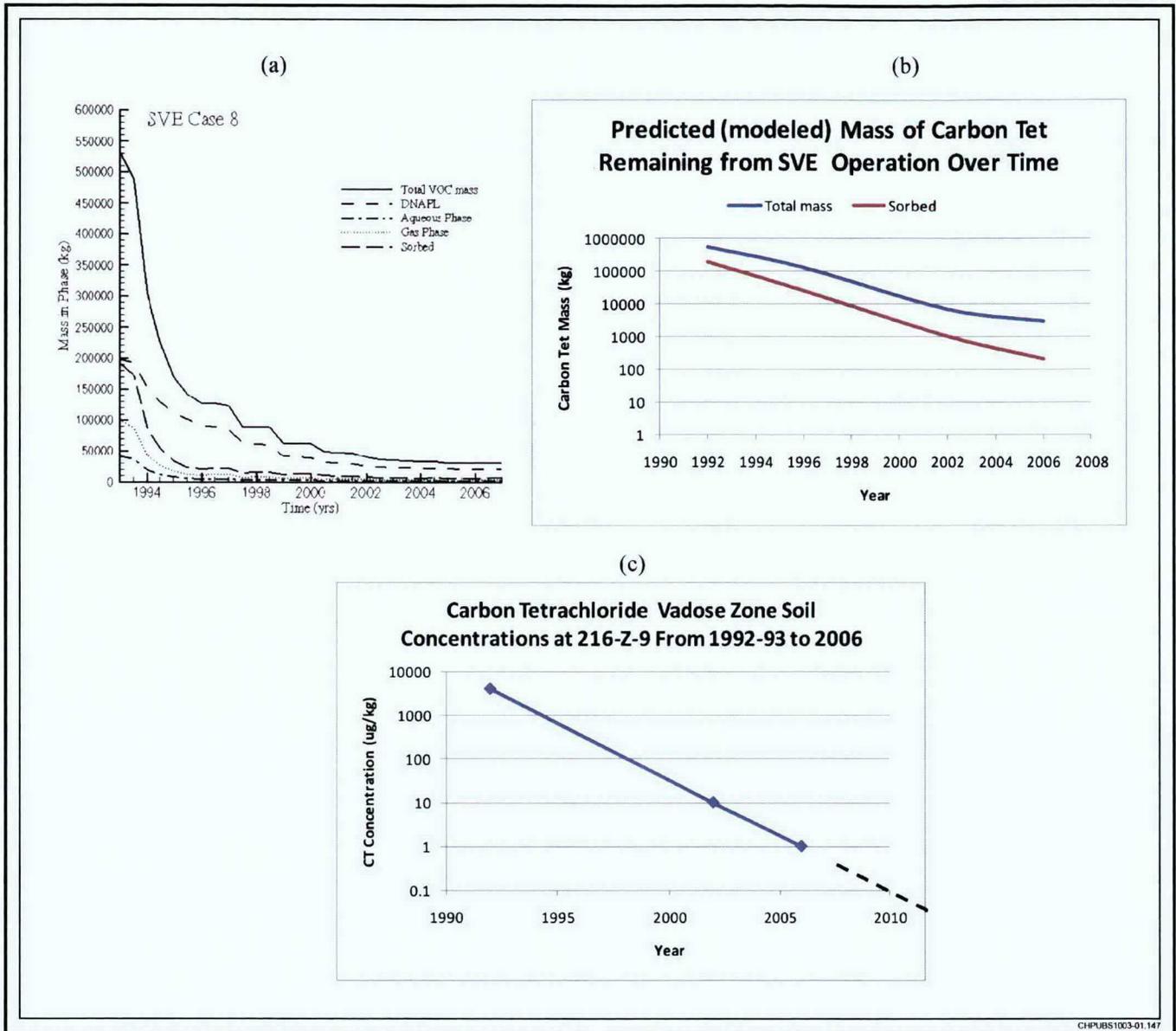
Conceptual spatial distribution of CT are from the 3-D model Base Cases reported in PNNL-16198, *Carbon Tetrachloride Flow and Transport in the Subsurface of the 216-Z-18 Crib and 216-Z-1A Tile Field at the Hanford Site: Multifluid Flow Simulations and Conceptual Model Update*.

Figure E4-23. Comparison of Conceptual Vapor Phase (gas) CT Concentrations in (a) Year 1995 Without SVE, and (b) Year 2000 with SVE



Note: Higher CT concentrations shown in red; lower CT concentrations shown in dark blue
Figure E4-24. Predicted (Modeled) Differences in CT Water Saturations Between the 1948 (Base Case) and CT Water Saturations

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Figure E4-25. (a) PNNL Predicted CT Mass Distribution over the DNAPL, Sorbed, Aqueous, and Gas Phases for 1993 - 2007 (SVE Case 8); (b) Plot of the Predicted (Modeled) Decreases in Total and Sorbed Mass of CT over Time from the Results Shown in (a); (c) Plot of Observed Average CT Concentrations for the Depth Interval 15 to 37 m (50 to 120 ft) bgs from the CT Isopleths over Time in Figure E4-12

1 This information also has relevance for evaluation of the nature and extent of mobile non-VOA COPCs
2 such as nitrogen (as nitrate+nitrite). Although mobile non-VOA contaminants are assumed to be
3 essentially unaffected by the SVE system, the spatial distribution 3-D modeling of the water-soluble
4 concentrations (dissolved CT plume) of a relatively mobile COPC such as CT, may be a reasonable
5 approximation for the spatial distribution of mobile contaminants, such as nitrate. This may be because
6 COPCs with small K_d values tend to follow the spatial distribution of the water plume. This conclusion
7 also appears to be corroborated by the estimated dimension of the contaminated soil volume for nitrogen
8 shown in Figures E4-17, E4-20, and Figure E4-21 as approximately two times the footprint dimensions of
9 the waste site. Based on this logic, it is also likely that the lateral dimensions of the contaminated soil
10 volumes for other non-VOA COPCs such as Tc-99 may be comparable to that of the nitrogen plume. For
11 contaminants such as Tc-99 that occur primarily concentrated in the Hanford formation rather than the
12 Cold Creek unit where lateral spreading appears to be greater, the lateral dimensions of the contaminated
13 soil volume may also be smaller than that of the nitrogen plume.

14 **E4.3.8 Dimensions of Contaminated Soil Volumes for Vadose Zone Fate and Transport Modeling**

15 The lateral dimensions were also defined by using specified length dimensions based on the evaluations
16 of the lateral extent of the contaminated soil volumes described in Section E4.3. The vertical (thickness)
17 dimensions of the contaminated soil volumes used to describe the source terms in the fate and transport
18 modeling were defined by assigning the depth intervals of the vadose zone contamination for each of the
19 waste sites in Table E4-1 to the corresponding parts of the domain stratigraphy. As described in
20 Section E4.2.4, three approaches to defining contaminant source term volumes were used to best
21 represent the vertical distribution of contaminants in the vadose zone:

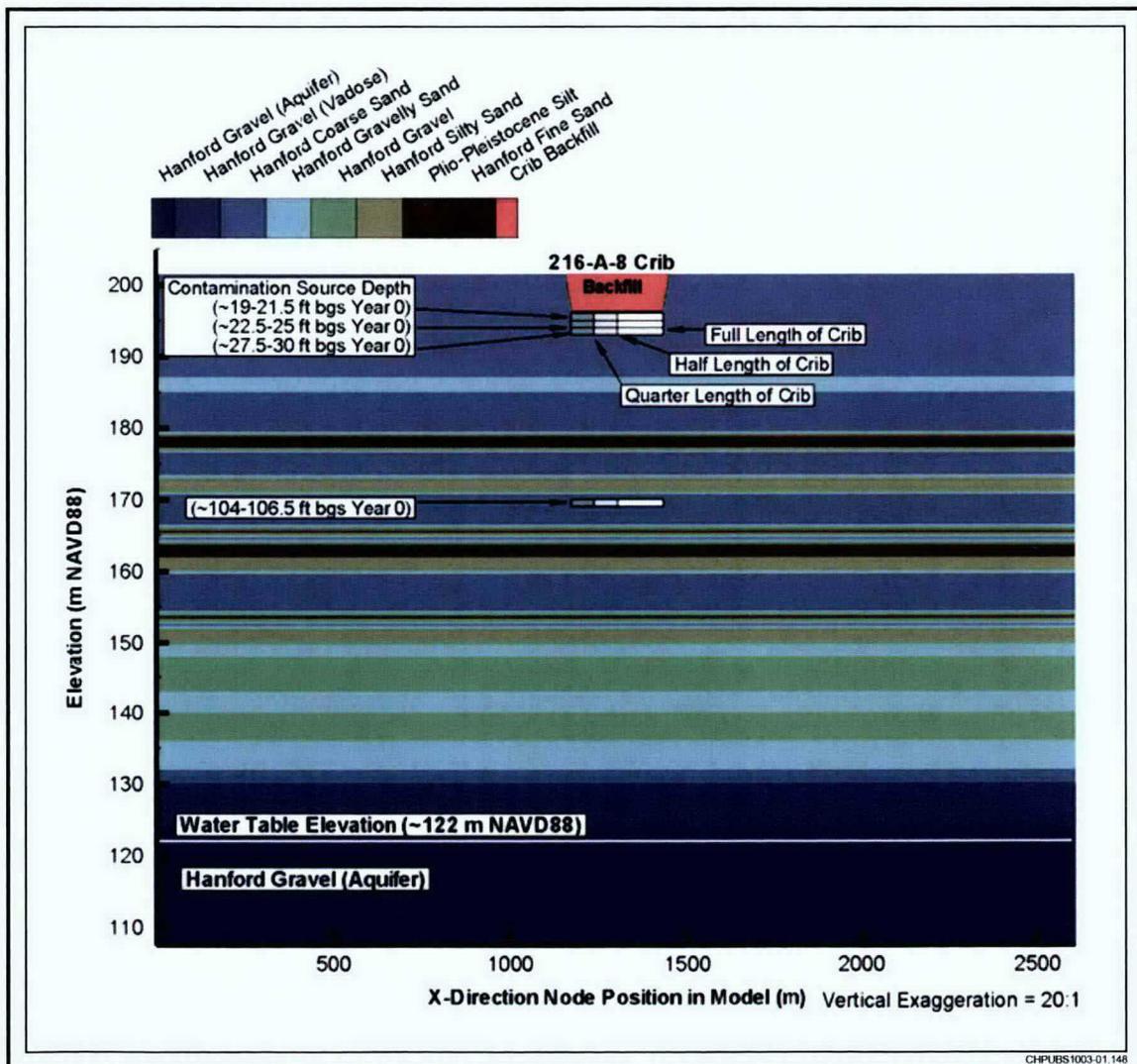
- 22 • Rectangular-shaped contaminated soil volumes for specific depth intervals
- 23 • Irregularly shaped contamination volumes where contamination is assumed to occur throughout a
24 geologic unit with variable thickness
- 25 • Contaminated source terms described as unit-thickness volumes, referred to as point source volumes

26 All three approaches for describing the contaminated soil volume source term configurations for the fate
27 and transport modeling base cases. The identification of discrete depth intervals for the contaminated soil
28 volumes allows the pooling of COPC data within the intervals to describe the population of soil
29 contamination data, from which soil concentrations for the intervals can be calculated. The dimensions of
30 the contaminated soil volumes used in the modeling is illustrated in Figures E4-26, E4-27 and E4-28 for
31 the vadose zone beneath the 216-A-8, 216-Z-1A and 216-Z-18, and 216-Z-9 waste sites, respectively.

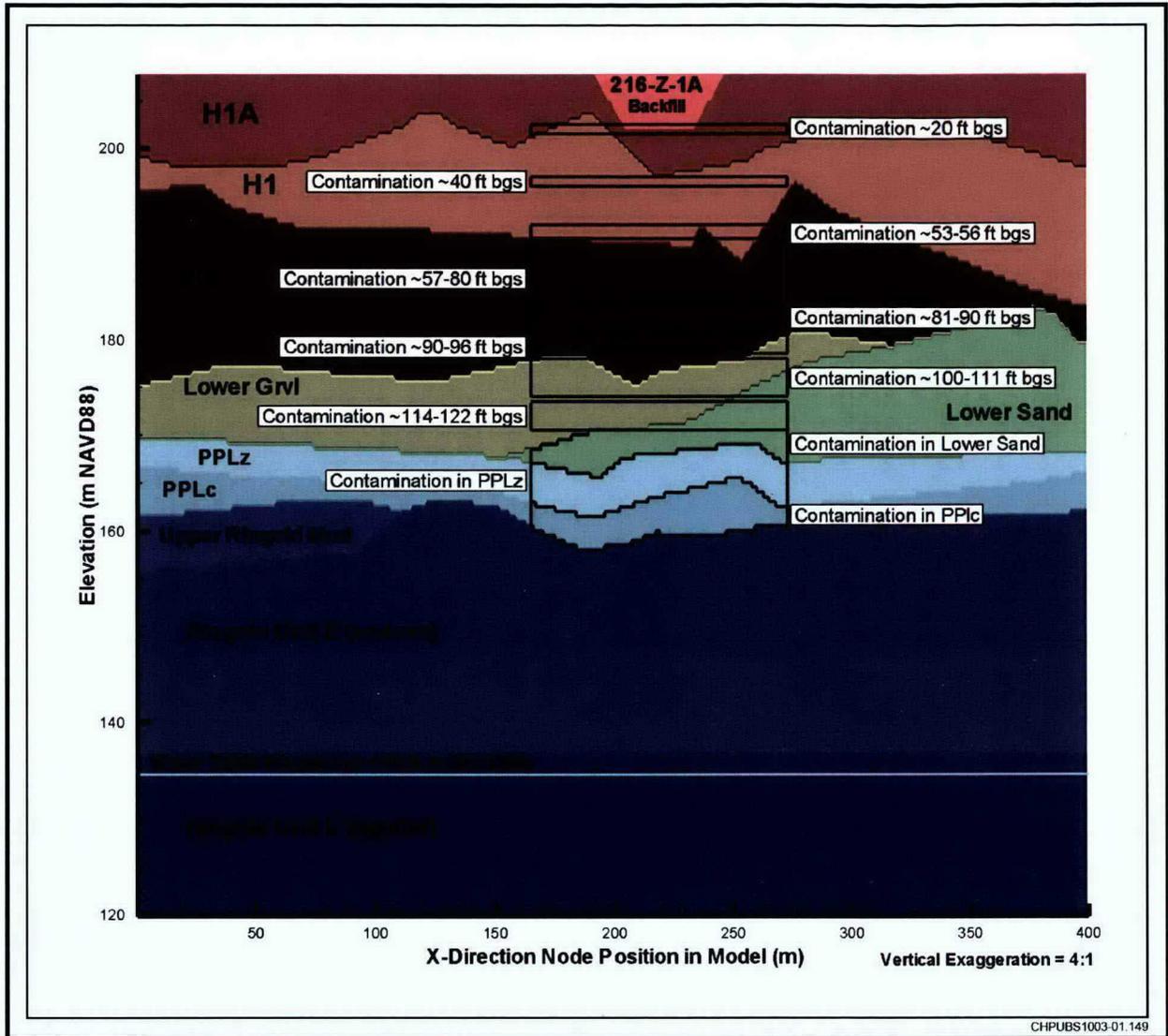
32 The contaminated soil source term volumes for the 216-A-8 Crib are described as 1 m (3.2 ft) thick point
33 source volumes in Figure E4-25 because the COPC data above screening levels primarily occur at only
34 single depths as described in Section E4.2.4. The contaminated soil volumes within the Hanford
35 formation and Ringold units beneath the 216-Z-1A, 216-Z-18, and 216-Z-9 Crib, were described as
36 essentially horizontal rectangular-shaped volumes with the thicknesses specified in Table E4-1, and
37 shown in Figures E4-26 to E4-28. The contaminated soil volumes within the upper and lower facies of the
38 Cold Creek formation at the 216-Z-1A and 216-Z-9 Crib are based on the integrated area of the
39 irregularly shaped upper and lower depth interval boundaries in the E-W cross-section shown in
40 Figures E4-27 and E4-28.

41 The lateral dimensions of the contaminated soil volumes (parallel to the direction of groundwater flow)
42 were based on the dimensions of the waste site footprint. Volumes based on the lateral dimensions of 1× and
43 2× the length of the waste site footprint parallel to the direction of groundwater flow were evaluated as base
44 cases for most waste sites. Lateral dimensions of 1×, 0.5×, and 0.25× the length of the waste site footprint

1 parallel to the direction of groundwater flow were evaluated for the contaminated soil volumes at the
 2 216-A-8 Crib. This approach allowed for flexibility in the interpretation of the model results for various
 3 COPCs in the context of the evaluation of the spatial relationships of the contaminated soil volumes
 4 presented in Section E4.3. Based on the results of the various lines of evidence presented in Section E4.3, it
 5 is indicated that the lateral dimensions of the COPC plumes in the vadose zone is estimated to be about $\leq 2\times$
 6 the dimension of the waste site footprint for mobile non-VOA COPCs, and $\leq 1\times$ the dimension of the waste
 7 site footprint for the VOAs. The use of lateral dimensions $\leq 1\times$ the dimension of the waste site footprint for
 8 the contaminated soil volumes of the less mobile COPCs is assumed to be a conservative assumption based
 9 on the contaminant behavior conceptual model. The calculation of all contaminated soil volumes were based
 10 on a width dimension of 1 m (3.2 ft) for the calculation of the COPC mass per meter width normal to the
 11 direction of groundwater flow (see Sections E4.1 and E5.4). Details on the assignment of contaminated soil
 12 volume source terms, and sensitivity cases evaluated are described in ECF-200PW1/3/6-10-0326.
 13 Sections E4.6 and E5.6 discuss associated uncertainties.

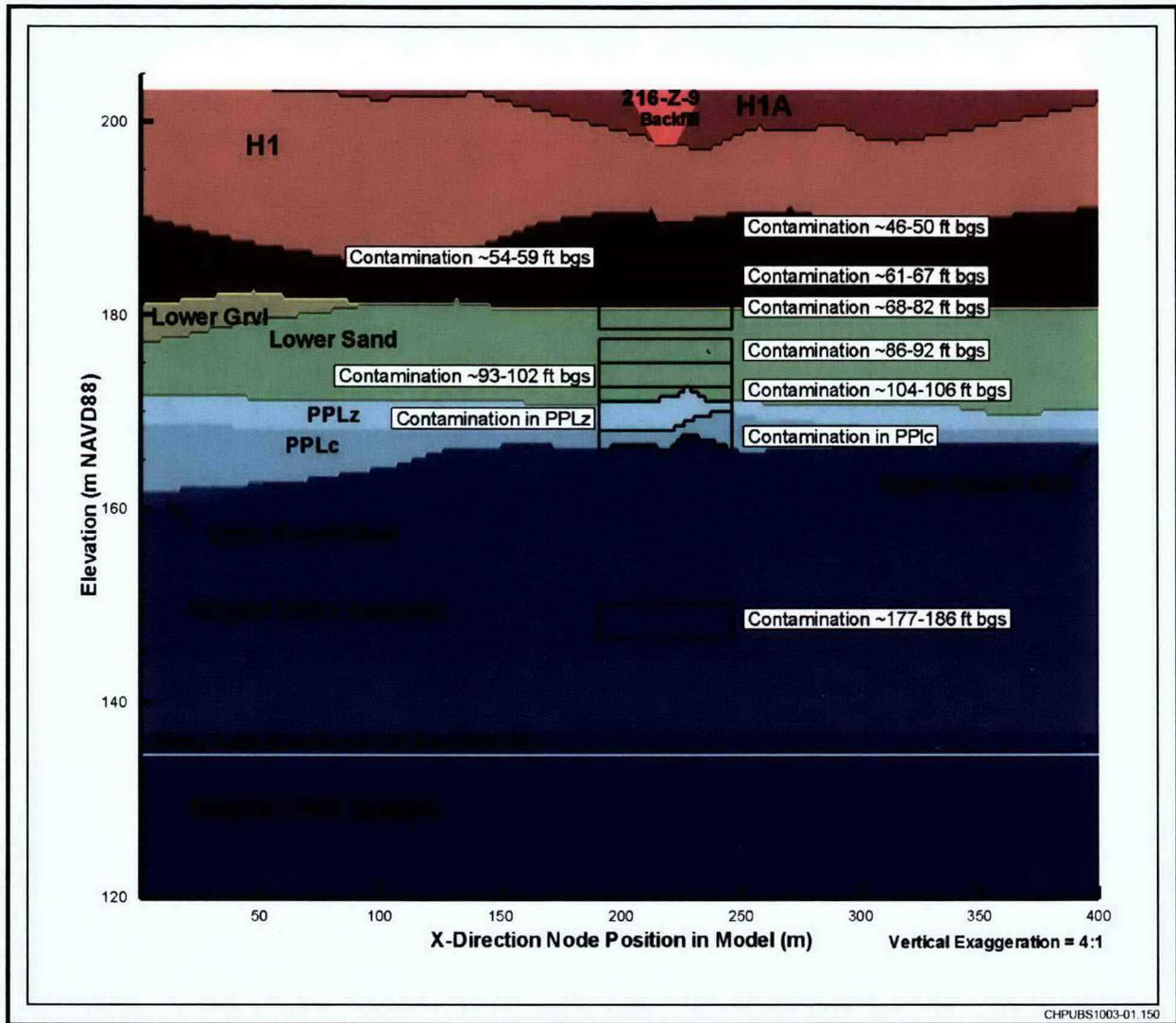


14
 15 **Figure E4-26. Locations and Distribution of Contaminated Soil Volume Source Terms Used in the**
 16 **216-A-8 Crib Contaminant Fate and Transport Analysis**



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Figure E4-27. Locations and Distribution of Contaminated Soil Volume Source Terms Used in the 216-Z-1A Crib Contaminant Fate and Transport Analysis



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Figure E4-28. Locations and Distribution of Contaminated Soil Volume Source Terms Used in the 216-Z-9 Crib Contaminant Fate and Transport Analysis

1 **E4.3.9 Calculation of Contaminated Soil Volume Concentrations**

2 The estimation of COPC soil concentrations for the contaminated soil volumes serve as the source term
3 inputs to vadose zone fate and transport modeling. This section describes the rationale and process for the
4 estimation of the concentration terms for the contaminated soil volumes at the 216-A-8, 216-A-1A,
5 216-Z-18, and 216-Z-9 waste sites described in Section E4.4.

6 At each waste site, soil concentrations were calculated for each contaminated soil volume depth interval
7 for each COPC passing the Phase I and Phase II screening, containing one or more data values above the
8 screening levels. In most cases, all of the data for a COPC evaluated within a depth interval were pooled
9 and treated as a data population for calculating concentrations intended to represent the contaminated soil
10 volume in the modeling.¹⁰ Thus, soil concentrations were only calculated for COPCs passing all
11 screening criteria, and generally only in depth intervals where all of the data were not all non-detect
12 values (“U” coded data), or not all less than the COPC screening levels described in Chapter E2.0.

13 Summary statistics were calculated from the population of data for each depth interval evaluated. The
14 calculated summary statistics include the maximum, average, 90th percentile, 95 percent upper
15 confidence limit (UCL) concentration values, and number of samples (n value) for each depth interval.
16 Tables E4-3 to E4-6 summarize the data sets and summary statistics for the data set for each COPC
17 evaluated in each depth interval for the 216-Z-1A, 216-Z-18, 216-Z-9, and 216-A-8 waste sites,
18 respectively. Data distribution types were identified for data sets with four or more data values ($n \geq 4$), and
19 the summary statistical values (e.g., mean, 90th percentile values, and 95 percent UCL values) were
20 calculated accordingly. For data sets with two values ($n=2$), the 90th percentile values were calculated as
21 $v_1 + 0.9*(v_2-v_1)$, where v_1 and v_2 equal the minimum and maximum value, respectively. For data sets with
22 three values ($n=3$), the 90th percentile values were calculated as $v_2 + 0.8*(v_3-v_2)$, where v_2 and v_3 equal
23 the median and maximum values of the data set, respectively.

24 Some summary statistical values (e.g., percentiles, UCLs) were not calculated where the numbers of
25 sample were insufficient to provide meaningful values. In those cases, only the numbers of samples,
26 maximum and average values are reported. Where the calculated values of the mean, 90th percentile, and
27 95 percent UCL values were all less than the COPC screening levels, the values in Tables E4-3 to E4-6
28 were highlighted and deemed inconsequential. This occurred for depth intervals in which there were
29 many more low, and/or non-detect data values, than data values above the screening criteria. The 90th
30 percentile and 95 percent UCL summary statistic values larger than the maximum value are also
31 highlighted and/or censored in the Tables E4-3 to E4-6 because they are not meaningful values.

32 The calculated soil concentration values for each COPC evaluated within each depth interval, based on
33 the mean, 90th percentile, and 95 percent UCL values, were all evaluated in the fate and transport
34 modeling to provide a statistical basis for the evaluation of model results and associated groundwater
35 impacts (Chapter E5.0). The use of these statistical values for source term concentration in the modeling
36 was intended to provide a basis for assignment of the source term concentration that can reduce some
37 uncertainties associated with the estimation of source term concentrations for a depth interval, versus the
38 use of e.g., maximum or average values alone. This approach was also intended to provide a basis for
39 evaluating the magnitude and direction of the source term uncertainty in the context of the overall
40 uncertainty in the modeling results. It is notable that the calculated 95 percent UCL values for many of
41 depth intervals differ only moderately from the mean values, especially where the population of COPC

¹⁰ In some cases, a value of zero was assigned to data values where reported values below detection limits exceeded the values of data above detection limits, to avoid the generation of summary statistics for soil concentrations dominated by data below detection rather than data above detection.

1 values includes a relatively large proportion of small and/or non-detect values together with a smaller
2 number of larger values.

3 **E4.3.10 Summary Statistic Calculation QA/QC**

4 Summary statistics were calculated from the population of data for each depth interval evaluated using
5 Microsoft Excel® statistical functions and the EPA ProUCL software, Version 4.0.4. The summary
6 statistical values (e.g., mean, 90th percentile values, and 95 percent UCL values) for data sets with four or
7 more data values ($n \geq 4$) were calculated using the ProUCL software to utilize the capability of the
8 ProUCL software to identify data distribution types, and to calculate 95 percent UCL values accordingly.
9 For data sets with only two or three values ($n=2$ or 3), the 90th percentile values were calculated using
10 Microsoft Excel statistical functions that implement the methods described in Section E4.3.9.

11 Because the input data, mathematical formulas, and calculations used in the Microsoft Excel and ProUCL
12 spreadsheets are wholly incorporated into the documentation and can be exactly verified, these
13 spreadsheet tools are exempt from the requirements of contractor-approved internal work requirements
14 and processes.

15 **E4.4 Comparison of Methods for Estimating Representative Concentrations of** 16 **Contaminated Soil Volumes**

17 One of the largest sources of uncertainty in the results of the fate and transport modeling is associated
18 with the calculation of the contaminant source term mass, which is based on the estimated values for the
19 contaminated soil volumes and the contaminant concentrations. The contaminant concentration term
20 appears to be the largest source of uncertainty in the source term definition for the 200-PW-1/3/6
21 modeling. The COPC concentration values assigned to a contaminated soil volume are intended to
22 represent the integrated range of concentrations throughout the volume, i.e., the average composition.
23 Contaminant masses are determined from these concentration values in the fate and transport models
24 based on the relationships described in Equation E4-1, and are used as the source term in the evaluation of
25 groundwater impacts. The source term mass is an especially significant parameter in the fate and transport
26 modeling because the modeled groundwater concentrations are proportional to the source term mass. The
27 capability of the model to yield meaningful results depends to a large extent on how well the estimates of
28 the source term concentrations represent those that actually occur in the natural system, and the
29 uncertainty associated with the estimation of the source term concentration. This significant factor must
30 be considered in the interpretation of model results and associated risk management decisions, because
31 the largest source of uncertainty is often associated with the source term definition involving estimation
32 of contaminated soil volumes and representative COPC soil concentrations, and/or associated
33 assumptions. Therefore, an assessment of the assumptions and uncertainties associated with the source
34 term definition for the 200-PW-1/3/6 modeling is warranted. The following is a discussion of the key
35 uncertainty factors associated with the estimation of the contaminated soil volumes and concentrations for
36 the 200-PW-1/3/6 modeling.

37

Table E4-3. 216-Z-1A Soil Concentration Data and Summary Statistics for the Depth Intervals Evaluated in Fate and Transport Modeling

216-Z-1A COPCs	1,1-Dichloroethane			Chloroform				Carbon Tetrachloride										
	57-80	100-111	Cold Creek Silt	57-80	114-122	Hanford L. Sand	Cold Creek Silt	20	40	53-56	57-80	81-90	90-96	100-111	114-122	Hanford L. Sand	Cold Creek Silt	Cold Creek Carb
Screening Level	0.0419			0.00751				0.00310										
Concentration Units	mg/kg			mg/kg				mg/kg										
Soil Concentration Data	0	0	0	0.003	0	0.012	0.135	0.003	0.026	0.031	0.133	0.056	0.018	0.016	0.024	0.789	0.317	0.772
	0	0	0	0	0	0.019	0.012			0.028	0.075	0.051	0.006	0.003	0.103	1.247	1.093	
	0	0	0	0.008	0	0	0			0.041	0.143	0.095	0.013	0.002	0.246	0.796	0.051	
	0	0	0.006	0	0	0	0.003			0.095	0.126	0.099	0.015	0.061	0.498	0.89	0.644	
	0	0	0.076	0	0	0	0				0.083	0.035	0.044	0.003	0.05	0.072	0.261	
	0	0		0	0	0.038					0.126	0.06	0.013	0	0.034	0.749		
	0.1	0		0.031	0	0					0.36	0.074	0.019	0.035	0.23	0.045		
	0	0		0	0	0.12					0.069			0.01	0.037	6.561		
	0	0		0	0	0.063					0.15			0.116	0.068	3.088		
	0.075	0		0.021	0	0.095					0.147				0.063	4.124		
	0	0.003		0	0	0					0.052				0.032	0.024		
	0	0		0.02	0	0.05					0.349				0.02	0.374		
	0			0	0						0.151				0.026			
	0			0	0.04						0.337				0.427			
	0			0	0.085						0.115				0.357			
	0			0.006							0.067							
	0			0.005							0.067							
	0			0							0.137							
n	18	12	5	18	15	12	5	1	1	4	18	7	7	9	15	12	5	1
min	0	0	0	0	0	0	0	0.003	0.026	0.028	0.052	0.035	0.006	0	0.02	0.024	0.051	0.772
max	0.100	0.003	0.076	0.031	0.085	0.12	0.135	0.0030	0.0260	0.0950	0.360	0.099	0.044	0.116	0.498	6.561	1.093	0.772
avg	0.0097	0.0003	0.0164	0.0052	0.0083	0.0331	0.0300	0.0030	0.0260	0.0488	0.1493	0.0671	0.0183	0.0273	0.1477	1.5633	0.4732	0.7720
90th Percentile	0.0225	0.0000	0.0410	0.0203	0.0200	0.0886	0.0735	-	-	0.0734	0.3390	0.0962	0.0265	0.0665	0.3920	3.9170	0.8690	0.7720
95% UCL	0.0215	0.0007	0.0483	0.0090	0.0191	0.0545	0.0862	-	-	0.0856	0.2000	0.0844	0.0272	0.0514	0.2530	3.5310	0.8610	

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Table E4-3. 216-Z-1A Soil Concentration Data and Summary Statistics for the Depth Intervals Evaluated in Fate and Transport Modeling

216-Z-1A COPCs	Methylene Chloride						Tetrachloroethene (PCE)						Trichloroethene (TCE)						Nitrogen (Nitrate+Nitrite)	
	40	57-80	81-90	90-96	100-111	114-122	57-80	81-90	100-111	114-122	Hanford L. Sand	Cold Creek Silt	57-80	81-90	100-111	114-122	Hanford L. Sand	Cold Creek Silt	53-56	81-90
Screening Level	0.0218						0.000859						0.0223						9.03	
Concentration Units	mg/kg						mg/kg						mg/kg						mg/kg	
Soil Concentration Data	4.679	0	0	0	0.194	0	0	0	0	0	0.047	0.001	0	0.002	0	0	0.061	56.5	0.5	
		0	0	0	0	0	0	0	0	0.008	0	0	0	0	0	0	0.003		121.7	
		1.062	0	0.181	0	0	0.005	0.005	0	0	0	0	0	0.005	0	0	0	0		0.54
		0	0		1.858	0	0.005	0.006	0.003	0	0	0	0.004	0.006	0.003	0	0	0.003		487
		0	0		0	0.113	0.004	0	0	0.002	0	0	0	0	0	0.003	0	0		
		2.264	0		0	0	0.007	0	0	0	0.024		0	0	0	0	0.031			
		0	0.116		0.153	0	0.021	0.002	0.003	0	0		0.03	0.002	0.005	0	0.002			
		0				0	0		0	0	0.029		0		0	0	0.041			
		0.771			0	0	0		0.004	0	0.033		0		0.004	0	0.042			
		0				0.122	0.01			0.002	0.05		0.021			0.002	0.068			
		0				0.578	0			0	0		0			0	0			
		0				0	0.004			0	0.034		0			0	0.044			
		0				0	0			0			0			0				
		0.538				0	0			0			0			0				
		0				0	0.004			0			0.004			0				
	0				0	0.003			0			0			0					
	0				0	0.003			0			0			0					
	0				0	0.005			0			0.004			0					
n	1	17	7	3	8	15	18	7	9	15	12	5	18	7	9	15	12	5	1	4
min	4.68	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	56.5	0.5
max	4.68	2.264	0.116	0.181	1.858	0.578	0.021	0.006	0.004	0.002	0.05	0.047	0.03	0.006	0.005	0.003	0.068	0.061	56.5	487
avg	4.68	0.2726	0.0166	0.0603	0.276	0.0542	0.0039	0.0019	0.0011	0.0003	0.0148	0.0094	0.0036	0.0019	0.0016	0.0003	0.0190	0.0134	56.5	152
90th Percentile	4.68	0.8580	0.0348	0.145	0.527	0.118	0.0076	0.0053	0.0031	0.0010	0.0338	0.0235	0.0074	0.0053	0.0041	0.0010	0.0436	0.0320	56.5	341
95%UCL	-	0.5290	0.0488	-	0.707	0.123	0.0061	0.0038	0.0022	0.0006	0.0242	0.0294	0.0070	0.0038	0.0028	0.0007	0.0317	0.0388	-	423

Note: Values reported only where calculable (n>3), and not greater than the maximum value.

Values in red denote values less than detection or less than the screening level, but used in the calculation of summary statistics. Summary statistics shaded in gray denote values less than the COPC screening level.

Table E4-4. 216-Z-18 Soil Concentration Data and Summary Statistics for the Depth Intervals Evaluated in Fate and Transport Modeling

216-Z-18 COPCs	Benzene	Carbon Tetrachloride											Chloroform				Ethylbenzene
Depth Interval/ Soil Volume	40	20	40	53-56	57-80	81-90	90-96	100-111	114-122	Hanford L. Sand	Cold Creek Silt	Cold Creek Carb	81-90	100-111	Hanford L. Sand	Cold Creek Silt	53-56
Screening Level	0.00448	0.00310											0.00751				0.0344
Concentration Units	mg/kg	mg/kg											mg/kg				mg/kg
Soil Concentration Data	0	0.004	0.006	0.009	0.122	0.139	0.099	0.111	0.034	0.041	1.618	0	0	0	0	0.007	0.027
	0		0.006	0.015	0.039	0.089	0.056	0.193	0.012	0.052	0.111	0	0	0	0	0.044	0.061
	0		0.007	0.024	0.031	0.133	0.188	0.168	0.006	0.009	0.017	0.002	0	0.023	0	0	
	0.004			0.013	0.074	0.079	0.124	0.053	0.028	0.041	0.134	0	0	0	0	0	
	0.011				0.216	0.093		0	0.007	0.068	0.717	0	0	0	0	0.004	
	0				0.184	0.566		0.004	0	0.005	0.786		0.016	0	0	0.007	
	0					0.332			0.242	0.008	0.759		0.021	0	0	0.005	
	0					0.44			0.127	0.058	0.334		0.004	0	0.018	0.004	
	0								0.14	0.065	0.494			0	0	0.004	
	0								0.014	0.043	0.481			0	0	0.004	
	0								0.044	0.028	0.861			0	0	0.005	
									0.01	0.039	0.714				0	0.004	
									0.004	0.016	0.626				0	0	
									0.017	0.014	0.024				0	0.004	
									0.005	0.028				0	0.003		
									0.004	1.957				0	0.008		
n	11	1	3	4	6	8	4	14	6	16	16	5	8	11	16	16	2
min	0	0.004	0.006	0.009	0.031	0.079	0.056	0	0	0.004	0.017	0	0	0	0	0	0.0270
max	0.011	0.004	0.0070	0.024	0.216	0.566	0.188	0.242	0.034	0.068	1.957	0.002	0.021	0.023	0.018	0.044	0.0610
avg	0.0014	0.0040	0.0063	0.0153	0.1110	0.2339	0.1168	0.0805	0.0145	0.0310	0.6038	0.0004	0.0051	0.0021	0.0011	0.0064	0.0440
90 th Percentile	0.0036	0.0040	0.0068	0.0213	0.1970	0.4650	0.1620	0.1830	0.0304	0.0608	1.1640	0.00100	0.0170	0.0000	0.0000	0.0074	0.0576
95% UCL	0.0032	-	-	0.0227	0.1740	0.4230	0.1820	0.1190	0.0256	0.0409	1.0450	0.00125	0.0108	0.0059	0.0031	0.0109	-

Table E4-4. 216-Z-18 Soil Concentration Data and Summary Statistics for the Depth Intervals Evaluated in Fate and Transport Modeling

216-Z-18 COPCs		Methylene Chloride									Tetrachloroethene (PCE)					Nitrogen (nitrate+nitrite)	
Depth Interval/ Soil Volume	20	40	53-56	57-80	81-90	90-96	100-111	114-122	Hanford L. Sand	Cold Creek Silt	57-80	90-96	100-111	Hanford L. Sand	Cold Creek Silt	81-90	100-111
Screening Level	0.0218									0.000859					9.03		
Concentration Units	mg/kg									mg/kg					mg/kg		
Soil Concentration Data	0.134	0	1.992	0	10.98	0	0	1.325	0	1.612	0	0	0	0	0.033	1.603	0.926
	0.08	0	0.237	0	0	0	0	0	0	0	0	0	0	0	0.033	994	223.5
	0	0	0.056	0.125	1.108	0.559	90.0	0	0	0	0	0.005	0.006	0	1.755		
		0.272		0	0	0	0	0	0.061	0.079	0	0	0	0	0.047		
		0		0.126	0	0	0	0	0	0	0	0	0	0	0.0003		
				0	0.083	0	0	0	0	0	0	0.002	0.002	0			
					0	0	0	0	0.085	0	0		0.002	0			
					0	0	0	0	88.8	0	0		0	0.002			
								0	0	0	27.7		0	0			
								0.089	0	0	0		0	0			
n	3	5	3	6	8	4	13	7	16	15	6	4	10	16	5	2	2
min	0	0	0.0560	0	0	0	0	0	0	0	0	0	0	0	0.0003	1.60	0.93
max	0.134	0.272	1.99	0.126	11.0	0.559	90.0	1.325	88.8	27.7	0.0020	0.0050	0.0060	0.0020	1.76	994	224
avg	0.0713	0.0544	0.762	0.0418	1.52	0.140	6.93	0.189	5.57	2.07	0.0003	0.00125	0.0010	0.000125	0.374	498	112
90th Percentile	0.123	0.136	1.641	0.125	3.08	0.335	0.0623	0.398	0.124	1.61	0.0008	0.0030	0.0020	0.0000	0.901	894	201
95%UCL	-	0.170	-	0.0951	4.10	0.469	19.3	0.557	15.3	5.31	0.0010	0.0042	0.0021	0.00034	1.11	-	-

Note: Values reported only where calculable (n>3), and not greater than the maximum value.
Values in red denote values less than detection or less than the screening level, but used in the calculation of summary statistics. Summary statistics shaded in gray denote values less than the COPC screening level.

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Table E4-5. 216-Z-9 Soil Concentration Data and Summary Statistics for the Depth Intervals Evaluated in Fate and Transport Modeling

216-Z-9 COPCs	1,1,2,2-Tetra-chloroethane		1,1,2-Tri-chloroethane	1-Butanol			Bromodi-chloromethane	Bromoform
	54-59	61-67	61-67	54-59	61-67	86-92	61-67	61-67
Screening Level	0.00123		0.00427	3.31			0.00368	0.0363
Concentration Units	mg/kg		mg/kg	mg/kg			mg/kg	mg/kg
Soil Concentration Data	0.015	0.0003	0.00029	0.0035	0	0.0036	0.000134	0.0002
	0.0038	0.0051	0.0003	0.075	0.0037	0.0037	0.00014	0.00025
		0.014	0.0003	4	0.0037	0.0762	0.000141	0.00026
		0.017	0.00031		0.0039	0.26	0.00018	0.00026
			0.00031		0.034	2.5	0.00034	0.00026
			0.00031		0.14	3.2	0.00035	0.00026
			0.00031		0.43	3.8	0.00035	0.00027
			0.00032		4	4.2	0.00036	0.00027
			0.00032		5.7	4.4	0.00036	0.00027
			0.000364			5	0.00036	0.00027
			0.000382				0.00037	0.00028
			0.0005				0.00037	0.000345
			0.00063				0.00038	0.000362
			0.019				0.012	0.051
			0.057				0.031	0.06
		0.067				0.037	0.12	
n	2	4	16	3	9	10	16	16
min	0.004	0.000	0.000	0.004	0.000	0.004	0.000	0.000
max	0.015	0.017	0.067	4.0	5.7	5.0	0.0370	0.120
avg	0.0094	0.0091	0.00923	1.36	1.15	2.34	0.0052	0.0147
90th Percentile	0.0139	0.0158	0.0342	3.22	4.17	4.40	0.0196	0.0546
95% UCL	-	-	0.0185	-	2.48	3.54	0.0103	0.0295

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Table E4-5. 216-Z-9 Soil Concentration Data and Summary Statistics for the Depth Intervals Evaluated in Fate and Transport Modeling

216-Z-9 COPCs	Carbon Tetrachloride								
Depth Interval/ Soil Volume	46-50	54-59	61-67	68-82	86-92	93-102	102-106	Cold Creek Silt	Cold Creek Carb
Screening Level	0.0031								
Concentration Units	mg/kg								
Soil Concentration Data	0.0003	0.0009	0.0003	0.0009	0.0002	0.0008	0.0003	0.00016	0.00016
	0.001	0.001	0.0003	0.0009	0.0002	0.0009	0.0007	0.001	0.00052
	0.014	0.27	0.0009	0.0009	0.0002	0.001	0.0007	0.0011	0.00078
		2.6	0.001	0.001	0.0009	0.001	0.0008	0.0011	
			0.001	0.001	0.001	0.0036	0.001	0.0011	
			0.001	0.001	0.001	0.005	0.001	0.002	
			0.001	0.001	0.005	0.02	0.001	0.0021	
			0.001	0.013	0.019	0.15	0.001	0.003	
			0.001		0.057	0.47	0.001	0.005	
			0.001		0.058		0.001	0.005	
			0.001		0.059		0.001	0.009	
			0.035				0.001	0.092	
			0.52				0.001	0.14	
			0.75				0.0011	0.19	
			1.5				0.0011	0.24	
			380				0.0012		
			390				0.0019		
							0.0042		
							0.005		
							0.005		
						0.0051			
						0.006			
						0.006			
						0.006			
						0.006			
						0.006			
						0.006			

Table E4-5. 216-Z-9 Soil Concentration Data and Summary Statistics for the Depth Intervals Evaluated in Fate and Transport Modeling

216-Z-9 COPCs	Carbon Tetrachloride								
Depth Interval/ Soil Volume	46-50	54-59	61-67	68-82	86-92	93-102	102-106	Cold Creek Silt	Cold Creek Carb
Screening Level	0.0031								
Concentration Units	mg/kg								
							0.0065		
							0.075		
							0.085		
							0.13		
							0.14		
							0.15		
							0.18		
							0.2		
							0.24		
							0.24		
							0.26		
							0.29		
							0.38		
							1.3		
							4.1		
							6.3		
n	3	4	17	8	11	9	43	15	3
min	0.000	0.001	0.000	0.001	0.000	0.001	0.000	0.000	0.000
max	0.014	2.6	390	0.013	0.059	0.470	6.30	0.240	0.00078
avg	0.0051	0.718	45.5	0.0025	0.0183	0.0725	0.329	0.046	0.0005
90th Percentile	0.0114	1.67	115	0.0034	0.0579	0.182	0.281	0.165	0.0007
95%UCL	-	2.20	99.6	0.0053	0.0326	0.170	0.620	0.0826	-

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Table E4-5. 216-Z-9 Soil Concentration Data and Summary Statistics for the Depth Intervals Evaluated in Fate and Transport Modeling

216-Z-9 COPCs	Chloroform						Methylene Chloride
	46-50	54-59	61-67	102-106	Cold Creek Silt	Cold Creek Carb	Cold Creek Silt
Screening Level	0.00751						0.0218
Concentration Units	mg/kg						mg/kg
Soil Concentration Data	0.0002	0.0001	0.0002	0.0002	0.00016	0	0
	0.0002	0.0002	0.0002	0.0002	0.00017	0	0
	0.016	0.0002	0.0002	0.0002	0.00024	0.00034	0
	0.11	0.0002	0.0003	0.0002	0.0012	0.000342	0
		0.0002	0.0031	0.0002	0.0014	0.00093	0
		0.0002	0.0036	0.0002	0.0021	0.0011	0
		0.0002	0.006	0.0002	0.003	0.0012	0
		0.0002	0.0093	0.0002	0.005	0.0019	0
		0.0002	0.024	0.0002	0.005	0.0026	0
		0.0002		0.0002	0.005	0.0027	0
		0.0002		0.0002	0.005	0.0027	0
		0.0022		0.0005	0.0087	0.0028	0
		0.034		0.0005	0.013	0.0028	0.00034
		0.053		0.0006	0.08	0.0028	0.000342
		0.076		0.0007	0.19	0.0029	0.00093
		4.9		0.0007		0.0029	0.0011
		5.3		0.0012		0.0031	0.0012
				0.0018		0.0031	0.0019
				0.0019		0.0036	0.0026
				0.002		0.0036	0.0027
			0.0024		0.0044	0.0027	
			0.003		0.0046	0.0028	
			0.005		0.0055	0.0028	
			0.005		0.0056	0.0028	
			0.006		0.022	0.0029	
			0.006		0.028	0.0029	
			0.006		0.12	0.0031	

Table E4-5. 216-Z-9 Soil Concentration Data and Summary Statistics for the Depth Intervals Evaluated in Fate and Transport Modeling

216-Z-9 COPCs	Chloroform						Methylene Chloride
	46-50	54-59	61-67	102-106	Cold Creek Silt	Cold Creek Carb	Cold Creek Silt
Screening Level	0.00751						0.0218
Concentration Units	mg/kg						mg/kg
	0.006						0.0031
	0.006						0.0036
	0.014						0.0046
	0.015						0.0056
	0.019						0.014
	0.024						0.02
	0.025						0.02
	0.071						0.022
	0.073						0.028
	0.073						0.03
	0.12						0.03
	0.14						0.12
	0.17						0.12
	0.25						0.198
	0.26						0.24
	0.36						0.338
	0.38						
n	4	17	9	43	15	27	44
min	0.000	0.000	0.000	0.000	0.000	0.000	0.000
max	0.110	5.30	0.024	0.360	0.190	0.120	0.380
avg	0.0316	0.6098	0.0052	0.0389	0.0213	0.0086	0.0365
90th Percentile	0.0724	1.523	0.0108	0.134	0.047	0.0105	0.120
95%UCL	0.0937	1.33	0.0220	0.0596	0.152	0.0162	0.0587

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Table E4-5. 216-Z-9 Soil Concentration Data and Summary Statistics for the Depth Intervals Evaluated in Fate and Transport Modeling

216-Z-9 COPCs	Tetrachloroethene (PCE)						Trichloroethene (TCE)
Depth Interval / Soil Volume	54-59	61-67	68-82	102-106	Cold Creek Silt	Cold Creek Carb	61-67
Screening Level	0.000859						0.022
Concentration Units	mg/kg						mg/kg
Soil Concentration Data	0.00028	0.00029	0.00027	0.00027	0.00028	0.00032	0.00026
	0.0003	0.00029	0.00028	0.00029	0.00029	0.00032	0.000287
	0.00031	0.0003	0.00028	0.0003	0.0003	0.00032	0.000302
	0.0083	0.0003	0.00029	0.00042	0.0003	0.00032	0.00037
	0.13	0.0003	0.0003	0.0014	0.0003	0.00041	0.00038
		0.0003	0.00031	0.002	0.0003	0.002	0.00038
		0.00031	0.0024	0.0036	0.0003	0.0021	0.00039
		0.00031		0.012	0.00031	0.003	0.00039
		0.00038			0.00031	0.005	0.00039
		0.0004			0.00031	0.005	0.0004
		0.0031			0.00032	0.0054	0.00046
		0.0052			0.00032	0.006	0.00052
		0.037			0.00032	0.006	0.0013
		0.073			0.00032	0.077	0.04
		0.22			0.00032	0.19	0.047
		12			0.00032		0.11
		17			0.00034		0.17
					0.0004		
					0.000402		
					0.00063		
				0.00066			
				0.00092			
				0.00094			
				0.0012			
				0.0012			
				0.0013			
				0.0014			

Table E4-5. 216-Z-9 Soil Concentration Data and Summary Statistics for the Depth Intervals Evaluated in Fate and Transport Modeling

216-Z-9 COPCs	Tetrachloroethene (PCE)						Trichloroethene (TCE)
Depth Interval / Soil Volume	54-59	61-67	68-82	102-106	Cold Creek Silt	Cold Creek Carb	61-67
Screening Level	0.000859						0.022
Concentration Units	mg/kg						mg/kg
					0.0016		
					0.0019		
					0.0026		
					0.005		
					0.005		
					0.006		
					0.006		
					0.006		
					0.006		
					0.006		
					0.012		
					0.015		
					0.032		
					0.069		
					0.12		
					0.13		
n	5	17	7	8	44	15	17
min	0.000	0.000	0.000	0.000	0.000	0.000	0.000
max	0.13	17	0.0024	0.012	0.130	0.190	0.170
avg	0.0278	1.7260	0.0006	0.0025	0.0101	0.0202	0.0219
90th Percentile	0.0692	3.75	0.0009	0.0053	0.0138	0.0415	0.0659
95%UCL	0.0824	3.80	0.0012	0.0074	0.0171	0.0433	0.042

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Table E4-5. 216-Z-9 Soil Concentration Data and Summary Statistics for the Depth Intervals Evaluated in Fate and Transport Modeling

216-Z-9 COPCs	Technetium-99			Hexavalent Chromium	Nitrogen (nitrate+nitrite)								
	46-50	54-59	61-67	Cold Creek Carb	46-50	61-67	68-82	86-92	93-102	102-106	Cold Creek Silt	Cold Creek Carb	177-186
Screening Level	3.60			0.192	9.03								
Concentration Units	pCi/g			mg/kg	mg/kg								
Soil Concentration Data	14.3	71.1	15.8	0.15	28.06	15.60	14.68	1670	58.7	129	205	14.3	19.8
	18		272	0.22	1.47	1.69		1540		236	157	21.7	21.2
				0.23	23.46	86.64		1290		187	0.00	18.9	22.5
					9.60	10.80		384			1403	26.0	22.1
											126	35.5	12.2
											103	0.181	17.2
											79.0	1.35	
											0.27	33.3	
											1261	515	
												361	
n	2	1	2	3	4	4	1	4	1	3	9	10	6
min	14.3	71.1	15.8	0.150	1.47	1.69	14.7	384	58.7	129	0.000	0.181	12.194
max	18.0	71.1	272	0.230	28.1	86.6	14.7	1670	58.7	236	1403	515	22.5
avg	16.2	71.1	144	0.2000	15.6	28.7	14.7	1221	58.7	184	370	103	19.2
90th Percentile	17.6	71.1	246	0.228	26.3	58.2	14.7	1618	58.7	226	1275	361	22.3
95%UCL	-	-	-	-	-	74.7	-	-	-	-	672	208	22.4

Notes: Values reported only where calculable (n >3), and not greater than the maximum value.

Values in red denote values less than detection or less than the screening level, but used in the calculation of summary statistics. Summary statistics shaded in gray denote values less than the COPC screening level.

Table E4-6. 216-A-8 Soil Concentration Data and Summary Statistics for the Depth Intervals Evaluated in Fate and Transport Modeling

216-A-8 COPCs	Carbon-14		Tc-99	Cr(VI)		N (Nitrate+Nitrite)
Depth Interval/Soil Volume (m [ft])	6.5 (21.5)	9.1 (30)	7.6 (25)	7.6 (25)	9.1 (30)	6.5 (21.5)
Screening Level	8		3.6	0.192		9.03
Concentration Units	pCi/g		pCi/g	mg/kg		mg/kg
Soil Concentration Data	81.4	89.7 0.0040	79.6	0.278	0.27 0.25	53.3 0.0609
n	1	2	1	1	2	2
avg	81.4	44.9	79.6	0.278	0.260	26.7
max	81.4	89.7	79.6	0.278	0.270	53.3
90th Percentile	-	80.7	-	-	0.268	48.0
Notes: Values in red denote values less than detection or less than the screening level. The maximum values were used as the point source term for the 216-A-8 modeling.						

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2 E4.4.1 Uncertainty Factors and Assumptions Associated with the Estimation of Contaminated Soil 3 Volumes

4 The primary uncertainty associated with the contaminated soil volumes used in the fate and transport
5 modeling is the estimation of the lateral dimension (L) of the 1 m (3.3-ft) wide reference volume modeled
6 as defined in Equation E4-1. The height dimension of the contaminated soil volumes (depth intervals) are
7 reasonably well constrained by the geologic and stratigraphic relationships described in Section E4.2.1 to
8 E4.2.4, and summarized in Table E4-1. However, the length of the contaminated soil volume parallel to
9 the direction of groundwater flow is the largest dimension in the calculation of the soil volume, and is
10 typically the factor with the greatest uncertainty in the volume calculation. The information necessary to
11 reduce this uncertainty involves the extent of lateral coverage of subsurface boreholes in the vicinity of
12 waste sites which is generally minimal (e.g., based on one to two borehole locations), and unavailable.
13 Thus, estimations of the lateral extent of contaminated soil volumes (plumes) are generally conservatively
14 bounding, based on assumptions or analogies to contaminant behavior conceptual models at other
15 comparable waste sites where more data and information are available.

16 The spatial extent of the contaminant plumes in the vadose zone beneath the 200-PW-1/3 waste sites can
17 be constrained to a greater degree than most other locations at the Hanford Site owing to the abundance of
18 subsurface boreholes present at representative waste sites (39 boreholes at 216-Z-9 and 7 near the
19 216-Z-1A and 216-Z-18 area). The extensive evaluation of the data and information on the weight of
20 evidence for the lateral extent of contamination in Section E4.3 presents the technical basis for the values
21 used to define this parameter summarized in Section E4.4. Although the inherent uncertainty associated
22 with the length and volume of the contaminated soil volumes (and calculated source term mass) is
23 significantly reduced because of this information and evaluation, some conservative assumptions
24 continued to be made in the estimation of the lateral dimension. As described in Section E4.4, multiples

1 or fractions of the waste site footprint dimensions were used to define the contaminant source term length
2 in the modeling. Some of the possible conservatisms associated with the source term length parameter
3 assignments include the use of the following:

- 4 • Lateral dimensions of $1\times$ the dimension of the waste site footprint for the contaminated soil volumes
5 for VOA COPCs
- 6 • Lateral dimensions of the nitrogen contaminant plume ($2\times$ the dimension of the waste site footprint
7 parallel to groundwater flow) for Tc-99
- 8 • Maximum length dimensions of the COPC contaminant plumes to describe the entire contaminated
9 soil volume in the vadose zone

10 The reason for the potential conservatism in the first assumption is that the data that serve as the basis for
11 defining the lateral dimensions of the VOA contaminant plumes at the 216-Z-1A and 216-Z-18 wastes
12 site are from 1992 to 1993, and those at the 216-Z-9 Crib are from 2001 to 2006. This is significant
13 because the VOA concentrations are shown to have decreased linearly by as much as three orders of
14 magnitude since the operation of the SVE began in 1992 to 1993. In addition, the VOA concentrations
15 most certainly have continued to decrease since from 2001 to 2006 with 5 to 10 years of continued
16 operation of the SVE (see Figures E4-11 and E4-24). These factors serve to quantify the magnitude and
17 direction of this potential source of uncertainty.

18 The use of the maximum overall dimension of the contaminant plume to describe the entire contaminated
19 soil volume in the vadose zone is conservative for contaminant plumes where the lateral dimension of the
20 plume varies with depth, as appears to be the case for the plumes that have been defined to date (see
21 Figures E4-18 and E4-20). Estimation of contaminated soil volumes based on a fixed length value
22 corresponding to the maximum dimension of the plume, therefore, tends to yield conservatively inflated
23 estimates of the volume. The magnitude of this conservatism is effectively the difference between a
24 rectangular-shaped volume, and that of irregular ellipsoid-shaped volumes. The magnitude of the
25 difference between rectangular-shaped volumes and spherical-shaped volumes, for example, where the
26 rectangle length equals the spherical diameter is a factor of about $2\times$ (1.91). The volume of ellipsoids are
27 even less than spherical volumes.

28 The potential conservatism associated with the third assumption is based on the observed differences in
29 the vertical distribution of nitrogen (nitrate) and Tc-99 concentrations beneath the 216-Z-9 Crib. The
30 maximum lateral dimensions of the nitrogen plume in the vadose zone beneath the 216-Z-9 Crib is shown
31 to be about $2\times$ the dimensions of the waste site footprint in Section E4.3. The lateral dimension of the
32 contaminated soil volume for Tc-99 at the 216-Z-9 Crib was assumed to be the same because both
33 Nitrogen and Tc-99 are non-VOA COPC that are regarded as mobile COPCs ($K_d=0$), and unaffected by
34 SVE operations. The volume of the nitrogen plume is based on the maximum lateral dimension of the
35 plume that occurs in the vicinity of the Cold Creek unit, where the lateral plume dimensions tend to be the
36 largest (see Figure E4-20); however, the contaminated soil volume for Tc-99 appears to reside primarily
37 within the upper part of the Hanford formation, where the extent of lateral spreading is significantly less,
38 based on the results of the PNNL studies (PNNL-14895; PNNL-15914; and PNNL-16198). Thus, the
39 lateral dimensions and the contaminated soil volumes for the Tc-99 plume may be less than those of
40 nitrogen, which would yield model results biased conservatively high for Tc-99.

41 **E4.4.2 Uncertainty Factors and Assumptions Associated with the Estimation of COPC** 42 **Concentrations**

43 Estimation of representative values for the concentration of contaminated soil volumes is one of the
44 greatest sources of uncertainty in fate and transport modeling. It is generally not known how

1 representative the data from limited characterization (often from one to two boreholes) are of the
2 concentrations in the actual or modeled plume volume. However, there are generally few alternatives to
3 the use of limited data to define source term concentrations, acknowledging the inherently large
4 uncertainties concerning the representativeness of the data, and invoking assumptions regarding the
5 conservative biases associated with such data where it is known or presumed to preferentially sample the
6 more contaminated parts of vadose zone plumes. The atypical number and density of subsurface borehole
7 samples from the 200-PW-1/3 waste sites evaluated here provide an opportunity for the other methods
8 and factors to be also be considered in the estimation of representative concentrations of contaminated
9 soil volumes. The following is a discussion of the basis and objectives for estimating soil volume
10 concentrations, and of some methods and factors that can potentially improve the accuracy and reduce the
11 uncertainty of the estimated concentrations for the modeled contaminated soil volumes.

12 The COPC concentration values assigned to the contaminated soil volumes are intended to represent the
13 integrated range of concentrations within the volume most appropriate for defining representative source
14 term masses in the modeling; therefore, entire soil volumes are treated as uniformly contaminated source
15 terms. This is a reasonable assumption for the estimation of the source term mass when the soil
16 concentration is indeed representative of the actual range and extent of contamination; i.e., actual average
17 concentrations. However, the COPC concentration and associated mass estimates can be significantly
18 biased when the data are not representative of the integrated (true) average. Common examples are when
19 there are very few data, and/or when data are biased toward higher concentrations in the most
20 contaminated parts of a contaminated soil volume, as is often the case with limited characterization.
21 Examples of uncertainties associated with sparse data in the 200-PW-1/3/6 modeling include the Tc-99
22 data for the 216-Z-9 Crib (Table E4-5) and for the 216-A-8 Crib (Table E4-6) where there are only 1 to 3
23 data points for most of the depth intervals of interest.

24 Biases and uncertainties in COPC concentration and associated mass estimates occur when the
25 concentration gradients and their spatial relationships are not appropriately weighted in the calculation of
26 the overall average for the contaminated soil volume. Figure E4-29 is a schematic example of a
27 contaminated soil volume for a generic COPC with concentration gradients depicted by the coloring
28 within the plume, and by the four hypothetical soil concentration measurements at the designated
29 locations within a lateral slice through the contaminated soil volume intended to represent borehole-type
30 samples. The concentration gradients for the plume are shown in the profile below the conceptual plume.
31 Figure E4-29 shows five scenarios for the calculation of soil concentrations from the four concentration
32 values in the conceptual contaminated soil volume. Examples of five scenarios for the calculation of
33 simple average concentrations for various combinations of the four data points are shown in the
34 accompanying table together with a weighted overall average concentration value based on the
35 dimensions and concentration gradients of the plume segments are also shown in Figure 6 (scenarios A-B,
36 B-C, and C-D). The ratios of the dimension-based weighted (true) average concentration to simple
37 averages of data point combinations calculated from spatially biased data range from 1.3 to 3.6 in this
38 example, which correspond to the magnitude by which the biased measurements differ from the true
39 average concentration of a lateral slice through the center of the plume. These values are also the
40 approximate magnitude of overestimation of the source term mass and associated groundwater
41 concentrations.

42 The magnitude of the difference (bias) between the estimated and actual "average" concentration would
43 also increase where the concentration gradients are steeper. For example, it is indicated from cursory
44 comparison of the average CT soil concentrations calculated for the contaminated soil volumes beneath
45 the 216-Z-9 Crib (Section E4.6) to average concentration estimates through the 3-D contaminant plumes
46 (Figures E4-18 to E4-21) that the use of the simple average of the data may overestimate the integrated
47 average concentration value by as much as two orders of magnitude for some contaminated depth

1 intervals. Similarly, it is also indicated that the integrated average concentration values for nitrogen (in
2 nitrate+nitrite) based on the simple average of the data may be overestimated by factors of 2 to 20 for
3 some contaminated depth intervals.

4 In such cases, there are two main components of sampling bias and associated sources of uncertainty that
5 can potentially be compounded:

- 6 • The bias associated with preferential sampling of the more contaminated portions of the contaminant
7 plume (unrepresentative spatial distribution of the sample population laterally and vertically within
8 the plume)
- 9 • Sampling bias associated with the sampling and measurement frequency resulting in unrepresentative
10 frequency of measurements, which can affect the value of summary statistics for the data

11 Thus, the use of simple averages of such soil data tend to result in COPC concentrations that are
12 conservatively biased toward the higher, or highest part of the population of concentrations within the
13 contaminated soil volume. This leads to overestimation of source term masses and groundwater impacts.
14 Conversely, sampling data that are biased by under-representing the most contaminated parts of a plume
15 would tend to underestimate source term masses and groundwater impacts. The most probable sampling
16 bias at most Hanford waste sites is likely toward conservatively high concentrations because the objective
17 of most sampling efforts is to determine the levels of contamination in the most highly contaminated parts
18 of the vadose zone.

19 Such biases are most likely to occur when the actual concentration gradients within a contaminant plume
20 volume are not well represented by the sampling for the following reasons:

- 21 • There are insufficient data to represent the plume concentration gradients.
- 22 • The apparent distribution of concentrations gradients in the evaluated volume is not appropriately
23 weighted (i.e., skewed from actual plume dimension relationships).

24 Additional biases can occur when the lateral extent of soil volumes used in the modeling (for a given
25 thickness) are larger or smaller than the actual lateral dimensions of the contaminated soil volume. The
26 mass of contamination within a contaminated soil volume varies linearly with changes in length and
27 volume size for any given (average) concentration value. This type of bias results in overestimation of the
28 mass and associated groundwater impacts when the contaminated soil volume is overestimated and
29 underestimation of the mass when the volume is underestimated. Chapter E3.0 further discusses these
30 uncertainties and potential biases. The model results are interpreted in the context of the risk analysis and
31 possible follow-on efforts to mitigate uncertainties, which appear to dominate potential risks associated
32 with the COPCs that have the largest uncertainties.

33

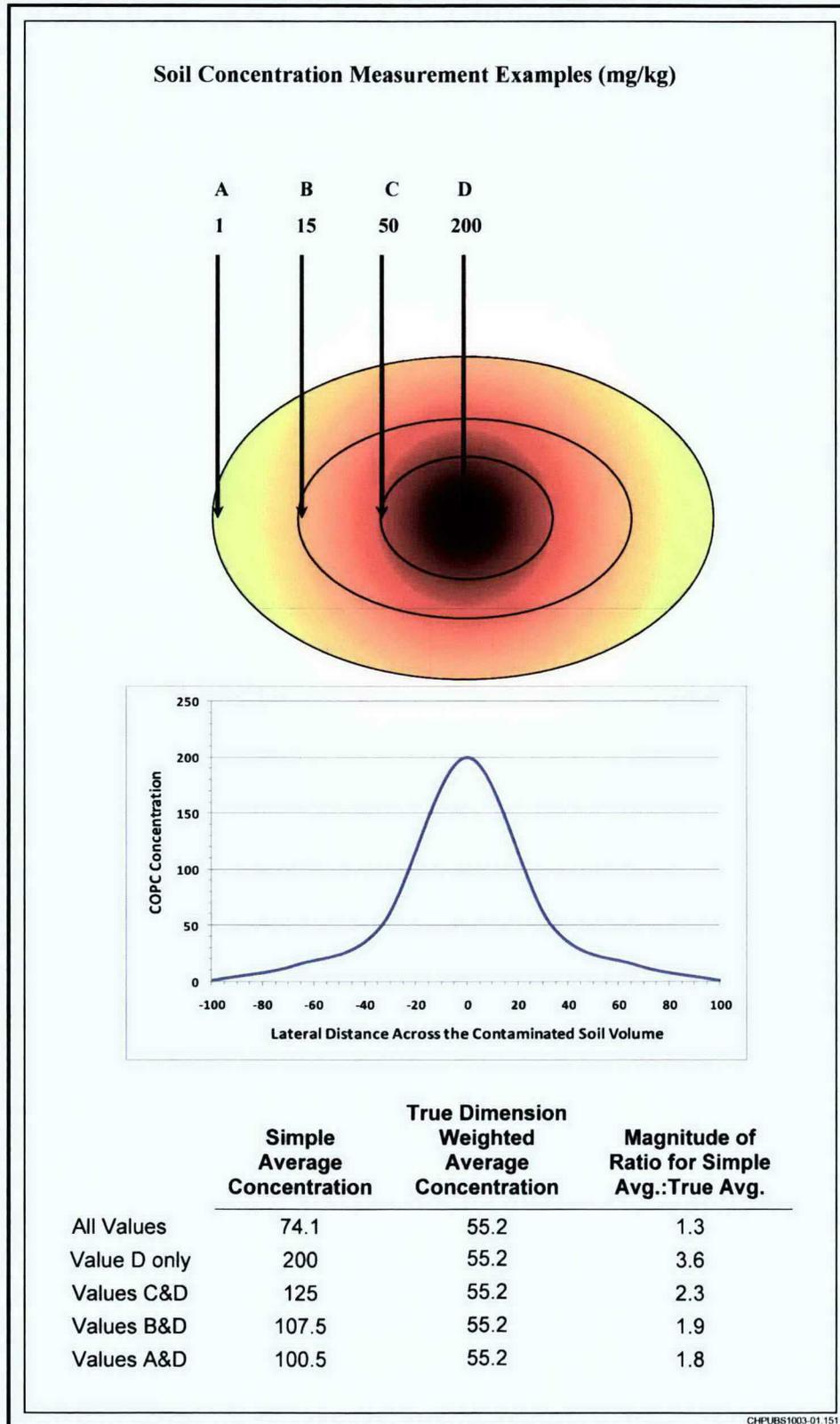


Figure E4-29. Schematic Illustration of the Direction and Magnitude of Biases in the Calculation of Average Concentrations of Contaminated Soil Volumes

1
 2
 3

E5.0 Model Results

The purpose of the fate and transport modeling is to evaluate the impacts to groundwater associated with contamination in the vadose zone at the 216-Z-1A, 216-Z-18, 216-Z-9, and 216-A-8 Cribs that are located in the 200-PW-1/3/6 OUs. The modeling includes both an additional screening phase and an evaluation of the groundwater concentrations and contaminant arrival times during the 1,000-year evaluation period. Options provided in EPA/540/F-95/041, *Soil Screening Guidance: Fact Sheet*, for screening include the use of site-specific results developed from detailed modeling. In the screening phase of the fate and transport modeling, contaminants are screened from further evaluation if the model results indicate that the contaminants do not reach the water table within 1,000 years. The results of contaminant screening in Section E3.0 provided the list of contaminants that could not be initially screened out as COPCs with respect to the protection of groundwater pathway.

Contaminants that are not screened out from consideration during this phase are included in the evaluation of the impacts to groundwater. Model predicted groundwater concentrations are then compared to the MCLs for the specific contaminants evaluated. Based on the federal guidelines for the selection and use of model types and codes specifically for risk characterization purposes, it is indicated that 2-D fate and transport modeling is an appropriate model type for the Central Plateau of the Hanford Site as a subsequent screening and/or risk characterization method for evaluation groundwater protection (EPA/540/F-95/041 and DOE/RL-2007-34, *Regulatory Criteria for the Selection of Vadose Zone Modeling in Support of the 200-UW-1 Operable Unit*).

The modeling to evaluate the possible impacts to groundwater resulting from vadose zone contamination at the 216-Z-1A, 216-Z-18, 216-Z-9, and 216-A-8 Cribs included the use of numerical two-dimensional flow, fate, and transport models. The basis and rationale for using this type of model for this type of evaluation, and the overall vadose zone model and code selection process, is described in DOE/RL-2007-34. The Subsurface Transport Over Multiple Phases (STOMP) code was used to perform the calculations based on its ability to incorporate adequately the vadose zone features, events, and processes (FEPs) relevant at the Hanford Site and to satisfy the other code criteria and attributes identified in DOE/RL-2007-34.

A sensitivity analysis was performed in which selected model parameters were varied in order to determine model results as a function of changes in parameter values. The key input parameters varied in the sensitivity analysis include the post-remediation recharge rate and the initial contaminant distribution in the vadose zone. For the purpose of this evaluation, statistical estimates of the contaminant concentration developed based on the sampling data were used for the inventory approximation. The reference case evaluation were based on the estimated long term recharge rate representing the most probable surface end state after the minimum remediation (reclamation of the shrub-steppe surface and vegetation) has occurred.

E5.1 Contaminants of Potential Concern

The COPCs addressed in this evaluation were identified by the screening process, as listed in Table E5-1. The contaminant screening process included a criterion developed based on the maximum contaminant K_d value that would reach the groundwater within 1,000 years from the maximum depth of contamination identified at the waste sites. For the 216-A-8 Crib screening analysis, contaminants that passed the initial screening analyses steps were assumed to exist in the model approximately 15.5 m (52 ft) bgs. Below this depth, none of the contaminants with K_d value greater than zero was detected at levels above background concentration values. For the 216-Z-1A, 216-Z-18, and 216-Z-9 Cribs screening analyses, contaminants that passed the initial screening analyses steps were assumed to exist in the model in the Cold Creek

1 carbonate unit because below this geologic unit none of the contaminants with K_d values greater than zero
2 were detected at levels above background concentration values, with one exception.¹¹ The results of the
3 models essentially provided a K_d screening step for the contaminants of potential concern. Based on the
4 screening model results, contaminants with K_d values greater than the particular value calculated in the
5 model do not arrive in groundwater within 1,000 years; therefore, these contaminants were screened from
6 further evaluation.

Table E5-1. COPCs Identified in the Screening Analysis to Include in the Fate and Transport Modeling for the Protection of Groundwater at the 216-Z-1A, 216-Z-18, 216-Z-9, and 216-A-8 Cribs

216-Z-1A	216-Z-18	216-Z-9	216-A-8
1, 1-Dichloroethane	Benzene	1,1,2,2-Tetrachloroethane	Hexavalent chromium
Carbon tetrachloride	Carbon tetrachloride	1,1,2-Trichloroethane	Nitrogen in nitrate and nitrite
Chloroform	Chloroform	1-Butanol	Carbon-14
Methylene chloride	Ethylbenzene	Bromodichloromethane	Technetium-99
Tetrachloroethene	Methylene chloride	Bromoform	
Trichloroethylene	Tetrachloroethene	Carbon tetrachloride	
Nitrogen in nitrate and nitrite	Nitrogen in nitrate and nitrite	Chloroform	
		Methylene chloride	
		Tetrachloroethene	
		Trichloroethylene	
		Technetium-99	
		Hexavalent chromium	
		Nitrogen in nitrate and nitrite	

7 The contaminant screening and evaluation of the groundwater impacts modeling at the 216-Z-1A, 216-Z-18,
8 216-Z-9, and 216-A-8 Cribs consisted of three stages. The first stage established steady state hydraulic
9 conditions within the model domain using boundary conditions consistent with conditions assumed to exist
10 prior to the construction of the Hanford Site in the early 1940s. The second stage represented transient
11 hydraulic conditions during the period from 1944 to 2010 (from the beginning time of Hanford Site
12 operations to the present). During this second stage, the recharge boundary condition applied to the crib
13 dimensions was increased to reflect the altered surface conditions associated with the construction of the
14 cribs, and water source terms were included to simulate the discharge histories of the cribs. The third stage
15 started in 2010 and represented future hydraulic and contaminant transport for future surface conditions. The
16 estimated vadose zone contaminant profile was input to the model as an initial condition at the beginning of
17 this third stage, and the contaminant transport through the vadose zone and resulting groundwater impacts
18 were calculated. Closure of the 216-A-8 Crib is assumed to occur no sooner than 2016, and closure of the
19 216-Z-1A, 216-Z-18, and 216-Z-9 cribs is assumed to occur no sooner than 2020. Boundary conditions
20 representing recharge for the changed surface conditions associated with the possible post-remedy surface
21 conditions commenced with the assumed dates of closure.

¹¹ A single value of radium-228 measured in sample collected from one of the 216-Z-9 characterization boreholes at a depth of 59.4 m (195 ft) bgs exceeded the screening criteria presented in Section E3.

1 **E5.2 Methodology and Approach for Fate and Transport Modeling**

2 DOE/RL-2007-34 contains the description of the generalized models, conditions, and parameters
3 applicable to the Hanford Site vadose zone, which were refined and augmented for the 216-Z-1A,
4 216-Z-18, 216-Z-9, and 216-A-8 Cribs evaluation. In addition, several vadose zone modeling evaluations
5 of the 216-Z-1A, 216-Z-18, and 216-Z-9 Cribs have been conducted as part of the investigation of the
6 distribution and mobility of discharged CT (e.g., PNNL-14895, PNNL-15914, and PNNL-16198). These
7 evaluations provide the basis for most of the conceptual model components and parameters for the 216-Z-
8 1A, 216-Z-18, and 216-Z-9 Cribs models.

9 **E5.3 Conceptual Model Components and Parameter Selection**

10 The site-specific conceptual model components for the 216-Z-1A, 216-Z-18, 216-Z-9, and 216-A-8 Cribs
11 evaluation are:

- 12 • Model domain and boundary conditions
- 13 • Geologic setting
- 14 • Source term
- 15 • Groundwater domain and characteristics
- 16 • Vadose zone hydrogeology and fluid transport
- 17 • Recharge
- 18 • Geochemistry

19 Although the model domain and boundary conditions are not generally regarded as conceptual model
20 elements, they are included in the list above to emphasize the fundamental nature of boundary conditions
21 in the modeling. Because of the proximity of the 216-Z-18 Crib to the 216-Z-1A Crib, and the similarity
22 of the conceptual model components, the model developed for the 216-Z-1A Crib was also used to
23 evaluate the COPCs identified for the 216-Z-18 Crib. Thus, the 216-Z-18 Crib model is identical to the
24 216-Z-1A Crib model, with the exception of the contaminant source terms.

25 Pursuant to CERCLA and pertinent applicant or relevant and appropriate requirement (ARAR)-driven
26 Washington State requirements for determining soil cleanup levels for the uppermost part of the vadose
27 zone soils, the evaluation used modeling assumptions and parameter estimates appropriate for the
28 216-Z-1A, 216-Z-18, 216-Z-9, and 216-A-8 Cribs site-specific conditions. Table E5-2 provides a
29 summary of key elements and parameters for the conceptual model components, which are identified in
30 the left hand column of the table. The following subsections for the individual conceptual model
31 components provide the basis, rationale, and references for the values. These parameters represent the
32 values selected for use in the model from the ranges of plausible parameter values. These values may
33 differ from parameter estimates for other Hanford Site modeling performed for different purposes or areas
34 of the Hanford Site, or at different scales.

35 **E5.3.1 Model Domain and Boundary Conditions**

36 The model domain and boundary conditions establish both a framework and limiting conditions for the
37 numerical model. The model domain for flow and transport in the vadose zone is represented numerically
38 as a 2-D, vertical cross-section aligned in the general direction of groundwater flow. Aligning the vertical
39 cross-sections with the general direction of groundwater flow allows concentrations to be calculated
40 downgradient of the waste sites. The numerical model adapts the physical elements of the conceptual
41 model to a Cartesian grid and assigns numerical values to the parameters used in algorithms to represent
42 the physical and geochemical systems and processes.

Table E5-2. Summary of Key Elements and Parameters Associated with Site-Specific Model Components for the 216-Z-1A, 216-Z-9, and 216-A-8 Cribs

Model Domain and Boundary Conditions	<p>216-Z-1A Crib, 400 m (1,312 ft) x 1 m x 88.5 m (290 ft) 216-Z-9 Crib, 440 m (1,444 ft) x 1 m x 84 m (276 ft) 216-A-8 Crib, 2610 m (6,660 ft) x 1 m x 95 m (312 ft)</p> <p>Prescribed flux across the top (recharge); no-flow along vertical side boundaries in the vadose zone; prescribed head at the along vertical side boundaries in the aquifer, including the capillary fringe; no-flow along the bottom of the model (aquifer)</p>
Geologic Setting	<p>216-Z-1A and 216-Z-9 Cribs geologic setting includes the following stratigraphic units that occur from surface to groundwater (PNNL-15914 and PNNL-16198):</p> <ul style="list-style-type: none"> • Backfill • Hanford Upper Fine (very coarse to medium sand to slightly pebbly very coarse sand, with some silty stringers) • Hanford H1 (open framework gravel to coarse to medium sand) • Hanford H2 (interbedded sand and slightly silty/clayey sand) • Hanford Lower Gravel (unconsolidated gravel, sandy gravel, and/or silty sandy gravel) • Hanford Lower Sand (coarse to medium sand to silty fine to very fine sand, with some silt to silty-clayey sand lenses) • Cold Creek silt (cohesive, compact, massive to laminated and stratified fine-grained sand and silt) • Cold Creek carbonate (fine- to coarse-grained, calcium-carbonate cemented paleosol) • Upper Ringold (slightly muddy, slightly gravelly, coarse to medium sand) • Ringold E (semi-indurated fluvial muddy sand gravel) <p>The 216-A-8 Crib geologic setting includes several stratigraphic units that alternate from surface to groundwater according to the following pattern (Figure E4-1(c)):</p> <ul style="list-style-type: none"> • Crib Backfill (6 m [20 ft]) • Hanford H1 Coarse Sand (9 m [30 ft]) • Hanford H1 Gravelly Sand (2 m [7 ft]) • Hanford H1 Coarse Sand (6 m [20 ft]) • Hanford H2 Fine Sand (2 m [7 ft]) • Hanford H2 Coarse Sand (4 m [13 ft]) • Hanford H2 Silty Sand (2 m [7 ft]) • Hanford H2 Coarse Sand (5 m [16 ft]) • Plio-Pleistocene Silt (1 m [3 ft]) • Hanford H2 Coarse Sand (1 m [3 ft]) • Plio-Pleistocene Silt (2 m [7 ft]) • Hanford H2 Silty Sand (2 m [7 ft]) • Hanford H2 Coarse Sand (6 m [20 ft]) • Plio-Pleistocene Silt (1 m [3 ft]) • Hanford H2 Coarse Sand (1 m [3 ft]) • Hanford H2 Silty Sand (2 m [7 ft]) • Hanford H3 Gravelly Sand (2 m [7 ft]) • Hanford H3 Sandy Gravel (5 m [16 ft]) • Hanford H3 Gravelly Sand (3 m [10 ft]) • Hanford H3 Sandy Gravel (4 m [13 ft]) • Hanford H3 Coarse Sand (4 m [13 ft]) • Ringold Gravel – Vadose (8 m [26 ft]) • Ringold Gravel – Aquifer (15 m [49 ft])

Table E5-2. Summary of Key Elements and Parameters Associated with Site-Specific Model Components for the 216-Z-1A, 216-Z-9, and 216-A-8 Cribs

Source Term	<p>Contamination Length Parallel to Groundwater Flow</p> <p>Specified contaminant source term dimensions for re-vegetated shrub or evapotranspiration barrier surfaces:</p> <ul style="list-style-type: none"> • 216- Z-1A Crib: 108 m (354 ft) (twice the length of the crib dimension at ground surface 53.3 m [175 ft] rounded to 54 m [177 ft] [Figure 2-4]) • 216-Z-9 Crib: 55 m (180 ft) (twice the length of the crib dimension at ground surface 27.4 m [90 ft] [Figure 2-3] rounded up) • 216-A-8 Crib: 65, 130, 130 m [213, 427, 853 ft] (one-quarter, one-half, and one times the length of the crib dimension at ground surface 259 m [850 ft] rounded to nearest even number: 260 m [853 ft] [Figure 2-10 and Figure E4-1(c)]) <p>Specified contaminant source term dimensions for non re-vegetated shrub surfaces:</p> <ul style="list-style-type: none"> • 216- Z-1A Crib: 54 m [177 ft] (the length of the crib dimension at ground surface [53.3 m {175 ft}] [Figure 2-4] rounded up) • 216-Z-9 Crib: 27 m [89 ft] (the length of the crib dimension at ground surface [27.4 m {90 ft}] rounded down [Figure 2-3]) • 216-A-8 Crib: No change <p>Source-term depths (m or ft-bgs, inclusive):</p> <ul style="list-style-type: none"> • 216- Z-1A Crib, 6 to 43 m (20 to 140.5 ft) • 216-Z-9 Crib, 6 to 37 m (20 to 186 ft) • 216-A-8 Crib, 6 to 9 m (21.5 to 106.5 ft) <p>Unlimited advective release, K_d control only</p>
Groundwater Domain and Characteristics	<p>Water table elevation calendar year 2009 approximately 134.5 m (441 ft) NAVD88 at 216-Z-1A and 216-Z-9 Cribs and approximately 119 m (390 ft) NAVD88 at 216-A-8 Crib</p> <p>Groundwater thickness limited to approximately 15 m (50 ft) in the aquifer; Groundwater concentrations evaluated for upper 5 and 10 m (16 and 33 ft) of aquifer</p> <p>Average hydraulic conductivity and 4.95 m/day at 216-Z-1A and 216-Z-9 Cribs and 1,000 m/day at 216-A-8 Crib</p> <p>Hydraulic gradient approximately 0.0011 m/m at 216-Z-1A and 216-Z-9 Cribs and 0.00001 m/m at 216-A-8 Crib</p>
Vadose Zone Hydrogeology and Fluid Transport	<p>K_d-control for contaminant transport</p> <p>Hydrogeologic properties for 216-Z-1A and 216-Z-9 Cribs models adapted from PNNL-14895, PNNL-15914, and PNNL-16198. Hydrogeologic properties for 216-A-8 Crib model derived from PNNL-14702</p> <p>Hydraulic Conductivity and Dispersion Horizontal to Vertical Anisotropy 10:1</p>
Recharge	<p>Pre-Operational; undisturbed ground: 4 mm/yr</p> <p>Operational through Pre-Remediation: 63 mm/yr [12/1955 through 2010]</p> <p>Post-Remediation:</p> <ul style="list-style-type: none"> • Surface evapotranspiration barrier: 0.5 mm/yr for 500 years, 1 mm/yr long-term • Revegetated shrub on disturbed soil: 8 mm/yr for 30 years, 4 mm/yr long-term • Non-revegetated shrub (grasses only) on disturbed soil: 22 mm/yr long-term • Continuation of operational: 63 mm/yr long-term

Table E5-2. Summary of Key Elements and Parameters Associated with Site-Specific Model Components for the 216-Z-1A, 216-Z-9, and 216-A-8 Cribs

Geochemistry	<p>Hexavalent Chromium $K_d = 0$ mL/g in all stratigraphic units</p> <p>Nitrogen in Nitrate and Nitrite $K_d = 0$ mL/g in all stratigraphic units</p> <p>1,1,2,2-Tetrachloroethane $K_d = 0.05$ mL/g in all stratigraphic units</p> <p>1,1,2-Trichloroethane $K_d = 0.05$ mL/g in all stratigraphic units</p> <p>1, 1-Dichloroethane $K_d = 0.05$ mL/g in all stratigraphic units</p> <p>1-Butanol $K_d = 0.01$ mL/g in all stratigraphic units</p> <p>Bromodichloromethane $K_d = 0.05$ mL/g in all stratigraphic units</p> <p>Bromoform $K_d = 0.1$ mL/g in all stratigraphic units</p> <p>Carbon Tetrachloride $K_d = 0.15$ mL/g in all stratigraphic units</p> <p>Chloroform $K_d = 0.05$ mL/g in all stratigraphic units</p> <p>Methylene Chloride $K_d = 0.01$ mL/g in all stratigraphic units</p> <p>Radium-228 $K_d = 3$ mL/g in all stratigraphic units</p> <p>Tetrachloroethene $K_d = 0.25$ mL/g in all stratigraphic units</p> <p>Trichloroethylene $K_d = 0.1$ mL/g in all stratigraphic units</p> <p>Carbon-14 $K_d = 0$ mL/g in all stratigraphic units</p> <p>Technetium-99 $K_d = 0$ mL/g in all stratigraphic units</p>
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Notes:

The basis for elements and parameters selection provided in the individual model components sections.

NAVD88, *North American Vertical Datum of 1988*.

PNNL-14702, *Vadose Zone Hydrogeology Data Package for Hanford Assessments*.

PNNL-14895, *Three-Dimensional Modeling of DNAPL in the Subsurface of the 216-Z-9 Trench at the Hanford Site*.

PNNL-15914, *Carbon Tetrachloride Flow and Transport in the Subsurface of the 216-Z-9 Trench at the Hanford Site: Heterogeneous Model Development and Soil Vapor Extraction Modeling*.

PNNL-16198, *Carbon Tetrachloride Flow and Transport in the Subsurface of the 216-Z-18 Crib and 216-Z-1A Tile Field at the Hanford Site: Multifluid Flow Simulations and Conceptual Model Update*.

1 The 216-Z-1A and 216-Z-9 Cribs model domains were 400 m (1,312 ft) and 440 m (1,444 ft)
 2 horizontally, respectively, by 1 m (3.3 ft), by approximately 88.5 m (290 ft) and 84 m (276 ft),
 3 respectively, vertically, extending about 15 m (49 ft) below the water table. A horizontal-to-vertical node
 4 spacing of 1 m:0.5 m was used throughout each model domain. The total number of nodes equaled
 5 70,800 and 73,920, respectively. Digitization of Figure 3.8 in PNNL-16198 and Figure 2.4 in
 6 PNNL-15914 provided the basis for the size of the 216-Z-1A and 216-Z-9 Cribs model domains,
 7 respectively. Two-dimensionally within the model grid, the 216-Z-1A Crib extended 54 m (175 ft) at the
 8 surface, tapering to 30 m (100 ft) at the base at a depth of 6 m (19 ft) (Figure E2-4). The 216-Z-9 Crib
 9 extended 27 m (90 ft) at the surface, tapering to 9 m (30 ft) at the base at a depth of 6 m (20 ft) (Figure
 10 E2-3).

11 The 216-A-8 Crib model domain was 2,610 m (8,560 ft) by 1 m (3.3 ft) horizontally, by 95 m (312 ft),
 12 vertically, extending about 15 m (49 ft) below the water table. Because of the size of the crib and the volume
 13 of water discharged to it, the grid for the 216-A-8 Crib required a relatively large domain to minimize
 14 boundary effects during the high volume discharge period 1955 to 1985. A horizontal-to-vertical node
 15 spacing of 3 m:1 m was used in the outer 870 m (2,854 ft) sides of the model, and a horizontal-to-vertical
 16 node spacing of 2 m:1 m was used through the center of the model domain 870 m (2,854 ft). The total

1 number of nodes equaled 96,425. Two-dimensionally, the 216-A-8 Crib extended 260 m (850 ft) at the
2 surface, tapering to 129 m (423 ft) at the base at a depth of 6 m (approximately 16 to 19 ft, the crib bottom is
3 sloped) (Figure E4-10 and drawing H-2-56157, *Crib 216-A-8 & Control Structure 216-A-508 Plan and*
4 *Details*).

5 A specified-flux boundary condition was applied at the surface to simulate recharge. Recharge rates
6 varied spatially and temporally along the upper boundary depending on site conditions, the location and
7 physical dimensions of the waste site, and the time of waste site operations and surface conditions
8 simulated. Boundary conditions at the sides of the model domain were assumed to be no flow in the
9 vadose zone and prescribed head in the aquifer, including the capillary fringe. Section E5.5 addresses the
10 function of these boundary condition assumptions. The bottom boundary of the unsaturated (vadose) zone
11 is the water table. The bottom of the model (aquifer) was defined as a vertical no flow boundary
12 condition.

13 PNNL-16198 provides estimates of the annual discharge volume to the 216-Z-1A Crib, shown in
14 Table E5-3. The Effluent Volume to Soil Disposal Sites (EVSDS) module of the Hanford Virtual Library
15 (available at: <http://vlprod.ri.gov/vlib/>) provides estimates of the annual discharge to the 216-Z-9 and
16 216-A-8 Crib, as summarized in Table E5-4.

Table E5-3. Discharged Aqueous Volumes and DNAPL Volumes for the 216-Z-1A Crib

Year	Aqueous Phase Volume (L)	DNAPL Volume (L)
1949	6.00E+04	—
1950	1.00E+05	—
1951	1.00E+05	—
1952	1.00E+05	—
1953	1.00E+05	—
1954	1.00E+05	—
1955	1.00E+05	—
1956	1.00E+05	—
1957	1.00E+05	—
1958	1.00E+05	—
1959	4.00E+04	—
1960 – 4/1963	—	—
Z-1AA		
5/1964 – 12/1964	4.20E+05	2.00E+04
1965	9.20E+05	4.10E+04
1/1966 – 5/1966	5.40E+05	2.52E+04
Z-1AB		
6/1966 – 12/1966	9.60E+05	4.48E+04
1/1967 – 9/1967	9.40E+05	3.94E+04

Table E5-3. Discharged Aqueous Volumes and DNAPL Volumes for the 216-Z-1A Crib

Year	Aqueous Phase Volume (L)	DNAPL Volume (L)
Z-1AC		
10/1967 – 12/1967	2.53E+05	1.06E+04
1968	1.00E+06	4.50E+04
1/1969 – 4/1969	1.55E+05	7.00E+03
Total	6.21E+06	2.42E+05

Source: Excerpted from PNNL-16198, Table 4.3.

1

Table E5-4. Discharge Volumes to the 216-Z-9 and 216-A-8 Crib

216-Z-9 Crib			216-A-8 Crib		
Year	Volume (L)	Cumulative	Year	Volume (L)	Cumulative
1955	2.60E+05	2.60E+05	1955	7.90E+07	7.90E+07
1956	4.60E+05	7.20E+05	1956	5.06E+08	5.85E+08
1957	5.40E+05	1.26E+06	1957	2.33E+08	8.18E+08
1958	7.00E+05	1.96E+06	1958	1.12E+08	9.30E+08
1959	5.60E+05	2.52E+06	1966	3.66E+06	9.34E+08
1960	6.20E+05	3.14E+06	1967	9.62E+07	1.03E+09
1961	7.70E+05	3.91E+06	1968	2.67E+07	1.06E+09
1962	1.80E+05	4.09E+06	1969	2.41E+07	1.08E+09
			1970	1.15E+07	1.09E+09
			1971	1.83E+07	1.11E+09
			1972	1.12E+07	1.12E+09
			1973	6.65E+06	1.13E+09
			1974	1.40E+07	1.14E+09
			1975	6.49E+06	1.15E+09
			1976	4.60E+05	1.15E+09
			1978	6.06E+02	1.15E+09
			1983	1.33E+05	1.15E+09
			1984	1.08E+06	1.15E+09
			1985	2.31E+05	1.15E+09

Notes: Red shading denotes maximum annual volume and blue shading denotes minimum annual volume.

Source: Hanford Virtual Library (<http://vlprod.ri.gov/vlib>)

2

1 E5.3.2 Geologic Setting

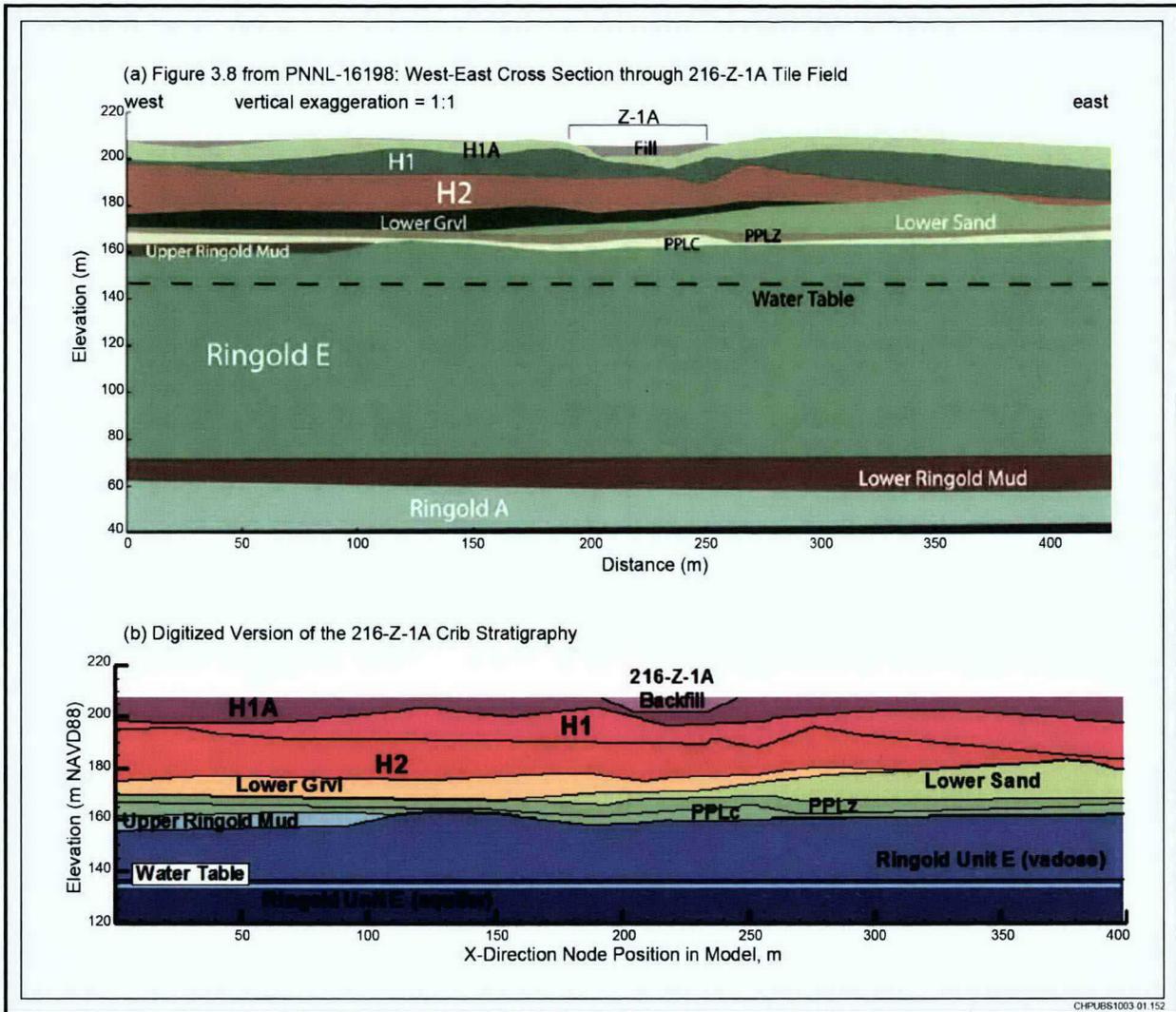
2 The stratigraphy shown in Figure 3.8 in PNNL-16198 and Figure 2.4 in PNNL-15914 provided the basis
 3 for the 216-Z-1A and 216-Z-9 Cribs model domains, respectively. Comparisons of those figures to the
 4 digitized versions of the figures used in this evaluation are shown in Figures E5-1 and E5-2, respectively.
 5 The water table elevation beneath the 216-Z-1A and 216-Z-9 Cribs was estimated to be approximately
 6 134.5 m (743 ft) NAVD88 (water level measured 134.4 m [441 ft] NAVD88 in March 2008 and 135 m
 7 [443 ft] in March 2009 NAVD88 in wells 299-W15-38 and 299-W15-42, respectively, Hanford Virtual
 8 Library, available at: <http://vlprod.rl.gov/vlib/>). Therefore, the total thickness of the vadose zone in the
 9 models is 73.5 m (241 ft) and 69 m (226 ft) bgs, respectively. Where crib backfill exists, it is contained
 10 within the depth of the Hanford H1A sand unit. The Ringold Gravel Aquifer includes 2 m (6 ft) of
 11 Ringold Gravel Vadose as capillary fringe. The approximate unit thicknesses of the stratigraphy included
 12 in the models are listed below.

Waste Site Models 216-Z-1A and 216-Z-18 Cribs

Backfill	6 m (20 ft)
Hanford Upper Fine (H1A)	4.2 m (14 ft)
Hanford H1	8.0 m (26 ft)
Hanford H2	13.7 m (45 ft)
Hanford Lower Gravel	5.3 m (17 ft)
Hanford Lower Sand	2.8 m (9 ft)
Cold Creek Silt	4.5 m (15 ft)
Cold Creek Carbonate	4.2 m (14 ft)
Upper Ringold	Not present beneath bottom of crib
Ringold Gravel – Vadose	22.9 m (75 ft)
Ringold Gravel – Aquifer	17 m (56 ft)

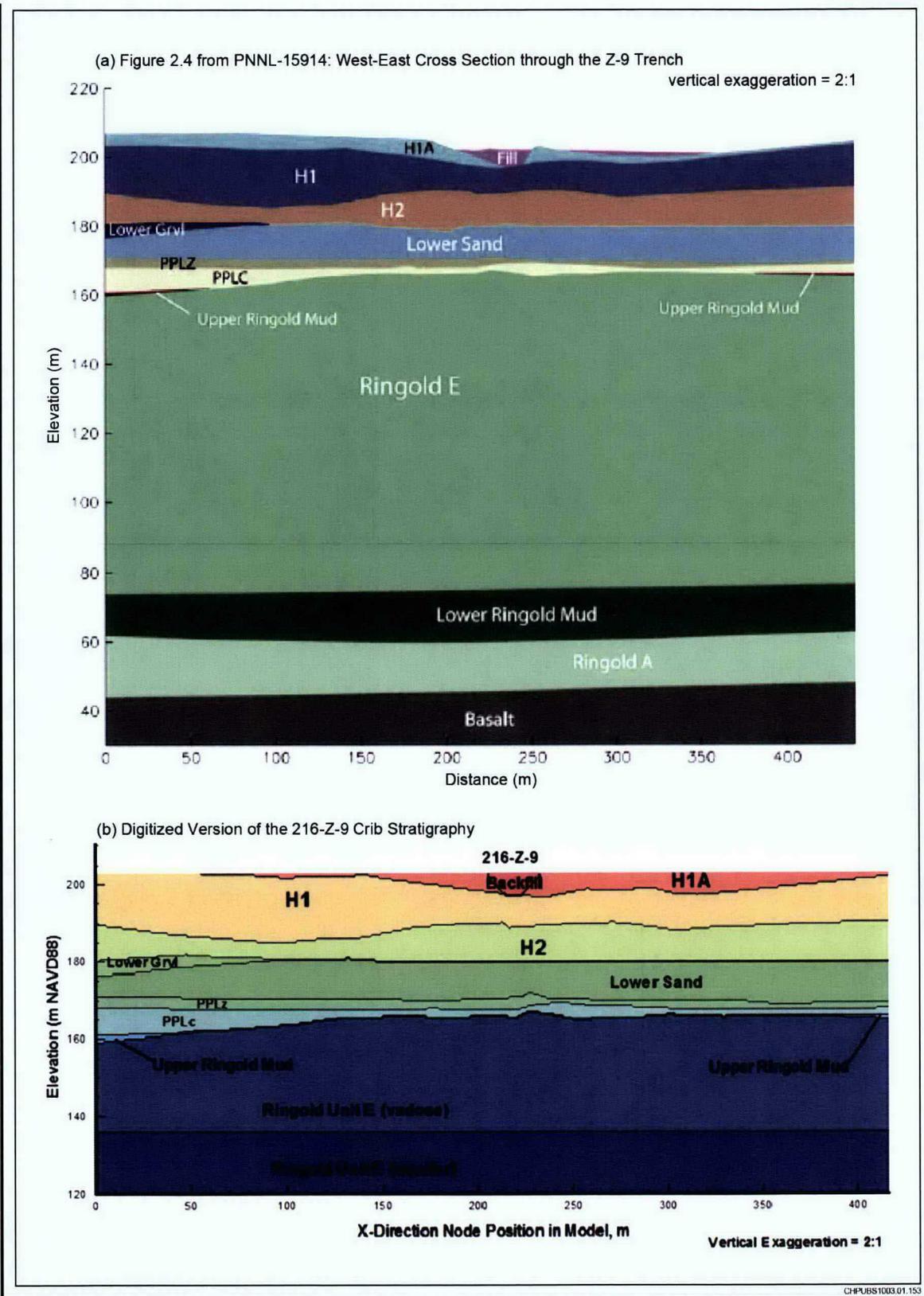
Waste Site Models 216-Z-9 Crib

Backfill	6 m (20 ft)
Hanford Upper Fine (H1A)	Not present beneath bottom of crib
Hanford H1	8.0 m (26 ft)
Hanford H2	9.0 m (30 ft)
Hanford Lower Gravel	Not present beneath bottom of crib
Hanford Lower Sand	9.1 m (30 ft)
Cold Creek Silt	3.3 m (11 ft)
Cold Creek Carbonate	1.9 m (6 ft)
Upper Ringold	Not present beneath bottom of crib
Ringold Gravel – Vadose	29.7 m (97 ft)
Ringold Gravel – Aquifer	17 m (56 ft)



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Figure E5-1. (a) Comparison of the 216-Z-1A Crib Stratigraphy Figure Presented in PNNL-16198 to the (b) Digitized Version of the Figure Used in this Evaluation (also applicable to 216-Z-18)



1
 2
 3

Figure E5-2. (a) Comparison of the 216-Z-9 Crib Stratigraphy Figure Presented in PNNL-15914 to the (b) Digitized Version of the Figure Used in this Evaluation

1 The stratigraphy near the 216-A-8 Crib is based on the borehole log from borehole C4545, which was
2 drilled through the bottom of the crib. The upper portion of borehole C4545 encountered 0.5 m (1.5 ft) of
3 crushed rock, used to construct the drill pad, overlying the crib construction backfill consisting of 1.4 m
4 (4.5 ft) of gravelly sand, 2.1 m (7.0 ft) of sand, and 1.8 m (6.0 ft) of very coarse gravel. The interval
5 beneath the crib construction backfill, extending from 5.8 to 54.3 m (19.0 to 178.0 ft) bgs, consists of
6 well-stratified, very fine to coarse-grained sands belonging to the sand dominated sequence of the
7 Hanford formation (H2). Several intervals within Hanford formation H2 contain finer grained silty sands.
8 The interval from 54.3 to 74.8 m (178.0 to 245.5 ft) bgs consists of the gravel-dominated sequence of the
9 Hanford formation (H3). These gravels consist of poorly sorted, angular to sub rounded heterolithic
10 cobbles (basalts and other dominantly igneous lithologies). The interval from 74.8 to 80.6 m (245.5 to
11 264.5 ft) bgs (total depth) consists of sandy gravels of the Ringold Formation unit 9. These sediments
12 consist of clast to matrix-supported pebble (2 to 64 mm [0.008 to 2.5 in.]) to cobble (64 to 256 mm [2.5 to
13 10 in.]) heterolithic gravels with a fine to coarse-grained sandy matrix. Lenticular sand and silt interbeds
14 also are characteristic of the Ringold Formation Unit 9. The stratigraphy generally is consistent with the
15 borehole logs from other wells adjacent to the crib. Groundwater beneath the 216-A-8 Crib was
16 approximately 80 m (261.7 ft) bgs at borehole C4545, thus the total thickness of the vadose zone is 80 m
17 (315 ft). Where crib backfill exists, it is contained within the depth of the Hanford H1 coarse sand. The
18 stratigraphy included in the model was divided into the hydrostratigraphic units with approximate unit
19 thicknesses as illustrated in Table E5-5.

20 The Ringold Gravel aquifer unit adds approximately 2 m (6.6 ft) of capillary fringe from the Ringold
21 Gravel vadose unit, which is directly above the water table. This model is proposed as an acceptable
22 representation of the geologic setting for the 216-A-8 Crib.

23 **E5.3.3 Contaminant Source Term**

24 For the screening analyses, the contaminant source terms were placed at the maximum depths at which
25 contaminants with K_d values greater than zero were detected at levels above background concentration
26 values. With respect to the 216-Z-1A, 216-Z-18, and 216-Z-9 Crib screening analyses, none of the
27 contaminants with K_d values greater than zero, with the exception of a single Rd-226 sample result, were
28 detected at levels above background concentration values below the Cold Creek carbonate unit. A range
29 of contaminant K_d values (specifically, 0.26 mL/g, 0.6 mL/g, 1.2 mL/g, and 1.9 mL/g, 2.85 mL/g,
30 2.90 mL/g, 3.0 mL/g, and 3.25 mL/g) was evaluated to determine the minimum contaminant K_d value
31 such that contaminants with this value and located as deep as the Cold Creek carbonate unit (see
32 Figure E2-4) would not arrive in groundwater within 1,000 years. These contaminants can be screened
33 from further evaluation. With respect to the 216-A-8 Crib screening analysis, none of the contaminants
34 with K_d value greater than zero was detected above background concentration values below
35 approximately 15.5 m (52 ft) bgs (Figure E2-5). A range of contaminant K_d values (specifically,
36 0.1 mL/g, 0.8 mL/g, and 1.0 mL/g) was evaluated to determine the minimum K_d value such that
37 contaminants with this K_d value and located as deep as 15.5 m (52 ft) bgs would not arrive in groundwater
38 within 1,000 years. Contaminants with K_d values greater than the minimum can be screened from further
39 evaluation. Contaminants with K_d values less than the minimum value and not screened for the other
40 reasons described in Sections E2 and E3 were then evaluated in the contaminant fate and transport model
41 to determine their impacts to groundwater.

42 In the contaminant fate and transport analyses, three types of contaminant source terms are considered to
43 be representative of the vertical profile of the contaminant distribution: point sources, contamination
44 contained in geologically similar material within a geologic unit, and contamination contained throughout
45 a geologic unit. The different contaminant source types are identified and described in Section E4. The
46 different contaminant source types are used to identify and approximate depth-based intervals in the

Table E5-5. Approximate Thicknesses of the Geologic Layers in the 216-A-8 Crib Model

Stratigraphic Unit	Approximate Thicknesses in 216-A-8 Crib Model	
	Geologic Cross-Section	Model Approximation
Crib Backfill ^a	5.8 m (19 ft)	6 m (20 ft)
Hanford H1 Coarse Sand	14.6 m (29 ft)	15 m (30 ft)
Hanford H1 Gravelly Sand	2.1 m (7 ft)	2 m (7 ft)
Hanford H1 Coarse Sand	6.4 m (21 ft)	6 m (20 ft)
Hanford H2 Fine Sand	2.4 m (8 ft)	2 m (7 ft)
Hanford H2 Coarse Sand	4.6 m (15 ft)	4 m (13 ft)
Hanford H2 Silty Sand	1.5 m (5 ft)	2 m (7 ft)
Hanford H2 Coarse Sand	4.6 m (15 ft)	5 m (16 ft)
Plio-Pleistocene Silt	1.2 m (4 ft)	1 m (3 ft)
Hanford H2 Coarse Sand	1.2 m (4 ft)	1 m (3 ft)
Plio-Pleistocene Silt	1.8 m (6 ft)	2 m (7 ft)
Hanford H2 Silty Sand	1.5 m (5 ft)	2 m (7 ft)
Hanford H2 Coarse Sand	6.2 m (20 ft)	6 m (20 ft)
Plio-Pleistocene Silt	1.1 m (4 ft)	1 m (3 ft)
Hanford H2 Coarse Sand	1.2 m (4 ft)	1 m (3 ft)
Hanford H2 Silty Sand	2.1 m (7 ft)	2 m (7 ft)
Hanford H3 Gravelly Sand	1.5 m (5 ft)	2 m (7 ft)
Hanford H3 Sandy Gravel	4.9 m (16 ft)	5 m (16 ft)
Hanford H3 Gravelly Sand	3.4 m (11 ft)	3 m (10 ft)
Hanford H3 Sandy Gravel	3.8 m (12 ft)	4 m (13 ft)
Hanford H3 Gravelly Sand	4.4 m (14 ft)	4 m (13 ft)
Hanford H3 Coarse Sand	1.7 m (6 ft)	2 m (7 ft)
Ringold Gravel – Vadose ^b	7.8 m (26 ft)	6 m (20 ft)
Ringold Gravel – Aquifer ^b	15.0 m (49 ft)	17 m (56 ft)

a. Crib Backfill is contained within the Hanford H1 coarse sand.

b. Ringold Gravel – Aquifer includes 2 m (6 ft) of Ringold Gravel – Vadose as capillary fringe.

1 vadose zone that are common to the various locations where contaminant data have been collected. As
2 described and indicated in Section E4, the vertical distribution of contamination appears to follow
3 consistent patterns from borehole to borehole that conform to the geologic description, i.e., finer textured
4 materials typically contain higher levels of contamination than coarser textured materials, where
5 contaminants are often not detected or not detected above background levels. Thus, the depth intervals
6 allow the pooling of contaminant data that describe the contamination in the same geologic interval
7 identified in multiple locations, i.e. a fine textured lens occurring in different characterization boreholes.
8 Contaminant sources are considered to be point sources where the sampling results indicated that the
9 contaminant was isolated depth-wise because it was detected only intermittently vertically and not
10 distributed throughout a lithologic layer. Point sources were assumed to have a thickness of 1 m (3.3 ft).

1 The sources contained in geologically similar material within a geologic unit were all assumed to be
2 rectangular shaped with a thickness approximately equal to the thickness of the geologically similar
3 material. The contaminant sources contained throughout a geologic unit possessed the shape of the
4 geologic unit.

5 Two source lengths for the 216-Z-1A, 216-Z-18, and 216-Z-9 Cribs were evaluated in the models. For the
6 evaluations imposing the lower recharge rates at the waste sites representing the two most probable
7 surface end states, either surface revegetation or construction of an evapotranspiration (ET) barrier, the
8 source length was assumed to equal twice the length of the surface dimension of the 216-Z-1A and
9 216-Z-9 Cribs parallel to the direction of groundwater flow (Figures E4-7 and E4-8, respectively).
10 Section E4 provides the basis and rationale for this approximation. For the evaluations imposing the
11 higher recharge rates representing continuation of current vegetation eradication practices or minimal
12 recovery of native vegetation, the source length was assumed to equal the length of the surface dimension
13 of the 216-Z-1A and 216-Z-9 Cribs parallel to the direction of groundwater flow. As neither of these
14 options is considered a viable remedy option for the waste sites, the intent of these evaluations is to
15 demonstrate, with the information currently available, that neither of these options appears to be capable
16 of adequately protecting groundwater, even if the smaller estimate of the areal extent of contamination
17 identified in Section E4 is used in the model. As surface revegetation or construction of an ET barrier
18 represents the two most probable post-remediation surface end states, the intent of these evaluations is to
19 provide a bounding estimate of the long-term effectiveness of these remedies.

20 For the 216-A-8 Crib model, contaminant sources are all point source types with a thickness of 1 m
21 (3.3 ft). Three source lengths were evaluated in the 216-A-8 Crib model: one equal to the lengthwise
22 dimension of the crib, the second equal to one-half of the lengthwise dimension of the crib, and the third
23 equal to one-quarter of the lengthwise dimension of the crib (Figure E4-6). Figure 2-10 indicates that the
24 contamination is limited to one-half of the length of the crib, but there are few data to provide the basis
25 for this approximation.

26 Sampling results representing the contaminant point source locations, the contaminant locations
27 comprised of geologically similar material, and the contaminant locations contained throughout a
28 geologic unit were pooled and evaluated statistically to determine mean values, the upper 95 percent
29 confidence limit of the mean, and the 90th percentile value of the data. In the cases where only one data
30 point was available for a particular depth interval, the single data point value substituted for the upper
31 95 percent confidence limit of the mean and the 90th percentile value of the data. Where more than one
32 data point was available for a particular depth interval but insufficient data were available to determine
33 the upper 95 percent confidence limit of the mean, the 90th percentile value of the data substituted for the
34 upper 95 percent confidence limit of the mean. Tables E4-3, E4-4, E4-5, and E4-6 present the results of
35 the statistical analyses and the initial source term contaminant concentrations for the 216-Z-1A, 216-Z-18,
36 216-Z-9, and 216-A-8 Crib models, respectively. The contaminant concentrations were assumed to be
37 constant within the individual source depth intervals.

38 For the purpose of this evaluation, the conceptual model considers only the advective release of
39 contaminants from the sediments. The release of contaminants is unlimited by any mechanisms that
40 would restrain the release, such as solubility limits, metal precipitation, or contaminant sequestration from
41 the advective flow path. All of the contamination in the source area is available for advective transport,
42 and the release occurs according to the equilibrium K_d .

43 **E5.3.4 Groundwater Domain and Characteristics**

44 The groundwater domain and characteristics are very different in 200 East Area than they are in 200 West
45 Area. The direction of groundwater flow around the 216-Z-1A and 216-Z-9 Cribs in 200 West Area is

1 generally west to east (DOE/RL-2008-66, *Hanford Site Groundwater Monitoring for Fiscal Year 2008*).
 2 The water table measures approximately 134.5 m (441 ft) in elevation NAVD88 (water level measured
 3 134.4 m (440.9 ft) NAVD88 in March 2008 and 135 m (442.9 ft) in March 2009 NAVD88 in wells
 4 299-W15-38 and 299-W15-42, respectively Hanford Virtual Library, available at: [http://vlprod.ri.gov/
 5 vlib/](http://vlprod.ri.gov/vlib/)). The groundwater table is expected to continue declining because the large discharges of
 6 operational liquid to the ground at 216-U-10 Pond and other large discharge sites in 200 West Area have
 7 ceased. For this modeling activity, a long-term average groundwater hydraulic gradient of 0.0011
 8 (estimated from Figure 2-8 in WHC-EP-0645, *Performance Assessment for the Disposal of Low-Level
 9 Waste in the 200 West Area Burial Grounds*). The aquifer, identified as Ringold Unit E – aquifer, is
 10 separated from that portion of the Ringold Unit E above the water table (Ringold Unit E – vadose),
 11 reflecting the distinctly different saturation conditions. Within the model domain, the aquifer extends to
 12 a depth of approximately 15 m (49 ft), but the model evaluates concentrations in the upper 5 m (16.4 ft) or
 13 10 m (33 ft) of the aquifer. The horizontal saturated hydraulic conductivity for the aquifer is estimated to
 14 be 4.95 m/day (16 ft/day) based on the hydraulic properties presented in PNNL-14895, PNNL-15914, and
 15 PNNL-16198. Table E5-6 presents a summary of the aquifer hydraulic parameters for the 216-Z-1A,
 16 216-Z-9, and 216-A-8 Cribs.

Table E5-6. Soil Hydraulic Properties for Aquifer Soil Type at 216-Z-1A, 216-Z-9, and 216-A-8 Cribs

Aquifer Soil Type	Bulk Density (g/cm)	Total Porosity	Saturated Moisture Content	Horizontal Saturated Hydraulic Conductivity^{a,b} (m/day)	Longitudinal Dispersivity^c (m)	Aquifer Hydraulic Gradient^d (m/m)
Ringold Unit E Gravel (aquifer) (216-Z-1A and 216-Z-9)	2.07	0.077	0.077	4.95	1.9	1.1E-03
Ringold Gravel (Aquifer) (216-A-8)	1.93	0.280	0.167	1,000	1.9	1.0E-05

Notes:

Aquifer soil hydraulic properties adopted from PNNL-14895, PNNL-15914, PNNL-16198, and PNNL-14702, with the following exceptions:

a. Horizontal Saturated Hydraulic Conductivity of Ringold Gravel (aquifer) (216-A-8) estimated from PNNL-14753.

b. Vertical Saturated Hydraulic Conductivity assumed equal to 1/10 of the Horizontal Saturated Hydraulic Conductivity.

c. Longitudinal Dispersivity calculated using Gelhar and Axness, 1983 equation; Transverse dispersivity assumed to be equal to 1/10 of the longitudinal dispersivity.

d. Aquifer Hydraulic Gradient estimated from 1944 hindcast water table map (WHC-EP-0645).

Gelhar and Axness, 1983, "Three-Dimensional Stochastic Analysis of Macrodispersion in a Stratified Aquifer"

PNNL, 14702, *Vadose Zone Hydrogeology Data Package for Hanford Assessments*

PNNL-14753, *Groundwater Data Package for Hanford Assessments*

PNNL-14895, *Three-Dimensional Modeling of DNAPL in the Subsurface of the 216-Z-9 Trench at the Hanford Site*

PNNL-15914, *Carbon Tetrachloride Flow and Transport in the Subsurface of the 216-Z-9 Trench at the Hanford Site: Heterogeneous Model Development and Soil Vapor Extraction Modeling*

PNNL-16198, *Carbon Tetrachloride Flow and Transport in the Subsurface of the 216-Z-18 Crib and 216-Z-1A Tile Field at the Hanford Site: Multifluid Flow Simulations and Conceptual Model Update*

WHC-EP-0645, *Performance Assessment for the Disposal of Low-Level Waste in the 200 West Area Burial Grounds*

1 The direction of groundwater flow in the area around the 216-A-8 Crib in 200 East Area is difficult to
 2 determine (DOE/RL-2008-66). The water table elevation is approximately 122 m (400 ft) NAVD88
 3 (e.g. the elevation in Well 299-E26-6 measured 121.9 m NAVD88 in 04/07/2009, Hanford Virtual
 4 Library, available at: <http://vlprod.ri.gov/vlib/>), but is expected to continue changing because the large
 5 discharges of operational liquid to the ground have ceased. Because of the uncertain nature of the flow
 6 direction and the changes expected to occur in the water table elevation, the 216-A-8 Crib is assumed to
 7 lay lengthwise parallel to the direction of groundwater flow. For this modeling activity, a long-term
 8 average groundwater hydraulic gradient of 0.00001 (estimated from the steady state gradient shown in
 9 Figure 2-8 in WHC-EP-0645) is assumed, with a groundwater table elevation of 122 m (400 ft) NAVD88.
 10 The aquifer, identified as Ringold Gravel - aquifer, is separated from that portion of the gravel above the
 11 water table (Ringold Gravel - vadose), reflecting the distinctly different saturation conditions. Within the
 12 model domain, the aquifer extends to a depth of approximately 15 m (49 ft) but the model evaluates
 13 concentrations in the upper 5 m (16.4 ft) or 10 m (33 ft) of the aquifer. The horizontal saturated hydraulic
 14 conductivity for the aquifer is estimated to be 1,000 m/day (3280 ft/day) based on the information
 15 presented in PNNL-14753, *Groundwater Data Package for Hanford Assessments*.

16 **E5.3.5 Vadose Zone Hydrogeology and Transport**

17 The flow and transport pathway process used for 216-Z-1A, 216-Z-9, and 216-A-8 Cribs zone modeling
 18 is porous media continuum flow. The vadose zone sediments at the Hanford Site are composed of
 19 sediments ranging in particle size associated with gravels to silts or clays. Porous media continuum
 20 transport in unsaturated media of this type is regarded as the fundamental process and feature for
 21 modeling contaminant fate and transport behavior in the vadose zone at the Hanford Site
 22 (DOE/RL-2007-34).

23 The hydraulic properties describing the water flow and retention characteristics associated with each of
 24 the 216-Z-1A, 216-Z-9, and 216-A-8 Cribs area geologic layers are approximated by average values, with
 25 each unit having different flow and transport parameter values (Tables E5-7 and E5-8). PNNL-14702,
 26 *Vadose Zone Hydrogeology Data Package for Hanford Assessments*, includes statistical summaries of
 27 measurements of the hydraulic properties for Hanford Site vadose zone sediments, and PNNL-14895,
 28 PNNL-15914, and PNNL-16198 include statistical summaries of measurements of the hydraulic
 29 properties for the vadose zone sediments around the 216-Z-1A and 216-Z-9 Cribs. The summary statistics
 30 include minimum, maximum, mean, standard deviation, and for hydraulic conductivity, mean and
 31 standard deviation of the natural log transforms of the data.

32 Estimates of longitudinal dispersivity for each of the hydrostratigraphic units were estimated using the
 33 Gelhar and Axness, 1983, "Three Dimensional Stochastic Analysis of Macrodispersion in a Stratified
 34 Aquifer," stochastic solution:

$$35 \quad A_L = \sigma_{\ln(K_s)}^2 \lambda$$

36 where:

37 A_L = longitudinal dispersivity (m or cm)

38 $\sigma_{\ln(K_s)}^2$ = the variance of the natural log of the saturated hydraulic conductivity measurements
 39 (dimensionless)

40 λ = vertical correlation scale (i.e., average distance over which conductivities are
 41 correlated) for log of the saturated hydraulic conductivity measurements (m or cm)

Table E5-7. Soil Hydraulic Properties for Vadose Zone Soil Types at 216-Z-1A and 216-Z-9 Cribs

Stratigraphic Unit	K^2 (cm/s)	Porosity	van Genuchten α (1/cm)	van Genuchten n	SrI
Ringold A	5.73E-3	0.0770	0.0090	1.6210	0.1299
Lower Mud	1.16E-8	0.0770	0.0090	1.6210	0.1299
Ringold E	5.73E-3	0.0770	0.0090	1.6210	0.1299
Upper Ringold	5.73E-3	0.0770	0.0090	1.6210	0.1299
Cold Creek C	6.72E-3	0.3203	0.0173	1.7705	0.2451
Cold Creek Z	1.48E-4	0.4238	0.0052	2.0671	0.0967
Lower Sand	1.87E-2	0.3359	0.1338	2.0475	0.0747
Lower Gravel	3.00E-2	0.2720	0.0270	1.9940	0.1471
Hanford 2	5.85E-3	0.3653	0.0448	2.3553	0.0846
Hanford 1	5.00E-2	0.1660	0.0830	1.6600	0.1386
Hanford 1A	5.98E-4	0.4478	0.0107	1.9229	0.1740
Backfill	1.5E-2	0.2620	0.0320	1.4000	0.3646

Source: Excerpted from PNNL-16198, Table 4.5.

1 This stochastic model relates macrodispersive spreading to the spatial variability of saturated hydraulic
2 conductivity in saturated porous media. The estimate of the correlation length, λ , is based on saturated
3 hydraulic conductivity estimates collected at approximate 30 cm (12 in.) intervals for a depth of 18 m
4 (59 ft) within the Hanford formation (RPP-17209, *Modeling Data Package for an Initial Assessment of*
5 *Closure of the S and SX Tank Farms*). The fitted spherical variogram of the data suggests a correlation
6 length of about 50 cm (20 in.) (see Figure D-1 in RPP-17209). However, as indicated by Russo, 1993,
7 “Stochastic Modeling of Macrodispersion for Solute Transport in a Heterogeneous Unsaturated Porous
8 Formation,” the correlation scale is expected to decrease as the moisture content decreases, hence a
9 smaller value (30 cm [12 in.]) is used to determine the dispersivities.

10 Longitudinal dispersivity also appears to be correlated with the model domain scale. The correlation
11 between the dispersivity and the model domain scale appears to be approximately 1:10 (e.g. RPP-17209,
12 Appendix D). Therefore, the dispersivity of any single unit was not allowed to exceed 1/10th of the
13 sediment type's total thickness in the model. The thicknesses of the geologic units in the 216-Z-1A and
14 216-Z-9 model domains were determined based on the average thickness throughout the model domain.
15 For the purpose of this calculation, the artificial division of Ringold – Vadose and – Aquifer was ignored.
16 For most of the vadose zone geologic units in the 216-Z-1A and 216-Z-9 model domains, the 1/10th
17 limitation dominated the determination of dispersivity coefficients (Table E5-9). Longitudinal dispersivity
18 (i.e., in the direction of flow) is assumed to be 10 times larger than dispersivity in the transverse direction,
19 which is consistent with the 10:1 anisotropy ratio of the hydraulic conductivity.

20

Table E5-8. Soil Hydraulic Properties for Vadose Zone Soil Types at 216-A-8 Crib

Soil Type	Bulk Density (g/cm ³)	Total Porosity ^a	Saturated Moisture Content	van Genuchten α (1/cm)	van Genuchten n	Residual Saturation	Residual Moisture Content ^b	Vertical Saturated Hydraulic Conductivity ^c (cm/s)	Longitudinal Dispersivity (m) ^d
Backfill (B)	1.94	0.276	0.262	0.019	1.4	0.162	0.042	5.98E-04	0.6
Hanford H1 Coarse Sand (Hcs)	1.93	0.377	0.349	0.061	2.031	0.134	0.047	2.27E-03	1
Hanford H1 Gravelly Sand (Hgs)	1.94	0.276	0.238	0.014	2.12	0.14	0.033	6.65E-04	1.1
Hanford H2 Sand (Hfs)	1.49	0.403	0.379	0.027	2.168	0.162	0.061	3.74E-04	0.2
Hanford H2 Silty Sand (Hss)	1.61	0.445	0.445	0.008	1.915	0.159	0.071	8.85E-05	0.6
Hanford H3 Sandy Gravel (Hg)	1.93	0.280	0.167	0.017	1.725	0.134	0.022	3.30E-04	0.9
Plio-Pleistocene (PPlz)	1.60	0.419	0.419	0.005	2.249	0.086	0.036	5.57E-05	0.4
Ringold Gravel - (vadose) (Hg)	1.93	0.280	0.167	0.017	1.725	0.134	0.022	3.30E-04	2.3

Notes:

Vadose zone soil hydraulic properties adopted from PNNL-14702, *Vadose Zone Hydrogeology Data Package for Hanford Assessments*, with the following exceptions:

a. Total porosity calculated from $1 - (\text{bulk density}/2.68 \text{ cm/g}^3)$.

b. Residual Moisture Content calculated from Saturated Moisture Content Residual Saturation.

c. Horizontal Saturated Hydraulic Conductivity is equal to 10 times the vertical saturated hydraulic conductivity (assuming an anisotropy ratio of 10:1), except for backfill soil types, for which the vertical and horizontal saturated hydraulic conductivities are equal.

d. Longitudinal Dispersivity calculated using Gelhar and Axness, 1983, "Three-Dimensional Stochastic Analysis of Macrodispersion in a Stratified Aquifer," equation. Transverse dispersivity equal to 1/10 of the longitudinal dispersivity.

Table E5-9. Dispersivity Values for Vadose Zone Soil Types at 216-Z-1A, 216-Z-9, and 216-A-8 Cribs

	Standard Deviation	Variance	Vertical Correlation Scale (cm)	Variance Vertical Correlation Scale (cm)*	Layer Thickness Check (10%, m)		Longitudinal Dispersivity (m)		Transverse Dispersivity (m)	
					216-Z-1A	216-Z-9	216-Z-1A	216-Z-9	216-Z-1A	216-Z-9
216-Z-1A and 216-Z-9										
Backfill	5.499	30.2	30	900	0.467	0.433	0.467	0.433	0.047	0.043
Hanford 1A	2.420	5.86	30	200	0.714	0.288	0.714	0.288	0.071	0.029
Hanford 1	3.322	11.0	30	350	0.935	1.180	0.935	1.180	0.094	0.118
Hanford 2	2.050	4.20	30	150	1.29	0.826	1.290	0.826	0.129	0.083
Lower Gravel	3.582	12.8	30	400	0.619	0.265	0.619	0.265	0.062	0.027
Lower Sand	1.960	3.84	30	100	0.829	0.952	0.829	0.952	0.083	0.095
Cold Creek Z	2.560	6.55	30	200	0.374	0.243	0.374	0.243	0.037	0.024
Cold Creek C	3.590	12.9	30	400	0.308	0.290	0.308	0.290	0.031	0.029
Upper Ringold	2.332	5.44	30	150	0.524	0.104	0.524	0.104	0.052	0.010
Ringold E	2.332	5.44	30	150	4.026	4.565	1.50	1.50	0.150	0.150
216-A-8										
Backfill	3.359	11.3	30	350	0.6		0.6		0.06	
Hanford H1 Coarse Sand (Hcs)	1.721	2.96	30	100	4.0		1.0		0.10	
Hanford H1 Gravelly Sand (Hgs)	2.290	5.24	30	150	1.1		1.1		0.11	
Hanford H2 Sand (Hfs)	2.657	7.06	30	200	0.2		0.2		0.02	
Hanford H2 Silty Sand (Hss)	1.885	3.55	30	100	0.6		0.6		0.06	
Hanford H3 Sandy Gravel (Hg)	3.265	10.7	30	300	0.9		0.9		0.09	
Plio-Pleistocene (PPlz)	3.805	14.5	30	450	0.4		0.4		0.04	
Ringold Gravel - (vadose) (Hg)	3.265	10.7	30	300	2.3		2.3		0.23	

* Rounded to nearest 50 cm increment.

1 **E5.3.6 Recharge**

2 The magnitude of recharge for soils at the Hanford Site varies as a function of the soil type, condition of
3 the vegetation cover, and soil integrity (e.g., disturbed versus undisturbed) (PNNL-13033, *Recharge Data*
4 *Package for the Immobilized Low-Activity Waste 2001 Performance Assessment*; PNNL-14744, *Recharge*
5 *Data Package for the 2005 Integrated Disposal Facility Performance Assessment*; PNNL 14702;
6 PNNL-14725, *Geographic and Operational Site Parameters List [GOSPL] for Hanford Assessments*; and
7 PNNL-16688, *Recharge Data Package for Hanford Single-Shell Tank Waste Management Areas*).

8 The range of recharge values reported in these documents represents distinct populations of data based on
9 lysimetry and isotopic measurements, and interpretation, and in some instances extrapolation, by Hanford
10 Site subject matter experts. The natural background recharge rates represent a population for natural
11 vegetated conditions. The range of values for operational, pre-remediation conditions represents a
12 population of recharge rates for vegetation-free disturbed soil (sand).

13 The most appropriate soil type for estimates of recharge rates in the 200 West and 200 East Areas of the
14 Hanford Site Central Plateau is the variety of Rupert sand appropriate for that area (PNNL-14702,
15 PNNL-14725). The recharge rates representing the pre-operational natural soil conditions and the 55-year
16 operational period prior to remedy implementation (1949 though 2020 for the 216-Z-1A Crib, 1955
17 though 2020 for the 216-Z-9 Crib, and 1955 though 2016 for the 216-A-8 Crib) are 4 mm/yr and
18 63 mm/yr, respectively. The most recent estimate of long term recharge through Rupert Sand surfaces
19 with a shrub-steppe plant community is 1.7 mm/yr (PNNL-16688), so the estimate of 4 mm/yr (from
20 PNNL-14725) may be considered to be conservatively biased. The recharge rates were selected from the
21 range of values reported as appropriate for the various soil types and conditions at the Hanford Site
22 (e.g., PNNL-14702, PNNL-14725).

23 The most appropriate surface condition for waste sites that undergo backfilling and post-remediation
24 re-vegetation is young shrub-steppe plant community that develops and matures (PNNL-14725,
25 DOE/RL-2007-34). The long term post-remediation recharge rate estimate of 4 mm/yr is based on
26 estimated values of long term recharge rates (LTRRs) for all Hanford Site soil types (PNNL-14702,
27 PNNL-14725, PNNL-16688). The estimates provided in PNNL-14702 and PNNL-14725 indicate that for
28 post-remedy LTRR, a post-remediation value of 8 mm/yr should be used for the first 30 years after site
29 closure, followed by the value of 4 mm/yr thereafter. This long-term value is more than twice the estimate
30 in PNNL-16688 for long-term recharge rate through Rupert Sand surfaces with a shrub-steppe plant
31 community, so the estimate of long-term post-remediation recharge rate may be considered to be
32 conservatively biased. The applicability of these recharge rates include the inherent assumption that the
33 natural shrub-steppe vegetation cover reclaims the ground surface. In the case representing no action
34 beginning present day (2010), only shallow rooted vegetation is assumed to revegetate the surface and the
35 long-term recharge rate is estimated to be 22 mm/yr (PNNL-14702, PNNL-14725). Table E5-10 presents
36 LTRRs for each of the pre-operational, operational, post-operational, and classes for the Rupert sand soil
37 type used in the modeling and evaluation.

38 The modeling assumptions and parameter estimates used here are based on the 216-Z-1A, 216-Z-9, and
39 216-A-8 Crib site-specific conditions, which may differ from those used for other Hanford Site modeling
40 performed for different purposes, areas, or scales. The recharge rate estimates selected for the 216-Z-1A,
41 216-Z-9, and 216-A-8 Crib site-specific conditions and therefore will differ from those used for
42 modeling at other scales because the most representative values appropriate for these modeling efforts
43 involve different population(s) of recharge rate.

Table E5-10. Recharge Rates for Surface Soil and Vegetation Types at 216-Z-1A, 216-Z-9, and 216-A-8 Cribs

Waste Site Surface Condition	Period of Time	Recharge Rate
Undisturbed Rupert sand with shrub-steppe plant community (natural condition)	Pre-Operational Period	4 mm/yr
Hanford sand - disturbed, with no vegetation	Operational period: 216-Z-1A: 1949 through 2020 216-Z-1A: 1955 through 2020 216-A-8: 1955 through 2016	63 mm/yr
Rupert sand - disturbed, with shallow rooted vegetation only	Present day (2010) forward*	22 mm/yr
Rupert sand-with young shrub-steppe plant community	Post-Remediation Period (30 years)	8 mm/yr
Long-Term Post-Remediation Rupert sand-with mature shrub-steppe plant community	Post-Remediation (after 30 years)	4 mm/yr
Evapotranspiration barrier	Post-Remediation Period (500 years)	0.5 mm/yr
Evapotranspiration barrier	Post-Remediation Period (after 500 years)	1.0 mm/yr

* For the purpose of evaluating the no action alternatives, current vegetation removal practices are assumed to end immediately

1 **E5.3.7 Geochemistry**

2 The geochemistry conceptual model component for the modeling involves the technical basis and
3 rationale for the specific contaminant partitioning behavior regarding release, retardation, and attenuation
4 mechanisms, and any simplifying assumptions. The key aspects of this geochemistry conceptual model
5 include the following, which are discussed in detail in DOE/RL-2007-34:

- 6 • The rationale for the simplifying assumption that the use of a linear K_d isotherm is a reasonable
7 conservative description for the release and attenuation of contaminants in the context of providing an
8 upper-bounding condition
- 9 • The rationale and source(s) of the data used in the selection of contaminant K_d values
- 10 • The rationale for the use of a single K_d for all vadose zone units

11 The geochemistry conceptual models for the Hanford Site are based on extensive laboratory studies,
12 testing, and measurements involving Hanford Site-specific sediments, contaminants, and conditions
13 performed using batch and column tests in measurements of adsorption and desorption coefficients under
14 saturated and unsaturated conditions (e.g., PNNL-13895, *Hanford Contaminant Distribution Coefficient
15 Database and Users Guide*; PNNL-11966, *Radionuclide Distribution Coefficients for Sediments
16 Collected from Borehole 299-E17-21: Final Report for Subtask 1a*; PNNL 13037, *Geochemical Data
17 Package for the 2005 Hanford Integrated Disposal Facility Performance Assessment*; PNNL-15502,
18 *Characterization of 200-UP-1 Aquifer Sediments and Results of Sorption-Desorption Tests Using Spiked
19 Uncontaminated Groundwater*; and PNNL-15121, *Uranium Geochemistry in Vadose Zone and Aquifer
20 Sediments from the 300 Area Uranium Plume*). Chapter E3.0 presents the basis and rationale for the K_d
21 values used to approximate the contaminant transport of the COPCs. Table E5-11 presents the values.

Table E5-11. Contaminant K_d Values Used in the 216-Z-1A, 216-Z-18, 216-Z-9, and 216-A-8 Cribs Models

Contaminant	K_d (mL/g)	Contaminant	K_d (mL/g)
1,1,2,2-Tetrachloroethane	0.05	Methylene chloride	0.01
1,1,2-Trichloroethane	0.05	Tetrachloroethene	0.25
1-Butanol	0.01	Trichloroethene	0.1
Benzene	0.05	Carbon-14	0
Bromodichloromethane	0.05	Radium-238	3
Bromoform	0.1	Technetium-99	0
Carbon tetrachloride	0.15	Hexavalent chromium	0
Chloroform	0.05	Nitrate/Nitrite as N	0
Ethylbenzene	0.2		

1 E5.3.8 Point of Calculation, Protectiveness Metric, and Timeframe Considerations

2 In accordance with risk assessment guidelines, the determination of soil contamination impacts to
3 groundwater also requires the definition and rationale for the following:

- 4 • The Point of Calculation (POCal) i.e., the place/point in the groundwater domain where modeled
5 groundwater concentrations are to be assessed for potential impacts and protectiveness
- 6 • The protectiveness metric, i.e., the groundwater metric(s) to be used in the assessment of
7 protectiveness at the POCal
- 8 • The timeframe considered applicable for the calculation of impacts to groundwater

9 The POCal for the protection of groundwater is related to the “Exposure Point” in the context of
10 conventional human health risk assessments (EPA/540/1-89/002) and to “Point of Compliance” in federal
11 and state regulations and guidelines (DOE/RL-2007-34). The POCal is intended to effectively serve as the
12 point where exposure point groundwater concentrations are evaluated in the model for evaluating
13 protectiveness.

14 The POCal used for the modeling results was the location according to the model results where maximum
15 concentrations in groundwater occurred during the evaluation period. This aspect of the model
16 methodology requires consideration of the model results as a function of distance downgradient in order
17 to determine the POCal that yields the highest peak concentrations within the groundwater. As calculated
18 in the model, lateral flow caused by the geologic stratigraphy and the contrast between the vertical and
19 horizontal transport in the capillary fringe results in the maximum concentrations occurring downgradient
20 from the waste site. For this evaluation, output groundwater concentrations were calculated at the edge of
21 the waste site and at 10, 20, 30, 40, 60, and 100 m (33, 66, 98, 131, 197, and 328 ft) downgradient from
22 the waste site.

23 The aquifer-mixing zone extended over the upper 5 and 10 m (16 and 33 ft) of the aquifer for the purpose
24 of the evaluations. The 5 m (16 ft) vertical interval corresponds to a conceptual groundwater monitoring
25 well with the 4.6 m (15 ft) well screen length (and mixing zone dimension) associated with state
26 monitoring well descriptions (e.g., see WAC 173-340-747). The 10 m (33 ft) vertical interval corresponds
27 to a conceptual groundwater production well with the 9.1 m (30 ft) well screen length (and mixing zone
28 dimension), which is consistent with the experience at the 200-ZP-1 OU pump-and-treat system.

1 To account further for the capillary fringe effects, the evaluation included two bases for calculating
2 groundwater concentration. The first basis included only the upper 5 or 10 m (16 or 33 ft) of the aquifer
3 rows in the groundwater concentration calculations, the second included the first row of the capillary
4 fringe with the upper 5 or 10 m (16 or 33 ft) of the aquifer rows. The highest calculated concentration
5 from either basis was used in the evaluation of impacts to groundwater.

6 The protectiveness metrics determined to be most appropriate for the evaluation of impacts to
7 groundwater from vadose zone contamination at the 216-Z-1A, 216-Z-18, 216-Z-9, and 216-A-8 Cribs
8 were the MCLs, except in the case of CT, which adopted the slightly more stringent cleanup level
9 identified in EPA et al., 2008, *Record of Decision Hanford 200 Area 200-ZP-1 Superfund Site Benton*
10 *County, Washington*. Use of the MCLs as a protectiveness metric for groundwater is consistent with the
11 intent of an effective "no growth" policy for groundwater contamination. In this context, the MCLs
12 represent the "allowable concentrations" and/or "acceptable limits" of a contaminant for minimizing
13 further degradation of groundwater in accordance with the conditions identified in state and federal anti-
14 degradation goals (e.g., EPA/540/R-92/003, *Risk Assessment Guidance for Superfund: Volume I—Human*
15 *Health Evaluation Manual [Part B, Development of Risk-Based Preliminary Remediation Goals, Interim;*
16 *EPA/530-SW-87-017, Alternate Concentration Limit Guidance; and DOE/RL 2002-59)*. Additional
17 reasons for the selection of the MCLs included the following:

- 18 • They are metrics appropriate for a reasonable maximum exposure scenario in groundwater
19 (i.e., potential future drinking water source).
- 20 • Their use is consistent with federal risk assessment guidance (EPA/540/R-92/003), and federal
21 regulatory requirements and guidelines for the establishment of media-specific cleanup levels
22 (40 CFR 300, "National Oil and Hazardous Substances Pollution Contingency Plan"; CERCLA; and
23 EPA/530-SW-87-017).
- 24 • Their use is consistent with the stated goals in the Hanford Site Groundwater Strategy
25 (DOE/RL-2002-59).
- 26 • They are appropriate metrics for identifying waste-site scale impacts to groundwater.

27 Defining the protection of groundwater in the context of vadose zone fate and transport requires
28 consideration of the soil and groundwater media as a hybrid or coupled pathway. This pathway involves
29 the determination of future concentrations in the groundwater medium that result from the transport of
30 contamination currently existing in the soil medium. Therefore, the working definition of protectiveness
31 for the protection of groundwater pathway at the 216-Z-1A, 216-Z-18, 216-Z-9, and 216-A-8 Cribs was
32 considered achieved if the contaminant levels in the vadose zone soil do not cause groundwater
33 concentrations to exceed MCLs at the POCal within the specified timeframe. The timeframe for the
34 evaluation period is limited to 1,000 years after remediation, which is assumed to begin in 2020 at
35 216-Z-1A, 216-Z-18, and 216-Z-9 and 2016 at 216-A-8.

36 **E5.3.9 Uncertainties, Assumptions, and Conservatism**

37 Potential sources of uncertainty in risk assessments are primarily in the categories of (a) model
38 uncertainties, (b) scenario uncertainties, and (c) parameter uncertainties. Model uncertainty pertaining to
39 the equations used as numerical representations of the natural processes is expected to be relatively small.
40 DOE/RL-2007-34 provides a summary evaluation of the comparisons of field data and field test results to
41 corresponding model results obtained using the STOMP code, and the evaluation indicates that the
42 equations used in STOMP adequately simulate the natural processes. The technical basis regarding
43 scenario and parameter selection and the evaluation of uncertainty and variability is also documented in
44 DOE/RL-2007-34 and in the conceptual model sections discussed previously. Documentation is provided

1 in Sections 4.0 and 5.0 of DOE/RL-2007-34 on (a) dominant model factors, (b) model parameter values
2 and plausible ranges of parameter values, (c) model assumptions and their effects on model results, and
3 (d) model limitations. The results of the sensitivity analyses are intended to address parameter uncertainty
4 and the impact of certain assumptions on the model results. It is notable that the main categories of factors
5 that dominate model results identified in DOE/RL-2007-34 are the same as those identified in the
6 evaluation of model assumptions, sensitivity analyses, and model limitations for the 200-PW-1,
7 200-PW-3, and 200-PW-6 OU modeling. It is further indicated from the uncertainty analysis that the
8 conservatism in the model assumptions, together with conservatism in parameter values, contribute to a
9 conservative bias in the model results overall (i.e., higher maximum concentrations in groundwater).

10 An evaluation of the primary assumptions associated with this vadose zone modeling approach at the
11 Hanford Site is summarized in Table 5-3 in DOE/RL-2007-34. The evaluation of these assumptions
12 indicates that (a) most of the assumptions involve hydrogeologic and geochemical factors, (b) most of the
13 assumptions are either conservative or neutral, (c) source-term uncertainty is potentially non-
14 conservative, and (d) the majority of conservative assumptions range from moderate to high magnitudes
15 in terms of their potential effect on risk and vadose zone model results. The evaluation of these
16 assumptions indicates that, with the exception of the source-term uncertainty, the assumptions associated
17 with model parameterization are largely conservative. The assumptions identified as non-conservative or
18 neutral are associated with the ability to approximate the geology in a finite difference grid, the
19 applicability of the porous media continuum to water flow in the vadose zone, and the hydrogeologic
20 parameterization of the main stratigraphic units. The magnitude of the effect of these assumptions on risk
21 estimates is identified in DOE/RL-2007-34 as neutral or low. Based on the assumptions evaluation,
22 results of vadose zone modeling for the 216-Z-1A, 216-Z-18, 216-Z-9, and 216-A-8 Cribs should provide
23 conservative estimates of risk in terms of impacts to groundwater from soil contaminants.

24 **E5.3.10 Numerical Solution Limitations**

25 Results determined using numerical models will possibly be influenced by numerical dispersion, which is
26 an artifact of the errors caused by the numerical discretization of the flow domain. To minimize these
27 errors, the grid should be designed so that the Peclet Number, the ratio of the grid cell length and the
28 dispersivity, is less than 1. However, maintaining this criterion can lead to grid spacing and an overall
29 domain size that are not practical to implement. The grid size selected for the model appeared to provide
30 an adequate balance between the two demands of solution integrity and practical implementation.
31 The 1 m (3.3 ft) vertical spacing in the 216-A-8 model and the 0.5 m (1.6 ft) vertical spacing in the
32 216-Z-1A and 216-Z-9 models were sufficiently small to allow delineation of the major geologic units
33 and the sloping of the contacts, and accommodate the 5 and 10 m (16 and 33 ft) well screen intervals used
34 to evaluate the impacts to groundwater.

35 **E5.4 Model Results**

36 The following sections describe the boundary evaluation, screening analysis, reference case and
37 sensitivity analysis used in the evaluations.

38 **E5.4.1 Boundary Evaluation**

39 The location of the side boundaries of the model domain is intended to prevent artificial boundary
40 conditions from interfering with the solution of the model in the area of interest. This premise is
41 confirmed by the results of the modeling from the period 1955 through 2010, which includes the high
42 volume discharges at the cribs. Figures E5-3, E5-4, and E5-5 present a time series plots of moisture
43 content during the period 1944-2010 for three selected locations near the downgradient boundary of the
44 216-Z-1A, 216-Z-9, and 216-A-8 Crib models, respectively. These locations in the model coincide with

1 stratigraphic unit changes in the model where pronounced lateral flow is most likely to occur. The results
2 presented in the time series plots indicate that the calculations may have included some boundary effects
3 due to the high volume discharges to the 216-A-8 Crib infringing upon the boundaries of the model.

4 No boundary effects appear to have occurred in the 216-Z-1A and 216-Z-9 Cribs models. Figure E5-6
5 presents profiles of the moisture content changes for three key times during the discharge period of the
6 216-A-8 Crib. These profiles indicate that the changes in the moisture content at the boundary of the
7 model occur relatively early during the simulation period (ca. 1958) and are contained within a relatively
8 small segment along the boundary near the water table and appear to be minor. These effects are
9 considered minimal and have dissipated by the year 2010 in the model calculations. Consequently, they
10 are not considered to effect adversely the evaluation of contaminant transport and groundwater impacts
11 associated with contamination in the vadose zone at the 216-A-8 Crib, which begins in year 2010.

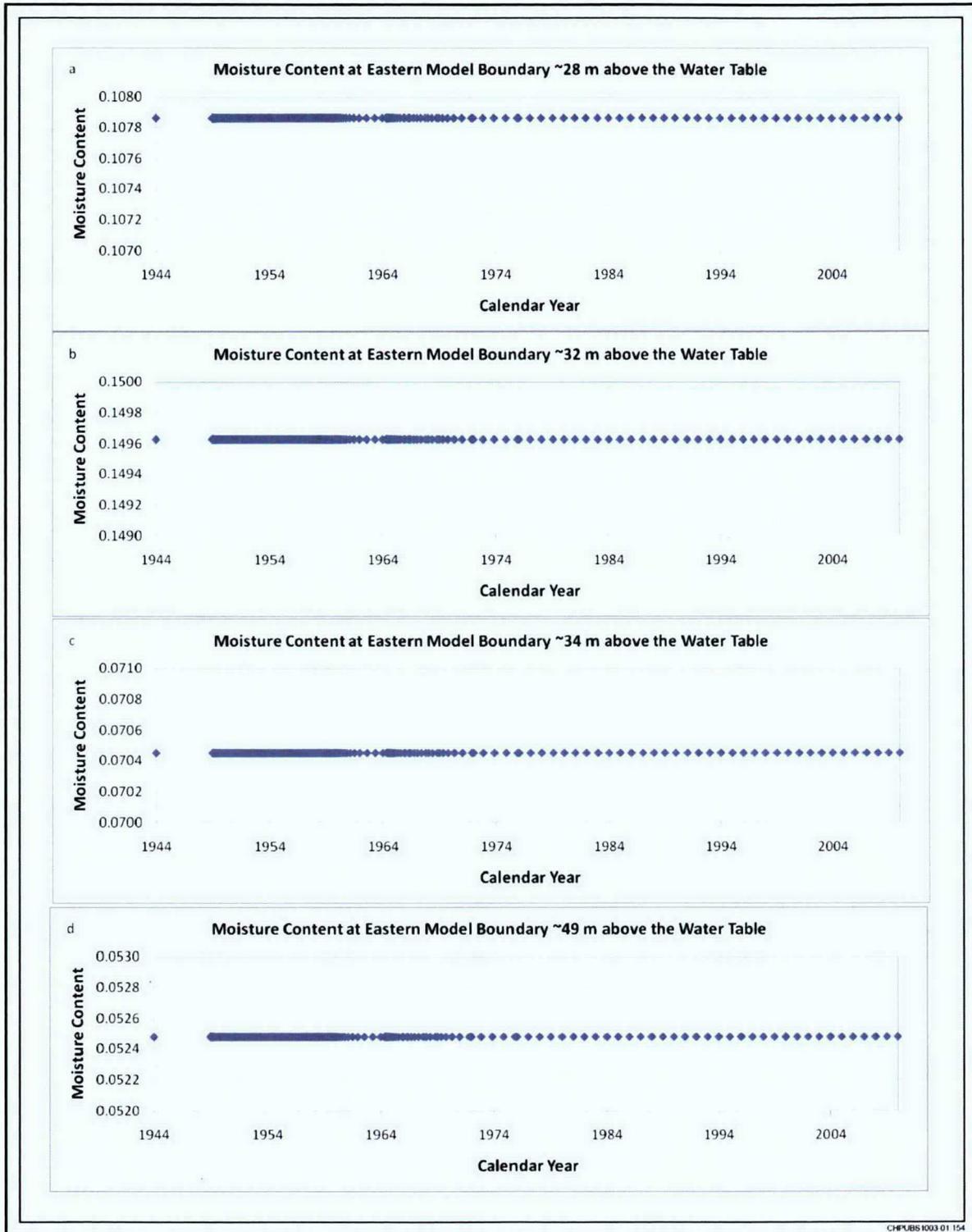
12 **E5.4.2 Screening Analysis**

13 Based on the screening model results, contaminants with K_d values greater than a particular value can be
14 screened from further evaluation because they do not arrive in groundwater within 1,000 years. At the
15 216-Z-1A and 216-Z-18 Cribs, the screening analysis results indicate that contaminants with K_d values
16 greater than 2.9 mL/g do not arrive in groundwater within 1,000 years and can be screened from further
17 evaluation (Table E5-12).

18 At the 216-Z-9 Crib, the screening analysis results indicate that contaminants with K_d values greater than
19 1.2 mL/g do not arrive in groundwater within 1,000 years and can be screened from further evaluation
20 (Table E5-13). Radium-228 can also be screened out because of the travel time to groundwater from a
21 depth of 59.4 m (195 ft) bgs and the short half-life of the radionuclide (5.8 years, ANL, 2007,
22 *Radiological and Chemical Fact Sheets to Support Health Risk Analyses for Contaminated Areas*). The
23 difference in the screening results between the two cribs is the distance between the water table and the
24 Cold Creek Carbonate unit. In the 216-Z-1A model, the bottom of the Cold Creek Carbonate unit is
25 approximately 8 m (26 ft) closer to the water table than it is in the 216-Z-9 model. At the 216-A-8 Crib,
26 the screening analysis results indicate that contaminants with K_d values greater than 0.8 mL/g do not
27 arrive in groundwater within 1,000 years and can be screened from further evaluation (Table E5-14).

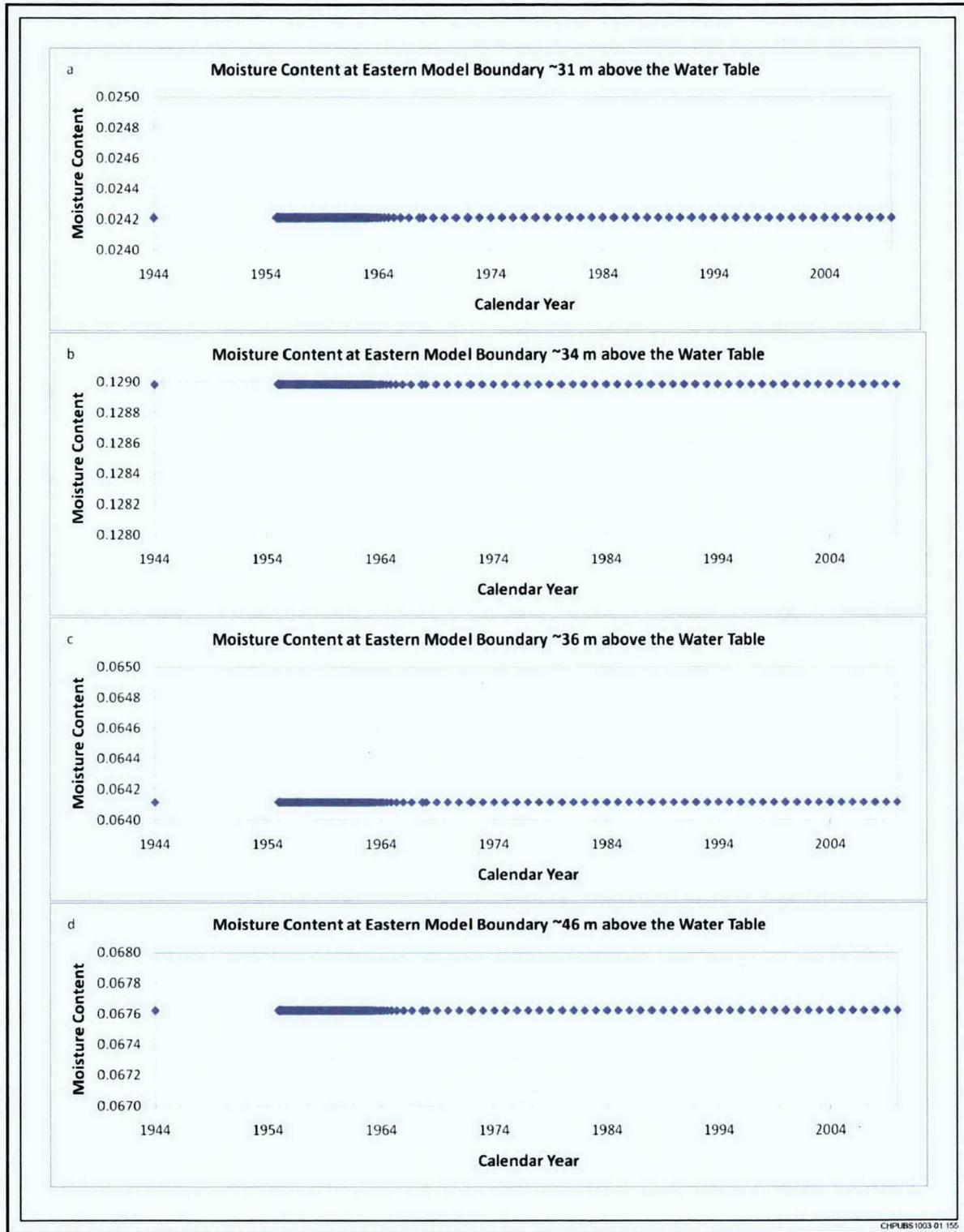
28 **E5.4.3 Reference Case**

29 The results of modeling provide an indication of the effectiveness of the different surface remedy
30 alternatives in achieving protection of groundwater at 216-Z-1A, 216-Z-18, 216-Z-9, and 216-A-8 Cribs.
31 For these evaluations, the average soil concentration value was considered to be the best estimate for the
32 source terms. EPA guidelines indicate that vadose zone models used to estimate exposure point
33 concentrations should utilize best estimate values for model parameters (EPA 540-R-02-002, *Risk
34 Assessment Guidance for Superfund: Volume III – Part A, Process for Conducting Probabilistic Risk
35 Assessment*). The guidelines indicate that the intent of risk characterization is to estimate the average
36 chemical exposure point concentration, therefore the average soil concentrations appear to be the best
37 estimate values for this purpose. Use of the average soil concentration values in the evaluations also
38 appears to be consistent with WAC 173-340-740(7)(c)(4)(B), “Unrestricted Land Use Soil Cleanup
39 Standards,” which states that the true mean soil concentration shall be used to evaluate compliance with
40 cleanup levels for cleanup levels based on chronic or carcinogenic threats. However, parameters
41 associated with the contaminant source term quantity, extent, and depth are highly variable and are
42 usually based on limited data. Consequently, they are significant sources of uncertainty in the model
43 results. Therefore, in addition to the results developed based on the average soil concentration values, the
44 results developed based on the 95 percent upper confidence limit on the mean, and the 90th percentile
45 value are also presented.



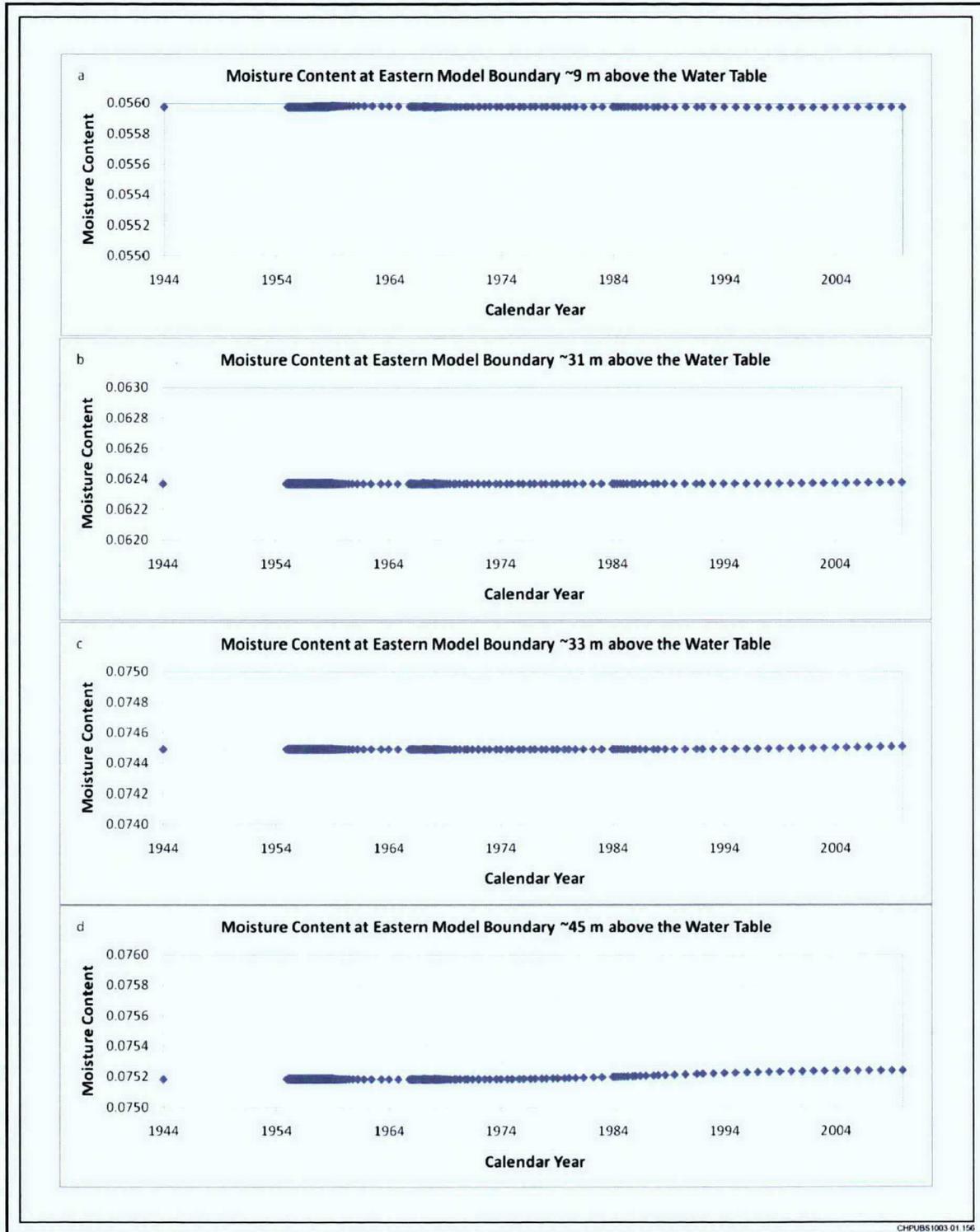
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Figure E5-3. Time Series Plots of Moisture Content During the Period 1944-2010 for Four Selected Locations near the Downgradient Boundary of the 216-Z-1A Crib Model: (a) at the PPIc - RUE Interface 28 m (92 ft) Above the Water Table, (b) at the PPIz - PPIc Interface 32 m (105 ft) Above the Water Table, (c) at the Lower Sand - PPIz Interface 34 m (111 ft) Above the Water Table, and (d) at the H1 - H2 Interface 49 m (161 ft) Above the Water Table



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Figure E5-4. Time Series Plots of Moisture Content During the Period 1944-2010 for Four Selected Locations Near the Downgradient Boundary of the 216-Z-9 Crib Model (a) at the PPIc – Ringold Mud Unit Interface 31 m (102 ft) Above the Water Table, (b) at the PPIz - PPIc Interface 34 m (111 ft) Above the Water Table, (c) at the Lower Sand - PPIz Interface 36 m (118 ft) Above the Water Table, and (d) at the H2 – Lower Sand Interface 46 m (151 ft) Above the Water Table



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Figure E5-5. Time Series Plots of Moisture Content During the Period 1944-2010 for Four Selected Locations Near the Downgradient Boundary of the 216-A-8 Crib Model; (a) at a Hgs - Hcs Interface 9 m (29 ft) Above the Water Table, (b) at a Hcs - Hss Interface 31 m (102 ft) Above the Water Table, (c) at a Hcs - PPIz Interface 33 m (108 ft) Above the Water Table, and (d) at a Hcs - PPIz Interface 45 m (147 ft) Above the Water Table

Table E5-12. Results of 216-Z-1A Crib Contaminant Screening Analysis

Contaminant K_d (mL/g)	Years to First Non-Zero Concentration Arrival at Water Table	Arrival < 1,000 Years?
216-Z-1A Maximum Depth of Contamination Cold Creek Carbonate		
Post-Remediation Long-Term Recharge Rate 4 mm/yr		
0.26	42	Yes
0.60	321	Yes
1.2	1,022	No
1.9	1,847	No
Post-Remediation Long-Term Recharge Rate 22 mm/yr		
0.26	54	Yes
0.60	177	Yes
1.2	397	Yes
1.9	656	Yes
2.8	994	Yes
2.9	1,031	No
Notes:		
Results also applicable to 216-Z-18.		

1

Table E5-13. Results of 216-Z-9 Crib Contaminant Screening Analysis

Contaminant K_d (mL/g)	Years to First Non-Zero Concentration Arrival at Water Table	Arrival < 1,000 Years?
216-Z-9 Maximum Depth of Contamination Cold Creek Carbonate		
Post-Remediation Long-Term Recharge Rate 4 mm/yr		
0.26	307	Yes
0.60	997	Yes
1.2	2,257	No
1.9	3,758	No
Post-Remediation Long Term Recharge Rate 22 mm/yr		
0.26	188	Yes
0.60	479	Yes
1.2	1,000	Yes
1.9	1,618	No

2

Table E5-14. Results of 216-A-8 Crib Contaminant Screening Analysis

Contaminant K_d (mL/g)	Years to First Non-Zero Concentration Arrival at Water Table	Arrival < 1,000 Years?
216-A-8 Maximum Depth of Contamination 15.7 m (51.5 ft) bgs		
Post-Remediation Long Term Recharge Rate 4 mm/yr		
0.1	449	Yes
0.8	4,123	No
1	5,158	No
Post-Remediation Long Term Recharge Rate 22 mm/yr		
0.1	155	Yes
0.8	1,025	No
1	1,275	No

1 The modeling results for the 216-Z-1A Crib indicate that with natural vegetation reestablished on the
 2 surface, the maximum concentrations of most, but not all, of the contaminants of potential concern do not
 3 exceed the MCL within 1,000 years (Table E5-15). The results of the modeling indicate that the
 4 maximum concentrations in groundwater of CT, methylene chloride, and nitrogen as nitrate and nitrite do
 5 exceed the respective MCLs within the 1,000-year evaluation period. Even if no efforts to reestablish
 6 natural vegetation are made and shallow rooted invasive species such as cheatgrass were to dominate the
 7 surface (i.e., recharge remains 22 mm/yr indefinitely), the modeling results indicate that only the
 8 maximum concentrations of those three COPCs at 216-Z-1A exceed the MCL within 1,000 years.

**Table E5-15. Results of 216-Z-1A Crib Contaminant Fate and Transport Modeling
Contaminant Concentrations in Groundwater**

Contaminant	K_d (mL/g)	MCL (μ g/L)	Length of Contamination Source Mixing Zone					
			Average Soil Concentration		95% UCL Average Soil Concentration		90 th Percentile Soil Concentration	
			5 m	10 m	5 m	10 m	5 m	10 m
Post-Remediation Long Term Recharge Rate 0.5 mm/yr; Source Length = 2 x Length of Waste Site								
1,1-Dichloroethane	0.05	NP ^a	0.7	0.4	1.9	1.2	1.7	1.0
Carbon tetrachloride	0.15	3.4 ^b	2.6	1.5	3.0	1.8	3.1	1.9
Chloroform	0.05	80 ^c	1.7	1.1	4.2	2.6	4.5	2.8
Methylene chloride	0.01	5	110	74	160	100	180	120
Tetrachloroethene	0.25	5	<1E-04	<1E-04	<1E-04	<1E-04	<1E-04	<1E-04
Trichloroethene	0.10	5	0.1	0.08	0.3	0.2	0.3	0.2
Nitrogen as nitrate and nitrite	0	10,000	11,700	7,600	30,200	19,600	24,600	16,000

**Table E5-15. Results of 216-Z-1A Crib Contaminant Fate and Transport Modeling
Contaminant Concentrations in Groundwater**

Contaminant	K _d (mL/g)	MCL (µg/L)	Length of Contamination Source Mixing Zone					
			Average Soil Concentration		95% UCL Average Soil Concentration		90 th Percentile Soil Concentration	
			5 m	10 m	5 m	10 m	5 m	10 m
Post-Remediation Long Term Recharge Rate 4 mm/yr; Source Length = 2 x Length of Waste Site								
1,1-Dichloroethane	0.05	NP ^a	1.0	0.7	2.7	1.7	2.5	1.6
Carbon tetrachloride	0.15	3.4 ^b	13	7.3	16	9.4	17	9.8
Chloroform	0.05	80 ^c	2.4	1.5	5.6	3.5	6.1	3.8
Methylene chloride	0.01	5	150	97	210	130	240	160
Tetrachloroethene	0.25	5	5E-04	3E-04	0.002	9E-04	0.001	8E-04
Trichloroethene	0.10	5	0.5	0.3	1.1	0.7	1.1	0.6
Nitrogen as nitrate and nitrite	0	10,000	16,100	10,400	41,100	26,600	33,500	21,700
Post-Remediation Long Term Recharge Rate 22 mm/yr								
1,1-Dichloroethane	0.05	NP ^a	1.7	1.0	4.7	2.8	4.2	2.5
Carbon tetrachloride	0.15	3.4 ^b	80	47	130	77	140	85
Chloroform	0.05	80 ^c	4.6	2.7	11	6.5	12	6.9
Methylene chloride	0.01	5	220	130	320	200	370	220
Tetrachloroethene	0.25	5	0.4	0.2	1.0	0.6	1.0	0.6
Trichloroethene	0.10	5	1.3	0.8	3.1	1.8	3.1	1.8
Nitrogen as nitrate and nitrite	0	10,000	22,900	13,700	58,700	35,000	47,900	28,600
Post-Remediation Long Term Recharge Rate 63 mm/yr								
1,1-Dichloroethane	0.05	NP ^a	4.4	2.7	12	7.1	11	6.4
Carbon tetrachloride	0.15	3.4 ^b	190	120	320	190	350	210
Chloroform	0.05	80 ^c	11	6.4	26	16	28	17
Methylene chloride	0.01	5	550	320	800	480	920	550
Tetrachloroethene	0.25	5	1.1	0.7	2.6	1.6	2.7	1.6
Trichloroethene	0.10	5	3.2	1.9	7.4	4.4	7.6	4.5
Nitrogen as nitrate and nitrite	0	10,000	54,800	32,300	140,000	82,100	114,000	67,000

**Table E5-15. Results of 216-Z-1A Crib Contaminant Fate and Transport Modeling
Contaminant Concentrations in Groundwater**

Contaminant	K _d (mL/g)	MCL (µg/L)	Length of Contamination Source Mixing Zone					
			Average Soil Concentration		95% UCL Average Soil Concentration		90 th Percentile Soil Concentration	
			5 m	10 m	5 m	10 m	5 m	10 m

Notes:

216-Z-1A Crib is approximately 53 m (174 ft) long. 1,000-year timeframe.

a. There is non-published (NP) EPA MCL specifically for 1,1-dichloroethane; there is a published EPA MCL for 1,2-dichloroethane (5 µg/L).

b. The EPA MCL for CT is 5 µg/L; the final cleanup level in the 200-ZP-1 Record of Decision is 3.4 µg/L (EPA et al., 2008, *Record of Decision Hanford 200 Area 200-ZP-1 Superfund Site Benton County, Washington*).

c. The EPA MCL for total trihalomethanes, which include bromodichloromethane, bromoform, and chloroform, is 80 µg/L.

- 1 The modeling results for the 216-Z-18 Crib indicate that with natural vegetation reestablished on the
2 surface, only the maximum concentrations of methylene chloride and nitrogen as nitrate and nitrite from
3 the list of contaminants of potential concern exceed the MCL within 1,000 years (Table E5-16). If the
4 long-term post-remediation recharge rate remains 22 mm/yr indefinitely, the modeling results indicate
5 that the maximum concentrations in groundwater of CT and tetrachloroethene also exceed the MCL
6 within 1,000 years.
- 7 The modeling results for the 216-Z-9 Crib indicate that with natural vegetation reestablished on the
8 surface, only the maximum concentrations of Tc-99 and nitrogen as nitrate and nitrite from the list of
9 contaminants of potential concern exceed the MCL within 1,000 years (Table E5-17). If the long-term
10 post-remediation recharge rate remains 22 mm/yr indefinitely, the modeling results indicate that the
11 maximum concentration in groundwater of CT also exceeds the MCL within 1,000 years.
- 12 The results of the modeling indicate that the contamination at 216-A-8 Crib may not require any specific
13 remedial action to achieve the protection of groundwater (Table E5-18). Because there are few data to
14 provide the basis for the approximation of the length dimension of the contamination source in the vadose
15 zone, three contamination source lengths were evaluated in the 216-A-8 Crib model (Figure E4-26):
- 16 • Equal to the lengthwise dimension of the crib
 - 17 • Equal to one-half of the lengthwise dimension of the crib
 - 18 • Equal to one-quarter of the lengthwise dimension of the crib
- 19 With natural vegetation reestablished on the surface, the model results indicate that the maximum
20 groundwater concentrations of all of the contaminants of potential concern remain less than the MCL
21 during the 1,000-year evaluation period for contamination source lengths up to the entire length of the
22 crib. If no efforts to reestablish natural vegetation are made and shallow rooted invasive species such as
23 cheatgrass were to dominate the surface (i.e., recharge remains 22 mm/yr indefinitely), the maximum
24 groundwater concentrations of carbon-14 and Tc-99 do exceed the MCL for contamination source lengths
25 greater than one-half of the lengthwise dimension of the crib.

E5.4.4 Sensitivity Analysis

The parameter uncertainty discussion in DOE/RL-2007-34 included vadose zone parameter sensitivity analyses from Hanford Site and non-Hanford Site sources. The results of the analyses indicate that vadose zone model results consistently have the greatest sensitivity to variability in infiltration/recharge rate, unsaturated zone thickness, and contaminant K_d . For this reason, the sensitivity analysis for the 216-Z-1A, 216-Z-9, and 216-A-8 Cribs included multiple contaminant distributions and inventory masses, multiple post-remediation recharge rate scenarios.

Comparable post-remediation long-term recharge rate scenarios were considered at all of the cribs. The reference cases adopted the recharge rate considered to be most applicable to waste sites that undergo backfilling and either no shrub re-vegetation or post-remediation shrub re-vegetation. The sensitivity analyses included scenarios representative of the installation and effective performance of an ET surface barrier that limits percolation of precipitated water by storage and ET processes. The no shrub re-vegetation and ET surface barrier cases are considered to be the upper and lower bounding cases for post-remediation long term recharge rates. The results of the ET surface barrier sensitivity cases are presented and discussed in the context of the effectiveness of the barrier in reducing the maximum concentration in groundwater of those COPCs for which the reference case results exceed the MCLs. An additional sensitivity analysis, representative of the cribs being actively maintained free of vegetation indefinitely into the future, was also included solely for the purpose of comparison. The tables provide the results.

**Table E5-16. Results of 216-Z-18 Crib Contaminant Fate and Transport Modeling
Contaminant Concentrations in Groundwater**

Contaminant	K_d (mL/g)	MCL (μ g/L)	Length of Contamination Source Mixing Zone					
			Average Soil Concentration		95% UCL Average Soil Concentration		90 th Percentile Soil Concentration	
			5 m	10 m	5 m	10 m	5 m	10 m
Post-Remediation Long Term Recharge Rate 0.5 mm/yr; Source Length = 2 x Length of Waste Site								
Benzene	0.05	5	0.06	0.04	0.1	0.09	0.1	0.1
Carbon tetrachloride	0.15	3.4 ^a	0.3	0.1	0.4	0.3	0.5	0.3
Chloroform	0.05	80 ^b	0.4	0.2	0.8	0.5	0.5	0.3
Ethylbenzene	0.20	700	<1E-04	<1E-04	<1E-04	<1E-04	<1E-04	<1E-04
Methylene chloride	0.01	5	980	630	2,700	1,700	270	180
Tetrachloroethene	0.25	5	0.01	0.008	0.04	0.02	0.03	0.02
Nitrogen as nitrate + nitrite	0	10,000	44,500	29,000	79,900	52,000	79,900	52,000
Post-Remediation Long Term Recharge Rate 4 mm/yr; Source Length = 2 x Length of Waste Site								
Benzene	0.05	5	0.09	0.06	0.2	0.1	0.2	0.1
Carbon tetrachloride	0.15	3.4 ^a	2.6	1.5	4.5	2.6	5.0	2.9
Chloroform	0.05	80 ^b	0.5	0.3	1.2	0.7	0.8	0.5
Ethylbenzene	0.20	700	<1E-04	<1E-04	<1E-04	<1E-04	<1E-04	<1E-04
Methylene chloride	0.01	5	1,300	850	3,600	2,300	380	250

**Table E5-16. Results of 216-Z-18 Crib Contaminant Fate and Transport Modeling
Contaminant Concentrations in Groundwater**

Contaminant	K _d (mL/g)	MCL (µg/L)	Length of Contamination Source Mixing Zone					
			Average Soil Concentration		95% UCL Average Soil Concentration		90 th Percentile Soil Concentration	
			5 m	10 m	5 m	10 m	5 m	10 m
Tetrachloroethene	0.25	5	0.2	0.1	0.6	0.4	0.5	0.3
Nitrogen as nitrate + nitrite	0	10,000	60,500	39,100	109,000	70,100	109,000	70,100
Post-Remediation Long Term Recharge Rate 22 mm/yr								
Benzene	0.05	5	0.1	0.06	0.2	0.1	0.3	0.2
Carbon tetrachloride	0.15	3.4 ^a	31	18	53	31	60	35
Chloroform	0.05	80 ^b	0.9	0.5	1.8	1.0	1.2	0.7
Ethylbenzene	0.20	700	0.2	0.1	0.2	0.1	0.2	0.1
Methylene chloride	0.01	5	2,100	1,200	5,800	3,400	570	350
Tetrachloroethene	0.25	5	9.7	5.6	29	17	23	14
Nitrogen as nitrate + nitrite	0	10,000	88,900	53,000	160,000	95,200	160,000	95,200
Post-Remediation Long Term Recharge Rate 63 mm/yr								
Benzene	0.05	5	0.3	0.2	0.7	0.4	0.7	0.4
Carbon tetrachloride	0.15	3.4 ^a	77	46	130	79	150	89
Chloroform	0.05	80 ^b	2.1	1.3	4.3	2.6	3.0	1.8
Ethylbenzene	0.20	700	0.9	0.5	1.2	0.7	1.2	0.7
Methylene chloride	0.01	5	5,000	3,000	13,800	8,200	1,500	890
Tetrachloroethene	0.25	5	23	14	69	41	56	33
Nitrogen as nitrate + nitrite	0	10,000	210,000	124,000	377,000	222,000	377,000	222,000

Notes:

216-Z-18 Crib is approximately 53 m (174 ft) long. 1,000-year timeframe.

a. The EPA MCL for CT is 5 µg/L; the final cleanup level in the 200-ZP-1 Record of Decision is 3.4 µg/L (EPA et al., 2008, *Record of Decision Hanford 200 Area 200-ZP-1 Superfund Site Benton County, Washington*).

b. The EPA MCL for total trihalomethanes, which include bromodichloromethane, bromoform, and chloroform, is 80 µg/L.

**Table E5-17. Results of 216-Z-9 Crib Contaminant Fate and Transport Modeling
Contaminant Concentrations in Groundwater**

Contaminant	K _d (mL/g)	MCL (µg/L)	Length of Contamination Source Mixing Zone					
			Average Soil Concentration		95% UCL Average Soil Concentration		90 th Percentile Soil Concentration	
			5 m	10 m	5 m	10 m	5 m	10 m
Post-Remediation Long Term Recharge Rate 0.5 mm/yr; Source Length = 2 x Length of Waste Site								
1,1,2,2-Tetrachloroethane	0.05	NP ^a	0.008	0.004	0.01	0.007	0.01	0.007
1,1,2-Trichloroethane	0.05	5	0.005	0.003	0.01	0.006	0.02	0.01
1-Butanol	0.01	NP ^b	130	72	230	130	300	170
Bromodichloromethane	0.05	80 ^c	0.003	0.002	0.006	0.003	0.01	0.006
Bromoform	0.10	80 ^c	<1E-4	<1E-4	<1E-4	<1E-4	<1E-4	<1E-4
Carbon tetrachloride	0.15	3.4 ^d	0.0004	0.0002	0.0007	0.0004	0.001	0.0006
Chloroform	0.05	80 ^c	1.1	0.7	4.6	2.7	2.9	1.7
Methylene chloride	0.01	5	1.6	0.9	2.6	1.5	5.3	3.1
Tetrachloroethene	0.25	5	<1E-4	<1E-4	<1E-4	<1E-4	<1E-4	<1E-4
Trichloroethene	0.10	5	<1E-4	<1E-4	<1E-4	<1E-4	<1E-4	<1E-4
Technetium-99	0	900	7,200	4,200	10,600	6,100	10,600	6,100
Hexavalent chromium	0	50	20	12	23	13	23	13
Nitrogen as nitrate + nitrite	0	10,000	83,500	48,700	120,000	70,300	166,000	97,700
Post-Remediation Long Term Recharge Rate 4 mm/yr; Source Length = 2 x Length of Waste Site								
1,1,2,2-Tetrachloroethane	0.05	NP ^a	0.08	0.05	0.1	0.08	0.1	0.08
1,1,2-Trichloroethane	0.05	5	0.05	0.03	0.1	0.05	0.2	0.1
1-Butanol	0.01	NP ^b	160	92	290	170	370	210
Bromodichloromethane	0.05	80 ^c	0.03	0.02	0.05	0.03	0.1	0.06
Bromoform	0.10	80 ^c	1E-04	<1E-4	3E-04	2E-04	5E-04	3E-04
Carbon tetrachloride	0.15	3.4 ^d	0.007	0.004	0.01	0.07	0.02	0.01
Chloroform	0.05	80 ^c	3.3	1.9	9.5	5.4	8.4	4.7
Methylene chloride	0.01	5	2.0	1.2	3.2	1.9	6.6	3.9
Tetrachloroethene	0.25	5	<1E-4	<1E-4	<1E-4	<1E-4	<1E-4	<1E-4
Trichloroethene	0.10	5	2E-04	1E-04	4E-04	2E-04	6E-04	3E-04
Technetium-99	0	900	8,900	5,200	13,100	7,500	13,100	7,500
Hexavalent chromium	0	50	21	12	24	14	24	14
Nitrogen as nitrate + nitrite	0	10,000	107,000	62,800	153,000	90,300	204,000	121,000

**Table E5-17. Results of 216-Z-9 Crib Contaminant Fate and Transport Modeling
Contaminant Concentrations in Groundwater**

Contaminant	K _d (mL/g)	MCL (µg/L)	Length of Contamination Source Mixing Zone					
			Average Soil Concentration		95% UCL Average Soil Concentration		90 th Percentile Soil Concentration	
			5 m	10 m	5 m	10 m	5 m	10 m
Post-Remediation Long Term Recharge Rate 22 mm/yr Source Length = Length of Waste Site								
1,1,2,2-Tetrachloroethane	0.05	NP ^a	0.3	0.2	0.5	0.3	0.5	0.3
1,1,2-Trichloroethane	0.05	5	0.2	0.09	0.3	0.2	0.6	0.3
1-Butanol	0.01	NP ^b	220	130	410	230	520	300
Bromodichloromethane	0.05	80 ^c	0.09	0.04	0.2	0.1	0.3	0.2
Bromoform	0.10	80 ^c	0.1	0.08	0.3	0.2	0.5	0.3
Carbon tetrachloride	0.15	3.4 ^d	110	63	250	140	290	160
Chloroform	0.05	80 ^c	11	6.5	27	15	28	16
Methylene chloride	0.01	5	3.0	1.7	4.9	2.8	10	5.7
Tetrachloroethene	0.25	5	0.05	0.03	0.1	0.05	0.1	0.05
Trichloroethene	0.10	5	0.2	0.1	0.4	0.2	0.7	0.4
Technetium-99	0	900	14,000	8,100	20,500	11,800	20,500	11,800
Hexavalent chromium	0	50	17	9.8	20	11	20	11
Nitrogen as nitrate + nitrite	0	10,000	157,000	89,900	224,000	128,000	288,000	165,000
Post-Remediation Long Term Recharge Rate 63 mm/yr Source Length = Length of Waste Site								
1,1,2,2-Tetrachloroethane	0.05	NP ^a	0.6	0.4	1.0	0.6	1.0	0.6
1,1,2-Trichloroethane	0.05	5	0.3	0.2	0.6	0.4	1.2	0.7
1-Butanol	0.01	NP ^b	450	260	820	480	1,000	610
Bromodichloromethane	0.05	80 ^c	0.2	0.1	0.4	0.2	0.7	0.4
Bromoform	0.10	80 ^c	0.3	0.2	0.6	0.3	1.1	0.6
Carbon tetrachloride	0.15	3.4 ^d	640	370	1,400	810	1,600	930
Chloroform	0.05	80 ^c	23	13	54	31	56	32
Methylene chloride	0.01	5	6.3	3.6	10	5.8	21	12
Tetrachloroethene	0.25	5	15	8.8	34	19	33	19
Trichloroethene	0.10	5	0.4	0.2	0.8	0.5	1.3	0.7
Technetium-99	0	900	26,700	15,500	39,100	22,800	39,100	22,800
Hexavalent chromium	0	50	35	20	40	23	40	23
Nitrogen as nitrate + nitrite	0	10,000	329,000	192,000	476,000	278,000	628,000	366,000

**Table E5-17. Results of 216-Z-9 Crib Contaminant Fate and Transport Modeling
Contaminant Concentrations in Groundwater**

Contaminant	K _d (mL/g)	MCL (µg/L)	Length of Contamination Source Mixing Zone					
			Average Soil Concentration		95% UCL Average Soil Concentration		90 th Percentile Soil Concentration	
			5 m	10 m	5 m	10 m	5 m	10 m

Notes:

216-Z-9 Crib is approximately 27 m (88 ft) long. 1,000-year timeframe.

a. There is no published EPA MCL specifically for 1,1,2,2-tetrachloroethane; there is a published EPA MCL for tetrachloroethane (5 µg/L).

b. There is no published EPA MCL for 1-Butanol.

c. The EPA MCL for total trihalomethanes, which include bromodichloromethane, bromoform, and chloroform, is 80 µg/L.

d. The EPA MCL for CT is 5 µg/L; the final cleanup level in the 200-ZP-1 Record of Decision is 3.4 µg/L (EPA et al., 2008, *Record of Decision Hanford 200 Area 200-ZP-1 Superfund Site Benton County, Washington*).

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**Table E5-18. Results of 216-A-8 Crib Contaminant Fate and Transport Modeling
Contaminant Concentrations in Groundwater**

Contaminant	K _d (mL/g)	MCL (pCi/L or mg/L)	Length of Contamination Source Mixing Zone					
			Full Length of Crib		Half Length of Crib		Quarter Length of Crib	
			5 m	10 m	5 m	10 m	5 m	10 m
Post-Remediation Long Term Recharge Rate 4 mm/yr (Unlimited Timeframe)								
Carbon-14	0	2,000	2,400	1,900	940	870	NE	NE
Technetium-99	0	900	1,300	1,000	510	470	NE	NE
Nitrogen as nitrate + nitrite	0	10	0.9	0.7	0.3	0.3	NE	NE
Hexavalent chromium	0	0.050	0.009	0.007	0.004	0.003	NE	NE
Post-Remediation Long Term Recharge Rate 4 mm/yr (1,000 year Timeframe)								
Carbon-14	0	2,000	1,500	1,200	570	530	NE	NE
Technetium-99	0	900	690	550	260	240	NE	NE
Nitrogen as nitrate + nitrite	0	10	0.5	0.4	0.2	0.2	NE	NE
Hexavalent chromium	0	0.050	0.006	0.004	0.002	0.002	NE	NE
Post-Remediation Long Term Recharge Rate 22 mm/yr (Unlimited Timeframe)								
Carbon-14	0	2,000	7,200	5,800	2,800	2,600	NE	NE
Technetium-99	0	900	3,500	2,800	1,400	1,300	NE	NE
Nitrogen as nitrate + nitrite	0	10	2.3	1.9	0.9	0.8	NE	NE
Hexavalent chromium	0	0.050	0.02	0.02	0.009	0.009	NE	NE

**Table E5-18. Results of 216-A-8 Crib Contaminant Fate and Transport Modeling
Contaminant Concentrations in Groundwater**

Contaminant	K _d (mL/g)	MCL (pCi/L or mg/L)	Length of Contamination Source Mixing Zone					
			Full Length of Crib		Half Length of Crib		Quarter Length of Crib	
			5 m	10 m	5 m	10 m	5 m	10 m
Post-Remediation Long Term Recharge Rate 63 mm/yr (Unlimited Timeframe)								
Carbon-14	0	2,000	NE	NE	NE	NE	2,200	2,300
Technetium-99	0	900	NE	NE	NE	NE	1,100	1,100
Nitrogen as nitrate + nitrite	0	10	NE	NE	NE	NE	0.7	0.7
Hexavalent chromium	0	0.050	NE	NE	NE	NE	0.007	0.007

Notes:

216-A-8 Crib is approximately 260 m (853 ft) long.

NE = not evaluated

1 The model results representing conditions associated with construction and placement of an ET barrier at
 2 216-Z-1A Crib indicate that the presence of the barrier would reduce the maximum concentration of CT
 3 in groundwater to less than the MCL. The maximum concentration of nitrogen as nitrate and nitrite would
 4 be only slightly over the MCL during the 1,000-year evaluation period. Even with the installation of an
 5 ET barrier at 216-Z-1A, the model results indicate that the maximum concentration of methylene chloride
 6 would still be well over the MCL. The model results for the 216-Z-18 Crib indicate that the presence of
 7 the barrier would reduce the maximum concentrations of methylene chloride and nitrogen as nitrate and
 8 nitrite by approximately 25 percent, but the maximum concentrations of both COPCs would still exceed
 9 the respective MCLs by a large margin. Similarly, the model results for the 216-Z-9 Crib indicate that the
 10 presence of the barrier would reduce the maximum concentrations of Tc-99 and nitrogen as nitrate and
 11 nitrite by approximately 20 percent, but the maximum concentrations of both COPCs would still exceed
 12 the respective MCLs by a large margin.

13 **E5.5 Summary and Conclusions**

14 The results of the modeling provide an indication as to the amount of remediation necessary to achieve
 15 protection of groundwater at the 216-Z-1A, 216-Z-18, 216-Z-9, and 216-A-8 Crib. The two most
 16 probable end states after remediation include naturally or artificially enhanced reclamation of the
 17 shrub-steppe surface and vegetation (long-term recharge rate of 4 mm/yr after 30 years of 8 mm/yr
 18 recharge). The other end state is an ET surface barrier that reduces or eliminates percolation of water
 19 through the contaminated soil (0.5 mm/yr for 500 years and 1.0 mm/yr thereafter). The model results for
 20 216-Z-1A Crib indicate that the maximum concentration of CT in groundwater exceeds the MCL during
 21 the evaluation period if the surface is revegetated, but does not exceed the MCL during the evaluation
 22 period if an ET surface barrier is constructed. The model results for methylene chloride and nitrogen as
 23 nitrate and nitrite at 216-Z-1A Crib indicate that the maximum concentrations exceed the MCL during the
 24 evaluation period whether or not an ET surface barrier is constructed. However, the results indicate that
 25 the maximum concentration of nitrogen as nitrate and nitrite is only slightly above the MCL with the
 26 barrier in place. The model results for the 216-Z-18 Crib indicate that the maximum concentrations of
 27 methylene chloride and nitrogen as nitrate and nitrite exceed the MCL by a large margin during the

1 evaluation period whether or not an ET surface barrier is constructed. Similarly, the model results for the
2 216-Z-9 Crib indicate that the maximum concentrations of Tc-99 and nitrogen as nitrate and nitrite
3 exceed the MCL by a large margin whether or not an ET surface barrier is constructed. The modeling
4 results for 216-A-8 indicate that none of the COPCs exceed the MCL during the evaluation period if the
5 shrub-steppe vegetation reclaims the surface.

6 If long-term post-remediation recharge remains 22 mm/yr indefinitely, e.g., no efforts to reestablish
7 natural vegetation are made and shallow rooted invasive species such as cheatgrass were to dominate the
8 surface, then the model results indicate that the maximum groundwater concentrations of the COPCs
9 during the 1,000-year evaluation period are greater than concentrations in the reference case results.
10 However, the maximum groundwater concentration of only a few COPCs increase from below the MCL
11 at 4 mm/yr long-term recharge rate to over the MCL at 22 mm/yr long-term recharge rate. The list of
12 COPCs with modeled concentrations in groundwater exceeding the MCLs at 22 mm/yr long-term
13 recharge rate does not change for 216-Z-1A but it does increase for the 216-Z-18, 216-Z-9, and 216-A-8
14 Crib, relative to the reference case results. For the 216-Z-18 Crib, the modeling results indicate that the
15 maximum concentrations of CT and tetrachloroethene exceed the MCLs if the long-term recharge rate
16 remains 22 mm/yr indefinitely. For the 216-Z-9 Crib, the modeling results indicate that the maximum
17 concentration of CT exceeds the MCL with the higher long-term recharge rate. For the 216-A-8 Crib, the
18 modeling results indicate that the maximum concentrations of carbon-14 and Tc-99 exceed the MCLs
19 with the higher long-term recharge rate if the contamination extends beyond one-half the length of the
20 crib. The trend in the results indicates that the maximum concentrations would not exceed the MCLs if
21 the contamination extended approximately one-quarter the length of the crib.

22 According to the modeling results calculated using best-estimate parameter values for evaluating
23 long-term impacts to groundwater, potentially adverse impacts appear to exist at three of the waste sites:
24 216-Z-1A, 216-Z-18, and 216-Z-9. There are only a small number of contaminants at each waste site,
25 from among the approximately 70 COPCs evaluated, that potentially pose adverse risk to groundwater:
26 nitrogen at all three cribs, methylene chloride, which is a degradation product of CT, at 216-Z-1A and
27 216-Z-18 Crib, and Tc-99 at 216-Z-9 Crib. The COPCs identified in the model results as having adverse
28 impacts to groundwater may not in actuality pose an adverse risk to groundwater due to the conservatism
29 included in the source term concentrations used in the modeling (Section E4).

30 The potential impacts to groundwater from CT and/or methylene chloride at the 216-Z-1A and 216-Z-18
31 Crib may be much less than estimated because the contaminant concentration estimates for the discrete
32 depth intervals are based on data collected prior to the onset of SVE operations. In addition, the
33 methylene chloride data with the highest concentration values appear to be suspect (Section E4). The data
34 collected near 216-Z-9 Crib include data collected both before the onset of SVE operations and data
35 collected as recently as 2006. These data indicate that the SVE has reduced the concentration levels of the
36 VOCs in the soil by more than a factor of 10. Operation of the SVE system has decreased the extent of
37 vadose zone contamination of the volatile COPCs in the area around the 216-Z-9 Crib to where it appears
38 to be less than the dimensions of the waste site footprint. The modeling results indicate that none of the
39 volatile COPCs associated with the 216-Z-9 Crib contamination pose an adverse risk to groundwater
40 within the 1,000-year evaluation period. Without more recent data to estimate the contaminant
41 concentration estimates for the discrete depth intervals for the 216-Z-1A and 216-Z-18 Crib, the
42 concentration estimates are based on sample measurements collected prior to and unaffected by SVE
43 operations. If the SVE has had the same affect around the 216-Z-1A and 216-Z-18 Crib as it has had
44 around 216-Z-9 Crib, then the model input estimates for both the discrete depth interval concentrations
45 and the lateral extent of the VOC are highly biased conservatively. CT and methylene chloride may not
46 actually pose an adverse risk to groundwater.

1 Additionally, the methylene chloride data with the highest concentration values appear suspect (possibly
2 resulting from laboratory contamination). Methylene chloride is a known laboratory contaminant and the
3 data do not follow the distribution pattern of the other volatile COPCs. The highest concentrations of
4 other volatile organic COPCs (e.g. 1,1-dichloroethane, CT, chloroform) occur in data collected from
5 within the waste site footprints, whereas the highest concentrations of methylene chloride occur outside
6 the waste site footprints. If the sample results were affected by laboratory contamination, then the model
7 results are not representative of the vadose zone contamination.

8 The highest COPC concentrations appear to occur directly beneath or very close to the footprints of the
9 waste sites (e.g., the highest contaminant concentrations at 216-Z-9 Crib appear to be within about 10 m
10 [33 ft] of the southern edge of the crib). The overall lateral extent of non-organic COPCs in the
11 subsurface appears to be contained within an area that extends approximately 2 times the dimensions of
12 the waste site footprint. In the modeling evaluations of the Z-area cribs that incorporate the best estimate
13 parameters, the extent of contamination is approximately 2 times the dimensions of the waste site
14 footprint. Applying highly biased average concentrations, compared to more representative
15 approximations of the average for the entire extent of contamination, results in an overestimation of the
16 potential impacts to groundwater.

17 The model results may overestimate the potential impacts to groundwater at all of the waste sites for the
18 non-organic COPCs (e.g., nitrogen and Tc-99). As discussed in Section E4, the estimates of average
19 contaminant concentration in the discrete depth intervals used in the models include a high level of
20 uncertainty. The estimates are typically based on only one to four data points within a depth interval.
21 These estimates are extrapolated to approximate the contaminant concentration throughout the extent of
22 contamination. These concentration estimates include a very high bias toward the maximum
23 concentrations observed in the plume because almost all of the non-organic COPC data were collected
24 from locations beneath or very close to the footprints of the waste sites. These locations were selected for
25 characterizing the maximum amount of contamination in the soil. Thus, the averages may be more
26 representative of the conditions in the plume where the concentrations are the highest, rather than the
27 conditions throughout the extent of contamination. This introduces two factors that bias the results
28 conservatively: the average concentrations are calculated using data points biased toward the maximum
29 values occurring in the plume, and this average concentration is applied to the entire length of
30 contamination in the model (i.e., two times the dimensions of the waste site footprint).

31 **E5.5.1 Implications for Barrier Effectiveness**

32 The main implication of these results for the four cribs is that recharge reduction to levels of about
33 0.5 mm/yr produce efficiencies in decreasing peak contaminant concentrations in groundwater, and
34 consequently reduction in peak groundwater arrival times, only slightly greater than those obtained with
35 natural vegetation conditions. Thus, it is indicated that the primary risk mitigation objectives of the
36 "ET-barrier/cover" remedy may well be achieved by the restoration of the site to natural vegetation
37 conditions, which is estimated to occur in a period of ≤ 30 years (DOE/RL-2007-34). The cost benefit of
38 an ET barrier for the mitigation of groundwater impacts of vadose zone contamination remaining at the
39 216-Z-1A, 216-Z-9, and 216-A-8 Cribs may, therefore, be minimal compared to restoration of the site(s)
40 to natural conditions, in conjunction with an ongoing remedy such as monitored natural attenuation.

41 **E5.5.2 Modeling QA/QC**

42 The vadose zone fate and transport calculations were performed using the STOMP Version 3.2 code,
43 HISI identification number 2471. DOE/RL-2007-34 contains a summary of the main model attributes and
44 code selection criteria that serve as the basis for the demonstration of the adequacy of the STOMP code
45 for use in vadose zone modeling at the Hanford Site. The results of the evaluation in DOE/RL-2007-34

1 show that the STOMP code is capable of meeting or exceeding the identified attributes and criteria. The
2 comparison of the code selection criteria to the STOMP code capabilities indicates the STOMP code is
3 capable of simulating all of the necessary FEPs, and that STOMP meets all of the other required code
4 selection criteria. Section 6.4.1 of DOE/RL-2007-34 addresses code selection criteria, including QA
5 documentation of verification studies for specific model attributes (e.g., unsaturated flow, solute
6 transport, infiltration, and drainage), and includes a discussion of other code related criteria (i.e., inter-
7 code comparisons, hardware requirements, solution methodology, dimensionality, and output capability).

8 STOMP was executed on the RANSAC Linux^{®2} Cluster (ransac-0.pnl.gov) that is managed by PNNL.
9 Excel³ spreadsheets were used to calculate contaminant inventory values and approximate contaminant
10 distributions, calculate crib discharge volumes, interpolate crib dimensions onto the numerical grid,
11 calculate dispersivity values, and evaluate the results produced by STOMP.

12 The results of CHPRC acceptance testing (CHPRC-00515, *STOMP Acceptance Test Report*.) demonstrate
13 that the STOMP software is acceptable for its intended use by the CHPRC. Installations of the software
14 are operating correctly, as demonstrated by the RANSAC Linux Cluster system producing the same
15 results as those presented for selected problems from PNNL-11216, *STOMP: Subsurface Transport Over*
16 *Multiple Phases Application Guide*.

17

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

³ Excel and Windows are registered trademarks of Microsoft Corporation in the United States and other countries.

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Appendix F

Evaluation of Future Risk Reduction for Various Soil Removal Alternatives at the 216-Z-1a Tile Field, 216-Z-9 Trench, and 216-Z-12 Crib

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Terms

ARARs	applicable or relevant and appropriate requirements
CCU	Cold Creek unit
CERCLA	<i>Comprehensive Environmental Response, Compensation, and Liability Act of 1980</i>
COC	contaminant of concern
COPC	contaminant of potential concern
EPA	U.S. Environmental Protection Agency
EPC	exposure-point concentration
OU	operable unit
RESRAD	RESidual RADioactivity (dose model)
RTD	removal, treatment, and disposal
UCL	upper confidence limit

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Appendix F

Evaluation of Future Risk Reduction for Various Soil Removal Alternatives at the 216-Z-1a Tile Field, 216-Z-9 Trench, and 216-Z-12 Crib

F1.0 Introduction

The human-health risk assessment for the 200-PW-1/3/6 Operable Units (OU) (see Appendix A) evaluated risks under current conditions (industrial land use, assuming the existing institutional controls with adult workers as the population potentially exposed) and future conditions (unrestricted land use if institutional controls fail in the future). The unrestricted land use scenario assumes that land use controls will remain in place for 150 years; after that time there is assumed to be a failure of institutional controls so potential exposures to a future residential farming population (adults and children) and a future working population (well drillers) are hypothetically possible.

This appendix summarizes the results of the baseline risk assessment from Appendix A for the future well driller and future subsistence farmer from soil contamination at the 216-Z-1A Tile Field, the 216-Z-9 Trench, and the 216-Z-12 Crib (subsistence farmer risks only). [Note, the 216-Z-12 Crib was not evaluated in Appendix A; however the same methodology that was used in the baseline risk assessment was employed to estimate subsistence farmer risks at this site.] The remaining sections of this appendix evaluate residual risk for the final contaminants of potential concern (COPC) if different depth intervals of soil were to be removed from these three waste sites (in general, shallower depths have higher concentrations). This appendix includes discussion of the selection of COPCs for the three waste sites, estimated soil concentrations for the COPCs assuming varying depths of soil removal, and calculation of health risks based on the remaining soil concentrations for the various soil-removal alternatives at these three waste sites.

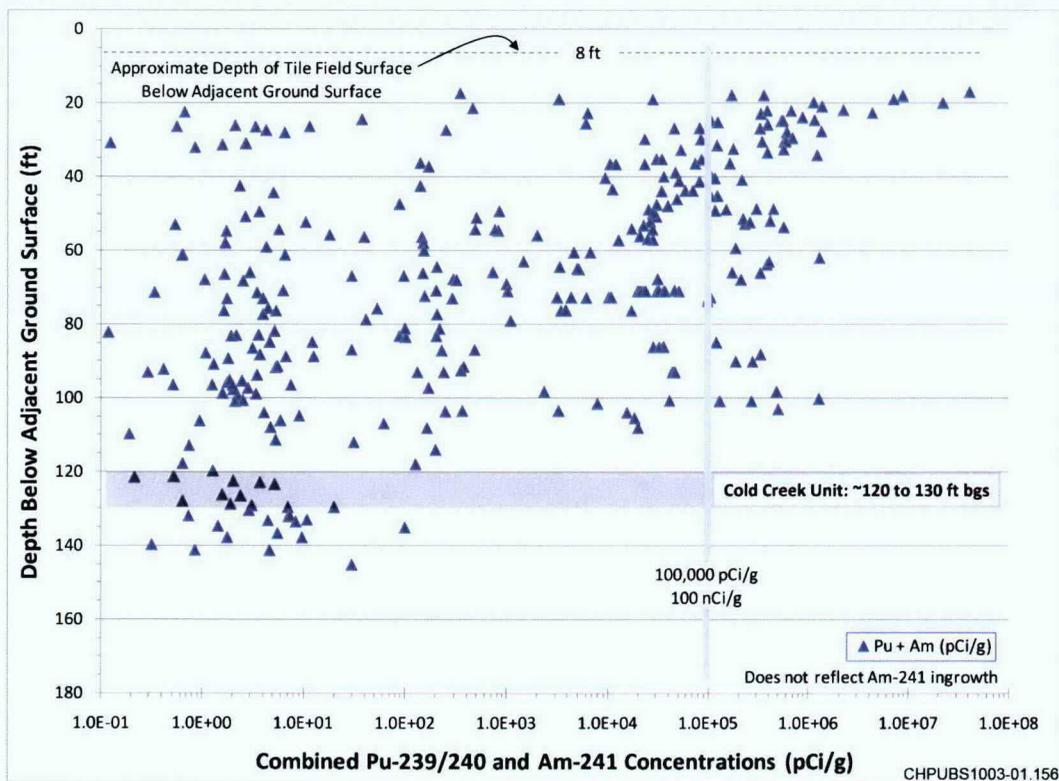
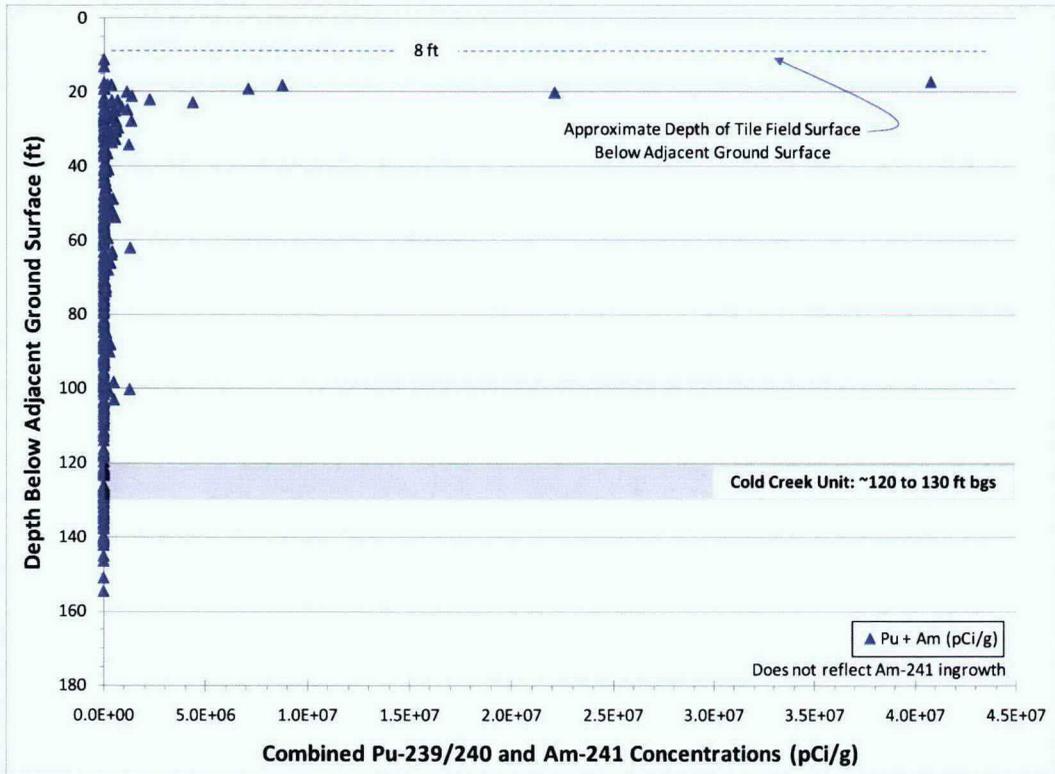
The results of this analysis support the evaluation of various removal, treatment, and disposal (RTD) alternative cases for the 216-Z-1A Tile Field, the 216-Z-9 Trench, the 216-Z-12 Crib, and their waste groups (see Chapters 6.0 and 7.0 of the main text).

1

1 **F2.0 Contaminant Distribution**

2 The human-health risk assessment (Appendix A) identified the primary risk drivers in soil to the future
3 subsistence farmer and future well driller at the 216-Z-1A Tile Field and the 216-Z-9 Trench as Am-241
4 and Pu-239/240. Through other site investigations, Am-241 and Pu-239/240 were also identified as the
5 likely COPCs at the 216-Z-12 Crib (RHO-ST-44, *216-Z-12 Transuranic Crib Characterization:
6 Operational History and Distribution of Plutonium and Americium*). The distribution of these
7 contaminants with depth at these three waste sites is shown in Figures F-1, F-2, and F-3. Although it is
8 generally true that the shallow depths near the liquid waste release points at these waste sites have higher
9 concentrations of these contaminants, significant concentrations also are found deeper in the vadose zone
10 at the high-salt waste sites (216-Z-1A Tile Field and 216-Z-9 Trench).

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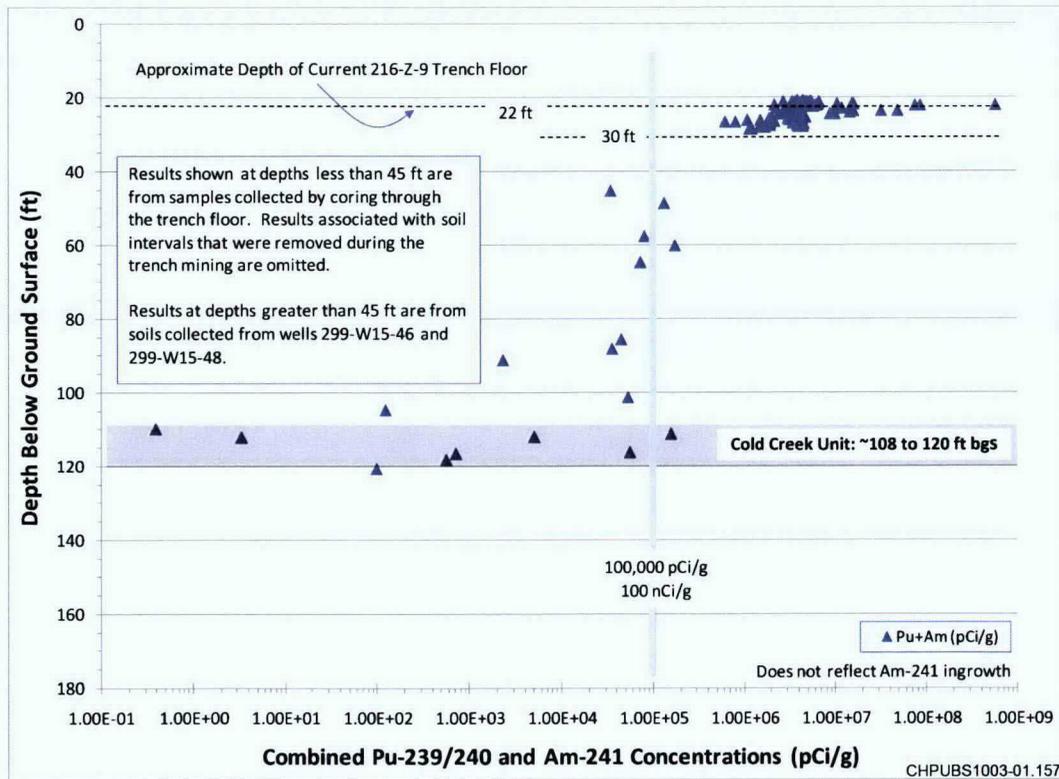
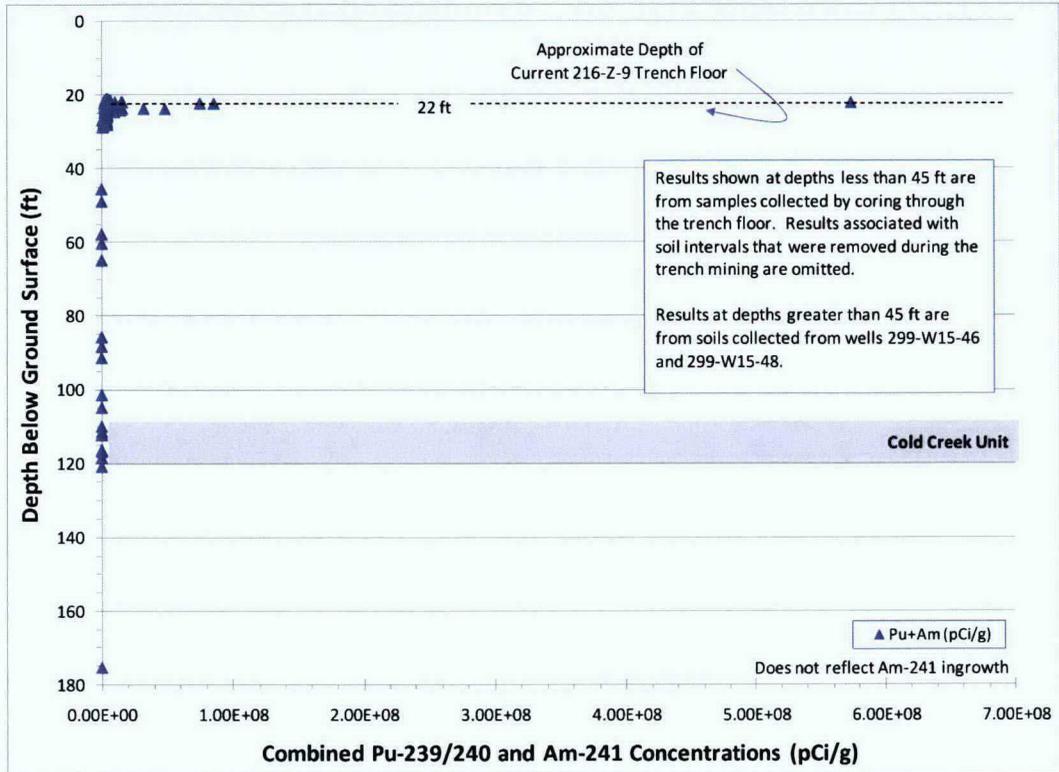


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Figure F-1. Distribution of Pu-239/240 and Am-241 (Combined Activities) in Soil Beneath the 216-Z-1A Tile Field (Linear and Log Scales)

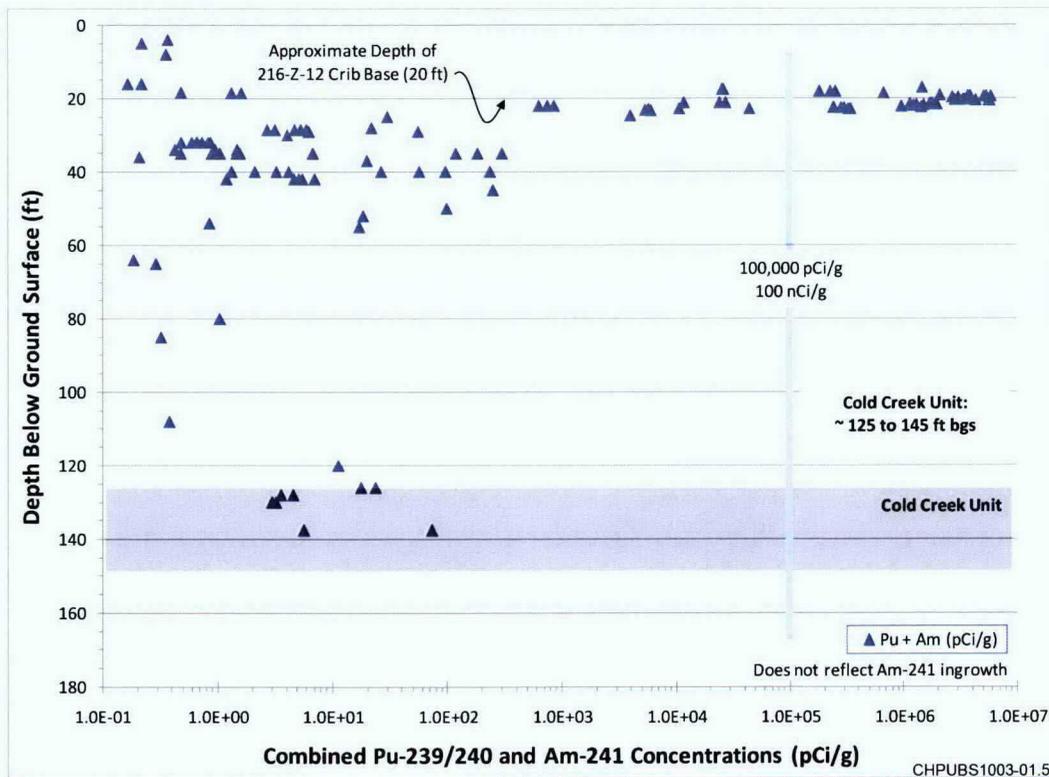
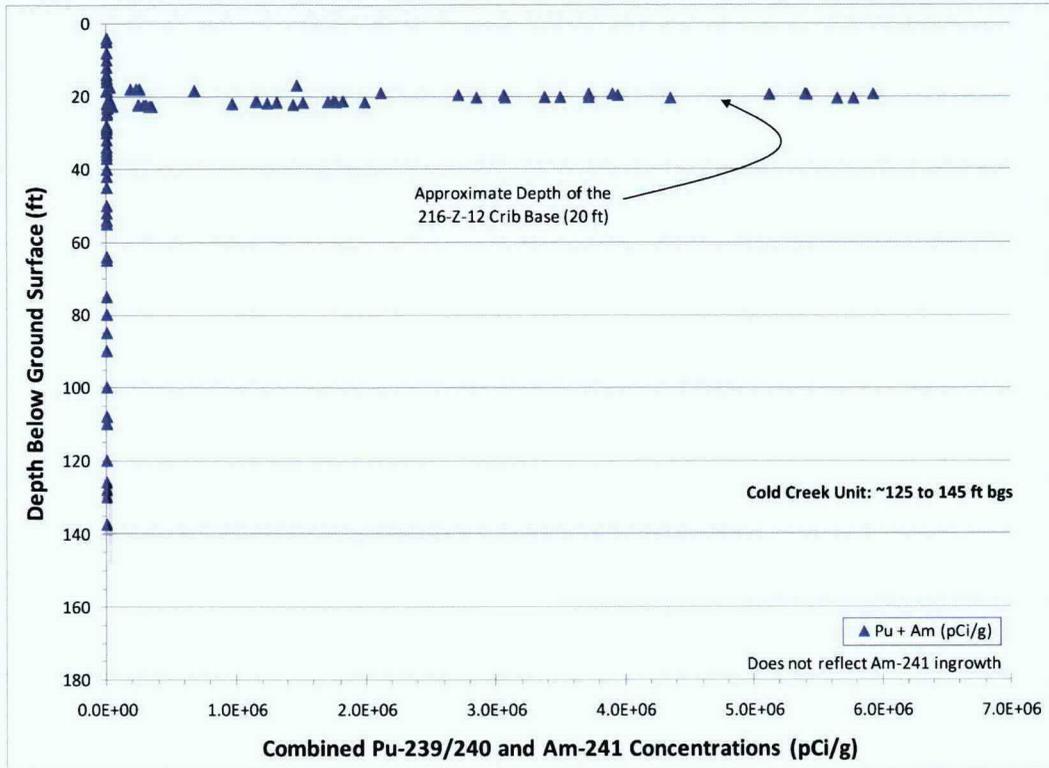


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Figure F-2. Distribution of Pu-239/240 and Am-241 (Combined Activities) in Soil Beneath the 216-Z-9 Trench (Linear and Log Scales)



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Figure F-3. Distribution of Pu-239/240 and Am-241 (Combined Activities) in Soil Beneath the 216-Z-12 Crib (Linear and Log Scales)

1 **F3.0 Future Well Driller Baseline Risk and Future Risk Reduction Evaluation**

2 In Appendix A (Sections A5.3 and A5.4), the risks were evaluated for a future well driller exposed to
3 contaminants in soil via drill cuttings while engaged in installing a water supply well through the
4 216-Z-9 Trench and 216-Z-1A Tile Field. Under this scenario 150 years in the future, all knowledge of
5 the site is lost, there is a failure of institutional controls, and the worst case is evaluated for a water well
6 drilled through each waste site. For the radionuclide contaminants of potential concern (COPC), the risks
7 presented are for 150 years in the future as it is anticipated that institutional controls would be unlikely to
8 fail before that time. However, because of the long half-lives of the principal radionuclide COPCs, the
9 risks at the 216-Z-9 Trench and 216-Z-1A Tile Field do not change significantly between 150 years and
10 1,000 years in the future.

11 The exposure routes evaluated for the future well driller were inhalation (including radon), ingestion, and
12 external radiation. At the 216-Z-9 Trench, three nonradionuclide COPCs (cadmium, carbon tetrachloride,
13 and manganese) were evaluated in addition to the radionuclides, and all non-cancer hazards were well
14 below a target hazard index of 1. The baseline risks for future well drillers are presented in Table F-1.
15 Well driller risks did not exceed 10^{-4} at either of these waste sites. The specific baseline risk results are
16 below:

- 17 • **216-Z-1A Tile Field:** Cumulative risks were 3×10^{-6} , due to Am-241 (80 percent of total risks),
18 followed by Pu-239 (18 percent of total). Risks are driven by the external radiation pathway for Am-
19 241.
- 20 • **216-Z-9 Trench:** Cumulative risks were 2×10^{-5} for the radionuclides, with Pu-239 (46 percent of
21 total), Am-241 (43 percent of total risks), and Pu-240 having risks in excess of 1×10^{-6} . Carbon
22 tetrachloride had the highest risks of the two nonradionuclide carcinogens, with risks of 2×10^{-6} .
23 Ingestion of Pu-239 and external radiation due to Am-241 are the pathways contributing to overall
24 risks.

25 In summary, the baseline risks for future well drillers at the 216-Z-9 Trench and 216-Z-1A Tile Field did
26 not exceed 10^{-4} at either waste site. Therefore, because the baseline risks for the future well drillers are
27 within acceptable levels with no soil removal at these waste sites, any soil-removal alternatives at these
28 waste sites would further reduce the future risk to the well drillers, but such action is not required by the
29 *Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA)* or other
30 potential applicable or relevant and appropriate requirements (ARARs). Although health risks to a future
31 well driller were not calculated for the 216-Z-12 Crib, the risks would be similar to those calculated at the
32 216-Z-9 Trench and 216-Z-1A Tile Field and would not exceed 10^{-4} , based on the similar concentrations
33 of plutonium and americium found at the three sites.

34 The future well driller is not considered further in the evaluation presented in this appendix.

1

Table F-1. Well Driller Baseline Risks from Soil

Radionuclide (Parent and Decay) or Contaminant	Total*	Inhalation	Ingestion	External Radiation	Radon
216-Z-1A Tile Field					
Am-241	3E-06	9E-10	5E-08	2E-06	--
Pu-239	5E-07	9E-09	4E-07	9E-08	--
Pu-240	1E-07	2E-09	1E-07	1E-08	--
Total – 150 years	3E-06	1E-08	6E-07	3E-06	6E-24
216-Z-9 Trench					
Am-241	7E-06	2E-09	1E-07	7E-06	--
Eu-152	1E-10	2E-18	1E-15	1E-10	--
Ni-63	4E-12	2E-15	4E-12	--	--
Np-237	7E-08	1E-12	5E-11	7E-08	--
Pu-238	8E-10	2E-11	7E-10	9E-11	--
Pu-239	7E-06	1E-07	6E-06	1E-06	--
Pu-240	2E-06	3E-08	1E-06	2E-07	--
Ra-226	8E-08	2E-13	4E-11	8E-08	--
Ra-228	5E-16	3E-21	1E-18	5E-16	--
Sr-90	5E-12	5E-17	1E-13	5E-12	--
Tc-99	6E-21	7E-25	1E-21	5E-21	--
Th-228	1E-15	1E-20	5E-19	1E-15	--
Th-230	3E-11	2E-13	1E-11	2E-11	--
Radionuclide Total – 150 years	2E-05	2E-07	7E-06	8E-06	3E-11
Cadmium	1E-12	1E-12	--	--	--
Carbon tetrachloride	2E-06	2E-06	1E-09	--	--
Contaminant Total*	2E-06	2E-06	1E-09	--	--

Notes:

*Totals are calculated using unrounded values

-- = indicates incomplete pathway or not applicable

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1 **F4.0 Future Subsistence Baseline Risk and Future Risk Reduction Evaluation**

2 In Appendix A (Sections A5.3 and A5.4) the human-health risk assessment found significant baseline
3 health risks for a future residential farming population if they were to be exposed to impacted subsurface
4 soils from the 216-Z-1A Tile Field and the 216-Z-9 Trench. Using the same inputs for the 216-Z-12 Crib
5 as in Appendix A, significant risks are also present at the 216-Z-12 Crib for future subsistence farmer
6 exposures to subsurface soil at that site. The remainder of this appendix evaluates future risk reduction to
7 the subsistence farmer from various soil removal cases at these three waste sites.

8 **F4.1 Selection of Contaminants of Concern**

9 Risk assessment procedures initially select COPCs by screening maximum concentrations of detected
10 contaminants against generic health-protective screening concentrations. Additional considerations also
11 factor into COPC selection, e.g., natural background levels, whether a contaminant is an essential
12 nutrient, chemical toxicity, and the magnitude and frequency of exceedances above screening levels.
13 Once COPCs are selected, the baseline risk assessment performs an in-depth, site-specific analysis to
14 determine whether health risks are potentially present at the site using conservative, health-protective,
15 assumptions. At the end of the risk assessment process, final COPCs are selected. A COPC becomes a
16 final COPC if at least one of the following applies:

- 17 • The contaminant exceeds a target health goal
- 18 • The contaminant does not exceed a target health goal but contributes a significant percentage to total
19 site risks (i.e., is a concern not necessarily alone, but contributes substantially to the site's cumulative
20 risks)

21 In addition to the above, a chemical may be included or excluded as a COPC regardless of risk results if
22 fate, transport, toxicity, or other special considerations warrant its inclusion or exclusion; however, the
23 rationale for such an inclusion or exclusion should be presented and approved by the applicable
24 regulatory agencies.

25 There are two sets of target health goals under CERCLA, determined by different methodologies: one for
26 contaminants where the toxic effect of concern is not cancer, and the other for carcinogens. The selection
27 of COPCs at 216-Z-9 and 216-Z-1A is made on the basis of their exceedances above cancer health goals
28 because, with the exception of carbon tetrachloride, no other contaminants have non-cancer hazards in
29 excess of health goals; however, carbon tetrachloride also has cancer risks exceeding the cancer health
30 goal. The U.S. Environmental Protection Agency's (EPA) target health goal for carcinogens is a cancer
31 risk range of 10^{-6} to 10^{-4} . Risks below 10^{-6} are considered to be acceptable. While EPA's target risk range
32 begins at 10^{-6} , EPA generally does not recommend taking action at a site unless the upper end of the
33 target risk range (i.e., 10^{-4}) is exceeded (Clay, 1991, "Role of the Baseline Risk Assessment in Superfund
34 Remedy Selection Decisions," OSWER Directive 9355.0-30). In addition, EPA does not necessarily
35 consider 10^{-4} a discrete line but will allow risks slightly higher than that to remain at a site if justified
36 based on site-specific conditions (EPA 540-R-97-013, *Rules of Thumb for Superfund Remedy Selection*,
37 OSWER 9355.0-69). Therefore, a site-specific risk above 10^{-4} was considered an initial threshold in
38 selecting COPCs for the three waste sites; however, a contaminant's contribution to the overall
39 cumulative risk total and special considerations for nonradionuclides also were considered in final COPC
40 selection. For the 216-Z-12 Crib, which did not go through the full risk assessment evaluation in
41 Appendix A, the only contaminant data were for Am-241, Pu-238, Pu-239, and Pu-240. Three of these
42 four radionuclides were evaluated as COPCs as described in Section F4.1.3. Table F-2 presents the

1 contaminants that exceeded 10^{-4} for the subsistence farmer scenario at all three waste sites, and selection
2 of final COPCs is detailed below.

3 **F4.1.1 216-Z-1A Tile Field Contaminants of Potential Concern**

4 As shown in Table F-2, Am-241, Pu-239, and Pu-240 are selected as final COPCs for this waste site.
5 These three contaminants were the only ones at this site with risks exceeding 10^{-4} and they make up
6 99.9 percent of the total site risks. The risk percentages were calculated including one additional COPC
7 evaluated at the site (Np-237) and an additional nine daughter products evaluated in the baseline risk
8 assessment (daughter products are automatically included in the risk modeling program used to estimate
9 radionuclide risks).

10 **F4.1.2 216-Z-9 Trench Contaminants of Potential Concern**

11 Americium-241, Pu-239, and Pu-240 also are selected as final COPCs at the 216-Z-9 Trench (see Table
12 F-2). These three contaminants make up 99.7 percent of the total radionuclide risks including all
13 radionuclide COPCs and daughter products evaluated at this site in the baseline risk assessment (10
14 additional radionuclide COPCs plus 10 daughter products were evaluated). Two other radionuclides,
15 Np-237 and Ra-226, had total risks of 2×10^{-4} each but were not selected as COPCs because (1) their
16 risks essentially were equal to the upper bound target health goal (and this goal is not a discrete line), and
17 (2) their combined risks contribute only 0.2 percent of the cumulative risks at this site. One
18 nonradionuclide COPC, carbon tetrachloride, had risks exceeding 10^{-4} due to ingestion of home-grown
19 produce. However, carbon tetrachloride is not considered a final COPC in soil because the risks and
20 hazards for this contaminant were estimated using current concentrations, and in 150 years (the earliest
21 assumed date at which residential exposure could occur), carbon tetrachloride concentrations in soil are
22 likely to be considerably lower due to weathering and degradation processes in the environment.
23 Therefore, concentrations (and consequently health risks) are expected to be lower than present values,
24 although the reduction in concentration was not quantified. In contrast, radionuclide concentrations 150
25 years in the future for Am-241, Pu-239, and Pu-240 will not be significantly lower than today due to the
26 long half-lives of these radionuclides.

27 **F4.1.3 216-Z-12 Crib Contaminants of Concern**

28 Americium-241, Pu-239, and Pu-240 were initially selected as COPCs at the 216-Z-12 Crib, based on the
29 frequency and magnitude of exceedances over their risk-based screening levels. Americium-241, Pu-239,
30 and Pu-240 are all also final COPCs at this site because their risks exceed 10^{-4} (see Table F-2) and each
31 radionuclide makes a significant contribution to cumulative site risks. Although Pu-238 was detected at
32 this site at concentrations exceeding its risk-based screening level of 2.9 pCi/g, the 95 percent upper
33 confidence limit (95 percent UCL) of its mean concentration of 1.08 pCi/g is below the risk-based
34 screening level. Therefore, Pu-238 was not identified as a COPC at the 216-Z-12 Crib and thus would not
35 be a final COPC.

Table F-2. Future Subsistence Farmer Baseline Risks for Contaminants with Risks Greater than 10⁻⁴

Radionuclide or Contaminant	Percentage of Total Risks Including all COPCs	Total Risk	Direct Exposure Pathways			Food Chain Pathway
			Inhalation	Ingestion	External Radiation	Produce*
216-Z-1A Tile Field						
Am-241	16%	2E-03	4E-07	4E-05	1E-03	3E-04
Pu-239	69%	8E-03	1E-05	9E-04	2E-04	7E-03
Pu-240	15%	2E-03	3E-06	2E-04	2E-05	2E-03
Radionuclide Total		1E-02	1E-05	1E-03	1E-03	8E-03
216-Z-9 Trench						
Am-241	3.5%	5E-03	1E-06	1E-04	4E-03	8E-04
Np-237	0.1%	2E-04	1E-09	1E-07	2E-04	1E-05
Pu-239	79%	1E-01	2E-04	1E-02	3E-03	9E-02
Pu-240	17%	2E-02	4E-05	3E-03	2E-04	2E-02
Ra-226	0.1%	2E-04	1E-10	6E-08	2E-04	2E-05
Radionuclide Total		1E-01	2E-04	2E-02	1E-02	1E-01
Carbon tetrachloride		1E-03	5E-05	3E-06	--	1E-03
216-Z-12 Crib						
Am-241	33%	1E-03	4E-07	3E-05	1E-03	2E-04
Pu-239	55%	2E-03	4E-06	3E-04	6E-05	2E-03
Pu-240	12%	5E-04	8E-07	6E-05	5E-06	5E-04
Radionuclide Total		4E-03	5E-06	4E-04	1E-03	3E-03

Notes:

Shading indicates the contaminant is a contaminant of concern.

* Produce grown in impacted soil is the only food chain pathway evaluated for soil. For beef cattle and dairy cattle, their exposures are due to drinking impacted water and foraging on plants irrigated with impacted water; thus, risk from ingesting beef cattle and dairy cattle are only due to exposures to contaminants in groundwater. Impacted soil is assumed to be limited to the garden area of the home.

-- = indicates incomplete pathway or not applicable

COPC = contaminant of potential concern

1 **F4.2 Exposure Point Concentrations**

- 2 To calculate a cancer risk, an estimate must be made of the radiological concentration to which an
3 individual may be exposed. According to EPA guidance (OSWER Publication 9285.7-081, *Supplemental*

1 *Guidance to RAGS: Calculating the Concentration Term*), the concentration term at the exposure point
2 (the exposure-point concentration [EPC]) should be an estimate of the average concentration to which an
3 individual would be exposed over a significant part of a lifetime. Because of the uncertainty associated
4 with estimating the true average concentration at a site, EPA generally recommends the use of the 95
5 percent UCL of the arithmetic mean as the appropriate estimate of the average site concentration for a
6 reasonable maximum exposure scenario (OSWER Directive 9285.6-03, *Risk Assessment Guidance for
7 Superfund Volume I: Human Health Evaluation Manual Supplemental Guidance "Standard Default
8 Exposure Factors" Interim Final*). At the 95 percent UCL, the probability of underestimating the true
9 mean is less than 5 percent. The 95 percent UCL can address the uncertainties surrounding a distribution
10 average due to limited sampling data. Calculation of the 95 percent UCL in the baseline risk assessment
11 and for the calculations in Section F4.2.2 was accomplished using EPA's ProUCL software (EPA, 2004,
12 *ProUCL Version 3.00.02*)¹.

13 The EPCs used to calculate the baseline future subsistence risks shown in Table F-2 included all the
14 subsurface soil data in the vadose zone at each waste site, modified to represent subsistence farmer
15 exposure conditions as described in Section F4.2.2. To assess the potential risk reduction if certain depth
16 intervals of impacted soil were removed from each waste site, EPCs must be recalculated after removing
17 the sampling point data from a specific depth interval. Once EPCs have been recalculated, risks can be
18 calculated for the new soil concentrations to which subsistence farmers would be exposed.

19 For the 216-Z-1A Tile Field, revised EPCs were calculated under seven removal scenarios (from current
20 ground surface):

- 21 • Removal of 0 to 6.1 m (20 ft) of soil
- 22 • Removal of 0 to 12.2 m (40 ft) of soil
- 23 • Removal of 0 to 18.3 m (60 ft) of soil
- 24 • Removal of 0 to 22.9 m (75 ft) of soil
- 25 • Removal of 0 to 24.4 m (80 ft) of soil
- 26 • Removal of 0 to 27.4 m (90 ft) of soil
- 27 • Removal of 0 to 30 m (95 ft) of soil

28 For the 216-Z-9 Trench, revised EPCs were calculated for one removal scenario: removal of soil located
29 0.36 to 2.7 m (1.2 to 9 ft) directly below the bottom of the trench.

30 For the 216-Z-12 Crib, revised EPCs were calculated under three removal scenarios (from current ground
31 surface):

- 32 • Removal of 0 to 6.1 m (20 ft) of soil
- 33 • Removal of 0 to 7.6 m (25 ft) of soil
- 34 • Removal of 0 to 9.1 m (30 ft) of soil

35 **F4.2.1 Estimation of Americium-241 Concentrations**

36 As noted above, the development of subsistence farmer EPCs for the baseline risk assessment started with
37 the available soil data in the vadose zone beneath each site. However, the available historical Am-241

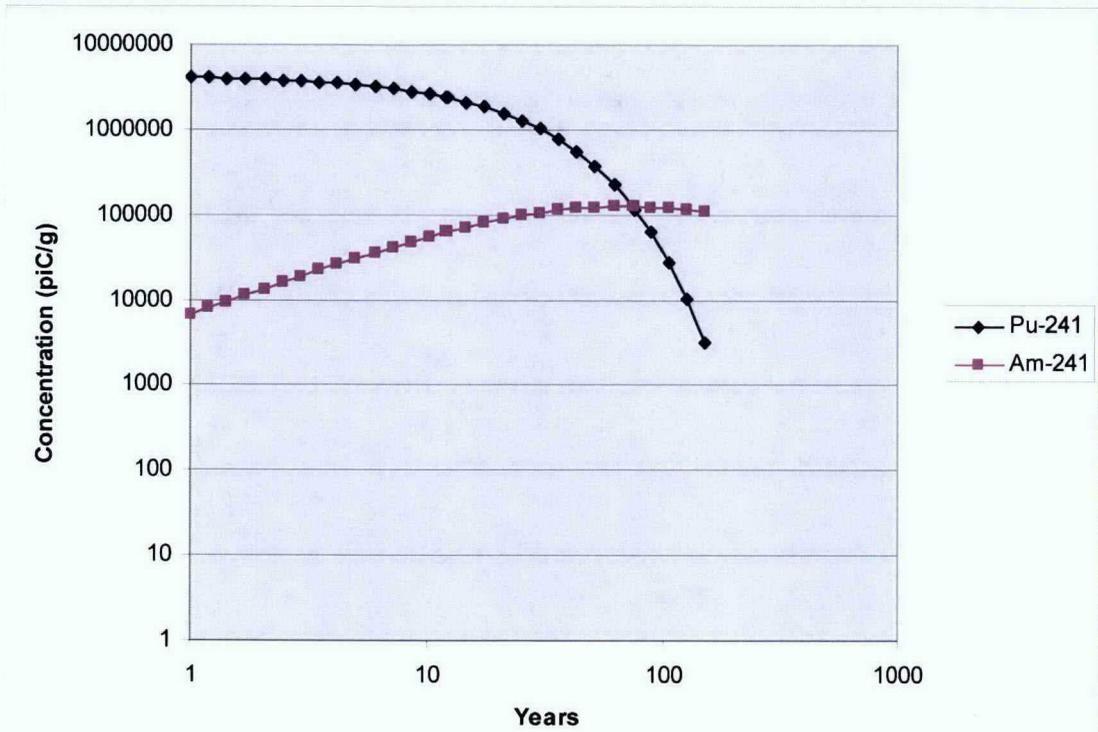
¹ After the baseline risk assessment was completed, EPA released a newer version of its ProUCL software. The calculations for 216-Z-9 and 216-Z-1A in this Appendix were accomplished using the older software (v.3.00.02) to provide consistency with the baseline risk assessment results. Because the 216-Z-12 Crib was not included in the original evaluation, 95% UCLs for the 216-Z-12 Crib were calculated using EPA 2007, ProUCL Version 4.00.02.

1 data underestimate the maximum future americium concentrations. Americium-241 is the daughter
2 product of Pu-241, which was produced as part of the plutonium-production processes, and there are no
3 data for Pu-241 because of the difficulties with analyzing for this isotope of plutonium. Plutonium-241
4 has a relatively short half-life of 14.5 years. The production of plutonium (including Pu-241) started in
5 1944 at the Hanford Site. The final waste disposal to the 200-PW-1 and -6 OU waste sites varied and,
6 therefore, some sites are further along the Am-241 in-growth curve than others. Because the Am-241 data
7 at the 216-Z-1A Tile Field, 216-Z-9 Trench, and 216-Z-12 Crib came from past laboratory analyses
8 (1979, 1963, 1973, and 1980, respectively), Am-241 concentrations in the available data sets likely do not
9 represent the maximum in-growth concentrations of this radionuclide. Therefore, maximum
10 concentrations of Am-241 were estimated using the disposal date information for each waste site, the date
11 of the available Am-241 laboratory data, and the RESidual RADioactivity (RESRAD) dose model, which
12 can estimate radiological concentrations in the future taking into consideration radionuclide decay and
13 in-growth.

14 Maximum Am-241 concentrations are estimated below:

- 15 • Liquid waste disposal at the 216-Z-1A Tile Field occurred from 1964 to 1969, at the 216-Z-9 Trench
16 from 1955 to 1962, and at the 216-Z-12 Crib from 1959 to 1973. The "0" year in the RESRAD model
17 therefore was estimated to be 1967 for the 216-Z-1A Tile Field, 1960 for the 216-Z-9 Trench, and
18 1966 for the 216-Z-12 Crib.
- 19 • Site-specific information on the vadose zone and the contaminant distribution for each site was
20 entered into RESRAD (see Chapters 2.0 and 3.0 of the main text).
- 21 • The known Am-241 concentration for each site was the 95 percent UCL of the available historical
22 data. This was 1979 for the 216-Z-1A Tile Field (year 12 in RESRAD), 1973 for the 216-Z-9 Trench
23 (year 13 in RESRAD), and 1980 for the 216-Z-12 Crib (year 14 in RESRAD).
- 24 • Plutonium-241 concentrations at year 0 were entered into RESRAD until the Am-241 concentrations
25 at the applicable year matched the existing data.

26 The resulting Am-241 in-growth curves were graphed for each site and are presented in Figures F-4, F-5,
27 and F-6 for the 216-Z-1A Tile Field, the 216-Z-9 Trench, and the 216-Z-12 Crib, respectively. At all three
28 sites, it appears that the maximum Am-241 concentration would occur around 60+ years from year 0.
29 Therefore, current Am-241 concentrations are likely 20 to 25 years from their maximum values. Because
30 year 2005 concentrations are aged to represent 150 years in the future (the earliest subsistence farmer
31 exposures; see Section 3.2 of the main text), use of the maximum Am-241 concentration as the current
32 concentration only slightly overestimates Am-241 concentrations in the year 2150. For the 216-Z-1A Tile
33 Field, the year 2005 concentrations are 93 percent of their maximum concentration (occurring
34 approximately 73 years from time 0, or year 2040 if time 0 is 1967). For the 216-Z-9 Trench, current year
35 concentrations are 96 percent of their maximum concentration, which occurs around 63 years from time
36 0, or year 2023 if time 0 is 1960. At the 216-Z-12 Crib, current concentrations are 95 percent of their
37 maximum concentration, which occurs around 64 years from time 0, or year 2030 if time 0 is 1966.
38 Because this analysis is meant to be a reasonable approximation of a maximum americium concentration,
39 an exhaustive analysis over exactly what year should be year 0, and the possible differing amounts of Pu-
40 241 that might have been disposed each year of operation, has not been performed. The maximum
41 concentrations estimated as described above were used as reasonably health-protective, given the lack of
42 Pu-241 data and the uncertainties in the estimation process. This slight potential overestimation does not
43 have a significant effect on estimates of health risk.

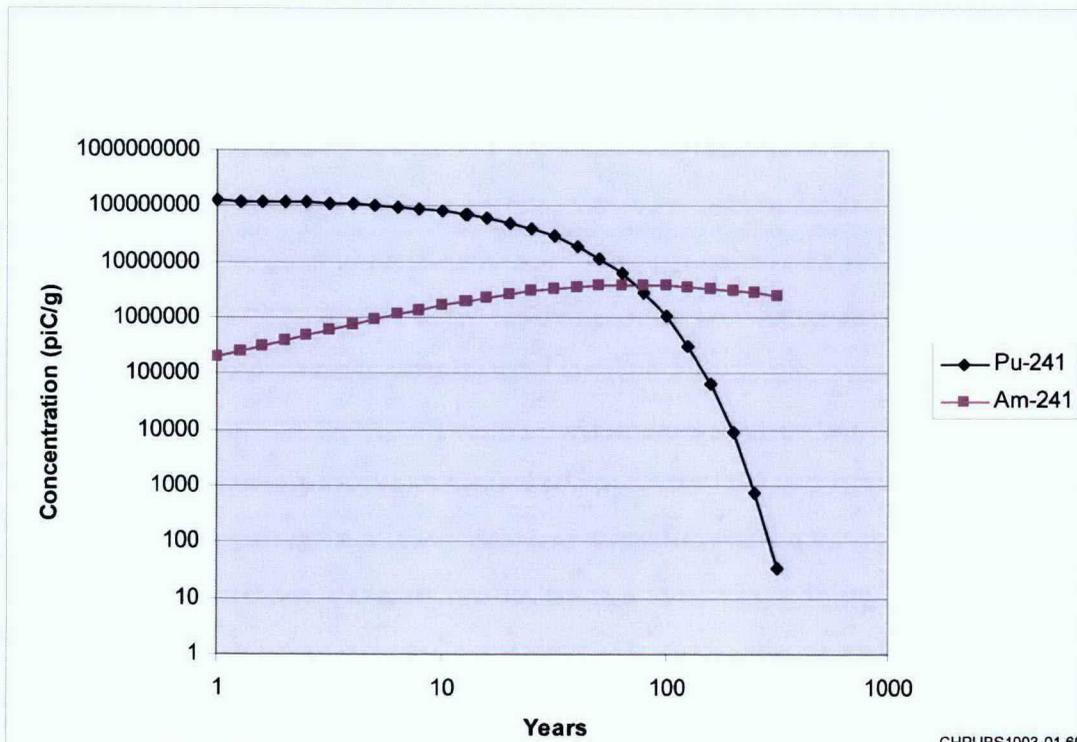


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Figure F-4. In-Growth of Americium-241 at the 216-Z-1A Tile Field

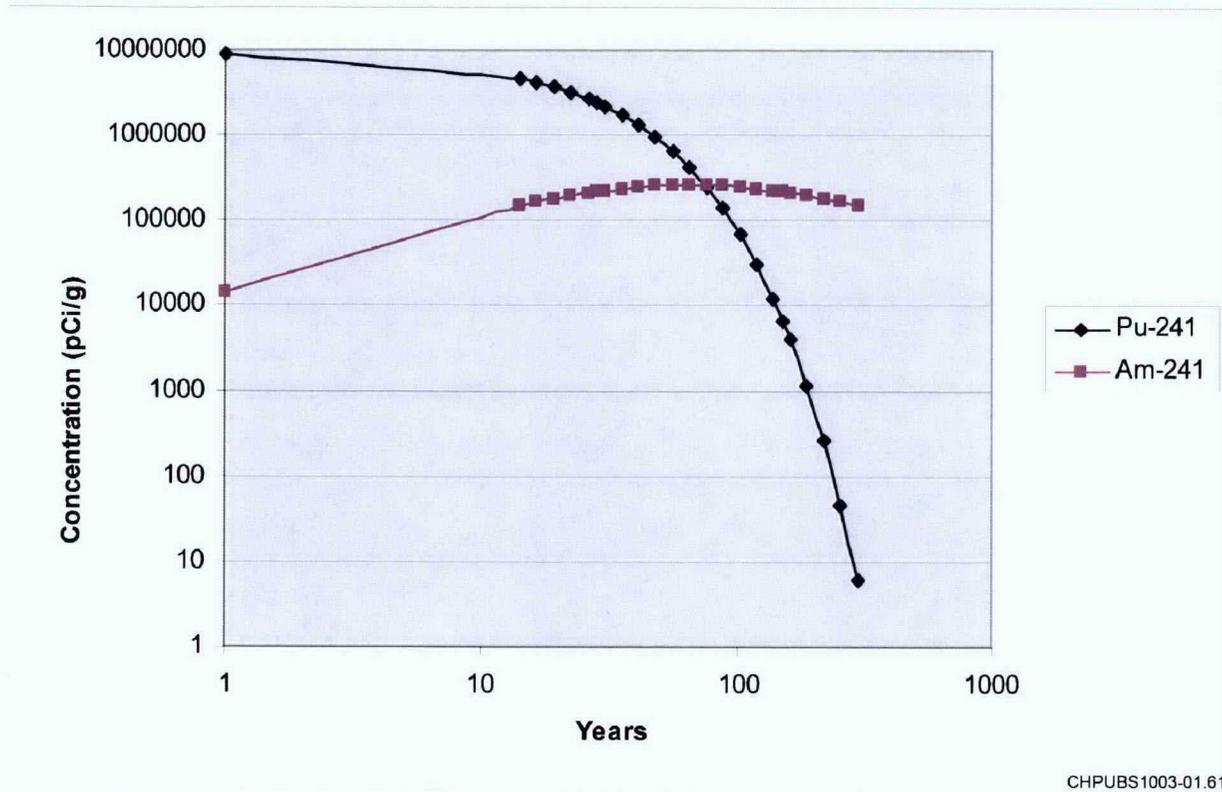


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Figure F-5. In-Growth of Americium-241 at the 216-Z-9 Trench



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Figure F-6. In-Growth of Americium-241 at the 216-Z-12 Crib

3 At the 216-Z-9 Trench where there is current (2005 to 2006) as well as historical data for Am-241, the
 4 current Am-241 data were not adjusted because it is sufficiently close to its maximum concentration. The
 5 maximum predicted values for the 216-Z-1A Tile Field, the maximum predicted values for the
 6 216-Z-12 Crib, and the maximum predicted values from the 1973 measurements combined with the 2005
 7 to 2006 data at the 216-Z-9 Trench were used to estimate soil concentrations and subsequent health risks
 8 in the sections that follow.

9 **F4.2.2 Subsistence Farmer Exposure Point Concentration Calculation Methodology**

10 For residents to come into contact with contamination in soil, the impacted soil at depth at the waste sites
 11 must be brought to the surface. As described in the baseline risk assessment, this scenario would only
 12 occur if all knowledge of the site is lost as are any markers or indicators that could be placed on the site,
 13 and this is not considered to be possible in this assessment until at least the year 2150. At this time, it is
 14 assumed that the likeliest way for subsurface material to be brought to the surface would be through
 15 drilling a well and the drill cuttings being spread in the area of a residential home and vegetable garden.
 16 Then, through daily activities, residents potentially could be exposed to surface soil through ingestion,
 17 inhalation of fugitive dust and vapors, external radiation, and ingestion of home-grown produce grown in
 18 impacted soils.

19 The majority of the baseline risk assessment assumptions that were required to estimate concentrations of
 20 contamination brought to the surface as well cuttings were developed in HNF-SD-WM-TI-707, 2004,
 21 *Exposure Scenarios and Unit Dose Factors for the Hanford Tank Waste Performance Assessment*. For
 22 details of formula derivation and assumption rationales, refer to HNF-SD-WM-TI-707 and the baseline
 23 risk assessment (Appendix A).

1 Calculation of a soil concentration in a home garden 150 years in the future was done in the baseline risk
2 assessment and in this appendix according to the following steps:

- 3 1. Estimate the current soil concentration in the vadose zone using the available data. This
4 concentration is referred to as Cwaste, and the baseline Cwaste concentrations for the final COPCs
5 are shown in Table F-3. The soil sample locations for each waste site that were used in the Cwaste
6 calculations are provided in Figures F-7 through F-9. Because a well could be drilled anywhere
7 within each of the waste areas, the entire vadose zone data set for each area was used in the 95
8 percent UCL calculation to represent a high-end estimate of the average contaminant concentration
9 in the vadose zone. For the 95 percent UCL calculations at the 216-Z-9 Trench, certain samples
10 were weighted differently due to uneven sampling within the vadose zone (i.e., some depth intervals
11 had much more data than others; see the footnote in Table F-3 and Figure F-7).

Table F-3. Baseline Risk Assessment Vadose Zone Concentrations (Cwaste)

Site Name	Contaminant Name	Cwaste (pCi/g)	Distribution	Statistical Basis of Cwaste 95UCL Recommended by ProUCL	No. of Samples
216-Z-1A Tile Field	Americium-241	122,528	Non-parametric	95% Chebyshev (Mean, Sd) UCL	458
	Plutonium-239/240	698,678	Non-parametric	95% Chebyshev (Mean, Sd) UCL	423
216-Z-9 Trench*	Americium-241	300,556	Gamma	Adjusted Gamma UCL	41
	Plutonium-239/240	8,903,844	Non-parametric	99% Chebyshev (Mean, Sd) UCL	25
216-Z-12 Crib	Americium-241	251,885	Non-parametric	97.5% KM (Chebyshev) UCL	217
	Plutonium-239/240	499,102	Non-parametric	97.5% KM (Chebyshev) UCL	228

Notes:

*At the 216-Z-9 Trench, there is a preponderance of data in the shallowest layer (ARH-2915), and these data also represent the highest concentrations. Therefore, to reasonably estimate vadose-zone concentrations, the following additional steps were used in the Cwaste exposure point concentration calculations at the 216-Z-9 Trench:

- (i) Because the sampling was biased toward the shallower depth in holes A, B, C, D, G, and H, whereas in wells 299-W15-46 and 299-W15-48, samples were collected in relatively even depth intervals at deeper depths, less "weight" must be given to each individual data point collected from the lettered "holes" (see Figure F-7).
- (ii) To "reduce" the effect of data points collected from the "holes," the average of data collected in each "hole" must first be taken into account and this average value was used as a single data point in calculating the 95% UCL.
- (iii) No averaging is needed for wells 299-W15-46 and 299-W15-48 because the depths are evenly spread out.
- (iv) Accordingly, the number of data points entered into the 95% UCL calculation is reduced, but the sample size is still adequate. The biased high concentrations from the "holes" are reduced in their importance.
- (v) Because more "weight" is not given to the data collected from deeper depths (greater than 36.6 m [120 ft]) where the concentrations are much lower even though there is a larger volume of cuttings from deeper depths, 95% UCLs are still likely overestimates of the concentrations in Cwaste.

ARH-2915, *Nuclear Reactivity Evaluations of 216-Z-9 Enclosed Trench.*

UCL = upper confidence limit

- 1 2. Enter the current Cwaste concentrations for radionuclides into RESRAD, where concentrations
2 150 years in the future are calculated taking into consideration radionuclide decay and in-growth.
3 Future Cwaste concentrations used in the baseline risk assessment are shown in Table F-4.

Table F-4. Baseline Exposure-Point Concentrations for Subsistence Farmer

Final COPC	Cwaste 150 Years in the Future	Ccutting 150 Years in the Future	Subsistence Farmer EPC Cgarden 150 Years in the Future	Units
216-Z-1A Tile Field				
Americium-241	89,640	29,037	10,609	pCi/g
Plutonium-239*	566,400	183,471	67,035	pCi/g
Plutonium-240*	127,300	41,236	15,066	pCi/g
216-Z-9 Trench				
Americium-241	221,000	80,156	28,152	pCi/g
Plutonium-239*	7,264,000	2,634,617	925,331	pCi/g
Plutonium-240*	1,574,000	570,882	200,505	pCi/g
216-Z-12 Crib				
Americium-241	167,400	23,206	8,479	pCi/g
Plutonium-239*	404,200	56,033	20,473	pCi/g
Plutonium-240*	90,810	12,589	4,600	pCi/g

Notes:

*Plutonium-239 and Pu-240 were analyzed together. Individual radionuclide concentrations were obtained assuming a ratio of 4.4:1 (Pu-239:Pu-240). The basis for this ratio is below:

- (vi) In weapons-grade plutonium, 94.2% of the weight of Pu-239/240 mixture is Pu-239 and 5.8% of the weight is Pu-240. Therefore, 1 g of weapons-grade Pu-239/240 contains 0.942 g of Pu-239 and 0.058 g of Pu-240
- (vii) The specific activity of Pu-239 is 61.5 mCi/g and the specific activity of Pu-240 is 227 mCi/g
- (viii) Therefore, the activity of Pu-239 in 1 g of weapons-grade Pu-239/Pu-240 is $61.5 \text{ mCi/g} \times 0.942 \text{ g} = 57.9 \text{ mCi}$ and
- (ix) The activity of Pu-240 in 1 g of weapons-grade Pu-239/Pu-240 is $227 \text{ mCi/g} \times 0.058 \text{ g} = 13.2 \text{ mCi}$.
- (x) Therefore, the relative activity of Pu-239 to Pu-240 in a weapons-grade mixture of Pu-239/240 = 4.4:1 (4.4 times as much Pu-239 as Pu-240 in units of activity).

COPC = contaminant of potential concern

EPC = exposure point concentration

1 3. Estimate the concentration in the drill cuttings (Ccut) according to the following formula:

2 $C_{cut} = C_{waste} \times (L_{waste}/L_{well})$ EQ-F1

3 where:

4 Lwell = the length (depth) of the groundwater well (the distance to the water table from ground
5 surface plus 15.2 m (50 ft), the assumed depth for completing a shallow irrigation well)

6 Lwaste = the thickness of the contaminated soil (determined by where concentrations exceed
7 health-based screening criteria)

8 4. Estimate the concentration in the garden soil (Cgarden) according to the following formula:

9 $C_{garden} = C_{cut} \times (V_{cut}/V_{garden})$ EQ-F2

10 where:

11 Vcut = the volume of soil brought to the surface as cuttings assuming a 26.7-cm
12 (10.5-in.)-diameter well is drilled (small-scale irrigation well, larger than a well used only for
13 drinking water 16.5 cm [6.5 in.] and smaller than a commercial irrigation well 40.6 cm
14 [16 in.]).

15 Vgarden = the volume of soil in the garden assuming drill cuttings would be spread over a
16 100-m² (1,076-ft²) area and the spreading depth of contaminated soil is 15 cm (6 in.), the
17 default shallowest tilling depth.

18 For all calculations, it is assumed that the average density in the soil is the same as the density in the
19 waste (a reasonable assumption for contamination in soil via infiltration of liquid wastes).

20 The Ccut and Cgarden values used in the baseline risk assessment are shown in Table F-4. Table F-5
21 presents values for Lwell, Lwaste, and Vcut for the 216-Z-1A Tile Field, the 216-Z-9 Trench, and the
22 216-Z-12 Crib for the removal scenarios; the different removal options affect the Lwaste value only. The
23 Cwaste, Ccut, and Cgarden concentrations for the removal scenarios (seven at the 216-Z-1A Tile Field,
24 one at the 216-Z-9 Trench, and three at the 216-Z-12 Crib) are presented in Table F-6. Table F-7 presents
25 the RESRAD site-specific parameters that were used with the Cwaste concentrations for each removal
26 scenario to estimate the “aged” Cwaste concentrations.

Table F-5. Summary of Parameters Used to Calculate Exposure-Point Concentrations

Vcut ^a (m3)	Ratio Lwaste to Lwell	Lwaste–Thickness of Waste (m)	Lwell–Depth of Well (m)	Depth to Groundwater (m)
216-Z-1A Tile Field^b				
Removal of 6.1 m (20 ft)				
5.480579867	0.3	23.74	87	71
Removal of 12.2 m (40 ft)				
5.480579867	0.2	17.64	87	71
Removal of 18.3 m (60 ft)				
5.480579867	0.1	11.54	87	71

Table F-5. Summary of Parameters Used to Calculate Exposure-Point Concentrations

Vcut ^a (m3)	Ratio Lwaste to Lwell	Lwaste-Thickness of Waste (m)	Lwell-Depth of Well (m)	Depth to Groundwater (m)
Removal of 22.9 m (75 ft)				
5.480579867	0.08	6.98	87	71
Removal of 24.4 m (80 ft)				
5.480579867	0.06	5.46	87	71
Removal of 27.4 m (90 ft)				
5.480579867	0.03	2.41	87	71
Removal of 28.9 m (95 ft)				
5.480579867	0.01	0.88	87	71
216-Z-9 Trench				
Removal of 2.7 m (9 ft)				
5.268303886	0.3	27.44	83	68
216-Z-12 Crib^c				
Removal of 6.1 m (20 ft)				
5.480579867	0.12	10.78	87	71
Removal of 7.6 m (25 ft)				
5.480579867	0.11	9.58	87	71
Removal of 9.1 m (30 ft)				
5.480579867	0.09	7.78	87	71

Notes:

a. $V_{cut} = \pi \times r^2 \times h \times (D_{initial}/D_{final})$

b. All removal depths include an assumption of a 1.8 m (6 ft) clean cover before buried waste is reached

c. All removal depths include an assumption of a 4.88 m (16 ft) clean cover before buried waste is reached

HNF-SD-WM-TI-707, Exposure Scenarios and Unit Factors for the Hanford Tank Waste Performance Assessment.

D_{final} = density of soil cuttings on surface (1.5 kg/L; HNF-SD-WM-TI-707)

D_{initial} = density of undisturbed soil (1.7 kg/L; HNF-SD-WM-TI-707)

h = L_{well} – depth of the well from surface to groundwater, plus 15.24 m (50 ft)

pi = 3.14159

r = radius of 26.67 cm (10.5-in.) well

V_{cut} = volume of cuttings

Table F-6. Removal Options Exposure-Point Concentrations for the Subsistence Farmer

Contaminant Name	Cwaste (pCi/g)	Distribution	Statistical Basis of Cwaste 95UCL Recommended by ProUCL	Number of Samples	Cwaste 150 Years in the Future (pCi/g)	Ccut ^a 150 Years in the Future (pCi/g)	Subsistence Farmer EPC Cgarden ^b 150 Years in the Future (pCi/g)
216-Z-1A Tile Field							
Removal of 6.1 m (20 ft)							
Americium-241	67,281	Non-parametric	95% Chebyshev	417	48,240	12,227	4,467
Plutonium-239/240	53,258	Non-parametric	95% Chebyshev	390	--	--	--
Plutonium-239 ^c	43,396	--	--	--	43,170	10,942	3,998
Plutonium-240 ^c	9,863	--	--	--	9,698	2,458	898
Removal of 12.2 m (40 ft)							
Americium-241	65,604	Non-parametric	95% Chebyshev	341	45,410	8,315	3,038
Plutonium-239/240	32,358	Non-parametric	95% Chebyshev	323	--	--	--
Plutonium-239 ^c	26,366	--	--	--	26,220	4,801	1,754
Plutonium-240 ^c	5,992	--	--	--	5,890	1,078	394
Removal of 18.3 m (60 ft)							
Americium-241	53,816	Non-parametric	95% Chebyshev	262	34,400	3,875	1,416
Plutonium-239/240	18,489	Non-parametric	95% Chebyshev	259	--	--	--
Plutonium-239 ^c	15,065	--	--	--	14,970	1,686	616
Plutonium-240 ^c	3,424	--	--	--	3,363	379	138
Removal of 22.9 m (75 ft)							
Americium-241	64,603	Non-parametric	95% Chebyshev	202	38,030	3,051	1,120
Plutonium-239/240	21,946	Non-parametric	95% Chebyshev	194	--	--	--
Plutonium-239 ^c	17,882	--	--	--	17,750	1,424	523
Plutonium-240 ^c	4,064	--	--	--	3,988	320	117
Removal of 24.4 m (80 ft)							
Americium-241	69,837	Non-parametric	95% Chebyshev	183	37,930	2,380	874

Table F-6. Removal Options Exposure-Point Concentrations for the Subsistence Farmer

Contaminant Name	Cwaste (pCi/g)	Distribution	Statistical Basis of Cwaste 95UCL Recommended by ProUCL	Number of Samples	Cwaste 150 Years in the Future (pCi/g)	Ccut ^a 150 Years in the Future (pCi/g)	Subsistence Farmer EPC Cgarden ^b 150 Years in the Future (pCi/g)
Plutonium-239/240	23,971	Non-parametric	95% Chebyshev	176	--	--	--
Plutonium-239 ^c	19,532	--	--	--	19,680	1,216	447
Plutonium-240 ^c	4,439	--	--	--	4,353	273	100
Removal of 27.4 m (90 ft)							
Americium-241	77,542	Non-parametric	95% Chebyshev	143	26,380	731	268
Plutonium-239/240	27,523	Non-parametric	95% Chebyshev	139	--	--	--
Plutonium-239 ^c	22,426	--	--	--	22,140	613	225
Plutonium-240 ^c	5,097	--	--	--	4,975	138	51
Removal of 28.9 m (95 ft)							
Americium-241	20,548	Non-parametric	95% Chebyshev	122	1,629	16	6
Plutonium-239/240	10,831	Non-parametric	95% Chebyshev	119	--	--	--
Plutonium-239 ^c	8,825	--	--	--	8,587	87	32
Plutonium-240 ^c	2,006	--	--	--	1,929	20	6
216-Z-9 Trench							
Removal of 2.7 m (9 ft)							
Americium-241	170,059	Non-parametric	95% Chebyshev	40	124,200	40,957	14,385
Plutonium-239/240	80,375	Gamma	Adjusted Gamma UCL	24	--	--	--
Plutonium-239 ^c	65,491	--	--	--	65,160	21,488	7,547
Plutonium-240 ^c	14,884	--	--	--	14,640	4,828	1,696
216-Z-12 Crib							
Removal of 6.1 m (20 ft)							
Americium-241	220,937	Non-parametric	97.5%KM (Chebyshev)	174	144,000	17,933	6,552
Plutonium-239/240	370,638	Gamma	97.5%KM (Chebyshev)	184	--	--	--
Plutonium-239 ^c	302,001	--	--	--	300,100	37372	13,655

Table F-6. Removal Options Exposure-Point Concentrations for the Subsistence Farmer

Contaminant Name	Cwaste (pCi/g)	Distribution	Statistical Basis of Cwaste 95UCL Recommended by ProUCL	Number of Samples	Cwaste 150 Years in the Future (pCi/g)	Ccut ^a 150 Years in the Future (pCi/g)	Subsistence Farmer EPC Cgarden ^b 150 Years in the Future (pCi/g)
Plutonium-240 ^c	68,637	--	--	--	67,430	8397	3,068
Removal of 7.3 m (25 ft)							
Americium-241	19.8	Non-parametric	97.5%KM (Chebyshev)	140	13	1.4	0.5
Plutonium-239/240	36	Gamma	97.5%KM (Chebyshev)	150	--	--	--
Plutonium-239 ^c	29	--	--	--	29	3	1.2
Plutonium-240 ^c	7	--	--	--	7	1	0.3
Removal of 9.1 m (30 ft)							
Americium-241	21.3	Non-parametric	97.5%KM (Chebyshev)	120	13	1.1	0.42
Plutonium-239/240	40.5	Gamma	97.5%KM (Chebyshev)	130	--	--	--
Plutonium-239 ^c	33	--	--	--	33	3	1.1
Plutonium-240 ^c	7	--	--	--	7	0.6	0.23

Notes:

^aCcut = Cwaste (Lwaste/Lwell)

^bCgarden = Ccut (Vcut/Vgarden)

^cIndividual radionuclide concentrations were obtained assuming a ratio of 4.4:1 (Pu-239: Pu-240)

Ccut = concentration of a radionuclide/chemical in the well cuttings (pCi/g or mg/kg)

Cwaste = concentration of radionuclide/chemical in the disposal site; maximum or calculated 95 UCL of the analytical data (pCi/g or mg/kg)

Lwaste = thickness of the waste (m)

Lwell = depth of the well from surface to groundwater (m), plus 15.2 m (50 ft), the average depth drilled into the aquifer.

Cgarden = concentration of a radionuclide/chemical in garden soil (pCi/g or mg/kg)

Ccut = concentration of a radionuclide/chemical in the well cuttings (pCi/g or mg/kg)

Vcut = volume of cuttings (m³)

Vgarden = volume of garden soil (15 m³)

EPC = exposure-point concentration

UCL = upper confidence limit

Table F-7. Summary of RESRAD Input Factors

Factor	Units	Value	Comments
Soil Concentrations			
Basic radiation dose limit	mrem/yr	100	Site specific
Concentration	pCi/g	Cwaste at "Time 0" or Cwaste at "Time 150 years"	Site-specific concentration set manually. Cwaste at "Time 0" is used to estimate the concentration at "Time 150 years." Cwaste at "150 years" is used to estimate the concentration in residential gardens (C _{garden}). See Table F-6 for details.
All other soil concentration factors	Varies depending on factor	Varies depending on factor	All default values used
Calculation Times			
1,2,3,4,5,6	years	0, 17, 28, 150, 500, 1000	Site-specific
Contaminated Zone Parameters (for "Time 0")			
Area of contaminated zone	square meters	Site-specific	See Table F-5 for details
Thickness of contaminated zone	meters	Site-specific	See Table F-5 for details
Length parallel to aquifer flow	meters	9.1	Site-specific information used for all sites (9.1 m [30 ft])
Contaminated Zone Parameters (for Residential Garden at "Time 150 years")			
Area of contaminated zone	square meters	100	Site-specific; size of a garden (p. 25, HNF-SD-WM-TI-707)
Thickness of contaminated zone	meters	0.15	Site-specific; tilling depth (p. 25, HNF-SD-WM-TI-707)
Length parallel to aquifer flow	meters	9.1	Site-specific information used for all sites (9.1 m [30 ft])
Cover/hydrol			Contaminated Zone = Hanford Sands
Cover depth	meters	0	Default value
Density of cover material	g/cm ³	Greyed out	Default value = 1.5
Cover erosion rate	m/yr	Greyed out	Default value = 0.001
Density of contaminated zone	g/cm ³	1.85	Hanford Sands = 1.4 – 2.3
Contaminated zone erosion rate	m/year	0	Set to zero
Contaminated zone total porosity		0.3	Hanford Sands value
Contaminated zone field capacity		0.1	Hanford Sands value

Table F-7. Summary of RESRAD Input Factors

Factor	Units	Value	Comments
Contaminated zone hydraulic conductivity	m/year	1,577	Hanford Sands = 0.005 cm/s; 1,577 m/yr
Contaminated zone b parameter		4.05	RESRAD value for sand from Appendix E
Humidity in air	g/cm ³	Greyed out	Default value
ET coefficient		0.5	Default value
Wind speed	m/s	3.4	Site-specific
Precipitation	m/yr	1	Default value
Irrigation	m/yr	0	Assume for Hanford Sands (default was 0.2)
Irrigation mode (overhead or ditch?)		Overhead	Default value
Runoff coefficient		0	Assume for Hanford Sands (default was 0.2)
Watershed area for nearby stream or pond	square meters	1,000,000	Default value
Accuracy for water/soil computations		0.001	Default value
Soil Properties			
Saturated Zone		Ringold	
Density of saturated zone	g/cm ³	1.5	Default value
Saturated zone total porosity		0.33	Ringold value
Saturated zone effective porosity		0.18	Ringold value
Saturated zone field capacity		0.21	Ringold value
Saturated zone hydraulic conductivity	m/yr	7,300	Ringold value = 7,300 m/yr
Saturated zone hydraulic gradient		0.002	Ringold value
Saturated zone b parameter		4.05	RESRAD value for sand from Appendix E
Water table drop rate	m/yr	0.2	Ringold value
Well pump intake depth	meters below water table	10	Default value
Model for water transport parameters (nondispersion or mass-balance)		Nondispersion	Default value

Table F-7. Summary of RESRAD Input Factors

Factor	Units	Value	Comments
Well pumping rate	m ³ /yr	30,000	10–20 gal/min or approx. 20,000–40,000 m ³ /yr
Number of Unsaturated Zones		3	Number of zones set manually
Unsaturated Zone #1	Soil type	Hanford Sands	Site-specific
Thickness	meters	33.5	33.5 m (110 ft)
Density	g/cm ³	1.85	Hanford Sands = 1.4 – 2.3; WHC-EP-0883, Appendix A
Total porosity		0.3	Hanford Sands value; WHC-EP-0883, Appendix A
Effective porosity		0.25	Hanford Sands value; WHC-EP-0883, Appendix A
Field capacity		0.25	Hanford Sands value; WHC-EP-0883, Appendix A
Hydraulic conductivity	m/yr	1,577	Hanford Sands = 0.005 cm/s; 1,577 m/yr; WHC-EP-0883, Appendix A
b parameter		4.05	RESRAD value for sand from Appendix E, Table E-2
Unsaturated Zone #2	Soil type	CCU (silt values; ignored caliche for model)	Site-specific
Thickness	meters	3.1	3.1 m (10 ft)
Density	g/cm ³	2.0	CCU (silt) value; WHC-EP-0883, Appendix A
Total porosity		0.37	CCU (silt) value; WHC-EP-0883, Appendix A
Effective porosity		0.29	CCU (silt) value; WHC-EP-0883, Appendix A
Field capacity		0.29	CCU (silt) value; WHC-EP-0883, Appendix A
Hydraulic conductivity	m/yr	2,740	CCU value = 8.69E-03 cm/s; 2,740 m/year; WHC-EP-0883, Appendix A
b parameter		5.3	RESRAD value for silty loam from Appendix E, Table E-2
Unsaturated Zone #3	Soil type	Ringold	Site-specific
Thickness	meters	32.3	32.3 m (106 ft)
Density	g/cm ³	1.85	Ringold = 1.4 – 2.3; WHC-EP-0883, Appendix A

Table F-7. Summary of RESRAD Input Factors

Factor	Units	Value	Comments
Total porosity		0.22	Ringold value; WHC-EP-0883, Appendix A
Effective porosity		0.13	Ringold value; WHC-EP-0883, Appendix A
Field capacity		0.13	Ringold value; WHC-EP-0883, Appendix A
Hydraulic conductivity	m/yr	7,300	Ringold = 7,300 m/yr; WHC-EP-0883, Appendix A
b parameter		4.05	RESRAD value for sand from Appendix E, Table E-2
Occupancy			
Inhalation rate	cm ³ /yr	8,400	Default value
Mass loading for inhalation	g/cm ³	3.70E-07	Site-specific based on a particulate emissions factor of 2.72E+09
Exposure duration	years	30	Default value
Indoor dust filtration factor		0.4	Default value
External gamma shielding factor		0.7	Default value
Indoor time fraction		0.5	Default value
Outdoor time fraction		0.25	Default value
Shape of contaminated zone		Circular	Default
Ingestion–dietary			
Fruits, vegetables, and grain	kg/year	106	Site-specific value; includes ingestion of fruits and vegetables only
Leafy vegetable	kg/year	10.5	Site-specific value; assuming 9% of fruit/vegetables intake is leafy
Soil ingestion	g/year	36.5	Default value
Contamination fraction–plant food		1	Evaluation of plant food only
Plant factors	Varies depending on factor	Varies depending on factor	All default values used
Radon data	Varies depending on factor	Varies depending on factor	All default values used

Table F-7. Summary of RESRAD Input Factors

Factor	Units	Value	Comments
Storage times	Days	Varies depending on factor	All default values used

HNF-SD-WM-TI-707, *Exposure Scenarios and Unit Factors for the Hanford Tank Waste Performance Assessment*

WHC-EP-0883, *Variability and Scaling of Hydraulic Properties for 200 Area Soils, Hanford Site*

CCU = Cold Creek Unit

RESRAD = RESidual RADioactivity (dose model)

1 **F4.3 Residual Risk Results**

2 The EPCs (C_{garden} values) calculated for each removal option were entered into RESRAD to calculate
3 health risks. The site-specific parameters that were entered into RESRAD for each site are presented in
4 Table F-7.

5 The maximum risk occurs when the subsurface material is initially brought to the surface, assumed to be
6 150 years in the future. Therefore, the risk results for the various removal options shown in Tables F-8
7 and F-9 represent risks at the time that the subsurface material is brought to the surface.

Table F-8. Risks and Concentration Changes with Selected Depth Intervals Removed at the 216-Z-1A Tile Field

Depth Interval Removed	Contaminant	Garden Concentration (pCi/g)	Total Risk
6.1 m (20 ft)	Americium-241	4,834	8E-04
	Plutonium-239	4,326	5E-04
	Plutonium-240	972	1E-04
			1E-03
12.2 m (40 ft)	Americium-241	3,381	6E-04
	Plutonium-239	1,952	2E-04
	Plutonium-240	439	5E-05
			9E-04
18.3 m (60 ft)	Americium-241	1,676	3E-04
	Plutonium-239	729	9E-05
	Plutonium-240	164	2E-05
			4E-04
22.9 m (75 ft)	Americium-241	1,120	2E-04
	Plutonium-239	523	6E-05

Table F-8. Risks and Concentration Changes with Selected Depth Intervals Removed at the 216-Z-1A Tile Field

Depth Interval Removed	Contaminant	Garden Concentration (pCi/g)	Total Risk
	Plutonium-240	117	1E-05
			3E-04
24.4 m (80 ft)	Americium-241	874	2E-04
	Plutonium-239	447	5E-05
	Plutonium-240	100	1E-05
			2E-04
27.4 m (90 ft)	Americium-241	268	5E-05
	Plutonium-239	225	3E-05
	Plutonium-240	51	6E-06
			8E-05
30 m (95 ft)	Americium-241	6	1E-06
	Plutonium-239	32	4E-06
	Plutonium-240	7	8E-07
			6E-06

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Table F-9. Risks and Concentration Changes with Selected Depth Intervals Removed at the 216-Z-9 Trench and 216-Z-12 Crib

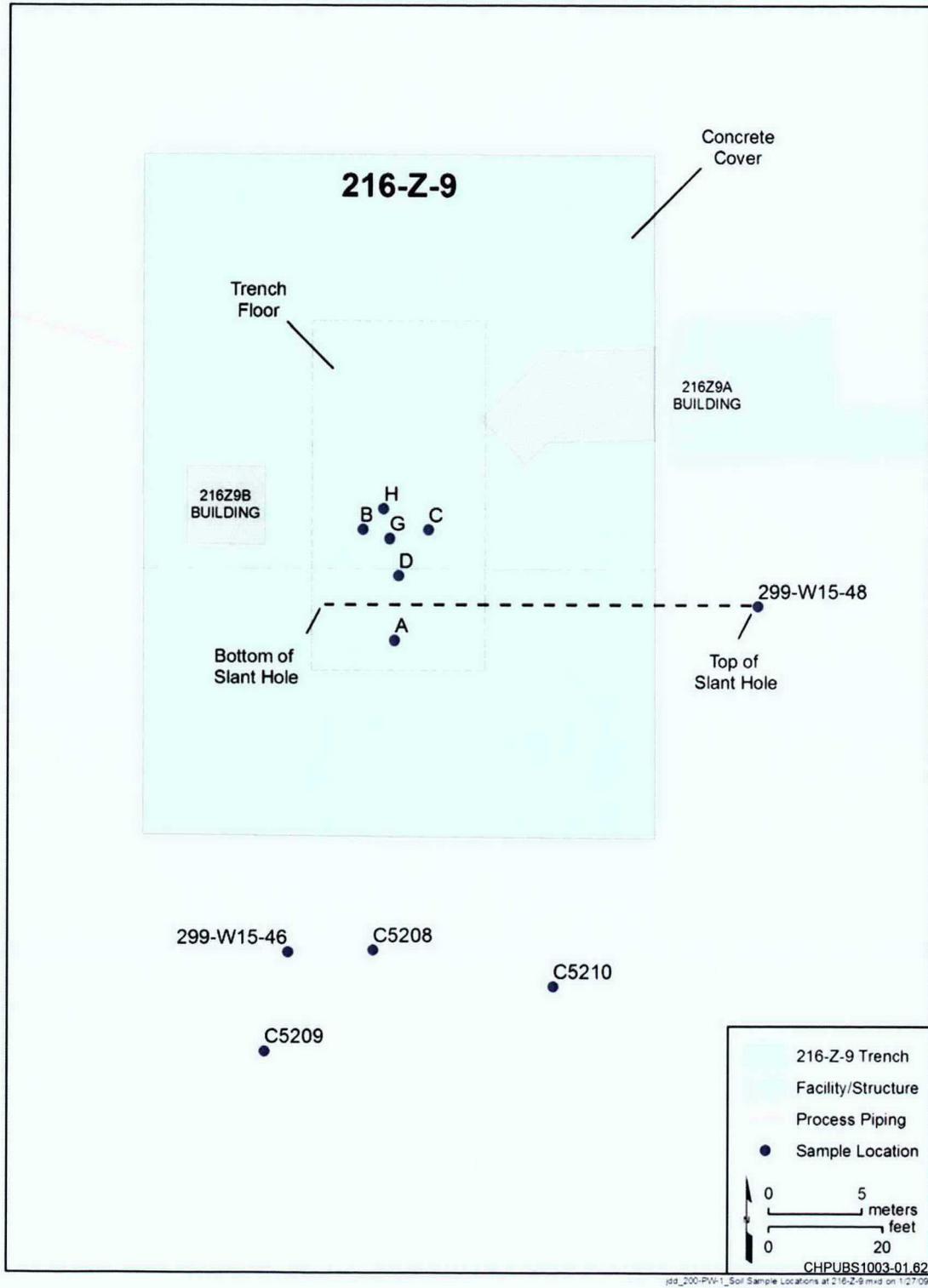
Depth Interval Removed	Contaminant	Garden Concentration (pCi/g)	Total Risk
216-Z-9 Trench			
2.7 m (9 ft)	Americium-241	14,385	2E-03
	Plutonium-239	7,547	9E-04
	Plutonium-240	1,696	2E-04
			4E-03
216-Z-12 Crib			
6.1 m (20 ft)	Americium-241	6,552	1E-03
	Plutonium-239	13,655	2E-03
	Plutonium-240	3,068	4E-04
			3E-03

Table F-9. Risks and Concentration Changes with Selected Depth Intervals Removed at the 216-Z-9 Trench and 216-Z-12 Crib

Depth Interval Removed	Contaminant	Garden Concentration (pCi/g)	Total Risk
7.6 m (25 ft)	Americium-241	0.5	9E-08
	Plutonium-239	1.2	1E-07
	Plutonium-240	0.3	3E-08
			3E-07
9.1 m (30 ft)	Americium-241	0.42	7E-08
	Plutonium-239	1	1E-07
	Plutonium-240	0.23	3E-08
			2E-07

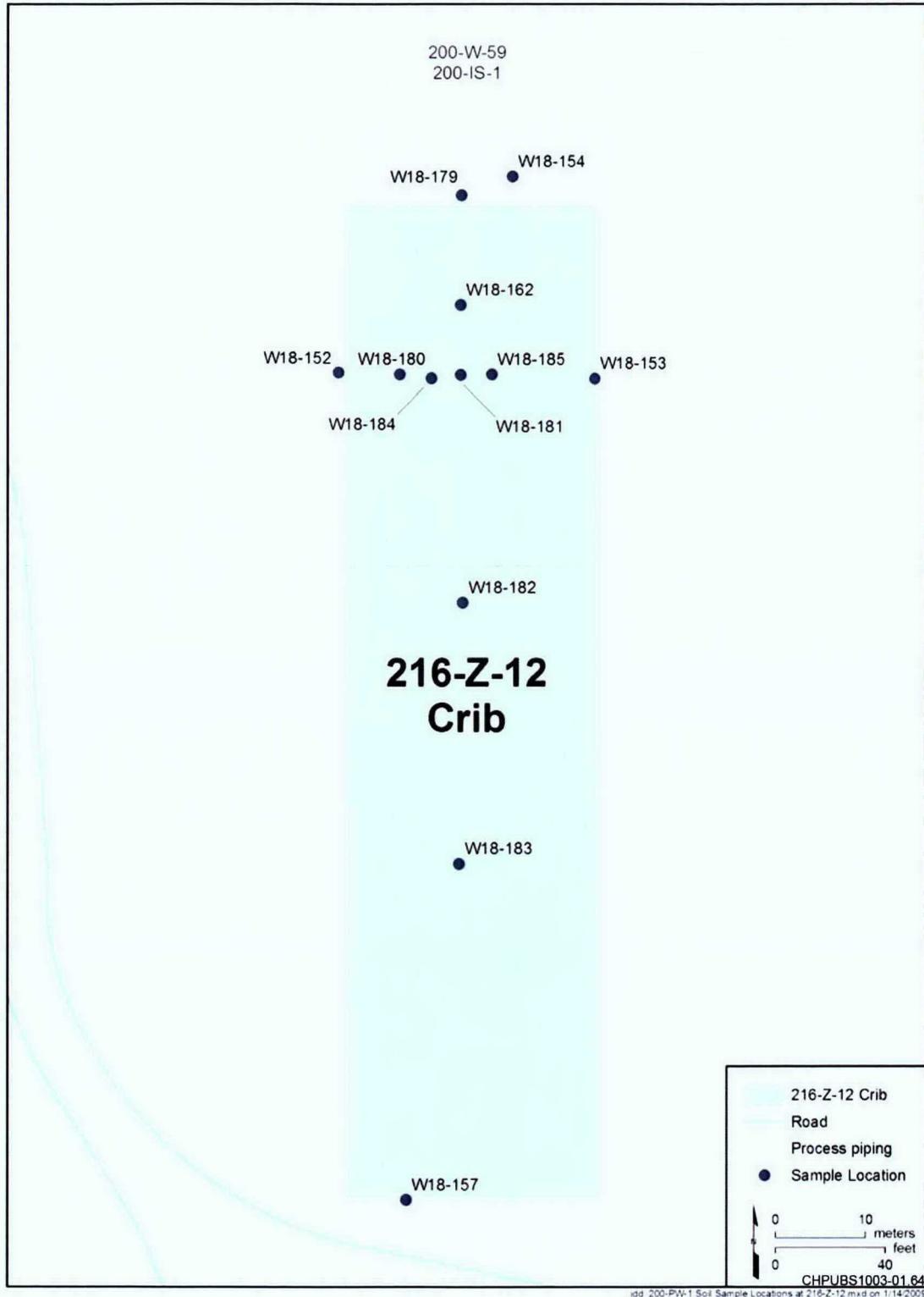
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Figure F-7. Soil Sampling Locations at the 216-Z-9 Trench



jdd_200-PW-1 Soil Sample Locations at 216-Z-12.mxd on 1/14/2009

Figure F-9. 216-Z-12 Crib Sample Locations for Soil

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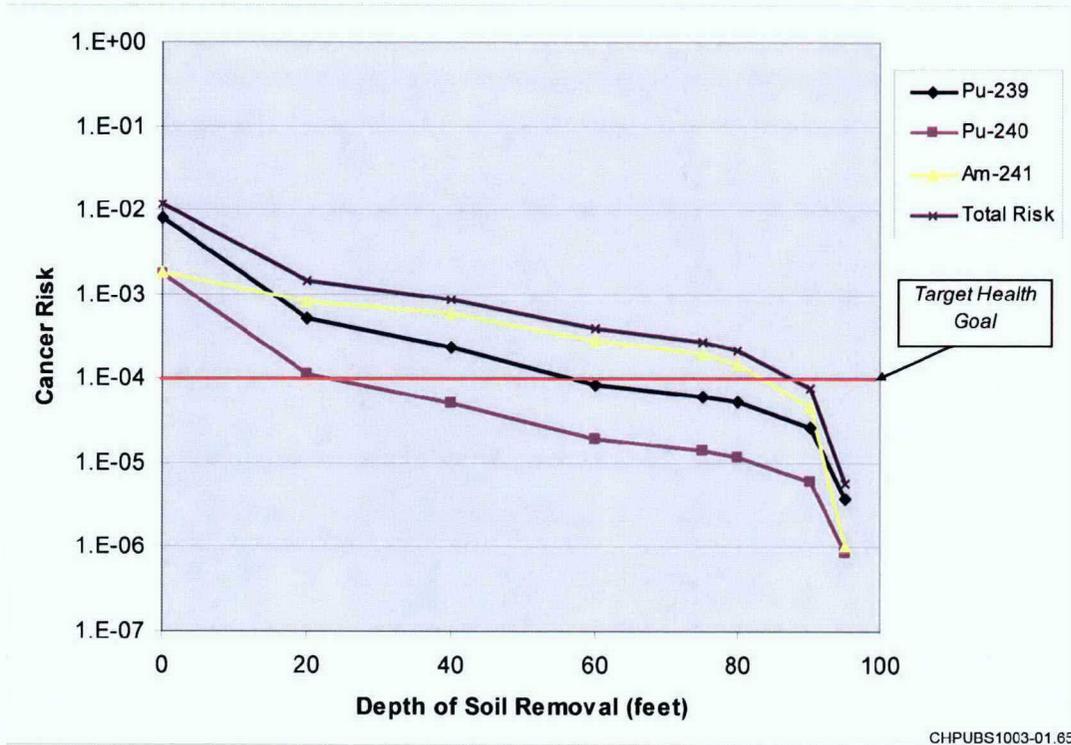
1 Figure F-10 shows a graph of risks for the baseline and seven removal options for the 216-Z-1A Tile
2 Field. Removing 20 m (60 ft) of soil reduces risks nearly two orders of magnitude below the baseline
3 risks and residual risks are within the range of acceptability, a cumulative risk of 4×10^{-4} (considering
4 that 10^{-4} is the acceptable upper risk range, and that EPA allows values above 10^{-4} to remain under certain
5 situations [Clay, 1991; EPA 540-R-97-013]). If 1×10^{-4} is considered a firm target health goal (rather
6 than risks up to 4×10^{-4} as potentially acceptable), then 27.4 m (90 ft) of soil must be removed before risk
7 levels drop below 10^{-4} . The increased removal depth is due to americium-241 concentrations at depth. As
8 shown in Figure F-10, risks from Pu-239 and Pu-240 drop below 10^{-4} after 20 m (60 ft) of soil is
9 removed.

10 For the 216-Z-9 Trench, baseline risks and risks from the one removal option examined are presented in
11 Figure F-11. Like the 216-Z-1A Tile Field, removal of the most-contaminated soil directly below the
12 trench (the top 2.7 m [9 ft] below the bottom of the trench), also reduces potential future risks by nearly
13 two orders of magnitude, a reduction from 1×10^{-1} to 4×10^{-3} ; however, cumulative risks are still well
14 above 10^{-4} .

15 For the 216-Z-12 Crib, baseline risks and risks from the three removal options examined are presented in
16 Figure F-12. Removal of the top 6 m (20 ft) below the ground surface only slightly reduces potential
17 future risks, a reduction from 4×10^{-3} to 3×10^{-3} . Removal of an additional 1.5 m (5 ft) for a total removal
18 of the top 7.6 m (25 ft) of soil significantly reduces potential future risks to well below the target goal of
19 10^{-4} , as well as below the de minimis risk level of 10^{-6} . Cumulative total risks after removal of the top
20 7.6 m (25 ft) of soil are reduced to 3×10^{-7} .

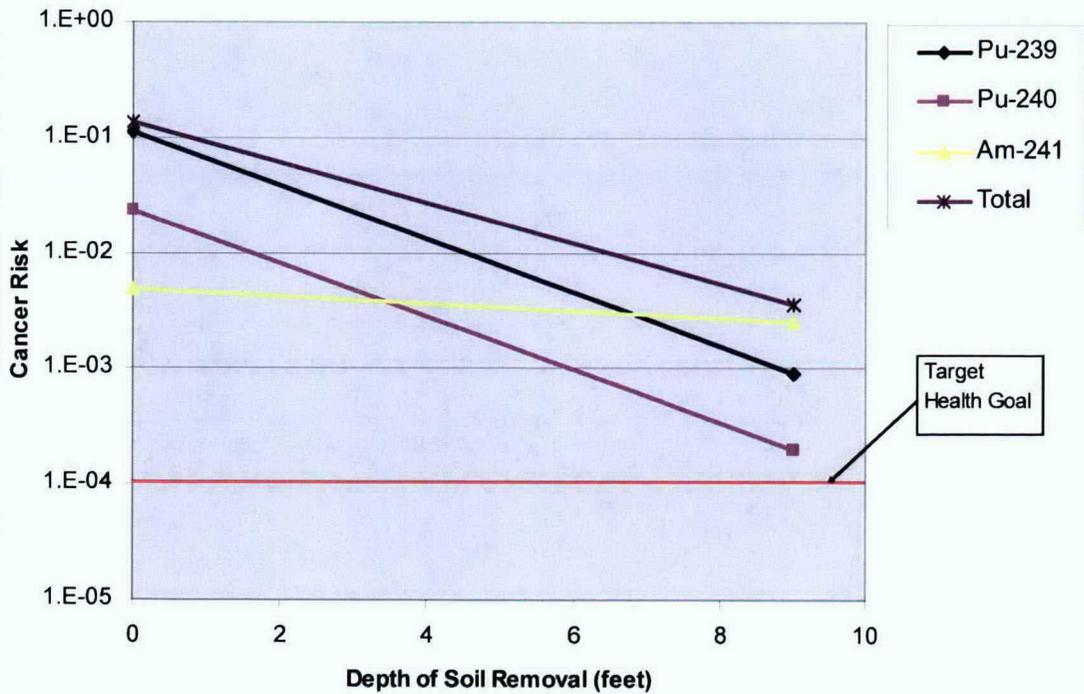
21 If the home-grown produce ingestion pathway is not considered in the cumulative risk totals (because this
22 pathway is associated with many assumptions and thus has a high degree of uncertainty) shallower soil
23 depths at 216-Z-1A (and potentially 216-Z-9) than those shown in Figure F-10 and Tables F-8 and F-9
24 may result in acceptable levels of residual risk remaining. At 216-Z-12, inclusion or exclusion of the
25 produce pathway is unlikely to have an impact – the “break point” for risk reduction appears to be at a
26 depth of 7.3 m (25 ft).

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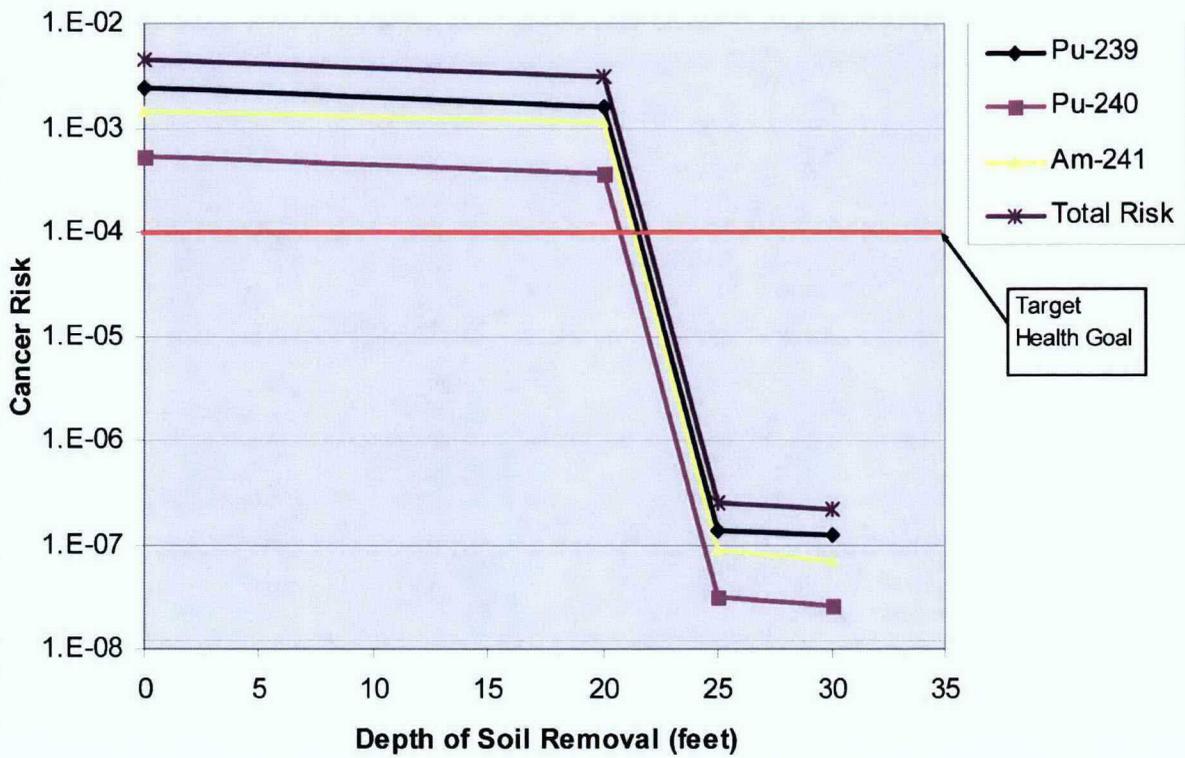
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Figure F-10. Risks Compared to Baseline and Different Removal Options at the 216-Z-1A Tile Field



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Figure F-11. Risks Compared to Baseline and One Removal Option at the 216-Z-9 Trench



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Figure F-12. Risks Compared to Baseline and Three Removal Options at the 216-Z-12 Crib

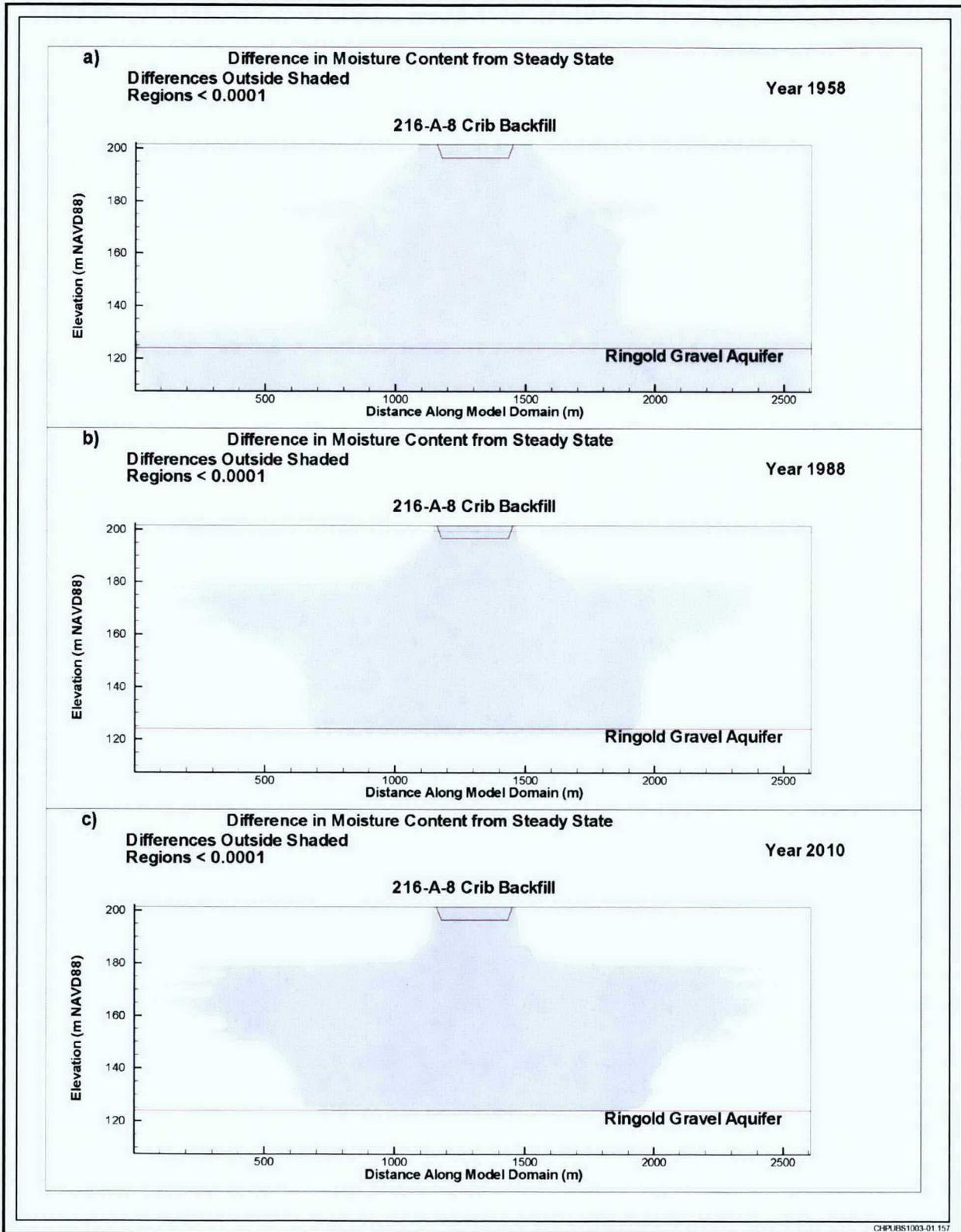
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F5.0 References

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Figure E5-6. Moisture Content Profiles of the 216-A-8 Crib Model Domain During the Period of 1944 to 2010 for Three Selected Times