1228921

RPP-RPT-58339 DRAFT A

PHASE 2 RCRA FACILITY INVESTIGATION REPORT FOR WASTE MANAGEMENT C

SECTION 1 OF 5

INFORMATION CLEARANCE REVIEW AND RELEASE APPROVAL

Part I: Background Information

Title:	Information Category:
Phase 2 RCRA Facility Investigation Report for Waste Management Area C	☐ Abstract ☐ Journal Article ☐ Summary ☐ Internet ☐ Visual Aid ☐ Software ☐ Full Paper ☒ Report ☐ Other
Publish to OSTI? ☐ Yes ☒ No	

Document Number: RPP-RPT-58339, Draft A | Date: 12/11/2014 JDA

Author: C. L. Tabor, J. R. Robertson

Purpose of Document: Presents nature and extent of soil contamination at WMA C

Part II: External/Public Presentation Information

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Sponsoring Organization(s): N/A

Date of Conference: N/A | Conference Location: N/A

Will Material be Handed Out? ☐ Yes ☒ No | Will Information be Published? ☐ Yes ☒ No | *(If Yes, attach copy of Conference format instructions/guidance.)*

Part III: WRPS Document Originator Checklist

Description	*Yes*	*N/A*	*Signature*
Information Product meets requirements in TFC-BSM-AD-C-01?	☐	☒	
Document Release Criteria in TFC-ENG-DESIGN-C-25 completed? (Attach checklist)	☐	☒	
If product contains pictures, safety review completed?	☒	☐	Approved by H.K. Lawrence (see attached e-mail)

Part IV: WRPS Internal Review

Pg. 3

Function	*Organization*	*Date*	*Print Name/Signature/Date*
Subject Matter Expert	Closure & Corr. Meas.	12/2/14	Cynthia Tabor 12/2/14 Pg.4
Responsible Manager	Closure & Corr. Meas.	12/02/14	S J Eberlein 12/02/14
Other:			

Part V: IRM Clearance Services Review

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Document is Subject to Release Restrictions? *If the answer is "Yes," please mark category at right and describe limitation or responsible organization below:*	☐	☒	Document contains: ☐ Applied Technology ☐ Protected CRADA ☐ Personal/Private ☐ Export Controlled ☐ Proprietary ☐ Procurement – Sensitive ☐ Patentable Info. ☐ Business - Sensitive ☐ Predecisional Info. ☐ UNCNI ☐ Restricted by Operational Security Guidelines ☐ Other (Specify)
Additional Comments from Information Clearance Specialist Review?	☐	☒	Information Clearance Specialist Approval APPROVED By Janis D. Aardal at 1:30 pm, Dec 15, 2014 Print Name/Signature/Date

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Part VI: Final Review and Approvals

INFORMATION CLEARANCE REVIEW AND RELEASE APPROVAL

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WRPS Office of Chief Counsel	☐	☐	C.B. Page, Email Pg.6
DOE – ORP Public Affairs/Communications	☒	☐	STEVE BOECKER
Other: ORP SME	☒	☐	RYAN BEACH
Other:	☐	☐	

Comments:

Appendices A, B, H, I, K and T already in public AR - R.S. Wiegman, Email Pg. 7

APPROVED
By Janis D. Aardal at 1:30 pm, Dec 15, 2014

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WRPS Administrative Checklist	☐	☐	
	☐	☐	
	☐	☐	

Mesford, Timothy B

From: Lawrence, Hugh K
Sent: Tuesday, December 02, 2014 2:29 PM
To: Mesford, Timothy B
Subject: RE: Files with photos for safety review

Tim,
I have reviewed the photos contained in the two documents provided, (RPP-RPT-58339, Rev. A DRAFT) *Miscellaneous Field Documents* and *C Farm Construction Photographs*, as requested, from an industrial safety point of view. Based on that review the photos contained in these documents are **approved** for use. Any question or comment, please ask.

Hugh Lawrence
WRPS Safety Programs

From: Mesford, Timothy B
Sent: Tuesday, December 02, 2014 12:23 PM
To: Lawrence, Hugh K
Subject: Files with photos for safety review

Hugh,

Sorry for the delay. Attached are the appendices of RPP-RPT-58339, *Phase 2 RCRA Facility Investigation Report for Waste Management Area C* containing photographs for which we need a safety review performed. Thanks in advance for dealing with this.

Tim

UNIBEST International
subcontractor to Washington River Protection Solutions,
contractor to the United States Department of Energy

Aardal, Janis D

From: Tabor, Cynthia L
Sent: Thursday, December 11, 2014 2:49 PM
To: ^Information Clearance; Mesford, Timothy B
Cc: Vorpagel, Lindsay R
Subject: RE: To clear - RPP-RPT-58339 - Phase 2 RCRA Facility Investigation Report for Waste Management Area C

Follow Up Flag: Follow up
Flag Status: Flagged

Categories: Janis

We were actually planning to leave the files separated (as they are). We have discussed this with DOE. It is easier to navigate thru the document, as it is 2,500 pages.

From: ^Information Clearance
Sent: Thursday, December 11, 2014 2:23 PM
To: Mesford, Timothy B; Tabor, Cynthia L
Cc: Vorpagel, Lindsay R; ^Information Clearance
Subject: RE: To clear - RPP-RPT-58339 - Phase 2 RCRA Facility Investigation Report for Waste Management Area C

Hi, The Draft A text and appendices should be combined before being cleared as public, unless the intent was to leave the final draft in separate files. Thanks very much,1 Janis Aardal, Information Clearance and Release

---

From: Vorpagel, Lindsay R
Sent: Thursday, December 11, 2014 1:23 PM
To: ^Information Clearance
Cc: Aardal, Janis D; Mesford, Timothy B; Tabor, Cynthia L
Subject: To clear - RPP-RPT-58339 - Phase 2 RCRA Facility Investigation Report for Waste Management Area C

To clear - RPP-RPT-58339 - Phase 2 RCRA Facility Investigation Report for Waste Management Area C

Information Clearance – please put the files in the folder "Already cleared appendices" (located in the above folder) into the folder "Items to Review" (also in the above folder). Then clear the entire contents of the above folder.

THANK YOU!!!

Sincerely,

Lindsay Vorpagel
WRPS - External Affairs and Procurement
509-376-5380

Vorpagel, Lindsay R

From: Roxburgh, Robert T
Sent: Thursday, December 11, 2014 1:05 PM
To: Vorpagel, Lindsay R
Subject: RE: Timely - Review - RPP-RPT-58339 - Phase 2 RCRA Facility Investigation Report for Waste Management Area C

Follow Up Flag: Follow up
Flag Status: Completed

Categories: burnt red

Approved

Rob Roxburgh
WRPS External Affairs
(509) 376-5188
WashingtonRiverProtection*Solutions*
Contractor to the U.S. Department of Energy
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From: Vorpagel, Lindsay R
Sent: Wednesday, December 10, 2014 9:26 AM
To: Page, Brad; Britton, John C; Roxburgh, Robert T; Cherry, Stephen B; Vorpagel, Lindsay R
Subject: Timely - Review - RPP-RPT-58339 - Phase 2 RCRA Facility Investigation Report for Waste Management Area C
Importance: High

Please coordinate within your organization regarding who will be reviewing the below ICR. It is due to DOE by Dec. 15.

RPP-RPT-58339 - Phase 2 RCRA Facility Investigation Report for Waste Management Area C

Sincerely,

Lindsay Vorpagel
WRPS - External Affairs and Procurement
509-376-5380

From: Vorpagel, Lindsay R
Sent: Tuesday, December 09, 2014 11:44 AM
To: Page, Brad; Cherry, Stephen B; Britton, John C; Roxburgh, Robert T; Beehler, Stephen J; Hildman, Cynthia M; Russell, Adam; Tabor, Cynthia L; Julie Robertson (JulieRobertson@gofreestone.com)
Subject: RE: Another large, cumbersome ICR - RPP-RPT-58339 - Phase 2 RCRA Facility Investigation Report for Waste Management Area C

Cynthia asked me to send a reminder that the date for submittal to DOE for Ecology is Dec 15.

Vorpagel, Lindsay R

From: Page, Brad
Sent: Thursday, December 11, 2014 1:11 PM
To: Vorpagel, Lindsay R
Cc: ^Consolidated Legal Emails
Subject: RE: Timely - Review - RPP-RPT-58339 - Phase 2 RCRA Facility Investigation Report for Waste Management Area C

Follow Up Flag: Follow up
Flag Status: Completed

Categories: Yellow Category

Lindsay,

I have reviewed this ICR and approve of its release.

Regards,
Brad

From: Vorpagel, Lindsay R
Sent: Wednesday, December 10, 2014 9:26 AM
To: Page, Brad; Britton, John C; Roxburgh, Robert T; Cherry, Stephen B; Vorpagel, Lindsay R
Subject: Timely - Review - RPP-RPT-58339 - Phase 2 RCRA Facility Investigation Report for Waste Management Area C
Importance: High

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RPP-RPT-58339 - Phase 2 RCRA Facility Investigation Report for Waste Management Area C

Sincerely,

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washington river protection solutions

From: Vorpagel, Lindsay R
Sent: Tuesday, December 09, 2014 11:44 AM
To: Page, Brad; Cherry, Stephen B; Britton, John C; Roxburgh, Robert T; Beehler, Stephen J; Hildman, Cynthia M; Russell, Adam; Tabor, Cynthia L; Julie Robertson (JulieRobertson@gofreestone.com)
Subject: RE: Another large, cumbersome ICR - RPP-RPT-58339 - Phase 2 RCRA Facility Investigation Report for Waste Management Area C

Cynthia asked me to send a reminder that the date for submittal to DOE for Ecology is Dec 15.

Vorpagel, Lindsay R

From: Wiegman, Rebecca S
Sent: Wednesday, December 03, 2014 1:08 PM
To: Vorpagel, Lindsay R
Cc: Tabor, Cynthia L
Subject: RE: Waste Management Area C RCRA Facility Investigation Report (RFI)

Hi Lindsay,
The following Appendices have either been cleared or are already in the administrative record:

Appendix A
Appendix B
Appendix H
Appendix I
Appendix K
Appendix T

Please let me know if you have further questions!
Thanks,
Becky

From: Vorpagel, Lindsay R
Sent: Wednesday, December 03, 2014 12:17 PM
To: Wiegman, Rebecca S; Vorpagel, Lindsay R
Subject: Waste Management Area C RCRA Facility Investigation Report (RFI)

Becky,

Cynthia said you have a list of which of the documents referenced in the link below have already been cleared. Could you please send me that and I will include it in the ICR, to save the reviewers' time.

Sincerely,

Lindsay Vorpagel
WRPS - External Affairs and Procurement
509-376-5380

washington river protection solutions

From: Tabor, Cynthia L
Sent: Wednesday, December 03, 2014 11:53 AM
To: Roxburgh, Robert T; Vorpagel, Lindsay R
Cc: Mesford, Timothy B; Julie Robertson; Robertson, Julie R; Wiegman, Rebecca S; Eberlein, Susan J; Haas, Christian R; shanna.muns@terragraphics.com; Hutchings, Kristopher
Subject: Waste Management Area C RCRA Facility Investigation Report (RFI)

RPP-RPT-58339
Revision A DRAFT

Phase 2 RCRA Facility Investigation Report for Waste Management Area C

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

Contractor for the U.S. Department of Energy
Office of River Protection under Contract DE-AC27-08RV14800

washingtonriver protectionsolutions

P.O. Box 850
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Approved for Public Release;
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RPP-RPT-58339
Revision A DRAFT

Phase 2 RCRA Facility Investigation Report for Waste Management Area C

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By Janis D. Aardal at 1:32 pm, Dec 15, 2014

Release Approval Date

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ACRONYMS

1C	First cycle decontamination (waste)
AEA	*Atomic Energy Act of 1954*
ALE	Fitzner-Eberhardt Arid Lands Ecology Reserve Unit
ARAR	applicable or relevant and appropriate requirements
AUF	area of contamination to the home range
BBI	Best Basis Inventory
BGO	bismuth-germanium oxide
bgs	below ground surface
CAD	computer-aided design
CERCLA	*Comprehensive Environmental Response, Compensation, and Liability Act of 1980*
Cesium Loadout Building	241-C-801 Cesium Loadout Facility
CFR	*Code of Federal Regulations*
CMS	corrective measures study
COPEC	contaminant of potential ecological concern
CRBG	Columbia River Basalt Group
CSR	B Plant cesium recovery (waste)
CTUIR	Confederated Tribes of the Umatilla Indian Reservation
CW	Cladding (coating) removal (waste)
CY	calendar year
DOE	U.S. Department of Energy
DQO	data quality objective
DRO	diesel range organics
DST	double-shell tank
EC	environmental compliance
Ecology	Washington State Department of Ecology
EcoSSL	ecological soil screening levels
EIS	Environmental Impact Statement
ELCR	excess lifetime cancer risk
EPA	U.S. Environmental Protection Agency
EPC	exposure point concentration
FIR	field investigation report
FSAP	Field Sampling Analysis Plan
GEA	gamma energy analysis
GPR	ground-penetrating radar
GRO	gasoline range organics
HCP EIS	Hanford Comprehensive Land-Use Plan Environmental Impact
HFFACO	Hanford Federal Facility Agreement and Consent Order
HHRA	human health risk assessment
HI	hazard index
HLO	Hanford 300 Area Laboratories (waste type)
HLW	high-level radioactive waste
HMS	Hanford Meteorological Station
HTWOS	Hanford Tank Waste Operations Simulator Model

HQ	hazard quotient
HWMA	Hazardous Waste Management Act
ICP	inductively coupled plasma
ICP-AES	inductively coupled plasma-atomic emission spectrometer
ICP-MS	inductively coupled plasma-mass spectrometer
IPA	Appendix I performance assessment
IUR	inhalation unit risk
IX	ion exchange
LOAEL	lowest observed adverse effect level
LLW	low-level waste
MARS	Mobile Arm Retrieval System
MDL	method detection limit
MLLW	mixed low-level waste
MSL	mean sea level
MW	metal waste
NEPA	*National Environmental Policy Act of 1969*
NOAEL	no observed adverse effect level
ORP	U.S. Department of Energy, Office of River Protection
OU	Operable Unit
PA	performance assessment
PNNL	Pacific Northwest National Laboratory
PSN	Plutonium Uranium Extraction HLW supernate
PSS	Plutonium Uranium Extraction sludge wash supernate
PUREX	Plutonium Uranium Extraction (Plant)
RCRA	*Resource Conservation and Recovery Act of 1976*
RCW	*Revised Code of Washington*
REDOX	Reduction-Oxidation (S Plant)
RESRAD	RESidual RADioactivity
RfC	reference concentration
RfD	reference dose
RFI	RCRA Facility Investigation
RI/FS	remedial investigation/feasibility study
RME	reasonable maximum exposure
ROD	Record of Decision
RSN	REDOX HLW supernate
SAP	sampling and analysis plan
SEPA	*State Environmental Policy Act of 1971*
SGE	surface geophysical exploration
SGLS	spectral gamma logging system
SLERA	screening level ecological risk assessment
SNF	spent nuclear fuel
SSL	soil screening level
SST	single-shell tank
Strontium Semiworks Facility	201-C Hot Semiworks Facility
SVOC	semi-volatile organic compound
TBP	tributyl phosphate

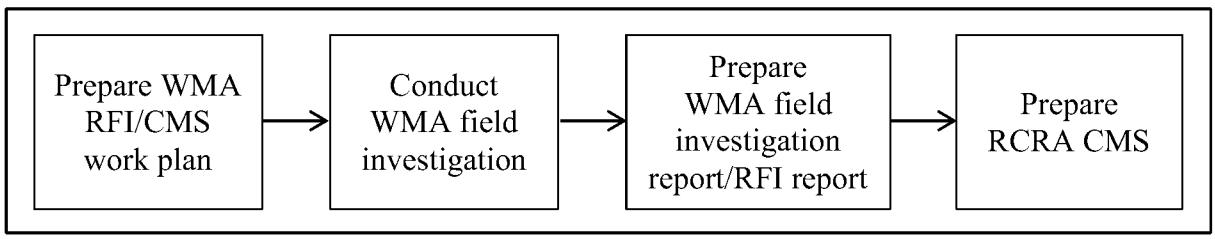
TC & WM EIS	Tank Closure and Waste Management Environmental Impact Statement
TIC	tentatively identified compounds
TRU	transuranic (waste)
TRV	toxicity reference values
TSD	treatment, storage, and disposal
UPR	unplanned release
VOC	volatile organic chemicals/contaminant
WAC	Washington Administrative Code
WIDS	Waste Information Data System
WMA	Waste Management Area

1.0 INTRODUCTION

In 1989, the U.S. Department of Energy (DOE), the U.S. Environmental Protection Agency (EPA), and the Washington State Department of Ecology (Ecology) signed the *Hanford Federal Facility Agreement and Consent Order* (Ecology et al. 1989) (HFFACO) to provide a framework for the cleanup of the Hanford Site in accordance with the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA), the National Contingency Plan (Title 300, *Code of Federal Regulations*, Part 300, "National Oil and Hazardous Substances Pollution Contingency Plan" [40 CFR 300]), Superfund guidance and policy, and *Resource Conservation and Recovery Act of 1976* (RCRA) guidance and policy (HFFACO Article III). Attached to the HFFACO is an Action Plan, which is an enforceable part of the HFFACO. The Action Plan provides the methods and procedures, and establishes the plans for (1) compliance, permitting, and closure under RCRA and Washington State's "Hazardous Waste Management Act" (HWMA) (*Revised Code of Washington* [RCW] 70.105, "Hazardous Waste Management"), and (2) cleanup of the Hanford Site under CERCLA and RCRA corrective action provisions.

Appendix I of the HFFACO Action Plan describes the waste retrieval and closure process that is to be implemented for Hanford Site single-shell tank (SST) systems. Section 2.3 of HFFACO Action Plan Appendix I states that closure decisions for Hanford Site SST system soils will be made through the RCRA corrective action process. As described in both HFFACO Action Plan Appendix I and EPA 530/SW-89-031, *Interim Final RCRA Facility Investigation (RFI) Guidance Volume I of IV Development of an RFI Work Plan and General Considerations for RCRA Facility Investigations*, the RCRA corrective action process is a multi-step process for evaluating the nature and extent of releases to the environment, determining whether corrective action is necessary, and implementing a corrective action. Figure 1-1 is a simplified depiction of this process.

Figure 1-1. Simplified Depiction of SST Waste Management Area Soil Corrective Action Process



CMS = corrective measures study
RCRA = *Resource Conservation and Recovery Act of 1976*
RFI = RCRA Facility Investigation
WMA = Waste Management Area

The corrective action process initially calls for preparation of a work plan to describe the actions that will be taken to conduct the investigation of releases to the environment. The purpose of the RCRA Facility Investigation (RFI) is to obtain information to characterize the nature, extent, and rate of migration of releases to the environment and to interpret this information to determine whether interim corrective measures and/or a corrective measures study (CMS) may be necessary. As envisioned in HFFACO Action Plan Appendix I, the RFI may be conducted in multiple phases, with the results documented in a Waste Management Area (WMA) field

investigation report (FIR) and RFI report. These reports summarize the characterization program and provide detailed results of the investigation and the interpretation of the data to support the determination of need for corrective measures.

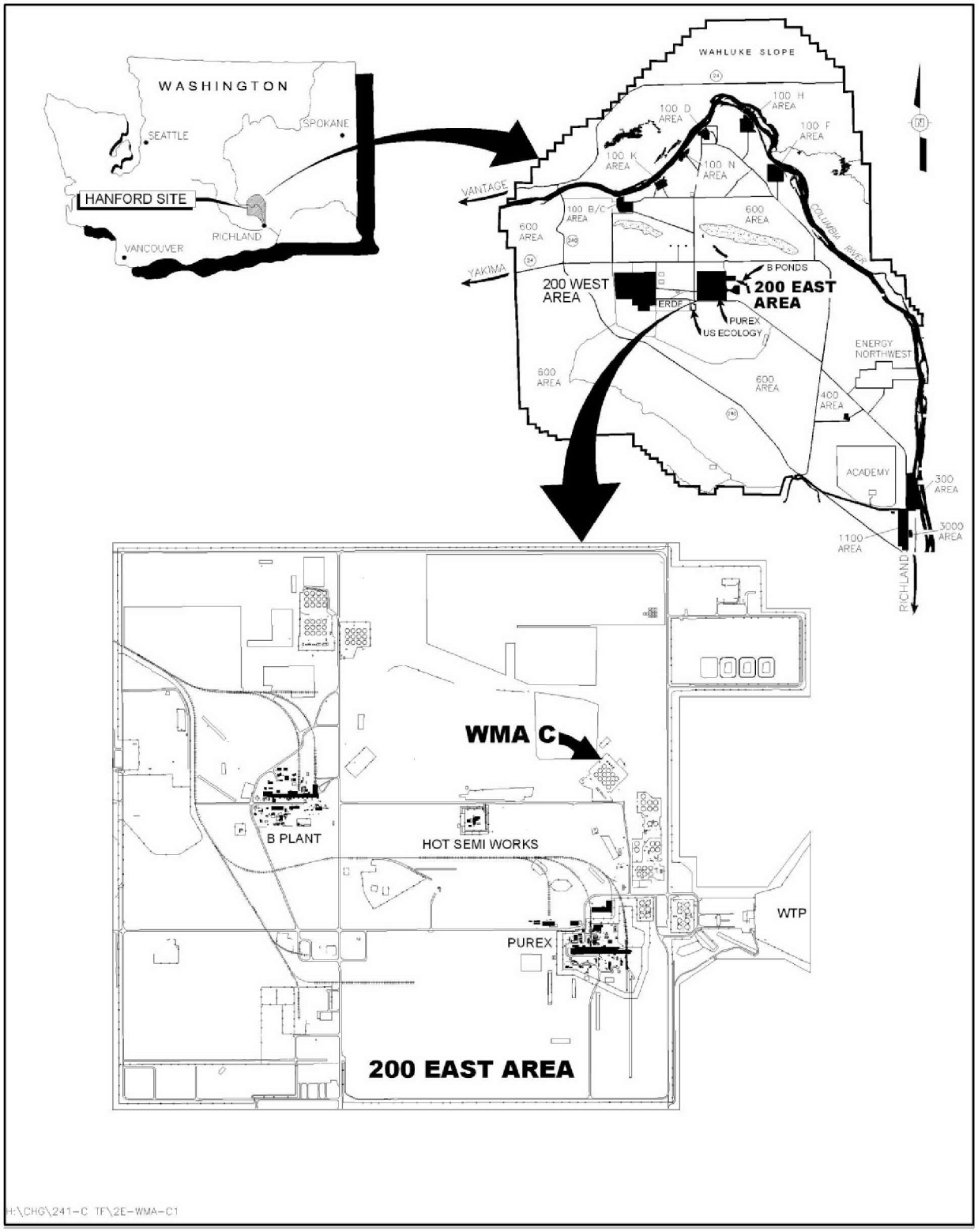
If the potential need for corrective measures is identified, a CMS is prepared to identify specific measures to address the release. Information generated during the RFI is used to aid in the selection and implementation of corrective measures. Implementation of corrective measures includes designing, constructing, operating, maintaining, and monitoring selected corrective measures.

This RFI report specifically presents the results of an RFI undertaken for the Hanford Site SST WMA C (Figures 1-2 and 1-3). Preparation of this report is part of the overall RCRA corrective action process for WMA C soils.

Over the span of many decades, DOE has undertaken numerous investigations of contaminant releases to the soil at WMA C. The more recent RFI work has been performed in multiple phases over a number of years. Documents summarizing the results of both the historic investigations and more recent RFI work are identified in this RFI report. The results of the various phases of the WMA C RFI are summarized in this RFI report. However, this report focuses on the results of the investigation conducted at WMA C per RPP-PLAN-39114, *Phase 2 RCRA Facility Investigation/Corrective Measures Study Work Plan for Waste Management Area C*. The WMA C Phase 2 work plan described the field work necessary to collect the data identified in RPP-RPT-38152, *Data Quality Objectives Report Phase 2 Characterization for Waste Management Area C RCRA Field Investigation/Corrective Measures Study* for WMA C.

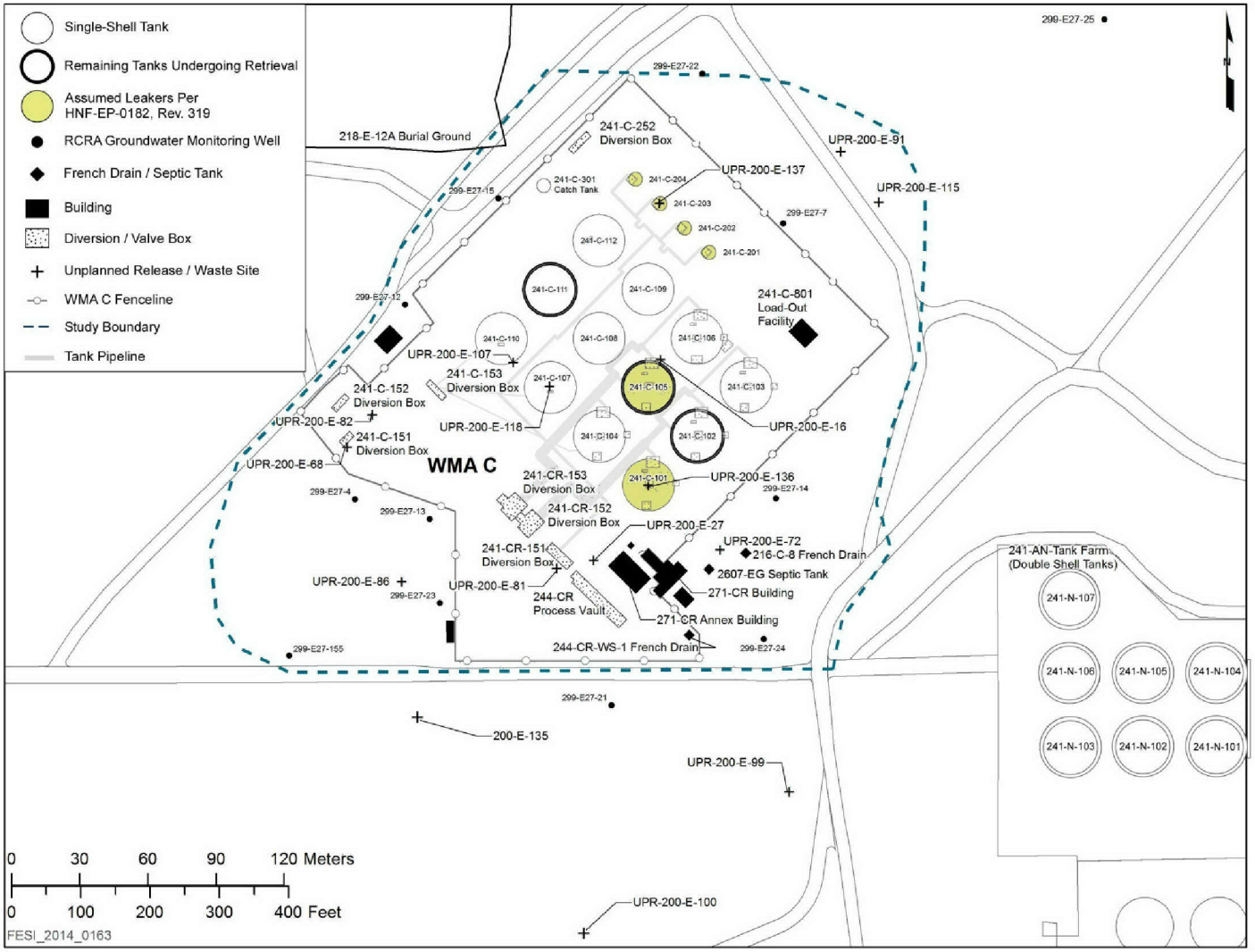
The HFFACO Action Plan identifies several milestones associated with the WMA C RCRA corrective action process. Interim HFFACO milestone M-045-61 requires DOE to "Submit to Ecology in accordance with HFFACO secondary document review process, Phase 2 RCRA Facility Investigation Report Draft A for WMA C" by December 31, 2014. Beginning in October 2013, DOE and Ecology held a series of meetings to discuss milestones related to WMA C closure (including interim milestone M-045-61), SST closure plan content, and permit modifications. Signed notes from these meetings were entered into the HFFACO Administrative Record and are contained in Appendix A. In January 2014 DOE, Ecology, and EPA initiated detailed discussions to align agency expectations for the content of this Phase 2 WMA C RFI report. Signed notes from these meetings were also entered into the HFFACO Administrative Record and are contained in Appendix B. In both sets of meetings, the agencies agreed that the M-045-61 deliverable would use available supporting information and would clearly identify where gaps in information exist. In keeping with the discussions documented in Appendices A and B, this document provides a summary and analysis of WMA C RFI work completed to date and identifies gaps where additional characterization efforts may be appropriate. An update to this document will be provided as part of the submission required by HFFACO interim milestone M-045-61A, due December 31, 2016.

Figure 1-2. Location Map of WMA C in the 200 East Area of the Hanford Site



PUREX = Plutonium Uranium Extraction (Plant)
WTP = Hanford Tank Waste Treatment and Immobilization Plant
WMA = Waste Management Area

Figure 1-3. WMA C Location and Surrounding Area



RCRA = *Resource Conservation and Recovery Act of 1976* WMA = Waste Management Area

Reference: HNF-EP-0182, *Waste Tank Summary Report for Month Ending July 31, 2014*, Rev. 319.

Consistent with Part One, Article IV, Paragraph 19 of the HFFACO, this RFI report addresses all aspects of contamination, including material subject to regulation under the *Atomic Energy Act of 1954* (AEA). However, the inclusion of information about such material in the report does not confer authority to Ecology under RCRA or RCW 70.105 over otherwise exempt spent, byproduct, and special nuclear material regulated under the AEA.

1.1 PURPOSE AND SCOPE

Consistent with agreements made by DOE, Ecology, and EPA regarding the contents of this RFI report (Appendix C), the report presents background information and contaminant distribution data necessary to draw conclusions about the nature and extent of soil contamination at WMA C and to support future corrective action decision-making for WMA C. This RFI report focuses primarily on the results of the Phase 2 RFI conducted under the WMA C Phase 2 work plan (RPP-PLAN-39114), which described characterization work to be performed at and around WMA C. These characterization activities were as follows:

- Soil collection and analysis through direct push technology
- Tissue sampling for ecological risk assessment
- Drywell and groundwater monitoring well geophysical logging
- Surface geophysical exploration (SGE).

Although this report focuses primarily on presenting information derived from the WMA C Phase 2 RFI, it also presents the results of several additional field investigations and studies, including but not limited to those addressed in the following documents:

- RPP-14430, *Subsurface Conditions Description of the C and A-AX Waste Management Area*
- RPP-35484, *Field Investigation Report for Waste Management Areas C and A-AX*
- RPP-ENV-33418, *Hanford C-Farm Leak Inventory Assessments Report*
- PNNL-13024, *RCRA Groundwater Monitoring Plan for Single-Shell Tank Waste Management Area C at the Hanford Site* (as revised).

Background information regarding the historic use of equipment in WMA C, waste managed at WMA C, and releases from WMA C equipment, which provided the basis for field investigation planning, is also provided in this report. This collective body of information is then factored into updated contaminant distribution models to draw conclusions about the nature and extent of contamination at WMA C to inform future corrective action decision-making.

1.1.1 Definitions

For the purposes of this RFI report, the following definitions are used.

- **Shallow vadose zone**: from ground surface to a depth of 4.6 m (15 ft). This depth interval is evaluated for protection of human health and ecological receptors as well as protection of groundwater and surface water.

- **Surface**: a shallow vadose zone soil sampling depth, ranging from ~ 0 to 0.3 m (0 to 1 ft) below ground surface (bgs).

- **Deep vadose zone**: from a depth of 4.6 m (15 ft) to the water table. This depth interval is evaluated for the protection of groundwater and surface water. Residual contaminant concentrations in this zone are evaluated for human health protection to provide risk management information.

1.1.2 SST System Closure

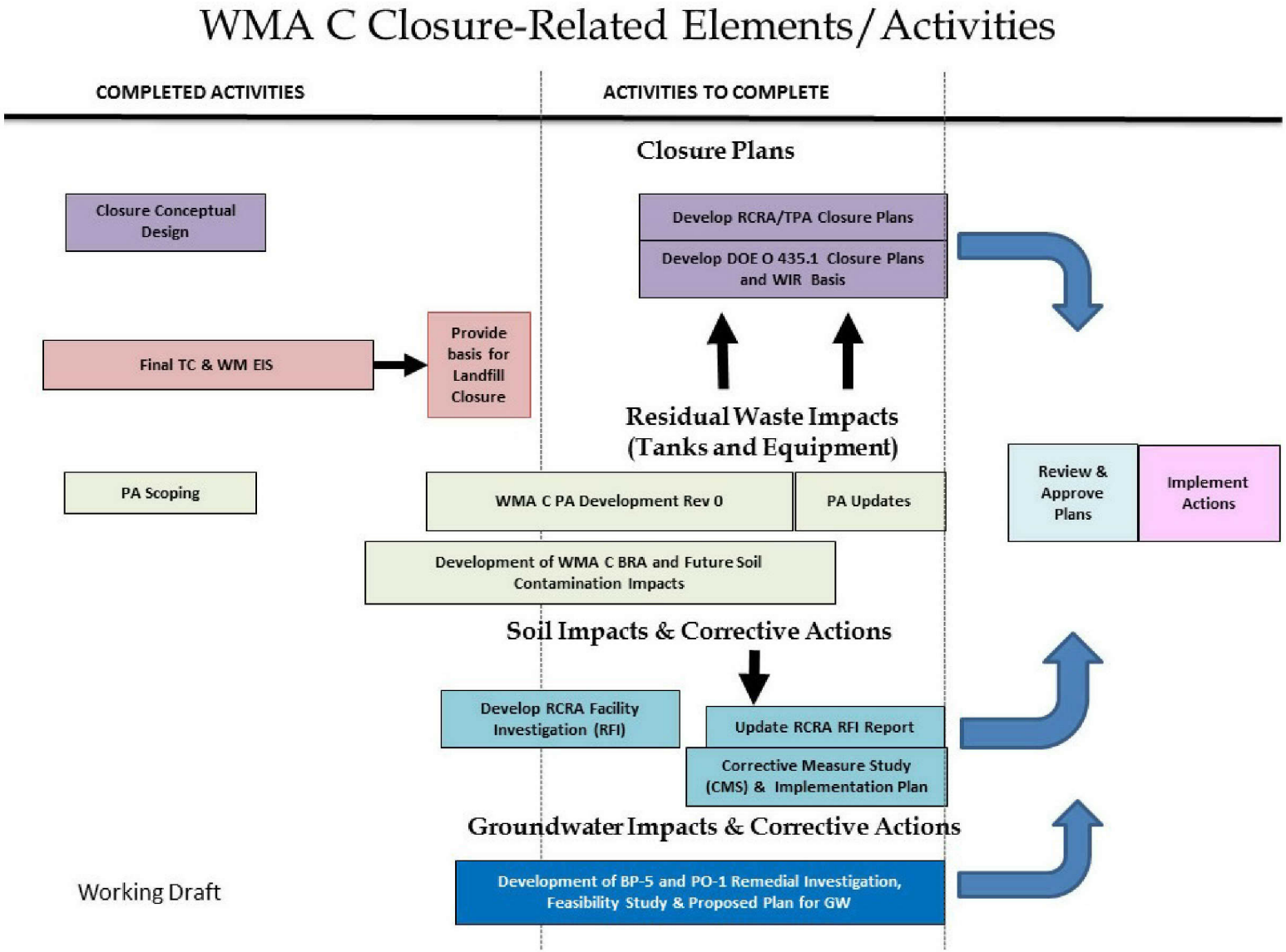
The WMA C soil corrective action process is an integral part of a larger effort being undertaken to close WMA C. Tank waste retrieval actions and WMA C SST system closure actions will be addressed in documents developed separately from but in concert with the WMA C soil corrective action process, as described (in part) in HFFACO Action Plan Appendix I. This section of the RFI report briefly addresses some of the other documents and processes required to accomplish WMA C closure. Figure 1-4 depicts these WMA closure-related elements and activities.

1.1.2.1 *National Environmental Policy Act of 1969* and *State Environmental Policy Act of 1971* Decisions. WMA C closure and corrective actions require that determinations be made under the *National Environmental Policy Act of 1969* (NEPA) and the State of Washington's "State Environmental Policy Act of 1971" (SEPA) (RCW 43.21C, "State Environmental Policy"). In December 2012, DOE published a NEPA environmental impact statement (EIS) for the closure of Hanford Site tanks: DOE/EIS-0391, *Final Tank Closure and Waste Management Environmental Impact Statement for the Hanford Site, Richland, Washington* (TC&WM EIS). The TC&WM EIS in part analyzes SST system closure alternatives, including clean, landfill, and hybrid clean/landfill closure. The summary to the TC&WM EIS states:

> *For closure of the SSTs, DOE prefers landfill closure…which may require soil removal or treatment of the vadose zone. Decisions on the extent of soil removal or treatment, if needed, will be made on the tank farm– or waste management area–basis through the RCRA closure permitting process.*

The DOE issued the TC&WM EIS Record of Decision in December 2013 (78 FR 75913, "Record of Decision: Final Tank Closure and Waste Management Environmental Impact Statement for the Hanford Site, Richland, Washington"). The decisions documented in the TC&WM EIS Record of Decision include a determination that following waste retrieval, SSTs and ancillary equipment will be filled with grout to immobilize residual waste, and contaminated soil may be removed. The SSTs will be landfill-closed, which means they will be stabilized, and an engineered, modified RCRA Subtitle C barrier put in place followed by postclosure care.

Figure 1-4. WMA C Closure-Related Elements and Activities



Under SEPA, Ecology is required to conduct an evaluation of proposals in accordance with WAC 197-11, "SEPA Rules" to determine the potential significance of impacts to the environment and public health. Ecology has the option to adopt a NEPA EIS instead of preparing a separate SEPA EIS. Ecology was a cooperating agency for the TC&WM EIS; Ecology's foreword to the TC&WM EIS states, "[w]hen Ecology makes decisions through its permitting process, Ecology will look to this *Final TC & WM EIS* and, if appropriate, adopt portions."

1.1.2.2 Closure Under RCRA. Closure planning for SSTs is occurring in parallel with waste retrieval and characterization activities. Closure decisions for both WMA C soil and structures will be authorized through WA7 89000 8967, *Hanford Facility Resource Conservation and Recovery Act Permit, Dangerous Waste Portion Revision 8C for the Treatment, Storage, and Disposal of Dangerous Waste* (better known as the Hanford Site-Wide RCRA Permit). Specific SST WMA closure objectives and standards will be delineated in the HWMA (RCW 70.105) closure plans in accordance with the process described in Appendix I, Section 2.2. In addition, in accordance with Appendix I, Section 3.1, "The 200 Areas of the Hanford Site have been placed by EPA on the National Priorities List (NPL). The completion of remediation of the 200 Areas overall will eventually be finalized via CERCLA decisions made by the EPA, and permitting decisions made by Ecology."

According to the HFFACO, closure planning under RCRA involves three levels of plans. The highest-level plan (Tier 1) documents requirements that apply to the SST System overall. It is commonly referred to as the "Framework Plan." Mid-level plans (Tier 2) document requirements for each of the seven specific SST WMAs and are referred to as "WMA Closure Action Plans." The lowest-level plans (Tier 3) document requirements for closure of individual SSTs and components (e.g., vaults, catch tanks, diversion boxes, and piping) within each WMA and are referred to as "Component Closure Activity Plans."

1.1.2.3 Closure Under AEA. The DOE implements the AEA through a series of orders. The order DOE O 435.1, *Radioactive Waste Management,* sets requirements for closure of radioactive waste management units. The associated implementing manual and guidance document (DOE M 435.1-1, *Radioactive Waste Management Manual*, and DOE G 435.1-1, *Implementation Guide for Use with DOE M 435.1-1, Radioactive Waste Management Manual*) contain specific closure requirements. To satisfy the requirements of DOE O 435.1, closure of WMA C will require preparation of the following documents:

- DOE O 435.1 closure plans
- Evaluations of tank waste sources, nature, and retrieval actions to support reclassification of remaining tank waste as "waste incidental to reprocessing"
- DOE O 435.1 radiological performance assessment (PA).

1.1.2.4 WMA C Performance Assessment. Concurrent with the preparation of this RFI report, DOE is preparing the required DOE O 435.1 radiological PA to support closure decision-making. In recognition of parallel RCRA and CERCLA risk assessment requirements

for closure of contaminated facilities, DOE, Ecology, and EPA have elected to develop a single WMA C PA for evaluating whether WMA C closure conditions will be protective of human health and the environment for all contaminants of concern, both radiological and non-radiological. The use of a single, integrated WMA C PA process is consistent with the SST system PA process described in HFFACO Appendix I, Section 2.5. This so-called Appendix I PA (IPA) for WMA C will address the requirements of RCRA, HWMA, *Federal Water Pollution Control Act* (Clean Water Act), AEA, *Safety of Public Water Systems* (Safe Drinking Water Act of 1974), and any other performance requirements that might be Applicable or Relevant and Appropriate Requirements under CERCLA. The IPA will be approved by Ecology and DOE pursuant to their respective authorities. The dangerous waste portion of the IPA will be included by reference into the RCRA closure plans.

The initial WMA C IPA will be based on the current state of knowledge at the time the IPA is prepared. The IPA will be updated with new information as retrievals, characterization, and closure activities are completed for individual components within the WMA. Because the IPA work and the preparation of this RFI report are occurring concurrently, only human health and ecological risk assessment information obtained prior to the completion of this RFI report has been included in this report.

1.1.3 Groundwater Remediation

The DOE, EPA, and Ecology have elected to investigate and remediate Hanford Site groundwater under a past practice process (HFFACO Action Plan Appendix I, Section 2.4). Characterization and remediation of groundwater in the vicinity of WMA C will occur solely through the past practice decision-making process associated with CERCLA Groundwater Operable Units (OU) 200-BP-5 and 200-PO-1. As required by HFFACO Action Plan Appendix I, Section 2.3, DOE has developed a corrective action master work plan that describes the overall corrective action conceptual process and sequencing approach for all SST farms. The master plan for integrating the RCRA corrective action process, the RCRA treatment, storage, and disposal (TSD) unit closure process, and the CERCLA groundwater OU remedial investigation/feasibility study (RI/FS) process is RPP-PLAN-37243, *Phase 2 RCRA Facility Investigation/Corrective Measures Study Master Work Plan for Single-Shell Tank Waste Management Areas*. The integration between the vadose zone program and the groundwater program is described in Section 5 of this master work plan (RPP-PLAN-37243). Additional detail regarding integration of RCRA and CERCLA requirements for closure of WMA C, specifically, is contained in RPP-46459, *Single-Shell Tank Waste Management Area C RCRA/CERCLA Integration White Paper*. Information in this paper also includes a comparison of RCRA and CERCLA performance standards and a discussion of integrating aspects associated with buildings and pipelines. Groundwater characterization information presented in this Phase 2 RFI report is included solely for the purposes of defining the nature and extent of soil contamination for use in subsequently evaluating soil corrective actions.

Groundwater monitoring has been conducted at all WMAs in accordance with WAC 173-303-400, "Interim Status Facility Standards," subsection (3) Standards and, by reference, 40 CFR 265, "Interim Status Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities," Subpart F, "Ground-Water Monitoring," since the

early 1990s. These regulations require monitoring to determine whether dangerous waste or dangerous waste constituents from the waste site have entered the groundwater. A RCRA groundwater monitoring program for WMA C was initiated in 1989 (WHC-SD-EN-AP-012, *40 CFR 265 Interim-Status Ground-Water Monitoring Plan for the Single-Shell Tanks*, Rev. 0, followed by WHC-SD-EN-AP-012, *Interim Status Groundwater Monitoring Plan for the Single-Shell Tanks*, Rev. 1 in 1991). From 2001 to the present, monitoring was conducted in accordance with PNNL-13024.

Groundwater beneath WMA C is now being monitored under a RCRA interim status groundwater quality assessment monitoring program. The assessment program is contained in DOE/RL-2009-77, *Groundwater Quality Assessment Plan for the Single-Shell Tank Waste Management Area C.*

1.2 DOCUMENT STRUCTURE

The content and structure of this RFI report reflect guidelines in EPA 530/SW-89-031, *Interim Final RCRA Facility Investigation (RFI) Guidance, Volume II of IV Soil, Ground Water and Subsurface Gas Releases*, with modifications to concurrently satisfy the additional CERCLA requirements in accordance with Appendix I of the HFFACO Action Plan.

This WMA C Phase 2 RFI report is organized as follows.

- **Section 1,** *Introduction*, identifies the approach, purpose and scope, regulatory framework, overview of the Phase 1 and 2 investigations, and organization of this report.
- **Section 2,** *Site Background and Environmental Setting*, describes the environmental setting from both a regional/Hanford perspective, and specific to WMA C.
- **Section 3,** *Waste Management Area C Site Description*, provides detailed descriptions of the area and components comprising WMA C.
- **Section 4,** *Field Investigation Program*, describes the soil investigation efforts completed to date and summarizes the results of the investigations.
- **Section 5,** *Nature and Extent of Contamination*, contains the data gathered during all phases of the RFI.
- **Section 6,** *Contaminant Fate and Transport*, describes the anticipated future behavior of selected contaminants of potential concern in the vadose zone and the underlying groundwater at WMA C.
- **Section 7,** *Human Health and Ecological Risk Assessment*, summarizes the work completed at the time of this report to support the WMA C IPA.

- **Section 8,** *Summary, Conclusions, and Recommendations*, provides a summary of investigation findings, information gaps, and recommendations for future action at WMA C.

- **Section 9,** *References*, provides references for material cited.

This RFI report includes extensive data used to perform calculations and assessments. Summaries of data are provided in this document and appendices, and clickable links may be used to take the reader to more detailed information contained in particular studies, databases, or reports found in the Administrative Record or on the internet. Additional supporting information is provided in appendices to this RFI report.

1.3 WMA C SITE DESCRIPTION

This RFI report addresses only WMA C and its surrounding vicinity as defined in RPP-RPT-38152. WMA C includes the 241-C Tank Farm (C Farm[1]); the C Farm fence line coincides with the boundary of WMA C. The Phase 2 RFI study area encompasses a slightly larger area, as shown in Figure 1-3.

The C Farm was constructed in 1944 and 1945 and was one of the first Hanford Site tank farms built. Operations at C Farm began in 1946. The C Farm is currently undergoing waste retrieval operations in preparation for closure as part of WMA C.

WMA C contains:

- Twelve 100-series SSTs, each with 1,892,700-L (535,000-gal) operating capacity
- Four 200-series SSTs, each with 208,000-L (55,000-gal) operating capacity
- Waste transfer lines
- Multiple drywells around each 100-series SST used as leak detection systems
- Tank ancillary equipment, including diversion boxes, catch tanks, and related structures
- Associated unplanned releases (UPR) to the soil.

WMA C also contains various utility supply lines/water lines, ventilation systems, and temporary facility components such as mobile trailers that will need to be addressed prior to or during the closure of WMA C.

A map depicting the locations of major WMA C components, equipment, groundwater monitoring wells, and waste sites is provided in Figure 1-3. A detailed description of the operational setting of WMA C, including unit design, equipment functions, waste streams, known releases, waste retrieval, and stabilization history is provided in Section 3 of this RFI report.

[1] All references made to a specific Tank Farm (i.e., 214-C Tank Farm) will be abbreviated and hereinafter referred to as "C Farm", "A Farm", "T Farm", etc.

1.4 SUMMARY OF RCRA FACILITY INVESTIGATIONS

In 1998 it was determined that groundwater under the SST WMAs was being impacted by historical releases of waste from four SST WMAs: S-SX, B-BX-BY, T, and TX-TY (PNNL-11810, *Results of Phase I Groundwater Quality Assessment for Single-Shell Tank Waste Management Areas S-SX at the Hanford Site*; PNNL-11826, *Results of Phase I Groundwater Quality Assessment for Single-Shell Tank Waste Management Areas B-BX-BY at the Hanford Site*; and PNNL-11809, *Results of Phase I Groundwater Quality Assessment for Single-Shell Tank Waste Management Areas T and TX-TY at the Hanford Site*). This determination resulted in a decision to evaluate the sources of these releases in the vadose zone through the corrective action process. Subsequently it became clear that if vadose zone contamination were present under any WMA, current or future groundwater contamination from these WMA sources would be plausible. Therefore, WMAs A-AX, C, and U were also brought into the corrective action process.

1.4.1 Phase 1 Investigation

The investigative approach for the RCRA corrective action process at the SST farms at the Hanford Site, including WMA C, was developed through negotiations with Ecology and DOE and was documented in DOE et al. 2001, *HFFACO Change Number M-45-98-03, Agreement Commitments Regarding Initial Single-Shell Tank Waste Management Area (WMA) Corrective Actions, Vadose Zone and Groundwater Characterization, Assessment, and the Integration of Vadose Zone and Groundwater Activities at specified Associated Sites*. The DOE-Office of River Protection (ORP) developed DOE/RL-99-36, *Phase 1 RCRA Facility Investigation/Corrective Measures Study Work Plan for Single-Shell Tank Waste Management Areas* in 2000 in response to the pending HFFACO milestones. This work plan was a "master" planning document that provided the framework for subsequent Phase 1 RFI characterization activities as well as for the anticipated remaining corrective action activities, such as FIRs and the evaluation of soil corrective measures.

Investigation of the soil at WMA C has been ongoing from the time of the construction of C Farm. From 1944 to 1982, a large number of leak detection drywells were drilled at WMA C. Over the years, geophysical data were obtained from these drywells to investigate suspected releases of tank waste to the soil. Limited soil sampling was also conducted to investigate suspected releases. The resulting data is summarized and evaluated in the following reports: HNF-2603, *A Summary and Evaluation of Hanford Site Tank Farm Subsurface Contamination* and RPP-14430. These reports document the characterization information available at the outset of the WMA C Phase 1 RFI.

Information in RPP-14430 and HNF-2603 was used to identify data gaps that would need to be addressed during the WMA C RFI. In 2003, ORP prepared RPP-16608, *Site-Specific Single-Shell Tank Phase 1 RCRA Facility Investigation/Corrective Measures Study Work Plan Addendum for Waste Management Areas C, A-AX, and U*, which guided the Phase 1 investigation of the vadose zone in a limited number of specific locations of concern at WMA C.

A summary of the Phase 1 investigation data was documented in individual FIRs; the FIR for WMAs C and A-AX was released as RPP-35484. Information from multiple FIRs was then summarized and evaluated in DOE/ORP-2008-01, *RCRA Facility Investigation Report for Hanford Single-Shell Tank Waste Management Areas*. The FIR for WMAs C and A-AX was appended to DOE/ORP-2008-01 as Appendix L.

The purpose of the Phase 1 RFI was to identify and evaluate known major release events that could require interim actions to protect human health and the environment. DOE/ORP-2008-01 presented the state of knowledge on characterization, research, and interim measure implementation developed during the 10 years of the SST WMA Phase 1 corrective action program. Its contents include SST WMA background information, an explanation of the field activities performed, and descriptions of the findings and results, including summaries from the individual WMA FIRs and DOE/ORP-2005-01, *Initial Single-Shell Tank System Performance Assessment for the Hanford Site*.

As documented in DOE/RL-99-36, the FIR for WMAs C and A-AX (RPP-35484) was produced to present the most recent assessment of existing and new information to clarify the existing understanding of the nature and extent of past major releases from SSTs in WMA C. Recommendations included in the FIR address interim measures, accelerated corrective measures, future tank operations, collection of additional WMA data and information, and lessons learned.

1.4.2 Phase 1 Near-Term Characterization

After the publication of the FIR for WMAs C and A-AX (RPP-35484) and before the completion of planning for the WMA C Phase 2 RFI, characterization activities continued at WMA C. This transitional characterization effort was called "near-term" characterization and focused on the limited installation of boreholes for geophysical logging and soil sample collection. RPP-35169, *Near Term Data Quality Objectives for Vadose Zone Characterization Waste Management Area C*, and RPP-PLAN-35341, *Work Plan for Near-Surface Vadose Zone Characterization Utilizing the Hydraulic Hammer/Direct Push Technology for 35 Direct Pushes in FY08,* were prepared to support characterization efforts at UPR-200-E-86 and UPR-200-E-81. The resulting data was used to support the planning for the Phase 2 RFI.

1.4.3 Phase 2 Investigation

In 2007, DOE and Ecology agreed that a Phase 2 corrective action program would be required to obtain further characterization data for final corrective action and closure of WMA C. The purpose of the Phase 2 program is to complete the characterization of the vadose zone in the WMA such that final soil remedy decisions can be made. After the near-term characterization data quality objectives (DQO) report (RPP-35169) was issued, additional data needs were identified and addressed in the Phase 2 RFI DQO process. In 2008, RPP-RPT-38152 identified the data required to support the evaluation of alternative corrective measures and subsequent decision making.

A Phase 2 master work plan, RPP-PLAN-37243, was released pursuant to HFFACO Milestone M-045-58. The purpose of the Phase 2 master work plan was to identify the overall conceptual process for performing Phase 2 corrective actions to support final closure of all of the SST WMAs. A WMA C-specific work plan, RPP-PLAN-39114, provided the investigative basis and approach to the Phase 2 characterization activities for WMA C.

The various WMA C decision documents described above are summarized in Table 1-1. A detailed description of each of the previous investigations and a summary of the results can be found in Section 4 of this RFI report.

Table 1-1. Summary of WMA C RCRA Facility Investigation Documents

Initial Date of Release	Applicability	RFI Phase	Document Type	Document Name and Number	Description
December 1998	Multiple SST WMAs, including WMA C	Phase 1	Report	*A Summary and Evaluation of Hanford Site Tank Farm Subsurface Contamination* (HNF-2603) Rev. 0 – December 1998	Reviews existing knowledge of geology, hydrology, and geochemical processes in the tank farms, as well as nature and extent of tank waste releases to the soil.
August 1999	Multiple SST WMAs, including WMA C	Phase 1	RFI Work Plan	*Phase 1 RCRA Facility Investigation/ Corrective Measures Study Work Plan for Single-Shell Tank Waste Management Areas* (DOE/RL-99-36) Rev. 0 – August 1999 Rev. 1 – June 2000	Provides the framework for Phase 1 characterization activities and for the anticipated remaining corrective action activities (e.g., FIRs and evaluations of soil corrective measures).
April 2003	Multiple SST WMAs, including WMA C	Phase 1	Report	*Subsurface Conditions Description of the C and A-AX Waste Management Area* (RPP-14430) Rev. 0 – April 2003	Discusses the subsurface conditions (contaminants and distribution) relevant to the occurrence and potential migration of contaminants in the groundwater underlying WMAs C and A-AX.
August 2003	Multiple SST WMAs, including WMA C	Phase 1	RFI Work Plan	*Site-Specific Single-Shell Tank Phase 1 RCRA Facility Investigation/Corrective Measures Study Work Plan Addendum for Waste Management Areas C, A-AX, and U* (RPP-16608) Rev. 0 – August 2003 Rev. 1 – April 2004	Provides the investigative basis and approach to Phase 1 characterization activities specific to WMAs C, A-AX, and U.
October 2007	WMA C	Phase 1 Near-Term Characterization	DQO Report	*Near Term Data Quality Objectives for Vadose Zone Characterization Waste Management Area C* (RPP-35169) Rev. 0 – October 2007	Identifies the data required to support the "near-term" characterization of WMA C between Phase 1 and Phase 2 activities (includes characterization of UPR-200-E-86 and UPR-200-E-81).

Table 1-1. Summary of WMA C RCRA Facility Investigation Documents

Initial Date of Release	Applicability	RFI Phase	Document Type	Document Name and Number	Description
October 2007	Multiple SST WMAs, including WMA C	Phase 1 Near-Term Characterization	Work Plan	*Work Plan for Near-Surface Vadose Zone Characterization Utilizing the Hydraulic Hammer / Direct Push Technology for 35 Direct Pushes in FY08* (RPP-PLAN-35341) Rev. 0 – October 2007	Provides the scope and logistics for "near-term" characterization of the vadose zone in WMAs C, U, B, and T.
December 2007	Multiple SST WMAs, including WMA C	Phase 1	FIR	*Field Investigation Report for Waste Management Areas WMA C and A-AX* (RPP-35484) Rev. 0 – December 2007 Rev. 1 – January 2008	Presents an assessment of existing and new information to clarify the current understanding of the nature and extent of past major releases from SSTs in WMA C.
January 2008	Multiple SST WMAs, including WMA C	Phase 1	FIR	*RCRA Facility Investigation Report for Hanford Single-Shell Tank Waste Management Areas Tier 1 & 2* (DOE/ORP-2008-01) Rev. 0 – January 2008 Rev. 1 REISSUE– January 2010 Rev. 1 REISSUE – March 2010	Summarizes the data documented in individual FIRs as required by HFFACO milestones M-45-55-T01, M-45-55-T02, and M-45-55-T03.
September 2008	Multiple SST WMAs, including WMA C	Phase 2	RFI/CMS Work Plan	*Phase 2 RCRA Facility Investigation/ Corrective Measures Study Master Work Plan for Single-Shell Tank Waste Management Areas* (RPP-PLAN-37243) Rev. 0 – September 2008 Rev. 1 – November 2008 Rev. 2 – February 2010	Identifies the overall conceptual process for performing Phase 2 corrective actions to support final closure of all of the SST WMAs.

Table 1-1. Summary of WMA C RCRA Facility Investigation Documents

Initial Date of Release	Applicability	RFI Phase	Document Type	Document Name and Number	Description
November 2008	WMA C	Phase 2	RFI/CMS Work Plan	*Phase 2 RCRA Facility Investigation/ Corrective Measures Study Work Plan for Waste Management Area C* (RPP-PLAN-39114) Rev. 0 – November 2008 Rev. 1 – September 2009 Rev. 1A – October 2010 Rev. 1B – March 2011 Rev. 2 – June 2012	Provides the investigative basis and approach to the Phase 2 characterization activities for WMA C.
December 2008	WMA C	Phase 2	DQO Report	*Data Quality Objectives Report Phase 2 Characterization for Waste Management Area C RCRA Facility Investigation/ Corrective Measures Study* (RPP-RPT-38152) Rev. 0 – December 2008	Identifies the data required to support the evaluation of alternative corrective measures and subsequent decision making for WMA C.

CMS = corrective measures study
DQO = data quality objectives
FIR = field investigation report
HFFACO = *Hanford Federal Facility Agreement and Consent Order*
RCRA = *Resource Conservation and Recovery Act of 1976*
RFI = RCRA facility investigation
SST = single-shell tanks
WMA = Waste Management Area

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2.0 SITE BACKGROUND AND ENVIRONMENTAL SETTING

This section provides the background on the regional aspects of the natural environment (vegetation, climate, wildlife, and geology/hydrology) and the human impacts on the area that encompasses the Hanford Site. Additional detail is then provided to focus more closely on the WMA C location and the immediate surrounding area. This section provides information that is critical to understanding the fate and transport of the process wastes stored in the WMA C SSTs.

2.1 SITE DESCRIPTION

The Hanford Site is located in south-central Washington State (Figure 2-1). The Hanford Site, spanning 50 km (30 mi) north to south and 40 km (24 mi) east to west, occupies an area of 1,517 km^2 (586 mi^2) north of the confluence of the Yakima River with the Columbia River. The Hanford Site has restricted public access, providing a buffer for areas currently used for storage of nuclear materials, waste treatment, and waste storage and/or disposal (PNNL-6415, *Hanford Site National Environmental Policy Act [NEPA] Characterization).*

After entering the Pasco Basin, a confined drainage area, the Columbia River flows through the northern part of the Hanford Site, before turning south to form part of the Hanford Site's eastern boundary. The Yakima River, which joins the Columbia River at the city of Richland, runs near the southern boundary of the Hanford Site. Rattlesnake Mountain, Yakima Ridge, and Umtanum Ridge form the southwestern and western boundaries, and the Saddle Mountains form the northern boundary. Two small east-west ridges, Gable Butte and Gable Mountain, rise above the plateau of the central part of the Hanford Site (RPP-RPT-46088, *Flow and Transport in the Natural System at Waste Management Area C*). Adjoining lands to the west, north, and east are principally range and agricultural land. The cities of Kennewick, Pasco, and Richland (the Tri-Cities), West Richland, and Benton City constitute the nearest population centers and are located south-southeast of the Hanford Site.

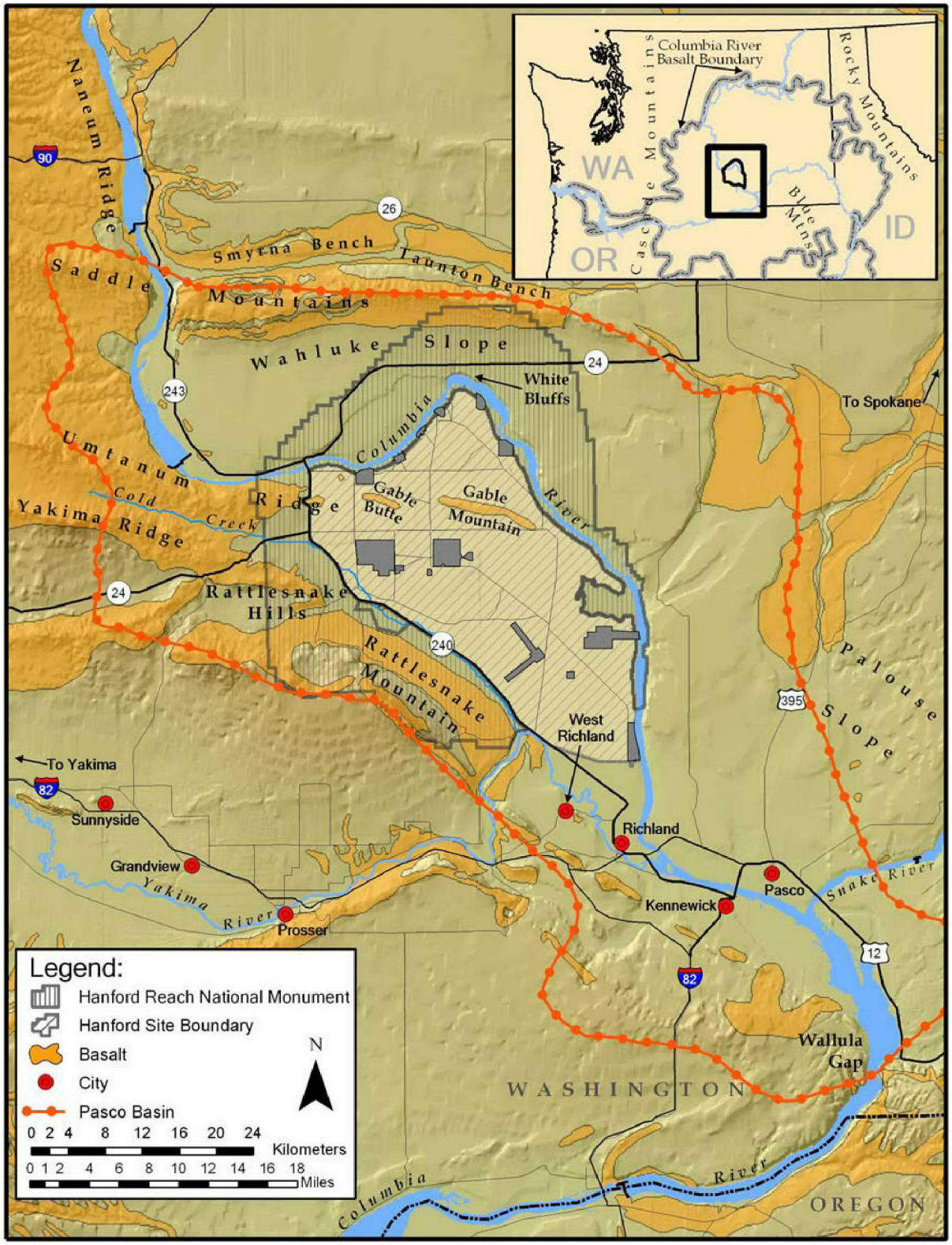
2.2 REGIONAL HISTORY AND HANFORD OPERATIONS

This section provides background material relevant to the industrial origin of the WMA C contamination.

2.2.1 Historical Overview

For centuries, the Hanford area was home to several tribes of Native Americans. Remnants, artifacts, and burial sites associated with historical Native American activity are found throughout the Hanford Site and are protected by law (WHC-MR-0293, *Legend and Legacy: Fifty Years of Defense Production at the Hanford Site*).

Figure 2-1. Location and Geographic Elements of the Hanford Site



Source: PNNL-6415, *Hanford Site National Environmental Policy Act (NEPA) Characterization*, Rev. 17, Figure 4.3-1.

Explorers, trappers, and pioneers traversed the region after the arrival of Europeans to North America. The advance of the railroad into the region in the mid-1800s brought ranching and farming settlement to the mid-Columbia region. The small towns of White Bluffs and Hanford grew up to support the farms and ranches of early residents (Figure 2-2).

After the start of World War II, the War Department located the plutonium production mission of the Manhattan Project in the area near the towns of White Bluffs, Hanford, and Richland in Washington State. The region was selected because of the remoteness and because it had abundant electrical power from Grand Coulee Dam, a functional railroad, clean water from the Columbia River, and available sand and gravel for construction.

When the U.S. Army Corps of Engineers began construction of the Hanford Site in 1943 to produce plutonium, it was among the first nuclear production facilities in the world. Under the careful supervision of such noted scientists as Enrico Fermi, crews built the production reactors along the Columbia River. Farther inland, on the plateau south of Gable Mountain (the Central Plateau), workers built the massive processing facilities where plutonium would be extracted from irradiated uranium fuel rods after removal from the reactors. The associated underground high-level waste (HLW) storage tanks and low-level waste (LLW) disposal facilities were constructed nearby.

From the project's inception in 1943 through 1989, the Hanford Site's mission encompassed defense-related nuclear research, development, and weapons production activities. This included the operation of the nuclear production complex that produced plutonium for the bomb that brought an end to World War II.

Post-World War II tensions between the U.S. and Russia brought about the "Cold War" and drove continued atomic weapons production including the Hanford Site's plutonium production mission. Additional reactors were constructed next to the Columbia River as the two nations began to develop and stockpile nuclear weapons. In 1959, construction began on the last Hanford Site reactor, the N Reactor, a dual-purpose facility that produced plutonium for atomic weapons as well as steam for generating electricity. Starting in the mid-1960s through 1971, the older reactors were shut down, leaving only N Reactor operating on the Hanford Site. N Reactor continued its mission of producing plutonium and electricity until 1987.

Additional historical information is provided in PNNL-6415 and supporting references.

2.2.2 Operations, Facilities, and Processes

The Hanford Site is divided into a number of operational areas (Figure 2-2). These include:

- **100 Areas**. The 100 Areas, situated along the shore of the Columbia River in the northern portion of the Hanford Site, were the location of the nine plutonium production reactors. The 100 Areas occupy a region of 11 km^2 (4 mi^2). Between 1943 and 1963, the plutonium production reactors were built in six operational areas: the 100-B, 100-D, 100-F, 100-H, 100-K, and 100-N Areas. The 100-B Reactor was constructed first, followed in chronological order by 100-D, 100-F, 100-H, 100-DR (built as a replacement

for 100-D), 100-C, 100-KE and 100-KW, and 100-N Reactors. Only the N Reactor was constructed with a closed loop coolant circuit, and a secondary use of steam production for power generation at the Hanford Generating Plant. Production of special nuclear materials (principally ^{239}Pu and tritium) was the primary function of the reactors. All reactors have been retired from service as detailed in DOE/RL-2008-46, *Integrated 100 Area Remedial Investigation/Feasibility Study Work Plan*. Liquid and solid wastes discharged during the reactor operational periods were the primary contaminant sources in the reactor areas. The irradiated fuel produced in the 100 Areas reactors was transported by rail to the 200 Areas.

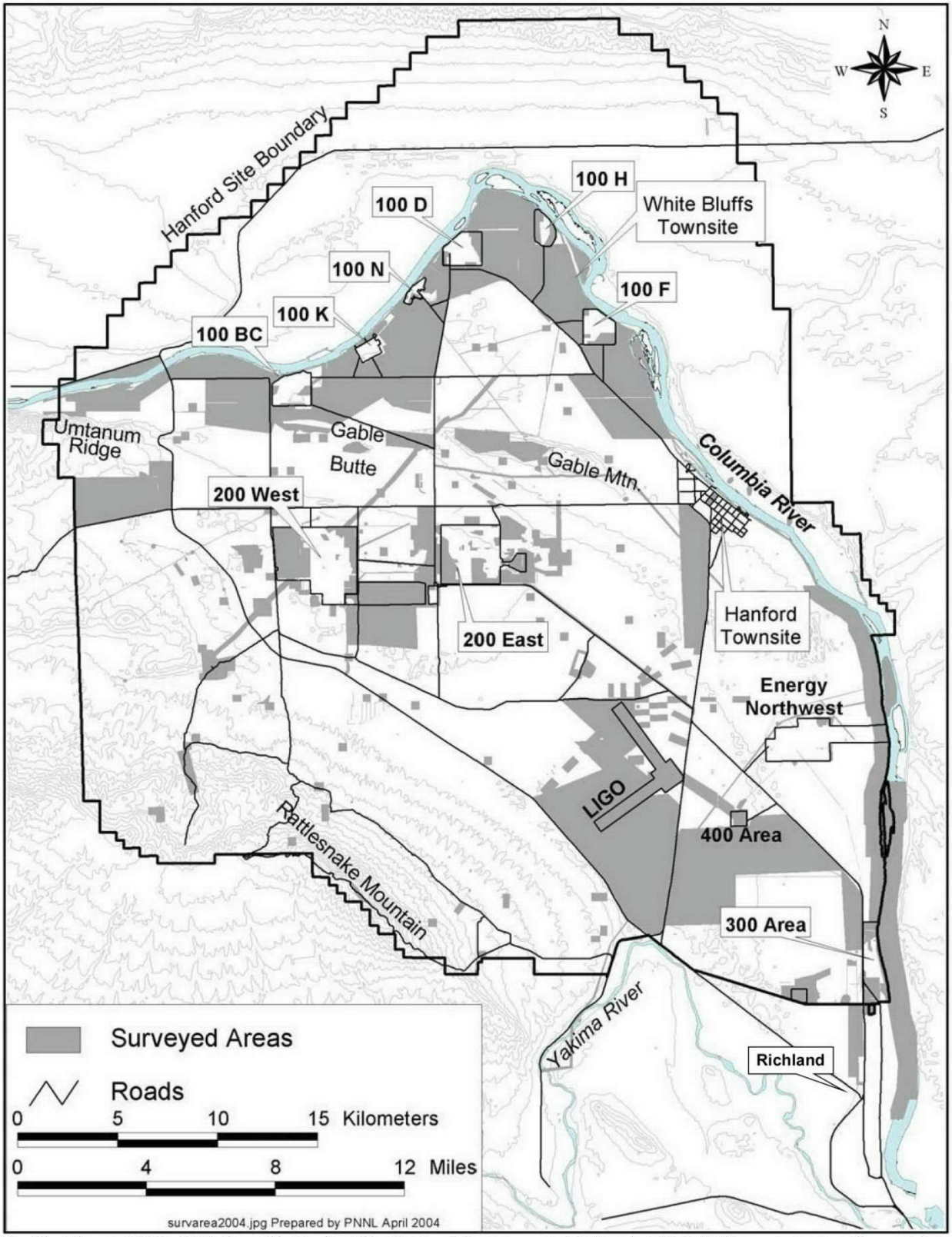
- **200 Areas**. The 200 East and 200 West Areas are located on the Central Plateau ~11 and 8 km (7 and 5 mi), respectively, south of the Columbia River. These areas housed facilities where plutonium was separated from dissolved irradiated fuel. Concurrent with reactor operations in the 100 Areas, spent fuel reprocessing, isotope recovery operations, and associated waste management activities occurred within the 200 East and 200 West Areas located in the central portion of the Hanford Site. Waste disposal within the 200 Areas began with startup of plutonium-separation operations in late 1944 (Chapter 4.0 of WHC-MR-0521, *The Plutonium Production Story at the Hanford Site: Processes and Facilities History*). Process wastes were neutralized and stored in large underground tanks. Wastes containing lower activity fission products, activation products, and nitrate were discharged to infiltration cribs. LLWs and cooling water from the plants were distributed by open ditch to surface ponds for evaporation and percolation into the ground.

  The Central Plateau is further divided into Inner and Outer Areas (Figure 2-3). As stated in DOE/RL-2009-81, *Central Plateau Cleanup Completion Strategy*, the Inner Area is intended to be the "final footprint area of the Hanford Site that will be dedicated to waste management and containment of residual contamination." The Outer Area encompasses the remainder of the Central Plateau.

- **300 Area**. The 300 Area, encompassing 1.5 km^2 (0.6 mi^2), is located just north of Richland and was the location of nuclear fuel fabrication and research and development activities. Nuclear fuel in the form of pipe-like cylinders (fuel slugs) was fabricated from purified uranium shipped in from offsite production facilities. The fabricated fuel slugs were shipped by rail from the 300 Area to the nuclear reactors in the 100 Areas.

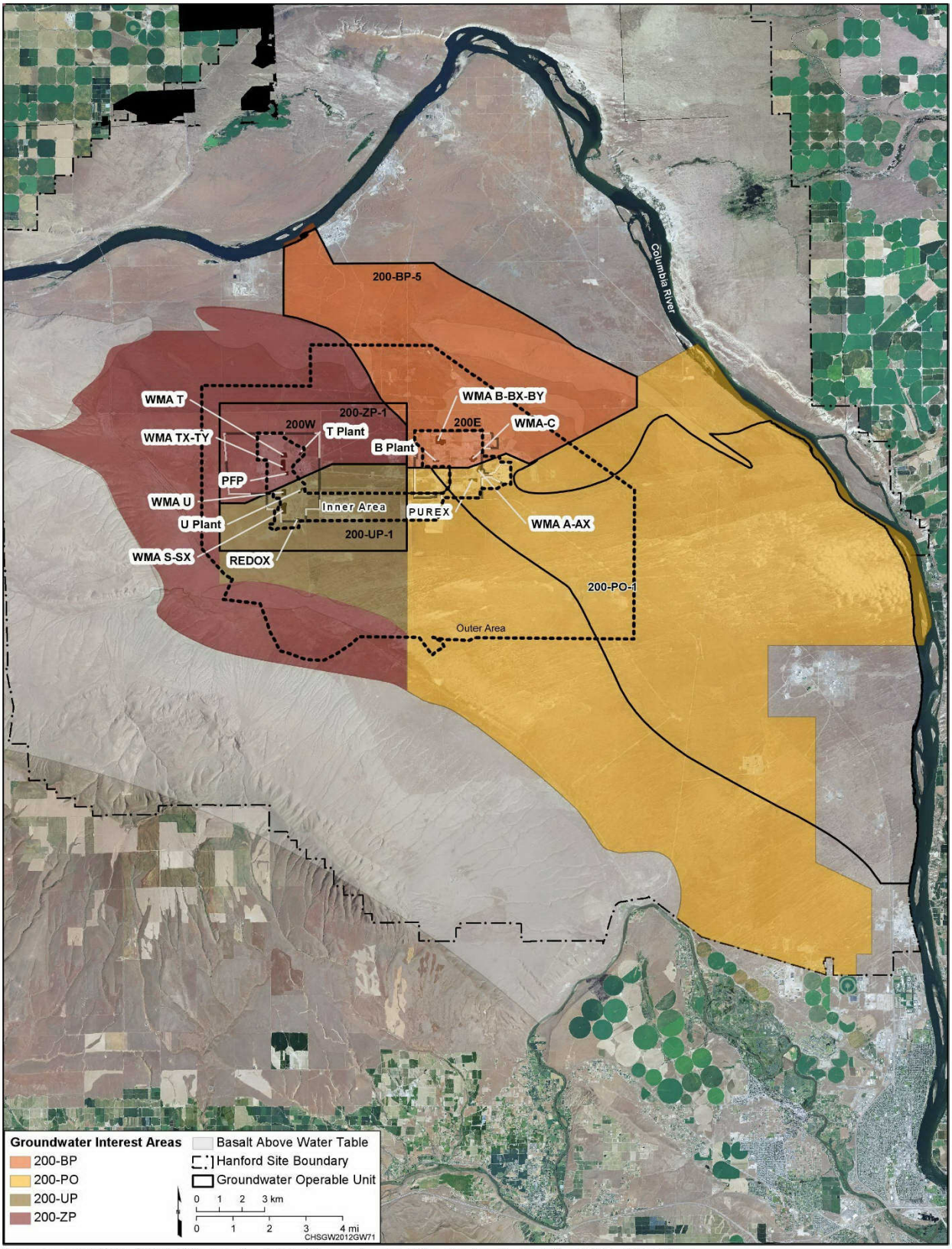
- **400 Area**. The 400 Area is located northwest of the 300 Area and covers 0.61 km^2 (0.23 mi^2). It is the location of the Fast Flux Test Facility, a 400-megawatt thermal, liquid-metal (sodium) cooled nuclear research and test reactor owned by the DOE. The facility, which operated for ~10 years, has been shut down since 1993.

Figure 2-2. Operational Areas of the Hanford Site



Modified from: PNNL-6415, Rev. 17, *Hanford Site National Environmental Policy Act (NEPA) Characterization*, Figure 4.6-1.

Figure 2-3. Details of the Central Plateau



Source: DOE/RL-2013-22, *Hanford Site Groundwater Monitoring Report for 2012*, Map CP.1.

- **600 Area**. The 600 Area includes all the land not in the 100, 200, 300, and 400 Areas of the Hanford Site and was set aside as undeveloped space for future expansion or as security and process safety boundaries. After the termination of the nuclear material production mission, a portion of the 600 Area was selected in 2000 to form the Hanford Reach National Monument (65 FR 37253, "Establishment of the Hanford Reach National Monument"). The monument totals 792.6 km^2 (306 mi^2) and includes Fitzner-Eberhardt Arid Lands Ecology Reserve Unit (ALE), Saddle Mountain Wildlife Refuge Unit, McGee Ranch/Riverlands Unit, and land 0.40 km (0.25 mi) inland from the mean high-water mark on the south and west shores of the 82 km (51 mi)-long Hanford Reach of the Columbia River. It also includes the Federally-owned islands in the Hanford Reach and the sand dune area northwest of the Energy Northwest site. This designation as a national monument establishes the protection and management of the land encompassing the monument. A separate memorandum allows for the incorporation of additional Hanford Site lands into the monument as the land is remediated. The U.S. Fish and Wildlife Service manages ~67,000 hectares (166,000 acres) of monument lands that are within the ALE and the Wahluke Slope (Wahluke Unit and Saddle Mountain Unit) under permit from DOE. The DOE manages the remainder of the monument. In August 2008, the U.S. Fish and Wildlife Service, as lead agency, issued the Final Comprehensive Conservation Plan and EIS (71 FR 74929, "Notice of Availability of the Draft Comprehensive Conservation Plan and Environmental Impact Statement for the Hanford Reach National Monument and Notification of Public Meetings") for management of the Hanford Reach National Monument.

  The purpose of a Comprehensive Conservation Plan is to specify a management direction for the refuge for at least a 15-year time span. The goals, objectives, and strategies for improving refuge conditions, including the types of habitat provided, partnership opportunities, and management actions needed to achieve desired conditions, are described in the Comprehensive Conservation Plan. The U.S. Fish and Wildlife Service's preferred alternative for managing the refuge and its effects on the human environment are described in the Comprehensive Conservation Plan as well.

  More recently, the Rattlesnake Mountain Public Access Act (H.R. 1157) is a bill introduced into the U.S. House of Representatives during the 113th U.S. Congress Session. The bill would require the U.S. Secretary of the Interior to provide public access to the summit of Rattlesnake Mountain in the Hanford Reach National Monument in the state of Washington. The bill passed the House on June 11, 2013 and was sent to the Senate.

- **Former 700 Area**. The 700 Area was the original location for administrative activities for the Hanford Site and was located in central Richland in the area surrounding the current Federal Building (DOE/EIS-0200-F, *Final Waste Management Programmatic Environmental Impact Statement For Managing Treatment, Storage, and Disposal of Radioactive and Hazardous Waste*). It is no longer part of the Hanford Site.

- **Former 1100 Area**. The former 1100 Area was the location of general warehouses and transportation maintenance facilities for the Hanford Site. The 1100 Area was located

between the 300 Area and the city of Richland, encompassing an area of 311 hectares (768 acres). In September 1996, the 1100 Area was declared remediated, and EPA issued a delisting of this area from the National Priorities List (DOE/RL-96-16, *Screening Assessment and Requirements for a Comprehensive Assessment: Columbia River Comprehensive Impact Assessment*). Most of the 1100 Area has been incorporated into the city of Richland and is no longer a part of the Hanford Site (DOE/RL-88-30, *Hanford Site Waste Management Units Report*).

In order to produce the metal plutonium, uranium metal (fuel rods) was irradiated in the production reactors located near the Columbia River. The irradiated uranium metal (spent nuclear fuel [SNF]) was then cooled and transported for treatment through a chemical separation process in the reprocessing plants located on the Central Plateau. At the reprocessing plants, the SNF was dissolved in acid and the plutonium was separated from the remaining uranium and byproducts.

The Hanford Site's SNF reprocessing generated several hundred thousand metric tons of chemical and radioactive waste. Included were HLW, transuranic (TRU) waste, LLW, mixed low-level waste (MLLW), and hazardous waste. The waste management process initially involved neutralizing the acidic waste with sodium hydroxide and sodium carbonate and storing the resulting caustic waste in large underground tanks until a long-term disposal solution could be found. To store the waste, 149 SSTs were built from 1943 through early 1964 in the 200 Areas of the Hanford Site.

During the 1950s, uranium was extracted from some of the waste stored in SSTs, a process that introduced new chemicals into the tanks. Beginning in the 1960s, some waste was retrieved from SSTs and transferred into B Plant at the Hanford Site, where cesium and strontium were extracted, placed in capsules, and stored in a separate facility. This process removed ~40% of the fission product inventory from the tank waste. The remaining waste was returned to the tanks.

In the mid-1950s, leaks were suspected or detected in some SSTs. To address concerns about SST designs, the Hanford Site adopted a new double-shell tank (DST) design that would allow for detection of leaks and effective corrective actions before the waste could reach the surrounding soil. Between 1968 and 1986, a total of 28 DSTs were constructed and filled with liquids pumped from SSTs. These SSTs were subsequently interim-stabilized to minimize the potential for future leaks. The interim stabilization program was completed in 2009. Newly generated waste is also stored in the DSTs.

The Hanford Site encompasses more than 2,963 waste management units and groundwater contamination plumes that have been grouped into 75 OUs. Each OU has complementary characteristics such as type of originating facility, waste characteristics, geography, and relationship of contaminant plumes. The grouping into OUs allows for economies of scale to reduce the cost and number of characterization investigations and remedial actions required to complete environmental cleanup (WHC-EP-0216, *Preliminary Operable Units Designation Project*). The 75 OUs are located in four areas: 17 in the 100 Areas, 52 in the 200 Areas, 2 in the 300 Area, and 4 in the former 1100 Area (DOE/RL-88-30). Detailed information concerning

the OUs and current maps showing the locations of the OUs can be obtained from DOE/RL-88-30. The various operational aspects of the Hanford Site are managed by either of DOE's Richland Operations Office or DOE-ORP. Each DOE Office oversees contractors responsible for various aspects of the cleanup operations.

2.2.3 Contaminant Sources

Soil and groundwater contamination sources at the Hanford Site are directly attributable to the production of plutonium for national defense purposes. Liquid and solid wastes discharged to the soil during plant operations were the primary contaminant sources in the 200 Areas (DOE/RL-2013-22, *Hanford Site Groundwater Monitoring Report for 2012*). Contaminant source locations in the 200 Areas included cooling and process water disposal sites, leaks in underground piping, liquid and solid waste disposal sites, leaks in the liquid waste storage tanks, and UPRs. Low-mobility contaminants, including many metals and radionuclides, sorbed to sediment grains in the vadose zone. These contaminants were found at the greatest concentrations within and near the areas of discharge. When little or no liquid effluent was discharged to a waste site, soil contamination remained in the shallow sediment. Disposal of large volumes of contaminated liquid waste resulted in dispersion of low-mobility contaminants deeper in the vadose zone in comparison to low-volume discharge sites.

2.2.4 Waste Management

Weapons production processes left solid and liquid wastes that posed a risk to the local environment, including the Columbia River. In 1989, DOE, EPA, and Ecology entered into a legally binding accord, the HFFACO (Ecology et al. 1989), to clean up the Hanford Site.

The DOE is processing the Hanford Site's contact-handled TRU waste (which does not require special protective shielding) for shipment to the Waste Isolation Pilot Plant near Carlsbad, New Mexico, an action consistent with previous Records of Decision (63 FR 3629, "Record of Decision for the Department of Energy's Waste Management Program: Treatment and Storage of Transuranic Waste;" 65 FR 10061, "Record of Decision for the Department of Energy's Waste Management Program: Treatment and Disposal of Low-Level Waste and Mixed Low-Level Waste; Amendment of the Record of Decision for the Nevada Test Site") addressing treatment and disposal of TRU waste (DOE/RL-97-02, *National Register of Historic Places Multiple Property Documentation Form - Historic, Archaeological and Traditional Cultural Properties of the Hanford Site, Washington*; and DOE/RW-0006, *Integrated Data Base Report—1996: U.S. Spent Nuclear Fuel and Radioactive Waste Inventories, Projections, and Characteristics*). The DOE is also disposing of the Hanford Site's LLW and MLLW on site.

2.3 HANFORD SITE AND REGIONAL ENVIRONMENTAL SETTING

This section presents a general overview of the environmental setting of the Hanford Site and the surrounding region. Relevant details of the environmental setting that are specific to WMA C are presented in Section 2.4.

2.3.1 Topography

The Hanford Site is located within the Pasco Basin, a sub-unit of the larger surrounding Columbia Basin. The Columbia Basin encompasses the entire area drained by the Columbia River and its tributaries (WHC-SD-ER-TI-003, *Geology and Hydrology of the Hanford Site: A Standardized Text for Use in Westinghouse Hanford Company Documents and Reports*; DOE/ORP-2008-01). The Pasco Basin is a broad, low-relief area and is bordered to the north by the Saddle Mountains, to the west by the Umtanum and Yakima Ridges and the Rattlesnake Hills, to the south by Rattlesnake Mountain, and to the east by the Palouse Slope. Site elevations range from ~1,067 m (3,500 ft) elevation at the Rattlesnake Mountain summit to less than 122 m (400 ft) elevation at the 300 Area shoreline southern site boundary.

The Hanford Site lands north of the Columbia River vary from relatively broad, flat areas along the northern banks of the Columbia River to steep bluffs and ridges farther north, closer to the Saddle Mountains. Elevations range from 122 m (400 ft) above mean sea level (MSL) near the river to over 1,518 m (700 ft) MSL in the Saddle Mountains (RHO-BWI-ST-4, *Compilation Geologic Map of the Pasco Basin, South-Central Washington*). Areas to the south and west of the Columbia River vary from small flat-lying areas along the eastern boundary (adjacent to Highway 240) to comparatively steep sloped hills and ridges (Umtanum Ridge) along the western boundary. Elevation varies from 244 m (800 ft) MSL adjacent to Highway 240 to over 732 m (2,400 ft) MSL at the western border (RHO-BWI-ST-4). The developed portion of the Hanford Site, including the 100 and 200 Areas, is characterized by a generally flat, low-relief area. Topographic exceptions are the anticlines of Gable Mountain (summit of 335 m [1,100 ft]) and Gable Butte due north of the 200 Areas. The previously mentioned ALE area varies from a flat gently sloping area south of Highway 240 to over 1,067 m (3,500 ft) MSL at the summit of Rattlesnake Mountain (RHO-BWI-ST-4).

2.3.2 Climate

The information provided in this section is a summary; additional detail can be found in PNNL-6415 and annual updates to the Hanford Site Environmental Report series (e.g., DOE/RL-2014-32, *Hanford Site Environmental Report for Calendar Year 2013*). Weather conditions are monitored and recorded at the Hanford Meteorological Station (HMS), located between the 200 East and 200 West Areas at 223 m (733 ft) elevation. Additional stations are located throughout the Hanford Site. Data from the HMS are representative of the general climatic conditions for the region and describe the specific climate of the 200 Areas. Real-time and historical data from the HMS can be obtained on the Internet[1]. The climate at the Hanford Site can be classified as either mid-latitude semiarid or mid-latitude desert, depending on which climatological classification system is used.

The Hanford Site temperatures, precipitation, and winds are affected by mountain barriers. The Cascade Range, beyond Yakima to the west greatly influences the climate of the Hanford Site because of its rain-shadow effect. The Rocky Mountains and ranges in southern British Columbia in Canada protect the region from severe, cold polar air masses moving southward across Canada and winter storms associated with them. Prevailing wind direction in the Central

[1] Available at: http://www.hanford.gov/hms

Plateau is from the northwest throughout the year. The secondary wind direction is from the southwest. Summaries of wind directions indicate that winds from the northwestern quadrant occur most often during winter and summer. During spring and fall, the frequency of southwesterly winds increases, with a corresponding decrease in the northwesterly flow. Monthly average wind speeds are lowest during winter months, averaging 10 kph (6 to 7 mph), and highest during summer, averaging 13 kph (8 to 9 mph). Wind speeds well above average are usually associated with southwesterly winds. However, summertime drainage winds are generally northwesterly and frequently exceed 48 kph (30 mph). These winds are most prevalent over the northern portion of the Hanford Site.

Large diurnal temperature variations are common, resulting from intense daytime solar heating and nighttime cooling. Daytime high temperatures from June through August can exceed 38°C (100°F). Daily maximum temperatures vary from a normal maximum of 1.7°C (35°F) in late December and early January to 36°C (96°F) in late July. The record maximum temperature is 45°C (113°F), and the record minimum temperature is -30°C (-23°F). On the average, 52 days during the summer months have maximum temperatures of 32°C (90°F) or higher and 12 days with maxima of 38°C (100°F) or higher. From mid-November through early March, average daily minimum temperatures are below freezing (≤0°C [32°F]), with the daily minima in late December and early January averaging 6°C (21°F). During the winter, on average, three days have minimum temperatures of -18°C (0°F) or lower; however, only about one winter in two experiences such temperatures.

Normal annual precipitation at the HMS is 18.1 cm (7.1 in.). Most precipitation occurs during the late autumn and winter, with more than half of the annual amount occurring from November through February. Days with more than 1.3 cm (0.5 in.) precipitation occur on average less than once each year. Rainfall intensities of 1.3 cm/hr (0.5 in./hr) persisting for 1 hour are expected once every 10 years. Rainfall intensities of 2.5 cm/hr (1 in./hr) for 1 hour are expected only once every 500 years. The wettest year on record, 1995, received 31 cm (12 in.) of precipitation; the driest, 1976, received 7.6 cm (3 in.). The record snowfall, measured in 1992 to 1993, was 142.5 cm (56.1 in.) (DOE/RL-2013-18, *Hanford Site Environmental Report for Calendar Year 2012*).

Overcast skies and fog occur predominantly during the late fall and winter months. About 38% of the precipitation during December through February falls as snow. Winter monthly average snowfall ranges from 1.3 cm (0.5 in.) in March to 13 cm (5 in.) in January. Only one winter in four is expected to accumulate as much as 15 cm (6 in.) of snow on the ground. During these winters, four days, on average, have 15 cm (6 in.) (or more) of snow on the ground.

2.3.3 Geology

The geology of Eastern Washington and the Hanford Area has been studied by numerous investigators since the arrival of settlers in the northwest. The most comprehensive research took place during the Basalt Waste Isolation Project and produced numerous reports including RHO-BWI-ST-4. Later research activities built on this framework to produce some of the documents referenced in the following summary.

The Hanford Site is located on the Columbia Plateau geologic region (shown as the Columbia Basin in Figure 2-4), a wide, flood basalt plateau situated between the Cascade Mountains to the west and the Rocky Mountains to the east. The Columbia Plateau is underlain by a thick sequence of volcanic Columbia River basalt, which forms the basement rock for the region. The main structural features of the Hanford Site formed under north-south compression that produced the Yakima Fold Belt. The Hanford Site is located on the end product of millions of years of flood-basalt volcanism, tectonic deformation, and deposition and erosion from the Columbia River. Cataclysmic flooding, eolian activity, and landslides have modified the surface topography of the Columbia River Basalt Group (CRBG) and overlying sediments of the Ringold Formation to create the current physiography of the Hanford Site.

The regional structure is controlled by a basement rock assemblage fused onto the structurally complex North American craton during the early Mesozoic Era to early Cenozoic Era. The terrains east of the Cascades now are mostly covered by a thick sequence of Cenozoic rocks that were folded and faulted in a north-south oriented compressive regime. The Columbia Plateau is a structurally and topographically low area surrounded by mountains ranging in age from the late Mesozoic to recent. The Hanford Site area of Columbia Plateau is composed of two fundamental subprovinces, the Palouse Subprovince and the Yakima Fold Belt (Figure 2-4). The Palouse Subprovince is a stable, undeformed area overlying the old continental craton that dips westward toward the Hanford Site. The Yakima Fold Belt is a series of anticlinal ridges and synclinal valleys in the western and central parts of the Columbia Plateau. The edge of the old continental craton lies at the junction of these two structural subprovinces east of the Hanford Site.

The Blue Mountains subprovince of the Columbia River flood-basalt province is a northeast trending anticlinorium that extends 250 km from the Oregon Cascades to Idaho and forms the southern border of the Columbia Plateau.

Rocks older than the CRBG are exposed mainly along the margin of the Columbia Plateau. The generalized stratigraphy beneath the Hanford Site consists of the CRBG and intercalated sediments of the Ellensburg Formation, the overlying sedimentary rocks of the Ringold Formation, Cold Creek unit and the Pleistocene cataclysmic Hanford formation flood deposits (Figure 2-5). Thin veneers of Holocene alluvium, colluvium, and/or eolian sediments discontinuously overlie these principle geologic units. The regional suprabasalt stratigraphy is described in more detail elsewhere (BHI-00184, *Miocene- to Pliocene-Aged Suprabasalt Sediments of the Hanford Site, South-Central Washington*; Open File Report 96-8, *The Miocene to Pliocene Ringold Formation and Associated Deposits of the Ancestral Columbia River System, South-Central Washington and North-Central Oregon*; DOE/RL-2002-39, *Standardized Stratigraphic Nomenclature for the Post-Ringold-Formation Sediments within the Central Pasco Basin*; DOE/ORP-2008-01).

The sedimentary geology varies across the Hanford Site. A generalized summary by area, including the characteristics of the individual formations is presented in the following sections.

Figure 2-4. Geologic Setting of the Pasco Basin within the Columbia Plateau

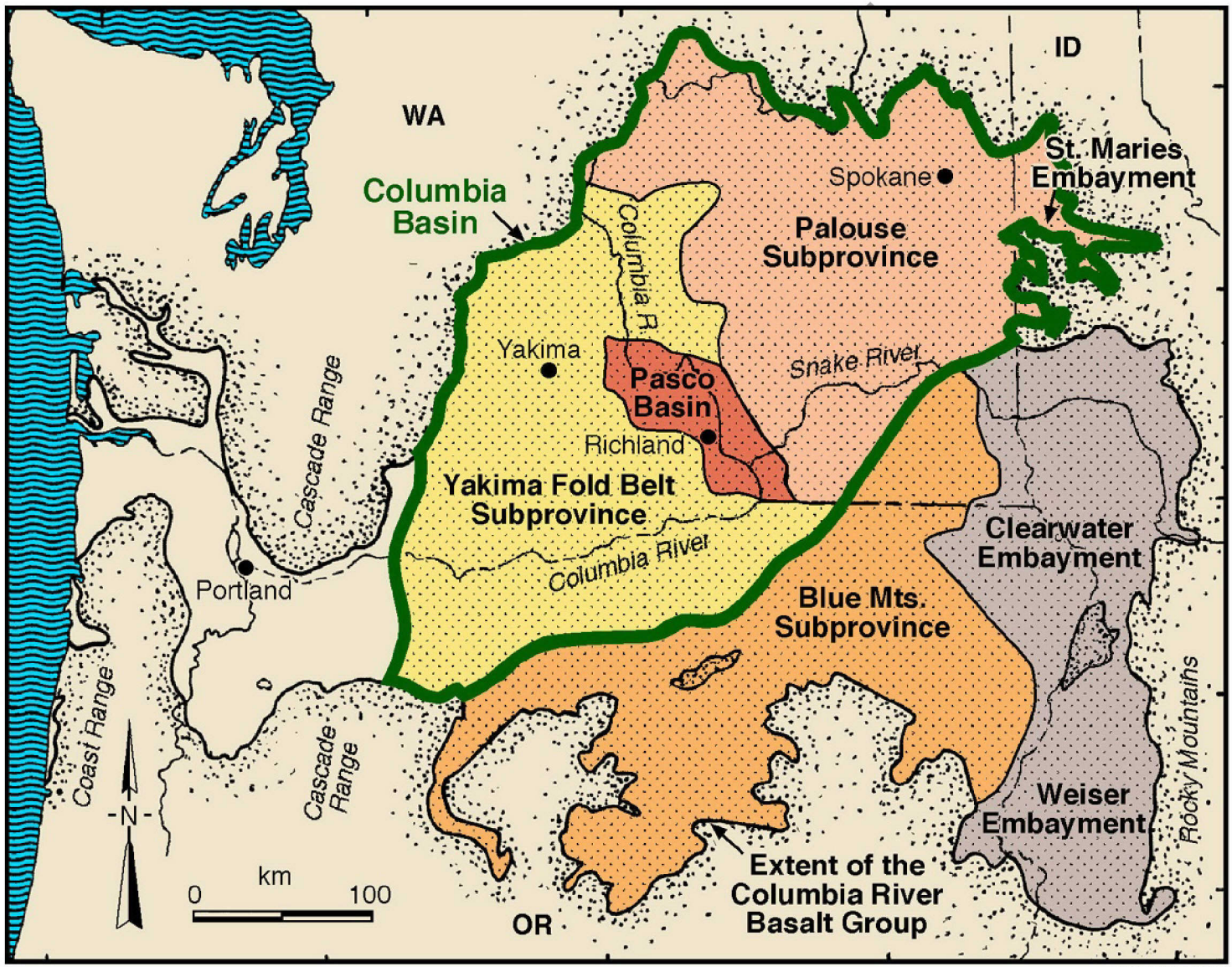
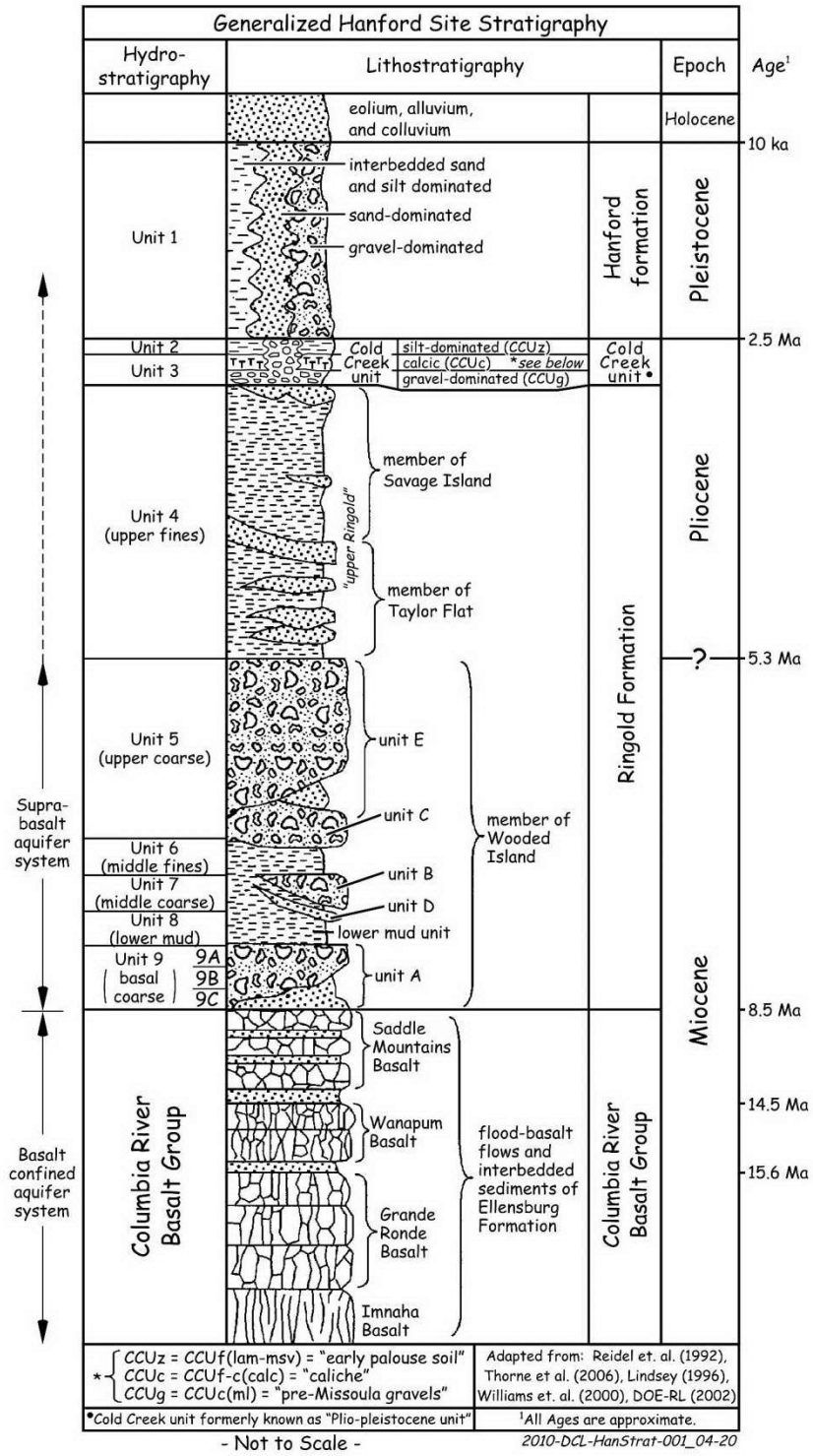


Figure 2-5. Generalized Stratigraphic Column of the Pasco Basin



Source: PNNL-18819, Rev. 1, *Hanford Site Guidelines for Preparation and Presentation of Geologic Information,* Figure 6-4.

2.3.3.1 100 Areas. The 100 Areas extend along the Columbia River in the northern portion of the Pasco Basin. With the exception of the 100-B/C Area, the 100 Areas lie on the northern limb of the Wahluke syncline. The 100-B/C Area lies over the axis of the syncline. The top of the basalt in the 100 Areas ranges in elevation from 46 m (150 ft) near the 100-H Area to -64 m (-210 ft) below sea level near the 100-B/C Area. The Ringold Formation and Hanford formation occur throughout this area; the Cold Creek unit may be present near the 100-B/C and 100-K Areas but is not readily distinguished from the Ringold and Hanford sediments.

The Ringold Formation shows a marked west-to-east variation in the 100 Areas (WHC-SD-EN-TI-012, *Geologic Setting of the 200 East Area: An Update*). The main channel of the ancestral Columbia River flowed along the front of Umtanum Ridge and through the 100-B/C and 100-K Areas, before turning south to flow along the front of Gable Mountain and/or through Gable Gap. This main channel deposited coarse-grained sand and gravel of the Ringold Formation (Units A, B, C, and E) in the western and southern parts of the Wahluke synclinal valley. However, farther to the north and east, the Ringold formation sediments gradually become dominated by the lake and river overbank deposits and associated paleosols of the Ringold Formation lower mud unit, with the 100-H Area showing almost none of the gravel sediments (BHI-00184, Open File Report 96-8).

The Hanford formation in the 100 Areas consists primarily of coarse sand and gravel sediments, with local minor occurrences of the sand-dominated sediments.

2.3.3.2 200 Areas. The uppermost basalt flow beneath the 200 Areas is the Elephant Mountain Member of the Saddle Mountains Basalt. Between the 200 East Area and Gable Gap to the north, several basalt flows have been eroded to expose the underlying Umatilla basalt. There is also a suspected window eroded through the Elephant Mountain Member near the northeast corner of the 200 East Area.

Unit A of the Ringold Formation overlies the basalt beneath much of the 200 Areas. The unit is thickest to the north and south of the 200 West Area. Generally, Unit A is a conglomerate with clasts of basalt and other lithologies in a silty sand matrix interbedded with sand and silt layers. The sediments are well compacted and/or cemented in places.

The Ringold Formation lower mud unit has had a complex history in the 200 Areas. The lower mud is eroded from or was never deposited beneath most of the 200 East Area. There is also a poorly defined channel cut through the lower mud unit in the northeastern corner of the 200 West Area. The lower mud unit consists primarily of lake bed silt and clay deposits, with at least one well-developed paleosol at the top of the sequence noted in the 200 West Area.

Unit E of the Member of Wooded Island is by far the thickest of the Ringold Formation units present beneath the 200 Areas. It consists of bimodal, well-rounded gravel in a sand and silt matrix deposited by major rivers. Erosion by the Columbia River during Cold Creek time and cataclysmic floods through Gable Gap during Hanford formation time has removed unit E from most of the northeastern part of the 200 East Area.

The Ringold Formation Member of Taylor Flat consists of a sequence of fluvial sands and overbank deposits. The Member of Taylor Flat has been eroded from beneath all of the 200 East

Area. Erosional remnants of the Member of Taylor Flat are found beneath parts of the 200 West Area (BHI-00184).

The laterally discontinuous Cold Creek unit overlies the tilted and eroded Ringold Formation in the vicinity of the 200 West Area. The lower Cold Creek unit in the 200 West Area is a highly weathered paleosurface that developed on top of the Ringold Formation. The lower Cold Creek unit consists of basaltic to quartzitic gravels, sands, silt, and clay that are cemented with one or more layers of calcium carbonate. Also included in the lower Cold Creek unit are basaltic gravel and calcic fine-grained sediments deposited by local side streams with sources in the nearby basalt ridges. The upper Cold Creek unit consists of a distinctive silt-rich interval representing wind blown deposits in the 200 West Area. Locally, interbedded layers of fine sand and silt, more characteristic of stream deposits, are found with the wind blown deposits. The silt-dominated deposits can be correlated across most of the 200 West Area.

The Cold Creek unit in the 200 East Area may be represented by the "pre-Missoula gravels" (PNNL-15955, *Geology Data Package for the Single-Shell Tank Waste Management Areas at the Hanford Site*). The exact origin of the sedimentary deposits overlying the CRBG and underlying the Hanford formation is uncertain and still open to interpretation. HNF-5507, *Subsurface Conditions Description of the B-BX-BY Waste Management Area* shows two Cold Creek unit sediment types beneath some of the 200 East Area tank farms: fine-grained silt up to 10 m (33 ft) thick and sandy gravel to gravelly sand.

The Hanford formation is the main stratigraphic unit at the surface for both the 200 Areas. The Hanford formation is thickest in the vicinity of the 200 East Area, where it is over 100 m (330 ft) thick. Gravel-dominated sediments make up most of the Hanford formation in the northern part of the 200 East and 200 West Areas and were deposited by high-energy water in or immediately adjacent to the main cataclysmic flood channels. The sand-dominated sediments are most common in the central to southern parts of the 200 Areas and were deposited adjacent to the main flood channels during the waning stages of flooding. Rhythmite deposits are primarily found south and west of the 200 Areas. More detailed information about the geology of the 200 Areas can be found in PNNL-15955 and DOE/RL-2002-39. Site-specific information regarding the geology beneath WMA C within the 200 East Area is provided in Section 2.4.2 of this document.

2.3.3.3 300 Area. The 300 Area, located in the southeastern portion of the Hanford Site, lies above the gentle eastern extension of the Cold Creek syncline. Over most of the Hanford Site, the uppermost basalt flows belong to the Elephant Mountain Member, but near the 300 Area younger flows belonging to the Ice Harbor Member are present, causing a relatively high region in the top of the basalt surface (PNL-6716, *Interim Characterization Report for the 300 Area Process Trenches*).

The Ringold Formation overlies the basalt in the 300 Area. The lower 17 m (56 ft) of Ringold Formation is composed of the lower mud sequence and is laterally extensive in the area. This is overlain by ~10 m (33 ft) of gravel that is correlated to Ringold Formation units B, C, and E of the Member of Wooded Island (PNNL-13645, *300 Area Process Trenches Groundwater Monitoring Plan*). There is evidence of erosion and formation of one or more channels in the top

of the Ringold Formation throughout the 300 Area. The eroded surface of the Ringold Formation is ~3 to 9 m (10 to 30 ft) lower in these channels (PNNL-13645).

The Hanford formation in the vicinity of the 300 Area is ~15 m (49 ft) thick and consists of both gravel-dominated and sand-dominated sediment. Locally, the gravel-dominated sediment can be divided into pebble to cobble gravel and boulder gravel. The pebble to cobble gravel is the most abundant Hanford formation sediment type beneath the 300 Area (PNNL-13645).

2.3.4 Surface Water

Regional surface water includes the Columbia and Yakima Rivers, springs, and ponds. In addition, there is surface water associated with irrigation east and north of the Hanford Site boundaries.

The only naturally occurring surface water pond on the Hanford Site is West Lake. An alkaline lake, West Lake is located north of the 200 East Area and resulted from an artificially elevated rise in the water table due to historic process wastewater disposal and water management practices on the Central Plateau (PNL-6415). West Lake has not received direct effluent discharges from Hanford Site facilities; rather, its existence is caused by intersection of the elevated water table with the land surface in the topographically low area between Gable Mountain and the Central Plateau. This elevated water table is dropping, and the size of West Lake is consequently diminishing.

Intermittent surface streams, such as Cold Creek (Figure 2-1), may also contain water after large precipitation or snowmelt events. Clusters of vernal pools have also been observed near Umtanum Ridge, in the central part of Gable Butte, and at the eastern end of Gable Mountain following significant precipitation events (TNC 1998, *Biodiversity Inventory and Analysis of the Hanford Site: 1997 Annual Report*). The pools were situated on top of an impermeable basalt layer that enabled water to pond in shallow depressions during wetter winter seasons.

The Columbia River is the fourth largest river in the contiguous U.S. in terms of total flow and is the dominant surface-water body in the region. The original selection of the Hanford Site for plutonium production and processing was based, in part, on the abundant water provided by the Columbia River. The existence of the Hanford Site has precluded development of this section of the river for hydroelectric production and barge transportation.

Originating in the Canadian Rockies of southeastern British Columbia, Canada, the Columbia River drains a total area of 680,000 km^2 (262,480 mi^2) en route to the Pacific Ocean. Most of the Columbia River is impounded by 11 dams within the U.S., 7 upstream and 4 downstream of the Hanford Site. Priest Rapids is the nearest upstream dam, and McNary is the nearest downstream dam. Lake Wallula, the impoundment created by McNary Dam, extends upstream past Richland, Washington, to the southern part of the Hanford Site. Except for the section between Bonneville Dam and the ocean, the only unimpounded stretch of the Columbia River in the U.S. is the Hanford Reach, which extends from Priest Rapids Dam downstream 82 km (51 mi) to Lake Wallula, north of Richland. The Hanford Reach of the Columbia River was recently incorporated into the land area established as the Hanford Reach National Monument.

Flows through the Hanford Reach fluctuate significantly and are controlled primarily by releases from three upstream storage dams: Grand Coulee in the U.S., and Mica and Keenleyside in Canada. Flows in the Hanford Reach are directly affected by releases from Priest Rapids Dam; however, Priest Rapids operates as a run-of-the-river dam rather than a storage dam. Flows are controlled for purposes of power generation and to promote salmon egg and embryo survival.

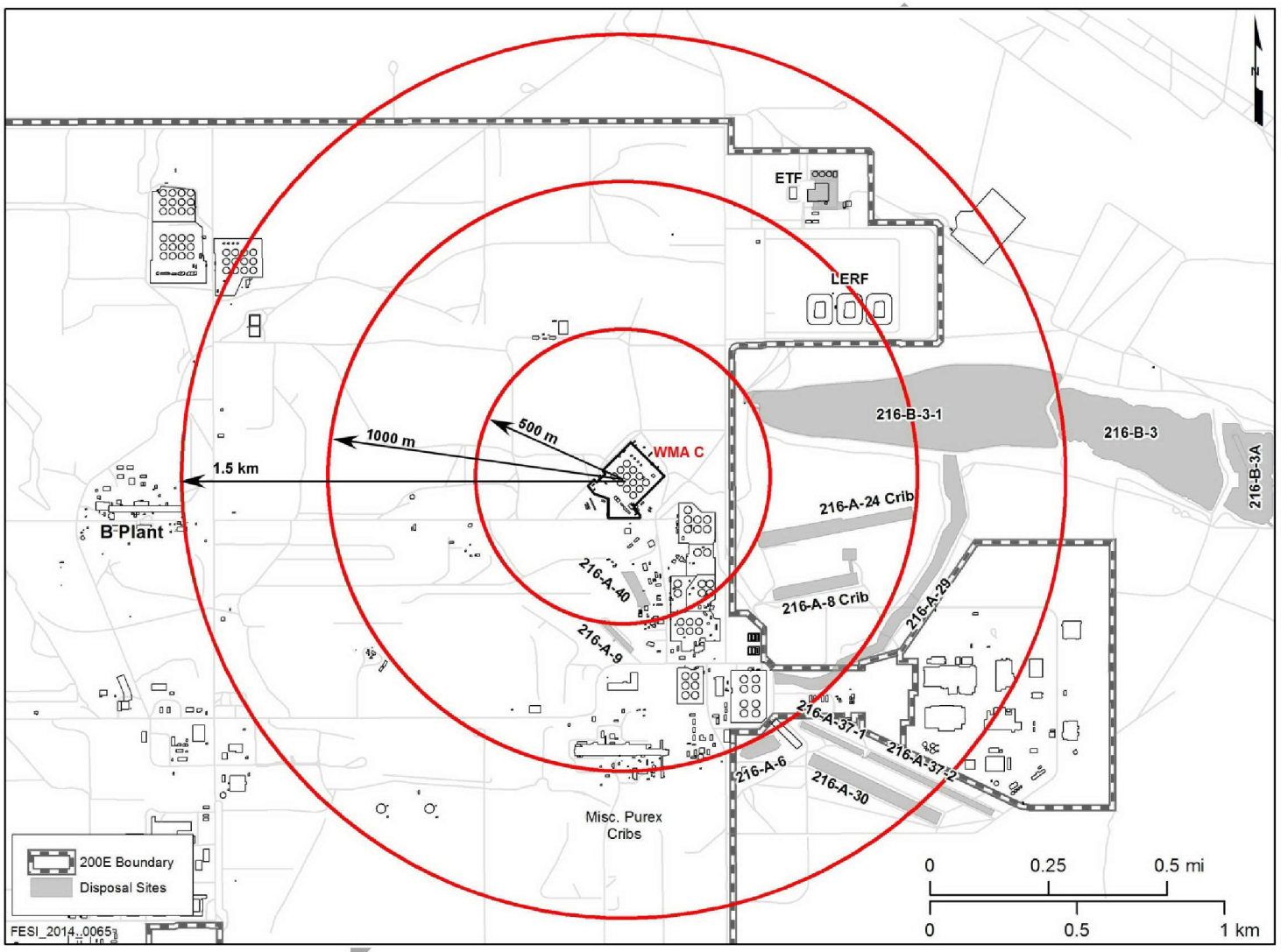
Other than the aforementioned rivers, springs, and ponds there are no other naturally-occurring bodies of surface water on the Hanford Site. Artificial wetlands (caused by irrigation) exist on the east and west sides of the Wahluke Slope portion of the Hanford Site, which lies north of the Columbia River. Additionally, there are hatcheries and canals associated with the Columbia Basin Irrigation Project across the river from the Hanford Site. On the Hanford Site, artificial wetlands, such as ponds and ditches, resulted from the disposal of large volumes of process wastewater. Examples of these features include 216-A-29 Ditch, 216-B-3 Main Pond, and 216-B-3 Expansion Ponds (B Pond system) in and near the 200 East Area (Figure 2-6).

2.3.5 Vadose Zone Recharge

Hydrogeologic conditions and movement through the vadose zone are important considerations for contaminant migration, understanding contaminant fate and transport, development of conceptual models, and planning corrective actions or mitigative measures to reduce exposure to hazardous substances. Hydrogeologic conditions including surface and stratigraphic permeability, infiltration, recharge, hydraulic conductivity, residence times, and effects from changes in water table elevation have been investigated at the Hanford Site.

Unsaturated flow of moisture/liquid in the vadose zone is complex and influenced by the hydraulic properties of soil, vegetation cover, and recharge. Movement of moisture in the vadose zone is mainly vertically downward under gravity drainage, controlled by the unsaturated hydraulic conductivity and the difference in hydraulic head between two points (i.e., hydraulic gradient). Typically, the moisture content in the Hanford formation sediments ranges from 5 to 15% in the vadose zone, largely dependent upon the grain size distribution. The flood deposits that constitute the Hanford formation tend to fine upward within each depositional sequence, resulting in alternating coarser- and finer-grained layers vertically, with the finer-grained zones able to retain more moisture due to their smaller pore size. Cross-beds found in the Hanford formation also may locally influence vertical migration of contaminated liquids, though the extent of influence is not quantified.

Figure 2-6. Location of Closest Liquid Waste Disposal Features to WMA C



ETF = Effluent Treatment Facility
LERF = Liquid Effluent Retention Facility
PUREX = Plutonium Uranium Extraction (Plant)
WMA = Waste Management Area

The vadose zone at the Hanford Site has been extensively studied since the 1980s. PNNL-5428, *Unsaturated Water Flow at the Hanford Site: A Review of Literature and Annotated Bibliography* provided an overview of the status of vadose zone studies in 1985. By 1992, a significant amount of data had been collected from lysimeters at a wide range of sites at the Hanford Site (Gee et al. 1992, "Variations in Recharge at the Hanford Site"). This study categorized the recharge response for a variety of surface covers at the Hanford Site for both soil type and vegetation cover. The most striking finding in this study was that recharge of 8.9 of the 16 cm (3.5 of the 6.3 in.) total annual precipitation was measured in vadose zone lysimeters with a clean gravel cover at the surface. In contrast, lysimeters under native vegetation showed no measurable recharge. This finding is significant since the WMAs have gravel-covered surfaces above the tanks and actively control the growth of invasive vegetation.

Site-specific information regarding moisture movement through the vadose zone beneath WMA C is provided in Section 2.4.4.

2.3.6 Groundwater

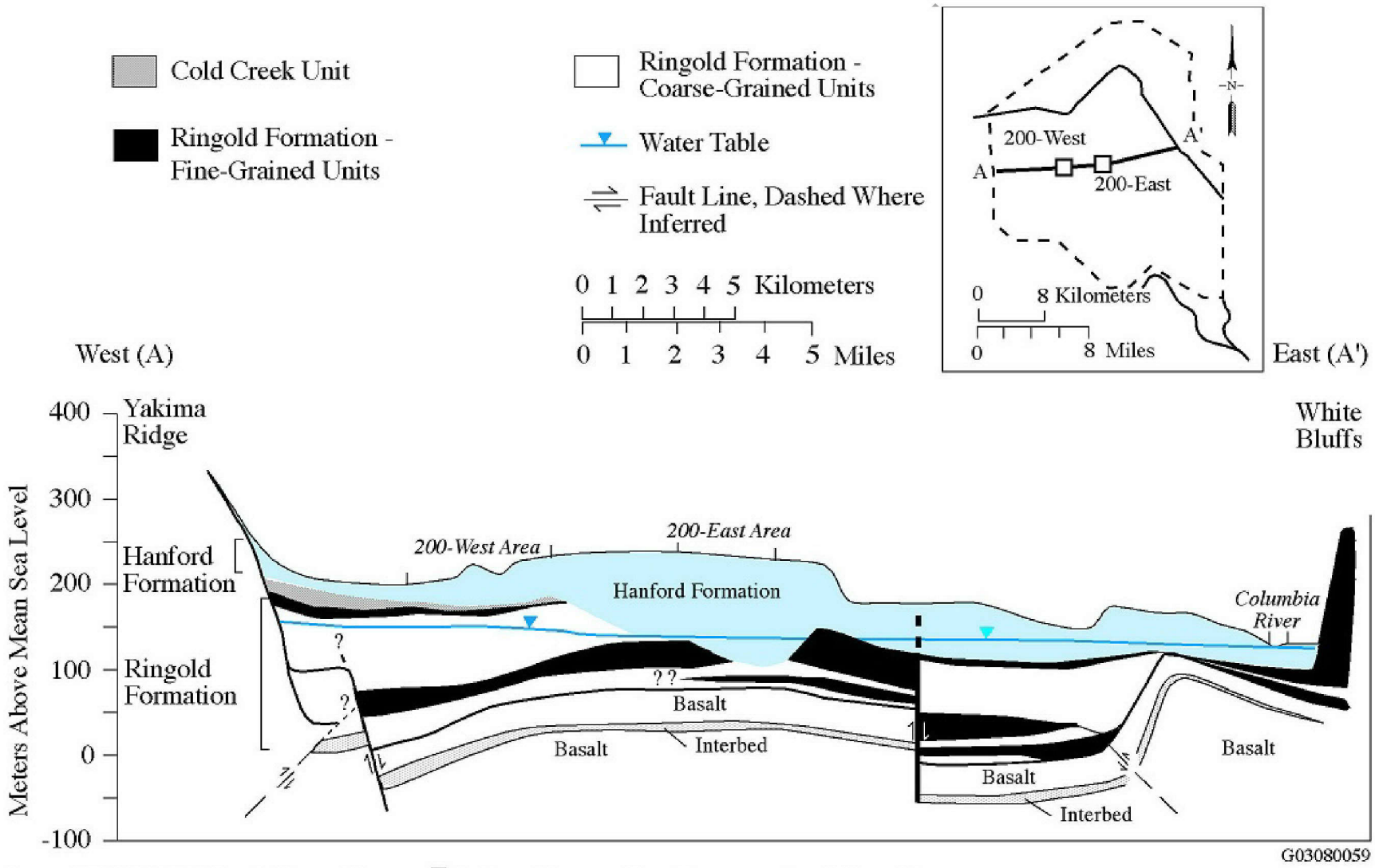
Groundwater at the Hanford Site originates mainly as regional recharge from rain and snowmelt, inflow from riverbank or canal seepage, or as excess irrigation water. Most of this groundwater will eventually discharge to the Columbia River. Some will be brought to the surface through wells or excavations, or through evaporation or transpiration in shallow water table areas.

Groundwater beneath the region is found in both an upper unconfined aquifer system and deeper basalt-confined aquifers. The unconfined aquifer system is also referred to as the suprabasalt aquifer system because it is within the sediments that overlie the basalt bedrock. Portions of the suprabasalt aquifer system are locally confined. However, because the entire suprabasalt aquifer system is interconnected on a regional scale, it is referred to as an unconfined aquifer system.

The suprabasalt aquifer is 180 m (591 ft) thick in the southern portion of the Hanford Site, but thins laterally under the Central Plateau in the center of the Hanford Site, where anticlinal basalt ridges extend above the water table. A generalized east to west geologic cross-section showing the position of the water table is shown in Figure 2-7

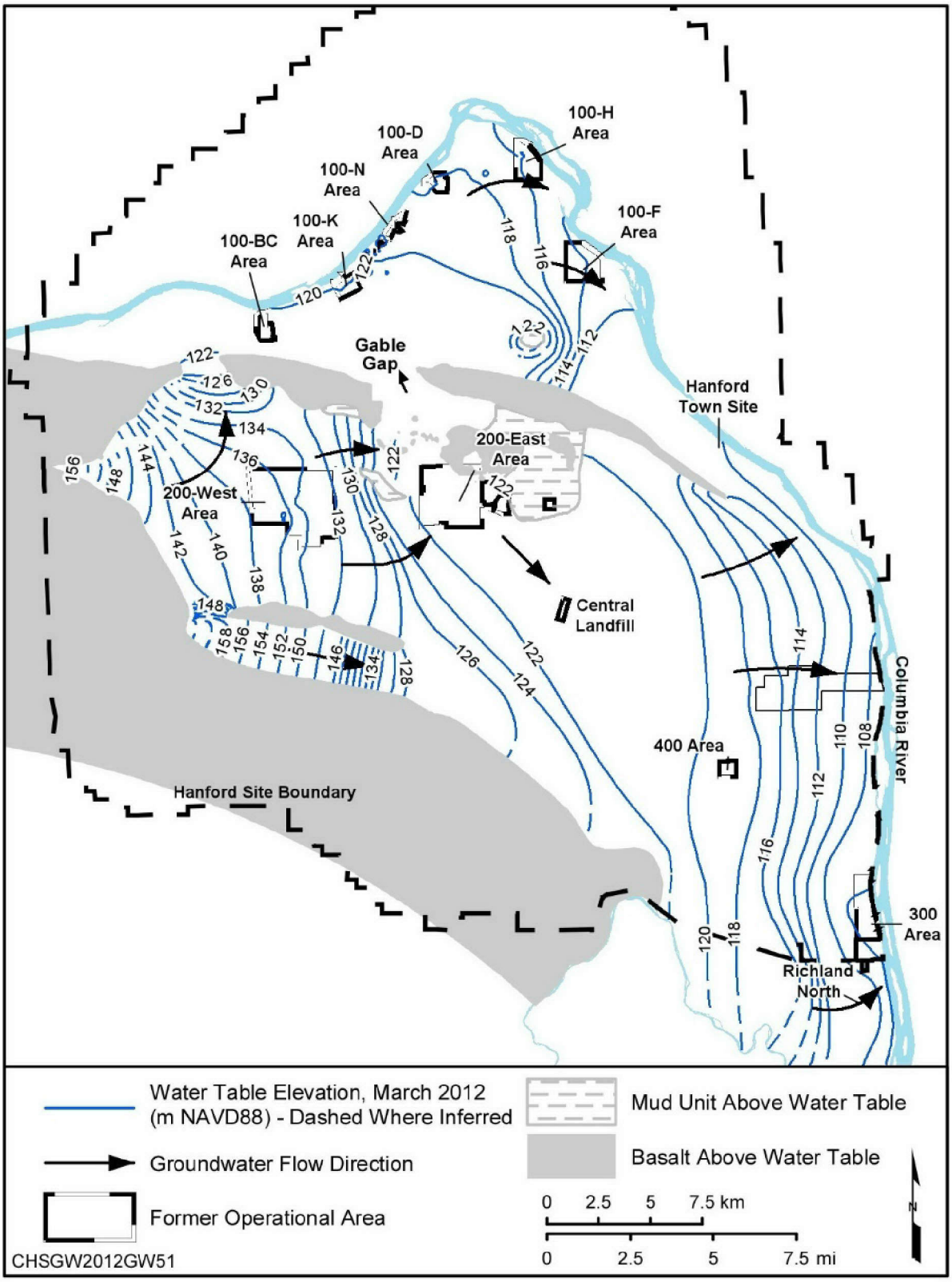
The general direction of groundwater flow is primarily from the natural recharge areas on the basalt ridges to the west to the regional discharge areas along the Columbia River. Figure 2-8 shows the water table elevation for the Hanford Site, as reported in DOE/RL-2013-22. The flow of water divides beneath the 200 East Area, with some water flowing toward the north through Gable Gap and some flowing southeast. Previous liquid waste disposal discharges caused groundwater mounds to form beneath the 200 Areas that significantly affected regional flow patterns in the past. These discharges largely ceased in the mid-1990s, and water levels have declined. Remnants of the groundwater mounds remain.

Figure 2-7. Generalized Geologic Cross-Section through the Hanford Site



Source: RPP-RPT-46088, Rev. 1, *Flow and Transport in the Natural System at Waste Management Area C*, Figure 5-1.

Figure 2-8. Central Plateau Water Table Elevation and Water Flow



Source: DOE/RL-2013-22, *Hanford Site Groundwater Monitoring Report for 2012*, Figure ES.1.

The Soil and Groundwater Remediation Project of the Central Plateau Remediation contract is responsible for assessing the distribution and movement of existing groundwater contamination (both radiological and chemical) and for identifying and characterizing potential and emerging groundwater contamination problems. Monitoring activities are performed to comply with requirements of the RCRA and State of Washington regulations, as well as requirements for operational monitoring around retired reactors and chemical-processing facilities, and requirements for environmental surveillance. Groundwater monitoring is performed during cleanup investigations under the requirements of CERCLA. Groundwater samples are currently analyzed from 780 wells, both on and off the Hanford Site.

The site-wide groundwater monitoring activities are described in DOE/RL-91-50, *Hanford Site Environmental Monitoring Plan.* Groundwater information discussed in this environmental monitoring plan includes program design, well locations, sampling frequencies, sampling procedures, analyses performed, data reviews, and rationale for the level of effort devoted to each activity.

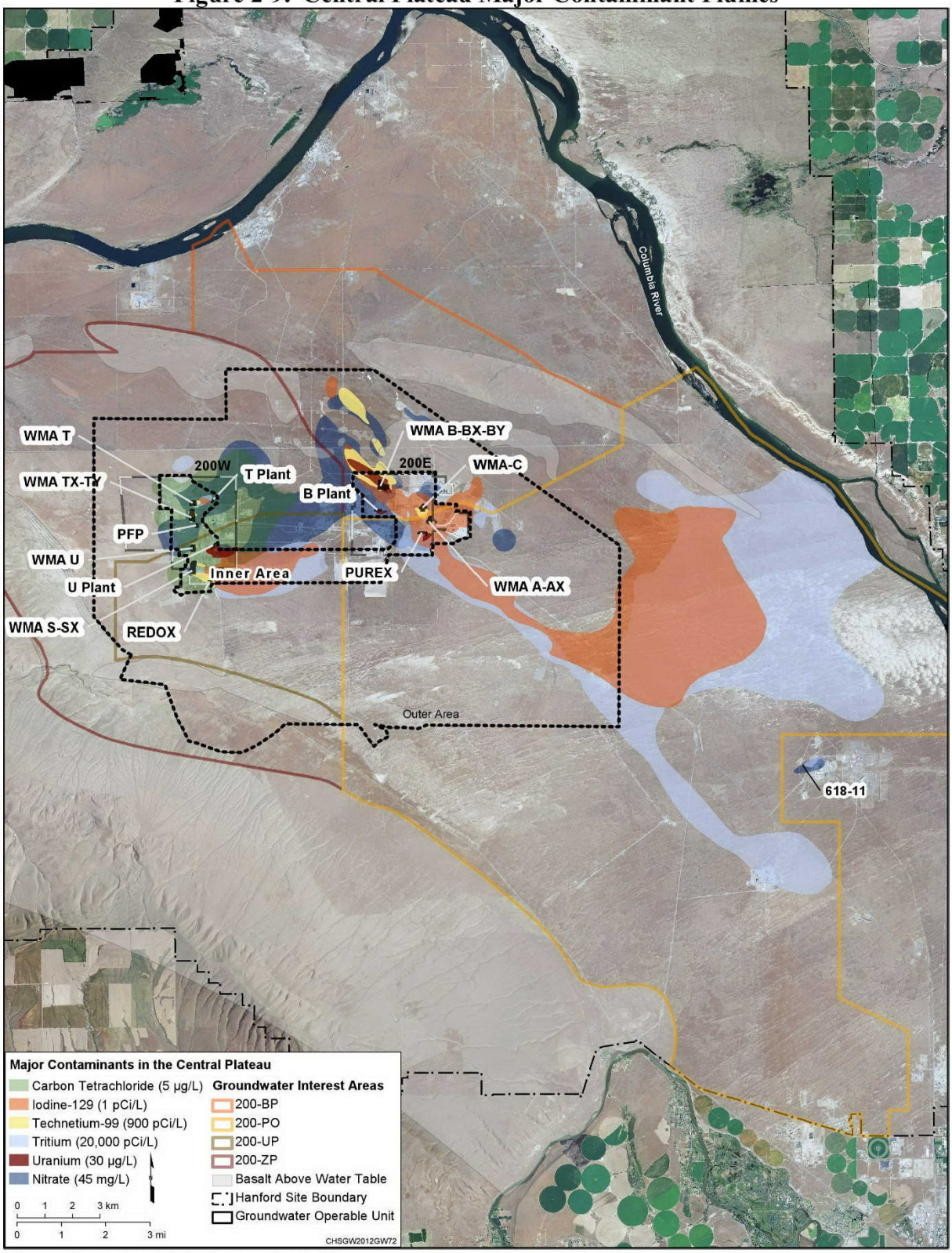
Groundwater contamination plumes beneath the Central Plateau formed when the waste discharged to ponds and cribs reached the aquifer and the contaminants formed regional plumes. These contaminants include tritium, nitrate, and ^{129}I. The tritium and nitrate plumes have shrunk over the years as a result of dispersion and radioactive decay. A large carbon tetrachloride plume originated in the 200 West Area. This plume is expanding at the edges, but the high-concentration core is contained by a pump-and-treat system located near the source in the 200 West Area. Other groundwater contaminants in the Central Plateau include ^{99}Tc, uranium, ^{90}Sr, trichloroethene, and cyanide (Figure 2-9). For the Central Plateau the investigation and remediation of the groundwater contamination under CERCLA is divided into four OUs, as shown in Figure 2-3. WMA C is located above the 200-BP-5 OU.

2.3.7 Vegetation and Wildlife

This section summarizes the regional ecology of the Hanford Site. This region consists primarily of abandoned agricultural or undeveloped land. Chemical processing facilities, shutdown nuclear reactors, and supporting facilities at the Hanford Site occupy a minor portion of the region with the Hanford Site not undergoing tillage or agricultural grazing since the early 1940s. The undisturbed portions of the region are characterized as a shrub-steppe ecosystem that is adapted to the mid-latitude semiarid climate of the region. These ecosystems are typically dominated by a shrub overstory with a grass understory. In the early 1800s, dominant plants in the area were big sagebrush (*Artemisia tridentata*) and an understory consisting of perennial Sandberg's bluegrass (*Poa sandbergii*) and bluebunch wheatgrass (*Pseudoregneria spicata*). Other species included threetip sagebrush, bitterbrush, gray rabbitbrush, spiny hopsage, bluebunch wheatgrass, needle-and-thread grass, Indian rice grass, and prairie June grass.

In the region, wheat, wine grape- and tree fruit-based agriculture are the dominant crops with minor livestock ranching also occurring.

Figure 2-9. Central Plateau Major Contaminant Plumes



Source: DOE/RL-2013-22, *Hanford Site Groundwater Monitoring Report for 2012*, Map CP.2.

PUREX = Plutonium Uranium Extraction (Plant) WMA = Waste Management Area
REDOX = Reduction-Oxidation (Plant)

The dominant non-native species, cheatgrass, is an aggressive colonizer and has become well established across the region. Over the past decade, several knapweed species also have become persistent invasive species in areas not dominated by shrubs. Range fires that historically burned through the area during the dry summers eliminated fire-intolerant species (e.g., big sagebrush) and allowed more opportunistic and fire-resistant species to establish. Of the 590 species of vascular plants recorded for the region, 20% are non-native. Wildfires are frequent in the region.

Hanford Site wildlife includes mammals, birds, reptiles, amphibians, fish, invertebrates, and insects. Site terrestrial wildlife communities are generally associated with specific vegetation communities. Approximately 300 species of terrestrial and aquatic vertebrates have been observed on the Hanford Site. To provide an indication of the diversity of biota on the Hanford Site, species lists have been compiled for the major classes of vertebrates that have been observed on the Hanford Site or within the Hanford Reach of the Columbia River. These lists are relatively complete for all groups with the exception of birds, which includes species that are most common, due to their mobility and migratory behavior. The species list of site inhabitants includes 46 species of mammals (Appendix B, Table B-2), 145 species of birds (Appendix B, Table B-3), 10 species of reptiles, 5 species of amphibians, and 45 species of fish (Appendix B, Table B-4) (Soll and Soper 1996, *Biodiversity Inventory and Analysis of the Hanford Site: 1995 Annual Report*; PNL-8935, *Plant Reestablishment After Soil Disturbance: Effects of Soil, Treatment and Time*; PNNL-6415, Rev. 18). PNNL-6415 provides a more complete description of the plant, insect, and animal life across the Hanford Site and surrounding region.

2.3.8 Land Use

Currently, land use within the Hanford Site vicinity includes wildlife protection areas and areas used for urban and industrial development, recreation, military training, irrigated and dryland farming, and grazing. At the time of the 2007 Census of Agriculture, Benton, Franklin, and Grant Counties had a total of 942,780 hectares (2.33 million acres) of land in farms. Of that farmland, 71 to 77% was used as cropland, 11 to 22% was pastureland, and 6 to 14% had other uses (AC-07-A-51, *2007 Census of Agricultural, United States Summary and State Data, Volume 1, Geographic Area Series, Part 51*). In 2006, land committed for the Conservation Reserve Program of the U.S. Department of Agriculture included 49,067 hectares (121,246 acres) in Benton County, 47,819 hectares (118,163 acres) in Franklin County, and 34,756 hectares (85,882 acres) in Grant County (USDA 2006, *The Conservation Reserve Program: 33rd Signup, County by County Summary*). Residential, commercial, and industrial land uses are predominant in the Tri-Cities area (Richland, Kennewick, and Pasco) southeast of the Hanford Site and around other cities near the southern boundary of the Hanford Site, including Benton City, Prosser, and West Richland (U.S. Department of Agriculture Census of Agriculture, 1997, Queried 06/18/2014, 1997 Census of Agriculture, Highlights of Agriculture: 1997 and 1992 Washington)[2].

[2] http://www.agcensus.usda.gov/Publications/1997/Census_Highlights/Washington/wast.txt

2.4 WMA C SITE ENVIRONMENTAL SETTING

This section provides an overview of the environmental setting specific to WMA C. Sections 2.4.2 through 2.4.8 describe the site-specific physical environmental setting, including topography, geology, hydrology (including relationships to groundwater and surface water), vegetation, wildlife, and land use.

2.4.1 Topography

Figure 2-10 provides a topographic map of WMA C along with two topographic profiles for Tanks 241-C-101 to 241-C-103 and 241-C-110 to 241-C-112[3]. The ground surface elevation above the tanks varies from 198 to 197 m (649 to 646 ft) above MSL. These profiles show a stair-step elevation drop trending from the higher elevations in the southwest to lower elevations in the northeast. The WMAs were intentionally constructed downhill from the waste generating facilities to allow gravity flow in the pipelines from the facilities to the tanks.

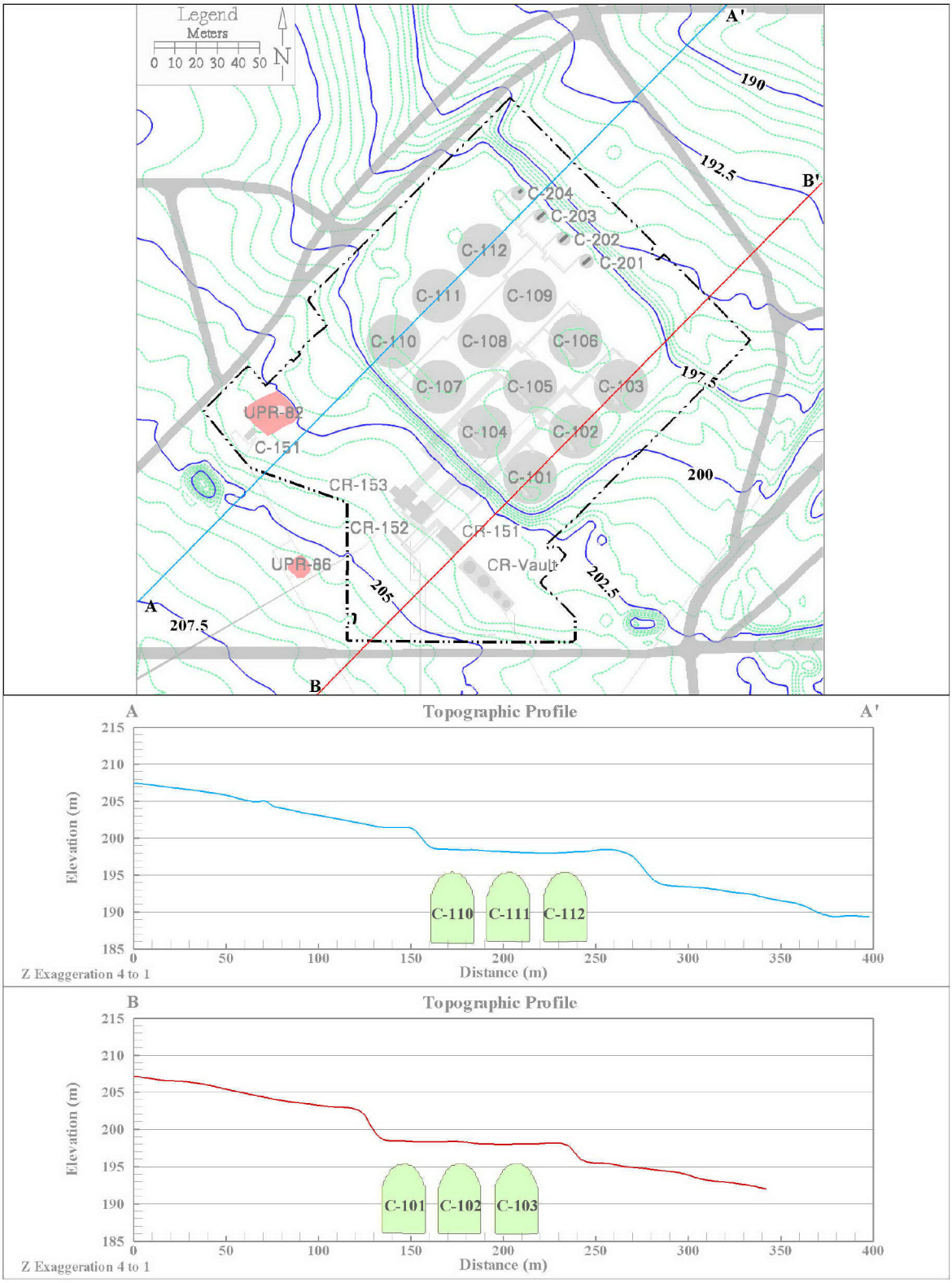
2.4.2 Geology

Since construction started on the Hanford Site in the early 1940s, a large volume of data on the geology and hydrogeology of the Hanford Site has been collected and evaluated. As part of the IPA process, a geologic data package (RPP-23748, *Geology, Hydrogeology, Geochemistry, and Mineralogy Data Package for the Single-Shell Tank Waste Management Areas at the Hanford Site*) was prepared that describes the geology, hydrogeology, and geochemistry of the region, the Hanford Site, and WMAs.

The geology of the major stratigraphic units underlying C Farm and vicinity is well understood as a result of several decades of site characterization activities. It has been described in numerous reports (HW-61780, *Subsurface Geology of the Hanford Separation Areas*; ARH-LD-132, *Geology of the 241-C Tank Farm*; RPP-14430; RPP-35484; and others). The main source of information about the geologic strata underlying the Hanford Site and the tank farms is data from the drilling of boreholes and monitoring wells and the analyses of the sediments and contaminants within them (e.g., PNNL-14656, *Borehole Data Package for Four CY 2003 RCRA Wells 299-E27-4, 299-E27-21, 299-E27-22, and 299-E27-23 at Single-Shell Tank, Waste Management Area C, Hanford Site, Washington*). More detailed discussion of the borehole-specific geologic and geochemical characteristics of the WMA C vadose zone are provided in RPP-23748 and PNNL-15955.

[3] Single-shell tank nomenclature will be abbreviated from this point on throughout the document. For example, "Tank 241-C-101" will be referred to hereafter as "Tank C-101".

Figure 2-10. Topography and Cross-Section of Topography through WMA C



The C Farm is underlain by sedimentary units in both the vadose and saturated zone with the igneous CRBG forming the base of the unconfined aquifer. The vadose zone sediments form the media through which contaminants migrate downward and laterally and provide the basis for interpretation and extrapolation of the physical and geochemical properties that control the migration and distribution of contaminants. Of particular importance are the interrelationships between the coarser- and finer-grained facies, and the degree of contrast in their physical and geochemical properties. While the exact configuration of these units is not well defined at C Farm, their contrast appears to have a strong influence on the migration of leak and meteoric waters and dissolved tank waste constituents in those fluids.

Backfill material, the Hanford formation, and the undifferentiated H3/Cold Creek unit/Ringold Formation make up the vadose zone at C Farm. The unconfined aquifer is generally contained within the undifferentiated H3/Cold Creek unit/Ringold Formation. All major stratigraphic units are inferred to be essentially continuous in this area, although unit thicknesses vary, and some subunits are not continuous. Overall, the vadose zone is approximately 76 m (250 ft) thick at WMA C. Figure 2-11 shows a fence diagram of the units underlying WMA C. Figure 2-12 is a WMA C cross section showing the undifferentiated H3/Cold Creek unit/Ringold Formation unit directly above the CRBG. The general characteristics of the Hanford formation and the undifferentiated H3/Cold Creek unit/Ringold Formation at WMA C are as follows.

2.4.2.1 Backfill Material. Backfill materials consisting of poorly sorted cobbles, pebbles, and coarse to medium sand derived from the H1 subunit of the Hanford formation are distributed around the tanks and tank infrastructure. The backfill was placed at the time of C Farm construction and was graded to support operational needs.

2.4.2.2 Hanford Formation. The Hanford formation is a cataclysmic flood deposit that is between 43 and 73 m (140 and 240 ft) thick and thickens slightly toward the south and west. Generally speaking, it consists of three subunits (H1, H2, and H3) that are distinguished by a change in the dominant particle-size distribution. The upper unit, H1, deposited in a high-energy environment, is loose, sandy gravel to gravelly sand and composed of poorly sorted basaltic, sandy gravels to silty sandy gravels. It is between 9 and 31 m (30 and 100 ft) thick in the area, thinning concentrically toward the middle of A Farm and generally thinning toward the north (e.g., at C Farm) (RPP-14430 and RPP-35484).

Figure 2-11. Fence Diagram for WMA C and Vicinity

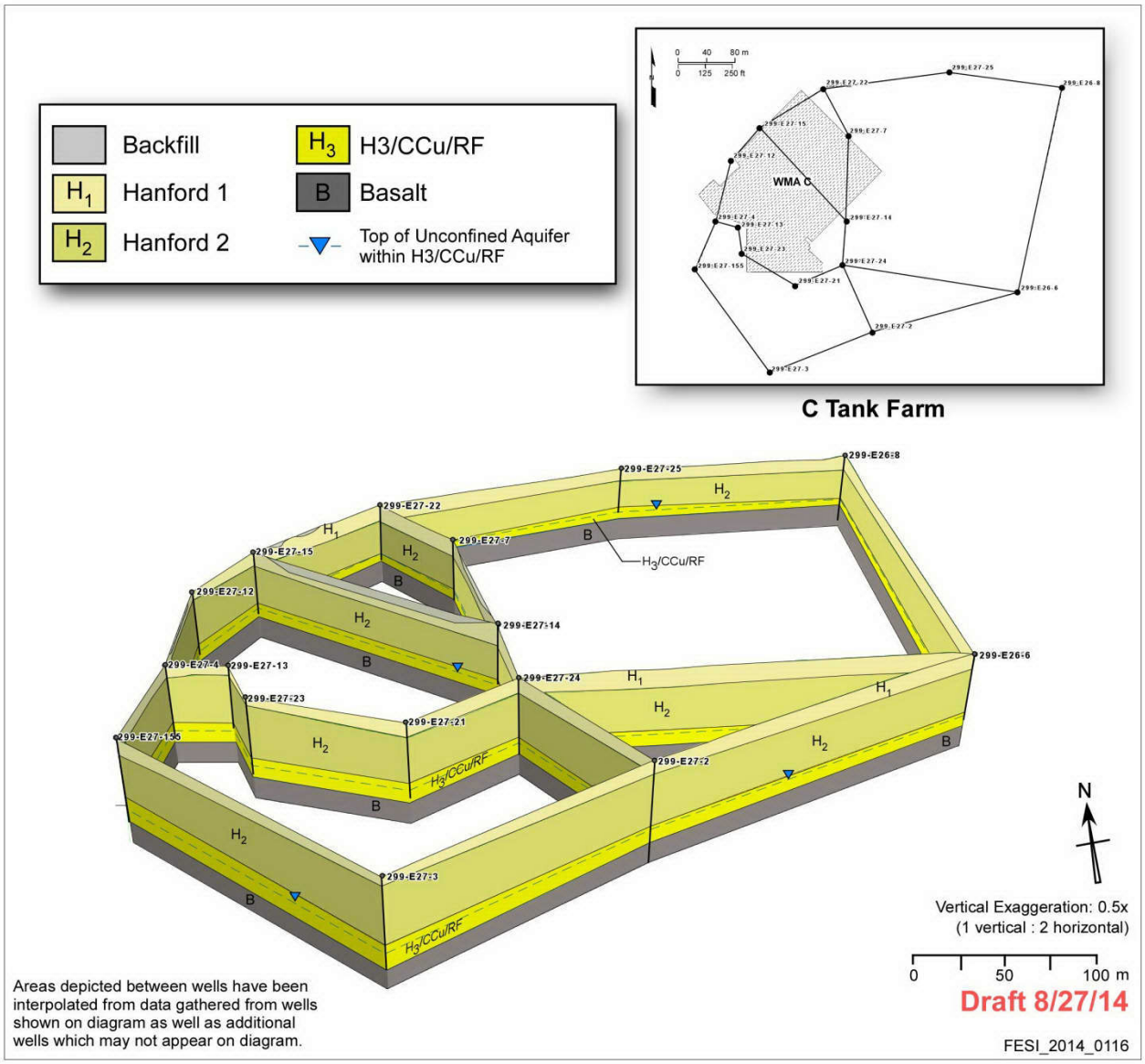
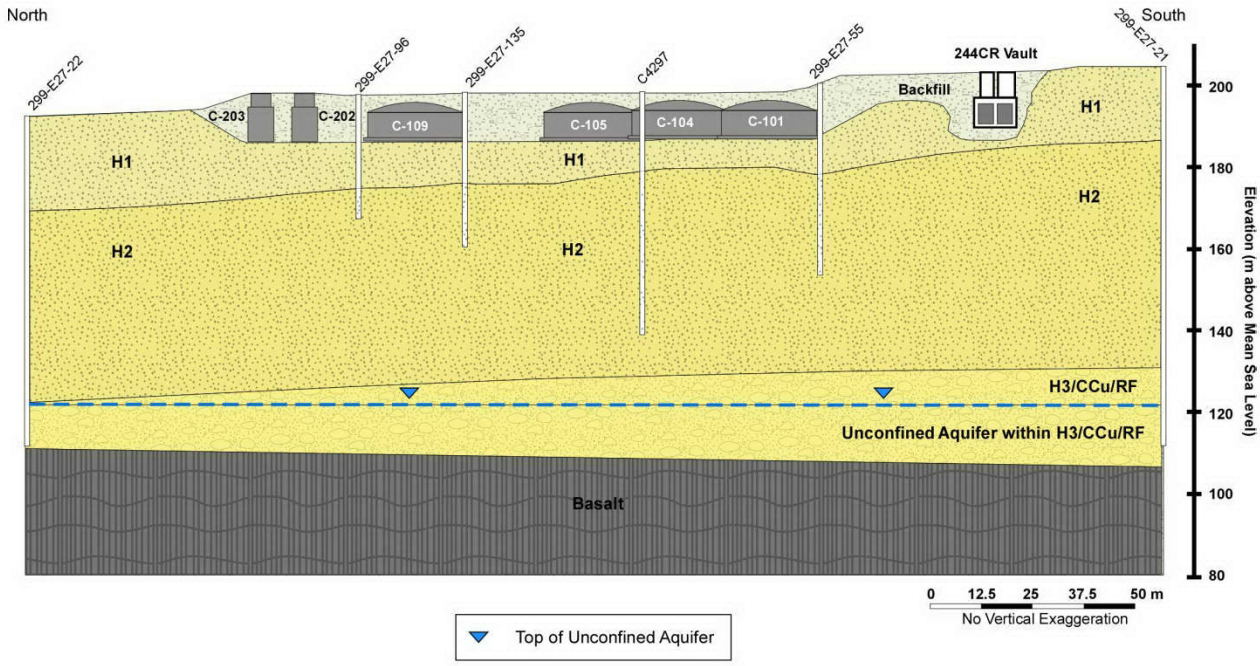
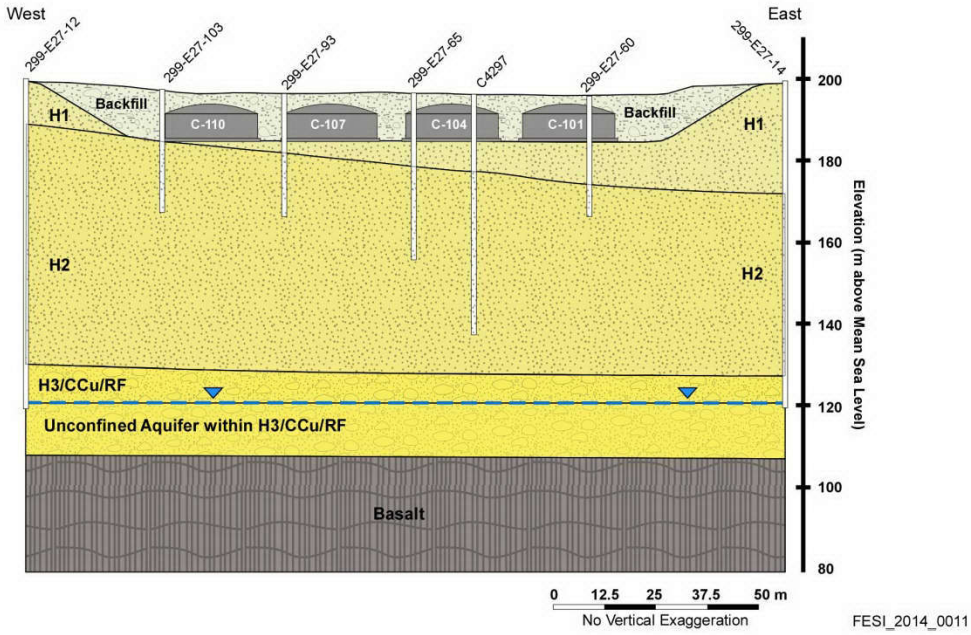


Figure 2-12. Cross-Sections through WMA C





The H2 unit, deposited in a lower-energy environment, is predominantly a sand-dominated sequence composed of mostly horizontal to tabular cross-bedded sands to gravelly sands. Thin silt lenses are occasionally present that occur on a scale too small to correlate between boreholes. The H2 unit is between 29 and 61 m (95 and 200 ft) thick in the area and generally thickens to the west with localized minimums on the west side of A Farm and the east side of AX Farm. An alternate interpretation of the stratigraphy is offered by the Nez Perce Tribe. This alternate interpretation of the stratigraphy has the H2 unit in the vicinity of WMA C divided into three units: a sand, a coarse gravely sand, and a sandy silt unit. Both the DOE and the Nez Perce Tribe interpretations are carried forward in the numerical modeling, which is discussed in Section 6 of this RFI report.

RPP-18290, *241-C Tank Farm Geologic and Stratigraphic Analysis* and PNNL-14656 identified a third unit (H3) of the Hanford formation, which is usually reserved for a clast-supported, gravel-dominated facies at the base of the Hanford formation (DOE/RL-2002-39). However, at C Farm, the overall texture of this unit is still predominantly sand, with only a minor component of pebbly to slightly pebbly sand. The H3 unit of RPP-18290 and PNNL-14656 does not contain appreciably more gravel than the H2 unit. Otherwise, thicknesses increase toward the east up to a maximum of approximately 15 m (50 ft) on the east side of AX Farm. At C Farm, the H3 unit may be present as part of the undifferentiated H3/Cold Creek Unit/Ringold Formation, discussed below.

2.4.2.3 Undifferentiated Hanford Formation/Cold Creek unit/Ringold Formation.

WMA C lies along the edge of a paleochannel that eroded much or all of the Ringold Formation during the time of the Cold Creek unit and/or Hanford formation. Because of the difficulty in distinguishing reworked Ringold Formation gravels and pre-Missoula Columbia River gravels from original Ringold Formation gravels, these undifferentiated units are identified as the H3/Cold Creek unit/Ringold Formation (RPP-PLAN-39114). This unit includes the H3 subunit of the Hanford formation, the Cold Creek unit, and the Ringold Formation's Wooded Island member.

Gravelly facies immediately overlying basalt within most of the study area belong to the H3/Cold Creek unit/Ringold Formation. These undifferentiated sediments consist of predominantly sandy pebble- to cobble-sized gravel with occasional boulders. Mineralogically, the sand fraction consists of 15 to 60% basalt grains with generally less than 1 wt% calcium carbonate. The total thickness of this unit is less than 27 m (90 ft), based on a limited number of boreholes where the upper and lower boundaries are represented. The top of H3/Cold Creek unit/Ringold Formation ranges from approximately 120 to 130 m (390 to 425 ft) above MSL. At WMA C, the water table occurs within the H3/Cold Creek unit/Ringold Formation.

East of the 200 East Area near the 216-B-3 Pond and the Treated Effluent Disposal Facility, low-permeability Ringold Formation muds occur above the water table and form a barrier to groundwater flow in the unconfined aquifer (DOE/RL-2013-22). This leads to the possibility of perched water layers located above the water table. No evidence of this perching layer has been identified in the vicinity of WMA C.

2.4.3 Surface Water

No natural surface water is present at WMA C. The closest distance to the Columbia River from WMA C is 10.5 km (6.5 mi) to the northeast. No flood plains exist in or between the 200 Areas. Floods of the intermittent Cold Creek surface stream (4.8 km [3 mi] south of WMA C) have occurred historically; however, there have been no observed flood events. Based on a probable maximum flood evaluation, no impact would occur at WMA C as a result of flooding by Cold Creek or the Columbia River (PNNL-6415).

Run-on control measures were constructed in WMA C in 2002, as part of the Phase 1 Interim Measures required for HFFACO Milestone M-045-56. Berms were placed to redirect surface water away from the tank farm surfaces, and curbs and gutters were placed along the roadways to redirect runoff. These controls were constructed outside the tank farm to prevent surface water from pressurized waterline leaks outside of the tank farm boundary and unusual meteorological events from flowing onto the tank farm areas. These run-on controls serve to prevent the accumulation of standing surface water within WMA C.

2.4.4 Vadose Zone Recharge

Moisture movement through the vadose zone is important because it is the driving force for migration of most contaminants to the groundwater. Radioactive and hazardous wastes in the soil column from liquid-waste disposals, unplanned leaks, solid waste burial, and underground tank storage are potential sources of continuing and future vadose zone and groundwater contamination. Contaminants may continue to move downward for long periods (tens to hundreds of years depending on recharge rates and the distribution coefficient (K_d) of the contaminant) after termination of liquid waste disposal.

WMA C was constructed with a gravelly sand surface layer that has been maintained free of vegetation with the use of herbicides. These conditions promote higher rates of infiltration of meteoric water that are expected to continue until the time of WMA closure. Interim measures to control infiltration have been implemented at the WMAs, and an evaluation of accelerated corrective measures is being conducted under a RCRA corrective action program. Tank farm surfaces are covered with gravelly sand to provide radiation shielding for site workers and sprayed with herbicides to prevent vegetation growth. However, bare gravel surfaces enhance the net infiltration of meteoric water immediately adjacent to the edge of a tank compared to undisturbed, naturally vegetated surfaces. Infiltration is further enhanced in the tank farms by the effect of percolating water being diverted by the impermeable, sloping surface of the tank domes. An umbrella effect is created by the buried tank domes. Water that is shed from the tank domes flows down the tank walls into the underlying sediments beneath the walls of the tanks. Sediments adjacent to the tanks, while remaining unsaturated, can attain elevated moisture levels relative to areas farther from the tanks (WHC-SA-2680-FP, *Effect of Moisture-Dependent Anisotropy and Enhanced Recharge Around Underground Storage Tanks*). Other sources of recharge included unintentional surface spills, infiltration of surface runoff, leaking waterlines, and leaks from ancillary tank-related equipment. Enhanced recharge from such sources is discussed in Section 2.4.5.

Natural recharge can vary greatly, depending on factors such as climate, vegetation, surface condition, and soil texture. Studies conducted at the Hanford Site suggest that recharge rates can range from less than 0.1 mm/yr on a variety of soil and vegetative combinations to greater than 130 mm/yr on bare basalt outcrops or bare, gravel-covered waste sites (Gee et al. 1992). Data from experimental sites such as the Field Lysimeter Test Facility and the prototype Hanford barrier (crib B-57) suggest that recharge through gravels can range from 15 to 70% of precipitation, with the lower amount occurring under vegetated conditions (PNNL-11367, *Hanford Prototype-Barrier Status Report: FY 1996*; PNL-10285, *Estimated Recharge Rates at the Hanford Site*; Fayer et al. 1996, "Estimating Recharge Rates for a Groundwater Model Using a GIS"). With a long-term annual average precipitation of 160 mm, the higher percentage translates into a recharge rate of ~100 mm/yr and was observed on sandy gravels that were kept free of vegetation (PNNL-16688, *Recharge Data Package for Hanford Single-Shell Tank Waste Management Areas*). Drainage is ~70 mm/yr from bare sand and ~100 mm/yr from sandy gravel under Hanford Site climatic conditions. There has been no direct measurement of recharge on tank farm gravels, which are known to contain a larger amount of fines compared to clean gravels. Thus, it is likely that the tank farms experience a recharge rate that ranges between that observed for bare sand and the rate for clean gravels (i.e., 70 to 100 mm/yr).

Recharge estimates based on environmental tracer techniques (Open File Report 94-514, *Using Chloride and Chlorine-36 as Soil-Water Tracers to Estimate Deep Percolation at Selected Locations on the US Department of Energy Hanford Site, Washington*; Murphy et al. 1996, "Geochemical Estimates of Paleorecharge in the Pasco Basin: Evaluation of the Chloride Mass Balance Technique") are generally consistent with those based on lysimeter studies. However, the tracer techniques are not applicable to disturbed sites such as the tank farms.

Perched water has been encountered locally in portions of the Central Plateau. In the 200 East Area, perched water has been encountered at the top of the fine-grained facies of the Cold Creek unit at WMA B-BX-BY. East of the 200 East Area, at the B Pond system, perched water was encountered on top of the Ringold Formation lower mud where the Ringold Formation has been removed by erosion above the lower mud so that the Hanford formation directly overlies the lower mud (RPP-RPT-46088). Due to the erosion of substantial portions of the Cold Creek unit and the Ringold Formation lower mud unit in the vicinity of WMA C such that the undifferentiated H3/Cold Creek unit/Ringold Formation directly overlies the basalt, the confining layer seen near WMA B-BX-BY is not encountered. The unconfined aquifer consists of open-framework gravels and is highly transmissive. The geologic model constructed for the WMA C IPA required for closure of the tanks concluded no evidence of perched water has been encountered under WMA C. While minor amounts of fine sand and silt were encountered, no thick, competent layer of silt was encountered. Elevated moisture levels, which would likely be associated with perched water, were not observed (RPP-RPT-56356, *Development of Alternative Digital Geologic Models of Waste Management Area C*).

2.4.5 Enhanced Recharge and Preferential Pathways

The rate of infiltration and the extent of migration of mobile contaminants through the WMA C vadose zone have almost certainly been affected over the years by sources of enhanced recharge to the soil column and by the presence of preferential pathways through the vadose zone.

This section discusses possible sources of contaminated and non-contaminated liquids to the surface and the shallow subsurface of WMA C that may have affected recharge and contaminant infiltration rates. Such liquids may come from natural sources (e.g., stormwater run-on/run-off, sudden snow melt) and from site operations (e.g., leaking pipes and water lines). This section also discusses preferential flow pathways that could influence the migration of mobile contaminants through the vadose zone. Preferential pathways also may be natural (e.g., clastic dikes) or a result of operations (e.g., groundwater wells and drywells).

Two key studies documented potential causes of enhanced recharge and development of preferential pathways in the Hanford Site SST Farms, including C Farm.

- In 1998, DOE issued GJO-98-39-TAR/GJO-HAN-18, *Vadose Zone Characterization Project at the Hanford Tank Farms: C Tank Farm Report*. This report documented the results of the baseline characterization of gamma-emitting radioactive contamination in the C Farm vadose zone. (An addendum, GJO-98-39-TARA/GJO-HAN-18, *Vadose Zone Characterization Project at the Hanford Tank Farms, Addendum to the C Tank Farm Report*, was issued in 2000.) The characterization work focused on gathering spectral gamma logging data from drywells surrounding the C Farm SSTs. Twelve tank summary reports were prepared to document the results of drywell investigations in the vicinity of each of the C Farm 100-series tanks. These tank summary reports include recommendations for replacing or sealing/plugging and abandoning a number of C Farm drywells.

- In 2001, CH2M Hill Hanford Group issued RPP-5002, *Engineering Report Single-Shell Tank Farms Interim Measures to Limit Infiltration Through the Vadose Zone*. This document identifies, evaluates, and recommends interim measures for reducing or eliminating water sources and preferential pathways within the vadose zone of the SST farms. Features studied included surface water infiltration and leaking, pressurized water lines that could provide recharge moisture, and wells that could provide pathways for contaminant migration. The document provides recommendations for construction of engineered run-on controls; cutting, capping, and abandoning water lines; and sealing potential preferential pathways associated with groundwater wells and drywells in accordance with WAC 173-160, "Minimum Standards for Construction and Maintenance of Wells."

From a vadose zone contaminant migration perspective, GJO-98-39-TAR/GJO-HAN-18 and RPP-5002 focus on the potential effects of run-on, leaking/failed pressurized water lines, and wells. This section of the RFI report expands upon information contained in these two reports to describe possible causes of enhanced recharge and preferential pathways in C Farm.

2.4.5.1 Meteorological Events. Rapid snowmelt events and rainfall from unusually large storms can contribute to increased infiltration due to surface ponding. Transient saturation from collection of runoff in low spots may be more significant than average annual infiltration. Rapid snowmelt events have taken place at least six times over the history of operations at the U Farm. The first recorded event took place in 1979, followed by one in 1985, two in 1993, and one each in 1995 and 1996 (PNNL-15160, *Hanford Site Climatological Data Summary 2004 with*

Historical Data). Such an event was documented at the T Farm in February 1979 when a large snow melt event created a temporary pond over the farm (Figure 2-13), allowing rapid infiltration into the subsurface. At that time, the drywells were not grouted to 27 m (90 ft) and could have provided preferential pathways for vertical migration to that depth (RPP-23752, *Field Investigation Report for Waste Management Areas T and TX-TY*). While there is no affirmative evidence of similarly significant flooding having happened in C Farm, the photo of T Farm is an indicator of the degree of flooding that was possible (Figure 2-13).

RPP-5002 recommended that run-on controls be established to prevent surface water from entering the SST farms from outside sources to reduce infiltration within each SST farm. Run-on controls, berms, and gutters, and diversions were installed around WMA C in calendar year 2002. These controls were emplaced to prevent or lessen the occurrence of this form of enhanced recharge.

2.4.5.2 Water Lines. Run-on controls constructed at C Farm also address potential increased infiltration resulting from leaking and/or failed water lines. Two types of water lines run across or are in the immediate vicinity of WMA C, potable water and raw water. The locations of these lines are shown in Figures 2-14 and 2-15, which are taken from site drawings H-2-830460, *Site Map Potable Water System 200 East Enlarged Plan*, Sheet 10, Rev. 9 and H-2-834062, *Site Map Raw Water System 200 East Enlarged Plan*, Sheet 10, Rev. 5. All water lines within WMA C have been cut and capped or pressure tested (RPP-35484), to minimize the potential for future water line releases.

A 1984 Basalt Waste Isolation Project water balance study (Internal letter 65633-128, "Status of the BWIP Water Balance Study") showed that between 1977 and 1984, between 15% and 41% (24% average) of the ~8 billion L (2 billion gal) of water discharged to the 200 East Area general raw water lines was unaccounted for, suggesting either error in process measurements or significant losses from the water lines. While raw water losses do not increase the inventory of waste lost to the soil, they can provide a substantial driving force to move mobile contaminants toward the water table. Two documented raw water line failures and losses were identified at WMA C and are listed in Table 2-1. There could have been additional releases in or near C Farm that were not documented or for which information is not available.

Water losses of several gallons per minute for several years above a vadose zone contaminated by tank waste could result in effective infiltration rates well above average natural recharge rates from precipitation (assumed to be 100 mm [4 in.] per year). For example, if a pipe joint leak occurs at the rate of 0.5 gpm, the yearly volume output is 1 million L (262,800 gal). If this fluid volume migrates through an effective area of 100 m^2, the equivalent annual volume discharge from ambient recharge of 100 mm/yr would be 10,000 L (2,642 gal). Thus, the leak recharge rate is effectively 100 times the ambient recharge rate. This differential can quickly increase with higher leak rates and/or distribution over smaller flux planes (RPP-RPT-38152).

Figure 2-13. Standing Water in T Farm Following Snow Melt Event, February 1979

Figure 2-14. Location of Potable Water Lines in and near WMA C

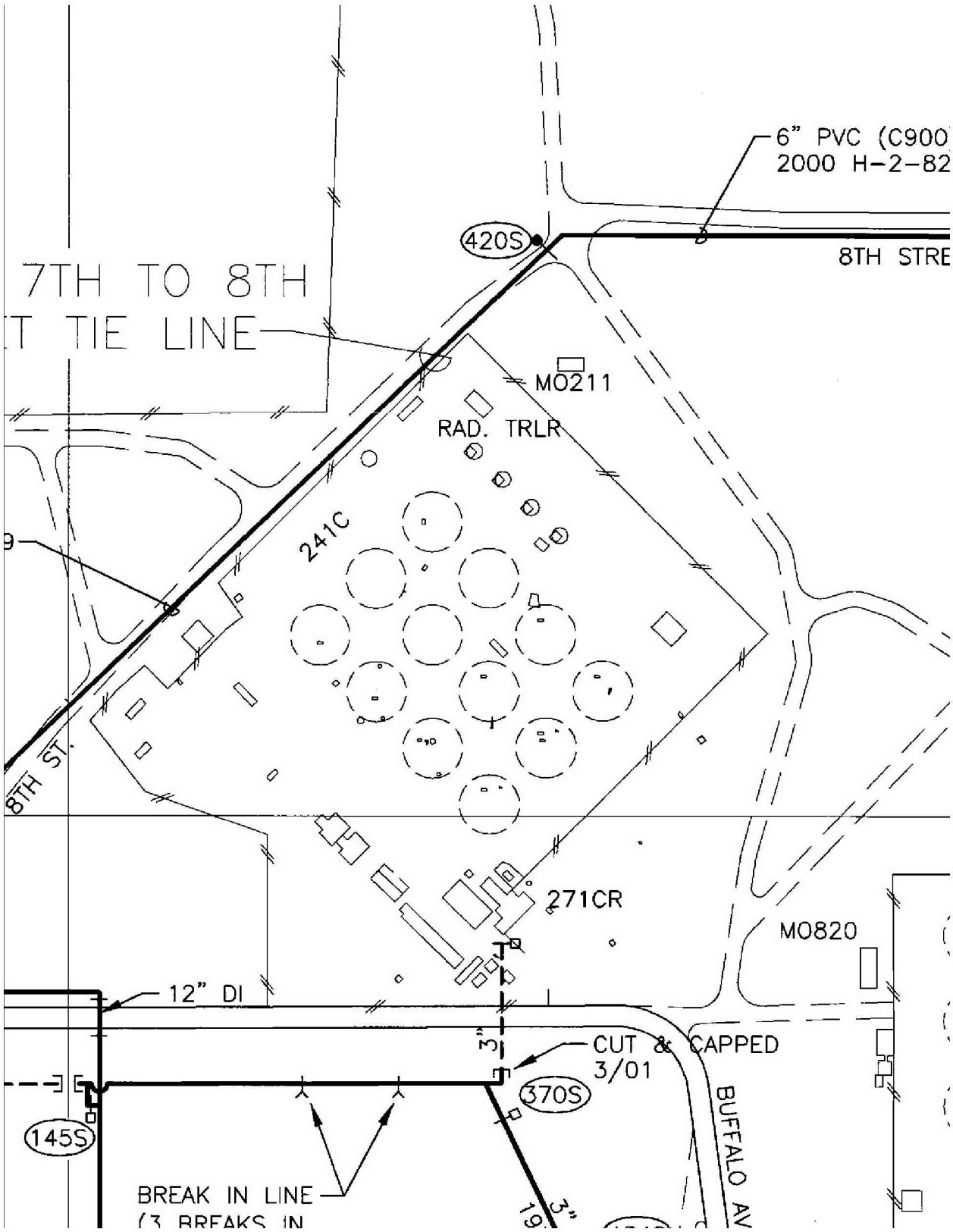


Figure 2-15. Location of Raw Water Lines in and near WMA C

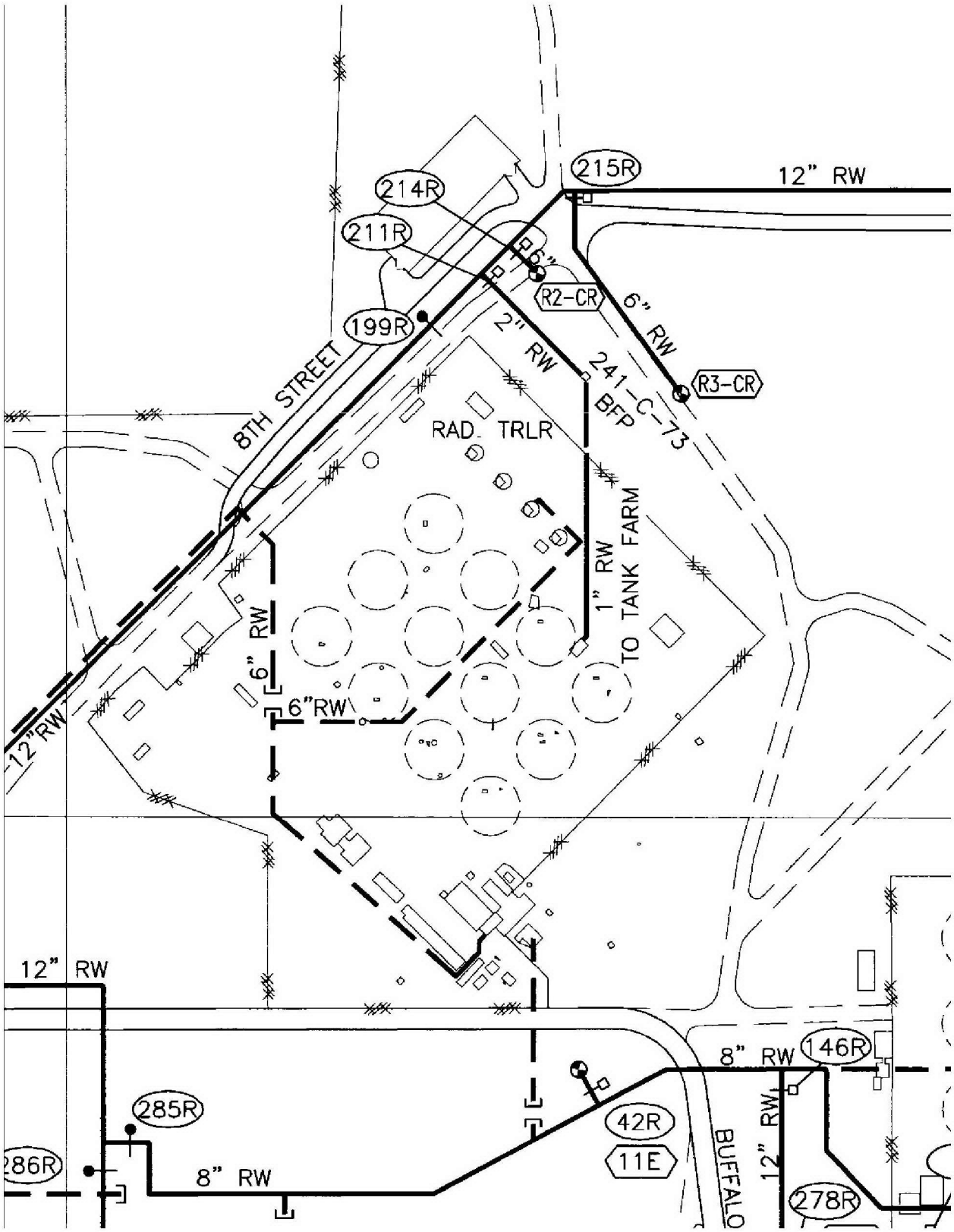


Table 2-1. Documented Water Line Releases in WMA C

Date	Source	Amount discharged	Event Description	References
7-1979	Raw water valve leak	5,000 gal raw water	At 6:00 PM on July 22, 1979 water was discovered coming from the ground at the southwest corner of C Farm. The water ran downhill to the tank area. A 75-in. by 200-in. puddle was formed at the west side of Tanks C-111 and C-112. The puddle partially covered the tanks. The cause of the occurrence was failure of a "stop and waste" valve in the 4-in. raw water line supplying water to C Farm.	Occurrence Report 79-73, *Release of Raw Water in 241C Tank Farm*
5-1993	Raw water line to Tank C-110	250 gal raw water	On 5/10/93 maintenance was being performed in Tank 110-C instrument cabinet. This work required raw water to supply system pressure to test a broken water line which had been repaired. Water was supplied from the 244-CR vault through a water service pit at Tank 107-C, to a quick disconnect located at the Tank 110-C instrument cabinet. No actual use of raw water was intended, as the line being repaired was simply to be pressure tested. However, an investigation found that the raw water line leaked 250 gal to the ground in C Farm.	RL--WHC-TANKFARM-1993-0047, *Leakage from a Raw Water Line Used for Maintenance Results in an Approximate 250 Gallon Water Release to 241-C Tank Farm*

A steam line runs east-west, on the south side of WMA C. The steam line is inactive but has not been removed. Two steam traps are located in the vicinity of WMA C. These could have provided a minor source of water to the subsurface in the past.

2.4.5.3 Fire Hydrants. Flushing and testing of fire hydrants is a periodic maintenance requirement which can result in the release of a large volume of water. There are two fire hydrants located in the vicinity of WMA C, designated as R2-CR and R3-CR, to the north and northeast of WMA C as shown on Figure 2-15. Both are located outside of the tank farm fenceline and would not directly flood the tank farm itself. However, infiltration of the large volumes of water from flushing and testing of the hydrants could impact other potentially contaminated soils in the vicinity.

2.4.5.4 Cribs/Ponds/Ditches/Trenches. Large volume, long duration intentional discharges of raw water or process wastewater occurred to cribs, ponds, and ditches close to the separations plants. WMA C is located between B Plant, which discharged large quantities of processed wastewater to various infiltration trenches, and the B Pond system. During early days of operation, C Farm was ~500 m (1,640 ft) west of the B Pond system, but over time, the centroid of the B Pond system migrated east and south away from C Farm as newer lobes of the pond were opened to enhance infiltration and evaporation (Figure 2-6). A few smaller liquid waste disposal facilities, such as 216-A-40, are located closer to WMA C.

2.4.5.5 Unplanned Releases and Waste Pipeline Leaks. Liquid wastes released during normal C Farm operations are known to have contaminated WMA C soils. Unplanned releases associated with off-normal events and leaks in the waste transfer pipeline system contributed additional contaminant mass and fluid volume to WMA C soils. These releases and leaks contributed fluids that artificially enhanced infiltration rates of already-present contamination into the subsurface and/or provided a driving force to move contamination farther and deeper into the vadose zone.

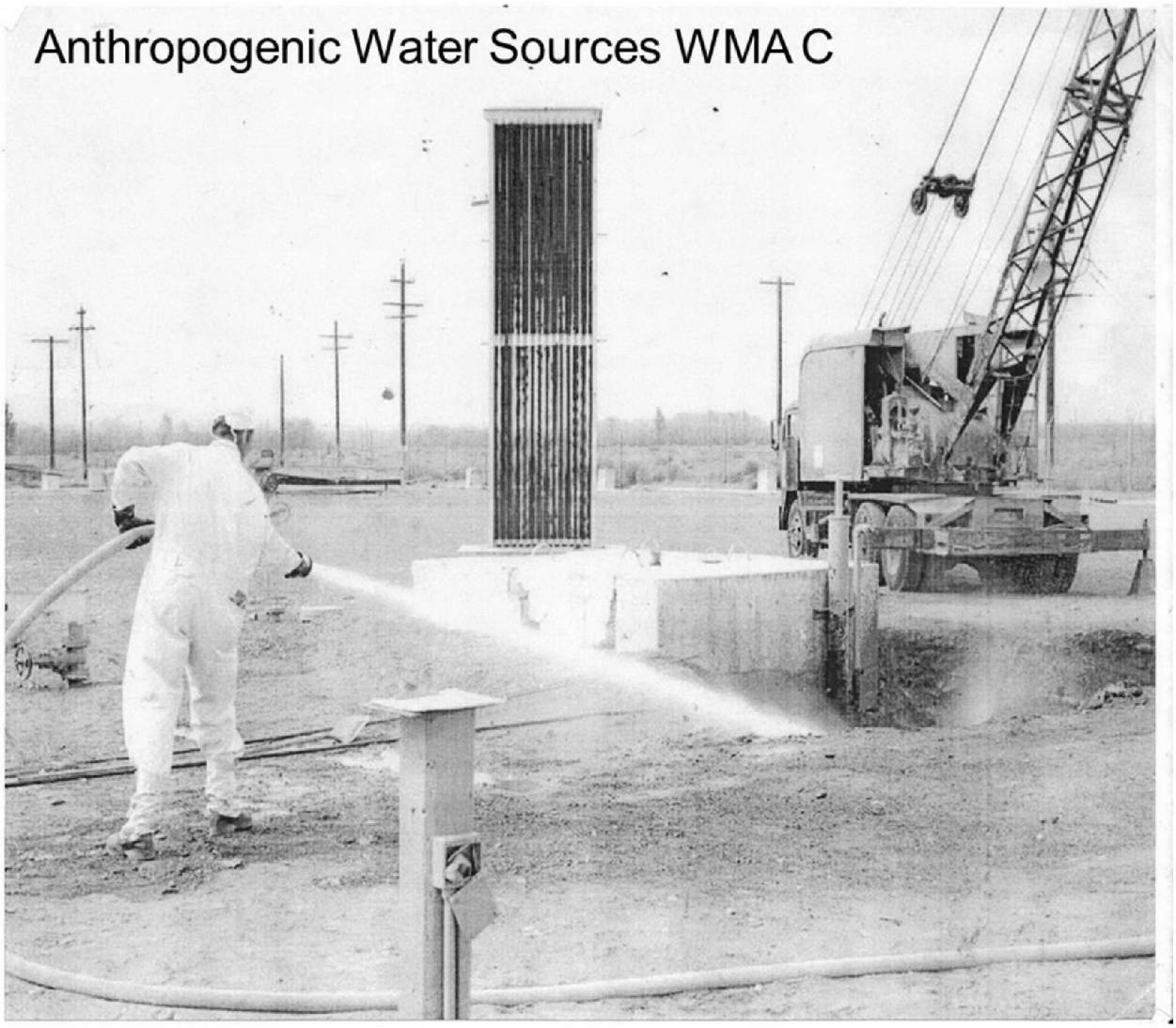
DOE/RL-88-30 is the official listing of known UPRs identified at the Hanford Site. The UPR information is included in the Waste Information Data System (WIDS) database. The UPRs associated with WMA C are discussed in Section 3.7 of this RFI report.

Additional events may have resulted in the release of wastes within WMA C that were not documented as UPRs. Potential sources of undocumented waste releases in WMA C include waste losses through spare inlet nozzles, cascade line waste releases, and other pipeline leaks. Such potential release sites were identified through review of the operational history for C Farm and are summarized in RPP-ENV-33418, *Hanford C-Farm Leak Assessment Report*.

2.4.5.6 Miscellaneous Structures. Septic tanks and French drains are types of intentional discharge facilities used to introduce fluids into the subsurface at the Hanford Site. At WMA C, three French drains and one septic system have been identified. Further information about these structures is provided in the summary of WMA C site components in Section 3.2 of this RFI report.

2.4.5.7 Decontamination Activities. A pit for steam cleaning heavy equipment was dug during 1954 northeast of Tank C-103 (241-CR Steam Cleaning Pit). The pit has been covered and is not identifiable above ground in any way other than being within the C Farm fence (HW-60807, *Unconfined Underground Radioactive Waste and Contamination in the 200 Areas–1959*). Thus, its exact location is unknown, and additional discharges of water from incidental field decontamination activities are possible, but not documented. Decontamination efforts within WMA C ranged from contaminant removal to wash down of the contaminants. In the past, at times an application of water at the surface was used within WMA C to shield, contain, and control the spread of contamination during maintenance and construction activities. The water was not collected during these actions but discharged to the soil and became part of the recharge. Figure 2-16 shows the application of water during such an activity within WMA C.

Figure 2-16. Water Spraying in WMA C



2.4.5.8 Drywells. Drywells are cased boreholes that do not extend to the water table and that provide access for geophysical probes into the subsurface to characterize the adjacent vadose zone. Many of these drywells have poor surface seals and/or are perforated at depth, providing a preferential pathway for the movement of contaminants into the lower vadose zone. Drywells located in WMA C (Figure 2-17) continue to be available for monitoring subsurface conditions with geophysical methods, and were logged as part of the Phase 2 RFI field activities. The results of the geophysical logging of these drywells are provided in Section 4.

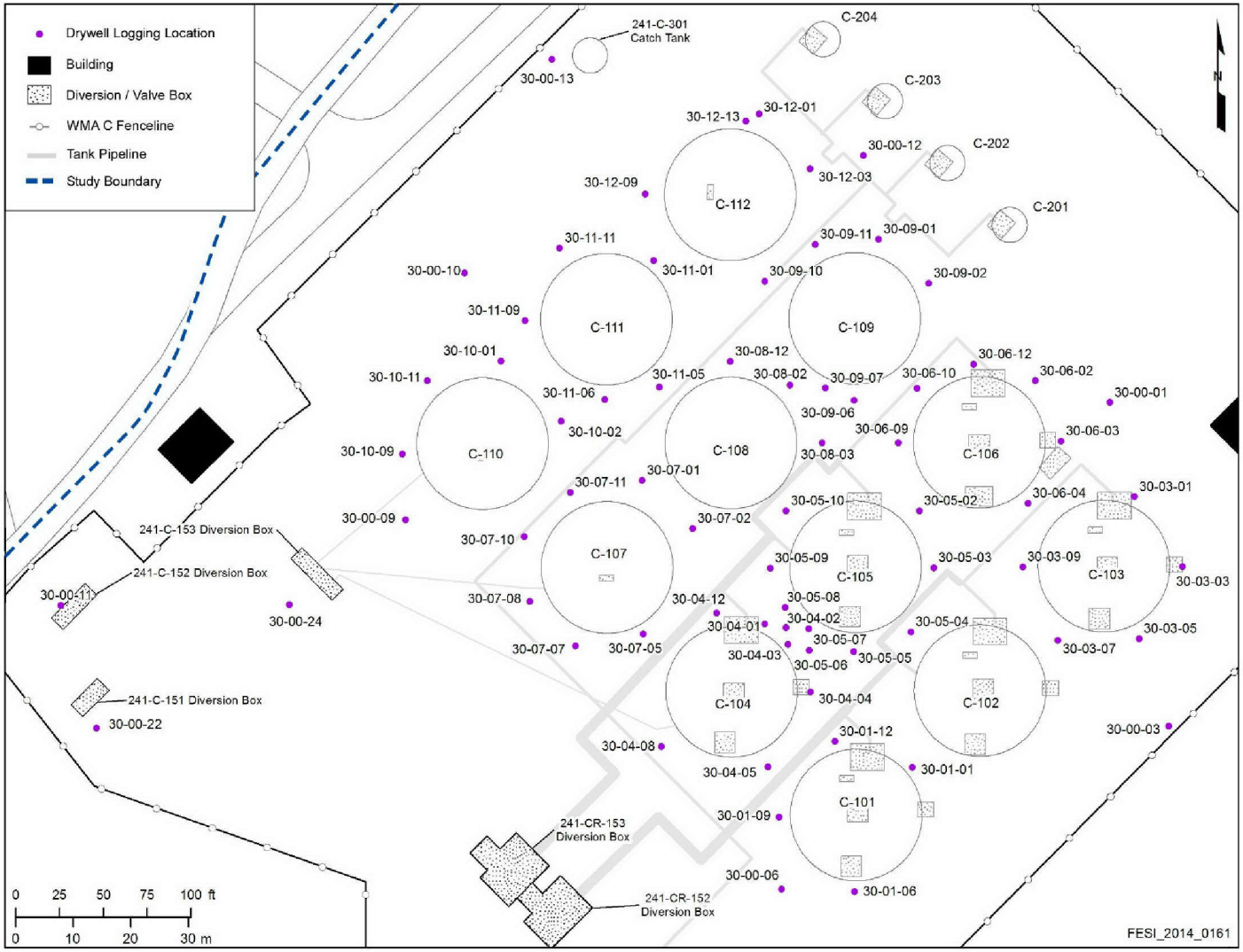
As noted in GJO-98-39-TAR/GJO-HAN-18 and RPP-5002, poorly constructed wells might allow groundwater and/or contaminants to move vertically downward between the casing and the surrounding media. Individual tank summary reports associated with GJO-98-39-TAR/GJO-HAN-18 (GJ-HAN-82, GJ-HAN-85, GJ-HAN-86, GJ-HAN-90, GJ-HAN-92, GJ-HAN-93, and GJ-HAN-94) recommended replacing and/or plugging/sealing and abandoning six WMA C drywells: 30-00-03, 30-00-06, 30-00-09, 30-00-10, 30-00-12, and 30-08-03.

A subsequent review of SST farm wells contained in RPP-5002 assigned a decommissioning priority to wells located in the SST farms based on the risk to groundwater, with Priority 1 being associated with the highest risk. RPP-5002 did not assign any Priority 1 wells to WMA C. However, seven drywells were identified as Priority 2 (lesser but still high risk to groundwater and of limited potential use for monitoring during SST waste retrieval activities due to distance from tank): 30-00-03, 30-00-10, 30-00-11, 30-00-12, 30-00-13, 30-00-22, and 30-00-24. None of these drywells has been abandoned to date.

The remaining WMA C drywells were listed as Priority 3, as they were considered close enough to the tanks to be used for vadose zone contamination monitoring during operations and waste retrieval activities. All of the WMA C drywells have perforated casing which may provide an avenue for accelerated migration downward into the vadose zone.

2.4.5.9 Clastic Dikes. Clastic dikes are vertical to subvertical sedimentary structures that cross-cut normal sedimentary layering and could locally affect the vertical and horizontal movement of water and contaminants. Clastic dikes are a common geologic feature of Pleistocene flood deposits of the Hanford formation, and have been described in detail in BHI-01103, *Clastic Injection Dikes of the Pasco Basin and Vicinity – Geologic Atlas Series*. Most do not penetrate through the Hanford formation but typically will turn horizontal as they bend. This horizontal bend has been interpreted as a key to the initial formation of the dikes. These dikes are interpreted as de-watering phenomena, and the bend from vertical to horizontal is the point where the original clastic dike formed (the horizontal bed) and then broke upward to the surface as the wet sediment de-watered (RPP-RPT-46088). The vertical extent of clastic dikes has been observed to range from 30 cm to more than 55 m (1 to 180 ft), while width ranges from 1 mm to greater than 2 m (0.04 in. to more than 6.6 ft).

Figure 2-17. Drywell Locations



Although clastic dikes have not been recorded in WMA C, they may exist. Numerous clastic dikes have been observed at the U.S. Ecology site southwest of the 200 East Area and elsewhere on the Hanford Site. In the vadose zone beneath WMA C, clastic dikes would not be expected to extend to or below the water table, in the H3/Cold Creek unit/Ringold Formation undifferentiated unit, which is much coarser than the sands and silts of the H1 and H2 units above. Previous modeling indicated that the presence of clastic dikes in unsaturated media may have little impact on migration of waste released to the soils (RPP-7884, *Field Investigation Report for Waste Management Area S-SX*).

2.4.6 Groundwater

Groundwater characterization information presented in this Phase 2 RFI report is included solely for the purposes of defining the nature and extent of sources of groundwater contamination for use in subsequently evaluating corrective actions for the soils. The unconfined aquifer at WMA C is found within the undifferentiated H3/Cold Creek unit/Ringold Formation unit. Both water level and general direction of groundwater flow in this region have been dynamically altered at times throughout Hanford Site operations history by high-volume wastewater discharges to various ponds, cribs, and ditches (DOE/RL-2013-22; DOE/RL-2011-118, *Hanford Site Groundwater Monitoring Report for 2011*).

Between 1944 and the mid-1990s, the volume of artificial recharge from Hanford Site operations wastewater disposal was significantly greater than recharge from precipitation. An estimated 1.68×10^{12} L (4.44×10^{11} gal) of liquid was discharged to disposal ponds, trenches, and cribs during this period. Wastewater discharge has decreased since 1984 and currently contributes a volume of recharge in the same range as the estimated natural recharge from precipitation.

After the beginning of Hanford Site operations during 1943, the water table rose under the B Pond system and the Gable Mountain pond on the south flank of Gable Mountain in response to the large volume of water discharged at those locations. The volume of water that was discharged to the ground at the 200 West Area was actually less than that discharged at the 200 East Area; however, the lower hydraulic conductivity of the aquifer beneath the 200 West Area inhibited horizontal groundwater movement in this area resulting in a higher groundwater mound. The presence of the groundwater mounds locally affected the direction of groundwater movement, causing radial flow from the discharge areas. PNL-5506, *Hanford Site Water Table Changes 1950 Through 1980 – Data Observations and Evaluation* documented changes in water table elevations between 1950 and 1980. Until about 1980, the edge of the mounds migrated outward from the sources over time. Groundwater levels have declined over most of the Hanford Site since 1984 because of decreased wastewater discharges (PNNL-14548, *Hanford Site Groundwater Monitoring for Fiscal Year 2003*; DOE/RL-2013-22).

In the 1980s, a groundwater mound in the vicinity of WMA C was maintained by liquid discharge to the B Pond system east-northeast of WMA C, elevating the water table and imposing a southwestern trend in groundwater flow under WMA C (PNNL-15837, *Data Package for Past and Current Groundwater Flow Contamination Beneath Single-Shell Tank Waste Management Areas*). Since that time the water table has shown a decrease in elevation.

As shown in Figure 2-18 comparing the water levels measured in the spring of 2011 and 2012, the decline in the water level elevation is continuing. For the 2012 measurements, many of the March measurements were flagged as suspect, so the April 2012 measurement is shown.

The aquifer properties beneath WMA C, including aquifer thickness, current flow directions, flow rates, and hydraulic properties are discussed in the following subsections. The discussion focuses on the unconfined aquifer that extends from the water table to the top of basalt.

2.4.6.1 Aquifer Thickness. Local and regional data indicate the thickness of the uppermost aquifer increases from north to south as the top of basalt dips into the Cold Creek syncline. Several wells fully penetrate the unconfined aquifer in WMA C to the top of the basalt and can be used to determine the thickness of the aquifer beneath WMA C. Based on the groundwater elevation and top of basalt contacts in wells 299-E27-22, 299-E27-24, 299-E27-25 and 299-E27-155 the aquifer thickness ranges from 9.9 to 16.7 m (32.4 to 54.8 ft) (Table 2-2).

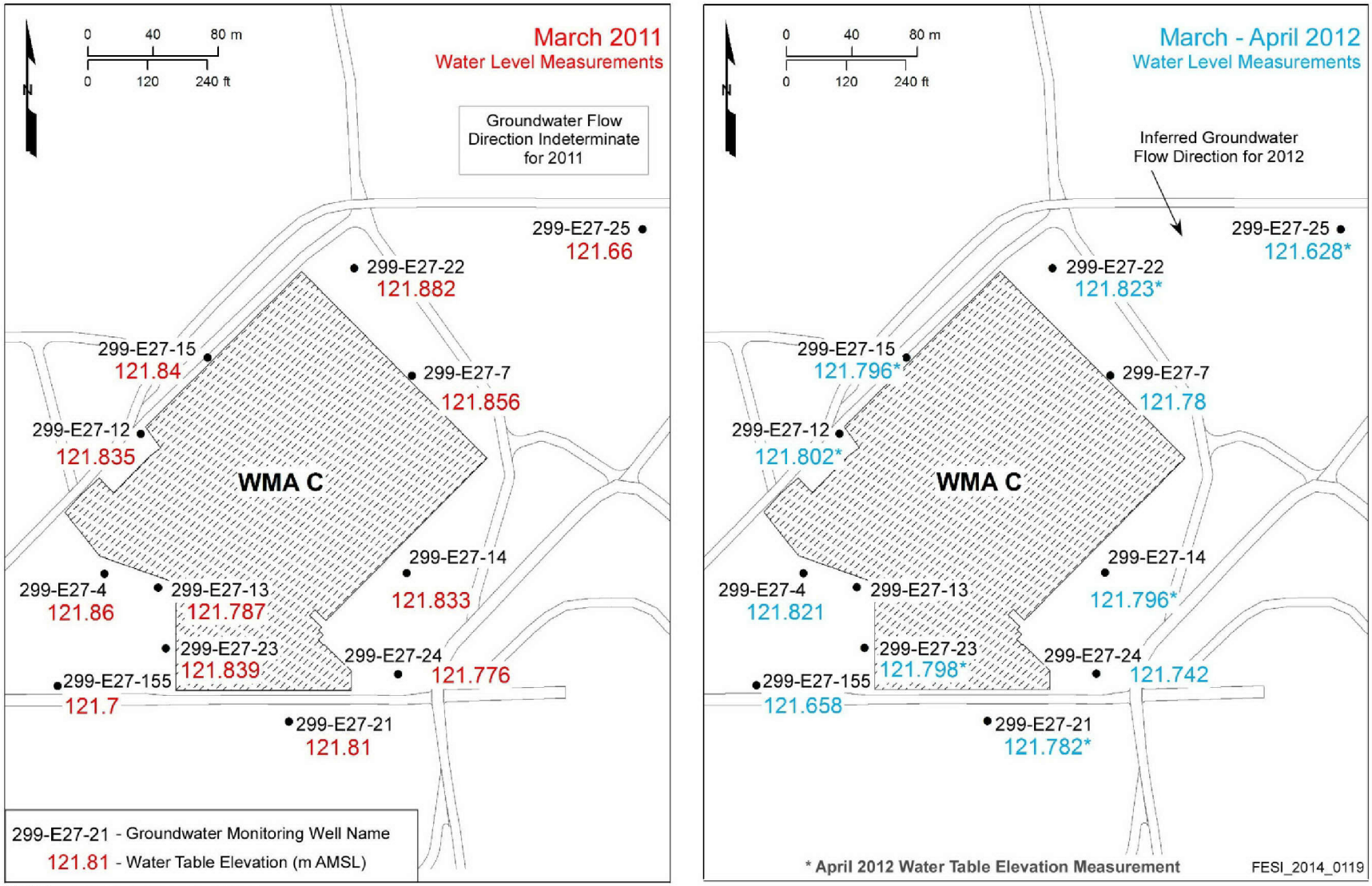
Table 2-2. Thickness of the Unconfined Aquifer beneath WMA C[a]

Well Name	Depth to Basalt[b] (ft bgs)	Depth to Water (ft bgs)	Water Level Date	Aquifer Thickness (ft)
299-E27-22	268	231.1	3/30/2009	36.9
299-E27-24	315	265.26	6/8/2010	49.7
299-E27-25	246	213.6	4/19/2010	32.4
299-E27-155	336	281.2	3/09/2009	54.8

[a] Information taken from Table A-1 "Waste Management Area C Groundwater Monitoring Well Attributes" in SGW-56515, *WMA C July through September 2013 Quarterly Groundwater Monitoring Report*.
[b] Actual depth, based on drilling depth to basalt.
bgs = below ground surface

2.4.6.2 Groundwater Flow Rate and Direction. Operations-related wastewater discharges raised the water table elevation beneath much of the Hanford Site (Newcomb et al. 1972, *Geology and Ground-Water Characteristics of the Hanford Reservation of the U.S. Atomic Energy Commission, Washington*). The general increase in groundwater elevation caused the unconfined aquifer to extend upward into the Hanford formation over a large area, particularly near the 200 East Area and resulted in an increase in groundwater velocity because of both the greater volume of groundwater and the higher permeability of the newly saturated Hanford formation sediments.

Figure 2-18. Comparison of Water Table Elevations: Spring 2011 to Spring 2012



AMSL = above mean sea level

With the end of plutonium production, as the site hydrologic conditions recover from the past wastewater discharges and return to the pre-Hanford conditions, evaluation of groundwater flow direction and rate of groundwater movement beneath WMA C is difficult due to a very low hydraulic gradient. The range in water table elevations is less than 10 cm (<0.3 ft) across the 200 East Area, and the water level measurements in wells exhibit a degree of variability attributed to a number of sources of measurement error or continuing local perturbations (differential reduction in the water table due to variations in vertical permeability).

As discussed in Section 3.0 of SGW-56515, *WMA C July through September 2013 Quarterly Groundwater Monitoring Report*, the average flow rate and direction is currently inferred, based in part on water-level measurements in another part of the 200 East Area and in the evaluation and interpretation of local-scale plume migration. The hydraulic gradient of the water table for WMA C is based on current water level evaluations measured from a 14-well low-gradient monitoring network in the northwest corner of the 200 East Area. The Low-Level Waste Management Area (LLWMA-1) low-gradient monitoring network is used to infer the hydraulic gradient for WMA C because it has been corrected for several measurement errors inherent in water level monitoring, where WMA C has not been corrected for all the inherent errors in measurement. The most significant source of error in the water level measurements has been associated with the deviation from vertical of the well bore. The correction for deviation from vertical error has been applied to eight of the WMA C wells ranged from 1.5 cm (0.6 in.) in Well 299-E27-7 to 38 cm (15 in.) in Well 299-E27-4.

In addition to the correction for well casing deviation from vertical, other corrections applied to the 14-well low-gradient network at LLWMA-1 include:

- Using precision geodetic surveys to a common benchmark
- Using the same E-tape to measure from a dedicated point at each well to the groundwater
- Adjusting measured water levels for barometric effects within the well
- Measuring all depths to water on one scheduled day per month by one person.

Plans are underway to complete barometric corrections at WMA C wells and include additional well measurement corrections at wells across the 200 East Area in an attempt to define the gradient and groundwater flow direction more accurately at WMA C and other sites in the 200 East Area.

Since April 2012, an average south-southeast gradient of 2.9 cm per km (2.9×10^{-5} m/m) has been derived from water level measurements in the vicinity of LLWMA-1. The average groundwater gradient using the July and August 2013 data was 2.5×10^{-5} m/m (SGW-56515).

The hydraulic parameters used to estimate rates of groundwater flow include effective porosity and hydraulic conductivity values developed from a variety of hydraulic tests and field observations. As discussed in SGW-56515 and previous quarterly monitoring reports for WMA C, the effective porosity was established at 0.1, and the most appropriate hydraulic conductivity range is from 100 to 2,100 m/day (328 to 6,890 ft/day).

Using these hydraulic parameters, estimates of the 2013 groundwater flow rate beneath WMA C range between 0.02 and 0.4 m/day (0.07 and 1.3 ft/day) (7 to 146 m [26 to 475 ft] per year) (DOE/RL-2014-32).

In 2011, a significant change in the groundwater flow direction was identified in the northwest corner of the 200 East Area. From some point in time after the start of process wastewater disposal until March 2011, groundwater flowed northward through Gable Gap. In September 2011 the return of the southward gradient through the gap was reported (DOE/RL-2011-118). The average groundwater flow direction in 2013 at WMA C was 147 degrees from north (southeast) with a range during the year of 132 to 171 degrees from the north (DOE/RL-2014-32). As discussed in SGW-56515, the flow change in the northwest corner of the 200 East Area appears to be the driver for the changing flow direction at WMA C. The best estimate for the flow direction in the vicinity of WMA C is to the southeast, comparable to the direction reported in the 2012 annual report (DOE/RL-2013-22). This newly identified flow direction is consistent with concentration patterns (increasing or decreasing) in some of the contaminants monitored in the vicinity of WMA C.

2.4.6.3 Groundwater Monitoring Program. The Hanford Groundwater Protection Program has extensively monitored the groundwater in and around WMA C as part of the 200-BP-5 OU. In addition, at WMA C groundwater monitoring is conducted for compliance with WAC 173-303-400 (and by reference 40 CFR 265, Subpart F) because WMA C is an HWMA (RCW 70.105) TSD unit. These regulations require monitoring to determine whether dangerous waste or dangerous waste constituents from the waste site have entered the groundwater. Data from groundwater monitoring wells are used to evaluate the 200-BP-5 OU.

RCRA Monitoring

A RCRA groundwater monitoring program for WMA C was initiated in 1989 (WHC-SD-EN-AP-012 [Rev. 0, followed by Rev. 1 in 1991]). Through 2009, groundwater monitoring was conducted in accordance with PNNL-13024. Due to recognition of a critical mean exceedance for specific conductance in 2009, groundwater beneath WMA C is being monitored under a RCRA interim status groundwater quality assessment monitoring program. The assessment program is described in DOE/RL-2009-77.

In accordance with 40 CFR 265, Subpart F, Section 265.93 "Preparation, evaluation, and response," subsection [d](7) (as referenced by WAC 173-303-400), the well network (Figure 2-18) is sampled quarterly in order to make continued determinations of the concentration and extent of cyanide in the groundwater (DOE/RL-2009-77). All of the wells were sampled quarterly, as required, during calendar year 2013 (DOE/RL-2014-32). SGW-55438, *Hanford Site Groundwater Monitoring for 2012: Supporting Information* includes a list of WMA C wells and constituents monitored.

As of the 2013 annual report (DOE/RL-2014-32), cyanide is the only dangerous waste constituent determined as impacting groundwater from C Farm. Concentrations were significantly below the 200 µg/L drinking water standard during all of calendar year 2013 for all

wells, and were found above detection limits (4 µg/L) in only three wells (299-E27-14, 299-E27-23 and 299-E27-24) during this period. Additional discussion is provided in Section 5.

CERCLA Monitoring

In addition to the WMA C RCRA groundwater monitoring, wells in and around WMA C are sampled as part of the CERCLA monitoring for the 200-BP-5 OU. As discussed in the 2012 Annual Report (DOE/RL-2013-22), plumes have been identified for the following constituents: nitrate, tritium, ^{129}I, ^{99}Tc, uranium, and ^{90}Sr for the 200-BP-5 OU. These are regional plumes, from multiple sources, most of which migrate into the area beneath WMA C. Additional discussion is provided in Section 5.

2.4.7 Vegetation and Wildlife

All WMAs in the tank farm system are actively managed to prevent vegetation, insects, and wildlife from using the WMAs as habitat. Herbicides and pesticides are used on a regular basis, and fences maintained around the perimeter keep larger animals out. Without a source of food within the WMAs, smaller animals are less likely to enter. Regular biological control work and prevention activities are performed by Hanford Site contractors to support this objective (DOE/CX-00025, *Categorical Exclusion for the Tank Farm Interim Surface Barriers, 200 Areas, Hanford Site, Richland, Washington*). All land within C Farm is considered a long-term industrial area that is highly disturbed, primarily consisting of graveled and paved areas and structures.

Most of the lands surrounding WMA C are highly disturbed industrial areas containing structures and exclusion fencing with limited open areas of land which have been regularly cleared, often leveled, and graveled or paved. Vegetation, when present, consists of invasive or industrial weeds with few native species other than the occasional native grass or forb.

Ecological compliance reviews were conducted for WMA C during RFI project planning to satisfy the NEPA requirements for evaluation of potential adverse effects to environmental receptors. A Categorical Exclusion (DOE/CX-00013, *Categorical Exclusion for Small Mammal Sampling Near Waste Management Area C, 200 East Area, Hanford Site, Richland, Washington*) was developed in response to a request for WMA C RFI Phase 2 work activities to include small mammal sampling at WMA C.

No Federally-listed threatened or endangered species or critical habitat were identified within or adjacent to WMA C. Additional compliance reviews are routinely performed prior to implementation of any ground-disturbing activities.

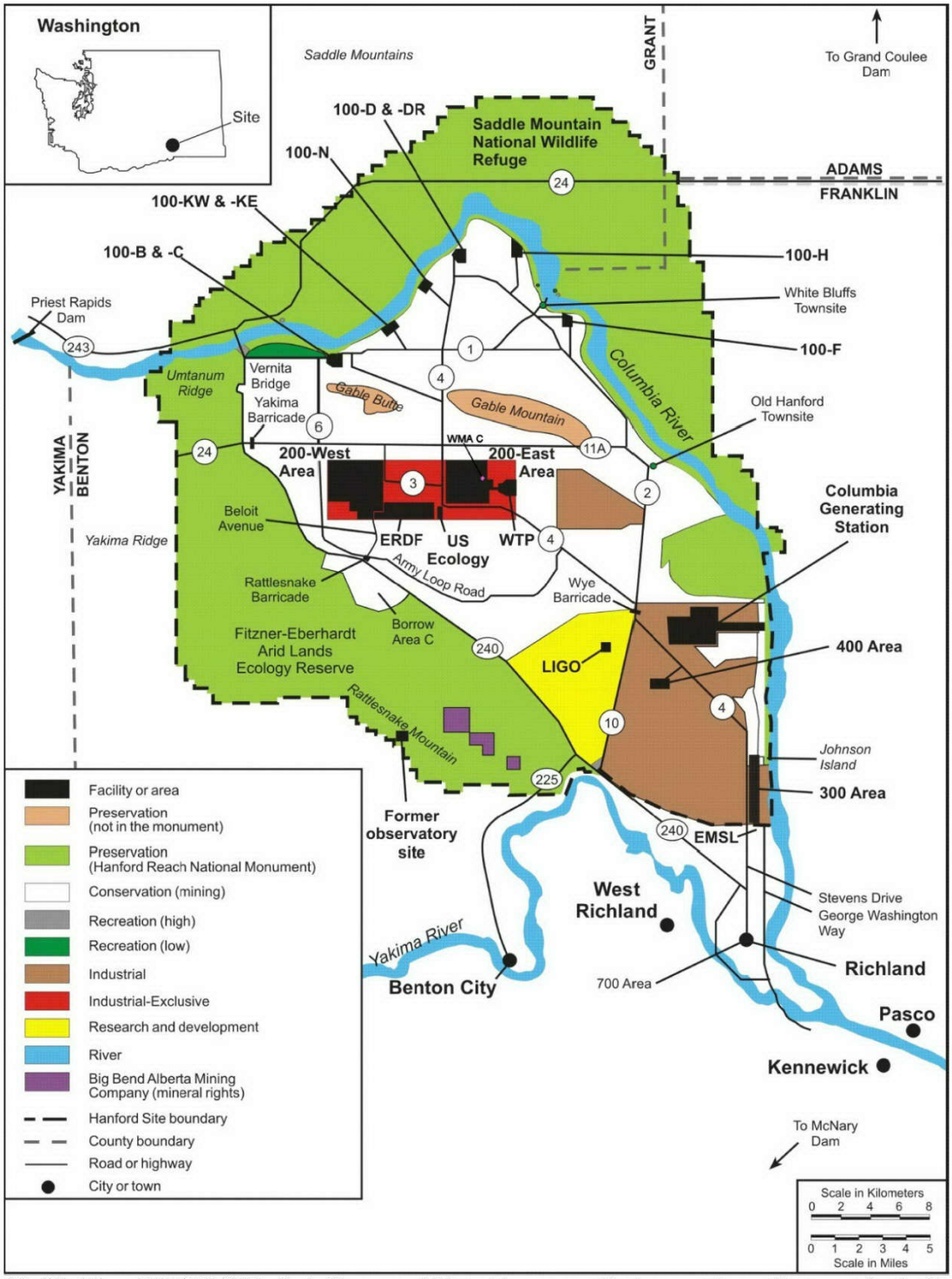
2.4.8 Land Use

Understanding current and reasonably anticipated future land use is integral to protecting human health and the environment as corrective measures are developed for WMAs of the Central Plateau. Currently, and for the foreseeable future, WMA C will be under Federal ownership and control and managed as an industrial area with restricted access and various institutional

controls. The NEPA EIS for DOE/EIS-0189, *Tank Waste Remediation System, Hanford Site, Richland, Washington, Final Environmental Impact Statement* addressed management and disposal of the contents of 177 high-level radioactive waste tanks and cesium and strontium capsules. This EIS committed the 200 Areas, including WMA C, to Industrial-Exclusive use during the retrieval, separation, and vitrification waste management process. It also constituted a long-term commitment of the 200 Areas for onsite disposal of low-level waste. DOE/EIS-0222-F, *Final Hanford Comprehensive Land-Use Plan Environmental Impact Statement* (HCP EIS) considered several land uses for the Hanford Site planned for at least the next 50 years (Figure 2-19). An Industrial-Exclusive land-use designation was applied to the Central Plateau, including WMA C, where DOE would continue waste management activities (DOE/EIS-0222-F).

As described in DOE/EIS-0391, a portion of the Central Plateau (the Core Zone) will be designated as a permanent WMA to remain under Federal control for the next 150 years or longer. A safety buffer area will be maintained between the Core Zone and the remainder of the Central Plateau during cleanup operations. Waste sites in the permanent WMA (Core Zone) will be addressed through the CERCLA process consistent with Industrial-Exclusive, Conservation (Mining), or Preservation land use scenarios identified in the land use plan and within the timeframe identified in the Hanford Comprehensive Land-Use Plan EIS Record of Decision (73 FR 55824, "Amended Record of Decision for the Hanford Comprehensive Land-Use Plan Environmental Impact Statement") (at least 50 years).

Figure 2-19. Generalized Land Use at the Hanford Site and Vicinity



Modified from DOE/EIS-0391, *Tank Closure and Waste Management Environment Impact Statement for the Hanford Site, Richland, Washington,* Figure 3-11.

EMSL = Environmental and Molecular Sciences Laboratory
ERDF = Environmental Restoration Disposal Facility
LIGO = Laser Interferometer Gravitational-Wave Observatory
WTP = Waste Treatment Plant

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3.0 WASTE MANAGEMENT AREA C SITE DESCRIPTION

This section provides a detailed description of the area and components compromising WMA C. This section also provides information about the operational setting of WMA C, including the system components, the designs and functions of the equipment and system, waste stream characteristics and compositions, waste transfer and tank receiving history, tank waste stabilization and retrieval history, tank and system residual waste inventory, and waste releases to the environment resulting from tank leaks and UPRs.

There are several reports that include information about WMA C waste releases. The following provide key waste release information that supports this document:

- HNF-EP-0182, *Waste Tank Summary Report for the Month Ending July 31, 2014* (Rev. 319)
- RPP-ENV-33418, *Hanford C-Farm Leak Inventory Assessments Report* (Rev. 2A)
- RPP-RPT-42294, *Hanford Waste Management Area C Soil Contamination Inventory Estimates* (Rev. 1)
- RPP-RPT-42323, *Hanford C-Farm Tank and Ancillary Equipment Residual Waste Inventory Estimates* (Rev. 2).

As new information has become available, these reports have been revised. For the purposes of this document, the information in the above noted revisions have been used. It should be noted that there are some inconsistencies with waste release information in these reports as they have been updated at different times and are all currently undergoing revisions. The source of information used in this report will be referenced in order to avoid confusion.

3.1 LOCATION AND SITE DESCRIPTION

WMA C is located in the Hanford Site 200 East Area as shown in Figure 1-1, and consists of the C Farm. C Farm construction began in 1944. Appendix D contains photographs of C Farm construction undertaken in the 1940s and 1950s and additionally includes photographs of C Farm during retrieval processes in 2008 through 2011. Operations at WMA C began in 1946, and the system is currently undergoing waste cleanup activities comprised of tank waste removal processes (waste retrieval) in preparation for closure. The WMA C fenceline is irregular in shape, with the overall extent of the footprint at (204 m by 239 m [670 ft by 785 ft]). C Farm consists of 16 SSTs, twelve 100-series 1,892,700 L (535,000 gal) capacity tanks, and four 200-series 208,000 L (55,000 gal) capacity tanks, and various waste transfer systems and supporting facilities.

The footprint of the 12-100-series tanks encloses an area (91 by 122 m [300 by 400 ft]). Four smaller 200-series tanks are located toward the northeast of the 100-series tanks. The C Farm system also encompasses waste transfer lines and tank ancillary equipment such as

diversion boxes, catch tanks, the process vault, and facilities such as a cesium loadout station. Multiple C Farm drywells are used to detect and monitor waste releases in and about the tank farm as part of the leak detection system. Elevated subsurface radiation levels as monitored by radiation detection instruments in the drywells could indicate waste releases. There are no drywells installed adjacent to or in close proximity the 200-series tanks.

Four diversion boxes (241-C-151, 241-C-152, 241-C-153, and 241-C-252) were originally constructed in C Farm. Another three diversion boxes (241-CR-151, 241-CR-152, 241-CR-153), the 244-CR Vault, the 271-CR Control House, 271-CRL Laboratory, and the 241-C-801 Cesium Loadout Facility (Cesium Loadout Facility) were built later. An eighth diversion box, 241-C-154, is located across from the C Farm at the former 201-C Hot Semiworks Facility (Strontium Semiworks Facility). The general layout of the WMA C tanks and structures is shown in Figure 1-1. The locations of the WMA C drywells are depicted in Figure 2-17.

Tank waste retrieval activities have added temporary surface facilities that include process skids, transfer piping, and ventilation systems along with process support trailers and associated utility infrastructure.

3.2 UNIT DESIGN AND OPERATING CHARACTERISTICS

RPP-50233, *Waste Management Area C Closure Conceptual Design Support Document*, describes the physical components located in WMA C. These include various underground structures (SSTs, catch tanks, vaults, diversion boxes, valve pits, and pipelines) and the above-grade buildings, and equipment (miscellaneous structures, drywells, and groundwater monitoring wells). As noted in RPP-50233, WMA C also contains various utility supply lines/water lines, ventilation systems and temporary facility components such as mobile structures and trailers. This section of the RFI report provides information about the large, underground storage tanks and the permanent ancillary equipment and components of WMA C. A list of these structures by category is provided in Table 3-1.

Table 3-1. WMA C Components

Component	Description	Characterization Reference Document
Tanks		
241-C-101[a]	530,000 gal SST removed from service in 1970.	RPP-RPT-42323, Rev. 2, *Hanford C-Farm Tank and Ancillary Equipment Residual Waste Inventory Estimates*
241-C-102[a]	530,000 gal SST removed from service in 1976.	RPP-RPT-42323, Rev. 2
241-C-103[a]	530,000 gal SST removed from service in 1979.	RPP-RPT-33060, *Retrieval Data Report for Single-Shell Tank 241-C-103*
241-C-104[a]	530,000 gal SST removed from service in 1980.	RPP-RPT-54072, *Retrieval Data Report for Single-Shell Tank 241-C-104*

Table 3-1. WMA C Components

Component	Description	Characterization Reference Document
241-C-105[a]	530,000 gal SST removed from service in 1979.	RPP-RPT-42323, Rev. 2
241-C-106[a]	530,000 gal SST removed from service in 1979.	RPP-20577, *Stage II Retrieval Data Report for Single-Shell Tank 241-C-106*
241-C-107	530,000 gal SST removed from service in 1978.	RPP-RPT-42323, Rev. 2
241-C-108	530,000 gal SST removed from service in 1976.	RPP-RPT-55896, Rev. 1, *Retrieval Data Report for Single-Shell Tank 241-C-108*
241-C-109	530,000 gal SST removed from service in 1976.	RPP-RPT-55284, *Retrieval Data Report for Single-Shell Tank 241-C-109*
241-C-110	530,000 gal SST removed from service in 1976.	RPP-RPT-56796, *Retrieval Data Report for Single-Shell Tank 241-C-110*
241-C-111	530,000 gal SST removed from service in 1978.	RPP-RPT-42323, Rev. 2
241-C-112	530,000 gal SST removed from service in 1976.	RPP-RPT-42323, Rev. 2
241-C-200 series tank[b]	Four 55,000-gal SSTs removed from service in 1977.	RPP-RPT-30181, *Retrieval Data Report for Single-Shell Tank 241-C-201*; RPP-RPT-29095, *Retrieval Data Report for Single-Shell Tank 241-C-202*; RPP-RPT-26475, *Retrieval Data Report for Single-Shell Tank 241-C-203*; RPP-RPT-34062, *Retrieval Data Report for Single-Shell Tank 241-C-204*
Ancillary Equipment		
Transfer line	Underground pipes used to transfer liquid waste and decontaminated solution.	RPP-PLAN-47559, Rev. 1, *Single-Shell Tank Waste Management Area C Pipeline Feasibility Evaluation*
Diversion box	Eight diversion boxes interconnecting C Farm vaults, boxes, and tanks. Removed from service in 1985.	RPP-RPT-42323, Rev. 2
241-C-301 Catch Tank	36,000-gal catch tank. 20-ft radius by 20.25-ft tall reinforced-concrete interior painted with two coats of Amercoat Paint.	RPP-RPT-42323, Rev. 2
244-CR Vault tank	Four vault tanks used for transfer of liquid waste and decontamination solution. Removed from service in 1988.	RPP-RPT-42323, Rev. 2
Valve pit Valve box	One valve pit located adjacent to Tank C-103. Three valve boxes serving 100-series tanks, located adjacent to 241-C-801 Building.	RPP-RPT-42323, Rev. 2

Table 3-1. WMA C Components

Component	Description	Characterization Reference Document
241-C-801	A facility used to recover and loadout cesium from high-activity waste supernatant solution.	RPP-RPT-42323, Rev. 2
French drain	Three gravel-filled culverts used to receive contaminated liquid waste and allow percolation into the subsurface.	RPP-RPT-42323, Rev. 2
Septic tank	Two septic tanks located southeast of C Farm. Tanks were emptied, filled with sand and abandoned in place.	RPP-RPT-42323, Rev. 2

[a] Tank pit: Six pump pits, six heel pits, and six sluice pits. Each tank from 241-C-101 to 241-C-106 has one pump pit, one heel pit and one sluice pit.
[b] Pump pit and condenser pit: Four pump pits and four condensers serving 200-series tanks.

3.2.1 Single-Shell Tanks

The C Farm contains twelve 100-series tanks and four 200-series tanks. The 100-series tanks are arranged in four rows of three tanks at different elevations to allow waste to cascade from tank to tank through connecting overflow lines. Tanks were built by installing a reinforced-concrete base at least 15 cm (6 in.) thick. Three layers of asphalt-impregnated waterproofing cotton fabric were then applied to the concrete base. After the waterproofing was applied, 5 cm (2 in.) of grout, and the fabricated steel liner were placed.

The 100-series tanks are 23 m (75 ft) in diameter and 4.9 m (16 ft) deep, with a capacity of 2 million L (530,000 gal). The 100-series tanks were constructed in place with 0.95 cm (0.38 in.) thick carbon steel lining the bottom and 0.64 cm (0.25 in.) thick carbon steel lining the sides of a structural reinforced-concrete shell. The tanks have dished bottoms (center of tank is lower than the perimeter) and a curved knuckle (transition) to the wall, where the carbon steel plate is 0.79 cm (0.31-in.) thick. Each row of three 100-series tanks are connected so that when the first tank fills (at a 0.3 m [1 ft] higher elevation than the next), the waste overflows by gravity (cascades) into the second tank, and the second into the third. The inlet and outlet lines are located near the top of the steel liners. Each tank is fitted with four inlet lines (nozzles). Tanks C-101, C-104, C-107, and C-110 are the initial tanks in a cascade. These tanks do not have an inlet cascade nozzle but do have an outlet nozzle to the next tank in the series. Tanks C-102, C-105, C-108, and C-111 each have an inlet nozzle and an outlet nozzle. Tanks C-103, C-106, C-109, and C-112 are the final tanks in the series. Each tank has a cascade line from the previous tank in the series.

The 200-series tanks are 6 m (20 ft) in diameter with a 7 m (24 ft) operating depth and an operating capacity of 208,000 L (55,000 gal) each. The 200-series tanks were constructed of 30 cm (12 in.) thick reinforced concrete with a 6 mm (0.25 in.) milled carbon steel liner on the

bottom and sides. The domed structural concrete top is 0.38 m (1.25 ft) thick. These tanks have a 15 cm (6 in.) dished bottom and a 0.9 m (3 ft) radius knuckle with a 5.7 m (18.7 ft) operating depth. The bottom center elevation of Tank C-201 is 185 m (607 ft). The four 200-series tanks of C Farm are not cascaded, but are joined together with piping at the same elevation to allow the waste volumes to equalize within the tanks. All are connected by inlets to a diversion box. The tanks are set on a reinforced-concrete foundation. The 200-series tanks typically have six risers, which range in size from 10 cm (4 in.) to 30 cm (12 in.) in diameter and provide surface level access to the underground tank, and four inlets and outlets.

Once constructed, the C Farm tanks were covered to grade with 21 m (7 ft) of backfill over the top of the dome to provide operating personnel shielding from radiation exposure (WHC-SD-WM-ER-349, *Historical Tank Content Estimate for the Northeast Quadrant of the Hanford 200 East Area*). Figure 3-1 shows a typical tank configuration. All of the SSTs in WMA C were taken out of service or declared inactive in the mid-1970s to early 1980.

3.2.2 Ancillary Equipment

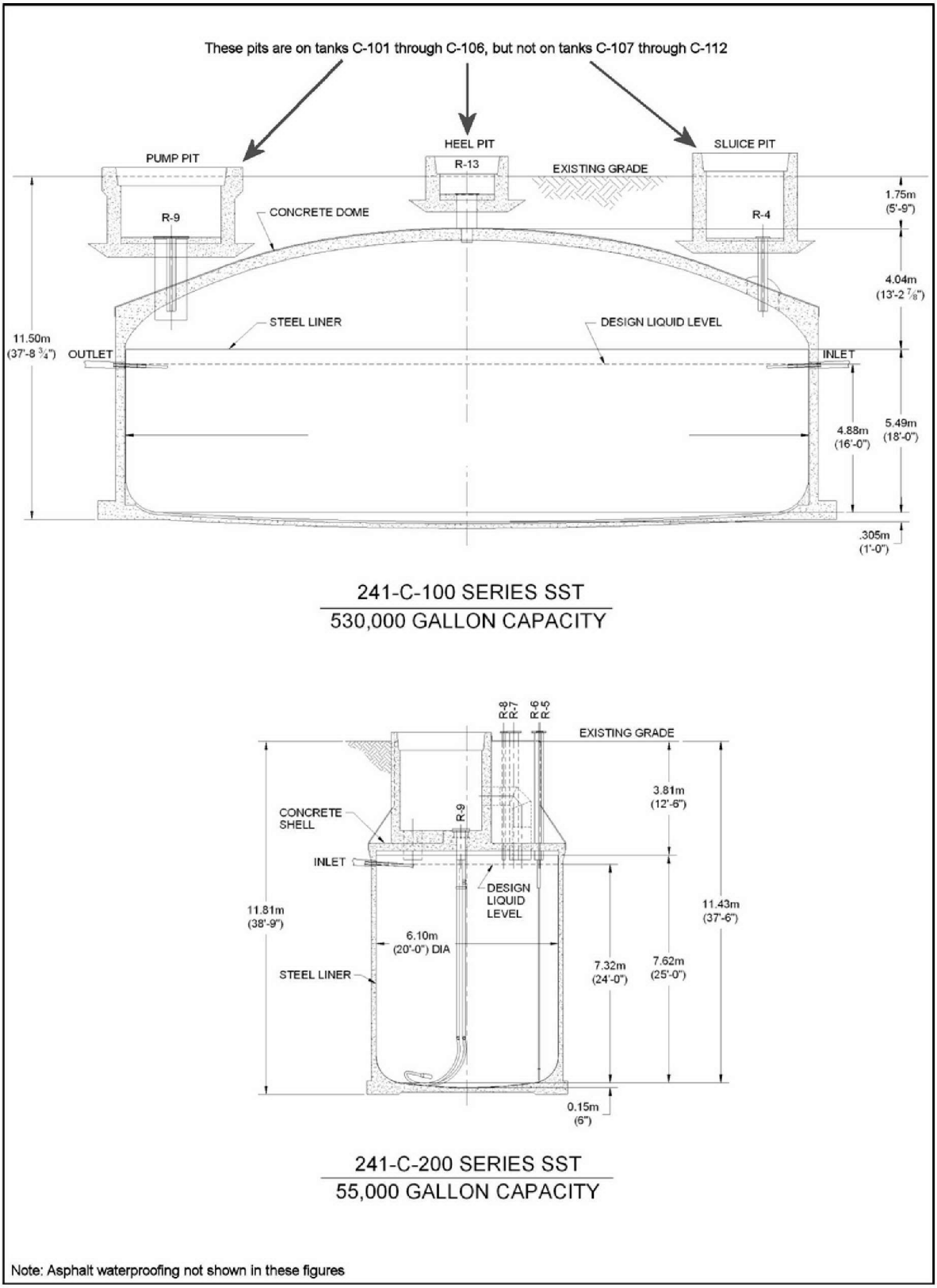
To support the transfer and storage of waste within WMA C SSTs, there is a complex transfer system of pipelines (transfer lines), diversion boxes, catch tanks, vaults, valve pits, and other support structures. Liquid waste was routed from the operation facilities to the tank farms using underground transfer lines and diversion boxes. Collectively, these are referred to as ancillary equipment.

3.2.2.1 Transfer Lines. Approximately 1,400 pipelines, ranging in size from 5.1 to 15.2 cm (2 to 6 in) in diameter, connect the various components of WMA C to other process facilities and tank farms. The pipeline network transferred many types of process wastes and comprises a total length of approximately 15 km (9 mi). Some lines were installed for specific purposes (e.g., drain lines, saltwell lines) while others were used for general transfers between facilities in the 200 Areas.

Underground transfer piping includes both direct buried lines and encased (concrete or pipe encased). The term “direct buried” indicates that the piping is not encased and is buried directly in the soil. The original direct buried pipelines from the diversion boxes to Tanks C-101, C-104, C-107, C-108, C-110, and C-111 are supported by a concrete support structures similar to a viaduct.

The term “encased” indicates that the primary transfer line is enclosed within a concrete jacket, or a pipe trench. After 1947, all pipelines installed in the tank farms were either concrete encased or pipe-in-pipe encased (new installations). The primary pipe used in underground waste transfer piping is typically composed of carbon or stainless steel. The concrete encasement used as secondary confinement consists of a reinforced-concrete trough and cover block. Today, all waste transfers for SSTs are made through shielded hose-in-hose transfer lines placed on the ground surface.

Figure 3-1. WMA C SSTs Cross Section



SST = single-shell tank

During operational years, 21 plugged lines and 11 failed lines were recorded at WMA C (RPP-RPT-29191, *Supplemental Information Hanford Tank Waste Leaks* and RPP-25113, *Residual Waste Inventories in the Plugged and Abandoned Pipelines at the Hanford Site*). In most cases, flushing procedures were followed to prevent the build-up of residual waste inside the piping. Most of the plugged lines were unplugged, except for the cascade line between Tanks C-110 and C-111.

RPP-PLAN-47559, *Single-Shell Tank Waste Management Area C Pipeline Feasibility Evaluation* provides detailed information on the transfer line configuration, UPRs, estimates residuals, characterization, and closure technologies.

3.2.2.2 Diversion Boxes. The diversion boxes are belowground, reinforcedconcrete boxes where two transfer lines are connected using remote pipeline connectors (jumpers). Diversion boxes were also designed to contain any waste that leaked from the waste transfer line connections. If waste leaked into a diversion box, it generally drained by gravity to nearby catch tanks where any spilled waste was stored and then transferred to an SST. Figure 3-2 shows a schematic of a typical diversion box.

There are seven diversion boxes located in C Farm, identified as 241-C-151, 241-C-152, 241-C-153, 241-C-252, 241-CR-151, 241-CR-152, and 241-CR-153. An eighth diversion box, 241-C-154, is located across from C Farm at the former Strontium Semiworks Facility. All 241-C series diversion boxes were built during the construction of WMA C, while the 241-CR series diversion boxes were added in the 1950s. The locations of the seven diversion boxes inside C Farm are shown in Figure 3-3. All eight units were isolated and weather covered in the mid-1980s.

3.2.2.3 C-301 Catch Tank. The C-301 Catch Tank received drainage from diversion boxes 241-C-151, 241-C-152, 241-C-153, and 241-C-252. These diversion boxes facilitated waste transfers from C Farm, B Plant, PUREX, and incidental wastes from the Strontium Semiworks Facility operations. The catch tank also received water from rainfall and snowmelt, as well as dust that entered the diversion boxes (the diversion boxes were later weatherproofed). The catch tank was coal tar coated for corrosion protection, and later underwent two cathodic protection upgrades. Figure 3-2 shows a schematic of a typical catch tank.

3.2.2.4 244-CR Vault. The 244-CR Vault is located in the southwest corner of the C Farm complex. The vault is a two-level, multi-cell, belowgrade reinforced concrete structure containing four underground tanks along with overhead piping and equipment. The lower level consists of four cells, each equipped with a concrete sump. The exterior walls and dividing walls between the cells are 0.6 m (2 ft) thick. Each cell houses a steel tank. Two tanks (TK-CR-001 and TK-CR-011) are made of stainless steel and have a capacity of 170,343 L (45,000 gal) each. The other two stainless steel tanks (TK-CR-002 and TK-CR-003) have capacities of 55,494 L (14,700 gal) each. The cells housing Tanks CR-011 and CR-001 are each 8 m (26 ft) long by 7 m (22 ft) wide and 9 m (29.5 ft) tall. The cells housing Tanks CR-002 and CR-003 are each 6 m (20 ft) long by 5 m (16 ft) wide and 5.9 m (19.5 ft) tall. This vault and associated diversion boxes 241-CR-151, 241-CR-152, and 241-CR-153 were constructed in 1951 and ceased operations in 1988. A cross-section schematic of the 244-CR Vault is shown in Figure 3-4.

Figure 3-2. Schematic of a Typical Diversion Box Transfer System

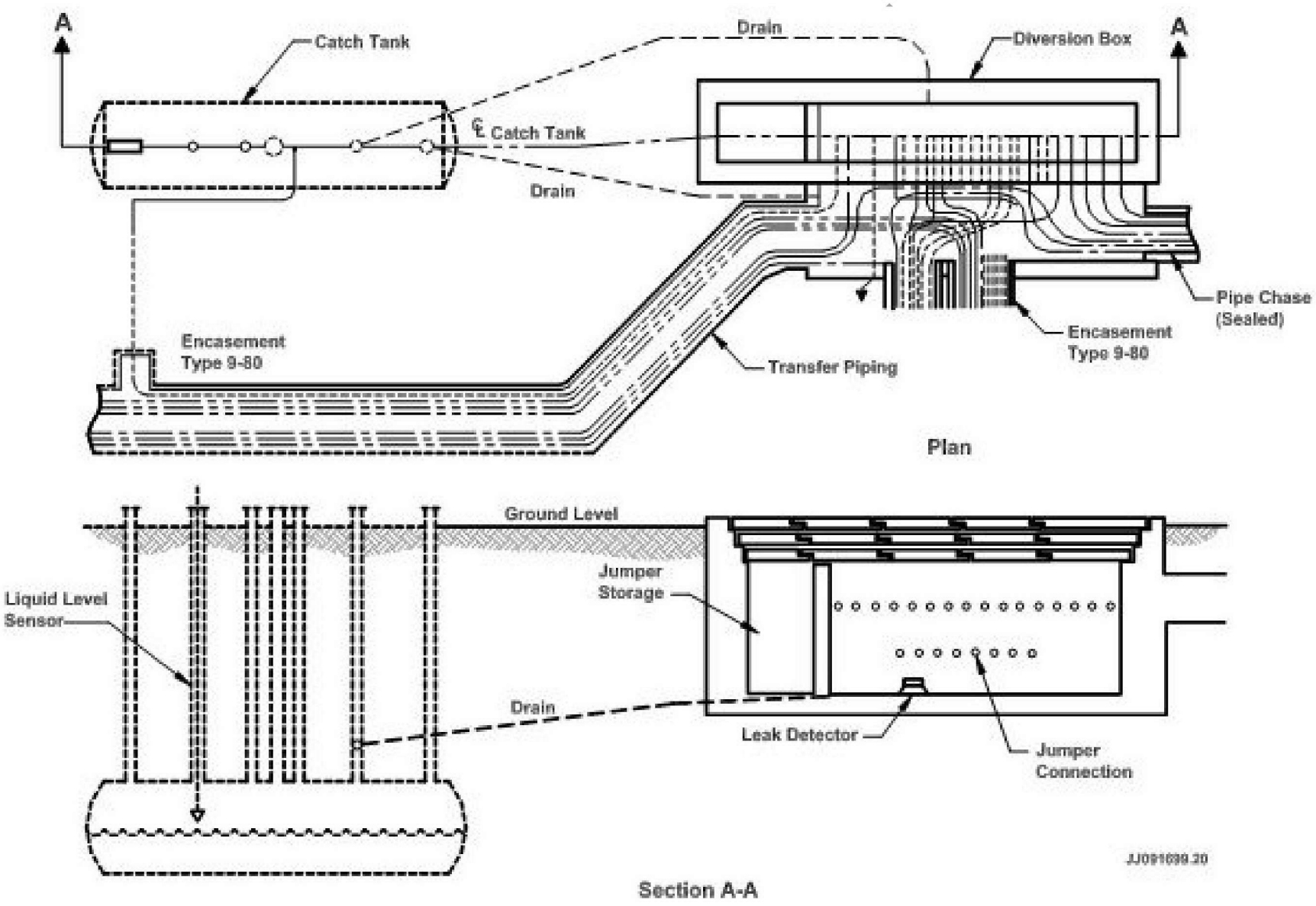


Figure 3-3. Diversion Box Locations in WMA C

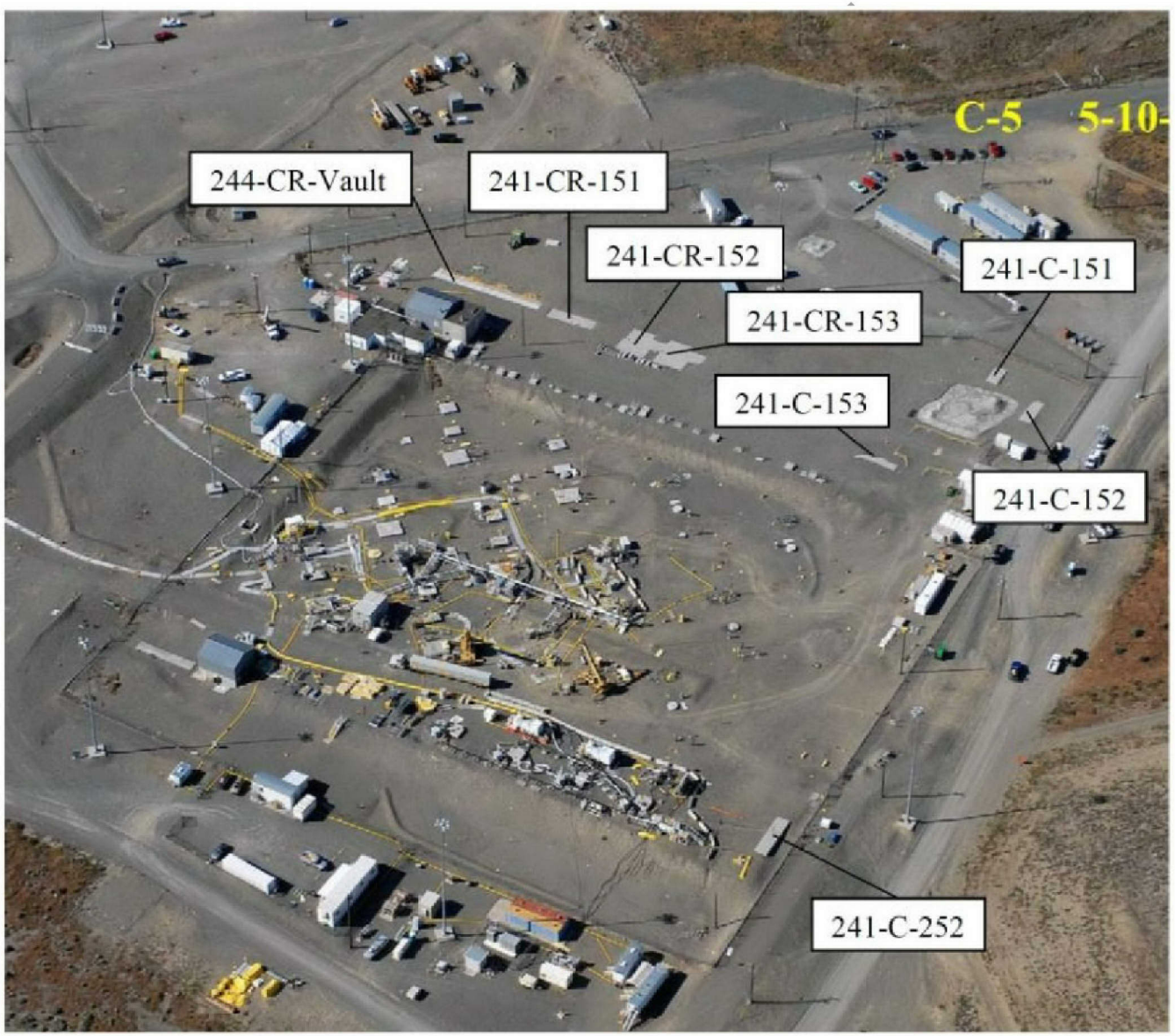
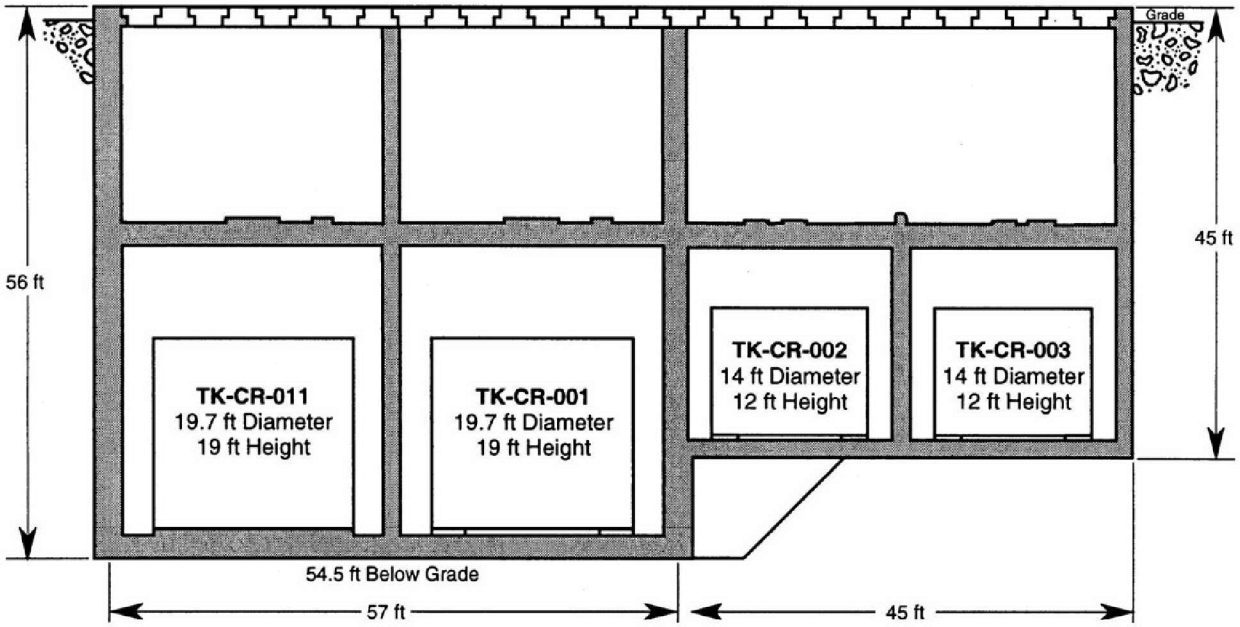


Figure 3-4. Schematic of the 244-CR Vault in WMA C



3.2.2.5 Valve Boxes/Pits. There are three valve boxes and one valve pit in C Farm. A fourth valve box is located at the former Strontium Semiworks Facility. The valve boxes and pit contained valve assemblies that were used to route the liquid waste through the transfer lines. The valve box associated with the Cesium Loadout Facility is on the north side of C Farm (H-2-4581, *Valve Pit Liner Arrangement*) and drained to a drywell. A second valve box is at the 6 o'clock position on the south side of Tank C-112. A third valve box is at the 6 o'clock position (H-2-2909, *Piping Arrangement & Details First Cycle Waste Scavenging 241-C Tank Farm*) on the south side of Tank C-111. These last two valve boxes drained directly to the soil. The only valve pit in C Farm is located at about the 9 o'clock position next to Tank C-103 (H-2-73876, *Piping Plan 241-C Tank Farm*). This valve pit is a belowground culvert with a reinforced-concrete floor with a drain to Tank C-103.

3.2.2.6 C-801 Cesium Loadout Facility. The Cesium Loadout Facility was constructed in 1962 to 1963 at the northeast corner of C Farm and adjacent to Tanks C-102 and C-103. The loadout facility provided a location for a one-step recovery and loadout of cesium from concentrated PUREX waste solutions. This facility freed up existing lines and facilities at the PUREX 202-A Building where cesium recovery operations were often in competition with other product processing and testing operations.

The Cesium Loadout Facility is a single-story building constructed of concrete support walls and foundations, with the upper part of the building constructed of prefabricated metal. The support walls and foundation are covered with earth berm. The main building sections include the loadout room and the operating room. A valve pit is located in the southwest part of the building floor. A rollup door on one wall allows truck access to the high bay portion of the building. The high bay occupies approximately half of the building and has a five-ton-capacity crane bridge.

During cesium recovery operations, diluted supernate was transferred from Tank A-103 to Tank C-103. From Tank C-103, the waste was pumped into the Cesium Loadout Facility, then into a truck mounted demineralizer (ion exchange [IX] material). The demineralizer removed the cesium from the liquid waste, and the cesium-depleted liquid waste was transferred to Tank C-102. The truck and shielded container containing the cesium were used to transport the cesium-enriched material offsite.

The shielded valve pit provided for enclosure of critical piping and control valves needed for cask loading operations. Pit walls were constructed of 46 cm (18 in.) thick concrete for radiation protection of operating personnel. Spray flush-down nozzles were provided in each corner of the pit walls to wash down the pit. Pit drainage is routed to a 122 cm (48 in.) diameter drywell.

The Strontium Semiworks Facility was also used in conjunction with the Cesium Loadout Facility to demonstrate the separation of ^{99}Tc from alkaline HLW solutions. Approximately 1 kg (2.2 lbs) of ^{99}Tc was separated from HLW that was stored in C Farm SSTs in October 1963.

The Cesium Loadout Facility has been reported to be a radioactively contaminated structure. Contamination levels were estimated at 30 curies beta in early 1980s data. Reports note that there may be residual chemicals in the processing equipment. Radiological survey results ranged from background to three times background. Three random smears were taken in the control

room (floor, pipes, and table), four in the loadout room (floor, exhauster, scaffold, and drape), and four in the pit room (cover block, tool bin, door, and grating) to test for radioactive contaminants. Smear results ranged from 1,500 to 4,500 dpm/100 cm^2.

The facility has been inactive since 1976 and was isolated in September 2002.

3.2.2.7 French Drains. French drain 216-C-8 is located southeast of C Farm, outside the tank farm perimeter fence. This site received radioactively contaminated IX waste from the 271-CR Building. Floor and process drains in the 271-CR and 271-CR Annex Buildings connected to an underground vitrified clay pipeline that discharged to the French drain 216-C-8. The unit is composed of a 1.8 m (6 ft) diameter by 2.4 m (8 ft) long concrete culvert, placed vertically 1.2 m (4 ft) below grade. The culvert is filled with gravel. It was placed into a 2.4 m (8 ft) diameter by 4.9 m (16 ft) deep excavation. A 5 cm (2 in.) diameter steel vent pipe was placed vertically through the center of the culvert and extended 1 m (3 ft) above the surface. The above-grade portion of the pipe has been removed. An underground feed pipe entered near the top of the culvert. Although process records are incomplete, a minimum of 120,300 L (31,780 gal) of treated tank farm process condensate was discharged to the French drain 216-C-8 from January 1960 through March 1965.

Two other French drains are associated with the Cesium Loadout Facility. The first French drain is located 31 m (100 ft) northeast of the Cesium Loadout Facility, just outside the tank farm fence. It is a 1.2 m (4 ft) diameter concrete pipe, 2.4 m (8 ft) long, placed vertically in the soil 0.9 m (3 ft) below grade. Nitric acid from the Cesium Loadout Facility nitric acid recovery portion of the cesium separation process may have been released to this drain. A second French drain is located just to the northeast of Cesium Loadout Facility. It received condensate from steam to the Cesium Loadout Facility. Three steam traps were routed through a 2.5 cm (1 in.) line to this French drain (RPP-6637, *Hazard Evaluation for 241-AX-IX, ITS1, 241-SX-401, 241-SX-402, 241-C-801, 241-A-431*).

3.2.2.8 2607-EG Septic System. There are two 2607-EG Septic Tanks. The first tank failed and was functionally replaced by the second tank in 1972. The 2607-EG septic system is marked by a large diameter, vertical concrete pipe. It received sanitary wastewater and sewage from the 271-CR Building. The associated drain field had a capacity of 2,350 L (619 gal) per day. This unit lies southeast of C Farm, northeast of the 271-CR Building, but within the WMA C Phase 2 study area. The system is located in a radiation zone. The 2607-EG septic system received sanitary sewer effluent from the 271-CR Building at a rate of 0.2 m^3 (6 ft^3) per day in 1987 (DOE/RL-88-30). The 2607-EG septic tanks have been pumped dry, filled with sand slurry, and abandoned in place.

3.3 WASTE TYPES AND WASTE PROCESSING HISTORY

Beginning in 1946, C Farm received process waste from B Plant. Metal waste (MW) from the bismuth phosphate process was sent to all 200-series tanks and Tanks C-101 to C-106. The first cycle decontamination waste (1C) mixed with cladding (coating) removal waste (CW) (designated as 1C/CW) was sent to Tanks C-107 through C-112. By the end of 1948, all tanks in

C Farm contained waste from the bismuth phosphate process. To free up tank space, in 1952 1C waste was transferred to the 242-B Evaporator.

In 1952 and 1953, MWs were sluiced from the tanks in C Farm and sent to 221-U Tri-Butyl Phosphate Plant (U Plant) for uranium extraction. Ancillary equipment involved in the MW transfer included the 244-CR Vault and diversion boxes 241-CR-151, 241-CR-152, and 241-CR-153. Subsequently, tribuytl phosphate (TBP) waste, a byproduct of the uranium recovery process, was returned to C Farm. From May 1955 until December 1957, the 244-CR Vault was used to scavenge TBP waste (i.e., to separate ^{137}Cs from the supernate). Waste from Tanks C-107 through C-112 was used as feed for the 244-CR Vault. The scavenged slurry was put back in Tanks C-109 and C-112 to settle, and the resultant supernate was discharged to the BC Cribs. The vault was used later as a receiving station.

Several other waste streams were routed to one or more tanks in C Farm. These include S Plant IX waste, N Reactor complex waste, evaporator bottom concentrate from B Farm and BX Farm, S Plant supernate, process development waste from the Strontium Semiworks Facility, LLW and MW from B Farm, and Hanford Site laboratory operations waste (DOE/RL-92-04, *PUREX Source Aggregate Area Management Study Report*).

Appendix E illustrates the operational waste storage timeline and processing for each of the C Farm 100-series and 200-series tanks. Waste types and waste processing operations conducted at C Farm are described in detail in HNF-SD-WM-TI-740, *Standard Inventories of Chemicals and Radionuclides in Hanford Site Tank Wastes,* and RPP-RPT-42294, *Hanford Waste Management Area C Soil Contamination Inventory Estimates*. In this RFI report the 100-series and 200-series tanks are discussed separately. Information from the two preceding referenced documents is summarized in the following sections by major processing campaigns.

3.3.1 100-Series Tanks Waste Streams

The waste streams resulting from the major processing campaigns that were transferred into and out of the C Farm 100-series tanks are discussed below. The history of the types and origins of the wastes are summarized in Table 3-2.

3.3.1.1 Bismuth Phosphate Process Wastes. The 100-series tanks in WMA C began to receive MW from the bismuth phosphate process conducted in B Plant in March 1946. By November 1947, Tanks C-101 through C-106 were filled with bismuth phosphate MW. Tanks C-107 through C-112 received 1C/CW waste from the B Plant operation starting in April 1946 and were filled by September 1948.

Precipitation of some components (e.g., phosphate, plutonium, and aluminum) in the 1C/CW waste occurred while this waste was stored in Tanks C-107 through C-112. Supernate was pumped out of the tanks in 1951 to enable the use of these tanks for storage of TBP waste from the U Plant. Removal of the 1C/CW supernate left some 1C/CW solids in each tank.

Table 3-2. Waste Storage History – 100-Series Tanks (1956 through 1978)

Year	C-101	C-102	C-103	C-104	C-105	C-106	C-107	C-108	C-109	C-110	C-111	C-112
1946-48	MW	MW	MW	MW	MW	MW	1C/CW	1C/CW	1C/CW	1C/CW	1C/CW	1C/CW
1952-55	TBP	TBP	TBP	TBP	TBP	TBP	TBP	TBP	TBP	TBP	TBP	TBP
1956	TFeCN			CW	CW					OWW	OWW	TFeCN
1957			PSN	CW	CW	PSN/ OWW		TFeCN	TFeCN		CW/ TFeCN	TFeCN
1958				CW	CW							
1959					CW				CW		CW	
1960	CW	CW	CW		CW			CW			CW	CW
1961		CW					CW	CW			CW	HS
1962		CW					CW		HS		HS	HS
1963	PSN	CW	PSN		PSN	PSN					HS	
1964	PSN	CW					HS		HS		HS	
1965		CW	PSN				HS	HS	HS			
1966		TH/CW	PSN				BNW/HS		HS			
1967		CW					HS					
1968		CW/OWW			PSN							
1969		OWW		OWW	PSN	PSS						
1970			IX	TH/OWW/PSN	PSN/RSN	PSS	IX	OWW/IX	IX	IX		IX
1971			IX	CW/OWW	PSS	PSS						
1972			CW/OWW	CW/OWW	PSS					IX		
1973			Misc	Misc	PSS		Misc	Misc				
1974			Misc	Misc	PSS	BL						
1975			Misc	Misc	PSS	BL						
1976			Misc	Misc	PSS	BL						
1977						BL						
1978						BL						

Definitions: Colors in table are used to highlight each waste type

- BL — 221-B Plant strontium processing wastes and miscellaneous wastes
- CW — cladding (coating) waste from Plutonium Uranium Extraction (PUREX) or Reduction-Oxidation (REDOX) Plants
- HS — 201-C Hot (Strontium) Semiworks waste
- IX — cesium denuded waste from ion exchange process in B Plant
- Misc — Sources may include research waste from Battelle Northwest (i.e., BNW) which is now Pacific Northwest National Laboratory, reactor decontamination waste, etc.
- OWW — Organic Wash Waste from PUREX Plant
- PSN — PUREX high-level waste (HLW) supernate
- PSS — PUREX Sludge Supernate derived from washing PUREX HLW sludges in 244-AR Vault or 241-A and 241-AX tanks
- RSN — REDOX HLW Supernate
- TFeCN — Ferrocyanide waste from 244-CR Vault treatment of TBP waste
- TH — Thorium process waste from PUREX Plant

Reference: RPP-RPT-42294, *Hanford Waste Management Area C Soil Contamination Inventory Estimates*, Rev. 2.

New pump pits, sluice pits, and heel pits were constructed at WMA C in 1951 and 1952 to enable removing the stored MW from Tanks C-101 through C-106. The 244-CR Vault was installed to acidify and dissolve solids, and blend the recovered MW slurries. Diversion boxes and concrete-encased pipelines were installed to transfer MW from the SSTs to the 244-CR Vault.

Beginning in October 1952, the MW supernate and solids stored in Tanks C-101 through C-106 were sluiced to the 244-CR Vault. Metal waste removal from Tanks C-101 through C-106 was completed in April 1955. Process records indicate that the tanks were empty, and all of the MW sludge was removed from the tanks.

3.3.1.2 TBP Waste. Tanks C-101 through C-112 were refilled with TBP waste from U Plant as the 1C/CW and MW was removed from these tanks starting in November 1952. With the exception of Tank C-104, the 100-series tanks were reported to be filled with TBP waste by early 1954. Tank C-104 received TBP waste from Tank C-112 in October 1955, after being used for MW storage until late 1954.

In November and December 1955, TBP supernate was transferred from Tank C-109 to the 244-CR Vault for precipitation of cesium and strontium using ferrocyanide (in-farm scavenging). In late December 1955, TBP supernate waste was transferred from Tank C-101 to the 244-CR Vault for in-farm scavenging. The TBP waste along with the ferrocyanide precipitate was discharged to Tank C-109 for settling of the precipitate, with the supernate then transferred to the 216-BC-4 Crib (216-B-17).

Tank C-101 continued to be used through 1957 as the feed tank to the in-farm scavenging process conducted in the 244-CR Vault. The scavenged waste was transferred to Tanks C-108, C-109, C-111, and C-112 for settling of ferrocyanide precipitate before discharge to the BC trenches and cribs. The in-farm scavenging of TBP wastes was completed in January 1958.

3.3.1.3 PUREX Plant, B Plant, S Plant, and Miscellaneous Wastes. Following the period of TBP waste storage, the C 100 series tanks were used to store a variety of waste types (Table 3-2).

With the exception of Tanks C-103 and C-106, coating waste from the PUREX Plant was received by all of the C 100-series tanks during 1956 to 1962. Tank C-102 continued to receive CW from PUREX until 1968 and also received waste from the thorium recovery process conducted at PUREX in 1966. Waste from washing the solvent in PUREX was received into Tanks C-102 (1968 to 1969), C-103 (1973), and C-104 (1969 to 1972). Tanks C-110 and C-111 also received organic wash waste in 1956. Tank C-104 also received waste from the thorium recovery process conducted at PUREX in 1970. The supernate fraction of the CW and organic wash waste wastes were transferred via tanks in BX Farm to the BY Farm for evaporation in the In-Tank Solidification system. Settled solids from the CW and organic wash waste wastes accumulated in the C Farm 100-series tanks.

Waste from the Strontium Semiworks Facility was received into Tanks C-107, C-108, C-109, C-111, and C-112 from 1961 through 1967. The Strontium Semiworks Facility separated

strontium from rare earth fission products from 1960 to 1967. In 1967 the Strontium Semiworks Facility was used for a campaign to separate the rare earth elements from an HLW stream. After radiolytic decay of the rare earth fission products, the Strontium Semiworks Facility wastes were transferred via tanks in C and BX Farms to BY Farm for evaporation in the In-Tank Solidification system.

Tanks C-101 (1963 and 1964), C-103 (1957, 1963 through 1966), C-105 (1963, 1968 through 1970), and C-106 (1957 and 1963) were used to store PUREX HLW supernate (PSN) from 241-A and 241-AX tanks. Tanks C-105 (1971 through 1976) and C-106 (1969 through 1971) also received PUREX sludge wash supernate (PSS) from 244-CR Vault and from 241-A and 241-AX tanks. Tank C-105 also received REDOX HLW supernate (RSN) from 241-SX and 241-TX tanks (1970 and 1971). The PSN, PSS, and RSN wastes were transferred to B Plant for IX processing to separate cesium. Tanks C-107 through C-112 (1970) received waste from the B Plant IX process. Tank C-106 also received waste from the B Plant strontium separation process (1974 through 1978).

Several other miscellaneous waste streams were routed to Tanks C-103 (1973 through 1976), C-104 (1973 through 1976), C-107 (1973), and C-108 (1973). These include N Reactor decontamination waste and waste from research activities at the Hanford 300 Area Laboratories (HLO waste type), known most recently as Pacific Northwest National Laboratory (PNNL).

3.3.2 200-Series Tanks Wastes Streams

The operating history of the 200-series tanks is detailed in RPP-15408, *Origin of Wastes in C-200 Series Single-Shell Tanks*, and summarized here. The C Farm 200-series tanks were constructed from 1944 to 1945. The tanks were available for use in January 1947 but not used until November 1947, when they received MW from B Plant. The 200-series tanks were filled with MW by January 1948 and continued to receive waste and be decanted until the end of 1948.

From December 1953 through February 1955, the MW supernate and sludges present in Tanks C-201 through C-204 were intermittently retrieved and transferred to 244-CR Vault and eventually to the 241-WR Vault. The MW sludge and supernate were dissolved in acid in the 244-BXR Vault and then transferred to the 221-U Building where uranium was recovered from the wastes using a TBP-based solvent extraction process. After completing the removal of MW, each tank was visually inspected and determined to be empty. However, given the inspection method (periscope optics), residual MW could have remained in each tank.

Tanks C-203 and C-204 received cold uranium waste (i.e., uranium that had not been irradiated in a reactor) from PUREX startup testing in November 1955. The cold uranium waste was removed from Tanks C-203 and C-204 in December 1955. Tanks C-201 through C-204 were then used from May 1956 through October 1956 to receive and store waste originating from research and development activities conducted at the Strontium Semiworks Facility.

After being filled with waste from the Strontium Semiworks Facility, the supernate in Tanks C-201, C-202, and C-204 was transferred to Tank C-104 in 1970. The supernate in Tank C-203 was transferred to Tanks C-104 and C-109 in 1970. Residual supernate was subsequently transferred from these tanks into Tank C-106 in 1980.

The 200-series tanks were interim stabilized in 1981 and 1982. The 200-series tanks underwent waste retrieval operations from June 2004 through December 2006 removing 22.7 kL (6,000 gal) of wastes from these tanks). The amount of residual waste within these tanks is less than 2,157 L (570 gal).

3.4 INTERIM STABILIZATION

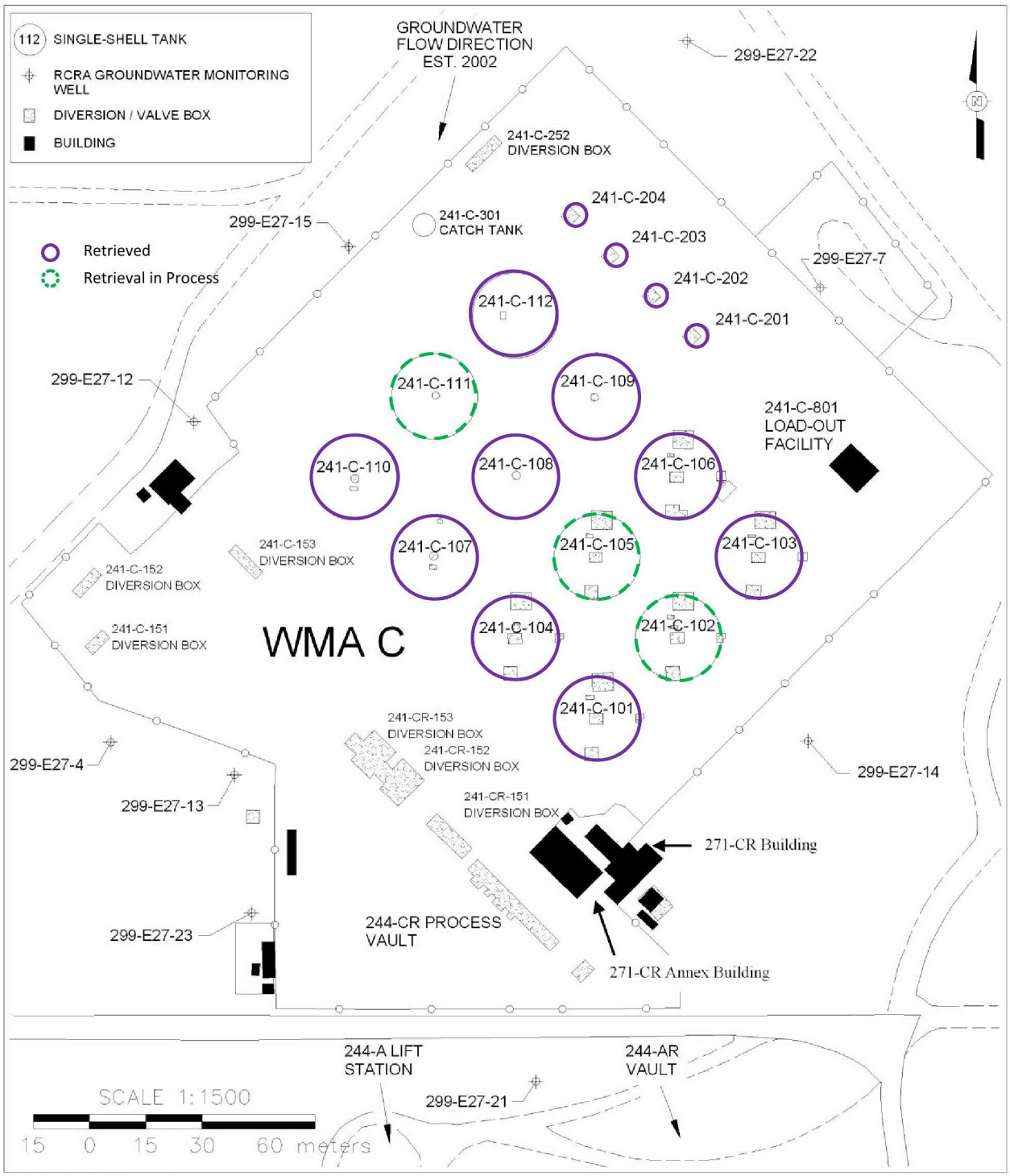
The SSTs were built between 1943 and 1964, and are well beyond their designed life of 20 years. Based on measured declines in tank waste liquid levels and geophysical monitoring data from soils around the tanks, seven tanks in C Farm were suspected of releasing waste to vadose zone soils. Some releases were attributed to tank liner failures; many were due to pipeline breaks and overfilling the tanks. Waste from past tank leaks has reached groundwater and is moving toward, but has not reached, the Columbia River. To provide safer storage for tank waste, DSTs were built to receive wastes transferred from the SSTs. Interim stabilization measures were conducted to reduce the potential or impede the movement and release of liquid waste to the soil. A Consent Decree between DOE and Ecology was established specifying the requirements to stabilize the tanks.

As a result of interim stabilization, liquid waste (supernate) and the major portion of the drainable interstitial liquids in the tanks were removed, thereby reducing the inventory (quantity) of drainable (releasable) liquid and mobile contaminants in the tanks. The remaining liquid was defined as being contained in waste pore spaces. After completing interim stabilization, transfer of remaining (sludge and solid) waste from SSTs to DSTs (retrieval) was initiated. HNF-SD-RE-TI-178, *Single-Shell Tank Stabilization Record*, provides stabilization information for the tanks.

3.5 WASTE RETRIEVAL TECHNOLOGY

Several retrieval technologies were used to remove wastes from SSTs and transfer them to DSTs pending treatment and disposal. Tank waste retrieval methods includes modified sluicing, mobile retrieval, vacuum-based retrieval, a chemical wash system, and water dissolution. Figure 3-5 shows the WMA C tank retrieval status. To date, waste has been removed (retrieved) to the limits of the deployed technology in all of the C 200-series tanks and nine of the C100-series tanks. Only Tanks C-102, C-105, and C-111 are still undergoing waste retrieval operations. Appendix D has photographs showing infrastructure changes in C Farm due to waste retrieval processes.

Figure 3-5. WMA C Tank Retrieval Status



Source: Modified from RPP-RPT-42323, *Hanford C-Farm Tank and Ancillary Equipment Residual Waste Inventory Estimates*, Rev. 2. Figure ES-1. Location Map of Waste Management Area C (241-C Tank Farm) and Surrounding Area of

RCRA = *Resource Conservation and Recovery Act of 1976* WMA = Waste Management Area

3.5.1 Modified Sluicing Technology

Tanks C-101, C-102, C-103, C-104, C-106, C-108, C-109, C-110, C-111, and C-112 were retrieved or initial retrieval actions were done using a modified sluicing method described in RPP-RPT-33060, *Retrieval Data Report for Single-Shell Tank 241-C-103*. Modified sluicing involves the use of a liquid (DST supernate) in a controlled manner to dissolve the soluble waste materials and/or break down solids into waste slurry (watery mixture of insoluble waste materials) for transfer from the SST to the DST. The supernatant liquid from the DST is reused to provide the liquid for subsequent sluicing. An in-tank camera is installed to monitor the tank waste retrieval operations during the sluicing process. A modified slurry distributor is installed in the double-shell receiving tank to distribute the waste slurry.

Some of these tanks have what are termed "hard waste heels" remaining after modified sluicing was completed to the limit of the technology. At Tank C-106, the hard heel in the tank could not be broken up with water. Supernate and oxalic acid were added to the tank to dissolve residual wastes and reduce particle size. The resulting waste slurry was then pumped to a receiving DST. For Tanks C-101, C-103, C-104, C-107, C-108, C-109, C-110, C-111, and C-112, retrieval operations have been completed to the limit of modified sluicing technology. Further retrieval operations in these tanks have taken place to meet the performance criteria, or are pending future deployment (RPP-21895, *241-C-103 and 241-C-109 Tanks Waste Retrieval Work Plan*; RPP-22393, *241-C-102, 241-C-104, 241-C-107, 241-C-108 and 241-C-112 Tanks Waste Retrieval Work Plan*; RPP-22520, *241-C-101 and 241-C-105 Tanks Waste Retrieval Work Plan*; RPP-33116, *241-C-110 Tank Waste Retrieval Work Plan*; RPP-37739, *241-C-111 Tank Waste Retrieval Work Plan*; and RPP-13707, *Process Control Plan for 241-C-106 Closure*).

3.5.2 Mobile Arm Retrieval System

Waste in Tank C-107 was retrieved using the mobile arm retrieval system (MARS) using a "sluicing" configuration. The MARS provided a mechanical platform to enable the solid tank waste to be physically dislodged and transferred from the tank by pumping the waste and sluicing liquid. The MARS can also be configured such that the dislodged waste can be then pumped out of the tank using a vacuum hose-and-nozzle assembly that is part of the articulated-mast system, minimizing the fluid volume within the tank. This latter configuration was used in Tank C-105. The MARS allows the liquid discharge nozzles on the mast to be moved and "fan" the waste to fluidize it, or to be placed in a stationary position with the mast positioned in the center of a tank (articulated mast system). In either mode the dislodged waste is then pumped out of the tank using a pump assembly or a vacuum hose-and-nozzle assembly. After retrieval, the mast can be used to rinse the tank walls and in-tank equipment. A 102 cm (40 in.) diameter hole was cut in the domes of Tanks C-105 and C-107 to provide access for the MARS (RPP-22520 and RPP-22393, respectively).

3.5.3 Vacuum Retrieval Technology

Vacuum-based retrieval uses a vacuum system deployed from an articulated-mast system in the center of the tank. The rotating arm can reach the entire tank base of 200-series tanks, but only a portion of the base of 100-series tanks, which have a larger diameter.

The 200-series tanks were retrieved using a vacuum retrieval system (RPP-RPT-30181, *Retrieval Data Report for Single-Shell Tank 241-C-201*; RPP-RPT-29095, *Retrieval Data Report for Single-Shell Tank 241-C-202*; RPP-RPT-26475, *Retrieval Data Report for Single-Shell Tank 241-C-203*; and RPP-RPT-34062, *Retrieval Data Report for Single-Shell Tank 241-C-204*). Because the 200-series tanks are assumed to have leaked, the vacuum retrieval technology was chosen because it minimized water addition to the tanks. The vacuum retrieval system consists of an articulating mast system with a vacuum head, a vacuum pump, a slurry vessel, and slurry transfer pumps. A ventilation system, control trailers, and associated piping and utilities make up the remaining system. The retrieval system and its operation are described in RPP-16945, *Process Control Plan for the 241-C-200 Series Waste Retrieval System*.

3.6 RESIDUAL WASTE INVENTORY

This section provides the estimated volume and radiological and non-radiological inventory for waste residuals that may remain in tanks, ancillary equipment, and pipelines in C Farm at the time of closure. The information is the summary of RPP-RPT-42323, *Hanford C-Farm Tank and Ancillary Equipment Residual Waste Inventory Estimates*. The document was released in May 2014. The report incorporated additional data obtained from and changes in tank inventories through January 1, 2014. These inventory estimates will be used as source terms for C Farm risk assessments.

3.6.1 Retrieved Tanks

As of January 2014, waste has been retrieved from 11 SSTs in C Farm (C-101, C-103, C-104, C-106, C-108, C-109, C-110, C-201, C-202, C-203, and C-204). As of September 2014, retrieval operations were certified complete for Tank C-107. Tank C-112 was declared retrieved to the limit of technology on January 31, 2014.

The waste residual inventory was calculated based on:

- Retrieval data reports
- Closure inventory reports
- Best basis inventory (BBI) data as of January 1, 2014
- Post-hard heel retrieval camera/computer-aided design (CAD) modeling system waste Volume Estimate for particular tanks.

Figure 3-5 identifies the status of the WMA C SSTs.

3.6.2 Not-Yet Retrieved Tanks

Residual inventory estimates for tanks not yet retrieved or in process as reported in RPP-RPT-42323, (Tanks C-102, C-105, C-107, C-111, and C-112) were projected using the

Hanford Tank Waste Operations Simulator Model (HTWOS) model (RPP-RPT-39908, *Hanford Tank Waste Operations Simulator Model [HTWOS] Version 3.0 Verification and Validation Report*). The estimates for residual waste inventories (post retrieval operations) were calculated assuming a final waste tank inventory volume of 10.2 m^3 (360 ft^3) (performance goal and the termed "threshold level").

The HTWOS model is a dynamic flowsheet mass balance model that tracks and predicts the transfers and storage of waste over the entire River Protection Project mission (from current tank contents through treatment to disposal). The HTWOS model estimates the time requirements of key process steps and the life-cycle system mass balance using a well-defined set of assumptions (the current set being described in ORP-11242, *River Protection Project System Plan,* Rev. 6).

3.6.3 Ancillary Equipment

Ancillary equipment in C Farm was used in support of the transfer and storage of waste within WMA C tanks; it is a complex waste transfer system comprised of pipelines/transfer lines, diversion boxes, valve pits, and other structures, including the C-301 Catch Tank and the tanks in the 244-CR Vault.

Waste residuals described in this section are based on an assumption that waste will not be removed from pits or transfer pipelines during or after retrieval, and waste volume and inventory for these system components will remain unchanged. However, waste will likely be removed from catch tanks and inactive miscellaneous underground storage tanks as determined during the closure process. No decision or direction has been given to date regarding removal of waste from ancillary equipment. Waste concentrations are assumed to be less than or equal to the average January 1, 2014 BBI concentration of C Farm tanks.

3.6.3.1 C-301 Catch Tank and 244-CR Vault. Tank C-301 is an underground tank classified as an inactive miscellaneous underground storage tank. The description and waste volume estimates for C-301 Catch Tank and the 244-CR Vault are found in the stabilization evaluation in WHC-SD-EN-ES-040, *Engineering Study of 50 Miscellaneous Inactive Underground Radioactive Waste Tanks Located at the Hanford Site, Washington*, RPP-RPT-45723, *Catch Tank 241-C-301 Retrieval Feasibility Study*, and RPP-RPT-24257, *244-CR Vault Liquid Level Assessment and Video Inspection Completion Report*.

3.6.3.2 Pits. The estimate for content of the pits will vary during retrieval of tanks. It was assumed that the 2002 estimate of 120 L (32 gal) of waste is in the pits now, and would remain in the pits at closure. This estimate was determined by multiplying the wetted surface area of the pits by a waste thickness of 0.40 cm (0.156 in.) times a grout formation factor of 0.30 (RPP-15043, *Single-Shell Tank System Description*).

It was assumed that waste will not be removed from pipelines during or after retrieval and waste volume and inventory for the pipelines will remain unchanged. Residual waste concentrations were assumed to be the average 2002 BBI concentrations for waste in C Farm tanks.

3.6.3.3 Diversion Boxes. Diversion boxes are flushed and drained after use. Tank farm operators indicate that little or no waste remains in the diversion boxes following retrieval. Therefore, it was assumed that diversion boxes are cleaned out and little or no waste will remain in the boxes at closure. No current waste estimates for diversion boxes were determined. It was also assumed that any waste in diversion boxes will be removed after retrieval.

3.6.3.4 Pipelines. Over 12.9 km (8 mi) (RPP-50233) and 230 separate pipelines with different diameters and lengths exist in C Farm. After their use, pipelines were flushed in an attempt to remove residual waste and it is expected that little residual waste remains in the pipelines. However, some pipelines may have been plugged, some leaked and little characterization of pipelines has been performed to date.

The amount of waste remaining in pipelines is unknown. For the purposes of re-estimating the pipeline residual, a conservative percent volume of residual was established. The method was developed based on the length and size of pipelines in the farms and operations information. These revised assumptions result in a residual pipeline volume of 6,000 L (1,600 gal) as documented in RPP-PLAN-47559. It was assumed that waste will not be removed from transfer pipelines during or after retrieval and waste volume and inventory for these system components will remain unchanged.

Pipeline residual volumes and concentrations remain the largest gap in current knowledge of the WMA C. However, given that pipelines were flushed and few pipelines in C Farm are believed to be plugged, pipeline residual volumes are expected to be orders of magnitude lower than catch tank and residual inventories. As a result, although uncertainty is high, pipeline residual inventory estimates are a small part of the overall residual waste inventory in C Farm. Table 3-3 provides 2014 waste volume estimates for C Farm tanks, ancillary equipment, and pipelines.

Table 3-3. Residual Waste Estimates for C Farm Tanks, Ancillary Equipment, and Pipelines

	Updated Estimates[a]		
Total Residual Inventory Estimate	**Volume (kL[(kgal])**	**Chemicals (kg)**	**Radionuclides (Ci)[b]**
Tanks retrieved	71.7 (18.9)	4.76E4	1.39E5
Tanks not retrieved or in-process	51.0 (13.5)	5.12E4	4.01E5
C-301 Catch Tank and 244-CR Vault	11.1 (2.9)	7.76E3	1.69E4
Pits	0.1 (0.03)	84.8	184
Pipelines	6.1 (1.6)	4.24E3	9.22E3

[a] Updated estimates based on information as of January 1, 2014 assume 360 ft^3 of residual waste for tanks not yet retrieved (C-102, C-105, C-107, C-111, and C-112) and 90% retrieval for waste in catch tanks.

[b] Radionuclides are decayed to January 1, 2020 for 241 C Tank Farm closure assessments.

3.7 ASSESSMENT OF KNOWN OR SUSPECTED UNPLANNED RELEASES AT WMA C

The release estimates and information presented in this section were developed and documented in RPP-ENV-33418, *C Farm Leak Inventory Assessments Report.* RPP-ENV-33418 was prepared in accordance with the process and conditions outlined in RPP-RPT-32681, *Process to Assess Tank Farm Leaks in Support of Retrieval and Closure Planning.*

The C Farm leak assessment work was started in 2006 and focused primarily on tanks classified as "assumed leakers" and three major UPRs in C Farm. The initial assessment discussed potential overflows from spare inlets and cascade lines, transfer line leaks, and sources of ^{60}Co plumes in the vadose zone. However, the assessment did not attempt to quantify the releases and did not review process waste information for tanks classified as "sound." In 2011, the tanks were reassessed to include review of additional field characterization data.

In RPP-ENV-33418, each release event is presented with a description of release, release type (point or non-point source), estimated depth of release, estimated time of release, and estimated magnitude of release (volume and inventory). Uncertainties associated with release parameters are also summarized.

Indications of tank waste losses at WMA C are derived from historical operations records (e.g., in-tank liquid level measurements) and subsurface monitoring data, mostly from drywells installed around the 100-series tanks to measure radiation from gamma-emitting radionuclides dissolved in leaked tank waste fluids. No drywells are installed adjacent to the 200-series tanks. Unexplainable liquid level drops in tanks and the occurrence of high radiation readings were also indicators of liquid loss events.

Known or suspected UPR sites are summarized below. The summary includes the original information used in the DQO (RPP-RPT-38152) which is presented first, followed by any updates that may have occurred since the DQO was published. Leak loss events related to the SSTs are given in Table 3-4.

Leak loss events related to the SSTs are discussed in Section 3.7.1 and waste release information is provided in Table 3-4. Table 3-4 also provides waste release information for the three main UPR sites (i.e., UPR-200-E-81, UPR-200-E-82, and UPR-200-E-86). Known or suspected UPR sites are summarized in Section 3.7.2. Information used in the DQO (RPP-RPT-38152) is presented in these sections, as necessary, along with relevant updates.

Table 3-4. Waste Releases From and Around Each 241 C Farm Tank*

Tank/ UPR	Waste Release Volume (gal)	^{60}Co, Ci	^{137}Cs, Ci	^{99}Tc, Ci	Basis
C-101	37,000 20,000 20,000	0.17 NA 0.202	800 NA 4,260	0.22 NA 1.12	Estimated waste release volume based on an assumed CW waste type and drywell readings. According to surface level measurements there was a waste release of up to 37,000 gal, likely a combination of a CW release from the spare inlet and condensate (depending on condenser operation).
C-104	28,000 0 0	1.3 NA NA	80 NA NA	0.03 NA NA	Cascade line leak next to Tank C-104. Tank C-104 was filled to 560,000 gal of CW waste in 1965. No transfer was identified; however, the surface level decreased to the spare inlet elevation of 532,000 gal resulting in a possible 28,000-gal release.
C-105	2,000 2,000 2,000	0.08 NA 0.306	2,500 NA 4,150	0.8 NA 1.51	Release range from 40 to 2,000 gal (<2,000 gal) of P1 supernate (PSN). Cascade line release and possible tank leak.
C-108	18,000 0 0	0.8 NA NA	50 NA NA	0.02 NA NA	Cascade line leak; Tank C-108 filled to 568,000 gal of CW-HS waste in 1965; decreased in surface level to 532,000 gal through a transfer to Tank C-102; waste loss assumed to be 18,000 gal based on ^{60}Co and soil moisture determinations. Waste volume based on CW waste composition.
C-110	2,000 0 2,000	0.3 NA 0.00619	300 NA 350	0.11 NA 0.114	No observed liquid level decrease and less than 1,000 pCi/g ^{137}Cs activity in drywell.
C-111	0 0 0	NA NA NA	NA NA NA	NA NA NA	Waste level decrease attributed to evaporation.
C-112	7,000 0 0	0.33 NA NA	20 NA NA	0.0075 NA NA	Transfer line leak from diversion box 252-C to Tank C-112. Line leak likely prior to 1974; waste type in Tank C-112 was CW-IX; 7,000 gal based on ^{60}Co plume and 5% soil moisture content above background.
C-201	0 550 550	NA NA 0.0405	NA NA 43	NA NA 0.0107	Surface level discrepancy likely due to evaporation.
C-202	0 450	NA NA	NA NA	NA NA	Surface level discrepancy likely due to evaporation.

Table 3-4. Waste Releases From and Around Each 241 C Farm Tank*

Tank/ UPR	Waste Release Volume (gal)	^{60}Co, Ci	^{137}Cs, Ci	^{99}Tc, Ci	Basis
	450	0.0331	35.2	0.00877	
C-203	0 400 400	NA NA 0.0313	NA NA 33.2	NA NA 0.00829	Surface level discrepancy likely due to evaporation.
C-204	0 350 350	NA NA 0.0266	NA NA 28.2	NA NA 0.00704	Surface level discrepancy likely due to evaporation.
UPR-200-E-81	36,000 NA 36,000	0.36 NA 11.5	350 NA 350	0.11 NA 0.112	Volume: 36,000 gal ^{137}Cs: 350 Ci
UPR-200-E-82	2,600 NA 2,100	0.4 NA 0.293	5,500 NA 4,400	3.0 NA 2.07	Volume: 2,600 gal ^{137}Cs is 5,500 Ci (sample concentration times volume). 1969 ^{137}Cs conc. = 4.28 Ci/gal For other analytes, the leak inventory values for radiological constituents are based on the activity per unit leak volume for the analyte in HDW P2 wastes times the ratio of the 1969 concentration for ^{137}Cs to the ^{137}Cs concentration in HDW for P2 waste, times the updated volume.
UPR-200-E-86	17,000 NA 17,000	0.7 NA 0.733	11,500 NA 11,500	2.9 NA 2.85	Volume: 17,000 gal Maximum, Based on mass balance estimate. Estimate appears to be high based on waste site investigations. ^{137}Cs is 11,500 Ci (1971 sample concentration times the updated volume).

*Cesium-137 and ^{60}Co values are approximations decayed to January 1, 2001.

CW = cladding waste, aluminum clad fuel
HS = Hot Semiworks strontium purification waste (1961-1968)
IX = ion exchange
NA = not available or not applicable
P1 = Plutonium Uranium Extraction high level waste (1956-1962), also referred to as PSN waste type

Reference: RPP-ENV-33418, *Hanford C-Farm Leak Assessments Report: 241-C-101, 241-C-110, 241-C-111, 241-C-105 and Unplanned Waste Releases*, Rev. 1. Information in yellow is from HNF-EP-0182, *Waste Tank Summary Report for Month Ending July 31, 2014*, Rev.319 and information in blue is from RPP-RPT-42294, *Hanford Waste Management Area C Soil Contamination Inventory Estimates,* Rev. 1. Information from RPP-RPT-42294, Rev. 1 is used in Section 5.5 discussions.

3.7.1 Releases from SSTs

The following subsections summarize the investigations undertaken of the vadose zone surrounding several SSTs that were considered as "sound" in WMA C. The original effort was to differentiate what were tank liner leaks of waste (loss of tank liner integrity) from what were waste releases due to process or ancillary system release of waste to the vadose zone (e.g., tank overfills and evaporation). In the progression of the investigation several C Farm tanks that were designated as "assumed" leakers were determined to have incurred a waste release and the tank integrity had not been lost. The investigations were performed to support the tank leak assessment report RPP-ENV-33418.

3.7.1.1 Tank C-101 Tank Leak Investigation. Based on the original assessment of Tank C-101 given in RPP-ENV-33418, it was concluded that available data are insufficient to establish a minimum range or leak volume (mass) for Tank C-101. The upper range is estimated to be 136,275 L (36,000 gal). The volume of the Tank C-101 waste release is in question because of inconsistencies in low-activity measurements in surrounding drywells and expected drywell radioactivity for a large leak of high-activity waste. As a result, the liquid level decrease was likely a dilute condensate loss through spare inlet nozzles rather than a leak of high-activity PUREX waste. It was concluded during the reassessment process that a 3,785 L (1,000 gal) release, as discussed in RPP-23405, is possible but indefensible and in the absence of better supporting evidence, to continue with the estimated leak volume at 75,708 L (20,000 gal) as reported in HNF-EP-0182, *Waste Tank Summary Report for Month Ending July 31, 2014*, Rev. 319. The 75,708 L (20,000 gal) leak volume estimate apparently represents a compromise estimate reached in 1980 and is based on unspecified evidence or an evaluation that is not documented in the record.

As a result of the reassessment, it was recommended that (1) the area in the vicinity of Tanks C-101, C-104, and C-105 undergo soil investigation directed by a DQO, (2) further tank assessments were needed to fully establish to the source of the nearby plume (Tanks C-104 and C-105), and (3) maintain HNF-EP-0182 waste volume estimate and notes related to Tank C-101.

Subsequent assessments concluded that Tank C-101 appears to have been overfilled (visual waste surface level staining shown on the concrete dome) as the probable cause of the observed waste release; however, the observed surface level decrease could also be attributed to evaporation. Liquid level measurements showed that the waste volume from 137 cm (54 in.) and below was steady, indicating the tank release was due to a spare inlet release or a tank liner leak high on the side of the tank. The estimated waste release volume was based on an assumed CW waste type and drywell readings. According to surface level measurements there was a waste release of up to 140,060 L (37,000 gal), likely a combination of a CW release from the spare inlet and condensate (depending on condenser operation). The estimated radionuclide release is 800 Ci of ^{137}Cs and 0.22 Ci of ^{99}Tc.

3.7.1.2 Tank C-105 Tank Leak Investigation. Tank C-105 is categorized as a "sound" tank (HNF-EP-0182, Rev. 319, pp. 23). The operational history for Tank C-105 for 1947 through 1980 is presented in WHC-MR-0132, *A History of the 200 Area Tank Farms*, and summarized in the following discussion. The radioactivity detected in drywells around Tank C-105 suggests

there may have been several waste release events. The pipeline, Tank C-104 to Tank C-105 cascade line, and spare inlet nozzle waste loss events are thought to be responsible for the radioactivity detected at one or more depth intervals in drywells 30-04-02, 30-04-03, 30-04-04, 30-04-05, 30-04- 08, 30-05-06, 30-05-09, and decommissioned borehole C4297.

Potential sources of the waste losses include the tank, nearby transfer pipelines, the cascade line from Tank C-104, waste releases around Tank C-104 atmospheric condenser, and/or the spare inlet lines to Tank C-105. The peak radioactivity detected in drywell 30-05-07 is approximately at the same elevation as the base of Tank C-105. Therefore, waste releases from Tank C-105 and even the loss of liner integrity may have occurred. Data recently collected from a nearby characterization borehole (C4297) showed nitrate and ^{99}Tc at greater depths supporting the plausibility of a liner leak event. Based on drywell calculations scenarios presented and the absence of ^{137}Cs contamination in borehole C4297 (within 3 m [9 ft] of drywell 30-05-07), contamination below the tank base was estimated to range from (152 to 7,571 L [40 to 2,000 gal]). It was concluded that the activity around Tank C-105 was from several different sources. Probable sources of waste releases to the soil include:

- Releases from the cascade line between Tanks C-104 and C-105
- A leak near the base of Tank C-105
- Releases from spare inlet nozzles
- Condenser leaks and leaks from pipeline V103.

A formal tank leak assessment (RPP-ASMT-46452, *Tank 241-C-105 Leak Assessment Completion Report*) was conducted and based on direct push logging results obtained for the assessment. It was concluded by the integrity assessment panel that the inlet cascade line to Tank C-105 leaked and the tank may have leaked, and the panel recommended that the tank classification be changed to "assumed leaker."

3.7.1.3 Tank C-110 Tank Leak Investigation. The Tank C-110 release appears to be the result of a tank overfill/overflow at the tank internal elevation of 5.3 m (17.3 ft) above the tank bottom. Because no liquid level decrease was observed based on liquid level accuracy for the manual tape and electrode instrumentation in the tank in 1971 and 1972, the volume of the loss was previously determined to be less than 7,571 L (2,000 gal). Rough calculations of the gamma activity observed in drywells indicate that the volume could have been significantly smaller. The supernate was predominantly B Plant cesium recovery (CSR) waste. Supernatant samples of this waste obtained in 1975 provide waste composition measurements. The measured 1975 Tank C-110 supernate composition appears to be consistent with the measured ^{106}Ru drywell activity.

An integrity assessment was conducted in 2008 for Tank C-110 (RPP-ASMT-38219, *Tank 241-C-110 Leak Assessment Report*). The assessment concluded that Tank C-110 spare inlets were the apparent source for the waste release based on the stable tank liquid level during the investigation period when the drywell gross gamma peak was discovered, the natural decay of the drywell gross gamma peak following discovery, and an interior tank photo showing evidence of waste in and above the tank inlet line penetrations. It was recommended that the tank be reclassified as "sound."

3.7.1.4 Tank C-111 Tank Leak Investigation. Tank C-111 was classified as questionable integrity in 1968 (Letter 8901832B R1, "Single-Shell Tank Leak Volumes") and declared a suspected leaker in late 1973 (ARH-2794-D, *Manufacturing and Waste Management Division Waste Status Summary October 1, 1973 through December 31, 1973*). As a result, supernatant was transferred out of Tank C-111 during 1974. Tank C-111 was removed from service in 1975 and the final waste transfer out of the tank was completed in 1976.

Evaporation calculations and plotted liquid level and evaporation rates clearly indicate that the liquid level decrease observed in Tank C-111 can be attributed to evaporation and suggest that high tank waste temperature information was apparently not available for previous assessments. A formal tank leak assessment (RPP-ASMT-39155, *Tank 241-C-111 Leak Assessment Report*) was conducted in 2008 and concluded that Tank C-111 likely did not leak and recommended that the Tank C-111 leak integrity status be revised to "sound." The report concluded that the most probable explanation for the 1965 to 1969 surface level decrease in Tank C-111 was evaporation due to the waste being at least 88°C (190°F).

3.7.1.5 200-Series Tank Leak Investigation. Liquid level decreases based on in-tank measurements and tank photo evaluations were observed in 1984 for Tank C-203, and tank photos showed that the liquid level decreased in Tank C-201 between 1981 and 1986 and in Tanks C-202 and C-204 between 1980 and 1983. Tanks C-201, C-202, and C-204 were filled above the spare inlet level of 208,000 L (55,000 gal) several times between 1955 and 1970 when the tanks contained Strontium Semiworks Facility process waste.

Further review of the 200-series tanks shows that the liquid level decreases were due to evaporation. It was concluded that the spare inlet overflows relative to Tanks C-201, C-202, or C-204 would likely result in releases too small to measure. However, ^{235}U and ^{238}U were detected in the vadose zone at concentrations of about 2 and 20 pCi/g, respectively at 31 m (100 ft) bgs in borehole 299-E27-7, 61 m (200 ft) northeast of the tanks. Uranium has not been detected at any other location in C Farm. Transfer line releases from the 200-series tanks appear to be the likely source for uranium and cyanide in well 299-E27-7. Other potential sources for such waste releases are overflows through spare inlets, discharges to French drains, and UPRs north of the well. Formal tank integrity assessments were recommended for all four tanks. Ongoing characterization around these tanks may aid in the integrity assessments.

3.7.2 Unplanned Releases

Sixteen UPRs have been documented within or adjacent to WMA C. The following brief descriptions of these UPRs are summarized from the WIDS General Summary Reports (DOE/RL-88-30) and represent the best available information on the nature and extent of releases at the time of the DQO (RPP-RPT-38152). Substantial uncertainty exists in the volume and content of UPRs from components within the WMA C. These UPRs are summarized below along with any available updates. A detailed description of UPRs recorded in and near WMA C is provided in Appendix F.

UPR-200-E-16 is a surface spill associated with an overground transfer pipeline between Tanks C-105 and C-108. The surface spill associated with this release is located 18 m (60 ft)

northeast of Tank C-105 and occurred in 1959. The spilled liquid was classified as CW from the PUREX process and was an estimated 189 L (50 gal).

UPR-200-E-27 was a particulate release that is located just east of the 244-CR Vault and extends east beyond the tank farm fenceline. DOE/RL-92-04 indicates the surface contamination was deposited in 1960, but does not identify the source(s) of the contamination. However, the November 1960 monthly report for the tank farm contractor reports the particulate contamination was due to work in C Farm diversion boxes and the 244-CR Vault (HW-67459, *Chemical Processing Department Monthly Report for November 1960*, pp. B-2 and B-3). Activity levels around the vault were on the order of 50 to 100 mrad/hr. Since the UN-200-E-27 release consisted of airborne particulate contamination, the impact was limited to the ground surface.

UPR-200-E-68 was a particulate release, wind-borne surface contamination spread from the diversion box 241-C-151. Activity consisted of beta/gamma particulates, with readings ranging from 2,000 counts per minute to 5 rad per hour on the diversion box cover blocks and other surfaces in 200 East Area. The release occurred in 1985 and was subsequently decontaminated to background radiation levels or covered with clean soil for later decontamination (the source document is inconclusive). Sometime after the release, the diversion box 241-C-151 was opened, flushed, and sprayed with Turco[1] Fabri-Film to physically fix contamination to the structure surface.

UPR-200-E-72 occurred in 1985 and is located south of WMA C near the 216-C-8 Crib. The source of the contamination was attributed to buried contaminated waste. The waste posed little release potential because the contamination was fixed in place with Turco FabriFilm. The source of the contamination was determined to be from the burial of previously undocumented contamination material. The area was surrounded with a chain and posted as a Surface Contamination Area; however, the site is no longer marked or posted. No information regarding the buried material was given in the WIDS report, and it is assumed that the contamination extends to the depth of the buried material, but the aerial extent and depth are not known. The volume of the contamination was not specified.

UPR-200-E-81 resulted from an October 1969 underground transfer pipeline leak/release located northeast of the 244-CR Vault near the diversion box 241-CR-151. The estimated 136,275 L (36,000 gal) of waste released from the pipeline consisted of PUREX CW. The site was covered with 0.5 m (18 in.) of backfill and clean gravel.

UPR-200-E-82 was a waste release in December 1969 from a feed line running between Tank C-105 and the 221-B Building. The release was discovered near the diversion box 241-C-152. The liquid release, an estimated 9,842 L (2,600 gal), flowed from the vicinity of the diversion box 241-C-152 to the northeast, downgrade, until it pooled into an area measuring 0.46 m^2 (5 ft^2) outside the WMA C fence. The contaminated site was covered with 0.6 m (2 ft) of dirt in 1969. The WIDS report states that additional decontamination of the area was done in 1985. A Gunite[2] cap was installed over the release site, but not until 20 years after the release.

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[1] Turco is a registered trademark of Henkel Corporation, Rocky Hill, Connecticut

[2] Gunite is a registered trademark of Allentown Equipment, Allentown, Pennsylvania.

Based on historical information a number of vertical direct push holes were drilled, logged, and sampled in the vicinity of the UPR in 2008 and 2009. Three slant direct push holes were also emplaced around the site of the pipeline leak and electrodes installed in the slant holes in 2006 (RPP-RPT-50052, *Surface Geophysical Exploration of UPR-200-E-82 Near the C Tank Farm*). Three-dimensional SGE investigations and analyses were performed for UPR-200-E-82 in 2011. Surface geophysical exploration and direct push results are presented in Section 5. Direct push results close to the Gunite cap showed some elevated gamma activity and slightly elevated nitrate (peak levels of 20 µg/g) and ^{99}Tc (peak levels of 4 pCi/g) in the soil. The SGE results showed a general distribution of high electrical resistivity values beneath the UPR-200-E-82 release. It was concluded that the pipeline release was either of low volume and not a source of groundwater contamination for the WMA, or actions taken to control exposure to the spill have resulted in it being diluted and/or flushed into the underlying groundwater. The size of the release favors the former interpretation. The SGE and direct push results appear to be consistent with a 9,842 L (2,600 gal) PSN line leak. Higher gamma activity was expected, but the high activity may be directly under the Gunite cap and direct push holes may have been too deep to detect it.

UPR-200-E-86 was a release of a pipeline used to transfer waste from the 244-AR Vault to WMA C. The depth of the pipeline was 2.5 m (8 ft) bgs. The release occurred in March 1971 near the southwest corner of WMA C, outside the fence. The spill was estimated to consist of 25,000 Ci of ^{137}Cs in 65,809 L (17,385 gal) of waste (RHO-CD-673, *Handbook 200 Areas Waste Sites*). The soils surrounding the pipeline were sampled, and it was determined the contamination had not penetrated below 6 m (20 ft). The contamination plume volume was estimated at 37 m^3 (1,300 ft^3). The surface of the release site has been stabilized. The release site is demarcated with concrete AC-540 marker posts and signs indicating "Underground Radioactive Material." A Gunite cap was subsequently installed on the soil surface above this leak location.

UPR-200-E-91 is located 30 m (100 ft) from the northeast side of the tank farm and resulted from surface contamination that migrated from WMA C. The date of the occurrence, its aerial extent, and the nature of the contamination are not specified. DOE/RL-92-04 states that the contaminated soil was removed, and the area was released from radiological controls.

UPR-200-E-99 is surface contamination that resulted from numerous piping changes associated with the 244-CR Vault. It is located south of 7th Street, directly south of the 244-CR Vault, and was established as a release site in 1980, although the actual occurrence date is unknown. A radiological survey conducted in support of herbicide applications in 1981 found no detectable contamination in the release area. As a result of the radiological survey, surface contamination postings were removed on March 5, 1981, and the area was released from the radiation zone designation.

UPR-200-E-100 this release area was determined to be due to windblown particulates and biological transport (rodent feces) from the tank farms and the 244-A Lift Station (WIDS) that occurred in the mid-1980s. It is located 60 m (197 ft) south and east of WMA C and surrounds the 244-A Lift Station.

UPR-200-E-107 resulted from a surface spill. The exact location of this release is unclear. WIDS states that the release was reported at the Tank 241 CR-100. The original incident report states it occurred at the Tank CR-110 in the 241 CR Farm. WIDS also states that the location should be Tank C-110 in C Farm. DOE/RL-92-04 states that a spill occurred on November 26, 1952, when a pump discharged an estimated 19 L (5 gal) of liquid to the ground surface during a pump installation. "Due to the magnitude of the ground contamination, it was decided to excavate a hole and blade the contamination earth into the hole" (RPP-RPT-29191, pp. 102).

UPR-200-E-115 is located east of C Farm, south of 8th Street, across an unnamed gravel road. As a result of routine radiological surveys that confirmed radiological contamination in this area, the Dyncorp Integrated Soil, Vegetation and Animal Control group submitted a Waste Site Information Form to WIDS in 2000. The site was classified as "Discovery" until programmatic responsibility and ownership were determined in March 2001. No radiological surveys can be found to provide information about the radiological conditions inside the posted area. Very little is known about this posted area. During an interview with the Dyncorp Radiological Group in October 2000, an assumption was made that the area was posted by the Tank Farm Contractor East Tank Farm Radiological Control Group. A review of underground pipeline locations did not indicate a pipeline at this location. In 1980, a larger area of posted contamination (UPR-200-E-91) had been located in the same vicinity. The contaminated soil from UPR-200-E-91 was removed in 1981. Because so much time has passed, it is difficult to determine if the two sites are related. In June 2004, UPR-200-E-115 was stabilized with gravel and posted as an Underground Radioactive Material Area.

UPR-200-E-118 is located in the northeast portion of the tank farm and extends north up to 305 m (1,000 ft) beyond the fenceline. It was the result of an airborne release from Tank C-107 that occurred in April 1957. The highest exposure rate was estimated at 50 mrem/hour at the ground surface (DOE/RL-92-04).

UPR 200-E-135 is located south and west of WMA C. This site was identified as contaminated vegetation which has subsequently been removed. The source of contamination is suspected to be an underground leaking pipe in the area.

UPR-200-E-136 is a release in 1969 of (64,345 to 90,840 L [17,000 to 24,000 gal]) of waste from Tank C-101. The quantity and type of waste released from Tank C-101 is uncertain (RPP-ENV-33418).

UPR-200-E-137 occurred when water entered Tank C-203, migrated through the saltcake, and either became entrained in the saltcake or leaked out of the tank. The leak was 1,514 L (400 gal) of PUREX HLW. The waste in Tank C-203 was subsequently determined to be sludge and was retrieved to a DST in 2006. Subsequent review indicated that the water evaporated and was not released (RPP-ENV-33418).

3.7.3 Waste Losses from Spare Inlet Nozzles and Cascade Lines

The tanks in WMA C were designed and equipped with spare inlet nozzles. Normal construction was to insert process waste transfer pipelines through the inlet nozzle and have the pipeline

protrude into the tank. A seal was installed around the process waste transfer pipeline at the nozzle. The 100-series tanks are also arranged in four cascades of three tanks each. After filling, the first tank's waste then flows to the second tank, and once that is filled, the waste flows to the third and final tank in the cascade.

Tank waste may have been discharged from the spare tank inlet nozzles if the waste elevation in the tank exceeded the elevation of the inlet nozzles. Cascade lines that lie below the spare inlets in elevation are also submerged when the waste level exceeds the spare inlet level. When the waste exceeds the operating capacity of the tank, it is likely that the waste would find an outlet over the top of the tank liner, breach a weak spot in the cascade (perhaps where it exits or enters the tank liner), or breach the spare inlet lines. Such events have occurred when the inlet nozzles on an SST were below the tank waste surface level. Although the inlet nozzles on several SSTs were known to be submerged, there are no operational records of the waste releases.

Tanks C-101, C-103, C-104, C-105, C-106, C-109, C-111, C-201, C-202, and C-204 were known to be filled with waste above the elevation of the spare inlet nozzles and cascade lines on several occasions. As previously stated, waste may have been released to the ground from these tanks as a result of overfilling. The date and waste type present in each SST when the tank was filled with waste above the elevation of the spare inlet nozzles are summarized in Table 3-5.

Table 3-5. Potential Waste Losses Through Spare Inlets on WMA C SSTs

Tank	Date	Waste Type Present in Tank
241-C-101	June 1965 to December 1967	Received waste from CR Vault. Tank contains 244-CR Vault waste (28,000 gal), PUREX P2 (452,000 gal), and CWP2 (94 kgal).
241-C-103	October 1953 to March 1957	Tributyl Phosphate Plant (TBP) Waste
	June 1961 to December 1961	PUREX CWP2
241-C-104	August 1958	PUREX CWP1
	June 1965 to March 1966	After receiving 15,000 gal of unknown waste type (likely PUREX CWP2 based on RL-SEP-332, page B-2) from 244-CR Vault, the tank was filled above the spare inlets. Majority of waste in tank is PUREX CWP2
241-C-105	Pre-October 1967	Waste type unknown; soil contamination found beneath spare inlet nozzles during excavation in October 1967
241-C-106	November 1951	Water added to metal waste (MW2)
	December 1965 to March 1966	PUREX P2 high-level waste supernate
241-C-109	June 1961 to December 1961	PUREX CWP2
	June 1965 to March 1968	Tank received 19,000 gal from Strontium Semiworks Facility purification waste (HS). Tank contains 112,000 gal of evaporator bottoms (BT-SltCk), 300,000 gal of PUREX CWP2, and 142,000 gal of HS.

Table 3-5. Potential Waste Losses Through Spare Inlets on WMA C SSTs

Tank	Date	Waste Type Present in Tank
241-C-111	May 1957	TBP Waste
	September 1957	Scavenged 242-B BT-SltCk waste (i.e., concentrated 1C/CW and TBP wastes)
241-C-201	December 1955 to January 1956 June 1961 to June 1963	Strontium Semiworks Facility waste from PUREX flowsheet tests (Note: this is not waste type HS).
241-C-202	January 1957 to March 1957 June 1957 to October 1958 June 1961 to December 1963	Strontium Semiworks Facility waste from PUREX flowsheet tests (Note: this is not waste type HS). Last waste transferred into tank was 201-C Building flush solutions.
241-C-204	March 1968 to March 1970	Strontium Semiworks Facility waste from PUREX flowsheet tests (Note: this is not waste type HS) and 201-C Building flush solutions.

BT-SltCk = Saltcake from operation of 242-B Evaporator (1951-1953) and 242-T Evaporator (1951-1955)
CWP1 = PUREX cladding (coating) waste, aluminum clad fuel (1956-1960)
CWP2 = PUREX cladding (coating) waste, aluminum clad fuel (1961-1972)
MW2 = Bismuth phosphate Metal Waste (1950-1956)
P2 = PUREX high-level waste (1963-1967)
PUREX = Plutonium Uranium Extraction

Reference: RL-SEP-332, *Chemical Processing Department Monthly Report for February, 1965.*

3.7.4 Suspected Pipeline Waste Loss Events

Several pipelines in the WMA C are known to have failed/breached while transferring tank wastes. Table 3-6 identifies seven pipelines in WMA C that are known or suspected to have released waste. The date the breach was detected and the waste type that was released to the soil (if known) are listed in the table. UPRs have been consolidated for some of the failed pipelines in UPR-200-E-133 (Table3-7 footnote). In some cases, the breached pipeline was contained within a concrete diversion box, vault, or pipeline encasement. The surfaces of the concrete structures were coated with a chemically resistant paint. However, the integrity of the coatings and the concrete structures are unknown. It is not known whether waste was released from such concrete structures. Seven potential tank waste loss events not previously reported in DOE/RL-88-30 are identified in Table 3-6. These potential waste loss events resulted from the following:

- Failure of pipeline V172 (June 1964)
- Possible failure of un-numbered pipeline from Cesium Loadout Facility to Tank C-103 (November 1964)
- PUREX coating waste transfer pipeline failure in diversion box 241-CR-151 (February 1965); pipeline number was not provided in reference and could be determined from available information

- Failure of pipeline 8041 (March 1965)
- Failure of a flexible jumper in diversion box 241-CR-152 (May 1966)
- Failure of pipeline V103 (pre-1988)
- Failure of pipeline V112 (date unknown).

Based on the Phase 1 RFI report and the process knowledge summarized above, it was concluded that waste has been released into the vadose zone at WMA C.

Table 3-6. Failed Pipelines in WMA C

Date	Waste Type[a]	Waste Discharged (gallons)	Event Description	References[b]
June 1964	HS - Strontium Semiworks Facility Waste	No estimate	"The underground process line from the 252-C diversion box to 112 tank, C Tank farm, failed. The failed pipeline was isolated. Jumpers were fabricated and installed to establish a new process route." The failed pipeline is line V172.	RPP-RPT-29191, *Supplemental Information Hanford Tank Waste Leaks*, pp. 115
November 1964	Cesium Depleted PUREX HLW (1956-1962) supernate (P1)	No estimate	"Installation was completed on an alternative effluent return route from the Cesium Loadout Building to Tank 103-C." "See drawing H-2-4574, *Process & Service Piping Tanks to Loadout Station* for details of this piping." A three-way ball valve was inserted in the 801-C effluent return line to single-shell tank (SST) C-102 to enable routing waste to SST C-103 or C-102.	RPP-RPT-29191, pp. 115
February 1965	PUREX cladding (coating) waste, aluminum clad fuel (1961-1972) (CWP2)	No estimate	"On February 18, 1965 the 244-CR vault was found flooded up to approximately the level of the tank tops. Immediate steps were taken to reduce the liquid level by jetting the solution to the 011 Tank. Partial cause of the flooding is attributed to a failure in the coating waste line which enters the 151-CR diversion box. Drainage from this diversion box collects in the 002-CR vault sump. Water from a sampler flush line and drainage from rain and snow contributed to the liquid level in the vault. To date, the 001, 002, and 003 sumps have been emptied, and the 011 sump is being emptied, to the 011 Tank. This liquid is being pumped from the 011 Tank to Tank 103-A in the 241-A Tank Farm. In trying to establish a coating waste routing from the Purex Plant to the 241-C Tank Farm a leak was also discovered in the underground line adjacent to the 152-A Diversion Box. Because of the two apparent leaks in this line it has been abandoned as being unusable."	RPP-RPT-29191, pp. 116

Table 3-6. Failed Pipelines in WMA C

Date	Waste Type[a]	Waste Discharged (gallons)	Event Description	References[b]
March 1965	PUREX CWP2	No estimate	"A liquid level rise in Tank 103-C, the cesium feed tank, was apparently caused by a failed line in the encasement between the 152-CR diversion box and Tank 102-C which permitted coating waste from the Purex Plant to leak into the encasement and drain to Tanks 101-C, 102-C, and 103-C via the tank pimp [*sic*] pits. Coating waste has been routed through a spare line to Tank 102-C and no further leaks have been detected. The coating waste solution accumulated in Tank 103-C did not significantly affect cesium loading capability as a cask was loaded normally following the incident." Note: Pipeline 8041 inside a concrete encasement was used to route the PUREX cladding (coating) removal waste (CW) to SST C-102 (see drawing H-2-44501, *Area Map 200 East "A" Plant Facilities*, sheet 92). This encasement traverses from diversion box 241-CR-152 along the west side of SSTs C-101, C-102, and C-103. In order for the PUREX CW to drain into SSTs C-101, C-102, and C-103, the encasement containing the failed transfer pipeline must have partially filled with waste. The integrity of this encasement is unknown and may have leaked waste to the soil. Drawing H-2-2338, sheet 45 indicates pipeline 8041 is out of service. Pipeline 8041 connects from nozzle U-3 in the 241-CR-152 diversion box and nozzle U-2 in pit 02C atop SST C-102.	RPP-RPT-29191, pp. 116
May 1966	PUREX CWP2	No estimate	"A leak in the PUREX coating waste route (152-CR diversion box) was detected by an abnormal liquid level increase of the 002CR vault sump. The leaking flexible jumper in the 152CR diversion box was replaced." Note: Diversion box 241-CR-152 and 244-CR Vault sump are concrete structures with painted surfaces. It is uncertain whether leaked waste was contained inside diversion box 241-CR-152 and 244-CR Vault sump.	RPP-RPT-29191, pp. 118

Table 3-6. Failed Pipelines in WMA C

Date	Waste Type[a]	Waste Discharged (gallons)	Event Description	References[b]
Pre-1988	PUREX HLW (1963-1967) supernate (P2)	No estimate	Pipeline V-103 - "Earlier investigations of the extremely high levels of contamination found between Tanks 104-C and 105-C are described in reference (10). The following observations were documented at that time and were the bases for the conclusion that both tanks were sound: … The fill line V-103 was stated to have been abandoned at an earlier date due to pipeline leakage, and the activity noted in DW 30-03-02 could have been due to migration of pre-existing contamination that was first seen in the exploratory well scans. This line was part of the old PUREX supernatant (PSN) transfer route from Tank 241-AX-101. The material was thermally hot, and water injection was required to maintain a temperature below 60°C. The cause of failure was believed to have been due to thermal shock induced by the intermittent transfers. In-tank photographs failed to show any evidence that either tank was unsound. However, the Tank 241-C-105 photos indicated that the tank had been filled to a level above that of the cascade and sidefill pipelines. The possibility of leakage through the wall penetration seals was discussed. The liquid levels in Tank 241-C-105 and -104 remained at a high level for almost six months after the first exploratory well scans, and the observed activities, including that in DW 30-03-02, had remained stable throughout, whereas seepage from either tank would normally have been seen as steadily increasing radiation at the 35 to 41 feet farm excavation depth. The activity at this depth however has diminished in all wells since 1974."	Internal Memo 13331-88-088, "Environmental Protection Deviation Report 87-10, Radiation Level Increase In Drywell 30-03-09," pp. 4
Unknown	Unknown	No estimate	Line V112 is identified as a leaker adjacent to diversion box 241-C-151. The date and amount of waste leaker from this pipeline is unknown.	RPP-25113,[c] pp. 7

[a] Waste types are defined in RPP-26744, *Hanford Soil Inventory Model, Rev. 1.*

[b] The unplanned releases listed have been combined with UPR-200-E-133, Contaminated Soil at 241-C Tank Farm in accordance with DOE/RL-88-30, *Hanford Site Waste Management Units Report*, Rev. 16, page 665.

[c] RPP-25113, *Residual Waste Inventories in the Plugged and Abandoned Pipelines at the Hanford Site.*

HLW = high-level radioactive waste

PUREX = Plutonium Uranium Extraction (Plant)

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4.0 WMA C FIELD INVESTIGATIONS PROGRAM

As identified in Section 1 of this report, per Appendix I of the HFFACO Action Plan, the RFI may be conducted in multiple phases, if necessary. Based on agreements between DOE-ORP and Ecology, the SST WMA RCRA corrective action program is divided into two phases. With respect to WMA C, the field investigations supporting the RFI were conducted in two main phases, supplemented by additional field work as the Phase 2 work plan was being developed.

The Phase 1 field investigation effort was specifically conducted to identify and confirm major release sites associated with WMA C, and the results from this effort are documented in RPP-35484, *Field Investigation Report for Waste Management Areas C and A-AX*, which is Appendix L of the SST Phase I RFI Report (DOE/ORP-2008-01). RPP-35484 includes a detailed description, gained over 10 years, about the tank farm vadose zone.

While the Phase 1 RFI report was being finalized and prior to the development of the Phase 2 planning documentation, characterization work in the WMA C continued. This transitional characterization effort was called "near-term characterization" (i.e., Phase 1.5) and focused on the deployment of hydraulically-driven direct push technology to push boreholes for geophysical logging, placement of deep electrodes, and collection of soil samples.

For Phase 2, field efforts primarily focused on collecting information to support both risk analyses and the evaluation of alternatives in the corrective measures study (CMS). It should also be noted that historical field efforts, prior to the phased-effort, obtained useful information that was presented in the Phase 1 RFI and will also be used to support the Phase 2 RFI process.

The information on the WMA C field investigations is in the following subsections:

- Pre-RFI Field Efforts (Section 4.1)
- Phase 1 RFI Field Efforts (Section 4.2)
- Phase 1.5 Near-Term Characterization (Section 4.3)
- Phase 2 RFI Field Efforts (Section 4.4).

Because field investigation information for the WMA C pre-RFI investigation and the Phase 1 RFI effort have already been presented in the Phase 1 RFI report, this report provides only a summary of these field investigation programs. The Phase 2 field investigation program, which is the focus of this report, has not been presented previously and is therefore presented in detail. The "near-term characterization" field program is also included in this report to fully present the field programs in which characterization data was obtained for WMA C.

Each of the field program subsections identified above includes the purpose and location of the field effort and identifies the reports documenting the results from these investigations. Figure 4-1 shows the locations of the phased field efforts along with the pre-RFI investigation sites. Additionally, Table 4-1 and Figure 4-2 summarize the overall areas investigated in WMA C for each field effort.

Table 4-1. WMA C Field Investigation Timeline

Field Investigation	Area Investigated (General Description)	Date Investigated
Pre-RFI	• UPR-200-E-82 (Soil sampling) • Overall WMA C (Drywell logging)	1971 1974 - 1994
Phase 1 RFI	• Tank C-105 C4297 (Soil sampling and logging) • UPR-200-E-82 (Soil sampling and logging) • Well 299-E27-22 (Soil sampling) • SGE (well-to-well)	2004 2004 – 2006 2006 2006
Near-term (Phase 1.5)	• UPR-200-E-81 (Soil sampling and logging) • UPR-200-E-86 (Soil sampling and logging)	2008 2007 – 2008
Phase 2 RFI	• Tank C-101 (Soil sampling, logging, and SGE) • Tank C-103 and Building C-801 (Soil sampling, logging, and SGE) • Between C-103 and C-106 (Soil sampling and logging, and SGE) • Tank C-104 (Soil sampling, logging, and SGE) • Tank C-105 (Logging) • Between C-106 and C-109 (Soil sampling, logging, and SGE) • Tank C-108 (Logging and SGE) • Tank C-110 (Soil sampling, logging, and SGE) • Tank C-111 (Logging and SGE) • Tank C-112 (Logging and SGE) • UPR-200-E-81 (Soil sampling, logging, and SGE) • UPR-200-E-82 (Logging and SGE) • UPR-200-E-86 (Logging and SGE) • UPR-200-E-and UPR-200-E-115 (Soil sampling, logging, and SGE) • 200-series tanks (Soil sampling, logging, and SGE) • Overall WMA C (Soil sampling, logging, and SGE)	2008 - 2013

Figure 4-1. Field Investigation Locations supporting WMA C Phase 2 RFI

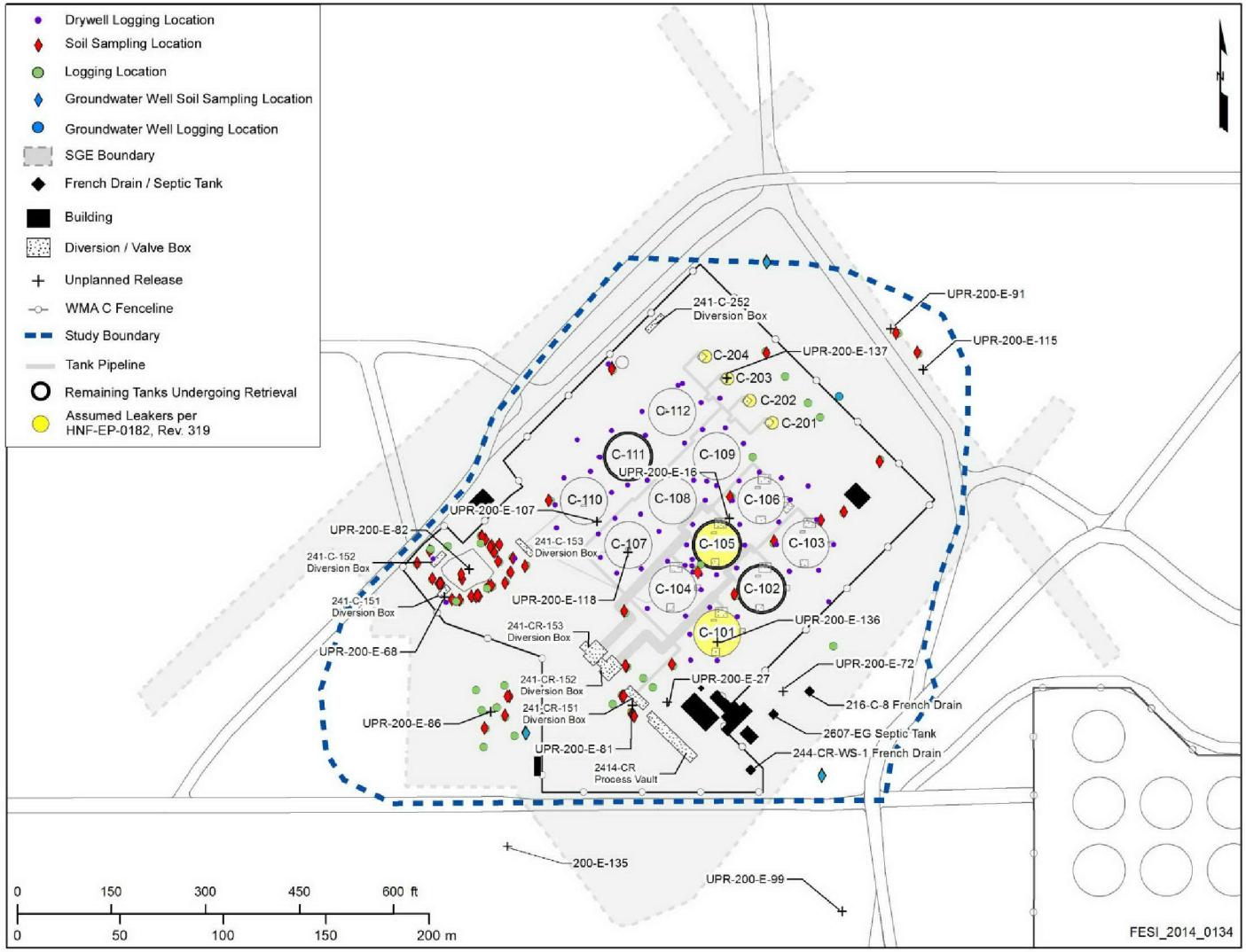
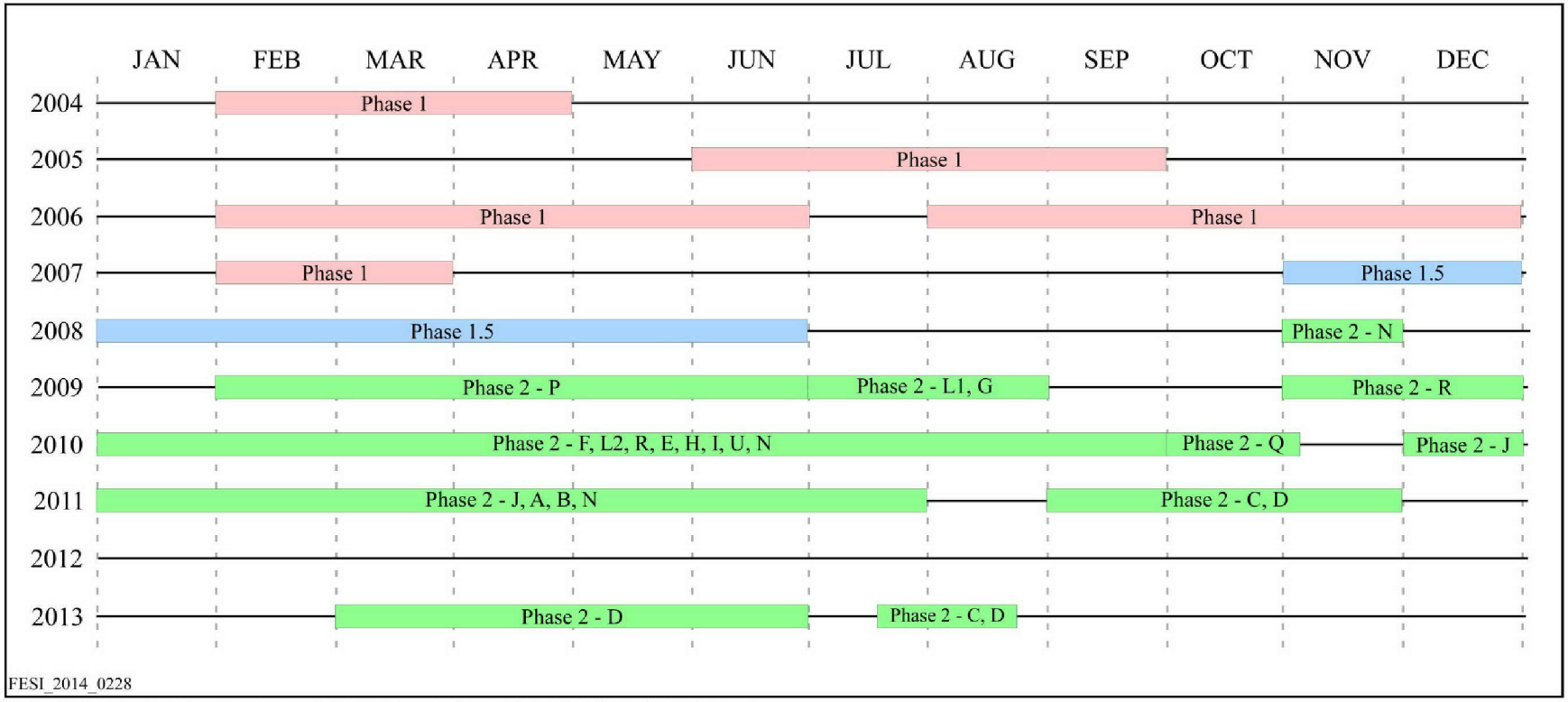


Figure 4-2. Field Investigation Timeline supporting WMA C Phase 2 RFI



Note: Letter designations correspond to site nomenclature from the Phase 2 work plan.

The field methods used to collect data for these programs are also described in each subsection. It should be noted that improvements to field methods have been made over time. Appendix G provides the information on the various methods used to collect data for WMA C RFI effort along with the improvements that have been made. The information and results obtained from these various field efforts are used to describe the nature and extent of contamination associated with WMA C vadose zone and are discussed in Section 5 of this report.

4.1 PRE-RFI FIELD EFFORTS

As identified, various historical investigations have been performed at WMA C over the years. The investigations included in this report include:

- Logging Drywells: WMA C has approximately 70 leak detection drywells that were drilled from 1944 to 1982. Most of the wells were drilled after 1970. The depth ranges for most of these drywells are between 31 and 46 m (100 and 150 ft) bgs. There are usually six drywells surrounding the 100-series tanks (circumference approximately 72 m [235 ft]).

  Gross gamma and spectral gamma logging at these locations have been used to investigate suspected releases. Gross gamma logging has been conducted since the 1940s; however, little data is available before 1974. Much of the digitized data collected after 1974, is available in RPP-8321. The logging used multiple probe types that make comparisons difficult. The probes measured radionuclide activity from 0.3 to 0.5 m (1 to 1.5 ft) of the well casing. Gross gamma logging was often collected well after leak events, sometimes by as much as several years. Baseline spectral gamma logging was conducted in C Farm in 1997 (GJO-98-39-TAR/GJO-HAN-18 and its addendum GJO-98-39-TARA/GJO-HAN-18) using high-purity germanium detection systems to assess the distribution of the gamma-emitting radionuclides in the sediments surrounding and below the C Farm tanks.

- Investigating Waste Sites: Various UPRs were investigated and information obtained has been centralized in WIDS (Section 3.7.3 of this report).

- Sampling Soil: Ten boreholes were drilled to characterize the soil from an UPR near diversion box 241-C-152 on the west side of C Farm (i.e., UPR-200-E-82) that occurred in December 1969. The boreholes were drilled at radial distances ranging from 0.3 to 0.5 m (1 to 1.5 ft) from the leak source and to depths of 9 m (30 ft) bgs. The ^{137}Cs results from this characterization effort were reported in ARH-1945, *B Plant Ion Exchange Feed Leak*. The results were used as the basis to determine the leak volume configuration and content.

Figure 4-3 shows the drywell locations and two of the boreholes from ARH-1945 in which ^{137}Cs data is available (identified as Tanaka Locations 5 and 11). Information about pre-RFI activities is summarized in RPP-14430, *Subsurface Condition Description for the C and A-AX Waste Management Area,* HNF-2603, A *Summary and Evaluation of Hanford Site Tank Farm Subsurface Contamination,* and RPP-35484, *Field Investigation Report for Waste Management Area C and A-AX.*

4.2 PHASE 1 RFI FIELD EFFORTS

Information from these pre-RFI investigations was used to determine data gaps to be filled by Phase 1 field efforts. RPP-16608, *Site-Specific SST Phase 1 RFI/CMS Work Plan Addendum for WMAs C, A-AX and U*, was prepared to outline the investigation efforts for collection of field characterization data in and near WMAs C, A-AX, and U to identify and confirm major release sites and to support WMA C waste retrieval and tank farm closure decision making. Characterization efforts specific to WMA C included:

- Installation of a borehole (C4297) southwest of Tank C-105 through a known contamination area (Section 4.2.1).
- Performance of direct pushes in the area associated with an UPR (UPR-200-E-82) resulting from a pipe leak, for near-surface characterization (Section 4.2.2).
- Collection of vadose zone characterization data from the installation of one RCRA groundwater monitoring well (299-E27-22) at the northern edge of WMA C (Section 4.2.3).

The locations of these characterization activities are shown on Figure 4-4. Additional field investigation outside the scope of the work plan included:

- Limited well-to-well SGE using electrical resistivity techniques (Section 4.2.4).
- Testing the direct push technology (Section 4.2.5).

A brief summary of conclusions from the Phase I RFI is presented in Section 4.2.6 to convey how the WMA C field efforts progressed.

4.2.1 Characterizing Soil Near Tank C-105 (Installation of C4297)

The purpose of this borehole was to characterize the soil south of Tank C-105, which was a known contamination area. The borehole was drilled and sampled in 2004 using a cable tool drill rig to a depth of 60 m (197 ft) bgs. The borehole was logged using spectral gamma logging and neutron moisture logging. Eleven depths were sampled using a split spoon system. An additional 95 grab samples were collected every 0.6 m (2 ft) as the hole was drilled. All samples were shipped to PNNL for analysis. Samples were analyzed for general chemistry constituents (e.g., anions, cations), metals, and radioisotopes.

Figure 4-3. WMA C Pre-RFI Locations

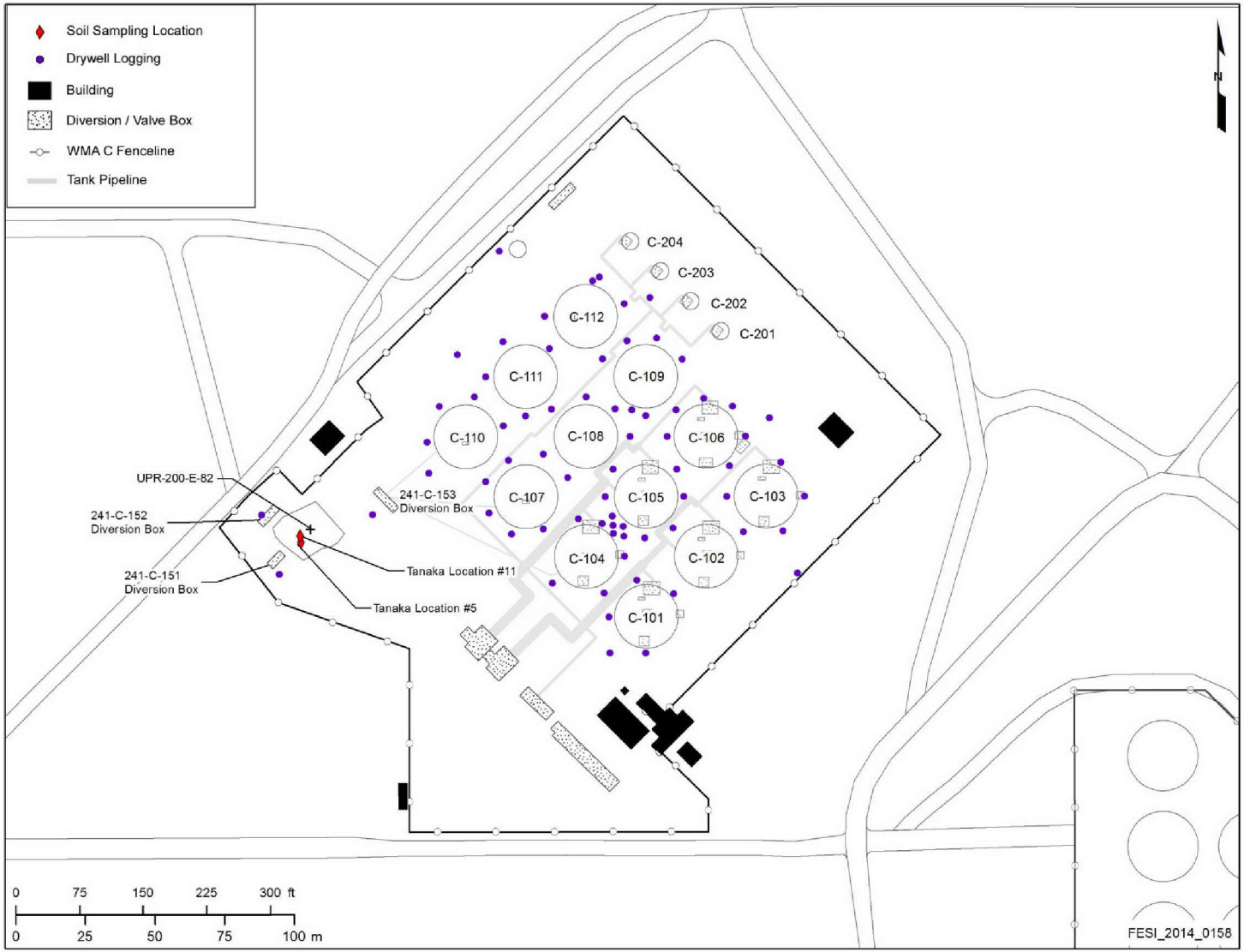
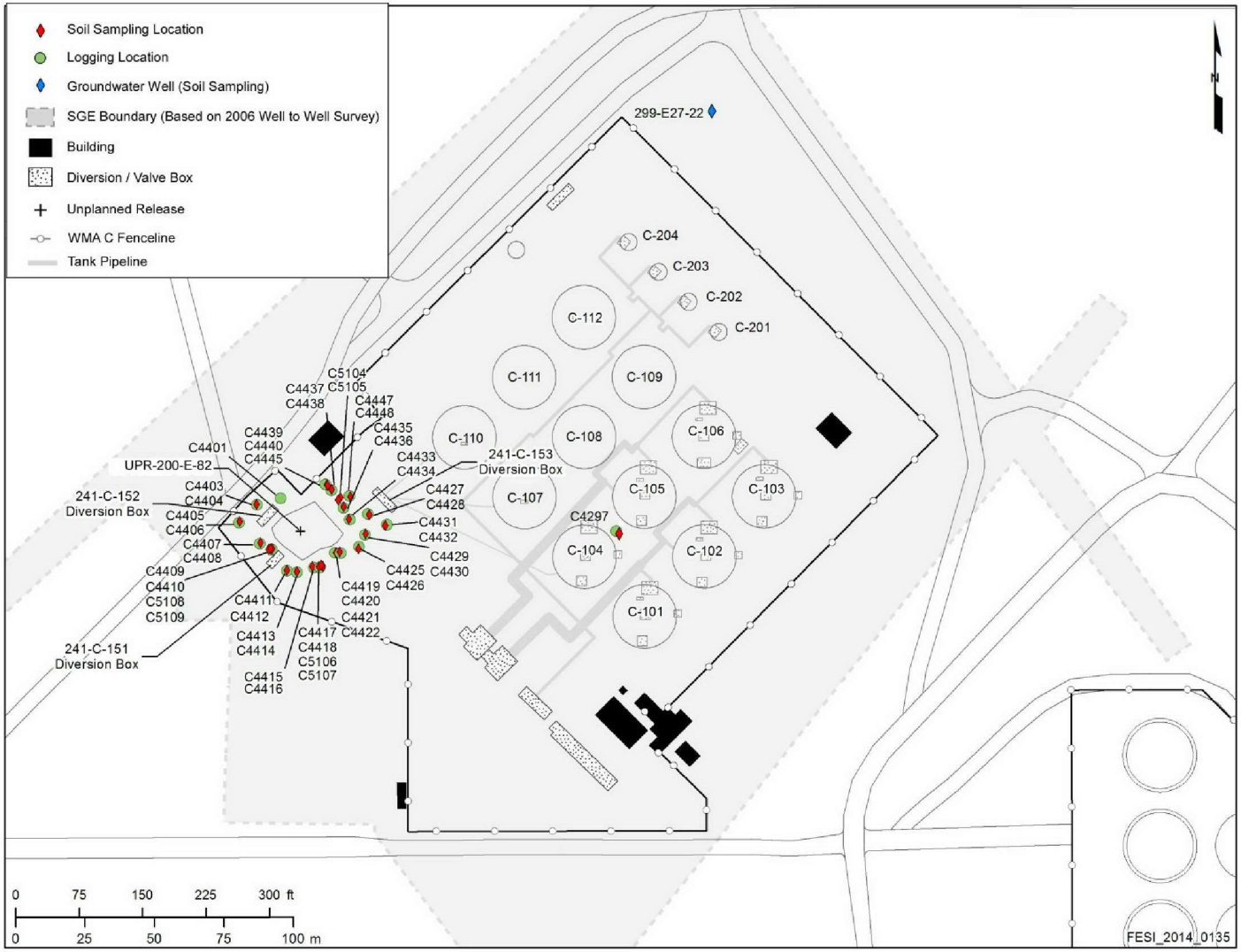


Figure 4-4. WMA C Phase 1 RFI Locations



4.2.2 Characterizing UPR-200-E-82

The purpose of this investigation was to characterize the soil from a UPR near the diversion box 241-C-152 (i.e., UPR-200-E-82) that occurred in December 1969. A combination of vertical and angled boreholes were placed surrounding the UPR. The goal of the angled boreholes was to collect samples from directly beneath the projected site of the UPR. The fieldwork was performed from October 2004 to June 2006. It included 20 vertical locations (one geophysical logging borehole and one sampling borehole at each location for a total of 40 boreholes). A cone penetrometer was used to push the first borehole. A high-impact hydraulic hammer unit mounted on a small tractor was used to push the remaining 39 vertical boreholes. These boreholes were pushed to an approximate depth of either 9 or 19 m (30 or 60 ft) deep.

Six angled boreholes holes were also pushed around the site at angles of 30 degrees, 45 degrees, or 60 degrees from horizontal, and extended to approximately 24 m (80 ft) bgs. Geophysical logging (spectral gamma, gross gamma, and neutron moisture) was performed.

Thirty-five samples were collected using a single-wall sampling system on the hydraulic hammer unit. These samples were sent to PNNL for analysis. This included one sample from each vertical sampling borehole and two or three samples from each angled borehole. Samples were analyzed for general chemistry constituents (e.g., anions, cations), metals, and radioisotopes.

4.2.3 Collecting Soil Samples from RCRA Monitoring Well (299-E27-22)

During the installation of RCRA monitoring well 299-E27-22 as part of the RCRA groundwater monitoring program, vadose zone samples were collected. No known spills have been recorded at the location where well 299-E27-22 was drilled. The goal was to characterize the uncontaminated soil and use it as a background to compare to contaminated soil during the WMA C characterization effort and to aid in the determination of groundwater flow direction.

A continuous core was collected between 6 and 34 m (19 and 111 ft) bgs. Between 34 and 70 m (111 and 230 ft) bgs, one 0.8 m (2.5 ft) split spoon sample was collected every 1.5 m (5 ft). No soil samples were collected between the ground surface and 6 m (19 ft) bgs or below 70 m (230 ft) bgs. The samples were analyzed by PNNL.

Elevated concentrations of chloride, nitrate, sulfate, phosphate, magnesium, calcium, strontium, and sodium were found in soil samples from various depths within the borehole. The data strongly suggest the soil had been in contact with a non-radiological waste stream. For this reason, it was suggested that soil from well 299-E27-22 not be used as background data (PNNL-15503).

4.2.4 Surface Geophysical Exploration

SGE is a term used to refer to the field of subsurface geophysical imaging at the tank farms. The SGE method employed at the WMA C is electrical resistivity imaging, also known as electrical resistivity tomography.

SGE using single long electrodes (i.e., well-to-well SGE) began in August 2006 and ended in December 2006. Figure 4-5 shows the electrode locations used as part of this survey. The perimeter blue dots represent surface electrodes, while the purple dots represent the long electrodes (i.e., location of drywells).

Over time, computing and processing capabilities associated with this technology have improved (Appendix G contains additional field methodology information). Given these improvements, in 2011 the data collected during Phase 1 was reprocessed and subsequently re-interpreted. A summary of the reprocessing is included in Section 4.4.3 and the results are presented in Section 5. In addition, a description of the reprocessed effort and results are included in RPP-RPT-49129, *C Farm Surface Geophysical Exploration – Reprocessing.*

4.2.5 Testing Direct Push Technology

The drilling technology progressed significantly over the duration of Phase 1. The initial boreholes were drilled using a cable tool drill rig. This drilling method brings soil up to the surface as the borehole is drilled, creating a potential radiological safety issue. Another technology for creating boreholes is direct push. Small diameter casing, ranging in size from 6.4 to 6.7 cm (2.5 to 2.6 in.) outside diameter and 2.8 to 4.5 cm (1.1 to 1.8 in.) inside diameter, are pushed into the ground compacting the soil to the sides of the borehole. This technology has undergone generational improvements from geoprobes to cone penetrometer to the technology currently used, the hydraulic hammer unit.

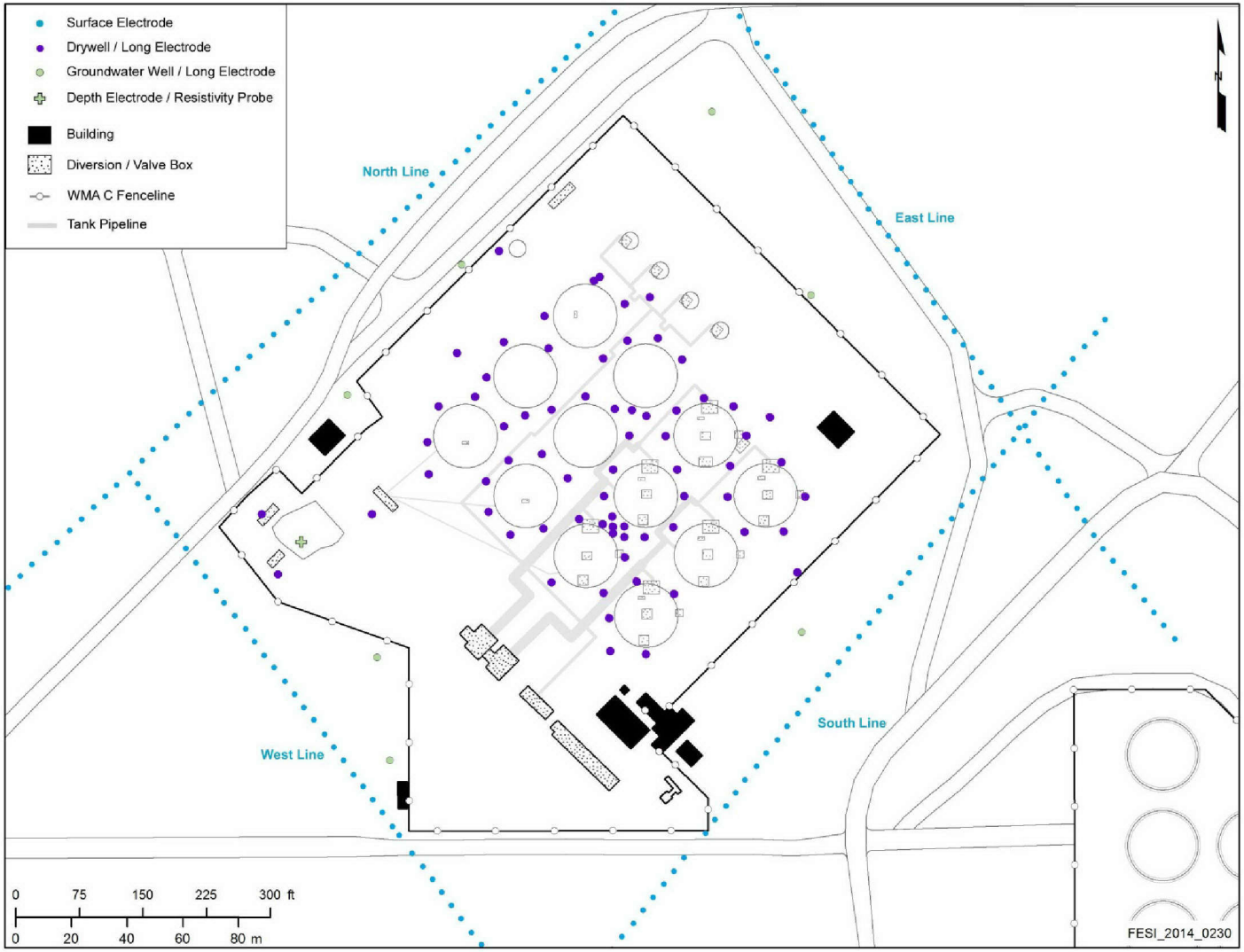
Moving from drilling technology to pushing technology has had advantages and disadvantages. The advantages were:

- Lower cost
- Better access to locations in cluttered tank farms
- Providing access to a variety of other technologies, although not as many as closed end boreholes
- Having the ability to be placed at an angle to avoid surface features.

The disadvantages were:

- Limited depth capabilities (i.e., the extent of the Hanford sand unit, ~31 to 37 m [100 to 120 ft] bgs in depth in the 200 West Area and ~61 to 76 m [200 to 250 ft]) bgs in the 200 East Area)
- Smaller sample size than boreholes from other drilling methods
- The inability to retrieve highly radioactive samples (greater than 10^3 pCi/g of ^{137}Cs)
- The inability to use large diameter geophysical tools

Figure 4-5. WMA C Phase 1 SGE



- Not having the ability to operate in highly contaminated areas

- Steel casing needed to avoid hole collapses makes many geophysical measurements not possible.

As improvements were made to the hydraulic hammer unit direct push technology, sampling and resistivity probe placement also improved (Appendix G contains additional field methodology information).

4.2.6 Phase 1 Conclusions and Recommendations

The following is a brief summary of the conclusions from the WMA C Phase 1 RFI:

- Contamination in the vadose zone from past releases from WMA C have impacted groundwater. Technetium-99 and nitrate exceeded drinking water standards in downgradient groundwater wells. Additional drinking water standards would be exceeded at the WMA C boundary if no further action were taken.

- Phase 1 field data improved the understanding of the conceptual models related to the nature and extent of contaminants at WMA C.

In addition, several recommendations were developed pertaining to interim measures, accelerated corrective measures, future tank operations, collection of additional data and information, and lessons learned. These recommendations expand upon those identified in GJO-98-39-TAR/GJO-HAN-18 and RPP-5002, which pre-dated RFI field efforts. Specific recommendations were to:

- Perform leak tests on active waterlines on a periodic basis (e.g., annual).

- Focus additional characterization on collecting soil samples at the following locations: UPR-200-E-86, UPR-200-E-81, the southeastern side of Tank C-101; Tanks C-108, C-109, and C-106 related to the ^{60}Co plume and its migration eastward.

- Evaluate near surface soil and ancillary equipment removal as part of the CMS process because surface contamination at depths of less than 5 m (15 ft) bgs was indicated by spectral gamma data.

- Perform additional detailed surface geophysical exploration at WMA C, with follow-on validation as recommended by an independent technical review panel.

- Prevent further vertical migration, develop and deploy interim surface barriers in areas where contamination is relatively near the surface (i.e., less than 30 m [100 ft] bgs), based on lessons learned from the T-106 interim barrier demonstration.

- Initiate and complete interim measures (e.g., capping boreholes, cutting off inactive waterlines, and building surface run-on barriers and diversions) identified in GJO-98-39-TAR/GJO-HAN-18 and RPP-5002.

Interim measures are defined as initial response actions that can be taken while characterization activities are under way and while long-term strategies are being developed to reduce the impacts of past releases on groundwater under RCRA. Interim measures do not require comprehensive evaluation in a CMS. Interim measures identified and implemented for WMA C have focused on actions to minimize infiltration and contaminant migration to groundwater. Specifically, the following measures have been completed:

- All waterlines within WMA C have been cut and capped or pressure tested.
- All groundwater wells and drywells have watertight caps.
- Several run-on control structures were constructed adjacent to WMA C.

In addition to the above, historical pipeline leak event locations (e.g., UPR-200-E-82 and UPR-200-E-86) have gunite caps placed on the surface. These gunite caps provide an interim solution to the long-term threats posed by contaminant releases by minimizing infiltration, contaminant migration to groundwater, and contaminant exposure to present-day workers.

4.3 PHASE 1.5 NEAR-TERM CHARACTERIZATION

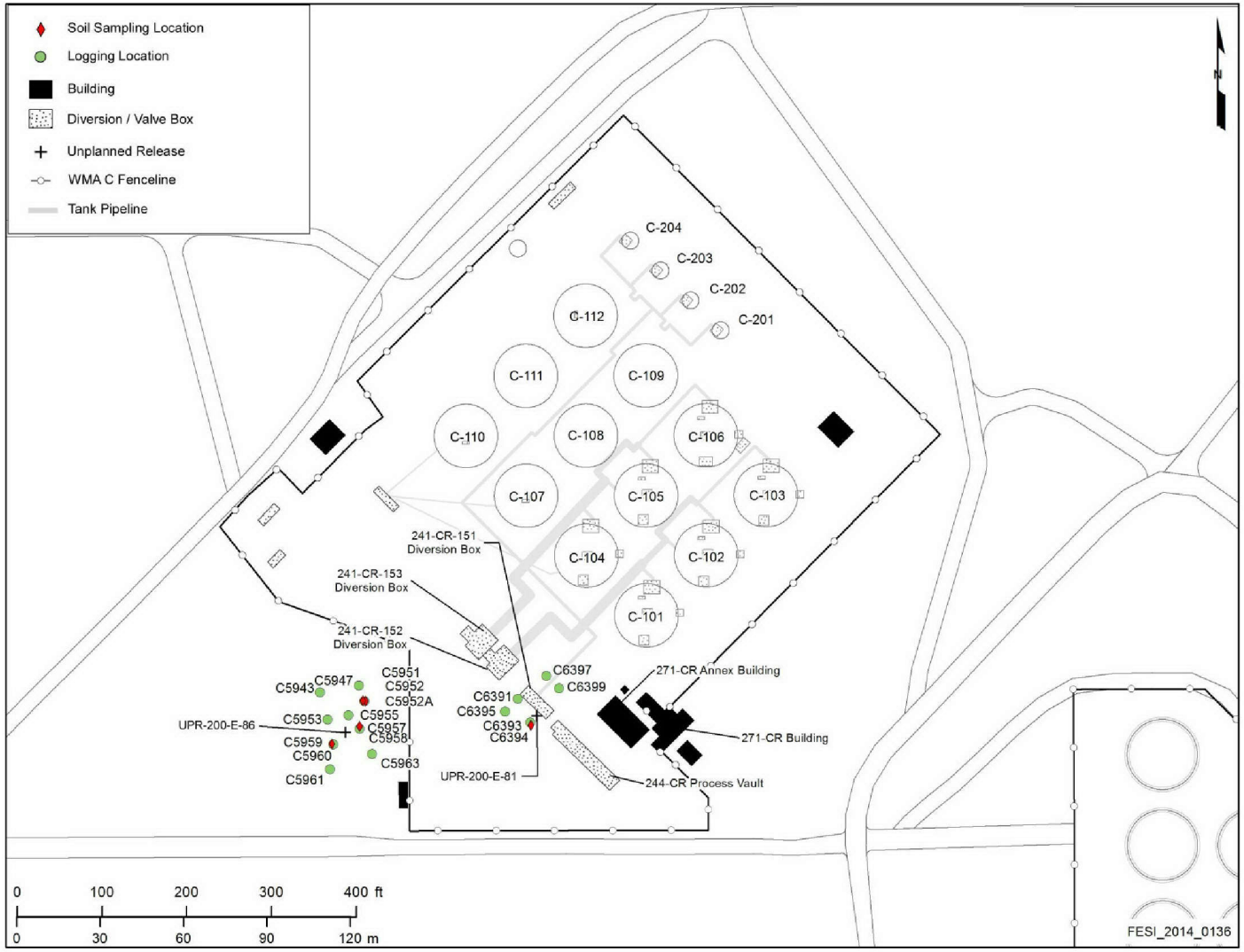
While the Phase 1 RFI report was being finalized and prior to the development of the Phase 2 RFI planning documentation, characterization work in the WMA C continued. This transitional characterization effort was called "near-term characterization" and focused on the deployment of hydraulically driven direct push technology to push boreholes (i.e., Phase 1.5) for geophysical logging, placement of deep electrodes, and to collect soil samples.

RPP-35169, *Near Term Data Quality Objectives for Vadose Zone Characterization Waste Management Area C,* and RPP-PLAN-35341, *Work Plan for Near-Surface Vadose Zone Characterization Utilizing the Hydraulic Hammer/Direct Push Technology for 35 Direct Pushes in FY08,* governed this supplemental work. The focus of the investigation in WMA C was UPR-200-E-81 and UPR-200-E-86 (Figure 4-6). These UPR sites were characterized in field efforts dating from November 2007 through June 2008.

4.3.1 UPR-200-E-86

UPR-200-E-86 was a waste loss event associated with a pipeline break in February 1971, near the southwest corner of WMA C. Fluids were being pumped from the 244-AR Vault to C Tank Farm. It is estimated that approximately 79,102 L (17,400 gal) of fluid containing an estimated 25,000 Ci of ^{137}Cs were lost to the soil (RHO-CD-673; UPR-200-E-86 is referred to as UN-216-E-14 in this report) from this pipeline break.

Figure 4-6. WMA C Phase 1.5 Near-Term Characterization Locations



From November 2007 to March 2008, nine exploratory boreholes were pushed using a hydraulic hammer unit. These exploratory boreholes (i.e., logging borehole) were logged with neutron moisture and gross gamma tools. These logging results showed that eight of the nine boreholes had only background activity. One borehole showed a maximum gamma activity of 40,000 pCi/g of ^{137}Cs.

Three locations for sampling were selected. When pushing sampling borehole C5952, the tubing deviated from vertical and encountered borehole C5951 at 13 m (44 ft) bgs. The sample borehole was abandoned (renamed C5952A) and a second sampling borehole, C5952, was pushed adjacent to the original site. A total of 24 samples were taken using the dual-wall sampling system. The maximum depth of sampling was 43 m (142 ft) bgs. The samples were analyzed by the PNNL for anions, total organic carbon, conductivity, pH, gamma energy, and radioisotopes. Results of the analysis were reported in PNNL-SA-60937, *Geochemical Study of Grab Samples Collected from UPR 200-E-86 Investigative Site*. (Note that the title of the laboratory analysis document mistakenly calls these "grab" samples; they were actually samples taken using a dual-wall sampling system which allows the collection of a soil sample from a specific depth and retrieves a "core" in relatively undisturbed form).

Figure 4-6 shows the location of the logging and sampling boreholes associated with UPR-200-E-86 investigation. Additional details of the field work associated with the UPR-200-E-86 investigation are summarized in RPP-37625, *Completion Report for UPR-200-E-86 Direct Push Drilling and Sampling*.

4.3.2 UPR-200-E-81

UPR-200-E-81 was a waste loss event associated with a pipeline break in October 1969, near the southwest corner of WMA C. Waste was being transferred from PUREX (202-A building) to Tank C-102 through diversion box 241-CR-151. Approximately 136,275 L (36,000 gal) of waste was lost to the soil (RHO-CD-673; UPR-200-E-81 is referred to as UN-216-E-9 in this report).

From April 2008 to June 2008, five exploratory (i.e., logging) boreholes (C6391, C6393, C6395, C6397, and C6399) were pushed using a hydraulic hammer unit to depths of either 46 m (152 ft) or 74 m (242 ft) bgs. These exploratory boreholes (i.e., logging borehole) were logged with neutron moisture and gross gamma tools (using sodium iodide). Three of these boreholes showed gamma activity above background levels. The maximum gamma activity encountered was 45,000 pCi of ^{137}Cs. During decommissioning, two boreholes had resistivity probes placed in them:

- C6395 at 15 m (50 ft) and 45 m (146 ft) bgs
- C6399 at 15 m (50 ft) bgs and 66 m (215 ft) bgs.

One borehole, C6394, was pushed for sampling and 11 samples were obtained. The maximum depth of sampling was 52 m (172 ft) bgs. The samples were analyzed at the PNNL for anions, total organic carbon, conductivity, pH, gamma energy, and radioisotopes. Results of the analysis were reported in PNNL-SA-61511, *Geochemical Characterization of Sediments from*

UPR 200-E-81. Note that two samples (11 m [37 ft] bgs and 52 m [169 ft] bgs) were analyzed at 222-S Laboratory under Phase 2 Characterization.

Figure 4-6 shows the location of the logging and sampling boreholes associated with UPR-200-E-81in relationship to Tank C-101, and diversion box 241-CR-151. Additional details of the field work associated with the UPR-200-E-81 investigation are reported in RPP-38927, *Completion Report for the 241-CR-151 Vault (UPR-200-E-81) Direct Push Characterization and Sampling*. Note that this area continued to be investigated under Phase 2.

4.4 PHASE 2 RFI FIELD EFFORTS

The Phase 2 effort began with the development of a DQO report (RPP-RPT-38152, *Data Quality Objectives Report Phase 2 Characterization for Waste Management Area C RCRA Field Investigation/Corrective Measures Study*), which identified the data required to support the evaluation of alternative corrective measures and subsequent decision-making for the RCRA corrective action process. The participants[1] of the DQO determined that the primary focus of the Phase 2 data collection effort at WMA C should be directed toward further characterizing the contamination sources in association with CMAs for the soils and the collection of near surface characterization data for direct contact and ecological risk. The understanding of the distribution of radionuclides in the contaminated vadose zone when the DQO as prepared was limited to the information obtained during Phase 1, which focused on two sites with high levels of contamination (UPR-200-E-86 and a release at the base of Tank C-105). The focus of the Phase 2 data characterization program at WMA C as defined in the DQO was to:

- Perform vadose zone soil sampling in areas of known releases that includes spills, tank leaks, and overfill events within WMA C
- Perform vadose zone soil sampling in areas where there has been a suspected release that has not been documented in WIDS
- Analyze the samples for a range of contaminants of interest
- Re-log drywells and groundwater wells for changes since previous logging activity
- Perform SGE
- Perform tissue sampling and analysis for ecological risk.

[1] The DQO process for Phase 2 was a collaborative effort that included DOE-ORP and DOE-Richland Operations Office, Ecology, DOE Tank Farm Contractor, Fluor Hanford (DOE Contractor) and Cenibark International Inc. Additionally, stakeholder input was solicited to help define the type of data the vadose zone characterization effort at WMA C needed to collect to help make decisions for the corrective action process. The process included meeting with the following stakeholders: Nez Perce Tribe, Confederated Tribes of the Umatilla Indian Reservation, the Yakama Nation, Oregon Department of Energy, and the Hanford Advisory Board. Meetings with the stakeholders occurred in March, May, and August of 2008.

As agreed upon by the participants, sampling of groundwater was not included as part of these soil characterization efforts. Investigations only included the efforts to collect the additional soil characterization data needed to fulfill the WMA C DQO (RPP-RPT-38152).

Ecology expressed the desire to achieve the following goals during this Phase 2 characterization effort:

- Evaluate UPR sites associated with WMA C
- Address stakeholder concerns related to contaminant migration
- Perform shallow soil sampling (i.e., less than 5 m [15 ft] bgs) to support direct contact and ecological risk assessment
- Investigate other potential areas of unintentional releases associated with the ^{99}Tc groundwater contamination and ability to close WMA C after retrieval completion.

Concurrent with the development of the DQO (RPP-RPT-38152), were the development of the:

- RPP-PLAN-39114, *RCRA Facility Investigation/ Corrective Measures Study Work Plan for Waste Management Area C* (work plan)
- RPP-PLAN-38777, *Sampling and Analysis Plan for Phase 2 Characterization of Vadose Zone Soil in Waste Management Area C* (SAP).

These three documents provide the investigative basis and approach to the Phase 2 characterization activities at WMA C. Both the work plan and SAP were primary HFFACO documents that were reviewed and approved by Ecology as the lead agency in March 2010 (Appendix H).

During the course of the Phase 2 RFI investigation, the work plan and SAP were revised a number of times. The reasons for the revisions were documented during monthly status meetings with the regulators from August 2010 through September 2011 and HFFACO change notices, as necessary. These meeting minutes and HFFACO change notices were submitted to the Administrative Record (Appendices I and H, respectively). Table 4-2 summarizes the plan revisions.

In order to support the DQO, the original work plan and SAP identified that characterization activities were to be performed at 22 investigation sites plus one to be determined site (i.e., Site T). Each investigation site was given a letter designation (Figure 4-7). Field efforts originally consisted of:

- Eighteen Direct Push Sites (A, B, C, D, E, F, G, H, I, J, K, L, P, Q, R, S, U, and V)
- Two Drywell Logging Sites (L [direct push also to be performed] and M)

Table 4-2. Summary of Revisions to Phase 2 RFI Work Plan and SAP

Document Number	Document Date	Revision Summary
RPP-PLAN-39114, Rev. 0 RPP-PLAN-38777, Rev 0	2/04/09 – 8/31/09	Initial Draft – Acknowledgement and Conditional Approval to Proceed given by Ecology on 2/4/2009 (Appendix H)
RPP-PLAN-39114, Rev. 1 RPP-PLAN-38777, Rev. 1	9/1/09 – 10/04/10	Incorporated comments from Ecology Investigation Site Update • None Analytical Update • Reduced required detection limit for total chromium • Defined detection limits for molybdenum and tin
RPP-PLAN-39114, Rev. 1A-1B RPP-PLAN-38777, Rev. 2-2A	10/5/10 – 6/12/12 10/5/10 – 6/16/12	Referenced renegotiated HFFACO milestone for RFI and CMS due dates Investigation Site Update • Site B – Modified location due to physical interferences[a] • Site Q – Added four direct push boreholes for SGE; modified direct push through center to be dependent on results of SGE • Site U - Added option for vertical push in addition to angle push [b] • Site W - Removed 299-E27-4 from investigation site Analytical Update • Modified data report format to Format VI • Added required reporting limit for cyanide Tissue (Small Mammal) Sampling Update[c] • Updated habitat transect locations to reflect changes in field conditions since issuance of original document • Added QA/QC requirements • Update analyte list • Clarified sample collection and preservation requirements • Updated list of typically required training • Deleted references to trap manufacturers
RPP-PLAN-39114, Rev. 2[d] RPP-PLAN-38777, Rev. 3	6/13/12 – present 6/17/12 – present	Investigation Site Update • Site C - Reduced to one angled direct push; future direct push dependent on SGE results from Site D • Site D - Changed to four vertical logging holes with resistivity probes for SGE; future direct push dependent on SGE results

Table 4-2. Summary of Revisions to Phase 2 RFI Work Plan and SAP

Document Number	Document Date	Revision Summary
		• Site K – Deleted; poor access and sampling results are unlikely to provide value to RFI investigation; replaced with Site X • Site M – Discontinued; additional drywell logging unlikely to yield information of value to RFI investigation. Logging performed for retrieval will be considered for the RFI report. • Site O – Deleted; reanalysis of existing well-to-well data was completed; additional SGE to be deployed selectively (e.g., at Sites C and D). • Site Q – Modified; deleted sampling direct push planned for center of UPR-82 to reduce risk of personnel exposure to high levels of ^{137}Cs. SGE results and previous soil samples from this site are adequate to document the nature and extent of the release. • Site S – Deleted; sampling results are unlikely to provide value to RFI investigation. • Site T – Deleted; if additional direct push work is deemed necessary to support the RFI, such work will be incorporated into a revision of the work plan. • Site V – Deleted; site is unlikely to provide value to RFI investigation. • Site W – Modified; added well 299-E27-4 back to site; deleted logging requirements for three groundwater wells. Access issues prevent logging in these three wells and logging results are unlikely to provide value to RFI investigation. • Site X – Added; to investigate ^{137}Cs plume near Tank C-105 • Site Z - Added; ^{99}Tc analysis of archive samples for 299-E27-20 • Site AA - Identified Tissue Analysis investigation with letter designation (no change to scope of investigation) Analytical Update • Implemented agreement to optimize organic analyses, which removed requirement to analyze for VOAs, gasoline, and diesel range organics, PCB congeners, ethylene glycol monobutyl/dibutly phosphate • Eliminated sulfide as a COPC and soil analyte • Documented analysis of full-suite of analytes vs. a two-step process to ensure holding times are not compromised • Clarified information in analyte tables

[a]Refer to November 17, 2010 work plan meeting notes (Appendix I) , which provide documentation on location change.
[b]Refer to "Site U email – C110 push" (Appendix L) which provides documentation on this change.
[c]Small mammal sampling and analysis information is Appendix B of RPP-PLAN-39114. It is not included in RPP-PLAN-38777 as this SAP pertains only to the direct push efforts.
[d]Refer to September 22, 2011 work plan meeting notes (Appendix I), which also provide documentation on investigation site updates.

- Two SGE Sites (N and O)

- Groundwater Well Logging Sites (W) (original work plan identified five wells to be logged)

- One Direct Push Site - to be determined for (T)

Table 4-3 identifies all locations from the original work plan along with the purpose of each investigation site and includes the additional sites added to the work plan as it was updated. The letter locations not included in the original work plan are:

- Site X, direct push at Tank C-105

- Site Y, soil sampling at the new groundwater well (299-E27-24, whose location and name was unknown at time of the original work plan)

- Site Z, laboratory analyses of archived soil samples at abandoned groundwater well 299-E27-20

- Site AA, areas in which tissue samples were collected for ecological risk

Site X was added in RPP-PLAN-39114, Rev. 2. Sites Y and Z, reflect the possible sampling of the vadose zone during the installation of any new groundwater wells within the vicinity of approximately 31 m (100 ft) of WMA C, which was not part of the original work plan. These sites were added through discussions with the regulatory agencies. Site AA, the tissue sampling, was included in the original work plan; however, it was not assigned a site letter designation until in later work plan revisions.

All investigation sites are discussed in the following sections by field activity along with all changes from the original work plan:

- Direct push vadose zone sampling, analysis, and logging (Section 4.4.1) - Sites A, B, C, D, E, F, G, H, I, J, K, L (L1+L2), P (P1-P5), Q, R, S, T, U, V, and X
  (Note that Sites K, S, and X are not shown on Figure 4-8 as these field sites were not completed.)

- Drywell and groundwater well logging (Section 4.4.2) – Sites L, M, and W

- SGE (Section 4.4.3) – Sites C, D, N, and O

- Tissue sampling and analysis (Section 4.4.4) – Site AA

- Vadose zone soil sampling of groundwater wells 31 m (100 ft) within the vicinity of WMA C (Section 4.4.5) – Sites Y and Z

Figure 4-7. Original WMA C Phase 2 RFI Locations

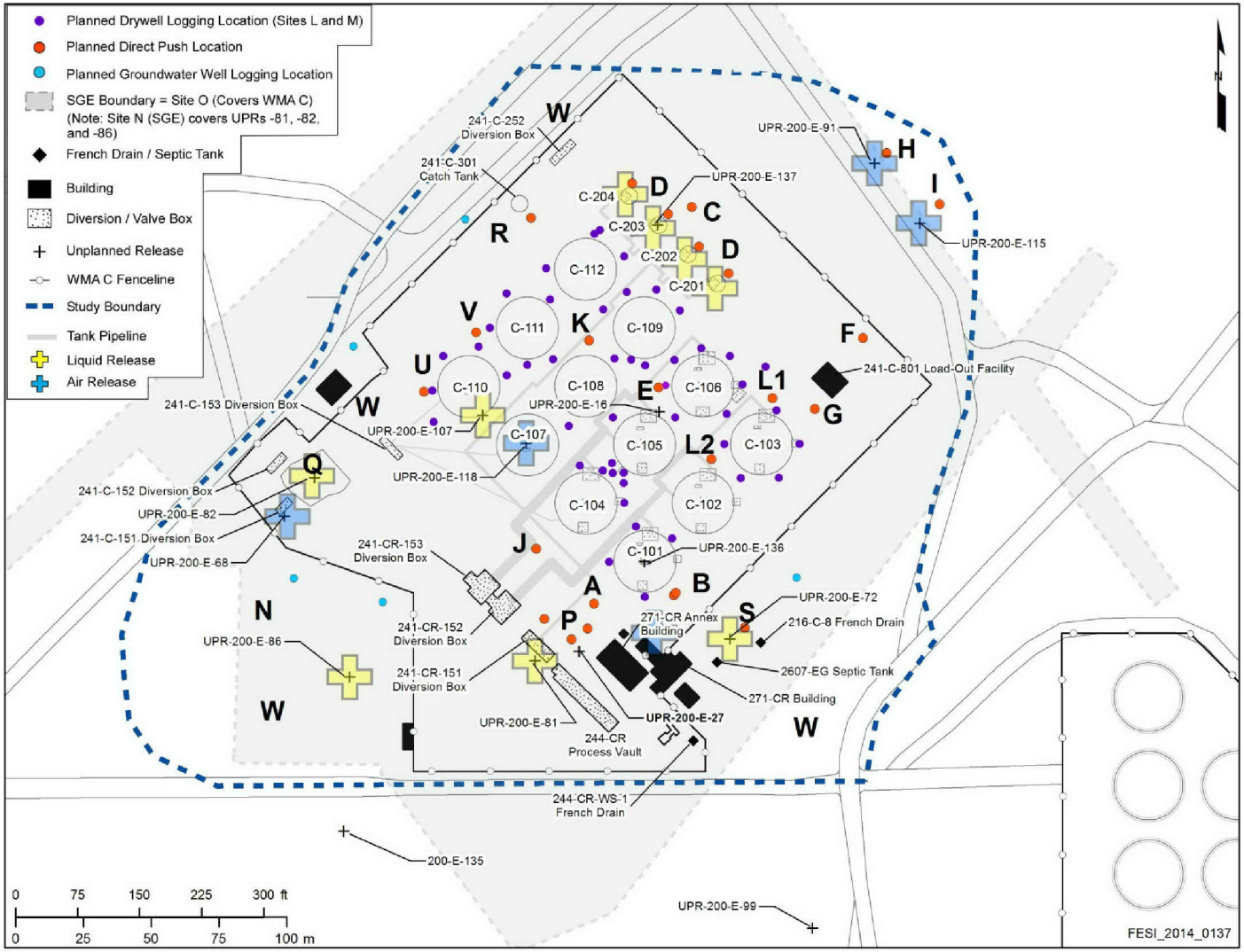


Figure 4-8. Completed WMA C Phase 2 RFI Locations

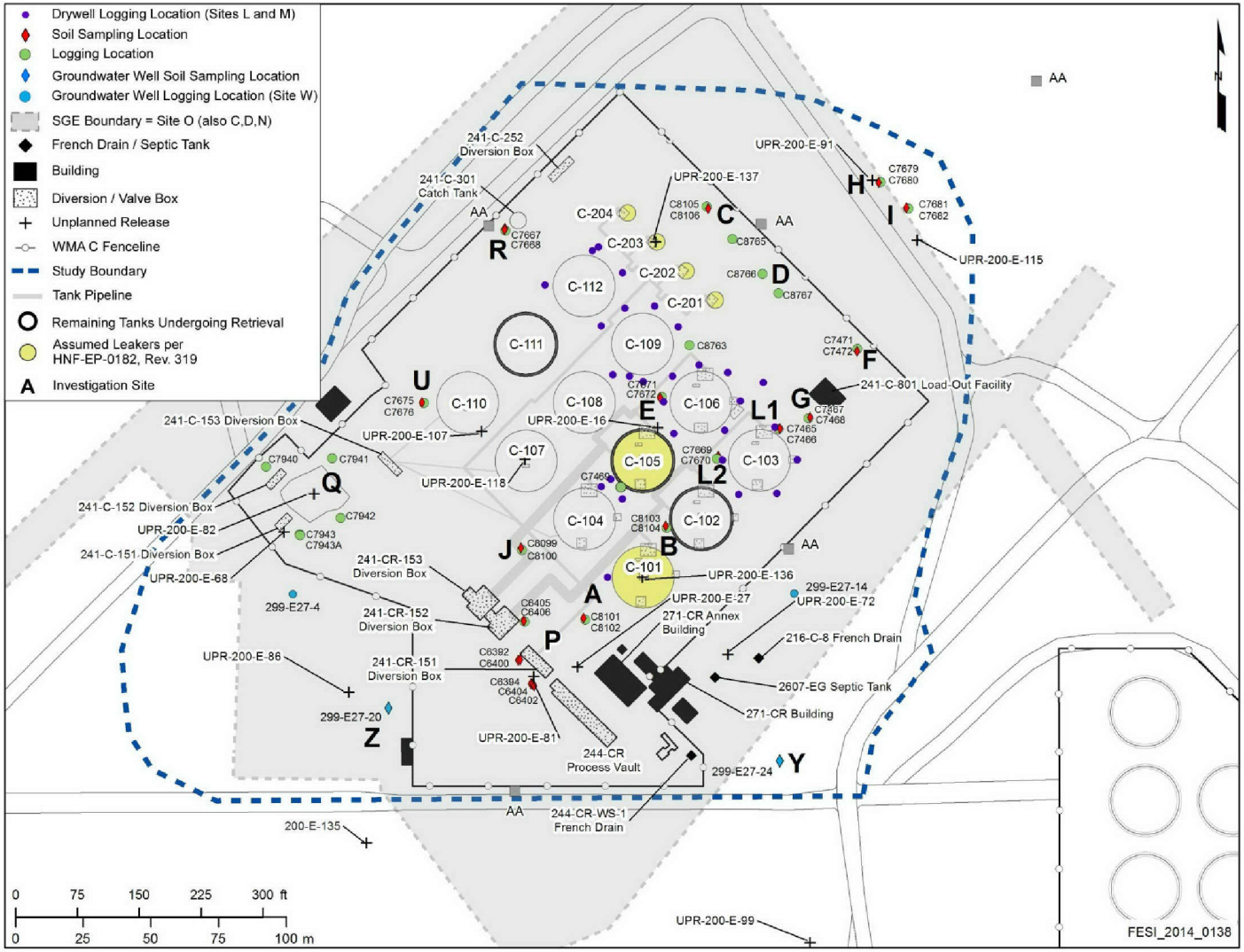


Table 4-3. Summary of WMA C Phase 2 RFI Locations

Investigation Site	Investigation Location Related Known or Suspected Event Investigation Objective (from Table 4-1 of RPP-PLAN-39114, Rev. 0)	Borehole Number	Activity	Push Orientation	Total Depth (ft bgs)[a] *Pipe run Total Depth (ft)[a]*	Depths of Resisitivity Probes or Sample Depths (ft bgs)[b]	Sample Depth Meetings[c]	Change Notice[d]	Field Summary Report	Laboratory Report *Validation Report*	Change from Work Plan, Rev 0 *Approval and Documentation*
A	Spare inlet C-101 Tank over fill, loss through spare inlet Characterize Tank C-101 release and refine conceptual models	C8101	Direct Push Logging	Angle	161.9 *232.5*	70.9 122	NA	NA	RPP-RPT-50581	NA	NA
		C8102	Direct Push Sampling	Angle	172.6 *223*	0.5, 6.8[e] 11.4[e], 14.1[e] 46.8, 69.7, 118.7, 144.9, 169.7	5/16/2011	CCN-WMAC-020, CCN-WMAC-021	RPP-RPT-50581	RPP-RPT-51759 (222-S), VAD011S (TASL) *VSR12-026*	
B	South side of Tank C-101 Tank Release Characterize Tank C-101 release and refine conceptual models	C8103	Direct Push Logging	Angle	188.2 *206*	87.2 151.9	NA	NA	RPP-RPT-50581	NA	Site relocated due to inaccessibility. Final Location was an angled direction to push target east side of C-101. *Work Plan Meeting 11/17/2010 discussed access issues*
		C8104	Direct Push Sampling	Angle	139.1 *159*	0.5, 5.1, 11.9, 14.2 36, 81.4, 102.1, 137	6/17/2011	NA	RPP-RPT-50581	RPP-RPT-51759 (222-S), VAD013S (TASL) *VSR12-026*	
C	Tank C-203 Tank leak and/or over fill, loss through spare inlet Determine if Tank C-200 actually leaked and refine conceptual models	C8105	Direct Push Logging	Angle	84.8 *166.6*	52.2	NA	NA	RPP-RPT-51384	NA	One site rather than three *RPP-PLAN-39114, Revision 2 documented agreement*
		C8106	Direct Push Sampling	Angle	87.9 *163.4*	0.5, 6.5, 11.5, 16.5 45.6, 57.3, 75.5, 87.8	10/18/2011	NA	RPP-RPT-51384	RPP-RPT-51759 (222-S), VAD015S (TASL) *VSR12-026*	
D	Tank C-203 Tank leak and/or over fill, loss through spare inlet Determine if Tank C-200 actually leaked and refine conceptual models	C8763	Direct Push Logging	Vertical	221	53, 73, 93, 113, 133, 153, 173, and 192	NA	NA	RPP-RPT-55481	NA	Sampling locations were replaced with four logging boreholes with resistivity probes for SGE *RPP-PLAN-39114, Revision 2 documented agreement* Note: Additional sampling is dependent on evaluation SGE results (Refer to Section 5.2.3).
		C8765	Direct Push Logging	Vertical	211	30, 50, 70, 90, 110, 130, 150, 170, and 189	NA	NA	RPP-RPT-55481	NA	
		C8766	Direct Push Logging	Vertical	211	30, 50, 70, 90, 110, 130, 150, 170, and 189	NA	NA	RPP-RPT-55481	RPP-RPT-49902 (222-S), VAD004S (TASL)	
		C8767	Direct Push Logging	Vertical	211	30, 50, 70, 90, 110, 130, 150, 170, and 189	NA	NA	RPP-RPT-55481	NA	
E	Between Tanks C-106 and C-109 Suspected release Assess ^{60}Co and refine conceptual model	C7671	Direct Push Logging	Vertical	221	40, 84, and 124	NA	NA	RPP-RPT-48029	NA	NA
		C7672	Direct Push Sampling	Vertical	124	0.5, 6, 11, 15 38, 74, 84, 123	7/7/2010	NA	RPP-RPT-48029	RPP-RPT-49902 (222-S), VAD004S (TASL) *VSR11-045*	
F	Building C-801 chemical drain Suspected release site Assess release of PUREX waste, ^{137}Cs and ^{99}Tc, and ^{60}Co and refine conceptual models	C7471	Direct Push Logging	Vertical	221.79	37, 57, 77, 97, 117, 137, 157, 177, 196	NA	NA	RPP-RPT-47461	NA	NA
		C7472	Direct Push Sampling	Vertical	218	0.5, 6, 13[e], 15 109.5, 130, 143, 159, 196, 217	12/17/2009	CCN-WMAC-004	RPP-RPT-47461	RPP-RPT-49050 (222-S), RJLG/CLS March 11, 2010 (RJLG/CLS) *VSR10-024, VSR11-015*	

Table 4-3. Summary of WMA C Phase 2 RFI Locations

Investigation Site	Investigation Location Related Known or Suspected Event Investigation Objective (from Table 4-1 of RPP-PLAN-39114, Rev. 0)	Borehole Number	Activity	Push Orientation	Total Depth (ft bgs)[a] *Pipe run Total Depth (ft)[a]*	Depths of Resisitivity Probes or Sample Depths (ft bgs)[b]	Sample Depth Meetings[c]	Change Notice[d]	Field Summary Report	Laboratory Report *Validation Report*	Change from Work Plan, Rev 0 *Approval and Documentation*
G	Between Bldg C-801 and Tank C-103 Suspected transfer line release site Assess release and ^{60}Co and refine conceptual models	C7467	Direct Push Logging	Vertical	174	46 126	NA	NA	RPP-RPT-42714	NA	NA
		C7468	Direct Push Sampling	Vertical	137	0.5, 6, 11, 15 44.5, 93, 98, 126, 136	7/28/2009	NA	RPP-RPT-42714	RPP-RPT-46241 (222-S), RJLG/CLS March 11, 2010 (RJLG/CLS) *VSR10-021, VSR10-024*	
H	Northeast side of UPR-200-E-91 Surface release Surface exposures and assess ^{60}Co and surface release conceptual models	C7679	Direct Push Logging	Vertical	222.3	36, 56, 76, 96, 116, 136, and 156	NA	NA	RPP-RPT-48029	NA	NA
		C7680	Direct Push Sampling	Vertical	144	0.5, 6, 11, 15 18, 44, 93, 117, 143	8/4/2010	NA	RPP-RPT-48029	RPP-RPT-50185 Rev 1 (222-S), VAD008S (TASL) *VSR11-046*	
I	Northeast side of UPR-200-E-115 Surface release Surface exposures and assess ^{60}Co and surface release conceptual model, refine conceptual models	C7681	Direct Push Logging	Vertical	222	27, 47, 67, 87, 107, 127, and 146	NA	NA	RPP-RPT-48029	NA	NA
		C7682	Direct Push Sampling	Vertical	124	0.5, 6, 13[e], 15 19, 46, 89, 123	8/4/2010	CCN-WMAC-012	RPP-RPT-48029	RPP-RPT-50443 (222-S), VAD007S (TASL) *VSR11-047*	
J	Tank C-104 Tank release Assess suspected release and refine conceptual models	C8099	Direct Push Logging	Angle	208.1 *256.3*	75 134	NA	NA	NA	RPP-RPT-49956	Three shallow sample depth intervals rather than four and six deep sample depth intervals rather than four *Sample Depth Meeting 2/15/2011 documented agreement*
		C8100	Direct Push Sampling	Angle	176.3 *224.8*	0.5, 4.9, 13.5[e] 38.8[e], 54.3, 90.1, 131.8, 157.7, 173.3	2/15/2011	CCN-WMAC-016, CCN-WMAC-018	RPP-RPT-49956	RPP-RPT-50615 (222-S), VAD001S (TASL) *VSR12-023*	
K	Tank C-108 Transfer line leak, hot drywell (09-02) Assess suspected release and refine conceptual models	NA	Direct Push	NA	NA	NA	NA	NA	NA	NA	Site deleted *RPP-PLAN-39114, Revision 2 documented agreement*
L1	Tanks C-103 and C-106[n] Potential transfer line leak and tank overfill Update logging data for ^{60}Co, ^{137}Cs, uranium, and moisture and assess potential release and refine conceptual models Assess suspected release and refine conceptual models	C7465	Direct Push Logging	Vertical	202	86 135	NA	NA	RPP-RPT-42714	NA	NA
		C7466	Direct Push Sampling	Vertical	135	0.5, 6, 11, 15 44.5, 85, 110.5, 115, 134	7/28/2009	NA	RPP-RPT-42714	RPP-RPT-46241 (222-S), RJLG/CLS March 11, 2010 (RJLG/CLS) *VSR10-021, VSR10-024*	
L2		C7669	Direct Push Logging	Vertical	222	32, 52, 72, 92, 112, 132, 152, 172, and 191	NA	NA	RPP-RPT-47461	NA	
		C7670	Direct Push Sampling	Vertical	224	0.5, 6, 12[e], 15 40, 140, 164, 222[e]	1/20/2010	CCN-WMAC-005, CCN-WMAC-006	RPP-RPT-47461	RPP-RPT-49185 (222-S), VAD002S (TASL) *VSR11-035*	

Table 4-3. Summary of WMA C Phase 2 RFI Locations

Investigation Site	Investigation Location Related Known or Suspected Event Investigation Objective (from Table 4-1 of RPP-PLAN-39114, Rev. 0)	Borehole Number	Activity	Push Orientation	Total Depth (ft bgs)[a] *Pipe run Total Depth (ft)*[a]	Depths of Resisitivity Probes or Sample Depths (ft bgs)[b]	Sample Depth Meetings[c]	Change Notice[d]	Field Summary Report	Laboratory Report *Validation Report*	Change from Work Plan, Rev 0 *Approval and Documentation*
M	Tanks C-104, C-105, C-108, C-109, C-110, C-111, and C-112 Update logging data for ^{60}Co, ^{137}Cs, uranium, and moisture	NA	Drywell Logging	NA							Elimination of some drywell logging. *RPP-39114, Revision 2, documented agreement*
N	UPR-200-E-86, UPR-200-E-82 and UPR-200-E-81 Test SGE: resolve depth with deep electrodes; define plume at UPR-200-E-81, UPR-200-E-82, and UPR-200-E-86; refine conceptual models	NA	SGE	NA							NA
O	WMA C 3-D vision of suspected releases – may lead to supplemental sample locations	NA	SGE	NA							NA
P1	UPR-200-E-81 Known release site Characterize release and refine conceptual models	C6391[o]	Direct Push Logging	Vertical	152	None	NA	NA	RPP-38927	NA	NA
		C6403	Direct Push Logging	Vertical	50	None	NA	NA	RPP-42221	NA	
		C6395[o]	Direct Push Logging	Vertical	152	50 146	NA	NA	RPP-38927	NA	
		C6392[f]	Direct Push Sampling	Vertical	58	15 20.5, 26, 43, 57	1/15/2009	NA	RPP-42221	RPP-RPT-44557 (222-S), RJLG/CLS March 11, 2010, RJLG/CLS April 7, 2010 (RJLG/CLS) *VSR10-013, VSR10-024*	
		C6400[f]	Direct Push Sampling	Vertical	134	6, 11 133.25	1/15/2009	NA	RPP-42221	RPP-RPT-44557 (222-S), RJLG/CLS March 11, 2010, RJLG/CLS April 7, 2010 (RJLG/CLS) *VSR10-024*	
P2	UPR-200-E-81 Known release site Characterize release and refine conceptual models	C6393[o]	Direct Push Logging	Vertical	242	None	NA	NA	RPP-38927	NA	
		C6394[o]	Direct Push Sampling	Vertical	172	37,169	1/15/2009	NA	RPP-38927	None[g]	
		C6402[h]	Direct Push Sampling	Vertical	16	7,11,15	1/15/2009	NA	RPP-42221	RPP-RPT-44557 (222-S), RJLG/CLS March 11, 2010, RJLG/CLS April 7, 2010 (RJLG/CLS) *VSR10-024*	
		C6404[h,i]	Direct Push Sampling	Vertical	59	7, 11, 15.5 20.5, 32, 43, 58	1/15/2009	NA	RPP-42221	RPP-RPT-44557 (222-S), RJLG/CLS March 11, 2010 RJLG/CLS *VSR10-024*	

Table 4-3. Summary of WMA C Phase 2 RFI Locations

Investigation Site	Investigation Location Related Known or Suspected Event Investigation Objective (from Table 4-1 of RPP-PLAN-39114, Rev. 0)	Borehole Number	Activity	Push Orientation	Total Depth (ft bgs)[a] *Pipe run Total Depth (ft)*[a]	Depths of Resisitivity Probes or Sample Depths (ft bgs)[b]	Sample Depth Meetings[c]	Change Notice[d]	Field Summary Report	Laboratory Report *Validation Report*	Change from Work Plan, Rev 0 *Approval and Documentation*
P3	UPR-200-E-81 Known release site Characterize release and refine conceptual models	C6405	Direct Push Logging	Vertical	144	30 134	NA	NA	RPP-42221	NA	NA
		C6406[i]	Direct Push Sampling	Vertical	54.5	6, 11, 15 19, 27, 55.5, 60	1/15/2009	NA	RPP-42221	RPP-RPT-44557 (222-S), RJLG/CLS March 11, 2010, RJLG/CLS April 7, 2010 (RJLG/CLS) *VSR10-024*	
P4	UPR-200-E-81 Known release site Characterize release and refine conceptual models	C6397[o]	Direct Push Logging	Vertical	152	None	NA	NA	RPP-38927	NA	NA
P5	UPR-200-E-81 Known release site Characterize release and refine conceptual models	C6399[o]	Direct Push Logging	Vertical	242	50 215	NA	NA	RPP-38927	NA	NA
Q	UPR-200-E-82 Known release site Penetrate center of mass, and refine conceptual models	C7940	Direct Push Logging	Vertical	203	14, 34, 54, 74, 94, 114, 134, 154, and 173	NA	NA	RPP- 48609	NA	Sampling location was replaced with four logging boreholes with resistivity probes for SGE *RPP-PLAN-39114, Revision 2 documented agreement*
		C7941	Direct Push Logging	Vertical	202	16, 36, 56, 76, 96, 116, 136, 156, and 176.5	NA	NA		NA	
		C7942	Direct Push Logging	Vertical	203	16, 36, 56, 76, 96, 116, and 135	NA	NA		NA	
		C7943/ C7943A[j]	Direct Push Logging	Vertical	180/ 203.9	37, 57, 77, 97, 117, 137, 157, 177, and 196	NA	NA		NA	
R	241-C-301 Catch Tank Unlined concrete catch tank Assess potential catch tank release and refine conceptual models	C7667	Direct Push Logging	Vertical	222	37, 57, 77, 97, 117, 137, 157, 177, and 196	NA	NA	RPP-RPT-47461	NA	NA
		C7668/ C7668A[k]	Direct Push Sampling	Vertical	134/41	0.5, 6, 12[e], 16[e] 28, 40, 81, 133	1/20/2010	CCN-WMAC-008		RPP-RPT-49238 (222-S), VAD003S (TASL) *VSR11-044*	
S	UPR-200-E-72 and C-8 Drain Buried radioactive material and French drain from 241 CR Building are in this area Assess presence of buried material and potential releases to 216-C-8 drain and refine conceptual models	NA	Direct Push	NA	NA	NA	NA	NA	NA	NA	Site deleted *Documented in: 9/22/2011 work plan meeting minutes and RPP-PLAN-39114 Revision 2*
T	Location TBD, based on SGE data for entire WMA C Previously unknown release sites Objective TBD refine conceptual models	NA	TBD, direct push vertical and/or slant	NA	NA	NA	NA	NA	NA	NA	The need for this site is being evaluated through this document

Table 4-3. Summary of WMA C Phase 2 RFI Locations

Investigation Site	Investigation Location Related Known or Suspected Event Investigation Objective (from Table 4-1 of RPP-PLAN-39114, Rev. 0)	Borehole Number	Activity	Push Orientation	Total Depth (ft bgs)[a] *Pipe run Total Depth (ft)[a]*	Depths of Resisitivity Probes or Sample Depths (ft bgs)[b]	Sample Depth Meetings[c]	Change Notice[d]	Field Summary Report	Laboratory Report *Validation Report*	Change from Work Plan, Rev 0 *Approval and Documentation*
U	Tank C-110 Tank leak and/or tank overfill. Loss through spare inlet. Characterize Tank C-110 release and conceptual models.	C7675	Direct Push Logging	Vertical	220.9	20, 38, and 78	NA	NA	RPP-RPT-48029	NA	NA
		C7676	Direct Push Sampling	Vertical	159	0.5, 7[e], 11, 16[e] 39, 129, 158	7/7/2010	CCN-WMAC-011	RPP-RPT-48029	RPP-RPT-50378 (222-S) VAD004S_RE (TASL) *VSR11-048*	
V	Tank C-111 Tank leak and/or tank overfill. Loss through spare inlet. Characterize Tank C-111 release and conceptual models	NA	Direct Push	NA	NA	NA	NA	NA	NA	NA	Site deleted Work plan meeting *7/29/2011 discussed deletion of direct push at Site K.* *RPP-PLAN-39114, Revision 2 documented agreement*
W	299-E27-4, 299-E27-12, 299-E27-13, 299-E27-14, 299-E27-15 Log wells to collect data on U, ^{60}Co, ^{137}Cs, and moisture	NA	Monitoring Well Logging	NA	NA	NA	NA	NA	NA	NA	Logging data found for 299-E27-4 and -14. Logging of 299-E27-12, -13, and -15 deleted *RPP-PLAN-39114, Revision 2 documented agreement*
X	Added to Revision 2 of RPP-PLAN-39114 Investigation associated with Tank C-105 Cascade line leak. Possible tank leak and/or tank over fill Investigate extent of high activity ^{137}Cs plume in drywell 30-05-07 near Tank C-105 and refine conceptual models	N/A	Direct Push	Angle	NA	NA	NA	NA	NA	NA	Site added *RPP-PLAN-39114, Revision 2 documented agreement* Work not performed due to accessibility issues caused by retrieval operations
Y	Added to Rev. 1A of RPP-PLAN-39114 Request from the Nez Perce for any new groundwater wells WMA C soil sample data compared against that of a direct push (Addition of letter designation for this document) 299-E27-24 (due east of CR vaults) Investigate soil for presence of ^{99}Tc	299-E27-24	Analysis of soil samples	Vertical	262[m]	NA	NA	NA	NA	RPP-RPT-50450	Scope added *RPP-PLAN-39114, Revision 1A documented agreement* Scope performed was different than that planned *Work Plan Meeting Minutes (10/27/10) documented scope change*
Z	Added to Revision 2 of RPP-PLAN-39114 Well 299-E27-20 (adjacent to 299-E27-23) Assess presence of potential release (^{99}Tc) to soil column impacting groundwater and conceptual models	299-E27-20	Analysis of archived soil samples	Vertical	275[m]	NA	NA	NA	NA	RPP-RPT-55217	Site added *RPP-PLAN-39114, Revision 2 documented agreement*

Table 4-3. Summary of WMA C Phase 2 RFI Locations

Investigation Site	Investigation Location Related Known or Suspected Event Investigation Objective (from Table 4-1 of RPP-PLAN-39114, Rev. 0)	Borehole Number	Activity	Push Orientation	Total Depth (ft bgs)[a] *Pipe run Total Depth (ft)[a]*	Depths of Resisitivity Probes or Sample Depths (ft bgs)[b]	Sample Depth Meetings[c]	Change Notice[d]	Field Summary Report	Laboratory Report *Validation Report*	Change from Work Plan, Rev 0 *Approval and Documentation*
AA	Addition of letter designation (AA) in this document Perimeter of the WMA C Ecological risk caused by the WMA C Evaluate contaminant pathways	NA	Analysis of mice	NA	NA	NA	NA	NA	MSA-1104854	Revised 112161-596299 (WSCF 3/29/2012) HIE170412 (TASL -6/1/11)	Updated transect locations, added QA/QC requirements, updated analyte list *RPP-PLAN-39114, Revision 1 documented agreement*

[a] Pipe run total depth only applicable to angle pushes.
[b] Probe and sample depths are reported as vertical depth from ground surface rather than pipe run. Sample depths are given as the midpoint from the interval from which the sample was collected.
[c] Sample depth meeting notes are provided in Appendix J.
[d] Change Notices are associated with Sampling and Analysis Plan RPP-PLAN-38777 and are provided in Appendix K.
[e] Sample recovery issue occurred at depth and additional soil needed to be collected (refer to associated Change Notice).
[f] Due to various issues (e.g., high radiation), sample depth intervals from borehole C6392 and C6400 represent one location.
[g] Some sample depths were analyzed by PNNL as part of Phase 1.5. The remaining sample depths were analyzed by 222-S as part of Phase 2. A formal laboratory data package was not produced; however, laboratory data was loaded into HEIS.
[h] Due to various issues (i.e., poor sample recovery), C6402 and C6404 represent one location. These boreholes are referred to as C6394 in the sample depth meeting notes (refer to Appendix J). All three boreholes represent Site P2.
[i] Surface sample could not be obtained due to gravely nature of the surface soil (refer to Appendix L).
[j] Tubing broke in C7943A before resistivity probes could be placed. C7943 was pushed nearby for resistivity probes; it met refusal at 180 ft bgs; however, the tubing broke at 148 ft bgs. As a result, the deepest resistivity probe placement was 135 ft bgs.
[k] C7688 was only driven to 41 ft bgs and C7688A was driven nearby. All samples are identified as being from C7688.
[m] Depth listed is the depth of the deepest archive sample analyzed
[m] Drywell logging was also performed at Site L; see Section 4.4.2.
[o] These boreholes were pushed during Phase 1.5.

CLS = Center for Laboratory Sciences
NA = not applicable
RJLG = RJ Lee Group
TASL = Test America St. Louis

The details provided in Table 4-3 will also be discussed in this section and Sections 4.4.2 through 4.4.5. Table 4-3 specifically identifies the following for each direct push investigation site:

- Investigation site letter designation
- Purpose and location of investigation site
- Logging and/or sampling borehole name
- Direct push type (i.e., angle or vertical)
- Depth of push
- Resistivity probe placement
- Sample depth intervals
- Sample meeting date (sample depth meeting notes are provided in Appendix K)
- Field report summary document number
- Laboratory report information
- Data validation report information
- Change from original work plan

Figure 4-2 shows when the Phase 2 site investigation field efforts were performed, and Figure 4-8 shows the location of the final investigation sites by letter designation. Figure 4-8 also shows the study boundary as defined in the Phase 2 DQO. Note that the soil investigation boundary was also defined vertically at 61 m (200 ft) bgs. The location of some of the sites are slightly different from the original work plan.

Figure 4-8 also shows the specific locations (e.g., boreholes names) associated with the site investigation letter designations. As identified in the work plan, this is a non-probabilistic (biased) sampling strategy that targets locations where contaminants are most likely to be encountered. SGE was employed in an effort to identify any unknown releases across WMA C. SGE is used as an alternative technique to random sampling for investigating unknown releases because, regardless of infrastructure interference, the target area is simply too large to permit, in terms of time and resources, a statistically valid random sampling effort.

Additionally, it should be noted that there were several challenges to conducting the Phase 2 RFI field efforts in WMA C. At the same time characterization activities for the Phase 2 RFI field efforts were being executed, retrieval operations were in full swing (Appendix D shows the impacts of retrieval operations on the WMA C landscape). These retrieval operations at times caused limited access to some of the selected investigation sites. These issues are discussed in the subsequent subsections. The specific timing and scope of the WMA C soil investigation work was also contingent on available funding and prioritization of the investigative work relative to other tank farm activities, such as waste retrieval operations. This also caused difficulties with respect to completely sampling, analyzing, and evaluating the data.

4.4.1 Direct Push Vadose Zone Sampling, Analysis, and Logging

Several options were considered for collection of vadose zone data; however, the preferred method of using direct push technology was selected. As identified in Section 4.2.5, direct push has the capability of obtaining more than one sample per borehole and does not bring up cuttings

that need to be disposed. Furthermore, it does not take up as much space as a conventional drilling rig, which allows it to be deployed at more locations within the WMA C.

The work plan and SAP identified various requirements for the direct push field efforts. The soil sampling and logging requirements from these plans for both vertical and angle pushes are identified in Table 4-4. Note that the purpose of angle direct pushes was to find evidence of tank fluids that have leaked into the vadose zone. Therefore, at these sites, the target region for samples was within 3 m (10 ft) of the tank bottom. The exact angle, 30 degrees, 45 degrees, or 60 degrees, of the borehole to intersect the target region was determined by field conditions (e.g., where the direct push rig could be set up to avoid existing infrastructure).

Table 4-4. Direct Push Requirements[a]

Requirements	Vertical Push	Angle Push	Location of information
Number of pushes	A minimum of two holes will be pushed at each investigation site: - (One logging hole) The first would be the exploration borehole for logging purposes - (One sampling hole) The second would be the sampling borehole based on data observed in the first borehole.		- Table 4-3 - Section 4.4.1 Investigation Group/Site discussion
Gyroscope	NA	A slim hole gyroscope will be used to track the deviation of the angle hole.	Completion Reports (Refer to Table 4-3)
Total Depth	~ 200 ft bgs	100-series tanks ~200 ft pipe run 200-series tanks ~160 ft pipe run	Table 4-3
Logging Hole	- Gross gamma logging will be performed using modified bismuth germinate oxide tool - Neutron moisture will be performed		Completion Reports (and Appendix T)
Resistivity probes (electrodes)	Strings of electrodes will be located ~ every 20 ft to a depth of ~ 40 ft bgs	One to two electrodes will be placed depending on the angle of slant	Table 4-3
Plan changes	RPP-PLAN-39114 (work plan) identifies that specific work scope elements might require modification or refinement as the work progresses. Changes that do not affect the overall intent of the approved work plan or schedule can be made in the field and documented in the daily log books that are maintained in the field as stated in Section 12.4 of the HFFACO Action Plan (Ecology et al. 1989). RPP-PLAN-38777 (SAP) identifies that changes to work scope may result in modifications (revision) to the plan. Minor work scope changes (e.g., sample recovery issues) can be made in the field or laboratory with the		Table 4-2, Appendices H and K

Table 4-4. Direct Push Requirements[a]

Requirements	Vertical Push	Angle Push	Location of information
	approval of the project manager or assigned task lead.		
Sampling	An average of eight samples will be collected per sample location		- Table 4-3 - Section 4.4.1 Investigation Group/Site discussion
	Surface samples will be collected from ~0 to 1 ft bgs.[b] If the surface sample is not possible due to the gravelly nature of the land surface, pictures will be taken and documented in the completion report. Surface samples will not collected via direct push rig.		- Table 4-3 - Section 4.4.1 Investigation Group/Site discussion - Appendix L and relevant Completion Reports
	Three samples will be collected at depths less than 15 ft bgs[b]: - 5 ft bgs - 10 ft bgs - 14 ft bgs	Three samples will be collected at depths less than 15 ft bgs[b]. The location of sample will be determined by angle of borehole but will represent the: - 5 ft bgs - 10 ft bgs - 14 ft bgs	Table 4-3
	For depths greater than 15 ft bgs (i.e., deep), sample intervals will be determined by reviewing the gamma and moisture logs of the first direct push and any of the following available information: - pertinent leak loss inventory information - geologic information - operational history - historical characterization data The selection of sampling horizons will be done in an open meeting with available WRPS, DOE, Ecology, EPA, and other site contractors.		Table 4-3 and Appendix J
	Collect Field QC samples: field blank, trip blanks, equipment rinsates, and field duplicates per HASQARD frequency requirements		Appendix M

[a]The approach to field work at several investigation sites got modified over the course of the field efforts. Specially, some sites only were logged and not sampled. The requirements identified in this table do not pertain to those sites that were replaced with logging boreholes (i.e., no sampling boreholes) with the exception of the first requirement (i.e., number of pushes: one logging hole and one sampling hole per site).
[b]The purpose of collecting samples in the first 15 ft bgs (i.e., shallow) is to provide data for the direct exposure pathway and to provide initial data for ecological risk.

As previously identified, direct push methodology also has the ability of obtaining samples as deep as 61 to 76 m (200 to 250 ft) bgs in the 200 East Area. This depth is significant because, as identified, the vertical boundary of this soil investigation is 61 m (200 ft) bgs (Table 4-4). The depth of the first direct push was planned at 61 m (200 ft) bgs. This target depth was based on

the observation of ^{99}Tc and nitrate at 49 m (160 ft) bgs at borehole C4297 and ^{60}Co between 46 and 49 m (150 and 160 ft) bgs at well 299-E27-4.

The original work plan direct push sites (by letter designation) along with the purpose of these efforts are shown on Figure 4-9. While the approximate locations for each borehole are shown on Figures 4-9, the exact location for each borehole was dependent on the accessibility and subsurface interferences to the site, which was determined by ground-penetrating radar (GPR). GPR was performed at all investigation site areas. The final location of the sites that got pushed are shown on Figure 4-10. As holes were completed (i.e., logged, resistivity probes placed, and/or sampled), they were decommissioned in accordance with WAC 173-160 requirements.

Both Figures 4-9 and 4-10 show that some of these investigation sites have similar purposes and are also in close proximity. Therefore, these sites were grouped together for discussion purposes. Table 4-5 identifies the direct push investigation sites as grouped along with the area investigated and purpose of investigation.

In order to facilitate the direct push sampling, logging, and analysis efforts, an additional document, the field sampling and analysis plan (FSAP), was written to provide implementation information specifically for the laboratory and field personnel. As field work progressed, the FSAP was revised, as needed, to incorporate those updates made to the work plan and SAP. In addition to revisions, several change notices were written to the FSAP during the course of the field work to address minor changes not impacting overall project requirements. As identified in Table 4-4, changes could be made in the field or laboratory with the approval of the project manager or assigned task lead in order to address minor unexpected field conditions (e.g., sample recovery issue). All change notices associated with the FSAP are provided in Appendix K. Change notices that impact field or laboratory efforts (i.e., sample recovery issues) are specifically presented in the investigation site/group discussions that follows and identified in Table 4-3.

The direct push information is discussed:

- By each investigation site/group as identified in Table 4-5
- In a field characterization summary (Section 4.4.1.1)
- By analytical requirements (Section 4.4.1.2).

In addition to the Phase 2 investigation sites/groups identified in Table 4-5, borehole C7469 is discussed. Borehole C7469 (located near Tank C-105 [Figure 4-8]) was not pushed for Phase 2 but was pushed to support retrieval efforts. This direct push was located by Tank C-105 (Figure 4-8) and information on this field effort is also presented below.

Figure 4-9. Original Phase 2 Direct Push Locations

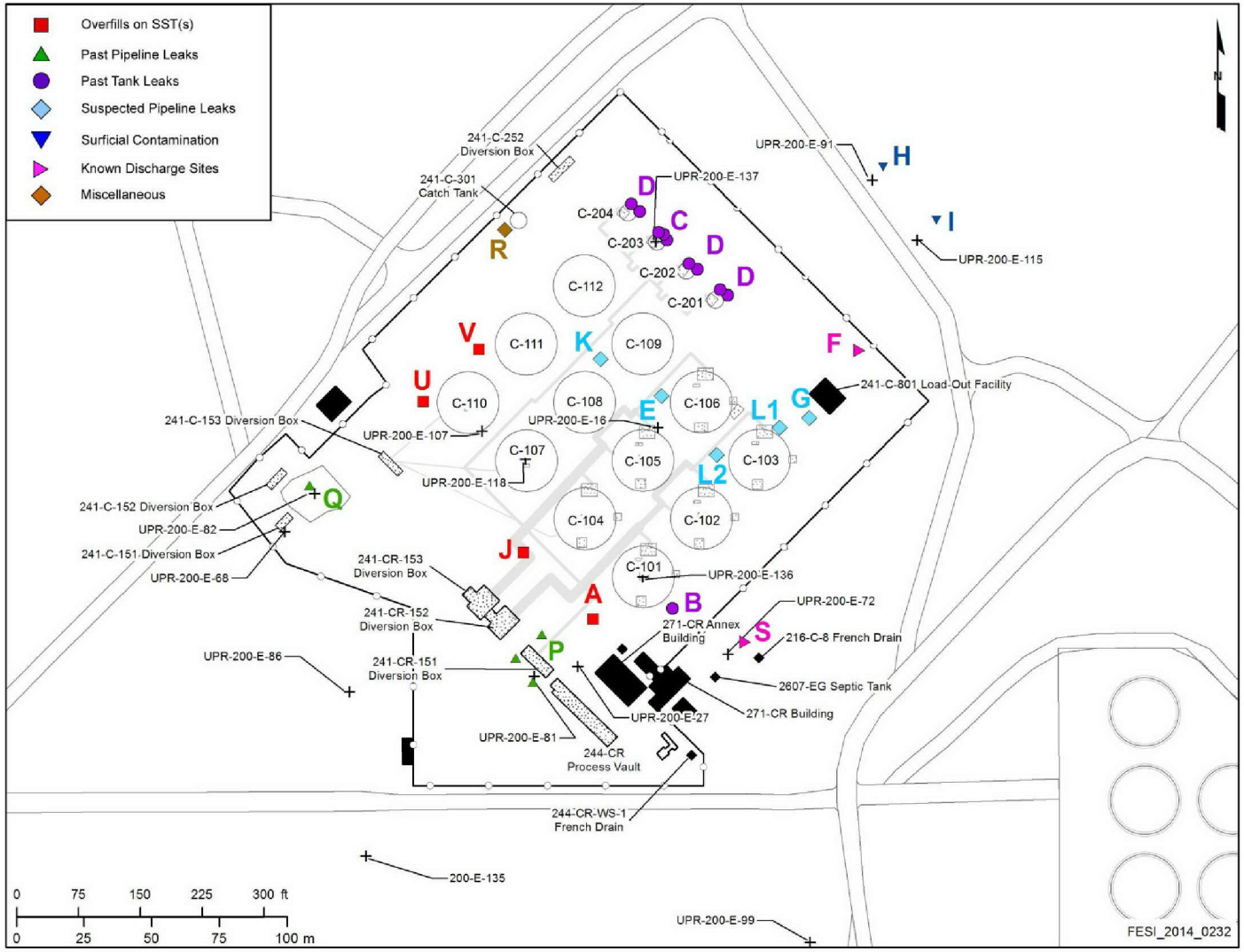


Figure 4-10. Phase 2 Direct Push Locations per RPP-PLAN-39114, Rev. 2

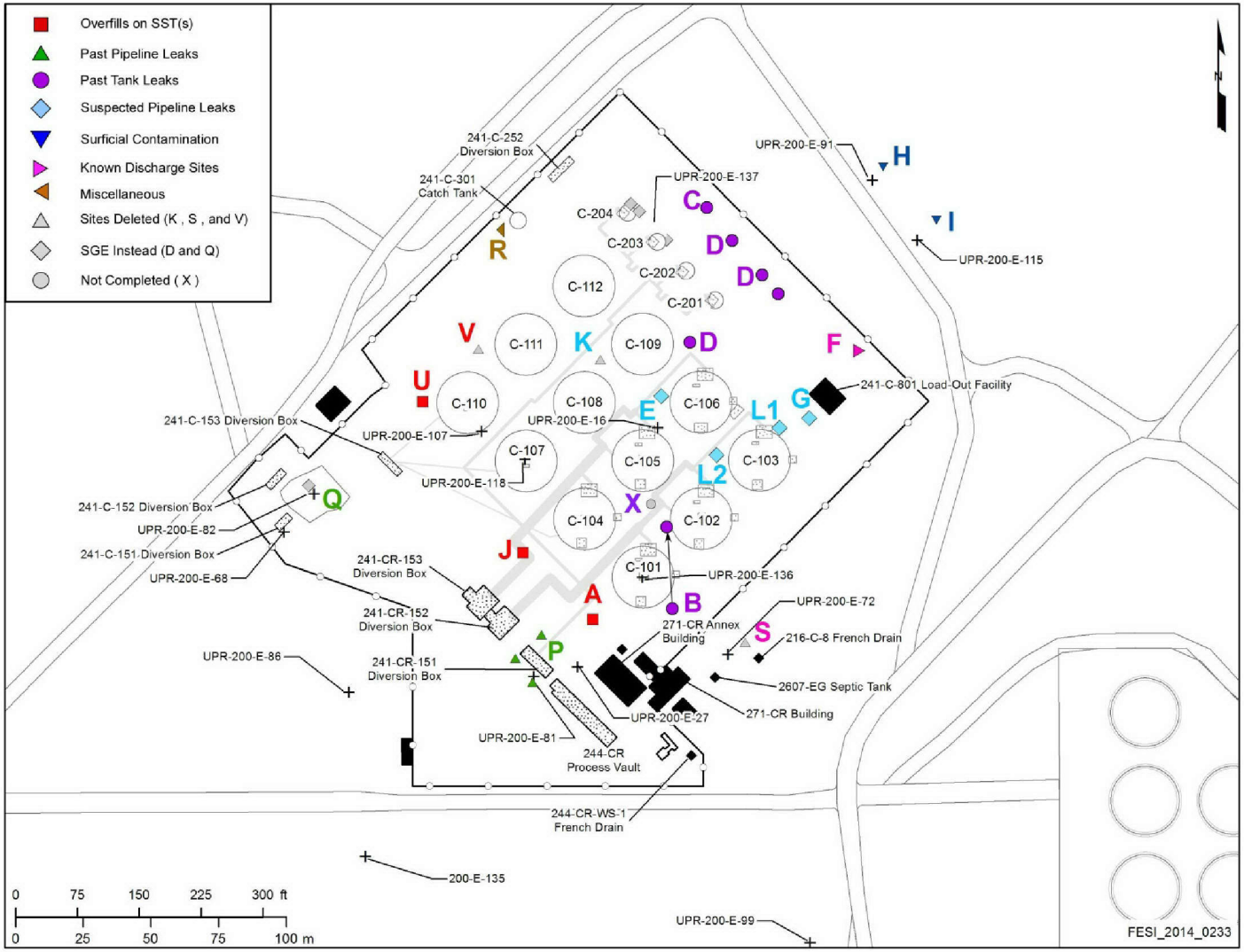


Table 4-5. Direct Push Investigation Sites and Groups

Direct Push Investigation Group/Site	General Location Within Waste Management Area C	Phase 2 Characterization Objective
A+B	Area near Tank C-101	Characterize releases and refine conceptual models
C+D	Area near 200-series tanks	Determine if 200-series tanks actually leaked, refine conceptual models and determine if any 200-series tank leaked during retrieval
E	Area between Tanks C-106 and C-109	Characterize soil for presence of ^{60}Co and refine conceptual models
F+G	Area near Tank C-103 and C-801 Building, and C-801 Building chemical drain	Characterize soil to assess release of PUREX plant waste, ^{137}Cs and ^{99}Tc,and ^{60}Co and refine conceptual models
H+I	Area northeast of UPR-200-E-91 and UPR-200-E-115	Assess surface exposures, and assess ^{60}Co and surface release conceptual models
J	Area near Tank C-104	Assess suspected release and refine conceptual models
K	Area near Tank C-108	Assess potential leak from transfer line and refine conceptual models
L1+L2	Area between Tanks C-103 and C-106	Updated logging data for ^{60}Co, ^{137}Cs, uranium, and moisture and assess potential release and refine conceptual models
P (P1 – P5)	Area near UPR-200-E-81	Characterize release and refine conceptual models
Q	Area near UPR-200-E-82	Characterize release and refine conceptual models
R	Area near C-301 Catch Tank	Assess potential catch tank release and refine conceptual models
S	Area near 216-C-108 French drain	Assess the presence of potential releases from the 216-C-8 French drain and refine conceptual models
T	To be determined	Characterize soil as necessary (based on evaluation of SGE results)
U	Area near Tank C-110	Characterize Tank C-110 release and refine conceptual models
V	Area near Tank C-111	Characterize suspected Tank C-111 leak and refine conceptual models
X	Area near Tank C-105	Assess extent of ^{137}Cs plume from drywell 30-05-07 and refine conceptual models

Investigation Group A+B: The original work plan identified one to two angle push locations for Site A and one vertical or angle push location for Site B. Specifically, low levels (0.6 pCi/g) of ^{60}Co were measured in the vadose zone between 40 and 76 m (130 and 250 ft) bgs at groundwater well 299-E27-14. It was speculated that the ^{60}Co migrated to this well from either a Tank C-101 leak or was the result of disposal to the 216-C-8 French drain. The purpose of this investigation group was to characterize the Tank C-101 release and refine the conceptual models.

One location, which consisted of an exploratory and sampling borehole, was pushed at both Sites A and B. All direct push boreholes were angled. Site A boreholes were placed near the spare inlet as identified in the work plan; however, Site B was relocated from the south side because of accessibility issues from retrieval activities (Appendix I). Site B pushes were angled direct pushes that targeted the east side of Tank C-101.

The following is a brief summary of the field work performed at this investigation group (Table 4-3):

- Fieldwork for these sites was conducted from February 2011 through July 2011
- Each investigation site (A and B) had one angle logging hole and one angle sampling hole (Figures 4-8 and 4-10)
  - Site A: logging hole C8101 and sampling hole C8102
  - Site B: logging hole C8103 and sampling hole C8104
- The target dip angle of all the boreholes was 60 degrees from horizontal. Site A had an azimuth of 47 degrees from true north and Site B had an azimuth of 163 degrees from true north (Figure 4-11 [Site A] and Figure 4-12 [Site B]).
- All sample intervals were collected per sample depth meetings (May 16, 2011 [Site A – C8102] and June 17, 2011 [Site B – C8104]) with the exceptions:

  Site A (C8102)

  - Documented in FSAP change notice WMAC-020
    - Due to poor sample recovery from the 1.7 to 2.4 m (5.7 to 7.7 ft) (pipe run) interval, an additional sample was taken from 2.4 to 3 m (7.7 to 10 ft) (pipe run) and these two samples were composited for analysis. Note that this corresponds to a vertical depth of 2.1 m (6.8 ft) bgs.

Figure 4-11. Site A Angle Push Location

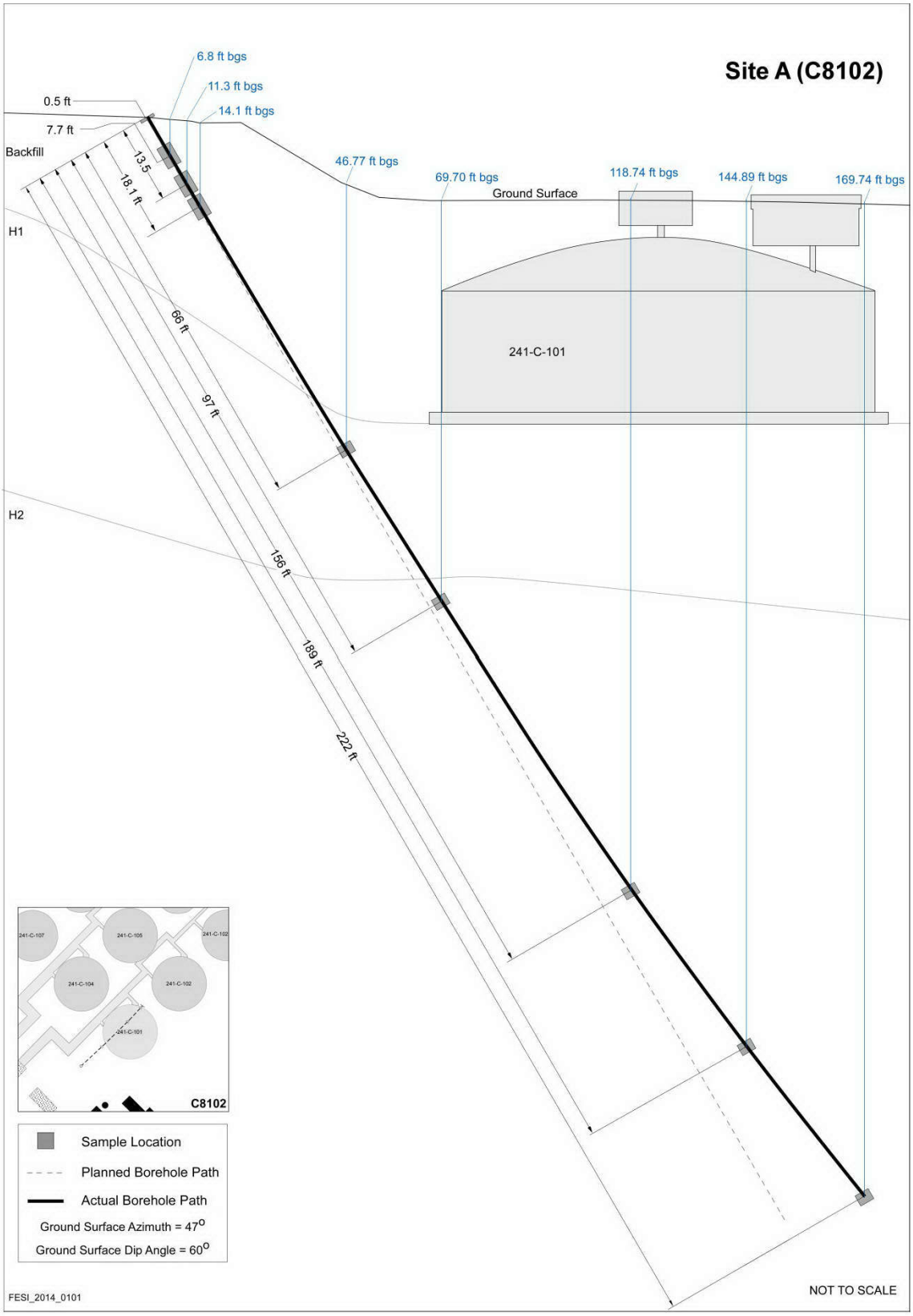
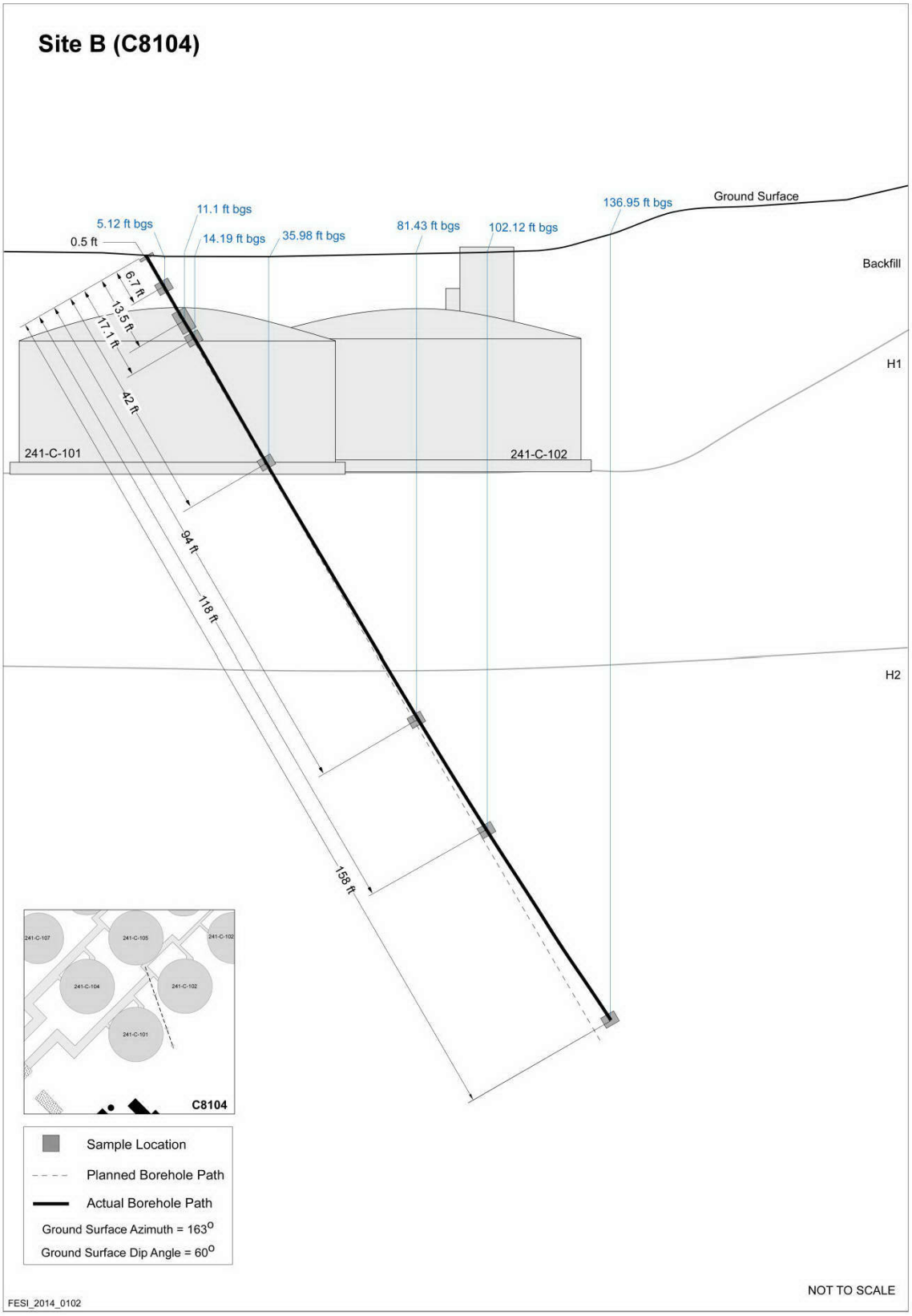


Figure 4-12. Site B Angle Push Location



- Due to poor sample recovery from the 3.5 to 4.1 m (11.5 to 13.5 ft) (pipe run) interval, an additional sample was taken from 4.1 to 4.7 m (13.5 to 15.5 ft) (pipe run), and these two samples were composited for analysis. Note that this corresponds to a vertical depth of 3.4 m (11.4 ft) bgs.

– Documented in FSAP change notice WMAC-021

- Due to poor sample recovery in the 4.9 to 4.5 m (16.1 to 18.1 ft) (pipe run) interval, an additional sample was attempted at 5.5 to 6.1 m (18.1 to 20.1 ft) (pipe run), but there was zero recovery from this interval. Because there was not enough sample for the complete suite of analyses, the change notice details the prioritized analysis list for these intervals. Note that this corresponds to a vertical depth of 4.3 m (14.1 ft) bgs.

Investigation Group C+D: The original work plan identified three angle push locations at Site C for Tank C-203 and one to two angle push locations at Site D for each of three tanks (Tanks C-201, C-202, and C-204). The purpose of this investigation group was to investigate whether or not any of the 200-series tanks had leaked and/or had an overfill event or loss through a spare inlet and to additionally refine the conceptual models.

Through a series of discussions, the Tri-Parties agreed to modify the investigation of Sites C and D to include use of SGE. The purpose of the SGE investigation of Sites C and D was to interrogate the subsurface beneath the 200-series tanks and the surrounding vicinity for the presence of tank farm related waste. These direct pushes were moved to examine the area between 200-series tanks and well 299-E27-7 where uranium was found in vadose zone. Although multiple 200-series tanks are assumed to have released waste to the environment in the past, only one UPR is identified for these tanks, UPR-200-E-137 for Tank C-203 (HNF-EP-0182). Evidence suggests that the 200-series tanks were filled several times, and liquid level decreases may in part have been the result of a tank overflow through spare inlet ports, or more likely can be attributed to evaporation (RPP-RPT-42294, *Hanford Waste Management Area C Soil Contamination Inventory Estimates*). The SGE investigation could also be used to evaluate whether there was any evidence of any leaks from the 200-series tanks during retrieval.

It was decided that four boreholes, near the 200-series tanks, would be equipped with deep electrodes to allow for three-dimensional SGE investigation of the area to identify geophysical anomalies that could indicate that soils have been affected by tank waste. The presence and intensity of any detected anomalies would be evaluated together with soil analytical results from the area, to determine whether there was a need for any further investigation using direct push sampling. For this reason, only one location, which included a sampling and an exploratory/logging borehole, was pushed at Site C and four locations, which consisted of logging boreholes, were pushed at Site D. This change was documented in RPP-PLAN-39114, Rev. 2.

The following is a brief summary of the field work performed at this investigation group (Table 4-3):

- Field work for Site C, which consisted of angle pushes, was initiated in September 2011 and finished in November 2011 and fieldwork for the vertical pushes at Site D was performed from March to June 2013 (Figures 4-8 and 4-10)
  - Site C: logging hole C8105 and sampling hole C8106
  - Site D: logging holes C8763, C8765, C8766, C8767
- The boreholes pushed at Site C had a target angle of 28 degrees from horizontal with an azimuth of 235° from true north (Figure 4-13).
- All sample intervals were collected per sample depth meeting (October 18, 2011 [Site C 8106]) and there were no samples taken from boreholes at Site D
- Site D consisted of four vertical boreholes

Investigation Site E: The original work plan called for one vertical push location for Site E. The purpose was to assess ^{60}Co levels in the soil due to a suspected release between Tanks C-106 and C-109 and to refine conceptual models (e.g., movement of contaminants down stratigraphic dip).

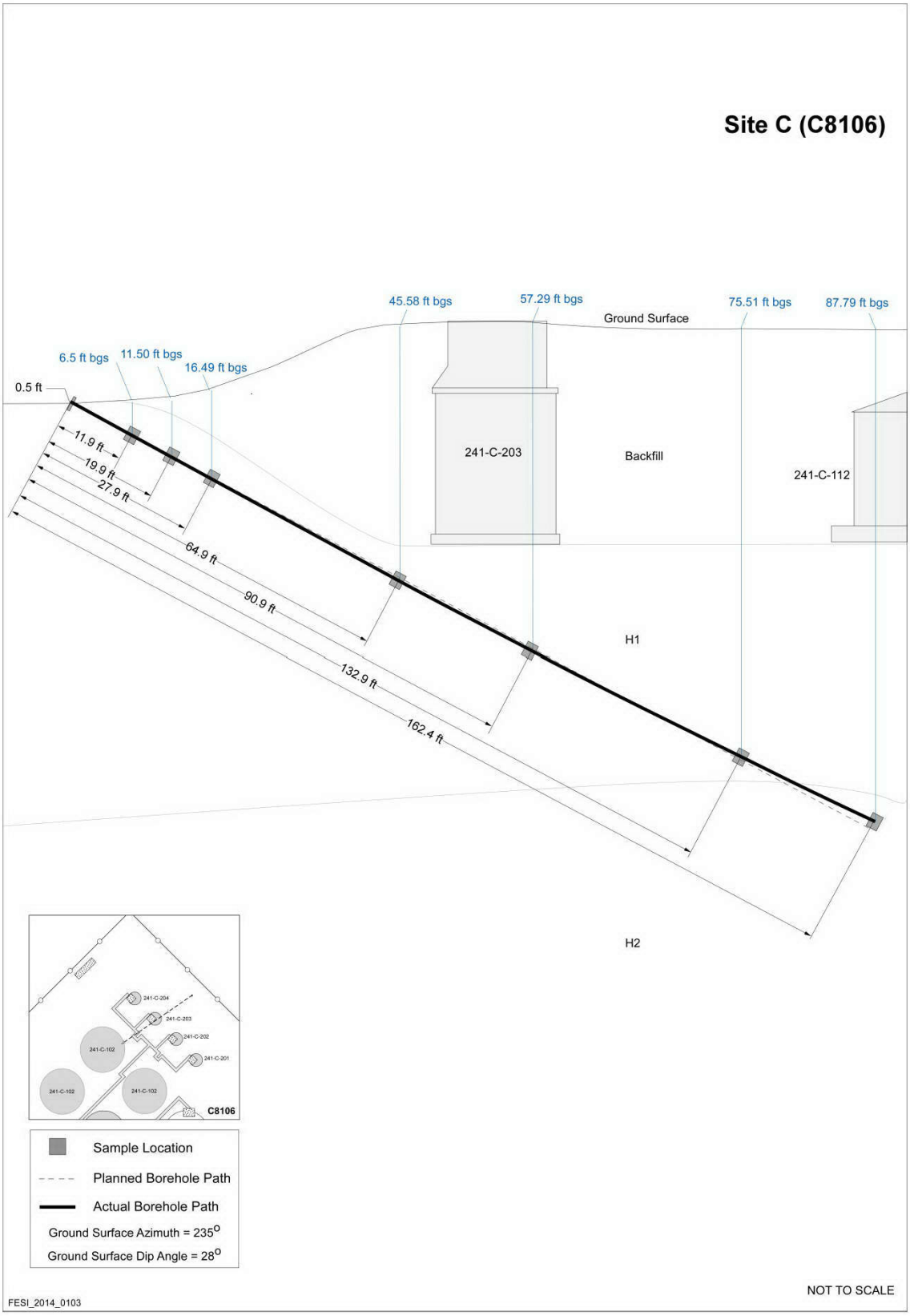
One vertical location was pushed as planned to characterize the investigation site. The following is a brief summary of the field work performed at this investigation site (Table 4-3):

- Fieldwork initiated in June 2010 and was completed in July 2010
- The investigation site had one vertical logging hole (C7671) and one vertical sampling hole (C7672) (Figures 4-8 and 4-10).
- All samples intervals were collected per sample depth meeting (July 7, 2010).

Investigation Group F+G: The original work plan identified one vertical push location for Site F and one vertical push location for Site G. The purpose of Site F was to assess the release of PUREX waste; characterize the soil for ^{137}Cs, ^{99}Tc, and ^{60}C for a suspected release site near C-801 Building chemical drain; and to refine conceptual models (e.g., movement of contaminants down stratigraphic dip). According to historical records, a pipeline was installed to complete an alternative effluent return route from C-801 Building to Tank C-103. Because a line to perform this function already existed, this new line installation could indicate that a problem existed in the old line, including a leaking pipeline. Site G was also chosen to investigate this area and to refine conceptual models.

One location, which consisted of an exploratory and sampling borehole, was pushed at both Sites F and G as planned. All direct push boreholes were vertical. The following is a brief summary of the field work performed at this investigation group (Table 4-3):

Figure 4-13. Site C Angle Push Location



- Fieldwork for Site F was conducted from November 2009 through June 2010 and fieldwork for Site G was conducted from July 2009 through August 2009 (Figures 4-8 and 4-10)

  - Site F: logging hole C7471 and sampling hole C7472
  - Site G: logging hole C7467 and sampling hole C7468

- All sample intervals were collected per sample depth meetings (July 28, 2009 [Site G - C7468] and December 17, 2009 [Site F - C7472]) with the following exception:

  Site F (C7472)

  - Documented in FSAP change notice WMAC-004

    - Due to poor sample recovery from the 3 to 4 m (10 to 12 ft) bgs interval, an additional sample was taken from 4 to 4.3 m (12 to 14 ft) bgs, and these two samples were composited for analysis.

Note that per the sample depth meeting on December 17, 2009 for Site F, two additional sampling intervals (49 m [159 ft] bgs and 59.7 m [196 ft] bgs) were selected to investigate "drier" areas (i.e., no moisture peak). The sample interval of 49 m (159 ft) bgs was also selected based on the depth of nitrate concentrations in borehole C4297 (by Tank C-105), which is 49 m (160 ft) bgs.

Investigation Group H+I: The original work plan identified one vertical push location for Site H and one vertical or angled push location for Site I. The purpose of Site H was to investigate surficial contamination at in the area of UPR-200-E-91, located north and east of WMA C. In 1981, contaminated soil was removed from this area and moved to another area (i.e., UPR-200-E-56). The radiological posting at UPR-200-E-91 was removed in 1981. Site H was selected to verify that the contaminated soils were removed. The site was also investigated for evidence of ^{60}Co and to refine conceptual models. The purpose of Site I was to address surficial contamination at UPR-200-E-115 discovered in October 2001; characterize the soil for ^{60}Co; and to refine conceptual models.

At both Sites H and I, the depth of the direct pushes were planned to be 46 m (150 ft) bgs, unless data from Sites F and G indicated that the direct pushes at Sites H and I should be deeper. The work plan provided the option to extend the depths of the direct pushes, if contaminants appeared to be moving down dip northeasterly. If contamination was found at depth at Sites F and G, then the depth of the direct pushes at Sites H and I would be extended based on the information from Sites F and G. The purpose of extending the depth of these direct pushes was to provide information related to contaminant movement down dip. Additionally, if contamination was not found at depth at Sites F and G, the depth of the direct push at Sites H and I would stop at 5 m (15 ft) bgs.

One location, which consisted of an exploratory and sampling borehole, was pushed at both Sites H and I as planned. All direct push boreholes were vertical. Based on logging results from

Sites F and G, the logging boreholes at Sites H and I were pushed to depths of approximately 67 m (220 ft) bgs.

The following is a brief summary of the field work performed at this investigation group (Table 4-3):

- Fieldwork was initiated in June 2010 and was completed in September 2010
- Each investigation site (Sites H and I) had one vertical logging hole and one vertical sampling hole (Figures 4-8 and 4-10)
  - Site H: logging hole C7679 and sampling hole C7680
  - Site I: logging hole C7681 and sampling hole C7682
- All samples intervals for Sites H and I were collected per sample depth meeting (August 4, 2010) with the exception:

  <u>Site I (C7682)</u>

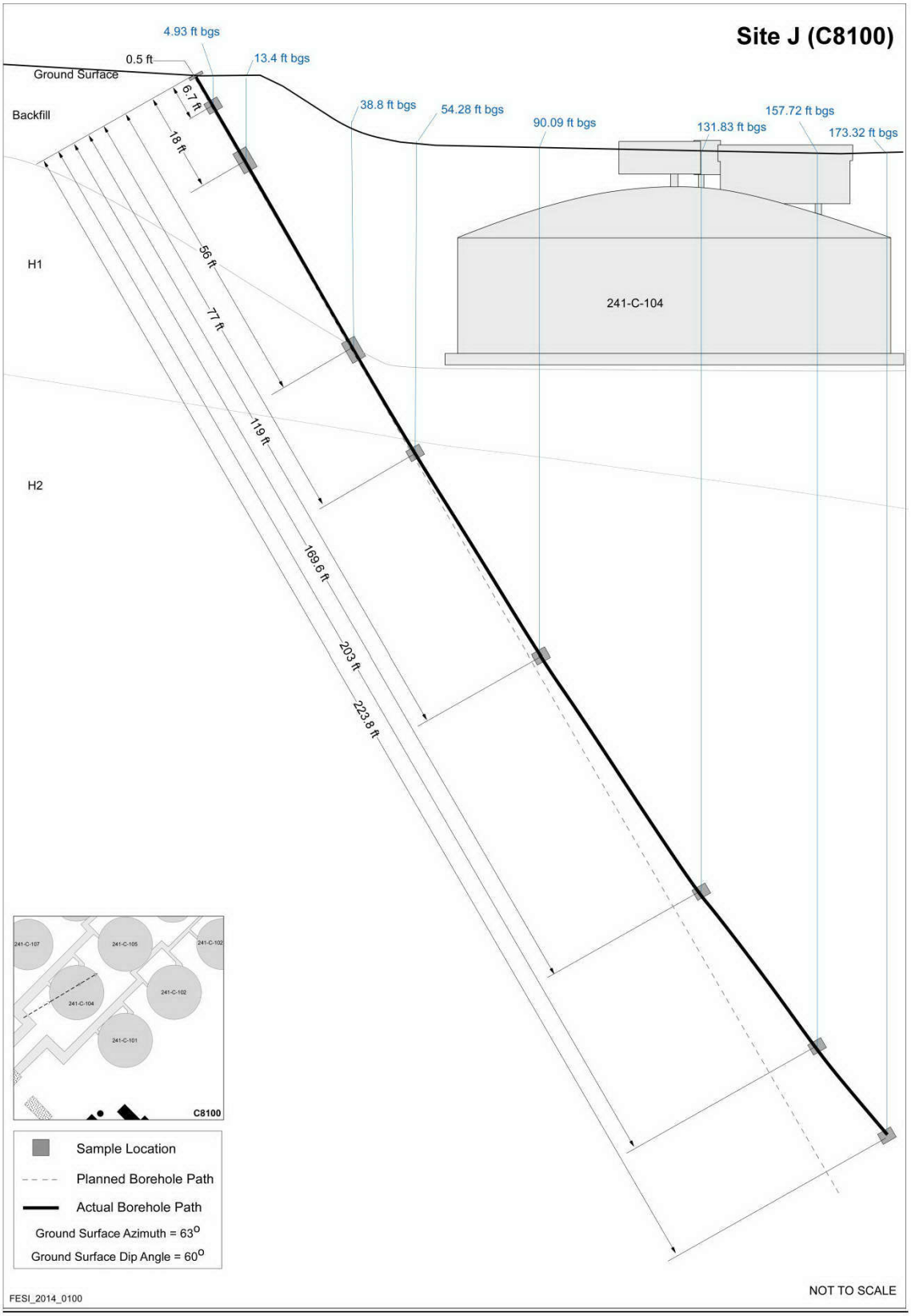
  - Documented in FSAP change notice WMAC-012
    - Due to poor sample recovery from the 3 to 4 m (10 to 12 ft) bgs interval, an additional sample was collected from 4 to 4.3 m (12 to 14 ft) bgs, and these two samples were composited for analysis.

<u>Investigation Site J:</u> The original work plan identified one angled push location for Site J. The purpose was to characterize a suspected release at Tank C-104 and to refine conceptual models.

One angled location was pushed as planned to characterize the investigation site, and the following is a brief summary of the field work performed at this investigation site (Table 4-3):

- Fieldwork was conducted from December 2010 to April 2011
- The investigation site had one angle logging hole (C8099) and one angle sampling hole (C8100) (Figures 4-8 and 4-10)
- The target dip angle of both boreholes was 60° from horizontal, with an azimuth of 63° from true north (Figure 4-14).
- All sample intervals were collected per sample depth meeting (February 15, 2011) with the exceptions:

Figure 4-14. Site J Angle Push Location



Site J (C8100)

- Documented in FSAP change notice WMAC-016
  - Due to poor sample recovery from interval 5 to 5.2 m (15 to 17 ft) (pipe run), an additional sample was taken from 5.2 to 6 m (17 to 19 ft) (pipe run), and the two samples were composited for analysis. Note that this corresponds to a vertical depth of 4.1 m (13.5 ft) bgs.
- Documented in FSAP change notice WMAC-018
  - Due to poor sample recovery interval 17 to 17.1 m (54 to 56 ft) (pipe run), an additional sample was taken from 17.1 to 18 m (56 to 58 ft) (pipe run), and the two samples were composited for analysis. Note that this corresponds to a vertical depth of 11.8 m (38.8 ft) bgs.

In the sample depth meeting, it was agreed that instead of taking four shallow sample depth intervals, three would be collected. Two additional deep sample depth intervals were collected, so a total of nine sample depth intervals were collected at this investigation site.

Investigation Site K: The original work plan identified one vertical or angle push location for Site K (Figure 4-7 shows the location of Site K). The purpose was to investigate whether or not a transfer line had leaked near Tank C-108; to assess the origin of contamination observed in drywell 30-09-02; and to refine conceptual models. Evaluation of available information indicated there were multiple leaks during operations from the cascade line between Tanks C-108 and C-109. The extent of the resulting plume was previously defined by the presence of ^{60}Co in drywells. However, the ^{60}Co associated with this plume has decayed to below the detection limit of geophysical logging tools.

Given the timing, content, and likely quantity of the releases, as well as results available from sampling at nearby Site E, sampling at Site K was expected to confirm a release at this location and that mobile contaminants (e.g., ^{99}Tc) have migrated deep into the vadose zone. It was believed that sampling at Site K was unlikely to yield additional results of value to the RFI investigation (to influence cleanup decisions). Additionally, the location was highly congested with infrastructure and Tank C-112 retrieval preparations. Access had been extremely poor and was expected to remain so until retrieval operations were complete. For these reasons, Site K was not pushed as planned. Site K was deleted in the approved Revision 2 of the work plan and replaced with Site X.

Investigation Group L1+L2: The original work plan identified two vertical push locations, which consisted of two exploratory and two sampling boreholes, for Site L (L1 and L2). The purpose of this site was to investigate if a transfer line had leaked; if a tank had overfilled near Tanks C-103 and C-106; and additionally to refine conceptual models (e.g., movement of contaminants down stratigraphic dip).

One location, which consisted of an exploratory and sampling borehole, was pushed at both Sites L1 and L2 as planned. All direct push boreholes were vertical. The following is a brief summary of the field work performed at this investigation group (Table 4-3):

- Fieldwork for Site L1 was conducted from July 2009 to August 2009 and fieldwork for Site L2 was conducted from November 2009 to June 2010

- Each investigation site (L1 and L2) had one vertical logging hole and one vertical sampling hole (Figures 4-8 and 4-10):

  - Site L1: logging hole C7465 and sampling hole C7466
  - Site L2: logging hole C7669 and sampling hole C7670

- All sample intervals were collected per sample depth meetings (July 28, 2009 [Site L1 – C7466] and January 20, 2010 [Site L2 – C7670]) with the exceptions:

  <u>Site L2 (C7670)</u>

  - Documented in FSAP change notice WMAC-005

    - Due to poor sample recovery from the 3 to 4 m (10 to 12 ft) bgs interval, an additional sample was taken from 4 to 4.3 m (12 to 14 ft) bgs, and the two samples were composited for analysis.

  - Documented in FSAP change notice WMAC-006

    - Due to poor sample recovery from the 67 to 68 m (220 to 222 ft) bgs interval, an additional sample was taken from 68 to 68.3 m (222 to 224 ft) bgs, and the two samples were composited for analysis. No high-level volatile organic compound (VOC) samples were collected.

<u>Investigation Group P (P1 through P5):</u> This investigation was conducted to characterize UPR-200-E-81, a 136,275 L (36,000 gal) pipeline leak that occurred in 1969 and to refine conceptual models. As identified in Section 4.3.2 part of this investigation was conducted during "near-term characterization" (Phase 1.5) and part was conducted under Phase 2. Per the original work plan only three locations were to be investigated. During the field effort, five locations were actually investigated at P (i.e., referred to as Investigation Group P, which consists of Sites P1 – P5):

- "Near-Term Characterization," fieldwork was performed at four locations at Site P. A total of five logging boreholes were pushed (C6391 [Site P1], C6393 [Site P2], C6395 [Site P1], C6397 [Site P4], and C6399 [Site P5]) and one sampling borehole (C6394 [Site P2]) was pushed (see Section 4.3.2 for additional details).

- Phase 2 included three sampling locations (C6392/C6400 [Site P1], C6394 [Site P2], C6402/C6404 [Site P2], and C6406 [Site P3]) and two additional logging locations (C6403 [Site P1], and C6405 [Site P3]).

Sampling borehole C6394 at Site P2 was sampled under "near-term characterization" (Phase 1.5) and under Phase 2. Eleven soil samples were collected from 3 m (9 ft) bgs to 52 m (172 ft) bgs. At this time, sample analysis was being transitioned from PNNL to 222-S Laboratory. For this reason, two sample intervals from this borehole were analyzed by 222-S Laboratory. The other sample intervals from C6394 were analyzed by PNNL as documented in Section 4.3.2. It should be noted that the samples from this borehole were not analyzed for all constituents identified in RPP-PLAN-39114.

The following is a brief summary of the field work performed at this investigation group (Table 4-3):

- Fieldwork began under "near-term characterization" from April 2008 through June 2008, and was completed during Phase 2 from February 2009 through June 2009. This was the first site investigated as part of Phase 2.

- All locations associated with Sites P1 – P5 were vertical boreholes (Figures 4-8 and 4-10):

  - P1 - three logging boreholes (C6391, C6403, and C6395) and two sampling boreholes (C6392/C6400)

  - P2 - one logging borehole (C6393) and three sampling boreholes (C6394 and C6402/ C6404)

  - P3 - one logging borehole (C6405) and one sampling borehole (C6406)

  - P4 - one logging borehole (C6397)

  - P5 - one logging borehole (C6399).

- Sample intervals were collected per sample depth meetings (January 15, 2009 [Site P1- C6392, Site P2 –C6404, and Site P3- C6406]. There were issues identified while field work was being conducted (both sampling and logging). These issues were either documented in the meeting notes or the associated completion reports (Table 4-3):

  - Site P1

    - Sample borehole C6392 was pushed adjacent to logging hole C6391. High radiation was encountered during collection of the sample from 1.5 to 2 m (5 to 7 ft) bgs. This sample was discarded, and it was decided not to collect the sample from 3 to 4 m (10 to 12 ft) bgs. The remaining sample intervals were collected as planned. Borehole C6400 was pushed adjacent to C6392 to sample shallow samples not collected at C6392 and to additionally collect one deep sample.

- Logging borehole C6403 was pushed adjacent to C6392 because of the high radiation found in C6392. This logging hole was pushed to a depth of 15 m (50 ft) bgs. Geophysical logging documented the presence of approximately 1,200,000 pCi/g of ^{137}Cs at a depth of 2 m (6 ft) bgs.

- Site P1 was logged at borehole C6403 during Phase 2 and at boreholes C6391 and C6395 during Phase 1.5. The resistivity probes were placed in borehole C6395 for Site P1. Site P1 was sampled at boreholes C6392/C6400. The gravelly nature of the land surface Site P1 (C6392) prevented the collection of surface samples (Refer to completion report). The total number of samples collected at Site P1 was three shallow samples and five deep samples.

– Site P2

- Sample borehole C6402 was pushed adjacent to logging borehole C6393. Due to poor recovery at the shallow depths, an additional borehole, C6404, was pushed adjacent to C6402.

- Site P2 was logged at borehole C6393. No resistivity probes were placed in C6393; however, resistivity probes were installed nearby at borehole C6399 (Site P5, Figures 4-8 and 4-10). Site P2 was sampled at boreholes C6402/C6404 and additionally C6394 (as identified above). The gravelly nature of the land surface at Site P2 prevented the collection of surface samples (Appendix L). The total number of samples collected at Site P2 was three shallow samples and six deep samples.

– Site P3

- Sample borehole C6406 is adjacent to C6405. The gravelly nature of the land surface at Site P3 (C6406) prevented the collection of surface samples (Appendix L). The total number of samples collected at Site P3 was three shallow samples and four deep samples.

– Site P4

- Based on SGE results, it was decided that it would be better to sample at Site P3 rather than at Site P4 (logging borehole C6397). Therefore, sampling was conducted at Site P3, north and east of diversion box 241-C-152 (January 15, 2009 meeting notes).

– Site P5

- It was decided that Sites P1 – P3 would be sampled. Therefore, no samples were collected at Site P5. Resistivity probes were installed in logging hole C6399.

Ultimately, three sites were sampled (Sites P1 - P3) and three sites have resistivity probes (Sites P1, P3, and P5).

Investigation Site Q: The original work plan identified one vertical push location for Site Q. The purpose was to further investigate UPR-200-E-82, by pushing directly through the center of the UPR site and to refine conceptual models. Note that this UPR was also investigated during Phase 1 (Section 4.2.2) and during the pre-RFI timeframe (Section 4.1).

Although a vertical push through the gunite cap had been proposed, it was not implemented due to radiological control requirements. Instead, four direct push holes were placed to a depth of 61 m (200 ft), one on each side of the UPR, and multi-depth electrodes were placed.

A three-dimensional SGE survey was then conducted to map the extent of any electrical anomaly resulting from this release. This change was documented in the approved Revision 2 of the work plan, which identifies that for UPR-200-E-82 (i.e., Site Q), four pushes will be made for the sole purpose of installing multi-depth electrodes in support of SGE.

Additionally, the September 22, 2011 work plan meeting notes identified that a wealth of SGE information and soil samples have been obtained from the UPR-200-E-82 area and that those results have not indicated any significant remaining moisture, ^{99}Tc or nitrate anomalies. However, as documented in RPP-14430, Rev. 0, Appendix F, high levels of ^{137}Cs were present in the soil at the site of the UPR-200-E-82 cap, based on historical sampling. If drilling was conducted beneath the cap, personnel exposures could occur since high levels of ^{137}Cs are still expected to be present. For these reasons, sampling at this location was not thought to likely yield information of value to the investigation

The following is a brief summary of the field work performed at this investigation site (Table 4-3):

- Fieldwork was conducted from October 2010 through November 2010
- A total of five vertical pushes were installed (one was a replacement borehole due to pipe failure in the first borehole, which prevented the installation of resistivity probes for SGE (Figures 4-8 and 4-10).
  - Logging holes: C7940, C7941, C7942, and C7943/C7943A
- No samples were taken at this site.

Investigation Site R: The original work plan identified one vertical push location for Site R. The purpose was to assess a potential release from the 241-C-301 Catch Tank and to refine conceptual models.

One vertical location, consisting of an exploratory and sampling borehole, was pushed as planned to characterize the investigation site. The following is a brief summary of the field work performed at this investigation site (Table 4-3):

- Fieldwork was conducted from November 2009 through June 2010
- This site had one vertical logging hole (C7667) and one sampling hole (C7668/C7668A) (Figures 4-8 and 4-10)
- All sample intervals were collected per sample depth meeting (January 20, 2010) with the exceptions:
  - Site R (C7688) documented in FSAP change notice WMAC-008
    - Due to poor sample recovery from the 1.5 to 2 m (5 to 7 ft) bgs interval, an additional sample was attempted from 2 to 3 m (7 to 9 ft) bgs; however, nothing was recovered from this second interval. Between these two intervals only 46 g of soil was collected. There was not enough sample for the complete suite of analyses. The change notice documented the prioritized analyses list for these intervals.
    - Due to poor sample recovery from the 3 to 4 m (10 to 12 ft) bgs interval, an additional sample was taken from 4 to 4.3 m (12 to 14 ft) bgs, and the two samples were composited for analysis. Between these two intervals only 117.5 g of soil was collected. There was not enough sample for the complete suite of analyses. The change notice documented the prioritized analyses list for these intervals.
    - Due to poor sample recovery from the 4.3 to 5 m (14 to 16 ft) bgs interval, an additional sample was taken from 4 to 4.3 m (12 to 14 ft) bgs, and the two samples were composited for analysis.

Note borehole C7668A was only driven to 13 m (41 ft) bgs because liquid was encountered on top of the sampler at 12 to 13 m (39 to 41 ft) bgs. Four shallow samples and one deep sample depth interval were collected from this location. Additionally, a liquid sample was collected at the 12 m (40 ft) bgs and analyzed for ^{99}Tc (FSAP change notice WMAC-009). Sampling borehole C7668 was placed nearby C7668A to collect additional deep soil samples. All analytical data is associated with the name C7668 rather than C7668A.

<u>Investigation Site S:</u> The original work plan identified one vertical push location, consisting of an exploratory and sampling borehole for Site S (Figure 4-7 shows the proposed location of Site S). The purpose of the investigation at Site S was to assess the presence of buried material and potential releases to the 216-C-8 drain and to refine conceptual models. Specifically, low levels (0.6 pCi/g) of ^{60}Co were measured in the vadose zone between 40 and 76 m (130 and 250 ft) bgs at groundwater well 299-E27-14 (near Site S). It was speculated that the ^{60}Co

migrated to this well from either a Tank C-101 leak or was the result of disposal to the 216-C-8 French drain.

As noted in the work plan, historical records showed that 121,133 L (32,000 gal) of PUREX tank farm condensate was discharged to the 216-C-8 French drain/crib. PUREX tank farm condensate discharge samples released to the 216-A-24 crib in 1963 and to the 216-A-8 crib in 1957 and 1969 were analyzed and contained low concentration of ^{60}Co ranging from (2×10^{-6} to 3×10^{-5} μCi/ml). Additionally, geophysical logging results in the surrounding area indicate that such low levels of ^{60}Co have already decayed to below detection levels. The above was discussed in the September 22, 2011 work plan meeting, and it was agreed that investigating Site S would not likely indicate if waste migrated from Tank C-101 or provide information valuable to final cleanup decisions. The deletion of Site S was documented in the approved Revision 2 of the work plan.

Investigation Site T: The original work plan identified Site T as a placeholder site for possible direct push locations at a later date, depending on results of SGE from the WMA C site (i.e., Site O, which is conducting whole farm SGE). Specifically, if previously unknown release sites were identified through SGE, additional direct pushes could be used to characterize the site.

No fieldwork has been performed to date. The need to perform additional field work at this site is being evaluated through this document. Note that field work via direct push may be needed post-CMS to support final closure configuration and post-closure monitoring needs.

Investigation Site U: The original work plan identified one angled push location for Site U. The purpose was to characterize a suspected release at Tank C-110 and/or to confirm the release was an overflow, and to refine conceptual models. It was previously assumed that Tank C-110 had leaked in the past; however more recent assessments have concluded that this is unlikely.

Originally, it was believed that the slope of the hill near Tank C-110 would prohibit the placement of the direct push rig close to the outlet ports at Tank C-110. Based on retrieval operations in the area and after field observations and discussions with the regulators, it was determined that a vertical push was possible and preferable (Appendix L). This change is reflected in the approved Revision 1A of the work plan, which identifies that Site U may be completed with either an angled or vertical push.

Based on agreements, one vertical location, consisting of an exploratory and sampling borehole, was pushed, and the following is a brief summary of the field work performed at this investigation site (Table 4-3):

- Fieldwork was conducted from June 2010 through September 2010.

- This site had one vertical logging hole (C7675) and one sampling hole (C7676) (Figures 4-8 and 4-10 show location of pushes)

- All sample intervals were collected per sample depth meeting (July 7, 2010) with the exceptions:
  - Site U (C7676) documented in FSAP change notice WMAC-0011
    - Due to poor sample recovery from the 1.5 to 2 m (5 to 7 ft) bgs interval, an additional sample was taken from 2 to 3 m (7 to 9 ft) bgs, and the two samples were composited for analysis.
    - Due to poor sample recovery from the 4 to 5 m (14 to 16 ft) bgs interval, an additional sample was taken from 5 to 6 m (16 to 18 ft) bgs, and the two samples were composited for analysis.

  Note: There were three rather than four deeper sample depths chosen at this location because there was no additional area of interest based on logs from this location and locations from the surrounding area (i.e., no grain size changes or high moisture zones). This was the decision made and documented in the sample meeting minutes on July 7, 2010.

Investigation Site V: The original work plan identified one vertical direct push location, consisting of an exploratory and sampling borehole, for this investigation site (Figure 4-7 shows the proposed location of Site V). The purpose was to characterize Tank C-111 due to a suspected tank leak due to overfill or loss through the spare inlet and to refine conceptual models.

It was previously assumed that Tank C-111 had leaked in the past; however, recent assessments have indicated that this was unlikely. Tank C-111 was previously classified an "assumed leaker" based on a liquid level decrease of 21.6 cm (8.5 in.) from 1965 through 1969 that would equal a total of 88,579 L (23,400 gal). Some of the loss was attributed to evaporation, and in 1989, assuming a tank waste temperature of 38°C (100°F), a leak loss of a 5.5 kgal was estimated. However, new data showed that the tank temperature was at least 88°C (190°F) at the time of the liquid level decrease. Calculations indicated that at 88°C (190°F), the entire liquid level decrease could be attributed to evaporation. Therefore, it was likely that little or no supernate was released from Tank C-111 to the soil (RPP-ASMT-39155). Additionally, historical logs and spectral gamma logging have shown no evidence of a past leak from Tank C-111. As a result, it was determined that a direct push sample near Site V would unlikely yield information valuable to the soil characterization effort and was not needed. Site V was deleted in the approved Revision 2 of the work plan (Appendix I).

Investigation Site X: The original work plan did not include Site X. It was added in Revision 2 of the work plan to investigate the extent of the ^{137}Cs plume from drywell 30-05-07 near Tank C-105 and to refine conceptual models. It was anticipated that a borehole would be pushed to intercept a postulated plume originating from Tank C-105. A high activity ^{137}Cs plume had been identified in drywell 30-05-07. The plume was assumed to be small because it was detected in only one drywell and nearby in direct push hole C7469, and because geophysical theory suggests that ^{137}Cs would be expected to migrate about the same horizontal distance in all directions in the soil.

The assumption that the plume was small was supported by the observation that high activity ^{137}Cs had not been detected in any of the other drywells or in borehole C4297 that were installed to investigate the extent of the Tank C-105 plume. However, another possibility was that a tank leak (either through a cascade/spare inlet line overfill release or tank liner breach) may have migrated from a point of release below the tank, may be much larger than assumed, and may be the source of ^{60}Co activity in drywells between Tanks C-105 and C-103 and northeast of Tank C-103.

Site X replaced Site K and field work was planned for 2013; however, Site X was not investigated due to accessibility problems associated with retrieval operations.

Supplemental Information

Location - C7469 (Tank C-105): This location was not a part of the WMA C Phase 2 RFI characterization effort, but was pushed to provide data for the tank integrity assessment of Tank C-105 after contamination was observed in drywells adjacent to Tank C-105. Location C7469 was pushed immediately adjacent to the cascade line penetration and as close to the tank footing as practical (Figure 4-8). The fieldwork was conducted from September 2009 to October 2009.

One logging borehole was pushed to unexpected refusal at 11 m (36 ft). Verification of the borehole depth resulted in the end of the tag tape being contaminated with 750,000 disintegrations per minute beta/gamma radiation. Geophysical logging was performed using a sodium-iodide scintillation gross gamma detector and a moderate sensitivity Geiger-Mueller gross gamma detector. Radiation levels exceeded the detection range of the geophysical instruments. Because of radiological concerns, a second logging borehole was cancelled. See RPP-RPT-43823, *Completion Report for Leak Detection Characterization Near Single-Shell Tank 241-C-105*, for further information.

The geophysical logging data indicated that tank waste had overflowed through the tank sidewall inlet cascade line penetration, and moved downward through the sol column close to the tank. The leak assessment panel also believed from available data that a tank leak was also plausible. The panel recommended that the leak integrity status of Tank C-105 be changed from “sound” to “Assumed Leaker” (RPP-ASMT-46452).

4.4.1.1 Direct Push Field Characterization Summary

In summary, 20 direct push sites were investigated in WMA C as part of the Phase 2 WMA C RFI. Two of these sites were investigated solely with logging technology (i.e., Sites D and Q). The remaining 18 sites were investigated by sampling and logging. Of the 20 sites investigated, four included angle pushes (i.e., Sites A, B, C, and J). A total of 47 pushes were made in WMA C with respect to these 20 sites:

- Nineteen holes were sampled, from which
  - 152 soil samples were collected
  - 34,130 results were obtained

- Twenty-eight holes were logged
- Twenty-four of the holes which were logged, contain resistivity probes

The final version of the approved work plan identifies the deletion of several sites (Sites K, S, and V) and also identifies the change from sampling and logging to solely logging at two sites (Sites D and Q). Additionally, Site X was supposed to be pushed on the southwest of Tank C-105; however, it was not possible due to retrieval activities.

4.4.1.2 Direct Push Analytical Requirements. The WMA C RFI Phase 2 DQO identified both primary and secondary analytes based on RPP-23403, *Single-Shell Tank Component Closure Data Quality Objectives,* historical knowledge, human-health risk assessment needs, and ecological risk assessment needs. Table 4-6 provides the list of primary and secondary analytes for samples analyzed under Revisions 0 through 2A of the SAP (corresponding to work plan Revisions 0 and 1A/1B, respectively).

Table 4-6. WMA C Phase 2 RFI Primary and Secondary Analytes

Constituent	CAS No[a]	SAP Revision Number				
		0	1	2	2A	3[n]
Inorganic						
Metals						
Aluminum	7429-90-5	P	P	P	P	P
Antimony	7440-36-0	P	P	P	P	P
Arsenic	7440-38-2	P	P	P	P	P
Barium	7440-39-3	P	P	P	P	P
Beryllium	7440-41-7	P	P	P	P	P
Bismuth	7440-69-9	S	S	S	S	S
Boron	7440-42-8	S	S	S	S	S
Cadmium	7440-43-9	P	P	P	P	P
Calcium	7440-70-2	S	S	P	P	P
Cerium	7440-45-1	S	S	S	S	S
Chromium	7440-47-3	P	P	P	P	P
Chromium, hexavalent[b]	18540-29-9	P	P	P	P	P
Cobalt	7440-48-4	P	P	P	P	P
Copper	7440-50-8	P	P	P	P	P
Europium	7440-53-1	S	S	S	S	S
Iron	7439-89-6	P	P	P	P	P
Lanthanum	7439-91-0	S	S	S	S	S
Lead	7439-92-1	P	P	P	P	P

Table 4-6. WMA C Phase 2 RFI Primary and Secondary Analytes

Constituent	CAS No[a]	SAP Revision Number				
		0	1	2	2A	3[n]
Lithium	7439-93-2	S	S	P	P	P
Magnesium	7439-95-4	S	S	P	P	P
Manganese	7439-96-5	P	P	P	P	P
Mercury	7439-97-6	P	P	P	P	P
Molybdenum	7439-98-7	S	S	P	P	P
Neodymium	7440-00-8	S	S	S	S	S
Nickel	7440-02-0	P	P	P	P	P
Niobium	7440-03-1	S	S	S	S	S
Palladium	7440-05-3	S	S	S	S	S
Phosphorus	7723-14-0	S	S	P	P	P
Potassium	7440-09-7	S	S	P	P	P
Praseodymium	7440-10-0	S	S	S	S	S
Rhodium	7440-16-6	S	S	S	S	S
Rubidium	7440-17-7	S	S	S	S	S
Ruthenium	7440-18-8	S	S	S	S	S
Samarium	7440-19-9	S	S	S	S	S
Selenium	7782-49-2	P	P	P	P	P
Silicon	7440-21-3	S	S	S	S	S
Silver	7440-22-4	P	P	P	P	P
Sodium	7440-23-5	S	S	P	P	P
Strontium	7440-24-6	P	P	P	P	P
Sulfur	7704-34-9	S	S	S	S	S
Tantalum	7440-25-7	S	S	S	S	S
Tellurium	13494-80-9	S	S	S	S	S
Thallium	7440-28-0	P	P	P	P	P
Thorium	7440-29-1	S	S	S	S	S
Tin	7440-31-5	S	S	S	S	S
Titanium	7440-32-6	S	S	S	S	S
Tungsten	7440-33-7	S	S	S	S	S
Uranium[c]	7440-61-1	P	P	P	P	P
Vanadium	7440-62-2	P	P	P	P	P
Yttrium	7440-65-5	S	S	S	S	S

Table 4-6. WMA C Phase 2 RFI Primary and Secondary Analytes

Constituent	CAS No[a]	SAP Revision Number				
		0	1	2	2A	3[n]
Zinc	7440-66-6	P	P	P	P	P
Zirconium	7440-67-7	S	S	S	S	S
Anions						
Bromide	24959-67-9	S	S	S	S	S
Chloride	16887-00-6	P	P	P	P	P
Fluoride	16984-48-8	P	P	P	P	P
Nitrate	14797-55-8	P	P	P	P	P
Nitrite	14797-65-0	P	P	P	P	P
Phosphate	14265-44-2	S	S	S	S	S
Sulfate	14808-79-8	P	P	P	P	P
Sulfide	18496-25-8	P	P	P	P[d]	--
Wetchemistry						
Acetate	71-50-1	P	P	P	P	P
Formate	FORMATE	P	P	P	P	P
Glycolate	666-14-8	P	P	P	P	P
Oxalate	338-70-5	P	P	P	P	P
Ammonium	14798-03-9	P	P	P	P	P
Cyanide	57-12-5	P	P	P	P	P
Ferrocyanide[b]	13601-19-9	P	P	P	P	P
pH[c]	PH	P	P	P	P	P
Bulk Density[f]	BULKDENSITY-WET	S	S	S	S	S
Percent Water[g]	%MOISTURE	P	P	P	P	P
Specific Conductance[h]	CONDUCT	--	--	--	--	S
Organics						
Petroleum Hydrocarbons						
Diesel-range organics	TPHDIESEL	P	P	P	P[d]	--
Gasoline-range organics	TPHGASOLINE	P	P	P	P[d]	--
Polychlorinated Biphenyls						
PCB Congeners[i]	(Various)	P	P	P	P[d]	--
Aroclor 1016	12674-11-2	P	P	P	P	P
Aroclor 1221	11104-28-2	P	P	P	P	P
Aroclor 1232	11141-16-5	P	P	P	P	P

Table 4-6. WMA C Phase 2 RFI Primary and Secondary Analytes

Constituent	CAS No[a]	SAP Revision Number				
		0	1	2	2A	3[n]
Aroclor 1242	53469-21-9	P	P	P	P	P
Aroclor 1248	12672-29-6	P	P	P	P	P
Aroclor 1254	11097-69-1	P	P	P	P	P
Aroclor 1260	11096-82-5	P	P	P	P	P
Pesticides						
4,4'-DDD[j]	72-54-8	P	P	P	P	P
4,4'-DDE[j]	72-55-9	P	P	P	P	P
4,4'-DDT[j]	50-29-3	P	P	P	P	P
Aldrin	309-00-2	P	S	P	P	P
alpha-BHC[k]	319-84-6	P	P	P	P	P
beta-BHC[k]	319-85-7	P	P	P	P	P
Chlordane	57-74-9	P	P	P	P	P
Delta-BHC[k]	319-86-8	P	P	P	P	P
Dieldrin	60-57-1	P	P	P	P	P
Endrin	72-20-8	P	P	P	P	P
gamma-BHC (Lindane)[k]	58-89-9	P	P	P	P	P
Heptachlor	76-44-8	P	P	P	P	P
Heptachlor epoxide	1024-57-3	P	P	P	P	P
Hexachlorobenzene	118-74-1	P	P	P	P	P
Pentachlorophenol	87-86-5	P	P	P	P	P
Semivolatile Organic Compounds						
1,1'-Biphenyl	92-52-4	S	S	S	S	S
1,1-Dimethylhydrazine	57-14-7	S	S	S	S	S
1,2,4-Trichlorobenzene	120-82-1	P	P	P	P	P
1,3-Dichlorobenzene	541-73-1	S	S	S	S	S
1,4-Dichlorobenzene	106-46-7	S	S	S	S	S
1,4-Dinitrobenzene	100-25-4	S	S	S	S	S
2,4,5-Trichlorophenol	95-95-4	P	P	P	P	P
2,4,6-Trichlorophenol	88-06-2	P	P	P	P	P
2,4-Dinitrotoluene	121-14-2	P	P	P	P	P
2,6-Bis (tert-butyl)-4-methylphenol	128-37-0	P	P	P	P	P
2-Chlorophenol	95-57-8	P	P	P	P	P

Table 4-6. WMA C Phase 2 RFI Primary and Secondary Analytes

Constituent	CAS No[a]	SAP Revision Number				
		0	1	2	2A	3[n]
2-Ethoxyethanol	110-80-5	P	P	P	P	P
2-Methylphenol (o-cresol)	95-48-7	P	P	P	P	P
2-sec-Butyl-4,6-dinitrophenol (Dinoseb)	88-85-7	S	S	S	S	S
3+4 Methylphenol (cresol, m+p)	65794-96-9	P	P	P	P	P
Acenaphthene	83-32-9	P	P	P	P	P
Acetophenone	98-86-2	S	S	S	S	S
Benzo(a) anthracene	56-55-3	P	P	P	P	P
Benzo(a)pyrene	50-32-8	P	P	P	P	P
Benzo(b)fluoranthene	205-99-2	P	P	P	P	P
Benzo(k)fluoranthene	207-08-9	P	P	P	P	P
Bis(2-ethylhexyl)phthalate	117-81-7	P	P	P	P	P
Butylbenzylphthalate	85-68-7	P	P	P	P	P
Chrysene	218-01-9	P	P	P	P	P
Cresylic acid (cresol, mixed isomers)	1319-77-3	P	P	P	P	P
Cyclohexanone	108-94-1	P	P	P	P	P
Dibenz(a,h)anthracene	53-70-3	P	P	P	P	P
Di-n-butylphthalate	84-74-2	P	P	P	P	P
Di-n-octylphthalate	117-84-0	P	P	P	P	P
Fluoranthene	206-44-0	P	P	P	P	P
Hexachlorobutadiene	87-68-3	P	P	P	P	P
Hexachloroethane	67-72-1	P	P	P	P	P
Hexachloronaphtahlene	1335-87-1	S	S	S	S	S
Indeno (1,2,3-cd) pyrene	193-39-5	P	P	P	P	P
Isodrin	465-73-6	S	S	S	S	S
Methylhydrazine	60-34-4	S	S	S	S	S
N,N-Diphenylamine	122-39-4	S	S	S	S	S
Naphthalene	91-20-3	P	P	P	P	P
Nitric acid, propyl ester	627-13-4	S	S	S	S	S
Nitrobenzene	98-95-3	P	P	P	P	P
n-Nitrosodi-n-butylamine	924-16-3	S	S	S	S	S
N-nitroso-di-n-propylamine	621-64-7	P	P	P	P	P
n-Nitrosomethylethylamine	10595-95-6	S	S	S	S	S

Table 4-6. WMA C Phase 2 RFI Primary and Secondary Analytes

Constituent	CAS No[a]	SAP Revision Number				
		0	1	2	2A	3[n]
n-Nitrosomorpholine	59-89-2	P	P	P	P	P
N-Nitroso-N,N-dimethylamine	62-75-9	S	S	S	S	S
Octachloronaphthalene	2234-13-1	S	S	S	S	S
o-Dichlorobenzene	95-50-1	P	P	P	P	P
o-Nitrophenol	88-75-5	P	P	P	P	P
p-Chloro-m-cresol (4-Chloro-3-methylphenol)	59-50-7	P	P	P	P	P
Pentachloronaphthalene	1321-64-8	S	S	S	S	S
Pentachloronitrobenzene (PCNB)	82-68-8	S	S	S	S	S
Phenol	108-95-2	S	S	S	S	S
p-Nitrochlorobenzene	100-00-5	S	S	S	S	S
Pyrene	129-00-0	P	P	P	P	P
Pyridine	110-86-1	P	P	P	P	P
Tetrachloronaphthalene	1335-88-2	S	S	S	S	S
Toxaphene	8001-35-2	S	S	S	S	S
Tributyl phosphate	126-73-8	P	P	P	P	P
Volatile Organic Compounds						
(m+p)Xylene	179601-23-1	P	P	P	P[d]	--
1,1 Dichloroethane	75-34-3	S	S	S	S[d]	--
1,1,1-Trichloroethane	71-55-6	P	P	P	P[d]	--
1,1,2,2-Tetrachloroethane	79-34-5	P	P	P	P[d]	--
1,1,2-Trichloro-1,2,2-trifluoroethane	76-13-1	P	P	P	P[d]	--
1,1,2-Trichloroethane	79-00-5	P	P	P	P[d]	--
1,1,2-Trichloroethylene	79-01-6	P	P	P	P[d]	--
1,1-Dichloroethene	75-35-4	P	P	P	P[d]	--
1,2-Dichloro-1,1,2,2-tetrafluoroethane	76-14-2	S	S	S	S[d]	--
1,2-Dichloroethane	107-06-2	P	P	P	P[d]	--
1,2-Dichloropropane	78-87-5	S	S	S	S[d]	--
1,3-Butadiene	106-99-0	S	S	S	S[d]	--
1,4-Dioxane	123-91-1	S	S	S	S[d]	--
1-Methylpropyl alcohol	78-92-2	S	S	S	S[d]	--
2-Butanone(MEK)	78-93-3	P	P	P	P[d]	--
2-Butenaldehyde (2-Butenal)	4170-30-3	S	S	S	S[d]	--

Table 4-6. WMA C Phase 2 RFI Primary and Secondary Analytes

Constituent	CAS No[a]	SAP Revision Number				
		0	1	2	2A	3[n]
2-Heptanone	110-43-0	S	S	S	S[d]	--
2-Hexanone	591-78-6	S	S	S	S[d]	--
2-Methyl-2-propanol	75-65-0	S	S	S	S[d]	--
2-Methyl-2-propenenitrile	126-98-7	S	S	S	S[d]	--
2-Nitropropane	79-46-9	P	P	P	P[d]	--
2-Pentanone	107-87-9	S	S	S	S[d]	--
2-Propanone (Acetone)	67-64-1	P	P	P	P[d]	--
2-Propyl alcohol	67-63-0	S	S	S	S[d]	--
3-Chloropropene (Allyl chloride)	107-05-1	S	S	S	S[d]	--
3-Heptanone	106-35-4	S	S	S	S[d]	--
3-Pentanone	96-22-0	S	S	S	S[d]	--
4-Heptanone	123-19-3	S	S	S	S[d]	--
4-Methyl-2-pentanone (MIBK)	108-10-1	P	P	P	P[d]	--
5-Methyl-2-hexanone	110-12-3	S	S	S	S[d]	--
Acetic acid, n-butylester	123-86-4	S	S	S	S[d]	--
Acetonitrile	75-05-8	S	S	S	S[d]	--
Acrolein (propenal)	107-02-8	S	S	S	S[d]	--
Acrylonitrile	107-13-1	S	S	S	S[d]	--
Benzene	71-43-2	P	P	P	P[d]	--
Bromomethane	74-83-9	S	S	S	S[d]	--
Butane	106-97-8	S	S	S	S[d]	--
Carbon disulfide	75-15-0	P	P	P	P[d]	--
Carbon tetrachloride	56-23-5	P	P	P	P[d]	--
Chlorobenzene	108-90-7	P	P	P	P[d]	--
Chlorodifluoromethane	75-45-6	S	S	S	S[d]	--
Chloroethane	75-00-3	S	S	S	S[d]	--
Chloroethene(vinyl chloride)	75-01-4	P	P	P	P[d]	--
Chloroform	67-66-3	P	P	P	P[d]	--
Chloromethane	74-87-3	S	S	S	S[d]	--
Cis-1,2-dichloroethylene	156-59-2	P	P	P	P[d]	--
cis-1,3-Dichloropropene	10061-01-5	S	S	S	S[d]	--
Cyclohexane	110-82-7	S	S	S	S[d]	--

Table 4-6. WMA C Phase 2 RFI Primary and Secondary Analytes

Constituent	CAS No[a]	SAP Revision Number				
		0	1	2	2A	3[n]
Cyclohexene	110-83-8	S	S	S	S[d]	--
Cyclopentane	287-92-3	S	S	S	S[d]	--
Dibutyl phosphate	107-66-4	P	P	P	P[d]	--
Dichlorodifluoromethane	75-71-8	S	S	S	S[d]	--
Dichlorofluromethane	75-43-4	S	S	S	S[d]	--
Dichloromethane (methylene chloride)	75-09-2	P	P	P	P[d]	--
Diethyl ether	60-29-7	P	P	P	P[d]	--
Ethyl Acetate	141-78-6	P	P	P	P[d]	--
Ethyl alcohol	64-17-5	S	S	S	S[d]	--
Ethylbenzene	100-41-4	P	P	P	P[d]	--
Ethylene dibromide (1,2, Dibromoethane)	106-93-4	S	S	S	S[d]	--
Ethylene glycol	107-21-1	P	P	P	P[d]	--
Isobutanol	78-83-1	P	P	P	P[d]	--
Methanol	67-56-1	P	P	P	P[d]	--
Methyl isocyanate	624-83-9	S	S	S	S[d]	--
Methylcyclohexane	108-87-2	S	S	S	S[d]	--
Monobutyl phosphate	1623-15-0	P	P	P	P[d]	--
n-Butyl alcohol (1-butanol)	71-36-3	P	P	P	P[d]	--
n-Heptane	142-82-5	S	S	S	S[d]	--
n-Hexane	110-54-3	S	S	S	S[d]	--
n-Nonane	111-84-2	S	S	S	S[d]	--
n-Octane	111-65-9	S	S	S	S[d]	--
n-Pentane	109-66-0	S	S	S	S[d]	--
n-Propionaldehyde	123-38-6	S	S	S	S[d]	--
n-propyl alcohol (1-propanol)	71-23-8	S	S	S	S[d]	--
Oxirane	75-21-8	S	S	S	S[d]	--
o-Xylene	95-47-6	P	P	P	P[d]	--
Propionitrile (Ethyl cyanide)	107-12-0	S	S	S	S[d]	--
Styrene	100-42-5	S	S	S	S[d]	--
Tetrachloroethene	127-18-4	P	P	P	P[d]	--
Tetrahydrofuran	109-99-9	S	S	S	S[d]	--
Toluene	108-88-3	P	P	P	P[d]	--

Table 4-6. WMA C Phase 2 RFI Primary and Secondary Analytes

Constituent	CAS No[a]	SAP Revision Number				
		0	1	2	2A	3[n]
Trans-1,2-dichloroethylene	156-60-5	P	P	P	P[d]	--
trans-1,3-dichloropropene	10061-02-6	P	P	P	P[d]	--
Trichlorofluoromethane	75-69-4	P	P	P	P[d]	--
Triethylamine	121-44-8	S	S	S	S[d]	--
Xylenes	1330-20-7	P	P	P	P[d]	--
Radionuclides[l]						
^{228}Actinium	14331-83-0	S	S	S	S	S
^{241}Americium	14596-10-2	P	P	P	P	P
^{125}Antimony	14234-35-6	P	P	P	P	P
^{133}Barium	13981-41-4	S	S	S	S	S
^{7}Beryllium	13966-02-4	S	S	S	S	S
^{212}Bismuth	14913-49-6	S	S	S	S	S
^{214}Bismuth	14733-03-0	S	S	S	S	S
^{109}Cadmium	14109-32-1	S	S	S	S	S
^{14}Carbon	14762-75-5	P	P	P	P	P
^{144}Cerium	14762-78-8	S	S	S	S	S
^{144}Cerium/Praseodymium	CE/PR-144	S	S	S	S	S
^{134}Cesium	13967-70-9	S	S	S	S	S
^{137}Cesium	10045-97-3	P	P	P	P	P
^{51}Chromium	14392-02-0	S	S	S	S	S
^{57}Cobalt	13981-50-5	S	S	S	S	S
^{60}Cobalt	10198-40-0	P	P	P	P	P
^{242}Curium	15510-73-3	P	P	P	P	P
$^{243/244}$Curium	CM-243/244	P	P	P	P	P
^{152}Europium	14683-23-9	P	P	P	P	P
^{154}Europium	15585-10-1	P	P	P	P	P
^{155}Europium	14391-16-3	P	P	P	P	P
^{129}Iodine	15046-84-1	P	P	P	P	P
^{131}Iodine	10043-66-0	S	S	S	S	S
^{59}Iron	14596-12-4	S	S	S	S	S
^{212}Lead	15092-94-1	S	S	S	S	S
^{214}Lead	15067-28-4	S	S	S	S	S

Table 4-6. WMA C Phase 2 RFI Primary and Secondary Analytes

Constituent	CAS No[a]	SAP Revision Number				
		0	1	2	2A	3[n]
^{54}Manganese	13966-31-9	S	S	S	S	S
^{237}Neptunium	13994-20-2	P	P	P	P	P
^{63}Nickel	13981-37-8	P	P	P	P	P
^{94}Niobium	14681-63-1	S	S	S	S	S
^{40}Potassium	13966-00-2	S	S	S	S	S
^{238}Plutonium	13981-16-3	P	P	P	P	P
$^{239/240}$Plutonium	PU-239/240	P	P	P	P	P
^{241}Plutonium^{m}	14119-32-5	P	P	P	P	P
^{224}Radium	13233-32-4	S	S	S	S	S
^{226}Radium	13982-63-3	S	S	S	S	S
^{228}Radium	15262-20-1	S	S	S	S	S
^{103}Ruthenium	13968-53-1	S	S	S	S	S
^{106}Ruthenium	13967-48-1	S	S	S	S	S
^{108m}Silver	14391-65-2	S	S	S	S	S
^{22}Sodium	13966-32-0	S	S	S	S	S
^{79}Selenium	15758-45-9	P	P	P	P	P
^{90}Strontium	SR-RAD	P	P	P	P	P
^{99}Technitium	14133-76-7	P	P	P	P	P
^{208}Thallium	14913-50-9	S	S	S	S	S
^{228}Thorium	14274-82-9	P	P	P	P	P
^{230}Thorium	14269-63-7	P	P	P	P	P
^{232}Thorium	TH-232	P	P	P	P	P
^{234}Thorium	15065-10-8	P	P	P	P	P
^{113}Tin	13966-06-8	S	S	S	S	S
^{126}Tin	15832-50-5	P	P	P	P	P
^{3}Tritium	10028-17-8	P	P	P	P	P
^{233}Uranium	13968-55-3	P	P	P	P	P
^{234}Uranium	13966-29-5	P	P	P	P	P
^{235}Uranium	15117-96-1	P	P	P	P	P
^{236}Uranium	13982-70-2	P	P	P	P	P
^{238}Uranium	U-238	P	P	P	P	P
^{65}Zinc	13982-39-3	S	S	S	S	S

Table 4-6. WMA C Phase 2 RFI Primary and Secondary Analytes

Constituent	CAS No[a]	SAP Revision Number				
		0	1	2	2A	3[n]
^{95}Zirconium/Niobium	ZR/NB-95	S	S	S	S	S

[a.] Chemical Abstract Service or unique identifier as listed in HEIS.
[b.] Neither hexavalent chromium nor ferrocyanide concentration was determined by analysis; but rather, chromium and cyanide concentrations were used as conservative estimates, respectively.
[c.] Uranium concentration either reported from analysis or calculated from isotopic uranium activities per all revisions of the SAP.
[d.] Not reported. Confirmed as removed from target analyte list through Letter 11-NWP-053, "*RE: Organic Analyses Optimization for Waste Management Area (WMA) C*" for samples collected and analyzed under Revision 2A of the SAP.
[e.] pH listed in Revisions 0 through 2A of the SAP as a primary analyte; however, Revision 3 of the SAP lists no priority level (primary or secondary) associated with pH. Considered a primary analyte for all revisions of the SAP.
[f.] Bulk density listed in Table 5-1 of each SAP revision with no priority level (primary or secondary).
[g.] Percent water listed in text of Revisions 0 through 2A as required for reporting of PCBs (primary analytes) on dry weight basis.
[h.] Specific Conductance not listed in Revision 0 through 2A of the SAP. Listed in Table A-2 of SAP Revision 3 with no priority (primary or secondary) assigned.
[i.] The 209 PCB congeners are combined and presented as one entry for purposes of this table.
[j.] Total DDD/DDE/DDT defined and reported as 4,4'-DDD, 4,4'-DDE, 4,4'-DDT for WMA C Phase 2 RFI.
[k.] Benzene hexachloride (including Lindane) included alpha-BHC, beta-BHC, gamma-BHC (Lindane), and delta-BHC, each of which was reported separately.
[l.] Secondary radionuclides by gamma energy analysis (GEA) only. List of secondary radionuclides for GEA differed between laboratories.
[m.] Pu^{241} activity was not measured; but rather, calculated from activities for Pu^{238} and $Pu^{239/240}$.
[n.] No samples were analyzed under SAP Revision 3.
P = Primary
S = Secondary

Preferred and alternate analytical methods were identified for the primary analytes. The primary analytes were to be analyzed with the level of quality control specified in the SAP. Several of these analytical methods could also detect concentrations of other analytes. A subset of these other analytes was identified in the SAP as secondary analytes. Secondary analytes were reported from methods used to determine metals, VOC, semi-volatile organic compounds (SVOC), and radionuclides by gamma energy analysis (GEA).

If a primary or secondary analyte was detected in a sample, the laboratory was required to report the numeric value found. For primary analytes not detected in a sample, the laboratory was required to report the result as not detected at the method detection limit (MDL). For secondary analytes not detected in a sample, the laboratory was not required to report a result. This was the same process used in the SST DQO (RPP-23403, Rev. 3).

Additionally, a two-step process for sample analysis optimization was presented in the WMA C RFI Phase 2 DQO and Revisions 0 through 2A of the SAP; whereby the first step, a method-based screening process to determine if the soil has been contaminated with tank waste, would be followed by analysis for the full suite of analytes in Step 2 if a tank waste indicator analyte threshold was met. As identified in Revision 3 of the SAP, this two-step process was not implemented; but rather, full characterization was performed on the samples. Completing the limited suite of analyses for Step 1 first would likely result in missed holding times for the other required constituents or required resampling. Therefore, the full suite of analyses was performed for samples to alleviate the risks to data quality (holding times) and cost (resampling).

Figure 4-15 identifies the sample locations and Figure 4-16 identifies when the various sites were sampled and under which SAP revision. This is important as Table 4-6 illustrates the change in required analytes for analysis per SAP revision.

Specifically, five sites were identified in the original work plan and SAP for organic analysis, three locations associated with UPR-200-E-81 (Site P) and two locations associated with Tank C-103 (Site L). Additional sites sampled for the full suites of organic constituents include Sites E, F, G, H, I, R, and U. Analytical results obtained from a total of 14 soil investigation locations (including the five at Sites L and P) were evaluated to determine whether to optimize the investigation at the remaining sites. Tributyl phosphate, the selected indicator for the potential occurrence of organic contamination associated with tank waste, was not identified in any of the samples. A letter (Letter 11-TPD-020, "Organic Analyses Optimization for Waste Management Area [WMA] C") from DOE was sent on March 29, 2011 to Ecology requesting the removal of the following from WMA C sample analysis:

- VOCs
- Ethylene glycol
- Monobutyl and dibutyl phosphate
- PCB congeners
- Gasoline range organics (GRO)
- Diesel range organics (DRO)

In addition, the SST closure DQO (RPP-23403, *Single-Shell Tank Component Closure Data Quality Objectives*) was modified to remove sulfide as a constituent associated with tank waste; therefore, discontinuing analysis for sulfide was also requested. Analysis of samples for PCB aroclors, pesticides, and SVOCs would continue without change.

An approval letter (11-NWP-053, "Re: Organic Analyses Optimization for Waste Management Area [WMA] C" from Ecology was received on June 1, 2011, confirming the removal of VOCs, ethylene glycol, monobutyl and dibutyl phosphates, PCB congeners, GRO, DRO, and sulfide from the analyte list for WMA C Phase 2 samples. This letter acknowledged the changes were implemented for the slant push at WMA C Tank C-104 (Site J [C8100]). Soil samples for (Site J [C8100], Site A [C8102], Site B [C8104], and Site C [C8106]) were analyzed for a reduced suite of organic analytes, focusing on constituents of highest concern. In effect, samples collected under Revision 2A of the SAP were analyzed with the changes set forth in letter 11-NWP-053 implemented.

Figure 4-15. Phase 2 Direct Push Sample Locations

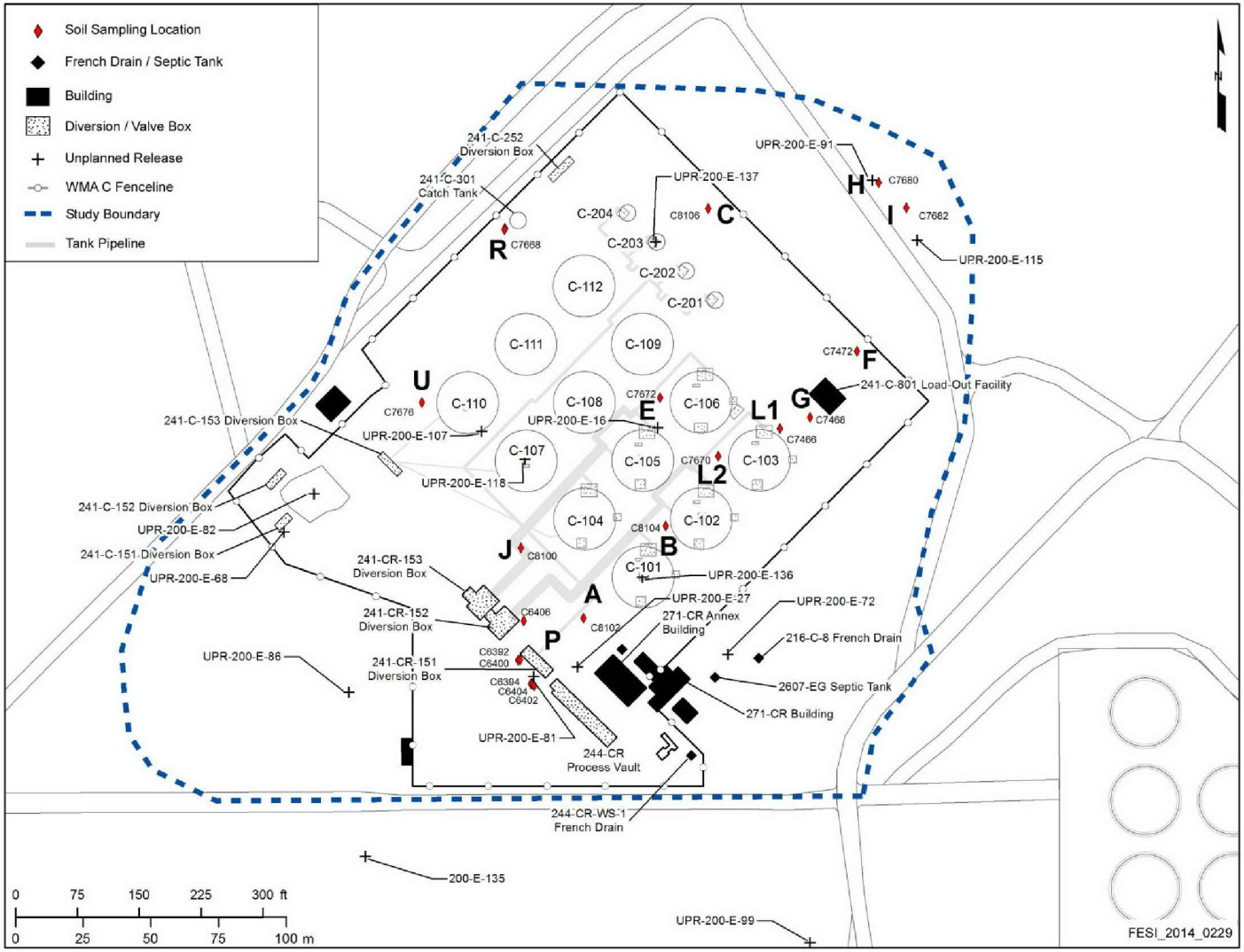
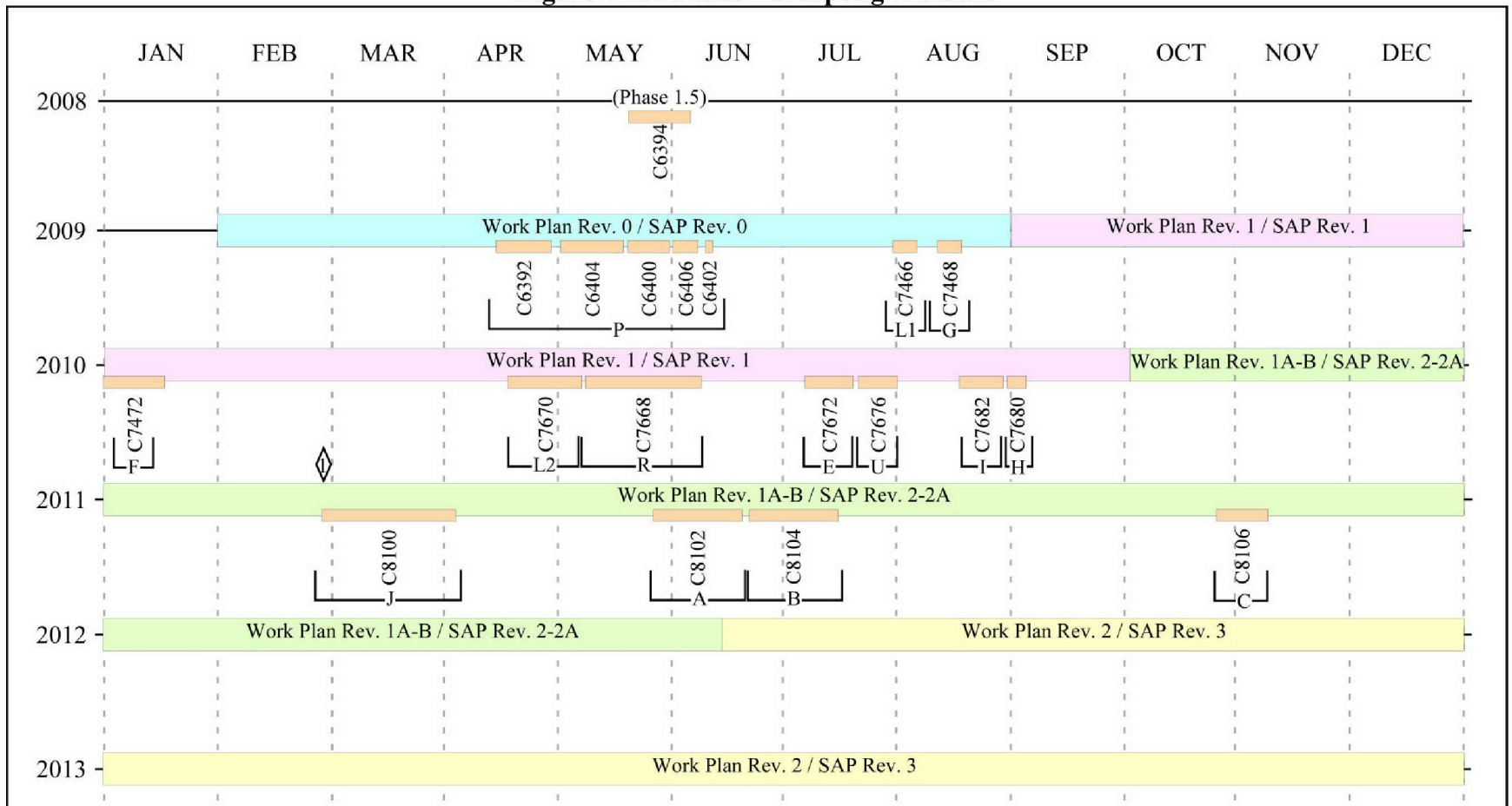


Figure 4-16. Phase 2 Sampling Timeline



Notes:

- Acknowledgement and conditional approval to proceed on Work Plan Rev. 0 given by Ecology on 2/4/2009 (Appendix H)
- C7472 borehole sampling dates occurred as shown on graphic. Surface samples were collected at this location on April 15, 2010
- Work Plan RPP-RPT-39114, Revision 1B solely impacted tissue sampling not soil sample analysIs
- Sampling and Analysis Plan (SAP) RPP-PLAN-38777, Revision 2A solely pertained to updating cyanide detection limit (February 2011) and adding a reference to Model Toxics Control Act (MTCA)

◊ - Implementation of Organic Analyses Optimization for WMA C and removal of sulfide as a target analyte.

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Samples were collected as described in Section 4.4.1. A summary accounting of analyses and results reported for these samples is presented by Investigation Group below. Table 4-3 lists the laboratory and data validation reports for the samples. As identified previously, Figure 4-16 depicts the timeline and SAP revision for sample collection and analysis. A listing of primary and secondary analytes, by SAP revision, is presented in Table 4-6. An overview of results is presented in Section 5. Details regarding data quality and usability, including limitations, are provided in Appendix M. Also included in Appendix M is an evaluation of field duplicate pair result precision.

Investigation Group A+B: Samples from boreholes at Site A (C8102) and Site B (C8104) were collected and analyzed under Revision 2A of the SAP. The following is a brief summary of the analyses performed and results reported for the samples collected:

- Ten samples from nine intervals at Site A boring (C8102) were submitted for analysis.
  - Sample depths are provided in Table 4-3.
  - A field duplicate pair from 0.2 m (0.5 ft) bgs was analyzed.
  - With one exception, samples were analyzed for metals, pesticides, PCB aroclors, radionuclides, SVOCs, wet chemistry, anions, and physical parameters. (Due to insufficient sample material, SVOC analysis was not performed for the sample collected from 4.3 m [14.1 ft] bgs).
  - Pesticide and PCB aroclor analyses were performed on the five samples collected from 0 to 5 m (0 to 15 ft) bgs.
  - Results for ^{99}Tc were reported from both water and acid extraction sample preparations.
  - Results for three tentatively identified compounds (TIC) were reported. An evaluation of TIC results is presented in Appendix M.
- Nine samples from eight intervals at Site B boring (C8104) were submitted for analysis.
  - Sample depths are provided in Table 4-3.
  - A field duplicate pair from 0.2 m (0.5 ft) bgs was analyzed.
  - Samples were analyzed for metals, pesticides, PCB aroclors, radionuclides, SVOCs, wet chemistry, anions, and physical parameters.
  - Pesticide and PCB aroclor analyses were performed on the five samples collected from 0 to 5 m (0 to 15 ft) bgs.

- Results for ^{99}Tc were reported from both water and acid extraction sample preparations.

- Due to laboratory outages, some samples were diverted from the primary laboratory (222-S) to an alternate laboratory (WSCF). Consequences of this diversion included:

  - Analysis by both laboratories for samples from the same interval for radiochemical parameters, either using the same or different methodology. An evaluation of these multiple results is presented in Appendix M.

  - The secondary GEA radionuclides reported by each laboratory differed based on the GEA libraries used by each laboratory.

  - Two hexachlorobenzene results were reported for five samples. Hexachlorobenzene was reported from pesticide analysis by one laboratory for 1.7 through 4.3 m (5.1 through 14.2 ft) bgs and SVOC analysis for all samples collected. An evaluation of these multiple results is presented in Appendix M.

  - A different SVOC list was reported.

    - Four SVOC primary analytes were not included in the reporting list of the alternate laboratory. Results are not available for 2,6-bis(tert-butyl)-4-methylphenol, 2-ethoxyethanol (Cellosolve solvent), total cresols, and n-nitrosomorpholine.

    - Results for an additional 37 analytes (neither primary nor secondary) were reported.

  - Results for two TICs were reported. An evaluation of TIC results is presented in Appendix M.

<u>Investigation Group C+D</u>: Samples from a borehole at Site C (C8106) were collected and analyzed under Revision 2A of the SAP. The following is a brief summary of the analyses performed and results reported for the samples collected:

- Nine samples from eight intervals at Site C boring (C8106) were submitted for analysis.

  - Sample depths are provided in Table 4-3.

  - A field duplicate pair from 0.2 m (0.5 ft) bgs was analyzed.

  - With the exception of the sample collected from 23 m (76 ft) bgs, samples were analyzed for metals, pesticides, PCB aroclors, radionuclides, SVOCs, wet chemistry, anions, and physical parameters. Bulk density was the only testing done for the sample from 23 m (76 ft) bgs.

  - Pesticide and PCB aroclor analyses were performed on the four samples collected from 0 to 5 m (0 to 15 ft) bgs.

  - Results for ^{99}Tc were reported from both water and acid extraction sample preparations.

- As per the approved work plan, no samples were collected from Site D (Table 4-3).

Investigation Site E: Samples from a borehole at Site E (C7672) were collected and analyzed under Revision 1 of the SAP. The following is a brief summary of the analyses performed and results reported for the samples collected:

- Nine samples from eight intervals at Site E boring (C7672) were submitted for analysis.

  - Sample depths are provided in Table 4-3.

  - A field duplicate pair from 0.2 m (0.5 ft) bgs was analyzed.

  - Samples were analyzed for metals, pesticides, PCB aroclors, PCB congeners, radionuclides, VOCs, SVOCs, GRO, DRO, wet chemistry, anions (including sulfide), and physical parameters.

  - Pesticide, PCB aroclor, PCB congener, DRO, and GRO analyses were performed on the five samples collected from 0 to 5 m (0 to 15 ft) bgs. However, neither hexachlorobenzene nor pentachlorophenol, both primary analytes, were reported.

  - Isobutyl alcohol, a primary analyte, was reported for five of nine samples 5, 12, 23, 26, and 38 m (15, 38, 74, 84, and 123 ft) bgs.

  - Methanol, listed as a primary VOC analyte in the SAP, is used during sample preparation and, therefore, could not be reported.

  - Results for ^{99}Tc were reported from both water and acid extraction sample preparations.

  - Results for two TICs were reported from various sample intervals. An evaluation of TIC results is presented in Appendix M.

Investigation Group F+G: Samples from boreholes at Site F (C7472) and Site G (C7468) were collected and analyzed under Revisions 1 and 0 of the SAP, respectively. The following is a brief summary of the analyses performed and results reported for the samples collected:

- Eleven samples from 10 intervals at Site F boring (C7472) were submitted for analysis.

- Sample depths are provided in Table 4-3. Samples for VOC analysis were not composited.

- A field duplicate pair from 0.2 m (0.5 ft) bgs was analyzed.

- Samples were analyzed for metals, pesticides, PCB aroclors, PCB congeners, radionuclides, VOCs, SVOCs, GRO, DRO, wet chemistry, anions (including sulfide), and physical parameters.

- Pesticide, PCB aroclor, PCB congener, DRO, and GRO analyses were performed on the five samples collected from 0 to 5 m (0 to 15 ft) bgs. However, hexachlorobenzene, a primary pesticide analyte, was reported for only three of these five samples (2, 3, and 5 m [6, 11, and 15 ft] bgs). In addition, pentachlorophenol, also a primary pesticide analyte, was analyzed as part of the SVOC suite; but reported for only five samples (2, 3, 5, 33, and 44 m [6, 11, 15, 109.5, and 143 ft] bgs).

- Methanol, listed as a primary VOC analyte in the SAP, is used during sample preparation and, therefore, could not be reported.

- Two cobalt results for the sample from 33.4 m (109.5 ft) bgs were reported. These results were from two different methods (ICP-AES and ICP-MS). An evaluation of these results is presented in Appendix M.

- Two nitrate results were reported each for samples from 40 and 60 m (130 and 196 ft) bgs. An evaluation of these results is presented in Appendix M.

- Results for ^{99}Tc were reported from both water and acid extraction sample preparations.

- Results for nine TICs, six SVOCs and three VOCs, were reported from various sample intervals. An evaluation of TIC results is presented in Appendix M.

• Ten samples from nine intervals at Site G boring (C7468) were submitted for analysis.

- Sample depths are provided in Table 4-3.

- A field duplicate pair from 0.2 m (0.5 ft) bgs was analyzed.

- Samples were analyzed for metals, pesticides, PCB aroclors, PCB congeners, radionuclides, VOCs, SVOCs, GRO, DRO, wet chemistry, anions (including sulfide), and physical parameters.

- Pesticide, PCB aroclor, PCB congener, DRO, and GRO analyses were performed on the five samples collected from 0 to 5 m (0 to 15 ft) bgs.

- Samples were analyzed for pentachlorophenol, a primary pesticide analyte, by both the pesticide method for 0 to 5 m (0 to 15 ft) bgs and the SVOC method for all intervals. An evaluation of the two pentachlorophenol results for samples from 0 to 5 m (0 to 15 ft) bgs is presented in Appendix M.

- Methanol, listed as a primary VOC analyte in the SAP, is used during sample preparation and, therefore, could not be reported.

- Results for ^{99}Tc were reported from both water and acid extraction sample preparations.

- Results for four TICs, all SVOCs, were reported from various sample intervals. An evaluation of TIC results is presented in Appendix M.

Investigation Group H+I: Samples from boreholes at Site H (C7680) and Site I (C7682) were collected and analyzed under Revision 1. The following is a brief summary of the analyses performed and results reported for the samples collected:

- Ten samples from nine intervals at Site H boring (C7680) were submitted for analysis.

  - Sample depths are provided in Table 4-3.

  - A field duplicate pair from 0.2 m (0.5 ft) bgs was analyzed.

  - Samples were analyzed for metals, pesticides, PCB aroclors, PCB congeners, radionuclides, VOCs, SVOCs, GRO, DRO, wet chemistry, anions (including sulfide), and physical parameters.

  - Pesticide, PCB aroclor, PCB congener, DRO, and GRO analyses were performed on the five samples collected from 0 to 5 m (0 to 15 ft) bgs.

  - Pesticide, PCB aroclor, PCB congener, DRO, and GRO analyses were performed on the five samples collected from 0 to 5 m (0 to 15 ft) bgs. However, neither hexachlorobenzene nor pentachlorophenol, both primary analytes, were reported.

  - Methanol, listed as a primary VOC analyte in the SAP, is used during sample preparation and, therefore, could not be reported.

  - Due to a laboratory error, no ammonium ion result was reported for the sample from 2 m (6 ft) bgs.

  - Results for ^{99}Tc were reported from both water and acid extraction sample preparations.

- Results for three TICs, all SVOCs, were reported from various sample intervals. An evaluation of TIC results is presented in Appendix M.

- Nine samples from eight intervals at Site I boring (C7682) were submitted for analysis.
  - Sample depths are provided in Table 4-3.
  - A field duplicate pair from 0.2 m (0.5 ft) bgs was analyzed.
  - Samples were analyzed for metals, pesticides, PCB aroclors, PCB congeners, radionuclides, VOCs, SVOCs, GRO, DRO, wet chemistry, anions (including sulfide), and physical parameters.
  - Pesticide, PCB aroclor, PCB congener, DRO, and GRO analyses were performed on the five samples collected from 0 to 5 m (0 to 15 ft) bgs.
  - Pesticide, PCB aroclor, PCB congener, DRO, and GRO analyses were performed on the five samples collected from 0 to 5 m (0 to 15 ft) bgs. However, neither hexachlorobenzene nor pentachlorophenol, both primary analytes, were reported.
  - Methanol, listed as a primary VOC analyte in the SAP, is used during sample preparation and, therefore, could not be reported.
  - Results for ^{99}Tc were reported from both water and acid extraction sample preparations.
  - Results for five TICs, three SVOCs and two VOCs, were reported from various sample intervals. An evaluation of TIC results is presented in Appendix M.

<u>Investigation Site J</u>: Samples from boreholes at Site J (C8100) were collected and analyzed under Revision 2A of the SAP. The following is a brief summary of the analyses performed and results reported for the samples collected:

- Ten samples from nine intervals at Site J boring (C8100) were submitted for analysis.
  - Sample depths are provided in Table 4-3.
  - A field duplicate pair from 0.2 m (0.5 ft) bgs was analyzed.
  - Samples were analyzed for metals, pesticides, PCB aroclors, radionuclides, SVOCs, wet chemistry, anions, and physical parameters.
  - Pesticide and PCB aroclor analyses were performed on the four samples collected from 0 to 5 m (0 to 15 ft) bgs.

- Results for ^{99}Tc were reported from both water and acid extraction sample preparations.

- Results for 20 TICs were reported. Of particular note, toluene, a primary analyte for the VOC suite eliminated via Letter 11-NWP-053, was reported as a TIC from the SVOC analysis for the sample from 16.6 m (54.3 ft) bgs. An evaluation of TIC results is presented in Appendix M.

Investigation Group L1+L2: Samples from boreholes at Site L1 (C7466) and Site L2 (C7670) were collected and analyzed under Revisions 0 and 1 of the SAP, respectively. The following is a brief summary of the analyses performed and results reported for the samples collected:

- Ten samples from nine intervals at Site L1 boring (C7466) were submitted for analysis.

  - Table 4-3 provides the sample depths.

  - A field duplicate pair from 0.2 m (0.5 ft) bgs was analyzed.

  - Samples were analyzed for metals, pesticides, PCB aroclors, PCB congeners, radionuclides, VOCs, SVOCs, GRO, DRO, wet chemistry, anions (including sulfide), and physical parameters.

  - Pesticide, PCB aroclor, PCB congener, DRO, and GRO analyses were performed on the five samples collected from 0 to 5 m (0 to 15 ft) bgs.

  - Samples were analyzed for pentachlorophenol, a primary pesticide analyte, by both the pesticide method from 0 to 5 m (0 to 15 ft) bgs and the SVOC method for all intervals. An evaluation of the two pentachlorophenol results for samples from 0 to 5 m (0 to 15 ft) bgs is presented in Appendix M.

  - Methanol, listed as a primary VOC analyte in the SAP, is used during sample preparation and, therefore, could not be reported.

  - Results for 3+4-methylphenol (m+p-cresol) were reported for all 10 samples in the hard copy results; however, the results for samples from 0.2 m (0.5 ft) bgs, are not present in HEIS. See Appendix M for a listing of updates to HEIS data being requested.

  - Results for ^{99}Tc were reported from an acid extraction sample preparation.

  - Results for four TICs, three SVOCs and one VOCs, were reported from various sample intervals. An evaluation of TIC results is presented in Appendix M.

- Nine samples from eight intervals at Site L2 boring (C7670) were submitted for analysis.
  - Sample depths are provided in Table 4-3. Samples for VOC analysis were not composited.
  - A field duplicate pair from 0.2 m (0.5 ft) bgs was analyzed.
  - Samples were analyzed for metals, pesticides, PCB aroclors, PCB congeners, radionuclides, VOCs, SVOCs, GRO, DRO, wet chemistry, anions (including sulfide), and physical parameters.
  - Pesticide, PCB aroclor, PCB congener, DRO, and GRO analyses were performed on the five samples collected from 0 to 5 m (0 to 15 ft) bgs. However, neither hexachlorobenzene nor pentachlorophenol, both primary analytes, were reported.
  - Methanol, listed as a primary VOC analyte in the SAP, is used during sample preparation and, therefore, could not be reported.
  - Results for ^{99}Tc were reported from an acid extraction sample preparation.
  - Results for nine TICs, eight SVOCs and one VOCs, were reported from various sample intervals. An evaluation of TIC results is presented in Appendix M.

Investigation Group P (P1 through P5): Samples from boreholes at Site P1 (C6392, C6400), Site P2 (C6402, 6404), and Site P3 (6406) were collected and analyzed under Revision 0 of the SAP. Samples from P2 borehole C6394 were collected and analyzed as part of Phase 1.5 of the WMA C RFI. The following is a brief summary of the analyses performed and results reported for the samples collected:

- Five samples from five intervals at Site P1 boring C6392 were submitted for analysis.
  - Sample depths are provided in Table 4-3.
  - Samples were analyzed for metals, pesticides, PCB aroclors, PCB congeners, radionuclides, VOCs, SVOCs, GRO, DRO, wet chemistry, anions (including sulfide), and physical parameters.
  - Pesticide, PCB aroclor, PCB congener, DRO, and GRO analyses were performed on the sample collected from 5 m (15 ft) bgs.
  - Pesticide analysis was performed 294 days after sample collection, grossly exceeding the extraction (14 days from collection) and analysis (40 days from extraction) holding time limits. All pesticide results were qualified as unusable (rejected) during data validation based on this gross exceedance of holding time criteria.

- Pentachlorophenol, a primary pesticide analyte, was reported by the SVOC method for all sample intervals.

- Monobutyl phosphate was not reported.

- Methanol, listed as a primary VOC analyte in the SAP, is used during sample preparation and, therefore, could not be reported.

- Results for ^{99}Tc were reported from an acid extraction sample preparation.

- Results for three TICs, one SVOC, and two VOC, were reported from various sample intervals. An evaluation of TIC results is presented in Appendix M.

- Three samples from three intervals at Site P1 boring C6400 were submitted for analysis.

  - Sample depths are provided in Table 4-3.

  - Samples were analyzed for metals, pesticides, PCB aroclors, PCB congeners, radionuclides, VOCs, SVOCs, GRO, DRO, wet chemistry, anions (including sulfide), and physical parameters.

  - Pesticide, PCB aroclor, PCB congener, DRO, and GRO analyses were performed on the samples collected from 0 to 5 m (0 to 15 ft) bgs.

  - Pesticide analysis was performed 261 to 276 days after sample collection, grossly exceeding the extraction (14 days from collection) and analysis (40 days from extraction) holding time limits. All pesticide results were qualified as unusable (rejected) during data validation based on this gross exceedance of holding time criteria.

  - Pentachlorophenol, a primary pesticide analyte, was reported by the SVOC method for all sample intervals.

  - Analysis for monobutyl and dibutyl phosphate in the sample collected from 40.6 m (133.3 ft) bgs was performed 265 days after the sample was collected. These results were qualified as unusable (rejected) during data validation.

  - Methanol, listed as a primary VOC analyte in the SAP, is used during sample preparation and, therefore, could not be reported.

  - Results for ^{99}Tc were reported from an acid extraction sample preparation.

- Results for three TICs, one SVOC, and two VOC, were reported from various sample intervals. An evaluation of TIC results is presented in Appendix M.

- Three samples from each of two intervals at Site P2 boring C6394 were submitted for analysis.
  - Sample depths are provided in Table 4-3.
  - Samples were collected prior to the approval of the Phase 2 documents and is associated with RPP-35169, *Near Term Data Quality Objectives for Vadose Zone Characterization Waste Management Area C,* and RPP-PLAN-35341. Samples were analyzed for select metals, radiochemicals, anions, and wet chemistry parameters.
  - Analysis of metals and select radiochemical parameters (by alpha energy analysis method) from acid and water extraction sample preparations was performed for all samples collected.

- Three samples from three intervals at Site P2 boring C6402 were submitted for analysis.
  - Sample depths are provided in Table 4-3.
  - Due to poor recovery in the field, insufficient volume was available for all analytes required in the SAP. Analyses were prioritized and performed as follows:
    - Analyses for pesticides, PCB aroclor, PCB congener, DRO, GRO, VOC, metals, radionuclides, ethylene glycol, and monobutyl and dibutyl phosphate were performed on all samples collected.
    - Analysis for SVOCs were performed for the sample collected from 3 m (11 ft) bgs only.
    - Analysis for ammonium ion, cyanide, and sulfide were done on all samples collected. Analysis for all other wet chemistry parameters and anions were performed on two (3 and 5 m [11 and 15 ft bgs]) of the three samples collected.
  - Samples were analyzed for pentachlorophenol, a primary pesticide analyte, by both the pesticide and SVOC methods. An evaluation of the two pentachlorophenol results for the sample from 3 m (11 ft) bgs is presented in Appendix M.
  - Isobutyl alcohol was reported from SVOC analysis. One sample 3 m (11 ft) bgs was analyzed for SVOCs; therefore, one isobutyl alcohol result was reported.

- Analysis for monobutyl and dibutyl phosphate was performed 253 days after the samples were collected. These results were qualified as unusable (rejected) during data review based on the gross holding time exceedance.

- Ethylene glycol analysis was performed 218 days after samples were collected. These results were qualified as unusable (rejected) during data review based on the gross holding time exceedance.

- Methanol, listed as a primary VOC analyte in the SAP, is used during sample preparation and, therefore, could not be reported.

- Results for ^{99}Tc were reported from an acid extraction sample preparation.

- Results for one TICs, an SVOC, were reported from various sample intervals. An evaluation of TIC results is presented in Appendix M.

• Seven samples from seven intervals at Site P2 boring C6404 were submitted for analysis.

  - Sample depths are provided in Table 4-3.

  - As stated in Section 4.4.1, this boring was adjacent to C6402 and added due to poor recovery in the field and insufficient volume was available for all analyses required in the SAP from C6402. Analyses were performed as follows:

    - Metals, SVOC, wet chemistry, and anions (including sulfide) analyses were performed on all samples collected except 3 m (11 ft) bgs.

    - Analysis for all radiochemical parameters were performed on samples collected except 3 m (11 ft) bgs. In addition, select radiochemical parameters (^{241}Am, ^{242}Cm, $^{243/244}$Cm, ^{129}I, ^{63}Ni, ^{238}Pu, $^{239/240}$Pu, ^{79}Se, and ^{90}Sr) were reported for the sample collected from 3 m (11 ft) bgs.

    - VOC analysis was performed on all samples collected.

    - Ethylene glycol, and monobutyl and dibutyl phosphate analyses were performed on samples collected from depths greater than 5 m (15 ft) bgs (6, 10, 13, and 18 m [20.5, 32, 43, and 58 ft] bgs).

    - Pesticide, PCB aroclor, PCB congener, DRO, and GRO analyses were not performed for any samples collected.

  - Pentachlorophenol, a primary pesticide analyte, was reported by the SVOC method.

  - Analysis for monobutyl and dibutyl phosphate in the samples collected was performed 278 to 285 days after the sample was collected. These results were

qualified as unusable (rejected) during data review based on gross exceedance of holding time criteria.

- Ethylene glycol analysis was performed for samples collected from 6 and 13 m (20.5 and 43 ft) bgs 111 and 32 days after sample collection. These results were qualified as unusable (rejected) during data review based on gross exceedance of holding time criteria.

- Results for 3+4-methylphenol (m+p-cresol) were reported for all 10 samples in the hard copy results; however, the results for samples from 0.2 m (0.5 ft) bgs are not present in HEIS. See Appendix M for a listing of updates to HEIS data being requested.

- Methanol, listed as a primary VOC analyte in the SAP, is used during sample preparation and, therefore, could not be reported.

- Results for ^{99}Tc were reported from an acid extraction sample preparation.

- Results for seven TICs, five SVOCs and two VOCs, were reported from various sample intervals. An evaluation of TIC results is presented in Appendix M.

• Seven samples from seven intervals at Site P3 boring C6406 were submitted for analysis.

  - Sample depths are provided in Table 4-3.

  - Due to poor recovery in the field, insufficient volume was available for all analyses required in the SAP. Analyses were prioritized and performed as follows:

    - Metals, radiochemical, SVOC, VOC, anion (including sulfide), and wet chemistry analyses were performed on all samples collected.

    - Ethylene glycol, and monobutyl and dibutyl phosphate analyses were performed on samples collected except the sample from 2 m (6 ft) bgs.

    - Analyses for DRO, GRO, PCB aroclors, and PCB congeners were performed on samples collected from 3 and 5 m (11 and 15 ft) bgs.

  - Samples were analyzed for pentachlorophenol, a primary pesticide analyte, by both the pesticide and SVOC methods. An evaluation of the two pentachlorophenol results for samples from 3 and 5 m (11 and 15 ft) bgs is presented in Appendix M.

  - Analysis for monobutyl and dibutyl phosphate was performed 258 to 263 days after the samples were collected. These results were qualified as unusable (rejected) during data review based on the gross holding time exceedance.

- Methanol, listed as a primary VOC analyte in the SAP, is used during sample preparation and, therefore, could not be reported.

- Results for ^{99}Tc were reported from an acid extraction sample preparation.

- Results for 10 TICs, eight SVOCs and two VOCs, were reported from various sample intervals. An evaluation of TIC results is presented in Appendix M.

- No samples for chemical or radiochemical analyses were collected from borings in Sites P4 or P5 (Section 4.4.1).

Investigation Site R: Samples from a borehole in Site R (C7668) were collected and analyzed under Revision 1 of the SAP. The following is a brief summary of the analyses performed and results reported for the samples collected:

- Nine samples from eight intervals at Site R boring C7668 were submitted for analysis.

  - Sample depths are provided in Table 4-3. Samples for VOC analysis were not composited.

  - A field duplicate pair from 0.2 m (0.5 ft) bgs was analyzed.

  - Due to poor recovery in the field, insufficient volume was available for all analyses required in the SAP. Analyses were prioritized and performed as follows:

    - Metals, SVOC, VOC, anion (including sulfide), and wet chemistry analyses were performed on all samples collected.

    - Analysis for all radiochemical parameters were performed on samples collected except those from 2 and 4 m (6 and 12 ft) bgs. Select radiochemical parameters reported for the sample collected from 2 m (6 ft) bgs were: ^{237}Np, ^{99}Tc, ^{230}Th, ^{232}Th, ^{126}Sn, ^{233}U, ^{234}U, ^{235}U, ^{236}U, ^{238}U. For the 4 m (12 ft) bgs sample, select radiochemical parameters reported were: ^{14}C, ^{129}I, ^{237}Np, ^{99}Tc, ^{230}Th, ^{232}Th, ^{126}Sn, H, ^{233}U, ^{234}U, ^{235}U, ^{236}U, and ^{238}U.

    - Ethylene glycol, and monobutyl and dibutyl phosphate analyses were performed on samples collected except those from 2 and 4 m (6 and 12 ft) bgs.

    - Analyses for DRO, GRO, pesticides, PCB aroclors, and PCB congeners were performed on samples collected from 0.2 and 5 m (0.5 and 16 ft) bgs. However, neither hexachlorobenzene nor pentachlorophenol, both primary pesticide analytes, were reported.

  - Isobutyl alcohol was reported from SVOC analysis for all samples. In addition, isobutyl alcohol was reported from the VOC analysis for samples collected from 5,

12, 25, and 41 m (15, 40, 81, and 133 ft) bgs. An evaluation of the two isobutyl alcohol results for these intervals is presented in Appendix M.

- No result for antimony was reported or available from the laboratory for the sample collected from 2 m (6 ft) bgs.

- Methanol, listed as a primary VOC analyte in the SAP, is used during sample preparation and, therefore, could not be reported.

- With one exception, results for ^{99}Tc were reported from both water and acid extraction sample preparations. For the sample from 2 m (6 ft) bgs, ^{99}Tc was reported from an acid extraction sample preparation only.

- Results for five TICs, four SVOC and one VOC, were reported from various sample intervals. An evaluation of TIC results is presented in Appendix M.

Investigation Site U: Samples from a borehole in Site U (C7676) were collected and analyzed under Revision 1 of the SAP. The following is a brief summary of the analyses performed and results reported for the samples collected:

- Eight samples from seven intervals at Site U boring C7676 were submitted for analysis.

  - Sample depths are provided in Table 4-3. Samples for VOC analysis were not composited.

  - A field duplicate pair from 0.2 m (0.5 ft) bgs was analyzed.

  - Samples were analyzed for metals, pesticides, PCB aroclors, PCB congeners, radionuclides, VOCs, SVOCs, GRO, DRO, wet chemistry, anions (including sulfide), and physical parameters.

  - Pesticide, PCB aroclor, PCB congener, DRO, and GRO analyses were performed on the five samples collected from 0 to 5 m (0 to 15 ft) bgs.

  - Two lead results, each from a different analytical method, were reported for the sample collected from 12 m (39 ft) bgs. An evaluation of these two results is presented in Appendix M.

  - Pentachlorophenol, listed as a primary pesticide analyte in the SAP, was not reported.

  - Methanol, listed as a primary VOC analyte in the SAP, is used during sample preparation and, therefore, could not be reported.

- Results for ^{99}Tc were reported from both water and acid extraction sample preparations.

- Results for 17 TICs, 7 SVOCs and 10 VOCs, were reported from various sample intervals. An evaluation of TIC results is presented in Appendix M.

4.4.2 Drywell and Groundwater Well Logging

The original work plan identified three sites associated with drywell and groundwater well logging (Sites L, M, and W) (Table 4-3):

- Site L consisted of logging drywells and direct push investigations around Tanks C-103 and C-106. The purpose of the drywell geophysical logging was to add additional information to the direct push geophysical logging and sampling in this area and to investigate the possible past releases from transfer lines as well as tank overfill events that may have impacted the soil in this vicinity.

- Site M consisted of logging drywells around Tanks C-104, C-108, C-109, C-110, C-111, and C-112. The purpose of the drywell geophysical logging was to identify any changes in logging results that may have occurred since 2000.

- Site W was designated for geophysical logging of groundwater wells 299-E27-4, 299-E27-12, 299-E27-13, 299-E27-14, and 299-E27-15 in the vicinity of WMA C. The purpose was to collect information on uranium, ^{60}Co, ^{137}Cs, and moisture to help in the evaluation of nature and extent of contamination associated with WMA C vadose zone soil.

The work plan specifically called for the re-logging of drywells and the logging of groundwater wells that had not been previously logged. Logging was identified to address the concerns raised by stakeholders and Tribal Nations relating to the presence and mobility of ^{60}Co. The purpose of the logging was to update the data collected during the baseline spectral gamma analysis conducted in 1998 (GJO-98-39-TAR/GJO-HAN-18) and 2000 (GJO-98-39-TARA/ GJO-HAN-18). The logging of drywells prior to WMA C RFI field efforts was previously discussed in Section 4.1.

Figure 4-17 shows the locations of the drywells and groundwater wells associated with WMA C that were planned to be logged for the Phase 2 RFI efforts. Figure 4-18 shows which drywells and groundwater wells were logged. Table 4-7 identifies the drywells in WMA C, whether or not they were planned to be re-logged for Phase 2 and if the re-logging was completed.

Of the 54 drywells (Sites L and M) to be re-logged, 29 were spectral gamma logged and 34 were logged with a manual neutron moisture probe (Table 4-7). Additionally, it was identified that two of the five groundwater wells identified for Site W logging, 299-E27-4 and 299-E27-14, had sufficient logging results. Table 4-8 provides the logging status and cross references to the applicable released data sources. Logging of the remaining wells and drywells was discussed in 2011 work plan meetings. During these meetings, it was identified that tank farm retrieval

operations presented significant access issues that in-turn prevented the completion of the remaining logging. Approval was received in the September 20, 2011 work plan meeting (Appendix I) to discontinue additional logging at the remaining groundwater wells and drywells at these sites. This is also documented in the approved RPP-PLAN-39114, Rev. 2.

The following reasons were identified as justification to discontinue logging (at Sites L, M, and W):

- WMA C drywells logged to date show no significant change in gamma or spectral gamma activity from previous logs.

- Cobalt-60, observed to migrate in many of the drywells in the past, has largely decayed below minimum detection limits for spectral gamma. Monitoring ^{60}Co movement was one the primary purposes for re-logging drywells.

- Newer logs showed little change in ^{137}Cs activities from those reported in 1998.

- Future gamma and neutron monitoring of drywells will continue to be undertaken in accordance with the retrieval requirements.

- Logging at the remaining three groundwater wells (299-E27-12, 299-E27-13, and 299-E27-15) is unlikely to yield information of value because well construction diagrams suggested that the wells were not suitable for geophysical logging because of a bentonite annulus.

Note that even though discontinuing logging had been approved in 2011 and in the revised work plan, five of the drywells (30-06-10, 30-06-12, 30-08-02, 30-09-06, and 30-09-07) were re-logged during 2013 in the vicinity between Tanks C-106, C-108, and C-109, in an effort to further observe migration of ^{60}Co (Table 4-7). Additionally, Appendix G provides information on the various geophysical logging approaches.

Figure 4-17. Original Phase 2 Drywell and Groundwater Well Logging

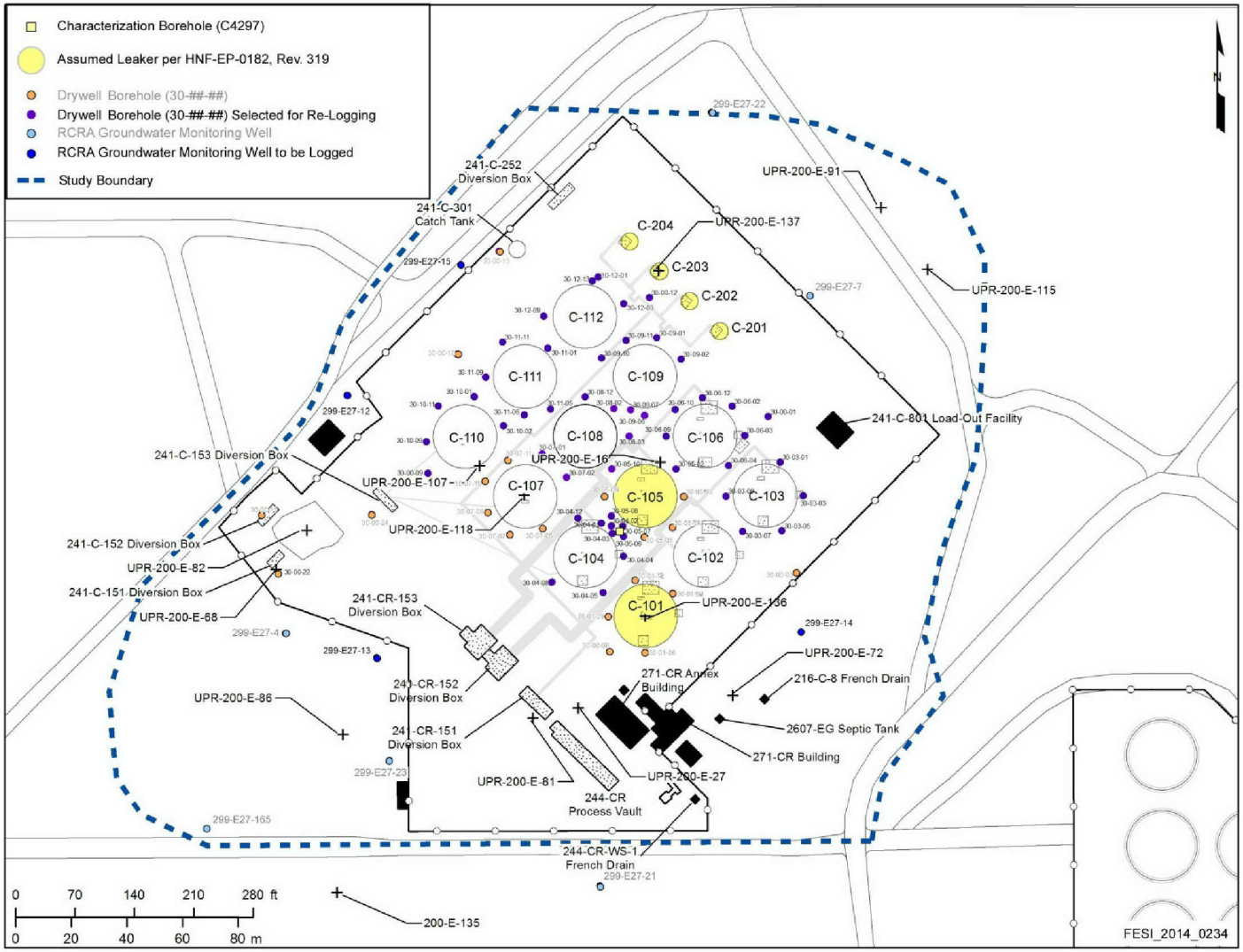


Figure 4-18. Phase 2 Drywell and Groundwater Well Logging

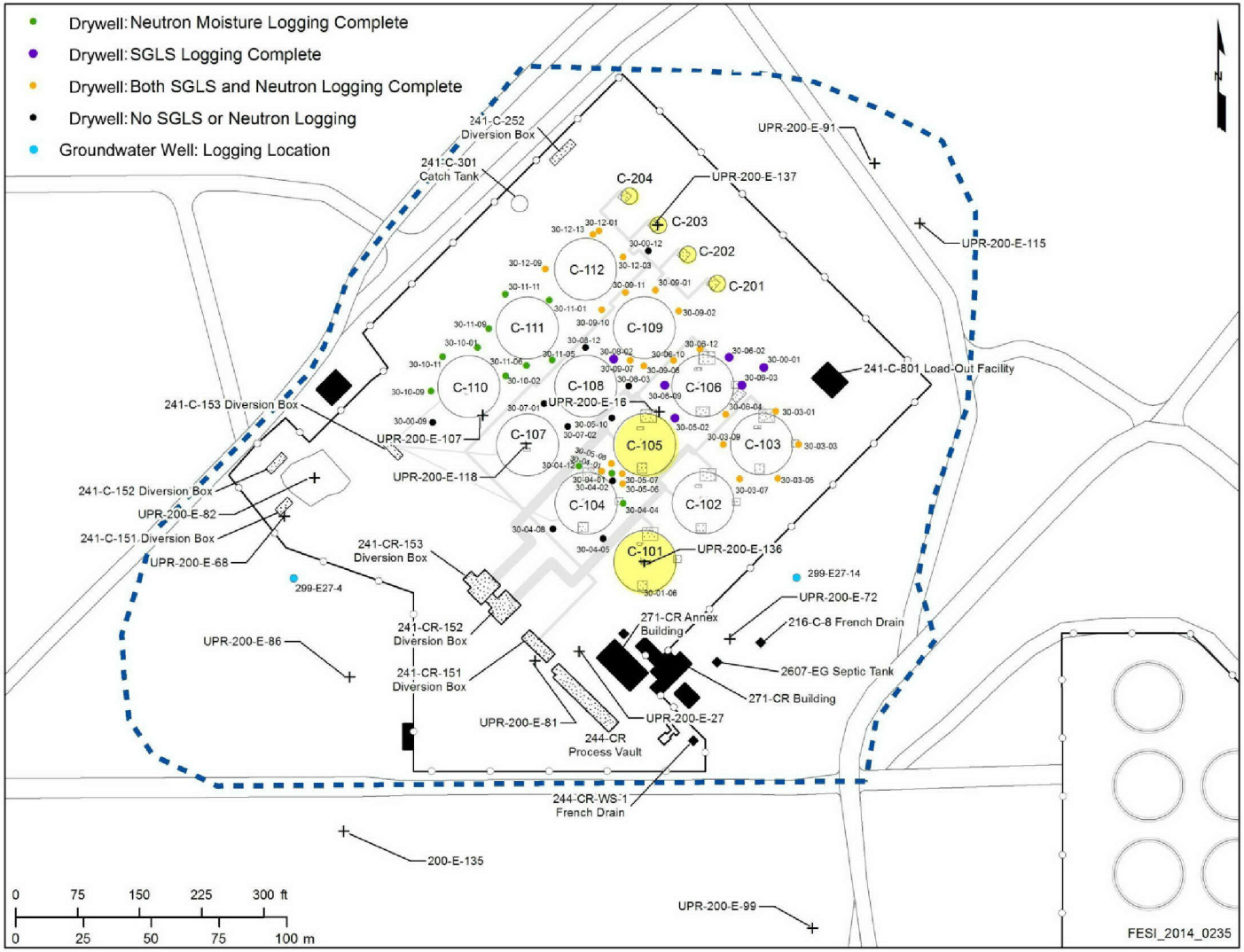


Table 4-7. WMA C Farm Drywells Logged for Phase 2

Drywell	Area of Interest in Work Plan	Logging Identified in Original Work Plan?	Spectral Gamma Re-logging Date	Neutron Logging Information
30-00-01	C-106 (Site L)	Yes	7/22/2010	-
30-00-03	-	No	-	-
30-00-06	-	No	-	-
30-00-09	C-110 (Site M)	Yes	-	-
30-00-10	-	No	-	-
30-00-11	-	No	-	-
30-00-12	C-112 (Site M)	Yes	No SGLS Access	-
30-00-13	-	No	-	-
30-00-22	-	No	-	-
30-00-24	-	No	-	-
30-01-01	C-101 (Sites A+B)	Yes, Rev 2[a]	-	-
30-01-06	C-101 (Sites A+B)	Yes, Rev 2[a]	-	-
30-01-09	C-101 (Sites A+B)	Yes, Rev 2[a]	8/31/2010	-
30-01-12	C-101 (Sites A+B)	Yes, Rev 2[a]	-	-
30-03-01	C-103 (Site L)	Yes	10/14/2010	Completed during retrieval
30-03-03	C-103 (Site L)	Yes	10/20/2010	Completed
30-03-05	C-103 (Site L)	Yes	11/1/2010	Completed during retrieval
30-03-07	C-103 (Site L)	Yes	10/27/2010	Completed during retrieval
30-03-09	C-103 (Site L)	Yes	10/22/2010	Completed during retrieval
30-04-01	C-104 (Site M)	Yes	8/4/2010	Completed during retrieval
30-04-02	C-104 (Site M)	Yes		Completed during retrieval
30-04-03	C-104 (Site M)	Yes	No SGLS access	-
30-04-04	C-104 (Site M)	Yes		Completed during retrieval
30-04-05	C-104 (Site M)	Access	No SGLS access	-
30-04-08	C-104 (Site M)	Access	No SGLS access	-

Table 4-7. WMA C Farm Drywells Logged for Phase 2

Drywell	Area of Interest in Work Plan	Logging Identified in Original Work Plan?	Spectral Gamma Re-logging Date	Neutron Logging Information
30-04-12	C-104 (Site M)	Yes	-	Completed during retrieval
30-05-02	C-105 (Site M)	Yes	9/8/2010	
30-05-03	-	No	-	-
30-05-04	-	No	-	-
30-05-05	-	No	-	-
30-05-06	C-104 (Site M)	Yes	7/30/2010	Completed during retrieval
30-05-07	C-105 (Site M)	Yes	8/3/2010	Completed
30-05-08	C-105 (Site M)	Yes	8/2/2010	Completed
30-05-09		No	-	-
30-05-10	C-108 (Site M)	Yes	-	-
30-06-02	C-106 (Site L)	Yes	9/29/2010	-
30-06-03	C-106 (Site L)	Yes	10/11/2010	-
30-06-04	C-106 (Site L)	Yes	11/4/2010	Completed during retrieval
30-06-09	C-106 (Site L)	Yes	9/27/2010	-
30-06-10	C-106 (Site L)	Yes	3/11/2011; 4/09/2013	Completed during retrieval
30-06-12	C-106 (Site L)	Yes	3/7/2011; 4/16/2013	Completed during retrieval
30-07-01	C-108 (Site M)	Yes	-	-
30-07-02	C-108 (Site M)	Yes	-	-
30-07-05	-	No	-	-
30-07-07	-	No	-	-
30-07-08	-	No	-	-
30-07-10	-	No	-	-
30-07-11	-	No	-	-
30-08-02	C-108 (Site M)	Yes	11/16/2010; 3/21/2013	-
30-08-03	C-108 (Site M)	Yes	No SGLS access	-
30-08-12	C-108 (Site M)	Yes	No SGLS access	-

Table 4-7. WMA C Farm Drywells Logged for Phase 2

Drywell	Area of Interest in Work Plan	Logging Identified in Original Work Plan?	Spectral Gamma Re-logging Date	Neutron Logging Information
30-09-01	C-109 (Site M)	Yes	12/30/2010	Completed during retrieval
30-09-02	C-109 (Site M)	Yes	12/20/2010	Completed during retrieval
30-09-06	C-109 (Site M)	Yes	3/1/2011; 4/4/2013	Completed during retrieval
30-09-07	C-108 (Site M)	Yes	11/9/2010; 3/26/2013	Completed during retrieval
30-09-10	C-109 (Site M)	Yes	11/29/2010	Completed during retrieval
30-09-11	C-109 (Site M)	Yes	12/7/2010	Completed during retrieval
30-10-01	C-110 (Site M)	Yes	-	Completed during retrieval
30-10-02	C-110 (Site M)	Yes	-	Completed during retrieval
30-10-09	C-110 (Site M)	Yes	-	Completed during retrieval
30-10-11	C-110 (Site M)	Yes	-	Completed during retrieval
30-11-01	C-111 (Site M)	Yes	-	Completed during retrieval
30-11-05	C-111 (Site M)	Yes	-	Completed during retrieval
30-11-06	C-111 (Site M)	Yes	-	Completed during retrieval
30-11-09	C-111 (Site M)	Yes	-	Completed during retrieval
30-11-11	C-111 (Site M)	Yes	-	Completed during retrieval
30-12-01	C-112 (Site M)	Yes	7/15/2010	Completed
30-12-03	C-112 (Site M)	Yes	7/13/2010	Completed
30-12-09	C-112 (Site M)	Yes	7/27/2010	Completed
30-12-13	C-112 (Site M)	Yes	7/20/2010	Completed

[a] Added to support leak assessment process (Refer to email in Appendix L).
SGLS = spectral gamma logging system

Table 4-8. WMA C RCRA Phase 2 Geophysical Logging Event Summary by Site ID.

Site ID	Site	Investigation Locations		Logging Technique		Report*	Logging Date
		Vertical	Slant	SG	NM		
A	C-101	--	1	1	1	RPP-RPT-50581	April 2011
B	C-101	--	1	1	1	RPP-RPT-50581	May 2011
C	C203 UPR-E-137	--	1	1	1	RPP-RPT-51384	Nov 2011
D	C-201 C-202 C-204	4	--	4	4	RPP-RPT-55481	April 2013- June 2013
E	C-106 C-109	1	--	1	1	RPP-RPT-48029	June 2010-
F	C-801	1	--	1	1	RPP-RPT-47461	Dec. 2009
G	C-801	1	--	1	1	RPP-RPT-42714	July 2009
H	UPR-E-91	1	--	1	1	RPP-RPT-48029	July 2010
I	UPR-E-91 E-115	1	--	1	1	RPP-RPT-48029	June 2010- July 2010
J	C-104	--	1	1	1	RPP-RPT-49956	
K	C-108	NC	NC	NC	NC	NC	NC
L	C-103 C-106	2	--	2	2	RPP-RPT-42714 RPP-RPT-47461	July 2009 Dec. 2009
M	C-104 C-105 C-108 C-109 C-110 C-111 C-112	33	--	33	28	RPP-RPT-55709 RPP-RPT-56085, RPP-RPT-56540, RPP-RPT-55709, RPP-RPT-57321	March 2009, July 2010- May 2011, March 2013- April 2013
P	UPR-200-E-81	7	--	7	7	RPP-38927 RPP-42221	April 2008 – May 2008
Q	UPR-200-E-82	4	--	4	4	RPP-48609	
R	C-301	1	--	1	1	RPP-RPT-47461	Dec. 2009
S	UPR-200-E-72	NC	NC	NC	NC	NC	NC
U	C-110	1	--	1	1	RPP-RPT-48029	
V	C-111	NC	NC	NC	NC	NC	NC
W	E27-12 E27-13 E27-15	NC	NC	NC	NC	NC	NC
X	C-105	NC	NC	NC	NC	NC	NC
--	WMA C	63	--	--	63	RPP-RPT-55709, RPP-RPT-56085, RPP-RPT-56540, RPP-RPT-55709, RPP-RPT-57321	2006-2013

*Logs are provided in the released reports and in Appendix T.
-- = not applicable
NC = not completed
NM = neutron moisture
SG = spectral gamma

4.4.3 SGE

SGE is a term used to refer to the field of subsurface geophysical imaging. The original work plan identified SGE to be performed at Sites N (UPR-200-E-81, UPR-200-E-82, and UPR-200-E-86) and Site O (overall WMA C). As identified in Section 4.4, Phase 2 field work is based on a non-probabilistic (biased) sampling strategy that targets locations where contaminants are most likely to be encountered. SGE has been employed in an effort to identify any unknown releases across WMA C. SGE is used as an alternative technique to random sampling for investigating unknown releases because, regardless of infrastructure interference, the target area is simply too large to permit, in terms of time and resources, a statistically valid random sampling effort. For the purposes of the Phase 2 investigation electrical resistivity imaging, also known as electrical resistivity tomography, was employed at WMA C.

Since waste fluids at tank farms contain nitrate that can reduce the electrical resistivity of the underlying strata, the resistivity measurements were completed first at Site N (UPR-200-E-81, UPR-200-E-82, and UPR-200-E-86) and compared against samples taken at these sites. As part of the Site N deployment, it was demonstrated that SGE could discriminate subsurface anomalies in the tank farm environment depending on the anticipated volume of the release and the relative concentration of ionic constituents.

Given the successful deployment of SGE at Site N, a plan was developed to deploy the method for Sites C+D. The original work plan identified installation of up to nine direct push sampling boreholes at Sites C and D to determine whether the 200-series tanks leaked. Installation of the first of these boreholes was initiated in 2011 (Site C, C8105 and C8106). While planning for installation of the first borehole at Site C, the final results of the SGE investigations at Site N became available. Through a series of discussions, the Tri-Parties agreed to modify the investigation at Sites C and D to include use of SGE (Refer to September 22, 2011 work plan meeting notes and the approved RPP-PLAN-39114, Rev. 2). The agreement was to push four boreholes near the 200-series tanks and to equip them with deep electrodes for three-dimensional SGE.

The purpose of the SGE investigation at Sites C and D was to interrogate the subsurface beneath the 200-series tanks and the surrounding vicinity for the presence of tank farm related waste and to evaluate whether there was any evidence of a leak from any of the 200-series tanks during retrieval. In addition, the SGE investigation was designed to maximize the subsurface information between the 200-series tanks and well 299-E27-7 in an effort to determine the source of the uranium and cobalt contamination.

Although multiple 200-series tanks are assumed to have released waste to the environment in the past, only one UPR is identified for these tanks, UPR-200-E-137 for Tank C-203 (HNF-EP-0182). Evidence suggests that the 200-series tanks were filled several times, and liquid level decreases may in part have been the result of a tank overflow through spare inlet ports, or more likely can be attributed to evaporation (RPP-RPT-42294). Additionally, results from gamma logging at groundwater monitoring well 299-E27-7, in January 2008, detected contamination indicative of tank farm waste streams. Uranium-238 and ^{235}U were detected between 29 and 33 m (93 and 108 ft) bgs, while ^{60}Co was detected at multiple isolated depth

intervals, including 41 to 41.2 m (133 to 135 ft) bgs and 46 to 48 m (150 to 158 ft) bgs. Groundwater level at the time was measured at 73 m (238 ft) bgs (HGLP-LDR-174, *299-E27-07 [A4816] Log Data Report*). Well 299-E27-7 is located on the northeast border of WMA C, due east of Tank C-202, and 34 m (110 ft) from Tank C-201.

Regarding Site O, access within the vicinity of the 100-series tanks was very limited due to retrieval activities. As such, completing a new investigation of Site O was not feasible. To address Site O, previous well-to-well SGE resistivity data were reprocessed taking advantage of advancements in computing and processing code enhancements, since the initial data were acquired in 2006 (RPP-RPT-31558). This previous work was not acquired at the same high resolution data density as the other 3D electrical resistivity imaging sites; however, advances in computing processing capability and speeds, as well as advances in geophysical data processing codes allowed for optimizations and the ability to effectively process data that could not previously be processed in its entirety given computer processing limitations. Report RPP-RPT-49288, *C Farm Surface Geophysical Exploration-Reprocessing* presents the results of the WMA C well-to-well resistivity reanalysis completed in 2011.

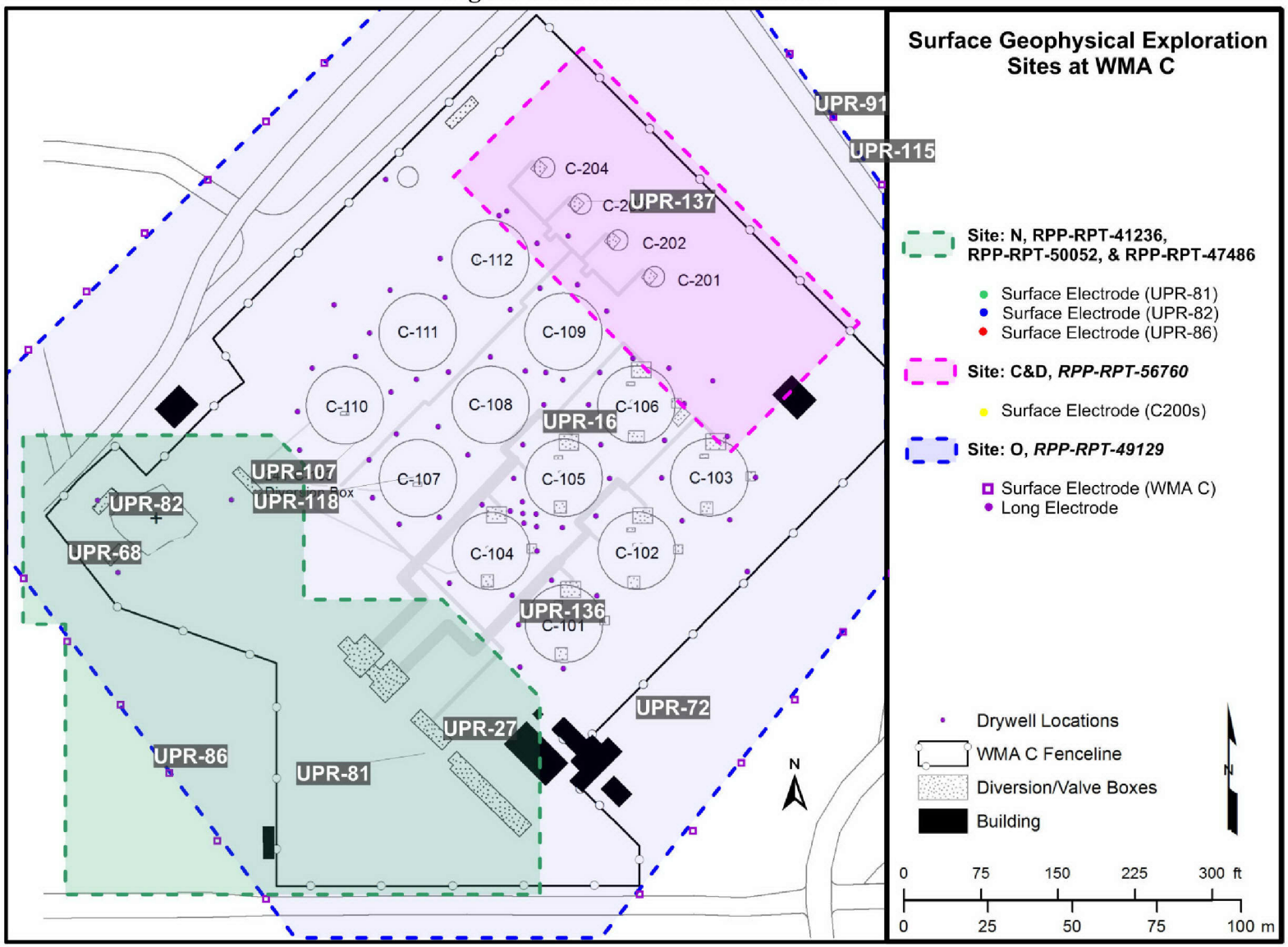
Figure 4-19 identifies the SGE survey boundaries, and Table 4-9 identifies the locations in which SGE was performed as part of Phase 2 RFI efforts:

- Site C+D: 200-UPR-E-137 including Tanks C-201 C-202, C-203, and C-204
- Site N: 200-UPR-E-81, 200-UPR-E-82, and 200-UPR-E-86
- Site O: overall WMA C

Table 4-9. SGE Investigations at WMA C

Investigation Group/Site	Site	Investigation Type	Report Number	Field Work/ Report
C+D	C200s 200-UPR-E-137	3D SGE with depth electrodes	RPP-RPT-56760	2013/2014
N	200-UPR-E-81 200-UPR-E-82 200-UPR-E-86	3D SGE with depth electrodes	RPP-RPT-41236 RPP-RPT-50052 RPP-RPT-47486	2009/2009 2010/2010 2011/2011
O	WMA C	3D Well-to-Well	RPP-RPT-49129	2006/2010

Figure 4-19. SGE Sites at WMA C



Note that the SGE effort at Site O is considered to be a three-dimensional well-to-well survey, where only the existing drywells were used as electrodes. This differs from the other surveys that use an array of surface electrodes and depth electrodes to perform the measurements. The well-to-well style survey results are typically presented in a two-dimensional plan view because the depth resolution is dependent on the length of the sensing drywells. This makes the SGE results very coarse in the vertical direction. As part of the direct push investigations at each of these sites depth electrodes were installed to enhance the depth resolution of the SGE methods. Field methods and data processing improvements are addressed in Appendix G.

4.4.4 Tissue Sampling and Analysis

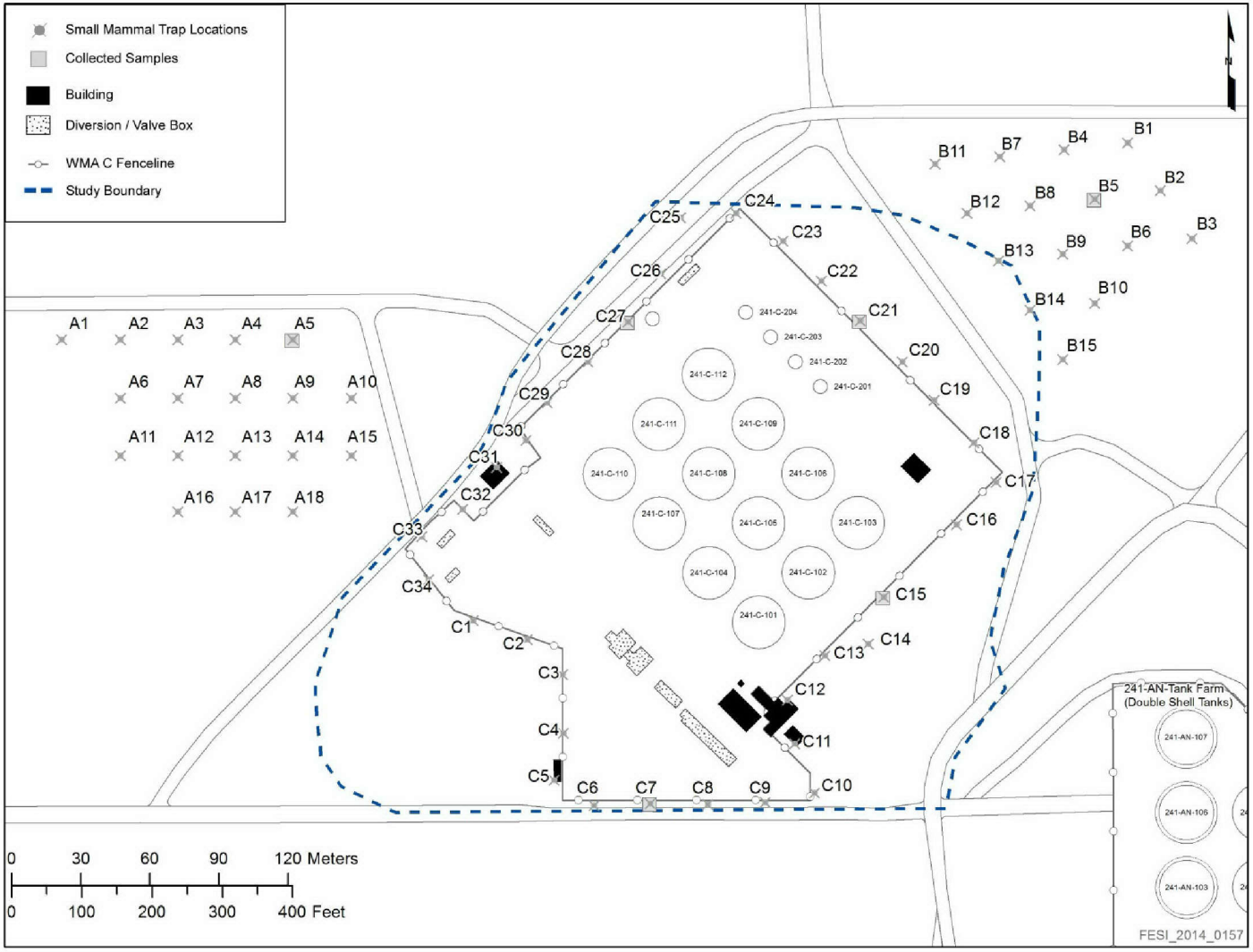
Site AA is the site that represents the collection of tissue samples as identified in the work plan. It should be noted that tank farms, including WMA C, are presently managed in a way to eliminate, to the extent possible, the intrusion of plants and animals into the facilities. However as identified in the work plan, impacts from past operations at WMA C may expose animals located outside WMA C to possible contamination. For this reason, small mammal tissue sampling and analysis was completed as a supplemental method for evaluating contaminant pathways and risks to wildlife receptors. Specifically, mice were the small mammals collected from around the perimeter of WMA C for tissue sampling. Population metrics, including gender, age, reproductive status, species, and body weight were also collected as part of the investigation.

The original work plan was revised to reflect field conditions that had been changed since the time the plan had been written. In addition, quality assurance and quality control requirements were discussed, and clarification and corrections were made to the analytes. These changes were documented in TPA-CN-382, dated February 23, 2011.

Wildlife habitat is sparse in the area immediately adjacent to WMA C. Small mammal collection for this effort was focused in two areas containing vegetation, which is used both for cover and food sources for small mammal populations. Dimensions of the small mammal study area were correlated to the average home range and dispersal distance of deer mouse (*Peromyscus maniculatus*) (RPP-PLAN-39114, Rev. 2). Three small-mammal collection transects were placed along the outside perimeter of the WMA C boundary. Transect Groups A and B were sited in perimeter vegetation, and Transect Group C was sited along the southeast WMA C boundary in a non-vegetated area (Figure 4-20).

Small mammal trapping began on March 7, 2011, and ended on April 14, 2011. Small mammal sampling was conducted under Washington Department of Fish & Wildlife Scientific Collection Permit # 10-329. Traps were checked daily when traps were open for collection, and trapping continued until sufficient sample masses were obtained from each of the study grids or until low-capture success rates were determined not likely to yield a sufficient sample mass in a reasonable amount of time for all analyses prescribed. Traps in the Transect Group A were closed on April 11, 2011, after the target total collection mass had been obtained. Transect Groups B and C were closed on April 14, 2011, because of low trapping success.

Figure 4-20. Phase 2 Tissue Sampling Trap Locations



A total of 21 small mammals were collected and prepared for analyses. Chemical analysis included metals, radionuclides, pesticides, and PCB congeners as per work plan requirements. Analytical performance requirements for tissue analyses (RPP-PLAN-39114, Appendix B, Table 1-2) were followed. Table 4-10 provides analytical suites and methods of analysis for small mammal tissues. Table 4-11 shows the list of small mammal species captured and submitted for analyses.

The target sample mass needed to meet the minimum requirements for all analyses (142 g) was only obtained from within Transect Group A. In Transect Group B (north of WMA C) only 65 g of the required 142 g were acquired. While in Transect Group C (along the WMA C boundary), only 12 g of the required 142 g were acquired. Note that reproductively active adults were targeted for collection and analyses, but females actively feeding young-of-year offspring were immediately released unharmed. Juvenile small mammals were collected only if reproductively active adults were scarce.

Poor trapping success in Transect Groups B and C prompted the need to cease field sampling events before enough mass was obtained for all planned analyses. Table 4-12 summarizes the final sample masses achieved and analyses performed for Transect Groups B and C. For Transect Groups A and B, multiple small mammal species (primarily deer mice and western harvest mice) were combined in an effort to attain the minimum masses requested by the analytical laboratories. Specimens were thoroughly homogenized in a laboratory-grade blender, bottled, digested, and shipped to analytical laboratories for the analyses detailed in Table 4-12. Organic and radiological constituents were reported in whole animal (including skin and viscera), whereas metal analyses were performed only on the liver/kidney. Tissue analytical results are presented in Section 5.

4.4.5 Vadose Zone Soil Sampling of Groundwater Wells

During the review of the original work plan, the Nez Perce Tribe requested the collection of "twin" soil samples from new groundwater well boreholes and soil samples from direct push, where possible. It was also identified that direct push and well location should be located a few feet (0.6 m [2 ft]) apart to allow for more valid comparisons of analytical results from soil samples and logging results. With respect to logging, the effort would allow for the comparison of the results obtained using spectral gamma logging tools and bismuth-germanium oxide (BGO) direct push logging tools. The "twinning" exercise would also support the technical merits of using moisture logging results as an indicator for soil sampling targets. The preferred location as recommended by the Nez Perce Tribe and concurred with by DOE-ORP and the contractor would be close to existing groundwater wells 299-E27-7 or 299-E27-14, which have shown groundwater impacts related to regional contamination as well as contamination associated with WMA C. However during discussions, it was noted that the location of the investigation may need to be modified due to existing site conditions and waste retrieval operations.

As identified in Revision 1 of the work plan, twinning was identified for direct push and any new groundwater wells that were to be installed within 31 m (100 ft) of the WMA C boundary. The two new groundwater wells to be installed in the vicinity of WMA C were wells 299-E27-24 and 299-E27-25.

Table 4-10. Analytical Suites and Methods for Small Mammal Tissues

Analyte Group	Analytical Methods[a]	Analyzed in Tissues[b]	Indicator Contaminants[c]
Inorganic chemicals (Metals)	6010	Yes	Arsenic, barium, cadmium, copper, lead, manganese, molybdenum, nickel, zinc
	200.8	Yes	Chromium, selenium, mercury
PCBs and pesticides	8082 (PCBs)	Yes	PCB aroclors
	1668A	Yes	PCB Congeners
	8081 (pesticides)	Yes	Aldrin, chlordane, dieldrin, endrin, 4,4'-DDT, 4,4'-DDD, 4,4'-DDE, gamma-BHC (Lindane) heptachlor, heptachlor epoxide
Semivolatile organic compounds	8270	Yes	Benzo(a)pyrene, Hexachlorobenzene, pentachlorophenol
Radionuclides	Alpha Liquid Scintillation Counter (LSC)	Yes	Gross alpha activity
	Beta LSC	Yes	Gross beta activity
	Gamma energy analysis (GEA)	Yes	^{134}Cs, ^{137}Cs, ^{60}Co, ^{152}Eu, ^{154}Eu, ^{155}Eu, ^{226}Ra
	Alpha energy analysis (AEA)	Yes	^{241}Am
	Isotopic plutonium (AEA)	Yes	^{238}Pu, $^{239/240}$Pu
	Isotopic thorium (AEA)	Yes	^{228}Th, ^{230}Th, ^{232}Th
	Isotopic uranium (AEA)	Yes	^{234}U, ^{235}U, ^{238}U
	Total radioactive strontium (GPC)	Yes	$^{89/90}$Sr

[a] All results obtained by these methods.
[b] Analyses were subject to obtaining a sufficient amount of small mammal whole organism tissue.
[c] Indicator contaminants for small mammal tissues were those that identified as *Washington Administrative Code* soil indicator contaminants for wildlife plus radionuclides.

GPC = gas proportional counting PCB = polychlorinated biphenyl

Table 4-11. Small Mammal Subsample Characteristics

Trap Area	Trap ID	EAS Sample ID	Date Captured	Species	Age (Adult [Ad], Juv [Juv])	Gender (male [M], female [F])	Mass (g)	Reproductive Status	Field Condition
A	A5	070411MA-5	4/7/2011	Pepa	Ad	F	16.51	Active	Normal
A	A9	070411MA-6	4/7/2011	Reme	Ad	F	13.17	Active	Normal
A	A10	070411MA-7	4/7/2011	Pepa	Ad	M	15.39	Active	Normal
A	A4	080311MA-2	3/8/2011	Pema	Ad	F	16.57	Active	Normal
A	A10	090311MA-1	3/9/2011	Pema	Ad	F	15.77	Active	Normal
A	A10	100311MA-1	3/10/2011	Pema	Ad	M	15.84	Active	Normal
A	A10	140311MA-1	3/14/2011	Pema	Ad	M	15.97	Active	Normal
A	A10	170311MA-1	3/17/2011	Reme	Ad	F	13.31	Active	Normal
A	A17	210311MA-1	3/21/2011	Pema	Ad	F	21.32	Active	Normal
A	A10	210311MA-2	3/21/2011	Pema	Ad	M	15.40	Active	Normal
A	A10	220311MA-1	3/22/2011	Reme	Ad	M	11.64	Active	Normal
A	A10	280311MA-1	3/28/2011	Reme	Ad	M	12.35	Active	Normal
A	A2	290311MA-1	3/29/2011	Pema	Ad	F	15.79	Active	Normal
A	A2	290311MA-2	3/29/2011	Pema	Ad	M	16.97	Active	Normal
B	B11	170311MB-1	3/17/2011	Reme	Ad	F	8.00	Active	Normal
B	B11	170311MB-2	3/17/2011	Pema	Juv	M	9.65	Inactive	Normal
B	B5	210311MB-1	3/21/2011	Pepa	Ad	F	16.75	Active	Normal
B	B9	220311MB-1	3/22/2011	Reme	Ad	M	10.80	Active	Normal
B	B13	280311MB-1	3/28/2011	Pepa	Ad	F	16.49	Active	Normal
B	B9	280311MB-2	3/28/2011	Reme	Ad	M	9.88	Active	Normal
C	C31	130411MC-1	4/13/2011	Reme	Ad	M	11.83	Active	Normal

Pema = Deer Mouse (*Peromyscus maniculatus*)
Pepa = Great Basin Pocket Mouse (*Perognathus parvus*)
Reme =Western Harvest Mouse (*Reithrodontomys megalotis*)

Table 4-12. Small Mammal Sample Processing Summary

Trap Area	MSA Sample ID	Tissue	Mass (g)	Vol (mL)	Preservative	Laboratory	Analyses
A	B2CL39	Liver/kidney	1.12	100	HNO3	WSCF	Metals
A	B2CL40	Carcass	100.04	500	HNO3	WSCF	Metals & Radionuclides [a]
A	B2CL40	Carcass	1.15	10	HNO3	WSCF	Radiation Screen
A	B2CL40	Carcass	90.04	95	MeCl	TAKN	Organics
A	B2CL40	Carcass	10.09	43	MeCl	TAKN	PCB Congeners
A	B2CL40	Carcass	5.17	50	HNO3	TARL	Isotopic Thorium
B	B2CL41	Liver/kidney	1.05	100	HNO3	WSCF	Metals
B	B2CL42	Carcass	1.09	5	HNO3	WSCF	Metals
B	B2CL42	Carcass	0.59	5	HNO3	WSCF	Radiation Screen
B	B2CL42	Carcass	32.41	36	MeCl	TAKN	Organics
B	B2CL42	Carcass	10.40	20	MeCl	TAKN	PCB Congeners
B	B2CL42	Carcass	5.09	50	HNO3	TARL	Isotopic Thorium
C	B2CL43	Liver/kidney	0.72	100	HNO3	WSCF	Metals
C	B2CL44	Carcass	0.57	5	HNO3	WSCF	Radiation Screen
C	B2CL44	Carcass	8.46	16	MeCl	TAKN	PCB Congeners
N/A	B29BW4	Water (equipment blank)	NA	8.5 L	NA	WSCF/ TARL/ TAKN	Full Suite

[a] Excluding isotopic thorium
NA = not applicable

It was identified that groundwater well 299-E27-25 was to be located greater than 152 m (500 ft) to the northeast of WMA C. Groundwater well 299-E27-24 was to be located 29 m (95 ft) due east of the southern boundary from the WMA C boundary and approximately 91 m (200 ft) east of the nearest facility (CR Vaults), which might have leaked waste into the environment. Geophysical logs from well 299-E27-24 did not indicate the presence of contamination at depths attainable using direct push methods. For this reason, twinning using direct push was not undertaken at either of these locations (Revision 2 of the work plan).

Direct comparisons of spectral gamma logging and BGO direct push logging results were accomplished outside WMA C at three locations inside other tank farms (200 West Area). In each of the three locations, a single drywell was logged using both geophysical tools. This work was completed at drywells 52-03-06 in TY Tank Farm, 50-01-04 in T Farm, and 21-02-04 in BX Farm. Testing showed good correlation of the results at all three locations (Refer to Revision 2 of the work plan, Figures 4-5 through Figure 4-7). Therefore, as identified in Revision 2 of the work plan, the intent of the twinning requirement was considered met.

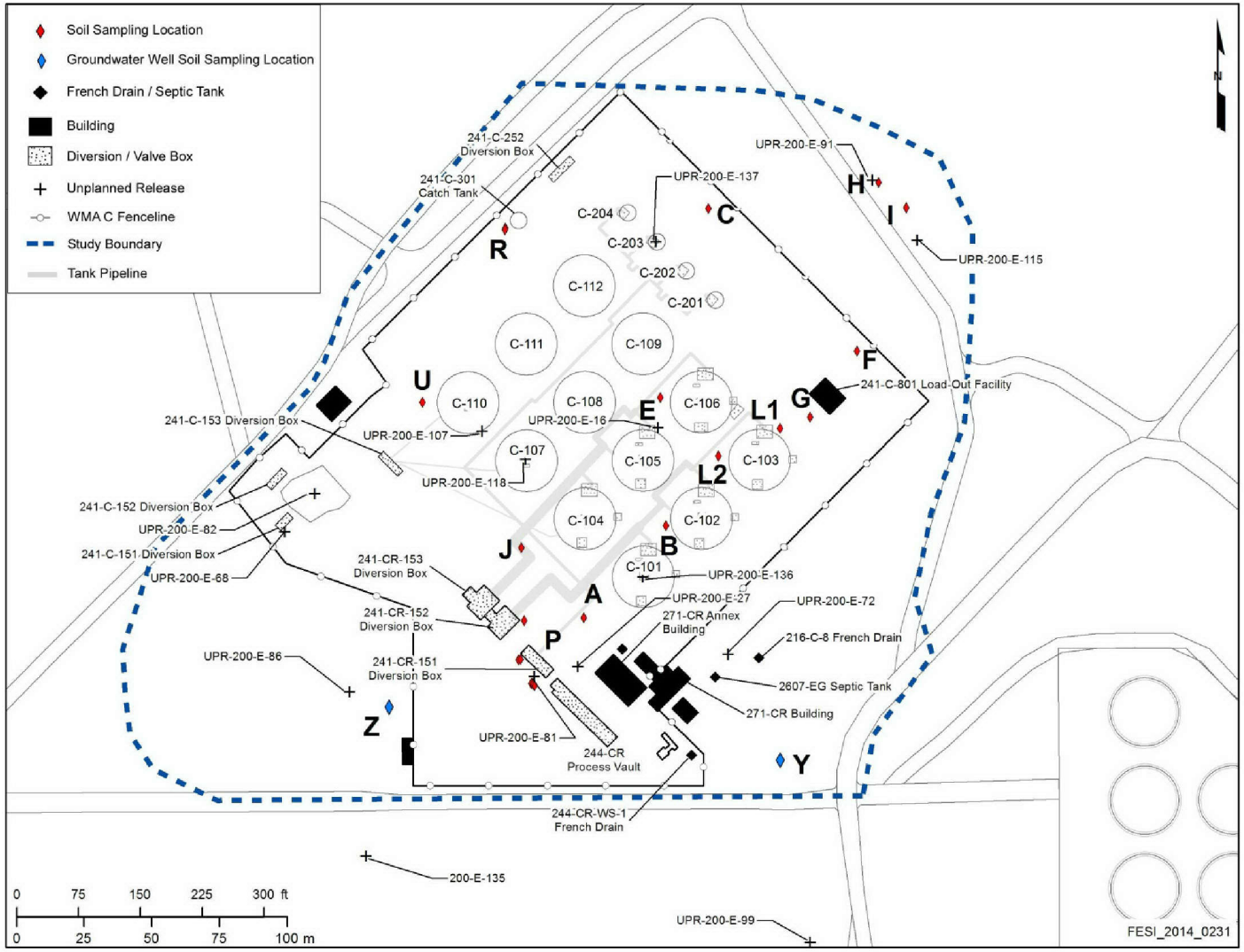
Even though the twinning effort was considered completed, it was decided through work plan meetings that it would be beneficial to analyze vadose zone soil samples from two wells within the vicinity of WMA C:

- 299-E27-24
- 299-E27-20

Well 299-E27-24 is located 29 m (95 ft) due east of the southern boundary from the WMA C boundary and approximately 61 m (200 ft) east of the nearest facility (CR Vaults). It was identified that this well had high ^{99}Tc concentrations in groundwater (2,100 pCi/L). For this reason, it was decided to take several soil samples from just above the water table (i.e., 2, 3, and 4 m [5, 10, and 13 ft]) and analyze these samples for ^{99}Tc, nitrate, soil moisture, and pH. A sampling and analysis plan was written to address the sampling and analysis effort (RPP-PLAN-44354, *Field Sampling and Analysis Plan for Soil Samples at Well C7570 - Waste Management Area C*).

Additionally, during 2011 work plan meetings, high ^{99}Tc concentrations at well 299-E27-23 were identified (>20,000 pCi/L, December 2010). This well was installed in 2003 to the southeast of UPR-200-E-86; however, sampling for ^{99}Tc began at this well in December 2010. In order to evaluate the possibility of a nearby source, it was decided that groundwater well drill cuttings would be retrieved from archive holding and analyzed for evidence of contamination. Unfortunately, no soil samples were taken during the drilling of well 299-E27-23; however, drill cuttings were archived every 1.5 m (5 ft) throughout the vadose zone during the 2003 drilling of nearby adjacent well 299-E27-20 (i.e., 4 m [12 ft] northwest of 299-E27-23). For this reason, it was decided that some of the archived drill cuttings from well 299-E27-20 would be retrieved from storage, transported to a laboratory, and analyzed for evidence of a ^{99}Tc contamination in the vadose zone. Additionally, samples were analyzed for nitrate, moisture and pH. The sampling of soil from this well was documented in the approved Revision 2 of the work plan. Figure 4-21 shows the locations of the groundwater wells, Sites Y and Z, where soil was analyzed for the WMA C Phase 2 field investigation activities.

Figure 4-21. Phase 2 Soil Sampling at Groundwater Wells



5. NATURE AND EXTENT OF CONTAMINATION

The purpose of this section is to describe the nature and extent of contamination for the WMA C vadose zone soil. Over the last 20 years, a number of studies have been conducted that support the WMA C RFI. As described in Section 4, field activities have focused on:

- Analysis of soil samples in areas where contamination was anticipated (Section 5.1)
- Gamma and moisture logging at borings, drywells, and groundwater wells in and around WMA C (Section 5.2)
- Conducting SGE at specific waste release areas and for the overall farm (Section 5.3)

The findings from soil investigation activities are presented in Sections 5.1 through 5.3. A brief summary of groundwater contamination is presented in Section 5.4. Results from biota tissue samples at WMA C are presented in Section 5.5. Section 5.6 provides an evaluation of data from all field activities combined (i.e., analytical data, logging data, and SGE results).

5.1 ANALYTICAL DATA

Vadose zone soils at WMA C have undergone multiple iterations of investigation to determine the type and concentration of chemicals and radionuclides potentially released from WMA C. The following sections present the analytical results from these efforts:

- Section 5.1.1 presents the results of a historical investigation performed at UPR-200-E-82 in the early1970s (ARH-1945, *B Plant Ion Exchange Feed Leak*) to evaluate an unplanned release of liquid waste containing ^{137}Cs.
- Section 5.1.2 presents the results of limited soil characterization performed during the Phase 1 RFI, which included the investigation of releases from Tank C-105, and characterization of soils from borehole C4297, well 299-E27-22, and UPR-82.
- Section 5.1.3 summarizes results of "Near-Term Characterization" soil sampling (also called "Phase 1.5"), which included characterization of soils associated with UPR-200-E-81 and UPR-200-E-86.
- Section 5.1.4 provides the results for vadose zone soils collected from investigation site/groups during the Phase 2 investigation are provided in Section 5.1.4.

Analytical results summarized from pre-RFI, Phase 1, and near-term characterization efforts are focused on the following chemical and radiological key constituents (Sections 5.1.1 through 5.1.3):

- Calcium
- Cesium-137
- Chloride
- Chromium
- Cobalt-60
- Europium-154
- Iodine-129
- Nickel
- Nitrate
- Potassium
- Potassium-40
- Sodium
- Strontium-90
- Sulfate
- Technetium-99
- Thorium-230
- Uranium
- Vanadium

In addition to the analytes above, reporting of Phase 2 analytical data includes results for primary and secondary analytes of interest identified in the Phase 2 DQO. A detailed discussion on data evaluation is provided in Section 5.1.4 and the associated data quality assessment of this data is provided in Appendix M.

5.1.1 Pre-RFI Analytical Data

In 1971, an investigation was made to establish the extent of a pipeline leak that occurred 3.4 m (11 ft) bgs between diversion box 241-C-152 and C Farm. The 1969 unplanned release (UPR-200-E-82) resulted from a gasket rupture in a pipeline that transported high-level liquid waste containing ^{137}Cs to the 221-B Building for waste processing. Cesium-137 analytical results from subsurface soil samples collected during characterization of UPR-200-E-82 were reported in ARH-1945.

The purpose of this section is to provide a summary of the original ^{137}Cs radiological data presented in ARH-1945 as well as a corresponding set of soil concentrations corrected for radioactive decay to the present time and to dates 500 and 1,000 years in the future. The corrected concentrations were prepared by:

- Tabulating the original laboratory-determined ^{137}Cs soil concentrations as reported in ARH-1945 with a decay date of June 30, 1970.

- Calculating soil current and predictive concentrations using rates of radioactive decay for ^{137}Cs. Decayed values of ^{137}Cs were calculated for the following dates: June 30, 2013, January 1, 2513, and January 1, 3013.

Original ^{137}Cs results reported in ARH-1945 for two depth-discrete sampling locations associated with UPR-200-E-82 (drill locations #5 and #11), are presented in Table 5-1. For comparison, the table includes both the original reported concentrations from ARH-1945, dated June 30, 1970, and corresponding results corrected for decay to June 30, 2013, January 1, 2513, and January 1, 3013.

Table 5-1. Summary of Cesium-137 Characterization Data Collected in the Vicinity of UPR-200-E-82 at WMA C

Drill Location Site from ARH-1945	Depth (ft bgs)	^{137}Cs (pCi/g) decayed to 6/30/1970	^{137}Cs (pCi/g) decayed to 06/30/2014	^{137}Cs (pCi/g) decayed to 01/01/2513	^{137}Cs (pCi/g) decayed to 01/01/3013
5	3	2.40	0.87	8.90E-06	8.79E-11
5	4	1.80	0.65	6.70E-06	6.59E-11
5	7	0.04	0.01	1.50E-07	1.46E-12
5	11	470.00	170.46	1.74E-03	1.70E-08
5	12	40.00	14.51	1.48E-04	1.50E-09
5	14	12.70	4.61	4.71E-05	4.65E-10
5	15	16.00	5.80	5.93E-05	5.86E-10
5	16	0.12	0.04	4.40E-07	4.39E-12
11	11	51.50	18.68	1.91E-04	1.90E-09
11	12	550.00	199.47	2.04E-03	2.00E-08
11	13	54.00	19.58	2.00E-04	2.00E-09
11	15	0.10	0.04	3.70E-07	3.66E-12
11	17	49.50	17.95	1.84E-04	1.80E-09

ARH-1945, *B Plant Ion Exchange Feed Leak*

5.1.2 Phase 1 Analytical Data

The Phase 1 Field Investigation was conducted to evaluate a potential leak from Tank C-105 and the pipeline leak to the west of C Farm near diversion box 241-C-152 (UPR-200-E-82). The field investigations conducted during the Phase 1 RFI included analysis of soil samples collected from the following:

- A vertical borehole (C4297) southwest of Tank C-105 through a known contamination area
- Collection of vadose zone characterization data from sediments associated with a pipeline leak within WMA C (UPR-200-E-82 site) using direct-push methods
- Collection of supplemental vadose zone characterization data from the installation of one RCRA groundwater monitoring well (299-E27-22) at the northern edge of C Farm.

At borehole C4297 near Tank C-105, soil samples were collected and analyzed for radionuclide and chemical constituents, and hydrogeologic characteristics. Results are summarized in this section, with additional soils characterization data provided in RPP-35484; DOE/ORP-2008-01;

and PNNL-15503, *Characterization of Vadose Zone Sediments Below the C Tank Farm: C4297 and RCRA Borehole 299-E27-22.*

At UPR-200-E-82, soil samples were taken from different direct pushes at different depths, and similar analyses were conducted. These data are summarized below with more detailed discussions of these data provided in PNNL-15617, *Characterization of Vadose Zone Sediments from C Waste Management Area: Investigation of the C-152 Transfer Line Leak.* Characterization of the UPR-200-E-82 site was selected preferentially over UPR-200-E-86 and UPR-200-E-81 during Phase 1 due to higher reported ^{137}Cs contamination (ARH-1945).

Figure 4-4 presents a map of Phase 1 sampling locations. Key findings are reported in RPP-35484 and are summarized below.

5.1.2.1 Borehole C4297. Borehole C4297 was drilled to investigate tank waste contamination in the vadose zone near drywell 30-05-07, where two high ^{137}Cs zones are located near and just below the bottom of Tank C-105. It is located approximately 9.14 m (30 ft) southwest of Tank C-105 and 6 m (18 ft) to the northwest of drywell 30-05-07.

During the drilling of this borehole, sediment samples were analyzed for moisture content and a screening analysis was performed. A 1:1 water extract of all samples was used for screening analyses. Screening analyses included measurement of nitrate, electrical conductance, total organic carbon/total carbon, GEA, pH, and ^{99}Tc. Based on the screening analysis, selected samples were analyzed for organic, inorganic, and radiological constituents; and physical characteristics.

Because of a lack of measurable contamination (i.e., nitrate and ^{99}Tc) (PNNL-15503), drilling was stopped at approximately 60 m (196 ft) bgs in borehole C4297 within the Hanford formation H2 unit.

Samples were collected at various depths ranging from 0.8 to 60 m (2.5 to 196 ft) bgs and analyzed for water-leachable chemical and radionuclide indicators of tank waste or other tank farm process releases. A summary of findings of the sample analysis is reported by analytical group and constituent below.

- Nitrate was detected in 51 of 72 soil samples from borehole C4297 with concentrations ranging from below detection to 19.5 μg/g (RPP-35484). The greatest number of nitrate detections were reported at depths below 18 m (60 ft) bgs. Only one of the 51 detected concentrations of nitrate (0.52 μg/g) was reported in shallow (≤5 m [15 ft] bgs) soil samples. The maximum nitrate concentration of 19.5 μg/g was reported at a depth of 41.68 m (136.75 ft) bgs. The highest concentrations of nitrate were reported between two depth intervals; between 40.77 and 41.68 m (133.75 and 136.75 ft) bgs, and between 46.2 and 49.15 m (151.6 and 161.25 ft) bgs. Elevated nitrate concentrations in the 40.77 and 41.68 m (133.75 and 136.75 ft) bgs interval were co-located with maximum concentrations of sulfate and calcium.

- Calcium was reported by acid extraction for 39 soil samples at borehole C4297. Calcium was not reported for 33 samples. Calcium concentrations ranged from 2,570 µg/g to a maximum of 10,000 µg/g. The highest concentrations of calcium were reported between 40.5 and 41.5 m (133 and 136 ft) bgs, coincident with higher concentrations of nitrate.

- Chloride was reported by water extract in one shallow sample and 38 deep samples from C4297. The highest concentration of chloride was 9.16 µg/g from a depth of 53.9 m (176.9 ft) bgs (H2). The extent of detection of chloride was 59.51 m (195.25 ft) bgs (H2) with a result of 21.2.

- Potassium was reported by acid extract in three shallow samples and 36 deep samples from C4297. Concentrations ranged from 649 µg/g at 19.1 m (62.5 ft) bgs (H1) to 1,690 µg/g at 40.77 m (133.75 ft) bgs (H2). All results for potassium were below Hanford Site background.

- Sulfate concentrations were reported for 72 soil samples from borehole C4297. The highest concentrations of sulfate (80.9 µg/g to 104 µg/g) were reported at depths ranging from 40.77 to 41.68 m (133.75 and 136.75 ft) bgs, coincident with elevated concentrations of nitrate and calcium.

- Sodium was measured in 39 samples from C4297 at concentrations ranging from 8.26 to 131 µg/g. The maximum concentration of sodium (131 µg/g) was reported at a depth of 13.85 m (45.45 ft) bgs where elevated pH (9.43) was present. The highest concentrations of sodium (ranging from 32.4 to 131 µg/g) were located below the tank, within the soil interval between 12.4 and 19 m (40.8 and 60 ft) bgs.

- Cesium-137 was detected in seven of the 73 soil samples analyzed for radionuclides at C4297. The highest concentrations of ^{137}Cs (ranging from 3 pCi/g to 31.4 pCi/g) were reported in shallow soils (backfill) at depths ranging from 0.8 to 4 m (2.5 to 12 ft) bgs. All results for ^{137}Cs in deep soils (≥ 5 m [15 ft] bgs) were reported as below detection or below the limit of quantitation.

- Cobalt-60 was detected in 22 out of 110 soil samples analyzed at C4297. Cobalt-60 was detected only at depths at or below 11.74 m (38.53 ft) bgs. Concentrations of ^{60}Co ranged from 0.0658 pCi/g and 0.497 pCi/g. The maximum concentration of 0.497 pCi/g was reported at a depth of 15.01 m (49.25 ft) bgs. The highest concentrations of ^{60}Co were coincident with higher or enriched concentrations of ^{238}U and ^{99}Tc (RPP-35484).

- Technetium-99 was reported for 98 of 110 soil samples analyzed for radionuclides at C4297. All detectable results for ^{99}Tc were found at depths below 5 m (17 ft) bgs. Concentrations ranged from -8.48 pCi/g to 8.42 pCi/g, with the maximum concentration occurring at depth of 41.68 m (136.75 ft) bgs. Enriched or elevated concentrations of ^{99}Tc were found namely at depths between 12.4 and 20.9 m (40.8 and 66.2 ft) bgs, and between 40.77 and 49 m (133.75 and 159 ft) bgs. At depths between 12.4 and 20.2 m (40.8 and 66.2 ft) bgs, ^{99}Tc was coincident with elevated concentrations of ^{238}U and ^{60}Co.

Co-occurrence of maximum concentrations of ^{99}Tc and nitrate were observed between 41 and 46 m (135 and 150 ft) bgs.

Chemical analyses of sediments retrieved from borehole C4297 showed several features characteristic of tank waste contamination within the vadose zone. Vertical extent of tank-related contamination at borehole C4297 was captured between 0.8 and 49 m (2.5 and 160 ft) bgs (total borehole depth was 59.9 m [196.5 ft] bgs) during the Phase 1 investigation. Observations noted from the Phase 1 investigation of borehole C4297 (RPP-35484) included the following:

- An elevated pH zone, 8 to 9.3, between 12 and 16 m (40 and 52 ft) bgs.

- Elevated water leachable anion concentrations of nitrate, carbonate, sulfate, chloride, and fluoride occur at discrete depth intervals. Elevated fluoride (1 to 2 μg/g) and carbonate (44 to 158 μg/g) occur just below the backfill from 12 to 16 m (40 to 52 ft) bgs for fluoride and from 12 to 18 m (40 to 60 ft) bgs for carbonate, generally coincident with the high pH zone. Conversely, the highest concentrations of nitrate, sulfate, and chloride are deeper in the vadose zone. Chloride concentrations (3 to 21 μg/g) are highest between 41 and 60 m (135 and 196 ft) bgs, nitrate concentrations (11 and 20 μg/g) are highest between 41 and 59 m (133 and 195 ft) bgs, and sulfate concentrations (52 to 133 μg/g) are highest between 41 and 49 m (133 and 161 ft) bgs.

- Variable water leachable concentrations of cations (sodium, calcium, magnesium, and strontium) occur at discrete depth intervals. Sodium concentrations are elevated (32 to 131 μg/g) between 12 and 18 m (40 and 60 ft) bgs, coincident with the high pH zone. A secondary zone of slightly elevated sodium concentrations (20 to 24 μg/g) occurs in the backfill between 4 and 12 m (12 and 40 ft) bgs. Calcium, magnesium, and strontium are clearly concentrated (25 to 30, 8 to 11, and 0.12 to 0.14 μg/g, respectively) between 41 and 42 m (133 and 137 ft) bgs. Conversely, these cations are depleted (< 2, < 0.5, and < 0.004 μg/g, respectively) in the high sodium concentration zone between 12 and 18 m (40 and 60 ft) bgs.

- Water leachable concentrations of trace constituents (^{99}Tc, uranium, and molybdenum) are present at distinguishable concentrations with depth. Technetium-99 is present between 12 and 49 m (40 and 159 ft) bgs, and concentrations are bimodal with depth. Highest concentrations (0.4 to 8.4 pCi/g) occur from 41 to 47 m (133 to 154 ft) bgs, with less elevated concentrations (0.14 to 2.6 pCi/g) between 12 and 20 m (40 and 66 ft) bgs. Elevated uranium concentrations (0.007 to 0.01 μg/g) occur between 12 and 18 m (40 and 60 ft) bgs, coincident with the high pH zone. Molybdenum is elevated (0.01 to 0.1 μg/g) between 17 and 20 m (55 and 65 ft) bgs.

- GEA for gamma-emitting radionuclides indicated ^{137}Cs activity (between 3 and 32 pCi/g) near the surface (0.6 to 4 m [2 to 12 ft] bgs) and ^{60}Co (between 0.1 and 0.5 pCi/g) at greater depth (13 to 20 m [41 to 66 ft] bgs).

5.1.2.2 UPR-200-E-82. UPR-200-E-82 was an unplanned release of high-level liquid waste near diversion box 241-C-152 that occurred in 1969. Key constituents of the liquid waste include ^{137}Cs, uranium, and ^{99}Tc. Initial characterization of the unplanned release was performed in 1971 and is reported in ARH-1945.

Twenty vertical and six slanted direct-push boreholes were sampled and logged near diversion box 241-C-152. The vertical boreholes were strategically placed around the documented leak location and the slanted boreholes were emplaced to sample beneath the projected site of the pipeline leak. Sediment analytical results for UPR-200-E-82 are below.

Analytical Results

Sediment samples from UPR-200-E-82 were collected from boreholes C4404, C4406, C4408, C4410, C4412, C4414, C4416, C4418, C4420, C4422, C4426, C4428, C4430, C4432, C4434, C4436, C4438, C4440, C4445, C4448, C5104, C5105, C5106, C5107, C5108, and C5109 at depths ranging from 1.7 to 7.9 m (5.5 to 25.8 ft) bgs. Sediment samples were analyzed for primary and secondary contaminants, including: inorganic analytes, general chemistry parameters, radionuclides, and organic constituents (i.e. pesticides, PCBs, SVOCs).

Analytical results for UPR-200-E-82 are reported in RPP-35484 and summarized as follows:

- Calcium was detected above background in four samples at shallow (≤ 5 m [15 ft] bgs) depths and one sample at deep (>5 m [15 ft] bgs) depths. The maximum shallow reported concentration was 27,000,000 µg/kg at a depth of 2.2 m (7.1 ft) bgs from borehole C4440. The maximum deep reported concentration was 20,900,000 µg/kg at a depth of 7.1 m (23.4 ft) bgs from borehole C4410, which is also the maximum depth of detection above background.

- Chloride was detected in 30 shallow soil samples and 43 deep soil samples from UPR-200-E-82. Concentrations ranged from 258 µg/kg at a depth of 5.3 m (17.4 ft) bgs from C4448 to 13,600 µg/kg at a depth 17.5 m (57.4 ft) bgs from borehole C5108. The maximum depth of detection was 24 m (79 ft) bgs from borehole C5106, with a concentration of 2,780 µg/kg.

- Potassium was detected in 26 shallow soil samples and 22 deep soil samples from UPR-200-E-82. Concentrations ranged from 718,000 µg/kg at a depth of 3.2 m (10.6 ft) bgs from borehole C4408 to 3,050,000 µg/kg at a depth of 2.2 m (7.1 ft) bgs from borehole C4440. The maximum depth of detection was 7.6 m (24.8 ft) bgs from borehole C4414 with a concentration of 1,480,000 µg/kg. Only two results exceeded Hanford Site background of 2,150,000 µg/kg: 3,050,000 at 2.2 m (7.1 ft) bgs from borehole C4440 and 2,190,000 µg/kg at 2.17 m (7.13 ft) from borehole C4445.

- Nitrate was not detected above background, but was detected below background in 106 samples at shallow (≤5 m [15 ft] bgs) depths and in 66 samples at deep (>5 m [15 ft] bgs) depths. The maximum shallow reported concentration was 29,300 µg/kg at a depth of 2 m (6.5 ft) bgs from borehole C4445. The maximum deep reported concentration was

12,800 μg/kg at a depth of 7.5 m (24.5 ft) bgs from borehole C4410. The maximum depth of detection is 7,370 μg/kg at 7.9 m (25.8 ft) bgs in borehole C5108.

- Sodium was detected above background in 20 samples at shallow (≤ 5 m [15 ft] bgs) depths, and in four samples at deep (>5 m [15 ft] bgs) depths. Sodium was also detected below background in 86 samples at shallow (≤5 m [15 ft] bgs) depths and in 61 samples at deep (>5 m [15 ft] bgs) depths. The maximum shallow reported concentration was 1,100,000 μg/kg at a depth of 2.1 m (6.9 ft) bgs from borehole C5105. The maximum deep reported concentration was 1,050,000 μg/kg at a depth of 7.5 m (24.5 ft) bgs from borehole C4410. The maximum depth of detection is 753,000 μg/kg at 7.9 m (25.8 ft) bgs in C5108.

- Cesium-137 was detected in one sample below background, out of 44 samples taken, at a concentration of 0.21 pCi/g at 7.1 m (23.4 ft) bgs from C4410. The lack of detection of ^{137}Cs in significant concentrations indicates that the ^{137}Cs was constrained laterally and at very shallow depths.

- Potassium-40 was detected in 53 samples at shallow (≤5 m [15 ft] bgs) depths and in 32 samples at deep (>5 m [15 ft] bgs) depths. The maximum shallow reported concentration was 19.6 pCi/g at a depth of 1.9 m (5.5 ft) bgs from borehole C4426. The maximum deep reported concentration was 22.1 pCi/g at a depth of 6.1 m (20 ft) bgs from borehole C4430. The maximum depth of detection is 16.94 pCi/g at 7.9 m (25.8 ft) bgs in borehole C5108.

- Technetium-99 was detected in 71 samples at shallow (≤5 m [15 ft] bgs) depths and in 43 samples at deep (>5 m [15 ft] bgs) depths. There is not a background value in which to compare the results. The maximum shallow reported concentration was 60.6 pCi/g at a depth of 2.9 m (9.7 ft) bgs from borehole C5104. The maximum deep reported concentration was 40.3 pCi/g at a depth of 5.3 m (17.5 ft) bgs from borehole C5106. The maximum depth of detection is 15.8 pCi/g at 7.9 m (25.8 ft) bgs in borehole C5108.

Key observations and conclusions reported in the Phase 1 investigation of UPR-200-E-82 (RPP-35484) include the following:

- Vertical borehole data showed two distinct near-surface areas (3 to 6 m [10 to 20 ft] bgs to the southwest and northeast of UPR-200-E-82) contaminated by ^{99}Tc (up to 3.3 pCi/g dry sediment) and Hanford Site processed uranium (up to 770 μg/kg dry sediment).

- Slant borehole data showed maximum ^{99}Tc concentrations at the deepest sampling location, approximately 24 m (80 ft) bgs, beneath the estimated leak location. These data suggest that the leak fluids and mobile contaminants have penetrated at least 24 m (80 ft) bgs and could be present at greater depths.

- Determination of the lateral extent was less certain, as multiple losses of waste fluids from separate pipeline leak events could have contributed to the contaminants identified in the sediments sampled.

More detailed discussions of these results are found in PNNL-15617 and RPP-35484.

5.1.2.3 Well 299-E27-22. During the Phase 1 investigation, a groundwater monitoring well was placed north of WMA C, to support the RCRA compliance monitoring network for the WMA. During drilling, well 299-E27-22 was sampled as a potential background well, to further characterize the nature of vadose zone soils thought to have not been subjected to tank leaks or crib/trench discharges (Section 3.1.2 of RPP-35484). The samples were analyzed for soil chemistry and physical attributes. Groundwater monitoring well 299-E27-22 remains in place as part of the compliance groundwater monitoring network.

Analytical results of well monitoring are reported in PNNL-15503, Rev. 1. Results from acid-extraction analysis of soils collected at 299-E27-22 (borehole C4124) during the Phase 1 characterization are summarized below. Sampling depths for 299-E27-22 ranged from 9 m (28 ft) bgs (H1) to 68.7 m (225.5 ft) bgs (H2). No samples were collected in shallow zone soils (i.e., ≤5 m [15 ft] bgs).

- Calcium was reported by acid-extraction for 20 borehole samples from well 299-E27-22 (C4124). Calcium, which was detected at all depths, ranged in concentration from 5.5E+03 μg/g to 1.1E+04 μg/g in soils. The maximum result for calcium was 1.1E+04 μg/g at a depth of 15 m (48 ft) bgs (H1).

- Chloride was reported by water extraction for 20 borehole samples from well 299-E27-22. Chloride was detected at all depths, ranging in concentration from 0.48 μg/g at 8.5 to 9.1 m (28 to 29.8 ft) bgs and at 15 m (48 ft) bgs (H1). All results for chloride were below the Hanford Site background value at C4124.

- Potassium was reported by acid extraction for 20 borehole samples from well 299-E27-22. Chloride was detected at all depths, ranging in concentration from 650 μg/g at 9 m (28 ft) bgs (H1) to 2,100 μg/g at 15 m (48 ft) bgs. All results for potassium were below Hanford Site background.

- Nitrate was detected in 17 of 20 sediment samples measured by water-extract. Detected concentrations of nitrate ranged from 1.92 μg/g to 19.9 μg/g, with the maximum result occurring a depth of 15 m (48 ft) bgs (H1).

- Sodium was reported by water-extraction method in 20 samples from well 299-E27-22. Sodium, which was detected in all samples, ranged in concentration from 10 μg/g to 28 μg/g, with the maximum concentration of 28 μg/g sodium occurring at a depth of 15 m (48 ft) bgs (H1).

- Sulfate was detected in all 20 sediment samples analyzed by water-extract. Sulfate concentrations ranged from 20.5 μg/g to 191 μg/g, with the maximum concentration occurring at a depth of 15 m (48 ft) bgs (H1).

- Chromium was detected in 20 samples using ICP acid-extract analysis. Concentrations of chromium ranged from 6.0 to 18 µg/g. The maximum concentration of chromium (18 µg/g) was reported at a depth of 15 m (48 ft) bgs.

- Technetium-99 was analyzed by acid-extraction in 20 samples at well 299-E27-22. All results were below the level of quantitation.

As summarized in RPP-35484, the sediment sample analyses from well 299-E27-22 suggest a non-radiological waste stream has contacted the sediment. The Phase 1 Investigation Report (RPP-35484) concluded that:

- No radionuclides were found in the vadose zone at well 299-E27-22.

- Technetium-99 was found in the groundwater at levels below 100 pCi/L.

- Given the contamination of sediments at the well 299-E27-22 location by a nitrate- and sodium-rich fluid, the use of their porewater chemistry as a comparison for contaminated sediments within WMA C is invalidated.

5.1.3 Near-Term Characterization (Phase 1.5) Analytical Data

Field work was conducted to investigate the waste releases due to pipeline breaks at UPR-200-E-86 and UPR-200-E-81. Vadose zone soil samples were collected from direct push boreholes in the two UPRs. The soil samples were submitted to PNNL for analysis. Soil samples were analyzed for metals, anions, and radionuclides. The analytical results are reported in PNNL-SA-60937, *Geochemical Study of Grab Samples Collected from UPR-200-E-86 Investigative Site*, and PNNL-SA-61511, *Geochemical Characterization of Sediments from UPR 200-E-81*. Near-term characterization sample collection and analytical results are summarized below.

5.1.3.1 UPR-200-E-86. Initially, nine exploratory boreholes were pushed and logged with neutron moisture and gross gamma tools. Following analysis of the logging results, three locations were selected for sampling. During the placement of the first borehole (C5952), it deviated from vertical and encountered exploratory borehole C5951, which had been used for geophysical logging, at 13 m (44 ft). A second sampling borehole (C5952A) was then pushed adjacent to the original site. Two additional boreholes (C5958 and C5960) were sampled in UPR-86.

Forty-five depth discrete intervals were sampled from the three completed boreholes and the top two sampling intervals of the deviated hole (C5952). The maximum depth of sampling was 43 m (142 ft) bgs in C5952A.

- Calcium was analyzed by acid extract in 88 samples (12 shallow and 76 deep) at depths ranging from 3 to 43.05 m (10 to 141.25 ft) bgs at UPR-86. Calcium concentrations ranged from 2.25 µg/g to 11,800 µg/g across shallow locations, and 9.22 µg/g to 10,400 µg/g across deep sampling locations. The maximum concentration of 11,800 µg/g was reported at a depth of 3.43 m (11.25 ft) bgs from borehole C5958.

- Chromium was analyzed by acid extract in 44 (6 shallow, 38 deep) samples from UPR-86. Shallow concentrations ranged from 2.23 µg/g to 6.29 µg/g. Deep soil concentrations ranged from 4.59 to 19.5 µg/g. The maximum concentration of 19.5 µg/g was reported at a depth of 41.3 m (135.5 ft) bgs from borehole C5958.

- Nickel was detected by acid extract in 43 samples (6 shallow, 37 deep) from UPR-86. Shallow concentrations ranged from 5.45 µg/g to 9.47 µg/g. Deep soil concentrations ranged from 6.79 µg/g to 20.1 µg/g. The maximum concentration of 20.1 µg/g was reported at a depth of 16.69 m (54.75 ft) bgs from borehole C5958.

- Nitrate was detected in 43 samples (6 shallow, 37 deep) from UPR-86. Shallow concentrations ranged from 1.95 µg/g to 9.55 µg/g. Deep concentrations ranged from 3.89 µg/g to 21.4 µg/g. The maximum concentration of 21.4 µg/g was reported at a depth of 5.72 m (18.75 ft) bgs at borehole C5960.

- Sodium was analyzed using ASTM method 6010 inductively coupled plasma acid extract for 44 samples at UPR-86. Results for sodium were reported as below detection for all samples.

- Sulfate was detected in 44 samples (6 shallow, 37 deep) from UPR-86. Shallow concentrations ranged from 14.3 µg/g to 37.1 µg/g. Deep concentrations ranged from to 31.9 µg/g to 195 µg/g. The maximum sulfate concentration of 195 µg/g was reported at a depth of 5.72 m (18.75 ft) bgs at borehole C5960.

- Vanadium was detected in 44 samples (6 shallow, 38 deep) from UPR-86. Concentrations ranged from 20.6 µg/g to 26.1 µg/g in shallow soils (≤ 5 m [15 ft] bgs) and 10.6 µg/g to 21 µg/g in deep soils. The maximum concentration of 26.1 µg/g was reported at a depth of 3.58 m (11.75 ft) bgs at borehole C5958.

- Potassium-40 was detected in 44 of 45 samples from UPR-86. Concentrations of the seven shallow samples ranged from 12.8 pCi/g to 21 pCi/g. Concentrations in deep soils ranged from 15 pCi/g to 23.4 pCi/g. The maximum concentration of 23.4 pCi/g was reported at a depth of 34.98 m (114.75 ft) bgs (deep) from borehole C5958.

Cesium-137, ^{60}Co, ^{154}Eu, ^{99}Tc, and ^{230}Th were reported as below detection for all samples from UPR-86.

5.1.3.2 UPR-200-E-81. Initially, five exploratory boreholes were pushed and logged with neutron moisture and gross gamma tools at UPR-200-E-81 (UPR-81). Following analysis of the logging results, one location was selected for soil sampling. Borehole C6394 was pushed for sampling (Figure 4-6).

Eleven depth discrete intervals were sampled from the borehole. The maximum depth of sampling was 52 m (172 ft) bgs. Samples from two of the sample depths (11 and 52 m [37 and 169 ft] bgs) were archived and analyzed as part of the Phase 2 investigation (Section 5.1.4).

Soil samples were measured for anions, metals, and radionuclides. Sampling results for UPR-81 are reported in PNNL-15503, Rev.1. Results from UPR-81 are summarized below.

- Chloride was reported in one shallow soil sample and 22 deep soil samples from borehole C6394. The single shallow sample and three deep samples were reported as below the quantitation limit. Detected concentrations ranged from 0.73 µg/g at 8 m (27 ft) bgs to 72.1 µg/g at 41 m (134 ft) bgs. All results were below the Hanford Site background value of 300,000 µg/g.

- Nitrate was detected in two shallow and 19 deep samples ranging in concentration from 1.54 µg/g at 23 m (76 ft) bgs to199 µg/g at 13 m (43 ft) bgs. Three results, including the maximum result, all reported at 13 m (43 ft) bgs, exceeded the Hanford Site background value for nitrate (52 µg/g). Results at all other depths were below background.

- Sulfate was detected in two shallow samples and in 21 deep samples from borehole C6394 during the near-term characterization. Concentrations ranged from 4.74 µg/g at 3 m (10 ft) bgs to 159 µg/g at 41 m (134 ft) bgs. All results were below Hanford Site background for sulfate.

- Sodium was detected in six deep samples (out of 23 total samples) from borehole C6394. Detected concentrations ranged from 1,770 µg/g at 8 m (27 ft) bgs to 2,090 µg/g at 13 m (43 ft) bgs. The maximum concentration (2,090 µg/g) was reported at a depth of 13 m (43 ft) bgs. All six detected results were above the Hanford Site background value of 237 µg/g for sodium.

- Potassium was detected in one shallow sample and 22 deep samples at borehole C6394. Concentrations ranged from 809 µg/g at 29 m (96 ft) bgs to 1,340 µg/g at 13 m (43 ft) bgs. All results from borehole C6394 were below the Hanford Site background value for potassium.

- Nickel was detected in one shallow soil sample and 19 deep soil samples from borehole C6394. Detected concentrations ranged from 7.31 µg/g at 3 m (10 ft) bgs to 15.9 µg/g at 23 m (76 ft) bgs. All results were above the Hanford Site background value of 3 µg/g for nickel.

- Chromium was detected in two shallow soil samples and 21 deep soil samples analyzed by acid extract at borehole C6394. Concentrations ranged from 3.59 µg/g at 8 m (27 ft) bgs to 24 µg/g at 23 m (76 ft) bgs. Only the maximum concentration (24 µg/g) exceeded the Hanford Site background value for chromium (18.5 µg/g).

- Technetium-99 was measured by ICP-MS water extract. Technetium-99 was detected in only two of 23 samples, both at a depth of 13 m (43 ft) bgs. Results were 3.26E-05 µg/g and 4.93E-05 µg/g, respectively.

- Cesium-137 was detected in one out of 23 samples from borehole C6394 at a concentration of 85 pCi/g with a depth of 3 m (10 ft) bgs (shallow).

- Cobalt-60 was detected in one of 23 samples from borehole C6394 at a depth of 13 m (43 ft) bgs and a concentration of 1.72 pCi/g. This result was above the Hanford Site background value for ^{60}Co (0.0084 pCi/g).

5.1.4 Phase 2 Analytical Data

Analytical data evaluated in this section consists of soil data collected to support the Phase 2 effort as prescribed by the DQO and work plan (RPP-RPT-38152 and RPP-PLAN-39114). Based on review of PCB congener analytical results, plans for Phase 2 sampling and analysis of PCBs were reevaluated and a recommendation was made to eliminate analysis of PCB congeners in further WMA C sampling activities, but continue to perform analyses of PCB Aroclors (letter 11-TPD-020, "Organic Analyses Optimization for Waste Management Area [WMA] C"). This recommendation was approved by Ecology (letter 11-NWP-053, "Re: Organic Analyses Optimization for Waste Management Area [WMA] C") and recommended changes for elimination of PCB congener analyses were incorporated in the work plan (RPP-PLAN-39114) and the SAP (RPP-PLAN-38777). Results for soil samples analyzed for PCB congeners are addressed separately in RPP-RPT-58056, *Summary of Polychlorinated Biphenyls (PCBs) Results from Analysis of Soil Samples Collected Within WMA* C. Results for PCB Aroclors are included in the Phase 2 investigation, as detailed below.

Phase 2 analytical data include soil results for 166 primary and 64 secondary constituents.

Summary of data collected:

- 465 vadose zone soil samples were collected from 21 locations consisting of ten Site/Investigation Groups and two wells within WMA C during the Phase 2 investigation.

- A total of 24,228 results were reported for the 230 primary and secondary constituents.

- 869 results were omitted from the nature and extent analysis and discussion due to result rejection by laboratory or validation qualification, sample analysis by water extraction method, duplicate analyte reporting by a preferable method, or reporting of the same analyte with a preferred (lower) detection limit.

The evaluation of Phase 2 analytical data is presented below by comparing soil concentrations of primary and secondary constituents to Hanford Site soil background values (Table 5-2). Analytes which have no Hanford Site background value are addressed in terms of the maximum detected quantity and the maximum depth of detection.

Primary and secondary constituents that were never detected, or were detected at concentrations below background are listed in Table 5-3. These constituents are dismissed from further discussion and interpretation. Hanford Site background values were available for 41 primary constituents and four secondary constituents. For constituents with Hanford Site background values, the following activities were performed:

- Denoted primary and secondary constituents never detected during Phase 2 soil investigation (Table 5-3)

- Compared soil results to Hanford Site background values for inorganic (including general chemistry parameters) and radionuclide constituents

- Characterized occurrence of results exceeding background by location and analytical class.

Soil background comparisons were performed for 24 primary and two secondary inorganic constituents, including metals and general chemistry parameters. All reported results (i.e., both detected and non-detect results) were screened against Hanford Site background values for inorganic constituents to determine extent of contamination and to characterize uncertainty associated with elevated detection limits. Note that detection limits were established during the DQO process and it was understood that based on the limited soil collected through the direct push process that some detection limits would be above site soil background levels. Table 5-4 identifies those constituents in which detection limits were established above site background levels.

Aluminum, cobalt, iron, lithium, manganese and potassium were not detected above background in any Phase 2 soil samples, therefore these analytes are omitted from further discussion of contaminant nature and extent. Two primary inorganic constituents, cyanide and uranium, were never detected in Phase 2 investigation soil samples.

Soil background comparisons were performed for 11 primary and two secondary radionuclides. All reported results (i.e., both detected and non-detect results) were screened against Hanford Site background values for radionuclides to determine extent of contamination and to characterize uncertainty associated with elevated detection limits. Several radionuclides demonstrated elevated detection limits relative to Hanford Site background values. These results are retained as uncertainties for WMA C soils.

Table 5-2. Hanford Site Soil Background Values

Analyte Name	Analyte Class	Units	Lognormal 90th Percentile Background Value	Maximum Background Value	Source of Background Value
Cesium-137	RAD	pCi/g	1.1	1.6	DOE/RL-96-12, Rev.0
Cobalt-60	RAD	pCi/g	0.0084	0.039	DOE/RL-96-12, Rev.0
Europium-154	RAD	pCi/g	0.033	0.079	DOE/RL-96-12, Rev.0
Europium-155	RAD	pCi/g	0.054	0.10	DOE/RL-96-12, Rev.0
Gross Beta	RAD	pCi/g	23	25	DOE/RL-96-12, Rev.0
Plutonium-238	RAD	pCi/g	0.0038	0.019	DOE/RL-96-12, Rev.0
Plutonium-239/240	RAD	pCi/g	0.025	0.033	DOE/RL-96-12, Rev.0

Table 5-2. Hanford Site Soil Background Values

Analyte Name	Analyte Class	Units	Lognormal 90th Percentile Background Value	Maximum Background Value	Source of Background Value
Potassium-40	RAD	pCi/g	17	20	DOE/RL-96-12, Rev.0
Radium-226	RAD	pCi/g	0.82	1.2	DOE/RL-96-12, Rev.0
Strontium-90	RAD	pCi/g	0.18	0.37	DOE/RL-96-12, Rev.0
Thorium-232	RAD	pCi/g	1.3	1.6	DOE/RL-96-12, Rev.0
Total beta radiostrontium	RAD	pCi/g	0.18	0.37	DOE/RL-96-12, Rev.0
Uranium-233/234	RAD	pCi/g	1.1	1.5	DOE/RL-96-12, Rev.0
Uranium-234	RAD	pCi/g	1.1	1.5	DOE/RL-96-12, Rev.0
Uranium-235	RAD	pCi/g	0.11	0.39	DOE/RL-96-12, Rev.0
Uranium-238	RAD	pCi/g	1.1	1.2	DOE/RL-96-12, Rev.0
Aluminum	Metal	µg/kg	1.18E+07	28,800,000	DOE/RL-92-24, V.1, Rev.4
Antimony	Metal	µg/kg	130	385	ECF-HANFORD-11-0038
Arsenic	Metal	µg/kg	6,470	27,700	DOE/RL-92-24, V.1, Rev.4
Barium	Metal	µg/kg	132,000	480,000	DOE/RL-92-24, V.1, Rev.4
Beryllium	Metal	µg/kg	1,510	10,000	DOE/RL-92-24, V.1, Rev.4
Cadmium	Metal	µg/kg	563	2,900	ECF-HANFORD-11-0038
Calcium	Metal	µg/kg	1.72E+07	105,000,000	DOE/RL-92-24, V.1, Rev.4
Chromium	Metal	µg/kg	18,500	320,000	DOE/RL-92-24, V.1, Rev.4
Cobalt	Metal	µg/kg	15,700	110,000	DOE/RL-92-24, V.1, Rev.4
Copper	Metal	µg/kg	22,000	61,000	DOE/RL-92-24, V.1, Rev.4
Iron	Metal	µg/kg	3.26E+07	68,100,000	DOE/RL-92-24, V.1, Rev.4
Lead	Metal	µg/kg	10,200	74,100	DOE/RL-92-24, V.1, Rev.4
Lithium	Metal	µg/kg	13,300	19,200	ECF-HANFORD-11-0038
Magnesium	Metal	µg/kg	7.06E+06	32,300,000	DOE/RL-92-24, V.1, Rev.4

Table 5-2. Hanford Site Soil Background Values

Analyte Name	Analyte Class	Units	Lognormal 90th Percentile Background Value	Maximum Background Value	Source of Background Value
Manganese	Metal	µg/kg	512,000	1,110,000	DOE/RL-92-24, V.1, Rev.4
Mercury	Metal	µg/kg	13	29	ECF-HANFORD-11-0038
Molybdenum	Metal	µg/kg	470	3,170	ECF-HANFORD-11-0038
Nickel	Metal	µg/kg	19,100	200,000	ECF-HANFORD-11-0038
Potassium	Metal	µg/kg	2.15E+06	7,900,000	ECF-HANFORD-11-0038
Silver	Metal	µg/kg	167	273	ECF-HANFORD-11-0038
Sodium	Metal	µg/kg	690,000	6,060,000	DOE/RL-92-24, V.1, Rev.4
Uranium	Metal	µg/kg	3,210	4,042	Isotopic Activity Conversion based on DOE/RL-96-12 values
Vanadium	Metal	µg/kg	85,100	140,000	DOE/RL-92-24, V.1, Rev.4
Zinc	Metal	µg/kg	67,800	366,000	DOE/RL-92-24, V.1, Rev.4
Ammonia	Metal	µg/kg	9,230	26,400	DOE/RL-92-24, V.1, Rev.4
Chloride	Metal	µg/kg	100,000	1,480,000	DOE/RL-92-24, V.1, Rev.4
Fluoride	Metal	µg/kg	2,810	73,300	DOE/RL-92-24, V.1, Rev.4
Nitrate	Metal	µg/kg	52,000	906,000	DOE/RL-92-24, V.1, Rev.4
Phosphate	Metal	µg/kg	785	225,000	DOE/RL-92-24, V.1, Rev.4
Sulfate	Metal	µg/kg	237,000	12,600,000	DOE/RL-92-24, V.1, Rev.4
Boron	Metal	µg/kg	3,890	5,860	ECF-HANFORD-11-0038
Selenium	Metal	µg/kg	780	840	Ecology 94-115
Thallium	Metal	µg/kg	185	523	ECF-HANFORD-11-0038

Table 5-2. Hanford Site Soil Background Values

Analyte Name	Analyte Class	Units	Lognormal 90th Percentile Background Value	Maximum Background Value	Source of Background Value

DOE/RL-92-24, Volume 1, Rev. 4, *Hanford Site Background: Part 1, Soil Background for Nonradioactive Analyte.*
DOE/RL-96-12, Rev. 0, *Hanford Site Background: Part 2, Soil Background for Radionuclides.*
Ecology 94-115, *Natural Background Soil Metals Concentrations in Washington State.*
ECF-HANFORD-11-0038, *Soil Background Data for Interim Use at the Hanford Site*

Table 5-3. List of Primary and Secondary Analytes Not Detected in Phase 2 Vadose Zone Soils

Class	Constituent	CAS Number	SAP Rev. 3 Status
Primary Analytes Never Detected			
Inorganics	Uranium	7440-61-1	Primary
	Cyanide	57-12-5	Primary
PEST/PCB	4,4'-DDD (Dichlorodiphenyldichloroethane)	72-54-8	Primary
	4,4'-DDE (Dichlorodiphenyldichloroethylene)	72-55-9	Primary
	4,4'-DDT (Dichlorodiphenyltrichloroethane)	50-29-3	Primary
	Aroclor-1016	12674-11-2	Primary
	Aroclor-1221	11104-28-2	Primary
	Aroclor-1232	11141-16-5	Primary
	Aroclor-1242	53469-21-9	Primary
	Aroclor-1248	12672-29-6	Primary
	Chlordane	57-74-9	Primary
	Dieldrin	60-57-1	Primary
	Endrin	72-20-8	Primary
	Heptachlor	76-44-8	Primary
	Heptachlor epoxide	1024-57-3	Primary
	Hexachlorobenzene	118-74-1	Primary
RAD	Curium-242	15510-73-3	Primary
	Curium-243/244	CM-243/244	Primary
	Europium-152	14683-23-9	Primary
	Thorium-228	14274-82-9	Primary
	Actinium-228	14331-83-0	Secondary
	Bismuth-212	14913-49-6	Secondary
	Bismuth-214	14733-03-0	Secondary
	Lead-212	15092-94-1	Secondary

Table 5-3. List of Primary and Secondary Analytes Not Detected in Phase 2 Vadose Zone Soils

Class	Constituent	CAS Number	SAP Rev. 3 Status
	Lead-214	15067-28-4	Secondary
	Manganese-54	13966-31-9	Secondary
	Potassium-40	13966-00-2	Secondary
	Radium-226	13982-63-3	Secondary
	Radium-228	15262-20-1	Secondary
	Thallium-208	14913-50-9	Secondary
	Zinc-65	13982-39-3	Secondary
SVOA	1,2,4-Trichlorobenzene	120-82-1	Primary
	1,2-Dichlorobenzene	95-50-1	Primary
	2,4,5-Trichlorophenol	95-95-4	Primary
	2,4,6-Trichlorophenol	88-06-2	Primary
	2,4-Dinitrotoluene	121-14-2	Primary
	2,6-bis(1,1-dimethylethyl)-4-methyl phenol	128-37-0	Primary
	2-Chlorophenol	95-57-8	Primary
	2-Methylphenol (cresol, o-)	95-48-7	Primary
	2-Nitrophenol	88-75-5	Primary
	3+4 Methylphenol (cresol, m+p)	65794-96-9	Primary
	4-Chloro-3-methylphenol	59-50-7	Primary
	Acenaphthene	83-32-9	Primary
	Benzo(a)anthracene	56-55-3	Primary
	Benzo(a)pyrene	50-32-8	Primary
	Benzo(b)fluoranthene	205-99-2	Primary
	Benzo(k)fluoranthene	207-08-9	Primary
	Cellosolve Solvent	110-80-5	Primary
	Chrysene	218-01-9	Primary
	Cyclohexanone	108-94-1	Primary
	Dibenz[a,h]anthracene	53-70-3	Primary
	Fluoranthene	206-44-0	Primary
	Hexachlorobutadiene	87-68-3	Primary
	Hexachloroethane	67-72-1	Primary
	Indeno(1,2,3-cd)pyrene	193-39-5	Primary
	Naphthalene	91-20-3	Primary

Table 5-3. List of Primary and Secondary Analytes Not Detected in Phase 2 Vadose Zone Soils

Class	Constituent	CAS Number	SAP Rev. 3 Status
	Nitrobenzene	98-95-3	Primary
	n-Nitrosodi-n-dipropylamine	621-64-7	Primary
	n-Nitrosomorpholine	59-89-2	Primary
	Pyrene	129-00-0	Primary
	Pyridine	110-86-1	Primary
	Total cresols	1319-77-3	Primary
	Tributyl phosphate	126-73-8	Primary
Secondary Analytes Never Detected			
Pest/PCB	Alpha-BHC	319-84-6	Secondary
	Toxaphene	8001-35-2	Secondary
	1,3-Dichlorobenzene	541-73-1	Secondary
	1,4-Dichlorobenzene	106-46-7	Secondary
	Pentachlorophenol	87-86-5	Secondary
	Phenol	108-95-2	Secondary
	1,1,1-Trichloroethane	71-55-6	*Dismissed*[a]
	1,1,2,2-Tetrachloroethane	79-34-5	*Dismissed*[a]
	1,1,2-Trichloro-1,2,2-trifluoroethane	76-13-1	*Dismissed*[a]
	1,1,2-Trichloroethane	79-00-5	*Dismissed*[a]
	1,2-Dichloroethane	107-06-2	*Dismissed*[a]
	2-Nitropropane	79-46-9	*Dismissed*[a]
	Carbon tetrachloride	56-23-5	*Dismissed*[a]
	Chlorobenzene	108-90-7	*Dismissed*[a]
	Chloroform	67-66-3	*Dismissed*[a]
	cis-1,2-Dichloroethylene	156-59-2	*Dismissed*[a]
	Diethyl ether	60-29-7	*Dismissed*[a]
	Dibutylphosphate	107-66-4	*Dismissed*[a]
	Ethyl acetate	141-78-6	*Dismissed*[a]
	Ethylbenzene	100-41-4	*Dismissed*[a]
	Isobutyl alcohol	78-83-1	*Dismissed*[a]
	Monobutyl phosphate	1623-15-0	*Dismissed*[a]
	Tetrachloroethene	127-18-4	*Dismissed*[a]
	trans-1,2-Dichloroethylene	156-60-5	*Dismissed*[a]

Table 5-3. List of Primary and Secondary Analytes Not Detected in Phase 2 Vadose Zone Soils

Class	Constituent	CAS Number	SAP Rev. 3 Status
	trans-1,3-Dichloropropene	10061-02-6	*Dismissed*[a]
	Trichloroethene	79-01-6	*Dismissed*[a]
	Vinyl chloride	75-01-4	*Dismissed*[a]
Rads	Barium-133	13981-41-4	Secondary
	Beryllium-7	13966-02-4	Secondary
	Cadmium-109	14109-32-1	Secondary
	Cerium/Praseodymium-144	CE/PR-144	Secondary
	Cerium-144	14762-78-8	Secondary
	Cesium-134	13967-70-9	Secondary
	Chromium-51	14392-02-0	Secondary
	Cobalt-57	13981-50-5	Secondary
	Iodine-131	10043-66-0	Secondary
	Iron-59	14596-12-4	Secondary
	Niobium-94	14681-63-1	Secondary
	Plutonium-239	15117-48-3	Secondary
	Radium-224	13233-32-4	Secondary
	Ruthenium-103	13968-53-1	Secondary
	Ruthenium-106	13967-48-1	Secondary
	Silver-108 metastable	14391-65-2	Secondary
	Sodium-22	13966-32-0	Secondary
	Tin-113	13966-06-8	Secondary
	Zirconium/Niobium-95	ZR/NB-95	Secondary

[a]Confirmed as removed from target analyte list through Letter 11-NWP-053, "RE: Organic Analyses Optimization for Waste Management Area (WMA) C" for samples collected and analyzed under Revision 2A of the SAP.
SVOA = semi-volatile organic analysis

Table 5-4. Constituents With Detection Limits Established Above Site Soil Background Levels

Analyte	Chemical Abstract Service ID	Hanford Site Background Value	Required Detection Limit	Target Detection Limit	Reporting Units
SAP Detection Limit Greater than Hanford Soil Background					
Antimony	7440-36-0	130	500	600	ug/kg

Table 5-4. Constituents With Detection Limits Established Above Site Soil Background Levels

Analyte	Chemical Abstract Service ID	Hanford Site Background Value	Required Detection Limit	Target Detection Limit	Reporting Units
Boron	7440-42-8	3,890	6,000		ug/kg
Molybdenum	7439-98-7	470	4,000	19,000	ug/kg
Silver	7440-22-4	167	200	2,000	ug/kg
Fluoride	16984-48-8	2,810	5,000	20,000	ug/kg
Cobalt-60	10198-40-0	0.01	0.05		pCi/g
Europium-154	15585-10-1	0.03	0.1		pCi/g
Europium-155	14391-16-3	0.05	0.1		pCi/g
Plutonium-239/240	PU-239/240	0.03	1		pCi/g
Strontium-90	10098-97-2	0.18	1		pCi/g
Uranium-235	15117-96-1	0.11	1		pCi/g
SAP Required Detection Limit Less than Hanford Soil Background; but Target Detection Limit Greater than Hanford Soil Background					
Mercury	7439-97-6	13	10	200	ug/kg
Selenium	7782-49-2	780	30	1,000	ug/kg
Thallium	7440-28-0	185	100	500	ug/kg

During the analysis of Phase 2 soil characterization samples, the analytical laboratory did not specifically analyze for ^{241}Pu. However, concentrations for ^{241}Pu were derived by multiplying the detected sampling results of $^{239/240}$Pu with the scaling factor of 3.73 for each sample location (SVF-3009, *Pu241_Soil_Estimate.xls*).

Results of the Hanford Site background comparison for primary and secondary constituents are summarized by location (investigation site/group) and analytical class in Appendix N. Results are reported in terms of concentrations and depth of detection above background by investigation site/group. Detected results for those constituents without Hanford Site background comparison values are also presented.

Site Contamination at Investigation Group A+B (Boreholes C8102 and C8104)

Investigation Group A+B (boreholes C8102 and C8104) was sampled to evaluate potential releases from Tank C-101. Direct push sampling and direct push logging were performed using angle-push technology to characterize the extent of potential release. Depths presented are the calculated depth from ground surface, based on the angle from grade and the section of pipe length sampled. Soil sample results are presented below.

Analytical Results

Soil samples from Investigation Group A+B were collected from two boreholes (C8102 and C8104) at depths ranging from surface 0.15 to 52 m (0.5 to 169 ft) bgs. Soil samples were analyzed for primary and secondary contaminants, including inorganic analytes (including general chemistry parameters), radionuclides, and organic constituents (including pesticides, PCBs, SVOCs).

Primary and secondary constituents reported above background at Investigation Group A+B included 10 inorganics and 9 radionuclides.

No background comparison values were available for 19 primary constituents or 20 secondary constituents detected at Investigation Group A+B. A summary of primary and secondary inorganic and radionuclide constituents reported above background are presented in Appendix N. Stratigraphy plots of maximum concentrations of primary and secondary analytes by depth are provided in Appendix O.

Investigation Group A+B was sampled using angle push technology. Depths presented are the calculated depth from ground surface, based on the angle from grade and the section of pipe length sampled.

Summary statistics for extent of contamination for Phase 2 soil analytical data exceeding Hanford Site background or detected without background values available for comparison are presented in Appendix P. The extent of contamination at Investigation Group A+B ranged from 0.15 to 52 m (0.5 to 169 ft) bgs.

Inorganic Chemicals and General Chemistry Parameters

Nine primary and two secondary inorganic analytes and general chemistry parameters were reported above background at Investigation Group A+B at depths ranging from 0.15 m (0.5 ft) bgs to 51.7 m (169.7 ft) bgs. Appendix N presents the inorganic and general chemistry results exceeding background by depth and borehole. A summary of maximum reported values and their geologic strata by borehole is presented below.

- Antimony was reported above background in 16 samples at Investigation Group A+B with a maximum result of 342 µg/kg at 0.15 m (0.5 ft) bgs (backfill) at borehole C8104 (Site B). The maximum depth of antimony reported above background was at 44.2 m (144.9 ft) bgs (at borehole C8102 [Site A]).

- Boron, a secondary analyte, was reported above background in nine soil samples from borehole C8104 a maximum concentration of 6,960 µg/kg at 11 m (36 ft) bgs (backfill).

- Calcium was reported above background in one sample from borehole C8104 at a depth of 11 m (36 ft) bgs (backfill) with a concentration of 32,200,000 µg/kg.

- Chromium was reported above background in five samples from Investigation Group A+B with a maximum result of 27,700 µg/kg at 24.8 m (81.4 ft) bgs at borehole C8104 (Site B). The maximum depth of detection was at 41.7 m (136.9 ft) bgs (H1) at borehole C8102 (Site A).

- Lead was reported above background in one sample at 11 m (36 ft) bgs with a value 11,900 µg/kg at 11 m (36 ft) bgs (backfill) from borehole C8104 (Site B).

- Molybdenum was reported above background in 19 samples from Investigation Group A+B. All values exceeding background were reported as non-detect results. The maximum reported value was 4,690 µg/kg at 0.15 m (0.5 ft) bgs (backfill).

- Mercury was reported above background in one sample from borehole C8104 (Site B). The result was 23 µg/kg at 11 m (36 ft) bgs (backfill).

- Nitrate was reported above background in two samples from borehole C8104. The maximum result was 121,000 µg/kg at a depth of 42 m (137 ft) bgs, which was the maximum depth of detection (H2).

- Phosphate, a secondary analyte, was reported above background in 14 soil samples from Investigation Group A+B. The maximum value was 8,280 µg/kg at 11 m (36 ft) bgs (backfill).

- Sulfate was reported above background in two samples at borehole C8104 (Site B). The maximum value was 592,000 µg/kg at 4.3 m (14.2 ft) bgs (backfill).

Seven primary and 10 secondary general chemistry and inorganic constituents for which there are no Hanford Site background values were detected at Investigation Group A+B. Detected primary compounds included phosphorus, strontium, acetate, ammonium ion, formate, nitrate, and oxalate. Extent of detection ranged from 0.15 m (0.5 ft) bgs to 51.7 m (169.7 ft) bgs. A summary of all detected concentrations by borehole and depth is presented in Appendix N.

Radionuclide Analytes

Seven primary and two secondary radionuclide analytes were reported above background at Investigation Group A+B at depths ranging from 0.15 m (0.5 ft) bgs to 51.7 m (169.7 ft) bgs. Appendix N presents the radionuclide results exceeding background by depth and borehole. Appendix O presents stratigraphy plots of maximum results by depth and borehole. A summary of maximum reported values and their geologic strata by borehole is presented below.

- Cesium-137 was reported above background (or reported as detected at depths below those where background applies) in four samples from Investigation Group A+B. The maximum reported concentration was 27.7 pCi/g from borehole C8104 at a depth of 0.15 m (0.5 ft) bgs (backfill). The maximum depth of detection was 0.15 m (0.5 ft) at both boreholes C8102 and C8104.

- Cobalt-60 was reported above background in 16 soil samples. The maximum observed value was a non-detect result of 0.157 pCi/g at 36.18 m (118.7 ft) bgs (H2) from borehole C8102 (Site A). The only detected result was 0.03 pCi/g at 35.6 to 36.3 m (117 to 119 ft) bgs (H2) from borehole C8104 (Site B).

- Europium-154 was reported above background in 14 soil samples. All values exceeding background were reported as non-detect results. The maximum reported result was 0.305 pCi/g at 0.15 m (0.5 ft) bgs (backfill) from borehole C8104 (Site B).

- Europium-155 was reported above background in 19 samples. All values exceeding background were reported as non-detect results. The maximum reported result was 0.378 pCi/g at 4.30 m (14.1 ft) bgs (backfill) from borehole C8102 (Site A).

- Plutonium-238 was reported above background in 19 samples. All values exceeding background were reported as non-detect results. The maximum reported result was 0.0526 pCi/g at 42 m (137 ft) bgs (H2) from borehole C8104 (Site B).

- Plutonium-239/240 was reported above background in 19 samples. The maximum value was 0.313 pCi/g at 0.15 m (0.5 ft) bgs (backfill) from borehole C8014 (Site B). Plutonium-239/240 was detected in one additional sample from borehole C8104 (0.198 pCi/g) at a depth of 0.15 m (0.5 ft) bgs. The remaining values exceeding background were all reported as non-detect results.

- Potassium-40, a secondary analyte, was reported above background in six samples. All reported concentrations were from borehole C8104 (Site B) with the maximum reported concentration was 31 pCi/g at 24.8 m (81.4 ft) bgs (H2). The maximum depth of detection was 42 m (137 ft) bgs (H2).

- Strontium-90 was reported above background in 15 samples. The maximum reported concentration was 24 pCi/g at 0.15 m (0.5 ft) bgs (backfill) from borehole C8102 (Site A). Strontium-90 was detected in one additional sample from borehole C8102 (17.4 pCi/g at 0.15 m [0.5 ft] bgs), and two samples from C8104 (8.12 and 11.8 pCi/g at 0.15 m [0.5 ft] bgs). The maximum depth of detected results was 0.15 m (0.5 ft) bgs (backfill). All other values exceeding background were reported as non-detect results.

- Radium-226, a secondary analyte, was reported above background in thirteen samples. The maximum reported concentration was 6.96 pCi/g at 21.25 m (69.73) ft bgs (H2) from borehole C8102 (Site A). The maximum depth of detection was 51.7 m (169.7 ft) bgs (H2).

Ten primary and nine secondary radionuclides for which no Hanford Site background value has been established were detected at Investigation Group A+B. Primary detected constituents included ^{241}Am, ^{14}C, ^{63}Ni, ^{79}Se, ^{99}Tc, ^{230}Th, ^{234}Th, ^{126}Sn, tritium, and ^{236}U. Secondary detected constituents included ^{228}Ac, ^{212}Bi, ^{214}Bi, ^{212}Pb, ^{214}Pb, ^{54}Mn, ^{228}Ra, ^{208}Tl, and ^{65}Zn. A summary of detected radionuclide concentrations by borehole and depth is presented in Appendix N.

Detected Organic Analytes

Three organic analytes were detected at Investigation Group A+B at depths ranging from 0.15 m (0.5 ft) bgs to 51.7 m (169.7 ft) bgs. Appendix N presents the concentrations of detected organic constituents by borehole and depth. Appendix O presents stratigraphy plots of detected organic constituents by depth and borehole.

- Aroclor-1254 was detected in three samples from Investigation Group A+B. The maximum results were 8.59 µg/kg at 0.15 m (0.5 ft) bgs from borehole C8104 (Site B). Aroclor-1254 was detected in one sample from borehole C8102 (6.46 µg/kg) at a depth of 0.15 m (0.5 ft) bgs and two samples (8.59 and 8.33 µg/kg) at depths of 0.15 m (0.5 ft) bgs from borehole C8104 (Site B). Aroclor-1254 was not detected in samples below 0.15 m (0.5 ft) bgs at Investigation Group A+B, therefore vertical extent is defined.

- Di-n-octylphthalate was detected in one sample from borehole C8102 (109 µg/kg at 3.5 m [11.4 ft]bgs), and one sample from borehole C8104 (300 µg/kg at 3.4 m [11.1 ft] bgs).

- N-heptane was detected in three samples from borehole C8102 (Site A). The maximum concentration was 340 µg/kg at 51.7 m (169.7 ft) bgs (H2), which was also the maximum depth of detection. Concentrations increased with depth at this location, therefore vertical extent is not defined.

Site Contamination at Investigation Site C (Borehole C8106)

Site C was sampled during Phase 2 to evaluate potential leaks or overfills from the 200-series tanks during active operations or retrieval. Direct push sampling and direct push logging using angle push technology were performed to characterize the extent of potential contamination from suspected releases. Depths presented are the calculated depth from ground surface, based on the angle from grade and the section of pipe length sampled. Soil sample results are presented below.

Analytical Results

Soil samples from Site C were collected from borehole C8106 at depths ranging from 0.15 to 26.8 m (0.5 to 87.8 ft) bgs. Soil samples were analyzed for primary and secondary contaminants, including inorganic analytes (including general chemistry parameters), radionuclides, and organic constituents (including pesticides, PCBs, SVOCs).

Primary and secondary constituents reported above background at Site C included nine inorganics and seven radionuclides. One organic constituent was also detected.

No background comparison values were available for 11 primary constituents or 17 secondary constituents detected at Site C. A summary of primary and secondary inorganic and radionuclide constituents reported above background are presented in Appendix N. Stratigraphy plots of

maximum concentrations of primary and secondary analytes by depth are provided in Appendix O.

Site C was sampled using angle push technology. Depths presented are the calculated depth from ground surface, based on the angle from grade and the section of pipe length sampled.

Summary statistics for extent of contamination for Phase 2 soil analytical data exceeding Hanford Site background or detected without background values available for comparison are presented in Appendix P. The extent of contamination at Site C ranged from 0.15 to 26.8 m (0.5 to 87.8 ft) bgs.

Inorganic Chemicals and General Chemistry Parameters

Eight primary and one secondary inorganic analyte were reported above background at Site C at depths ranging from 0.15 to 26.8 m (0.5 to 87.8 ft) bgs. Appendix N presents the inorganic results exceeding background by depth and borehole. A summary of maximum reported values and their geologic strata by borehole is presented below. Secondary analytes are noted, all other analytes are primary.

- Antimony was reported above background in seven samples in borehole C8106. The maximum reported concentration was 721 µg/kg at 1.9 m (6.5 ft) bgs (H1). The maximum depth of detection above background was 26.8 m (87.8 ft) bgs (H2).

- Arsenic was reported in three samples above background in borehole C8106. The maximum reported concentration was 21,200 µg/kg at 1.9 m (6.5 ft) bgs (H1). The maximum depth of detection above background was at 26.7 m (87.7 ft) bgs (H2).

- Calcium was reported above background in one sample from borehole C8106 with a value of 17,500,000 at a depth of 1.9 m (6.5 ft) bgs (H1).

- Chromium was reported above background in three samples from borehole C8106. A maximum concentration of 22,000 µg/kg was reported at depths of 5 m (16.5 ft) bgs and 17.5 m (57.3 ft) bgs. The maximum depth of detection above background was 26.8 m (87.8 ft) bgs (H2) with a result of 21,400 µg/kg.

- Lead was reported above background in one sample from borehole C8106 with a value of 10,600 µg/kg at a depth of 1.9 m (6.5 ft) bgs (H1).

- Magnesium was reported above background in one sample from borehole C8106 with a value of 8,620,000 µg/kg at a depth of 1.9 m (6.5 ft) bgs (H1).

- Molybdenum was reported above background in nine samples from borehole C8106. The maximum reported value was 2,790 µg/kg at 0.15 m (0.5 ft) bgs (H1). All values exceeding background were reported as non-detect results.

- Thallium was reported above background in seven samples from borehole C8106. The maximum reported concentration was 304 µg/kg at 0.15 m (0.5 ft) bgs (H1). The maximum depth of detection above background was 17.5 m (57.3 ft) bgs (H1).

- Phosphate, a secondary analyte, was reported above background in four samples from borehole C8106. The maximum reported concentration was 4,570 µg/kg at 0.15 m (0.5 ft) bgs (H1). The maximum depth of detection above background was 3.5 m (11.5 ft) bgs (H1).

Seven primary and 11 secondary general chemistry and inorganic constituents for which there are no Hanford Site background values were detected at Site C. Detected primary compounds included phosphorus, strontium, acetate, ammonium ion, formate, nitrate, and oxalate. A summary of all detected concentrations by borehole and depth is presented in Appendix N.

Radionuclide Analytes

Seven primary radionuclide analytes were reported above background at Site C at depths ranging from 0.15 to 26.8 m (0.5 to 87.8 ft) bgs. Appendix N presents the radionuclide results exceeding background by depth and borehole. Appendix O presents stratigraphy plots of maximum results by depth and borehole. A summary of maximum reported values and their geologic strata by borehole is presented below.

- Cesium-137 was reported above background (or reported as detected at depths below those where background applies) in two samples from borehole C8106, both at depths of 0.15 m (0.5 ft) bgs (H1). The maximum reported concentration was 7.09 pCi/g.

- Strontium-90 was reported above background (or reported as detected at depths below those where background applies) in three samples from borehole C8106. The maximum reported concentration was 3.0 pCi/g at a depth of 1 m (0.5 ft) bgs. The maximum depth of detection was 5.3 m (16.5 ft). Five additional results were reported as non-detects at depths where Hanford Site background does not apply.

- Cobalt-60, ^{154}Eu, ^{155}Eu, ^{238}Pu, and $^{239/240}$Pu were reported above background in all samples and depth from borehole C8106, however, all results were reported as non-detects.

Two primary and six secondary radionuclides for which no Hanford Site background value has been established were detected at Site C. Detected primary constituents included ^{63}Ni and ^{126}Sn. Detected secondary constituents included ^{228}Ac, ^{212}Bi, ^{214}Bi, ^{212}Pb, ^{214}Pb, and^{208}Tl. A summary of detected radionuclide concentrations by borehole and depth is presented in Appendix N.

Detected Organic Analytes

Only one organic analyte, butylbenzylphthalate, was detected at borehole C8106. Butylbenzylphthalate was reported with concentration of 80.7 µg/kg at 0.15 m (0.5 ft) bgs (H1).

Appendix N presents the concentrations of detected organic constituents by borehole and depth. Appendix O presents stratigraphy plots of detected organic constituents by depth and borehole.

Site Contamination at Investigation Site E (Borehole C7672)

Site E was sampled to determine the extent of surface contamination associated with a suspected transfer line release located between Tanks C-106 and C-109. Cobalt-60 was identified as the main contaminant of interest.

Vertical borehole C7672 was sampled using direct push technology. The results of laboratory analyses for soil at Site E are presented below.

Analytical Results

Soil samples from Site E were collected from borehole C7672 at depths ranging from 0.15 to 38 m (0.5 to 123 ft) bgs. Soil samples were analyzed for primary and secondary contaminants, including inorganic analytes (including general chemistry parameters), radionuclides, and organic constituents (including pesticides, PCBs, SVOCs).

Primary and secondary constituents reported above background at Site E included nine inorganics and eight radionuclides. Six organic constituents were also detected.

No background comparison values were available for 18 primary constituents or 8 secondary constituents detected at Site E. A summary of primary and secondary inorganic and radionuclide constituents reported above background are presented in Appendix N. Stratigraphy plots of maximum concentrations of primary and secondary analytes by depth are provided in Appendix O.

Site E contains analytical data from borehole C7672 only.

Summary statistics for extent of contamination for Phase 2 soil analytical data exceeding Hanford Site background or detected without background values available for comparison are presented in Appendix P. The extent of contamination at Site E ranged from 0.15 to 38 m (0.5 to 123 ft) bgs.

Inorganic Chemicals and General Chemistry Parameters

Eight primary and one secondary inorganic chemical were reported above Hanford Site background concentrations at Site E, at depths ranging from 0.15 to 8 m (0.5 to 123 ft) bgs. Appendix N presents the inorganic results exceeding background by depth and borehole. A summary of maximum reported values and their geologic strata is presented below.

- Antimony was reported above background in five samples from borehole C7672. The maximum reported concentration was 263 µg/kg at 26 m (84 ft) bgs (H2). The maximum depth of detection above background was 26 m (84 ft) bgs (H2).

- Cadmium was reported above background in nine samples from borehole C7672. The maximum concentration was 3,280 µg/kg at 0.15 m (0.5 ft) bgs (backfill). The maximum depth of detection above background was 38 m (123 ft) bgs (H2).

- Chromium was reported above background in three samples from borehole C7672. The maximum concentration was 29,800 µg/kg at 12 m (38 ft) bgs (backfill). The maximum depth of detection was 38 m (123 ft) bgs (H2).

- Molybdenum was reported above background in nine samples from borehole C7672. The maximum concentration was 2,540 µg/kg at 38 m (123 ft) bgs (H2). The maximum depth of detection was 38 m (123 ft) bgs (H2). The eight remaining values exceeding background were reported as non-detects.

- Nickel was reported above background in two samples from borehole C7672. The maximum concentration was 25,300 µg/kg at a depth of 23 m (74 ft) bgs (H2). The maximum depth of detection was 23 m (74 ft) bgs (H2).

- Sodium was reported above background in one sample from borehole C7672 at a concentration of 972,000 µg/kg from 12 m (38 ft) bgs (backfill).

- Mercury was reported above background in two samples from borehole C7672. The maximum concentration was 23.2 µg/kg at a depth of 0.15 m (0.5 ft) bgs. The maximum depth of detection above background was at 0.15 m (0.5 ft) bgs (backfill).

- Fluoride was reported above background in one sample from borehole C7672. The maximum concentration was 2,870 µg/kg at 12 m (38 ft) bgs (backfill).

- Phosphate, a secondary analyte, was reported above background in five samples from borehole C7672. The maximum concentration was 1,650 µg/kg from 0.15 m (0.5 ft) bgs (backfill). The maximum depth of detection above background was at 5 m (15 ft) bgs (backfill).

Eight primary and seven secondary general chemistry and inorganic constituents for which there are no Hanford Site background values were detected at Site E. Detected primary compounds included phosphorus, strontium, acetate, ammonium ion, formate, nitrate, oxalate, and sulfide. A summary of all detected concentrations by borehole and depth is presented in Appendix N.

Radionuclide Analytes

Seven primary and one secondary radionuclide were reported above background at borehole C7672 at depths ranging from 0.15 to 38 m (0.5 to 123 ft) bgs. Appendix N presents the radionuclide results exceeding background by depth and borehole. Appendix O presents stratigraphy plots of maximum results by depth and borehole. A summary of maximum reported values and their geologic strata is presented below.

- Cesium-137 was above background (or reported as detected at depths where background does not apply) in two samples, both at a depth of 0.15 m (0.5 ft) bgs (backfill). The maximum concentration was 5.13 pCi/g.

- Strontium-90 was reported above background (or reported as detected at depths where background does not apply) in two samples from borehole C7672. The maximum concentration was 2.5 pCi/g at a depth of 0.15 m (0.5 ft) bgs (backfill). Strontium-90 was only detected at 0.15 m (0.5 ft) bgs (backfill), all other results were non-detects at depths where background does not apply.

- Cobalt-60, ^{154}Eu, ^{155}Eu, ^{238}Pu, and $^{239/240}$Pu were reported above background in all samples and depth from borehole C7672, however, all results were reported as non-detects.

- Potassium-40, a secondary analyte, was reported above background in one sample. The maximum reported concentration was 17.6 pCi/g at 26 m (84 ft) bgs (H2) from borehole C7672.

Five primary and three secondary radionuclides for which no Hanford Site background value has been established were detected at Site E. Detected primary constituents included ^{79}Se, ^{230}Th, ^{126}Sn, ^{233}U, and ^{236}U. Detected secondary contaminants included^{214}Bi, ^{212}Pb, and^{214}Pb. A summary of detected radionuclide concentrations by borehole and depth is presented in Appendix N.

Detected Organic Analytes

Six organic constituents were detected at borehole C7672 at depths ranging from 0.15 to 38 m (0.5 to 123 ft) bgs. Appendix N presents the concentrations of detected organic constituents by borehole and depth. Appendix O presents stratigraphy plots of detected organic constituents by depth and borehole.

- Aldrin was detected in one sample at a concentration of 2 µg/kg from 3.4 m (11 ft) bgs (backfill).

- Butylbenzylphthalate was detected in five samples with a maximum concentration of 125 µg/kg at 11.58 m (38 ft) bgs (backfill). The maximum depth of detection was 23 m (74 ft) bgs (H2).

- 2-butanone was detected in one sample at a concentration of 6.58 µg/kg at 23 m (74 ft) bgs (H2).

- Acetone was detected in four samples from borehole C7672 with a maximum concentration of 6.63 µg/kg at 3.35 m (11 ft) bgs (backfill). The maximum depth of detection was 38 m (123 ft) bgs (H2).

- Styrene was detected in one sample from borehole C7672 at a concentration of 0.784 from 26 m (84 ft) bgs (H2).

- Toluene was detected in eight samples from borehole C7672. The maximum concentration was 0.734 at a depth of 22.56 m (74 ft) bgs (H2). The maximum depth of detection was 38 m (123 ft) bgs (H2).

Site Contamination at Investigation Group F+G (Boreholes C7472 and C7468)

Investigation Group F+G was sampled during Phase 2 to determine the extent of contamination associated with a suspected release northeast of the Cesium Loadout Facility (Site F), and a suspected transfer line release between C-801 Building and Tank C-103 (Site G). For the suspected release at Site F, ^{137}Cs, ^{99}Tc and ^{60}Co were contaminants of interest. For the suspected transfer line release at Site G, ^{60}Co was the main contaminant of interest.

Direct push sampling and direct push logging were performed at boreholes C7472 and C7468. The results of laboratory analyses for soil at Investigation Group F+G are summarized below.

Analytical Results

Soil samples from Investigation Group F+G were collected from boreholes C7472 and C7468 at depths ranging from 0.15 to 66 m (0.5 to 217 ft) bgs. Soil samples were analyzed for primary and secondary contaminants, including inorganic analytes (including general chemistry parameters), radionuclides, and organic constituents (including pesticides, PCBs, SVOCs).

Primary and secondary constituents reported above background at Investigation Group F+G included 10 inorganics and eight radionuclides.

No background comparison values were available for 28 primary constituents or 23 secondary constituents detected at Investigation Group F+G. A summary of primary and secondary inorganic and radionuclide constituents reported above background are presented in Appendix N. Stratigraphy plots of maximum concentrations of primary and secondary analytes by depth are provided in Appendix O.

Summary statistics for extent of contamination for Phase 2 soil analytical data exceeding Hanford Site background or detected without background values available for comparison are presented in Appendix P. The extent of contamination at Investigation Group F+G ranged from 0.15 to 66 m (0.5 to 217 ft) bgs.

Inorganic Chemicals and General Chemistry Parameters

Nine primary and one secondary inorganic chemical were reported above Hanford Site background concentrations at Investigation Group F+G at depths ranging from 0.15 to 66 m (0.5 to 217 ft) bgs. Appendix N presents the inorganic results exceeding background by depth and borehole. A summary of maximum reported values and their geologic strata is presented below.

- Antimony was reported above background in 20 samples from boreholes C7472 and C7468. The maximum reported concentration was 262 µg/kg at 2 m (6 ft) bgs (H1). The maximum depth of detection above background was 40 m (130 ft) bgs (H2).

- Calcium was reported above background in one sample from a depth of 2 m (6 ft) bgs (H1) in borehole C7472 at a concentration of 19,600,000 µg/kg.

- Chromium was reported above background in three samples from borehole C7472. The maximum reported concentration was 22,100 µg/kg at a depth of 66 m (217 ft) bgs (H2). The maximum depth of detection was at 66 m (217 ft) bgs.

- Molybdenum was reported above background in all 21 samples from Investigation Group F+G. The highest reported concentration was 17,300 µg/kg from borehole C7472 at a depth of 4 m (12 ft) bgs (H1). The maximum depth of detection was 66 m (217 ft) bgs (H2 in borehole 7472).

- Selenium was reported above background in all 10 samples from borehole C7468. The maximum reported concentration was 2,410 µg/kg at a depth of 0.15 m (0.5 ft) bgs (backfill). While all selenium results were above background, they were reported as not detected.

- Uranium was reported above background in all 10 samples from borehole C7468. The maximum reported concentration was 19,700 µg/kg at a depth of 0.15 m (0.5 ft) bgs (backfill). While all uranium results were above background, they were reported as not detected.

- Mercury was reported above background in 10 samples from borehole C7468 and one sample from C7472. The maximum reported concentration was 30.4 µg/kg from borehole C7472 at a depth of 0.15 m (0.5 ft) bgs. The maximum depth of detection was 0.15 m (0.5 ft) bgs at borehole C7472. The ten results exceeding background from borehole C7468 were reported as not detected.

- Fluoride was reported above background in one sample from borehole C7472 (Site F) at a concentration of 3,290 µg/kg at a depth of 2 m (6 ft) bgs (H1).

- Nitrate was reported above background in two samples from borehole C7468. The maximum concentration was 192,000 at a depth of 38 m (126 ft) bgs (H2). The maximum depth of detection was 42 m (136 ft) bgs (H2).

- Phosphate, a secondary analyte, was reported above background in 10 samples from Investigation Group F+G. The maximum reported value was 2,790 µg/kg at a depth of 0.15 m (0.5 ft) bgs from borehole C7468 (Site G).

Eight primary and 17 secondary general chemistry and inorganic constituents for which there are no Hanford Site background values were detected at Investigation Group F+G. Detected primary compounds included phosphorus, strontium, acetate, ammonium ion, formate, nitrate, oxalate,

and sulfide. A summary of all detected concentrations by borehole and depth is presented in Appendix N.

Radionuclide Analytes

Seven primary and one secondary radionuclide were reported above background at Investigation Group F+G at depths ranging from 0.15 to 66 m (0.5 to 217 ft) bgs. Appendix N presents the radionuclide results exceeding background by depth and borehole. Appendix O presents stratigraphy plots of maximum results by depth and borehole. A summary of maximum reported values and their geologic strata is presented below.

- Cesium-137 was reported above background (or reported as detected where background does not apply) in five samples from boreholes C7472 and C7468. The maximum reported concentration was 4.75 pCi/g at depth of 0.15 m (0.5 ft) bgs (backfill) from borehole C7468. The maximum depth of detection was 13.6 m (44.5 ft) bgs (H1) in borehole C7468.

- Strontium-90 was reported above background (or reported as detected where background does not apply) in three samples from boreholes C7472 and C7468. The maximum reported concentration was 2.3 pCi/g at 30 m (98 ft) bgs (H2) from borehole C7468, which was also the maximum depth of detection.

- Cobalt-60, ^{154}Eu, ^{155}Eu, ^{238}Pu, and $^{239/240}$Pu were reported above background in all samples and depths from boreholes C7472 and C7468, however, all results were reported as non-detects.

- Potassium-40, a secondary analyte, was reported above background in one sample. The maximum reported concentration was 19.1 pCi/g at 38 m (126 ft) bgs (H2) from borehole C7468 (Site G).

Eight primary and three secondary radionuclides for which no Hanford Site background value has been established were detected at Investigation Group F+G. Detected primary constituents included ^{14}C, ^{79}Se, ^{99}Tc, ^{230}Th, ^{126}Sn, tritium, ^{233}U, and ^{236}U. Detected secondary contaminants included ^{214}Bi, ^{212}Pb, and ^{214}Pb. A summary of detected radionuclide concentrations by borehole and depth is presented in Appendix N.

Detected Organic Analytes

Fifteen organic compounds were detected at Investigation Group F+G at depths ranging from 0.15 to 66 m (0.5 to 217 ft) bgs. Aroclor-1260, Gamma-BHC (Lindane), 2-Hexanone, (m+p)-Xylene, o-xylene, and Xylenes (total) were each detected only once from Investigation Group F+G (Appendix N). Analytes detected more than once are described below. Appendix N presents the concentrations of all detected organic constituents by borehole and depth. Extent of occurrence of detected organic constituents is depicted by borehole in Appendix O.

- Beta-1,2,3,4,5,6-Hexachlorocyclohexane (beta-BHC) was detected in five samples from borehole C7468 with a maximum concentration of 25.3 µg/kg reported at a depth of 2 m (6 ft) bgs (backfill). The maximum reported depth of detection was 5 m (15 ft) bgs at borehole C7568.

- Bis(2-ethylhexyl) phthalate was detected in eight samples at Investigation Group F+G. The maximum detected concentration was 7.420 µg/kg at a depth of 5 m (15 ft) bgs from borehole C7468. The maximum depth of detection was 42 m (136 ft) bgs (H2).

- Butylbenzylphthalate was detected in two samples from borehole C7472. The maximum concentration was 72.6 µg/kg at a depth of 5 m (15 ft) bgs (H1), which was also the maximum depth of detection.

- 2-Butanone was detected in five samples from borehole C7472. The maximum concentration was 3.18 µg/kg, reported at the maximum depth of detection, 66 m (217 ft) bgs (H2).

- 4-Methyl-2-pentanone was detected at a maximum concentration of 2.04 µg/kg from borehole C7472 with a depth of 33.4 m (109.5 ft) bgs (H2). The maximum depth of detection was 40 m (130 ft) bgs (H2).

- Hexane was detected in 10 samples from borehole C7468. The maximum concentration was 35.9 µg/kg at a depth of 5 m (15 ft) bgs (backfill) from borehole C7468. The maximum depth of detection was 42 m (136 ft) bgs (H2).

- Methylene chloride was detected in eight samples from borehole C7468. The maximum concentration was 2.8 µg/kg at a depth of 42 m (136 ft) bgs (H2), which was also the maximum depth of detection.

- Styrene was detected in six samples from borehole C7448 with a maximum concentration of 0.654 µg/kg at a depth of 2 m (6 ft) bgs (H1). The maximum depth of detection was 42 m (136 ft) bgs (H2).

- Toluene was detected in nine samples from borehole C7472. The maximum concentration was 0.978 µg/kg at a depth of 2 m (6 ft) bgs (H1). The maximum depth of detection was 66 m (217 ft) bgs (H2).

Site Contamination at Investigation Group H+I (Boreholes C7680 and C7682)

Investigation Group H+I consists of UPRs 200-E-91 and 200-E-115. The Phase 2 investigation for these sites characterized the extent of surface contamination associated with the two UPRs. Cobalt-60 was identified as the main contaminant of interest.

Direct push sampling and direct push logging were performed at boreholes C7680 and C7682. The results of laboratory analyses for soil at Investigation Group H+I are summarized below.

Analytical Results

Soil samples from Investigation Group H+I were collected from two boreholes (C7680 and C7682) at depths ranging from surface 0.15 to 44 m (0.5 to 143 ft) bgs. Soil samples were analyzed for primary and secondary contaminants, including inorganic analytes (including general chemistry parameters), radionuclides, and organic constituents (including pesticides, PCBs, SVOCs).

Primary and secondary constituents reported above background at Investigation Group H+I included nine inorganics and seven radionuclides at depths ranging from surface 0.15 to 44 m (0.5 to 143 ft) bgs.

No background comparison values were available for 19 primary constituents or 15 secondary constituents detected at Investigation Group H+I. A summary of primary and secondary inorganic and radionuclide constituents reported above background are presented in Appendix N. Stratigraphy plots of maximum concentrations of primary and secondary analytes by depth are provided in Appendix O.

Summary statistics for extent of contamination for Phase 2 soil analytical data exceeding Hanford Site background or detected without background values available for comparison are presented in Appendix P. The extent of contamination at Investigation Group H+I ranged from 0.15 to 44 m (0.5 to 143 ft) bgs.

Inorganic Chemicals and General Chemistry Parameters

Nine primary and one secondary inorganic analytes and general chemistry parameters were reported above background at Investigation Group H+I at depths ranging from surface 0.15 to 44 m (0.5 to 143 ft) bgs. Appendix N presents the inorganic and general chemistry results exceeding background by depth and borehole. A summary of maximum reported values and their geologic strata by borehole is presented below.

- Antimony was reported above background in ten samples from Investigation Group H+I. The maximum concentration was 420 µg/kg from borehole C7682 at a depth of 2 m (6 ft) bgs (H1). The maximum depth of detection was 38 m (123 ft) bgs (H2) from borehole C7582.

- Arsenic was reported above background in one sample at a concentration of 7,000 µg/kg at a depth of 0.15 m (0.5 ft) bgs (H1) from borehole C7682.

- Chromium was reported above background in five samples at Investigation Group H+I with a maximum concentration of 28,700 µg/kg at a depth of 28 m (93 ft) bgs (H2) at borehole C7680. The maximum depth of detection was 28 m (93 ft) bgs (H2) at borehole C7680.

- Lead was reported above background in two samples from borehole C7682. The maximum concentration was 11,300 at a depth of 2 m (6 ft) bgs (H1) and the maximum depth of detection was 6 m (19 ft) bgs (H1).

- Molybdenum was reported above background in all 19 samples from Investigation Group H+I. The maximum reported concentration was 2,000 µg/kg at a depth of 5 m (15 ft) bgs (H1) from borehole C7682. The maximum depth of detection was 5 m (15 ft) bgs (H1) from borehole C7682. Molybdenum was only reported above detection in one other sample at a depth of 4 m (13 ft) bgs. The remaining 17 values exceeding Hanford Site background were reported as non-detects.

- Selenium was reported above background in ten samples from Investigation Group H+I. The maximum reported value was 1,000 µg/kg, reported in nine samples from borehole C7682 at depths ranging from 0.15 to 38 m (0.5 to 123 ft) bgs. The maximum depth of detection was 38 m (123 ft) bgs at borehole C7682.

- Sulfate was reported above background in one sample from borehole C7680 at a concentration of 458,000 µg/kg at a depth of 3 m (11 ft) bgs (H1).

- Thallium was reported above background in two samples from borehole C7682. The maximum concentration was 194 µg/kg at a depth of 4 m (13 ft) bgs (H1). The maximum depth of detection was 6 m (19 ft) bgs (H1).

- Nitrate was reported above background in two samples from borehole C7682. The maximum concentration was 54,600 µg/kg at a depth of 0.15 m (0.5 ft) bgs (H1). The maximum depth of detection was 0.15 m (0.5 ft) bgs (H1).

- Phosphate, a secondary analyte, was reported above background in 11 samples from Investigation Group H+I. The maximum reported concentration was 5,740 µg/kg at a depth of 0.15 m (0.5 ft) bgs (H1) at borehole C7682. The maximum depth of detection was 14 m (46 ft) bgs (H1).

Eight primary and nine secondary general chemistry and inorganic constituents for which there are no Hanford Site background values were detected at Investigation Group H+I. Detected primary compounds included phosphorus, strontium, acetate, ammonium ion, formate, nitrite, oxalate, sulfide, cerium, lanthanum, ruthenium, silicon, sulfur, titanium, tungsten, yttrium, and zirconium. A summary of all detected concentrations by borehole and depth is presented in Appendix N.

Radionuclide Analytes

Six primary radionuclides were reported above background at Investigation Group H+I at depths ranging from surface 0.15 to 44 m (0.5 to 143 ft) bgs. Appendix N presents the radionuclide results exceeding background by depth and borehole. Appendix O presents stratigraphy plots of maximum results by depth and borehole.

Cobalt-60, ^{154}Eu, ^{155}Eu, ^{238}Pu, $^{239/240}$Pu, and ^{90}Sr were reported above background in all samples and depths from boreholes C7680 and C7682, however, all results were reported as non-detects. One secondary radionuclide was also reported above background at this investigation area.

Potassium-40 was reported in two samples. The maximum reported concentration was 20 pCi/g at 0.15 m (0.5 ft) bgs (H1) from borehole C7680 (Site H). The maximum depth where ^{40}K was reported above background was 27 m (89 ft) bgs (H2).

Seven primary and three secondary radionuclides for which no Hanford Site background value has been established were detected at Investigation Group H+I Detected primary constituents included ^{14}C, ^{79}Se, ^{230}Th, ^{126}Sn, tritium, ^{233}U, and ^{236}U. Detected secondary contaminants included ^{214}Bi, ^{212}Pb, and ^{214}Pb.

A summary of detected radionuclide concentrations by borehole and depth is presented in Appendix N.

Detected Organic Analytes

Eight organic analytes were detected at Investigation Group H+I at depths ranging from surface 0.15 to 44 m (0.5 to 143 ft) bgs. Appendix N presents the concentrations of detected organic constituents by borehole and depth. Appendix O presents stratigraphy plots of detected organic constituents by depth and borehole.

- Bis(2-ethylhexyl) phthalate was detected in two samples from borehole C7680. The maximum reported concentration was 5620 µg/kg at a depth of 36 m (117 ft) bgs (H2), which was also the maximum depth of detection.

- Butylbenzylphthalate was detected in one sample at a concentration of 200 µg/kg from a depth of 5 m (15 ft) bgs (H1) at borehole C7682.

- Di-n-butylphthalate was detected in one sample from borehole C7680 at a concentration of 570 µg/kg from a depth of 0.15 m (0.5 ft) bgs (H1).

- 3-Heptanone was detected in one sample at a concentration of 2.5 µg/kg from a depth of 38 m (123 ft) bgs (H2) at borehole C7682.

- Styrene was detected in twelve samples from Investigation Group H+I with a maximum concentration of 0.46 µg/kg at a depth of 5 m (15 ft) bgs (H1) from borehole C7682. The maximum depth of detection was 36 m (117 ft) bgs (H2).

- Tetrahydrofuran was detected in one sample with a concentration of 27.4 µg/kg at a depth of 14 m (46 ft) bgs from borehole C7682.

- Toluene was detected in 15 samples from Investigation Group H+I with a maximum concentration of 1.05 µg/kg at a depth of 5 m (15 ft) bgs (H1). The maximum depth of detection was 44 m (143 ft) bgs (H2) at borehole C7680.

- Total petroleum hydrocarbons - diesel range was detected in one sample with a concentration of 12,000 µg/kg at a depth of 0.15 m (0.5 ft) bgs (H1) from borehole C7682.

Site Contamination at Investigation Site J (Borehole C8100)

Direct push sampling and direct push logging were performed at Site J using angle push technology to evaluate the extent of contamination from a suspected release near Tank C-101. Depths presented are the calculated depth from ground surface, based on the angle from grade and the section of pipe length sampled. Soil sampling results are presented below.

Analytical Results

Soil samples from Site J were collected from borehole C8100 at depths ranging from surface 0.15 to 53 m (0.5 to 173 ft) bgs. Soil samples were analyzed for primary and secondary contaminants, including inorganic analytes (including general chemistry parameters), radionuclides, and organic constituents (including pesticides, PCBs, and SVOCs).

Primary and secondary constituents reported above background at Site J included nine inorganics and nine radionuclides.

No background comparison values were available for 17 primary constituents or 19 secondary constituents detected at Site J. A summary of primary and secondary inorganic and radionuclide constituents reported above background are presented in Appendix N. Stratigraphy plots of maximum concentrations of primary and secondary analytes by depth are provided in Appendix O.

Site J was sampled using angle push technology. Depths presented represent the calculated depth from ground surfaced, based on the angle from grade and the section of pipe length sampled.

Summary statistics for extent of contamination for Phase 2 soil analytical data exceeding Hanford Site background or detected without background values available for comparison are presented in Appendix P. The extent of contamination at Site J ranged from 0.15 to 53 m (0.5 to 173 ft) bgs.

Inorganic Chemicals and General Chemistry Parameters

Seven primary and two secondary inorganic analytes and general chemistry parameters were reported above background at Site J at depths ranging from surface 0.15 to 53 m (0.5 to 173 ft) bgs. Appendix N presents the inorganic and general chemistry results exceeding background by depth and borehole. A summary of maximum reported values and their geologic strata by borehole is presented below.

- Antimony was reported above background in eight samples from borehole C8100 with a maximum concentration of 2,160 µg/kg at a depth of 4.1 m (13.4 ft) bgs (backfill). The maximum depth of detection was 40.2 m (131.8 ft) bgs (H2).

- Arsenic, chromium, and mercury were each reported above background in one sample from C8100. Arsenic was reported at a concentration of 7,890 µg/kg and a depth of 4.1 m (13.4 ft) bgs (backfill). Chromium was reported at a concentration of 27,400 µg/kg at a depth of 52.8 m (173.3 ft) bgs (H2). Mercury was reported at a concentration 16.2 µg/kg at a depth of 0.15 m (0.5 ft) bgs (backfill).

- Barium was reported above background in two samples from borehole C8100. The maximum result was 244,400 µg/kg at a depth of 0.15 m (0.5 ft) bgs (backfill), which was also the maximum depth of detection.

- Molybdenum was reported above background in ten samples from borehole C8100. The maximum reported result was 3,580 µg/kg at a depth of 52.8 m (173.3 ft) bgs (H2), the maximum depth of sampling. The nine remaining samples exceeding background were reported as non-detects.

- Selenium was reported above background in ten samples from borehole C8100. The maximum reported concentration was 1,350 µg/kg at depths of 40.2 (131.8 ft) bgs (H2) and 52.8 m (173.3 ft) bgs (H2). All selenium results exceeding background at this location were reported as non-detects.

- Phosphate, a secondary analyte, was reported above background in four samples from borehole C8100. The maximum reported concentration was 3,290 µg/kg at a depth of 11.8 m (38.8 ft) bgs (backfill). The maximum depth of detection above background was 11.8 m (38.8 ft) bgs (backfill).

- Boron, a secondary analyte, was reported above background in five samples from borehole C8100. The maximum reported concentration was 43,900 µg/kg at a depth of 0.15 m (0.5 ft) bgs (backfill). The maximum depth of detection above background was at 11.8 m (38.8 ft) bgs (backfill).

Seven primary and twelve secondary general chemistry and inorganic constituents for which there are no Hanford Site background values were detected at Site J. Detected primary compounds included phosphorus, strontium, acetate, ammonium ion, formate, nitrite, and oxalate. Detected secondary compounds included bismuth, cerium, lanthanum, praseodymium, silicon, sulfur, tantalum, tellurium, tin, titanium, yttrium, and zirconium. A summary of all detected concentrations by borehole and depth is presented in Appendix N.

Radionuclide Analytes

Seven primary and two secondary radionuclides were reported above background at Site J at depths ranging from surface 0.15 to 52.82 m (0.5 to 173.3 ft) bgs. Cobalt-60, ^{154}Eu, and ^{155}Eu were reported above background in all samples and depths from borehole C8100, however, all

results were reported as non-detects. Appendix N presents the radionuclide results exceeding background by depth and borehole. Appendix O presents stratigraphy plots of maximum results by depth and borehole.

- Cesium-137 was reported above background (or reported as detected at depths at which background does not apply) in two samples from borehole C8100. The maximum reported results were 5.71 pCi/g at a depth of 0.15 m (0.5 ft) bgs (backfill). The maximum depth of detection was 0.15 m (0.5 ft) bgs (backfill).

- Plutonium-238 was reported above background in ten samples from borehole C8100. The maximum reported result was 0.0666 pCi/g at a depth of 0.15 m (0.5 ft) bgs (backfill), which was also the maximum depth of detection. All other results reported above background were non-detects.

- Plutonium-239/249 was reported above background in nine samples from borehole C8100. The maximum reported result was 0.0439 pCi/g at a depth of 52.82 m (173.3 ft) bgs (H2), which was also the maximum depth of detection. One other result reported above background was detected (0.0378 pCi/g at 0.15 m [0.5 ft] bgs [BF]), but all others were non-detects.

- Strontium-90 was reported above background (or as detected at depths where background does not apply) in two samples at a depth of 0.15 m (0.5 ft) bgs from borehole C8100. The maximum reported results were 4.01 pCi/g at a depth of 0.15 m (0.5 ft) bgs (backfill), which was also the maximum depth of detection. Strontium-90 was reported as non-detects below depths where background applies.

- Potassium-40, a secondary analyte, was reported above background in one sample. The maximum reported concentration was 17.4 pCi/g at 27.46 m (90.1 ft) bgs (H2) from borehole C8100.

- Radium-226, a secondary analyte, was reported above background in three samples. The maximum reported concentration was 1.91 pCi/g at 0.15 m (0.5 ft) bgs (backfill) from borehole C8100. The maximum depth of reporting above background was a non-detect result of 1.39 pCi/g at a depth of 52.82 m (173.3 ft) bgs (H2).

Five primary and five secondary radionuclides for which no Hanford Site background value has been established were detected at Site J. Detected primary constituents included ^{241}Am, ^{125}Sb, ^{14}C, ^{79}Se, and ^{126}Sn. Detected secondary contaminants included ^{228}Ac, ^{214}Bi, ^{212}Pb, ^{214}Pb, and ^{208}Tl. A summary of detected radionuclide concentrations by borehole and depth is presented in Appendix N.

Detected Organic Analytes

Six organic analytes were detected at Site J at depths ranging from surface 0.15 to 48.1 m (0.5 to 157.7 ft) bgs. Appendix N presents the concentrations of detected organic constituents by

borehole and depth. Appendix O presents stratigraphy plots of detected organic constituents by depth and borehole.

- Bis(2-ethylhexyl) phthalate was detected in one sample from borehole C8100 with a concentration of 2,070 µg/kg at a depth of 4.1 m (13.4 ft) bgs (backfill).

- Butylbenzylphthalate was detected in three samples from borehole C8100 with a maximum result of 85.5 µg/kg at a depth of 48.1 m (157.7 ft) bgs (H2). The maximum depth of detection was 48.1 m (157.7 ft) bgs (H2).

- Di-n-octylphthalate was detected on five samples from borehole C8100 with a maximum result of 159 µg/kg at a depth of 1.5 m (4.9 ft) bgs (backfill). The maximum depth of detection was 48.1 m (157.7 ft) bgs (H2).

- n-Heptane was detected in six samples from borehole C8100 with a maximum result of 15,000 µg/kg at a depth of 16.6 m (54.3 ft) bgs. Concentrations of n-heptane increased from 0.15 m (0.5 ft) bgs to a maximum depth of detection at 16.6 m (54.3 ft) bgs.

- Tetrahydrofuran was detected in one sample from borehole C8100 with a concentration of 1,400 µg/kg at a depth of 16.6 m (54.3ft) bgs (H1).

- Toluene was detected in one sample from borehole C8100 with a concentration of 220 µg/kg at a depth of 16.6 m (54.3 ft) bgs (H1).

Site Contamination at Investigation Group L1+L2 (Boreholes C7466 and C7670)

Investigation Group L1+L2 (boreholes C7466 and C7670) was characterized in Phase 2 to assess a potential transfer line leak and to update logging data for ^{60}Co, ^{137}Cs, uranium and soil moisture in the vicinity of Tank C-103.

Soils from two vertical boreholes were sampled using direct push technology. Direct push logging was also performed. The results of laboratory analyses for soil at Investigation Group L1+L2 are summarized below.

Analytical Results

Soil samples from Investigation Group L1+L2 were collected from boreholes C7466 and C7670 at depths ranging from surface 0.15 to 68 m (0.5 to 223 ft) bgs. Soil samples were analyzed for primary and secondary contaminants, including inorganic analytes (including general chemistry parameters), radionuclides, and organic constituents (including pesticides, PCBs, SVOCs).

Primary and secondary constituents reported above background at Investigation Group L1+L2 included eleven inorganics and seven radionuclides. No background comparison values were available for 26 primary constituents or 21 secondary constituents detected at Investigation Group L1+L2. A summary of primary and secondary inorganic and radionuclide constituents

reported above background are presented in Appendix N. Stratigraphy plots of maximum concentrations of primary and secondary analytes by depth are provided in Appendix O.

Summary statistics for extent of contamination for Phase 2 soil analytical data exceeding Hanford Site background or detected without background values available for comparison are presented in Appendix P. The extent of contamination at Investigation Group L1+L2 ranged from 0.15 to 68 m (0.5 to 223 ft) bgs.

Inorganic Chemicals and General Chemistry Parameters

Ten primary and one secondary inorganic analytes and general chemistry parameters were reported above background at Investigation Group L1+L2 at depths ranging from surface 0.15 to 68 m (0.5 to 222 ft) bgs. Appendix N presents the inorganic and general chemistry results exceeding background by depth and borehole. A summary of maximum reported values and their geologic strata by borehole is presented below.

- Antimony was reported above background in 15 samples from Investigation Group L1+L2. The maximum reported concentration was 500 µg/kg at a depth of 0.15 m (0.5 ft) bgs (backfill) from borehole C7466. The maximum depth of detection was at 68 m (222 ft) bgs (H2) from borehole C7670.

- Chromium was reported above background in three samples from borehole C7670. The maximum concentration of 32,200 µg/kg was reported at the maximum depth of sampling, 68 m (222 ft) bgs (H2).

- Copper was reported above background in one sample from borehole C7670 with a concentration of 27,100 µg/kg at a depth of 68 m (222 ft) bgs (H2).

- Lead was reported above background in one sample from borehole C7670 with a concentration of 13,800 µg/kg at a depth of 43 m (140 ft) bgs (H2).

- Molybdenum was reported above background in 19 samples from Investigation Group L1+L2. The maximum result was 5120 µg/kg at a depth of 68 m (222 ft) bgs (H2) from borehole C7670. The maximum depth of detection was 68 m (222 ft) bgs (H2) from borehole C7670. All molybdenum results reported above background from borehole C7466 were reported as non-detects.

- Nickel was reported above background in one sample from borehole C7670 at a concentration of 20,200 µg/kg and a depth of 12 m (40 ft) bgs (backfill).

- Selenium was reported above background in one sample from borehole C7670 at a concentration of 1,350 µg/kg and a depth of 4 m (12 ft) bgs (backfill).

- Mercury was reported above background in 12 samples from Investigation Group L1+L2. The maximum reported concentration was 68.1 µg/kg at a depth of 68 m (222 ft) bgs

(H2) from borehole C7670. The maximum depth of detection was 68 m (222 ft) bgs at borehole C7670.

- Nitrate was reported above background in two samples from borehole C7466. The maximum reported concentration was 903,001 µg/kg at a depth of 35 m (115 ft) bgs (H2), which was the maximum depth of detection.

- Uranium was reported above background in all 10 samples from borehole C7466. The maximum reported concentration was 2,410 µg/kg at a depth of 0.15 m (0.5 ft) bgs (backfill). While all selenium results were above background, they were reported as not detected.

- Phosphate, a secondary analyte, was reported above background in 10 samples from Investigation Group L1+L2. The maximum reported concentration was 1,590 µg/kg at a depth of 0.15 m (0.5 ft) bgs (backfill) from borehole C7466. The maximum depth of detection was 68 m (222 ft) bgs at borehole C7670.

Nine primary and 14 secondary general chemistry and inorganic constituents for which there are no Hanford Site background values were detected at Investigation Group L1+L2. Detected primary compounds included phosphorus, strontium, 2-hydroxyacetate, acetate, ammonium ion, formate, nitrite, oxalate, and sulfide. Detected secondary compounds included bismuth, cerium, europium, lanthanum, neodymium, praseodymium, samarium, silicon, sulfur, tellurium, titanium, tungsten, yttrium, and zirconium. A summary of all detected concentrations by borehole and depth is presented in Appendix N.

Radionuclide Analytes

Seven radionuclides were reported above background at Investigation Group L1+L2. Cobalt-60, ^{154}Eu, ^{155}Eu, ^{238}Pu, and $^{239/240}$Pu were reported above background for all results reported from boreholes C7466 and C7670, however, all results were reported as non-detects. Appendix N presents the radionuclide results exceeding background by depth and borehole. Appendix O presents stratigraphy plots of maximum results by depth and borehole.

- Cesium-137 was reported above background (or detected at depths where background does not apply) in four samples from Investigation Group L1+L2. The maximum reported concentration was 7.52 pCi/g at a depth of 0.15 m (0.5 ft) bgs (backfill) from borehole C7670. The maximum depth of detection was 2 m (6 ft) bgs (backfill) from borehole C7466.

- Strontium-90 was reported above background (or detected at depths where background does not apply) in four samples from Investigation Group L1+L2. The maximum reported concentration was 4.01 pCi/g at a depth of 0.15 m (0.5 ft) bgs (backfill) from borehole C7466. The maximum depth of detection was 2 m (6 ft) bgs (backfill) from borehole C7670.

Nine primary and five secondary radionuclides for which no Hanford Site background value has been established were detected at Investigation Group L1+L2. Detected primary constituents included ^{14}C, ^{63}Ni, ^{79}Se, ^{99}Tc, ^{230}Th, ^{126}Sn, tritium, ^{233}U, and ^{236}U. Detected secondary contaminants included ^{228}Ac, ^{214}Bi, ^{212}Pb, ^{214}Pb, and ^{208}Tl. A summary of detected radionuclide concentrations by borehole and depth is presented in Appendix N.

Detected Organic Analytes

Ten organic analytes were detected at Investigation Group L1+L2 at depths ranging from surface 0.15 to 68 m (0.5 to 223 ft) bgs. Appendix N presents the concentrations of detected organic constituents by borehole and depth. Appendix O presents stratigraphy plots of detected organic constituents by depth and borehole.

- Beta-1,2,3,4,5,6-Hexachlorocyclohexane (beta-BHC) was detected in five samples from borehole C7466. The maximum detected result was 23.4 µg/kg at a depth of 0.15 m (0.5 ft) bgs. The maximum depth of detection was 5 m (15 ft) bgs (backfill) from borehole C7466.

- Bis(2-ethylhexyl) phthalate was detected in three samples from borehole C7466. The maximum reported concentration was 1,840 µg/kg at a depth of 2 m (6 ft) bgs (backfill). The maximum depth of detection was 41 m (134 ft) bgs (H2).

- Butylbenzylphthalate was detected in two samples from borehole C7466. The maximum detected concentration was 59.2 µg/kg at a depth of 0.15 m (0.5 ft) bgs (backfill). The maximum depth of detection was 5 m (15 ft) bgs (backfill).

- Di-n-octylphthalate was detected in one sample with a concentration of 1,220 µg/kg at a depth of 68 m (222 ft) bgs (H2) from borehole C7670.

- 1-Butanol was detected in one sample with a concentration of 22.2 µg/kg at a depth of 0.15 m (0.5 ft) bgs (backfill) from borehole C7670.

- Acetone was detected in six samples from Investigation Group L1+L2 with a maximum concentration of 72.5 µg/kg at a depth of 12 m (40 ft) bgs (H1) from borehole C7670. The maximum depth of detection was 68 m (223 ft) bgs (H2) from borehole C7670.

- Hexane was detected in ten samples from borehole C7466. The maximum detected concentration was 60.5 µg/kg at a depth of 5 m (15 ft) bgs (backfill). The maximum depth of detection was 41 m (134 ft) bgs (H2).

- Styrene was detected in two samples from borehole C7466 with a maximum concentration of 0.506 µg/kg at a depth of 35 m (115 ft) bgs (H2). The maximum depth of detection was 41 m (134 ft) bgs (H2).

- Toluene was detected in three samples from borehole C7670, with a maximum concentration of 0.331 µg/kg at a depth of 43 m (140 ft) bgs (H2). The maximum depth of detection was 68 m (223 ft) bgs (H2).

Site Contamination at Investigation Group P (Boreholes C6392, C6394, C6400, C6402, C6404, and C6406)

Phase 2 characterization of Investigation Group P (boreholes C6392, C6394, C6400, C6402, C6404, and C6406) included the characterization of a known release of PUREX coating waste at UPR-200-E-81 near diversion box 241-CR-151.

Direct push sampling and direct push logging were performed at Investigation Group P. Constituents of interest included ^{137}Cs, nitrate, and sulfate. Soil analytical results for Investigation Group P are presented below.

Analytical Results

Soil samples from Investigation Group P were collected from boreholes C6392, C6394, C6400, C6402, C6404, and C6406 at depths ranging from 2 to 52 m (6 to 169.75 ft) bgs. Soil samples were analyzed for primary and secondary contaminants, including inorganic analytes (including general chemistry parameters), radionuclides, and organic constituents (including pesticides, PCBs, SVOCs).

Primary and secondary constituents reported above background at Investigation Group P included 19 inorganics and 9 radionuclides.

No background comparison values were available for 32 primary constituents or 21 secondary constituents detected at Investigation Group P. A summary of primary and secondary inorganic and radionuclide constituents reported above background are presented in Appendix N. Stratigraphy plots of maximum concentrations of primary and secondary analytes by depth are provided in Appendix O.

Summary statistics for extent of contamination for Phase 2 soil analytical data exceeding Hanford Site background or detected without background values available for comparison are presented in Appendix P. The extent of contamination at Investigation Group P ranged from 2 to 52 m (6 to 170 ft) bgs.

Inorganic Chemicals and General Chemistry Parameters

Seventeen primary and two secondary inorganic analytes and general chemistry parameters were reported above background at Investigation Group P at depths ranging from 2 to 52 m (6 to 170 ft) bgs. Appendix N presents the inorganic and general chemistry results exceeding background by depth and borehole. A summary of maximum reported values and their geologic strata by borehole is presented below.

- Antimony was reported above background in 30 samples from Investigation Group P. The maximum reported concentration was 18,100 µg/kg at a depth of 11 m (37 ft) bgs (H1) from borehole C6394, however, this result was reported as a non-detect. The highest detected concentration was 367 µg/kg from borehole C6402 at a depth of 2 m (7 ft) bgs (backfill). The maximum depth of detection above background was 5 m (15 ft) bgs (backfill) from borehole C6392.

- Arsenic was reported above background in six samples from borehole C6394. The maximum reported concentration was 11,200 µg/kg at a depth of 11 m (37 ft) bgs (H1), which was also the maximum depth of detection. Concentrations exceeding background were reported at a maximum depth of 52 m (169 ft) bgs (H2), however these values were reported as non-detects.

- Cadmium was reported above background in six samples from borehole C6394. The maximum reported concentration was 1,690 µg/kg at a depth of 11 m (37 ft) bgs (H1). The maximum depth of detection was 52 m (169 ft) bgs (H2).

- Chromium was reported above background in five samples from Investigation Group P. The maximum reported concentration was 32,700 µg/kg at a depth of 52 m (169 ft) bgs (H2) from borehole C6494. The maximum depth of detection was 52 m (169 ft) bgs (H2) at borehole C6494.

- Lead was reported above background in two samples from borehole C6394. The maximum reported concentration was 14,100 µg/kg at a depth of 11 m (37 ft) bgs (H1), which was also the maximum depth of detection.

- Molybdenum was reported above background in all 30 samples from Investigation Group P, with a maximum concentration of 20,200 µg/kg at a depth of 5 m (15 ft) bgs (backfill) from C6392. It should be noted however that all reported concentrations exceeding background for Investigation Group P were reported as non-detects.

- Nickel was reported above background in five samples from Investigation Group P. The maximum reported concentration was 30,600 µg/kg at a depth of 8 m (26 ft) bgs (H1) from borehole C6392. The maximum depth of detection above background was 52 m (169 ft) bgs (H2) at borehole C6394.

- Selenium was reported above background in six samples from borehole C6394 with a maximum concentration of 18,100 µg/kg at a depth of 11 m (37 ft) bgs (H1). It should be noted that all selenium results reported above background were reported as non-detects.

- Silver was reported above background in ten samples from Investigation Group P. The maximum reported concentration was 933 µg/kg at a depth of 11 m (37 ft) bgs (H1) from borehole C6394. The maximum depth of detection was 13 m (43 ft) bgs (H2) from borehole C6404.

- Sodium was reported above background in eight samples from Investigation Group P. The maximum reported concentration was 1,930,000 µg/kg from a depth of 5 m (15 ft) bgs (backfill) at borehole C6392. The maximum depth of detection was 13 m (43 ft) bgs (H2) from borehole C6406.

- Thallium was reported above background in six samples from borehole C6394. The maximum reported concentration was 20,800 µg/kg at a depth of 11 m (37 ft) bgs (H1). All subsequent results exceeding background at deeper depths were reported as non-detects.

- Uranium was reported above background in 24 samples from Investigation Group P. The maximum reported concentration was 10,1000 µg/kg at a depth of 5 m (15 ft) bgs (backfill) from borehole C6392. While all uranium results were above background, they were reported as not detected. One result for calculated total uranium, estimated from isotopic ratios of uranium radioisotopes, was reported above background at a depth of 13 m (43 ft) bgs (H1) and a concentration of 6440 µg/kg from borehole C6404.

- Vanadium was reported above background in two samples from borehole C6404. The maximum reported concentration was 110,000 at a depth of 5 m (15 ft) bgs (backfill). The maximum depth of detection above background was at 6 m (19 ft) bgs (H1).

- Zinc was reported above background in two samples from Investigation Group P. The maximum reported concentration was 305,000 µg/kg at a depth of 3.4 m (11 ft) bgs (backfill) from borehole C6400. The maximum depth of detection above background was at 52 m (169 ft) bgs (H2) from borehole C6394.

- Mercury was reported above background in six samples from Investigation Group P. The maximum reported concentration was 22.1 µg/kg reported as a non-detect at a depth of 8 m (26 ft) bgs (H1) from borehole C6392. The maximum depth of detection above background was 4.7 m (15.5 ft) bgs (backfill) from borehole C6404.

- Fluoride was reported above background in five samples from Investigation Group P. The maximum reported concentration was 7,410 µg/kg at a depth of 11 m (37 ft) bgs (H1) from borehole C6394. The maximum depth of detection above background was 13 m (43 ft) bgs (H2) form borehole C6404.

- Nitrate was reported above background in one sample from borehole C6404 with a concentration of 143,000 µg/kg at a depth of 13 m (43 ft) bgs (H2).

- Phosphate, a secondary analyte, was reported above background in 19 samples from Investigation Group P. The maximum reported concentration was 11,600 µg/kg at a depth of 5 m (15 ft) bgs (backfill) from borehole C6392. The maximum depth of detection above background was 13 m (43 ft) bgs (H2) from borehole C6404.

- Boron, a secondary analyte, was reported above background in six samples from borehole C6394. The maximum reported concentration was 5,430 µg/kg at a depth of 11 m (37 ft) bgs (H1), however, all results for boron were reported as non-detects.

Eight primary and 17 secondary general chemistry and inorganic constituents for which there are no Hanford Site background values were detected at Investigation Group P. Detected primary compounds included phosphorus, strontium, acetate, ammonium ion, formate, nitrite, oxalate, and sulfide. Detected secondary compounds included cerium, europium, lanthanum, neodymium, palladium, praseodymium, rubidium, ruthenium, silicon, sulfur, tantalum, tin, titanium, tungsten, yttrium, zirconium, and bromide. A summary of all detected concentrations by borehole and depth is presented in Appendix N.

Radionuclide Analytes

Nine primary and two secondary radionuclides were reported above background at Investigation Group P at depths ranging from 2 to 51.74 m (6 to 169.75 ft) bgs. Appendix N presents the radionuclide results exceeding background by depth and borehole. Appendix O presents stratigraphy plots of maximum results by depth and borehole. Maximum results and maximum depth of detection for radionuclides exceeding background are summarized below.

- Cesium-137 was reported above background (or detected at depths where background does not apply) in 13 samples from Investigation Group P. The maximum reported concentration was 73.1 pCi/g at a depth of 5 m (15 ft) bgs (backfill) from borehole C6392. The maximum depth of detection was 13 m (43 ft) bgs (backfill) from borehole C6392.

- Cobalt-60 was reported above background in 30 samples from Investigation Group P. The maximum reported concentration was 3.13 pCi/g at a depth of 2.1 m (7 ft) bgs (backfill) from borehole C6402, however this result was reported as a non-detect. The maximum depth of detection above background was 11 m (37 ft) bgs (H1) at borehole C6394. It should be noted that ^{60}Co was only reported as detected in two samples from borehole C6392 and three samples from borehole C6394, the remaining 25 results exceeding background were reported as non-detects.

- Europium-154 was reported above background in 30 samples from Investigation Group P. The maximum reported result was 9.45 pCi/g at a depth of 3.4 m (11 ft) bgs (backfill) from borehole C6406, however, this result was reported as a non-detect. The maximum depth of detection above background was 6.3 m (20.5 ft) bgs (H1) from borehole C6392. It should be noted that ^{154}Eu was only detected in one sample from Investigation Group P with a concentration of 2.28 pCi/g at a depth of 6.3 m (20.5 ft) bgs (H1). The 29 remaining results above background were reported as non-detects.

- Europium-155 was reported above background in 30 samples from Investigation Group P. The maximum reported result was 6.7 pCi/g at a depth of 2.1 m (7 ft) bgs (backfill) from borehole C6402, however, this result was reported as a non-detect. The maximum depth of detection above background was 6.3 m (20.5 ft) bgs (H1) from borehole C6392.

It should be noted that ^{155}Eu was only detected in one sample from Investigation Group P with a concentration of 0.81 pCi/g at a depth of 6.3 m (20.5 ft) bgs (H1). The 29 remaining results above background were reported as non-detects.

- Plutonium-238 was reported above background in 25 samples from Investigation Group P. All results were reported as non-detects. The maximum reported result was 1.48 pCi/g at a depth of 3.4 m (11 ft) bgs (backfill) from borehole C6404.

- Plutonium-239/240 was reported above background in 25 samples from Investigation Group P. The maximum reported concentration was 10.7 pCi/g at a depth of 5 m (15 ft) bgs (backfill) from borehole C6392. All other values exceeding background were reported as non-detects.

- Strontium-90 was reported above background (or detected at depths where background does not apply) in 16 samples from Investigation Group P. The maximum reported concentration was 120 pCi/g at a depth of 5 m (15 ft) bgs (backfill) at borehole C6392. The maximum depth of detection was 18 m (58 ft) bgs (H2) from borehole C6404.

- Uranium-234 was reported above background in two samples from Investigation Group P. The maximum result was 2.76 pCi/g at a depth of 13 m (43 ft) bgs (H2) from borehole C6404. The maximum depth of detection above background was 13 m (43 ft) bgs (H2).

- Uranium-238 was reported above background in one sample with a concentration of 2.15 pCi/g at a depth of 13 m (43 ft) bgs (H2) from borehole C6404.

- Potassium-40, a secondary analyte, was reported above background in two samples. The maximum reported concentration was 19.4 pCi/g at 17.37 m (57 ft) bgs (H1) from borehole C6392. The maximum depth of reporting above background was 40.6 m (133.25 ft) bgs (H2) from borehole C6400.

- Radium-226, a secondary analyte, was reported above background in six samples. All values were reported as non-detects. The maximum reported concentration was 5.26 pCi/g at 11 m (37 ft) bgs (H1) from borehole C6394.

Twelve primary and four secondary radionuclides for which no Hanford Site background value has been established were detected at Investigation Group P. Detected primary constituents included ^{241}Am, ^{125}Sb, ^{14}C, ^{129}I, ^{63}Ni, ^{79}Se, ^{99}Tc, ^{230}Th, tritium, ^{233}U, and^{236}U. Detected secondary contaminants included ^{214}Bi, ^{212}Pb, ^{214}Pb and ^{208}Tl. A summary of detected radionuclide concentrations by borehole and depth is presented in Appendix N.

Detected Organic Analytes

Twelve organic analytes were detected at Investigation Group P at depths ranging from 2 to 41 m (6 to 133 ft) bgs. Appendix N presents the concentrations of detected organic constituents by

borehole and depth. Appendix O presents stratigraphy plots of detected organic constituents by depth and borehole.

- Aroclor-1260 was detected in two samples from Investigation Group P. The maximum detected concentration was 26.8 µg/kg at a depth of 3 m (11 ft) bgs (backfill) from borehole C6402. The maximum depth of detection was 3 m (11 ft) bgs (backfill) in boreholes C6400 and C6402.

- beta-1,2,3,4,5,6-Hexachlorocyclohexane (beta-BHC) was detected in four samples from Investigation Group P. The maximum reported concentration was 25.8 µg/kg from a depth of 2 m (6 ft) bgs (backfill) from borehole C6400. The maximum depth of detection was 5 m (15 ft) bgs (backfill) at borehole C6406.

- Bis(2-ethylhexyl) phthalate was detected in ten samples from Investigation Group P. The maximum reported result was 5,050 µg/kg at a depth of 13 m (43 ft) bgs (H1) from borehole C6392. The maximum depth of detection was 40.6 m (133.2 ft) bgs (H2) from borehole C6400.

- Di-n-butylphthalate was detected in four samples from borehole C6404. The maximum detected concentration was 863 µg/kg from a depth of 2.1 m (7 ft) bgs (backfill). The maximum depth of detection was 10 m (32 ft) bgs (H1).

- Ethylene glycol was detected in two samples from borehole C6392. The maximum result was 1,030 µg/kg from a depth of 13 m (43 ft) bgs (H1), with a maximum depth of detection of 17 m (57 ft) bgs (H2).

- 1,1-Dichloroethene was detected in one sample from borehole C6404 at a depth of 18 m (58 ft) bgs (H2) and a concentration of 0.323 µg/kg.

- Acetone was detected in 16 samples from Investigation Group P. The maximum detected concentration was 13.1 µg/kg at a depth of 3 m (11 ft) bgs (backfill) from borehole C6406. The maximum depth of detection was 40.6 m (133.2 ft) bgs (H2) at borehole C6400.

- Carbon disulfide was detected in one sample from borehole C6406 at a depth of 6 m (19 ft) bgs (H1) and a concentration of 0.261 µg/kg.

- Methylene chloride was detected in five samples from borehole C6404. The maximum detected concentration was 2.61 µg/kg at a depth of 5 m (15 ft) bgs (backfill). The maximum depth of detection was 8 m (27 ft) bgs (H1).

- Toluene was detected in two samples from borehole C6392 with a maximum concentration of 1.36 µg/kg at a depth of 6.3 m (20.5 ft) bgs (H1). The maximum depth of detection was 6.3 m (20.5 ft) bgs (H1).

- Total petroleum hydrocarbons - diesel range were detected in seven samples from Investigation Group P. The maximum detected result was 135,000 µg/kg from borehole C6402 at a depth of 5 m (15 ft) bgs (backfill). The maximum depth of detection was 5 m (15 ft) bgs (H1).

- Total petroleum hydrocarbons - gasoline range were detected in one sample from borehole C6402 with a concentration of 100 µg/kg at a depth of 2.1 m (7 ft) bgs (backfill).

Site Contamination at Investigation Site R (Borehole C7668)

Phase 2 sampling of Site R (borehole C7668) characterized the extent of contamination associated with a potential release at C-301 Catch Tank. Direct push soil sampling and direct push logging were performed. The results of laboratory analyses for soil at Site R are presented below.

Analytical Results

Soil samples from Site R were collected from borehole C7668 at depths ranging from surface 0.15 to 41 m (0.5 to 133 ft) bgs. Soil samples were analyzed for primary and secondary contaminants, including inorganic analytes (including general chemistry parameters), radionuclides, and organic constituents (including pesticides, PCBs, SVOCs).

Primary and secondary constituents reported above background at Site R included seven inorganics and seven radionuclides.

No background comparison values were available for 19 primary constituents or 14 secondary constituents detected at Site R. A summary of primary and secondary inorganic and radionuclide constituents reported above background are presented in Appendix N. Stratigraphy plots of maximum concentrations of primary and secondary analytes by depth are provided in Appendix O.

Summary statistics for extent of contamination for Phase 2 soil analytical data exceeding Hanford Site background or detected without background values available for comparison are presented in Appendix P. The extent of contamination at Site R ranged from 0.15 to 41 m (0.5 to 133 ft) bgs.

Inorganic Chemicals and General Chemistry Parameters

Six primary and one secondary inorganic analytes and general chemistry parameters were reported above background at Site R at depths ranging from 0.15 to 41 m (0.5 to 133 ft) bgs. Appendix N presents the inorganic and general chemistry results exceeding background by depth and borehole. A summary of maximum reported values and their geologic strata by borehole is presented below.

- Antimony was reported above background in six samples from borehole C7668 with a maximum concentration of 303 µg/kg at a depth of 9 m (28 ft) bgs (H1). The maximum depth of detection above background was 41 m (133 ft) bgs (H2).

- Cadmium was reported above background in nine samples from borehole C7668 with a maximum concentration of 3,470 µg/kg at a depth of 2 m (6 ft) bgs (backfill). The maximum depth of detection above background was 41 m (133 ft) bgs.

- Molybdenum was reported above background in nine samples from borehole C7668 with a maximum concentration of 2,230 µg/kg, at a depth of 9 m (28 ft) bgs (H1). All molybdenum results exceeding background were reported as non-detects.

- Thallium was reported above background in six samples from borehole C7668 with a maximum result of 1,220 µg/kg at a depth of 0.15 m (0.5 ft) bgs (backfill). The maximum depth of detection above background was 9 m (28 ft) bgs (H1).

- Mercury was reported above background in one sample from borehole C7668 with a concentration of 13.5 µg/kg at a depth of 0.15 m (0.5 ft) bgs (backfill).

- Fluoride was reported above background in one sample from borehole C7668 with a concentration of 3,530 µg/kg at a depth of 4 m (12 ft) bgs (backfill).

- Phosphate, a secondary analyte, was reported above background in six samples from borehole C7668 with a maximum concentration of 2,960 µg/kg at a depth of 0.15 m (0.5 ft) bgs (backfill).

Eight primary and nine secondary general chemistry and inorganic constituents for which there are no Hanford Site background values were detected at Site R. Detected primary compounds included phosphorus, strontium, acetate, ammonium ion, formate, nitrite, oxalate, and sulfide. Detected secondary compounds included bismuth, cerium, europium, lanthanum, silicon, sulfur, titanium, yttrium, and zirconium. A summary of all detected concentrations by borehole and depth is presented in Appendix N.

Radionuclide Analytes

Six primary and one secondary radionuclide were reported above background at Site R at depths ranging from 0.15 to 41 m (0.5 to 133 ft) bgs. Appendix N presents the radionuclide results exceeding background by depth and borehole. Appendix O presents stratigraphy plots of maximum results by depth and borehole. Maximum results and maximum depth of detection for radionuclides exceeding background are summarized below.

- Strontium-90 was reported above background (or detected at depths where background does not apply) in two samples from Site R. The maximum reported concentration was 1.19 pCi/g at a depth of 0.15 m (0.5 ft) bgs (backfill), which was reported as a non-detect. The maximum depth of detection was 0.15 m (0.5 ft) bgs (backfill) with a concentration of 0.371 pCi/g.

- Potassium-40, a secondary analyte, was reported above background in one sample. The maximum reported concentration was 18.1 pCi/g at 25 m (81 ft) bgs (H2) from borehole C7668.

Cobalt-60, ^{154}Eu, ^{155}Eu, ^{238}Pu, and $^{239/240}$Pu were reported above background in all six samples and depths from borehole C7668, however, all results were reported as non-detects.

Five primary and three secondary radionuclides for which no Hanford Site background value has been established were detected at Site R. Detected primary constituents included, ^{79}Se, ^{99}Tc, ^{126}Sn, tritium, and ^{233}U. Detected secondary contaminants included ^{214}Bi, ^{212}Pb, and ^{214}Pb. A summary of detected radionuclide concentrations by borehole and depth is presented in Appendix N.

Detected Organic Analytes

Eight organic analytes were detected at Site R at depths ranging from 0.15 to 41 m (0.5 to 133 ft) bgs. Appendix N presents the concentrations of detected organic constituents by borehole and depth. Appendix O presents stratigraphy plots of detected organic constituents by depth and borehole.

- Butylbenzylphthalate was detected in seven samples from borehole C7668 with a maximum concentration of 114 µg/kg at a depth of 12 m (40 ft) bgs (H1). The maximum depth of detection was 41 m (133 ft) bgs (H2).

- Di-n-octylphthalate was detected in four samples from borehole C7668 with a maximum concentration of 572 µg/kg at a depth of 4 m (12 ft) bgs (backfill). The maximum depth of detection was 9 m (28 ft) bgs (H1).

- 2-Hexanone was detected in three samples from borehole C7668 with a maximum concentration of 2.77 µg/kg at a depth of 2 m (6 ft) bgs (backfill). The maximum depth of detection was 3.4 m (11 ft) bgs (backfill).

- 3-Heptanone was detected in one sample from borehole C7668 with a concentration of 3.3 µg/kg at a depth of 9 m (28 ft) bgs (H1).

- Acetone was detected in six samples from borehole C7668 with a maximum concentration of 10 µg/kg at a depth of 41 m (133 ft) bgs (H2). The maximum depth of detection was 41 m (133 ft) bgs (H2).

- Methylene chloride was detected in four samples from borehole C7668 with a maximum concentration of 6.9 µg/kg at a depth of 41 m (133 ft) bgs (H2). The maximum depth of detection was 41 m (133 ft) bgs (H2).

- Toluene was detected in five samples from borehole C7668 with a maximum concentration of 0.592 µg/kg at a depth of 0.15 m (0.5 ft) bgs (backfill). The maximum depth of detection was 9 m (28 ft) bgs (H1).

- Trichloromonofluoromethane was detected in three samples from borehole C7668 with a maximum concentration of 11 µg/kg in two samples from two separate depths (12 m [40 ft] bgs [H1] and 41 m [133 ft] bgs [H2], respectively).

Site Contamination at Investigation Site U (Borehole C7676)

Site U (borehole C7676) was sampled using direct push soil sampling and direct push logging to characterize a presumed tank release from Tank C-110. Results of laboratory analyses for soil at Site U are summarized below.

Analytical Results

Soil samples from Site U were collected from borehole C7676 at depths ranging from surface 0.15 to 48 m (0.5 to 158 ft) bgs (H2). Soil samples were analyzed for primary and secondary contaminants, including inorganic analytes (including general chemistry parameters), radionuclides, and organic constituents (including pesticides, PCBs, SVOCs).

Primary and secondary constituents reported above background at Site U included ten inorganics and nine radionuclides.

No background comparison values were available for 21 primary constituents or 13 secondary constituents detected at Site U. A summary of primary and secondary inorganic and radionuclide constituents reported above background are presented in Appendix N. Stratigraphy plots of maximum concentrations of primary and secondary analytes by depth are provided in Appendix O.

Summary statistics for extent of contamination for Phase 2 soil analytical data exceeding Hanford Site background or detected without background values available for comparison are presented in Appendix P. The extent of contamination at Site U ranged from 0.15 to 48 m (0.5 to 158 ft) bgs.

Inorganic Chemicals and General Chemistry Parameters

Eight primary and two secondary inorganic analytes and general chemistry parameters were reported above background at Site U at depths ranging from surface 0.15 to 48 m (0.5 to 158 ft) bgs. Appendix N presents the inorganic and general chemistry results exceeding background by depth and borehole. A summary of maximum reported values and their geologic strata by borehole is presented below.

- Antimony was reported above background in seven samples from borehole C7676 with a maximum concentration of 300 µg/kg reported at depths of 39 and 48 m (129 and 158 ft) bgs (H2). The maximum concentrations were reported as non-detects. The

maximum depth of detection above background was 5 m (16 ft) bgs (backfill) with a concentration of 139 µg/kg.

- Arsenic was reported above background in two samples from borehole C7676. The maximum concentration was 20,000 µg/kg at a depth of 5 m (16 ft) bgs (backfill), which was also the maximum depth of detection above background.

- Chromium was reported above background in one sample from borehole C7676 at a concentration of 44,500 µg/kg and the maximum sampling depth of 48 m (158 ft) bgs (H2).

- Molybdenum was reported above background in eight samples from borehole C7676 with a maximum concentration of 2,380 µg/kg at a depth of 0.15 m (0.5 ft) bgs (backfill). The maximum depth of detection above background was the deepest depth sampled, at 48 m (158 ft) bgs (H2).

- Nickel was reported above background in one sample from borehole C7676 with a concentration of 29,400 µg/kg at a depth of 48 m (158 ft) bgs (H2).

- Selenium was reported above background in eight samples from borehole C7676 with a maximum concentration of 2,000 µg/kg at a depth of 2 m (7 ft) bgs (backfill). The maximum depth of detection was 48 m (158 ft) bgs (H2).

- Mercury was reported above background in one sample from borehole C7676 with a concentration of 20.6 µg/kg at a depth of 0.15 m (0.5 ft) bgs (backfill).

- Nitrate was reported above background in one sample from borehole C7676 with a concentration of 71,600 µg/kg at a depth of 39 m (129 ft) bgs (H2).

- Phosphate, a secondary analyte, was reported above background in four samples from borehole C7676. The maximum reported concentration was 1,640 µg/kg at a depth of 0.15 m (0.5 ft) bgs (backfill). The maximum depth of detection above background was 5 m (16 ft) bgs (backfill).

- Boron, a secondary analyte, was detected in one sample from borehole C7676 with a concentration of 6,420 µg/kg at a depth of 0.15 m (0.5 ft) bgs (backfill).

Eight primary and eight secondary general chemistry and inorganic constituents for which there are no Hanford Site background values were detected at Site U. Detected primary compounds included phosphorus, strontium, acetate, ammonium ion, formate, nitrite, oxalate, and sulfide. Detected secondary compounds included cerium, lanthanum, neodymium, silicon, sulfur, titanium, yttrium, and zirconium. A summary of all detected concentrations by borehole and depth is presented in Appendix N.

Radionuclide Analytes

Eight primary and one secondary radionuclide were reported above background at Site U at depths ranging from surface 0.15 to 48 m (0.5 to 158 ft) bgs. Appendix N presents the radionuclide results exceeding background by depth and borehole. Appendix O presents stratigraphy plots of maximum results by depth and borehole. Maximum results and maximum depth of detection for radionuclides exceeding background are summarized below.

- Cesium-137 was reported above background (or detected at depths where background does not apply) in two samples from borehole C7676. The maximum reported concentration was 2.06 pCi/g at a depth of 0.15 m (0.5 ft) bgs (backfill), which was the maximum depth of detection.

- Strontium-90 was reported above background (or detected at depths where background does not apply) in two samples from borehole C7676. The maximum reported concentration was 4.2 pCi/g at a depth of 0.15 m (0.5 ft) bgs (backfill), which was also the maximum depth of detection.

- Thorium-232 was reported above background in one sample from borehole C7676 with a concentration of 1.8 pCi/g at a depth of 5 m (16 ft) bgs (backfill).

- Potassium-40, a secondary analyte, was reported above background in one sample. The maximum reported concentration was 21.7 pCi/g at 48 m (158 ft) bgs (H2) from borehole C7676.

Cobalt-60, ^{154}Eu, ^{155}Eu, ^{238}Pu, and $^{239/240}$Pu were reported above background in all eight samples and depths from borehole C7676, however, all results were reported as non-detects.

Nine primary and one secondary radionuclide for which no Hanford Site background values have been established were detected at Site U. Detected primary constituents included ^{14}C, ^{237}Np, ^{79}Se, ^{99}Tc, ^{230}Th, ^{126}Sn, tritium, ^{233}U, and ^{236}U. Lead-214 was the only secondary radionuclide detected. A summary of detected radionuclide concentrations by borehole and depth is presented in Appendix N.

Detected Organic Analytes

Eight organic analytes were detected at Site U at depths ranging from surface 0.15 to 48 m (0.5 to 158 ft) bgs. Appendix N presents the concentrations of detected organic constituents by borehole and depth. Appendix O presents stratigraphy plots of detected organic constituents by depth and borehole.

- 2-Butanone was detected in one sample from borehole C7676 with a concentration of 13.8 μg/kg at a depth of 48 m (158 ft) bgs (H2).

- 2-Pentanone was detected in one sample from borehole C7676 with a concentration of 6.8 μg/kg at a depth of 48 m (158 ft) bgs (H2).

- 3-Heptanone was detected in one sample from borehole C7676 with a concentration of 11 µg/kg at a depth of 48 m (158 ft) bgs (H2).

- Acetone was detected in three samples from borehole C7676 with a maximum concentration of 25.7 µg/kg at a depth of 48 m (158 ft) bgs (H2), which was the maximum depth of detection.

- Benzene was detected in one sample from borehole C7676 with a concentration of 0.328 µg/kg at a depth of 5 m (15 ft) bgs (backfill).

- Hexane was detected in one sample from borehole C7676 with a concentration of 4.16 µg/kg at a depth of 48 m (158 ft) bgs (H2).

- Styrene was detected in two samples from borehole C7676 with a maximum concentration of 0.377 µg/kg at a depth of 0.15 m (0.5 ft) bgs (backfill). The maximum depth of detection was 48 m (158 ft) bgs (H2).

- Toluene was detected in seven samples from borehole C7676 with a maximum concentration of 0.738 µg/kg at a depth of 0.15 m (0.5 ft) bgs (backfill). The maximum depth of detection was 48 m (158 ft) bgs (H2)

Site Contamination at Well 299-E27-20

Four archived soil samples were analyzed to evaluate the potential release of ^{99}Tc at well 299-E27-20 at depths ranging from 79 to 84 m (260 to 275 ft) bgs. Technetium-99 has been identified in groundwater in the area.

Of the four soil samples collected from well 299-E27-20 analyzed for nitrate and ^{99}Tc, all results for nitrate were below background and all ^{99}Tc results were reported as non-detects. Neither nitrate nor ^{99}Tc were retained for further analysis at this location.

Site Contamination at Well 299-E27-24

Four archived soil samples collected from well 299-E27-24 at depths ranging from 75 to 79 m (247 to 260 ft) bgs were analyzed for pH, nitrate, and ^{99}Tc. pH measurements ranged from 8.53 to 8.7, showing slight alkalinity. All nitrate results were below Hanford Site background and ^{99}Tc was not detected in any of the soil sampling intervals from well 299-E27-24.

5.1.5 Summary of Phase 2 Soil Investigation Results

Of the 230 primary and secondary constituents measured during the Phase 2 WMA C investigation, 39 inorganic and radionuclide constituents were reported at concentrations exceeding Hanford Site background. An additional 83 primary or secondary inorganic, organic and radionuclide analytes were detected without a Hanford Site background value available for comparison. Of the 122 constituents, 23 are considered to be dangerous waste constituents (see

Appendix R for the list of dangerous waste constituents). Dangerous waste constituents are defined in WAC 173-303.

Appendix R also provides a comprehensive summary these exceedances by constituent along with identifying the number of investigation sites/groups impacted by the constituents (i.e., number of areas encountered). Exceedances are identified as occurring within shallow and deep soils for each investigation site/group (i.e., denoted with "S" for shallow and/or "D" for deep exceedances).

The text below briefly summarizes the frequency of occurrence of primary and secondary constituents across WMA C.

Constituents having exceedances at all investigation sites, both shallow and deep included:

- Acetate
- Ammonium ion
- Antimony
- Cerium
- Cobalt-60
- Europium-154
- Europium-155
- Formate
- Lanthanum
- Molybdenum
- Nitrite
- Oxalate
- Phosphate
- Phosphorus
- Plutonium-238
- Plutonium-239/240
- Silicon
- Strontium
- Strontium-90
- Sulfur
- Titanium
- Yttrium
- Zirconium

Constituents having only shallow exceedances (investigation site/group):

- Barium (J)
- Magnesium (C)
- Palladium (F+G, P)
- Rubidium (P)
- Antimony-125 (J, P)

- Iodine-129 (P)
- Total petroleum hydrocarbons - gasoline range (E)
- Aldrin (A+B)
- Aroclor-1254 (F+G, P)
- Aroclor-1260 (F+G)
- Gamma-BHC (Lindane) (F+G, P)
- Ethylene glycol (P)
- (m+p)-Xylene (F+G)
- 1-Butanol (L1+L2)
- o-Xylene (F+G)
- Xylenes (total) (F+G)

Constituents having only deep exceedances (investigation site/group):

- 2-Hydroxyacetate (L1+L2)
- Copper (L1+L2)
- Nickel (E, L1+L2, P U)
- Manganese-54 (A+B)
- Thorium-232 (U)
- Uranium-235 (P)
- Uranium-238 (P)
- Zinc-65 (A+B)
- 1,1-Dichloroethene (P)
- 2-Pentanone (U)
- 3-Heptanone (H+I, R, U)
- 4-Methyl-2-pentanone (F+G)
- Carbon disulfide (P)
- Tetrahydrofuran (H+I, J)
- Trichloromonofluoromethane (R)

Inorganic constituents most widely reported above background included antimony, molybdenum, and phosphate. Antimony and molybdenum were reported above background in both shallow and deep soil samples from all investigation sites/groups. Phosphate was reported above background in shallow soil samples from all investigation sites/groups, but above background in deep soils at eight of ten investigation sites/groups.

Radionuclide constituents most widely reported above background included ^{60}Co, ^{154}Eu, ^{155}Eu, ^{238}Pu, $^{239/240}$Pu, and^{90}Sr. With the exception of ^{90}Sr the aforementioned constituents were reported above background in both shallow and deep soils from all locations. Strontium-90 was reported above background in shallow and deep soils from all locations except Sites R and U, where it was reported only in shallow soils.

Organic constituents were sparsely detected in soils collected at WMA C during the Phase 2 investigation.

5.2 GEOPHYSICAL LOGGING

As indicated in Section 4 of this report, geophysical logging activities were completed in all phases of the RFI. This section summarizes Pre-RFI, Phase 1, and Phase 1.5 geophysical logging activities and results from the documents shown in Table 5-5. Phase 2 logging reports, for the most part, are identified in Table 4-3. Any relevant logging report to Phase 2, not identified in Table 4-3, will be provided in the subsequent sections. Additionally, Appendix S shows selected groupings and statistical results for spectral gamma obtained since 1997 and Appendix T provides logging results that are being used to support the Phase 2 RFI effort. Note that quarterly and annual monitoring was conducted as a function of routine monitoring from 2001 to 2005 and monitoring was also conducted during tank waste retrievals.

Table 5-5. Pre-RFI, Phase 1, and Phase 1.5 Geophysical Logging Documentation

Location	Activity	Documents
PRE-RFI		
C Farm Drywells	Gross gamma Logging 1974 -1994	RPP-8321, *Analysis & Summary Report of Historical Dry Well Gamma Logs for the 241-C Tank Farm - 200 East Area*
C Farm Drywells	Spectral gamma logging, 1997 and repeat logging/ high rate logging, 1999.	GJPO-HAN-18, *Vadose Zone Characterization Project at the Hanford Tank Farms: C Tank Farm Report.* GJO-98-39-TARA/ GJO-HAN-18, *Vadose Zone Characterization Project at the Hanford Tank Farms: Addendum to the C Tank Farm Report.*
Tank C-101	Spectral gamma logging, 1997	GJ-HAN-85, *Vadose Zone Characterization Project at the Hanford Tank Farms: Tank Summary data Report for Tank C-101.*
Tank C-102	Spectral gamma logging, 1997	GJ-HAN-86, *Vadose Zone Characterization Project at the Hanford Tank Farms: Tank Summary data Report for Tank C-102.*
Tank C-103	Spectral gamma logging, 1997	GJ-HAN-82, *Vadose Zone Characterization Project at the Hanford Tank Farms: Tank Summary data Report for Tank C-103.*
Tank C-104	Spectral gamma logging, 1997	GJ-HAN-87, *Vadose Zone Characterization Project at the Hanford Tank Farms: Tank Summary data Report for Tank C-104.*
Tank C-105	Spectral gamma logging, 1997	GJ-HAN-83, *Vadose Zone Characterization Project at the Hanford Tank Farms: Tank Summary data Report for Tank C-105.*
Tank C-106	Spectral gamma logging, 1997	GJ-HAN-84, *Vadose Zone Characterization Project at the Hanford Tank Farms: Tank Summary data Report for Tank C-106.*
Tank C-107	Spectral gamma logging, 1997	GJ-HAN-88, *Vadose Zone Characterization Project at the Hanford Tank Farms: Tank Summary data Report for Tank C-107.*
Tank C-108	Spectral gamma logging, 1997	GJ-HAN-90, *Vadose Zone Characterization Project at the Hanford Tank Farms: Tank Summary data Report for Tank C-108.*
Tank C-109	Spectral gamma logging, 1997	GJ-HAN-91, *Vadose Zone Characterization Project at the Hanford Tank Farms: Tank Summary data Report for Tank C-109.*
Tank C-110	Spectral gamma logging, 1997	GJ-HAN-92, *Vadose Zone Characterization Project at the Hanford Tank Farms: Tank Summary data Report for Tank C-110.*
Tank C-111	Spectral gamma logging, 1998	GJ-HAN-85, *Vadose Zone Characterization Project at the Hanford Tank Farms: Tank Summary data Report for Tank C-101.*

Table 5-5. Pre-RFI, Phase 1, and Phase 1.5 Geophysical Logging Documentation

Location	Activity	Documents
Tank C-112	Spectral gamma logging	GJ-HAN-85, *Vadose Zone Characterization Project at the Hanford Tank Farms: Tank Summary data Report for Tank C-101.*
UPR-200-E-82, near diversion box 241-C-152	10 auger holes drilled to 9.1 m (30 ft) bgs depth and sampled	ARH-1945, *B-Plant Ion Exchange Feed Line Leak.*
PHASE 1		
Borehole C4297, near Tank C-105	Drill, log and sample borehole	RPP-32073, *Completion Report for C4297 (C-105) C Tank Farm Drilling and Sampling*
UPR-82, near diversion box 241-C-152	Vertical and Slant direct pushes, logging and sampling	RPP-34644, *Small Diameter Geophysical Logging at the 241-C-152 Diversion Box.* RPP-34643, *Small Diameter Slant-Hole Logging at the 241-C-152 Diversion Box.*
Borehole 299-E27-22, NE of C Farm	Drill, log and sample borehole	PNNL-14656, *Borehole Data Package for Four CY 2003 RCRA Wells 299-E27-4, 299-E27-21, 299-E27-22, and 299-E27-23 at Single-Shell Tank, Waste Management Area C, Hanford Site, Washington.*
PHASE 1.5		
UPR-200-E-81, near 241-CR-151 Vault	Vertical direct pushes, logging and sampling.	RPP-38927, *Completion Report for the 241-CR-151 Vault (UPR-200-E-81) Direct Push Characterization and Sampling.*
UPR-200-E-86, near	Vertical direct pushes, logging and sampling.	RPP-37625, *Completion Report for UPR-200-E-86 Direct Push Drilling and Sampling*

5.2.1 Pre-RFI Drywell Logging

Two types of geophysical logging data have been collected for WMA C from a set of drywells placed around and between C Farm tanks (Figure 4-3). Since the 1950s, gross gamma logging has been used as a secondary tank leak monitoring system. In practice, strategically placed shallow boreholes, called drywells, extending 24 to 46 m (80 to 150 ft) bgs were routinely monitored for changes in total gamma activity. The gross gamma-logging data were digitized and electronic data was obtained from 1974 until about 1994. Several drywells were identified where changes in the gamma flux were taking place. The mobile gamma-emitting radionuclide tracked in the gamma-logging data was identified as ^{60}Co ($t_{1/2}$ = 5.271 yr), a known mobile radionuclide that occurs in a number of tank waste types. This contamination was moving downward at approximately 0.3 to 0.6 m (1 to 2 ft)/yr.

In 1997, a spectral gamma logging system (SGLS) was used to assess the nature and extent of gamma-emitting radionuclides in the C Farm vadose.

The gamma-emitting contaminants ^{137}Cs ($t_{1/2}$ = 30.17 yr), ^{60}Co ($t_{1/2}$ = 5.271 yr), ^{152}Eu ($t_{1/2}$ = 13 yr), and ^{154}Eu ($t_{1/2}$ = 8.5 yr) were detected in the drywells.

RPP-35484 summarizes Pre-RFI C Farm logging results as follows.

In drywell 30-01-09, near Tank C-101, a ^{137}Cs peak of ~600 pCi/g was measured at 9 m (28 ft) bgs along with traces of ^{60}Co, ^{152}Eu, and ^{154}Eu. The position of this peak suggests a small isolated leak from piping or a spare inlet port at this location. The SGLS indicated a second small ^{137}Cs peak (about 50 pCi/g) at around 12 m (40 ft) bgs near drywell 30-01-06. The logging results appeared to be inconsistent with an assumed 75,708.24 L (20,000 gal) leak from the tank.

Although Tank C-111 was designated as a leaking tank based on liquid level decreases, no historical gamma or SGLS data indicate the presence of a leak near this tank and drywell contamination near Tank C-110 was determined to be from a spare inlet overflow.

High gamma activity ($>1x10^7$ pCi/g) was measured near Tank C-105 in drywell 30-05-07, when it was drilled in 1974. Additional drywells were drilled in an attempt to characterize the nature and extent of the plume, but none of drywells encountered the level of gamma activity found in drywell 30-05-07. Large liquid level drops (about 91 cm [36 in.]) were observed in Tank C-105 between 1963 and 1967. Cascade line and spare inlet port waste loss events were identified as release sources for the contamination at drywell 30-05-07 and between Tanks C-104 and C-105 (WHC-SD-EN-TI-185, *Assessment of Unsaturated Zone Radionuclide Contamination around Single-Shell Tank 241-C-105 and 241-C-106,* and LAUR-93-3605, *Analysis of the 241-C Farm*).

Two other drywells indicate outer edges of the plume near Tank C-105. In drywell 30-05-05 just south of drywell 30-05-07, a ^{137}Cs peak (about 70 pCi/g) occurred between 18 and 20 m (60 and 65 ft) bgs and a ^{60}Co peak occurred at 21 m (70 ft) bgs. Proximity of the two drywells, and the consistent ^{137}Cs peaks, suggest the same leak source. Similarly, a ^{137}Cs peak (15 pCi/g) occurred at 14 m (47 ft) bgs in drywell 30-05-08. Cobalt-60 was also present between 11 and 15 m (35 and 50 ft) bgs.

Contamination movement of ^{60}Co has been detected from the vicinity of Tank C-108 laterally to the east and downward to greater than 37 m (120 ft) bgs near drywell 30-06-10. Between Tanks C-108 and C-109, a transfer line leak source is indicated by shallow contamination in drywell 30-08-02. High ^{137}Cs concentrations occurred between 6.1 and 6.7 m (20 and 22 ft) bgs and peak at 1,100 pCi/g in this zone. A ^{154}Eu peak (24 pCi/g) is coincident with ^{137}Cs and the more mobile ^{60}Co is present between 15 and 24 m (50 and 80 ft) bgs at concentrations up to 10 pCi/g. These contaminants were present when the drywell was installed in 1974. This contaminant plume appears to extend at least to drywell 30-06-10, where a similar ^{60}Co plume occurred between 26 and 35 m (86 and 115 ft) bgs at lesser concentrations (up to 1 pCi/g). Cobalt-60 also occurred to a lesser degree in drywell 30-09-01 at 27 to 29 m (90 to 95 ft) bgs. The deep ^{60}Co plumes may have originated from transfer line leaks or may be from another leak source.

Note that drywells were not installed near the 17 m (55 ft) diameter 200-series tanks.

5.2.2 Phase 1 Geophysical Logging

This section provides an overview and summary of observations for the following Phase 1 logging activities:

- Installation of characterization borehole (C4297) near Tank C-105
- Installation of vertical and slant direct pushes around UPR-200-E-82 near diversion box 241-C-152 with gamma measurements in direct-push holes
- Installation and logging of one characterization borehole outside WMA C (299-E27-22 northeast of C Farm).

See Figure 4-4 for Phase 1 borehole and direct push locations.

5.2.2.1 Borehole C4297. Borehole C4297 was constructed in C Farm using a cable-tool (percussion) drilling method. Total depth of the borehole was 60 m (197 ft). Both SGLS and neutron moisture logging were performed in this borehole during March 2004 on four separate days. Higher moisture levels were observed in the top 12 m (40 ft) bgs with peak readings at between 11 and 12 m (35 and 40 ft) bgs, near the base of the C Farm excavation backfill layer.

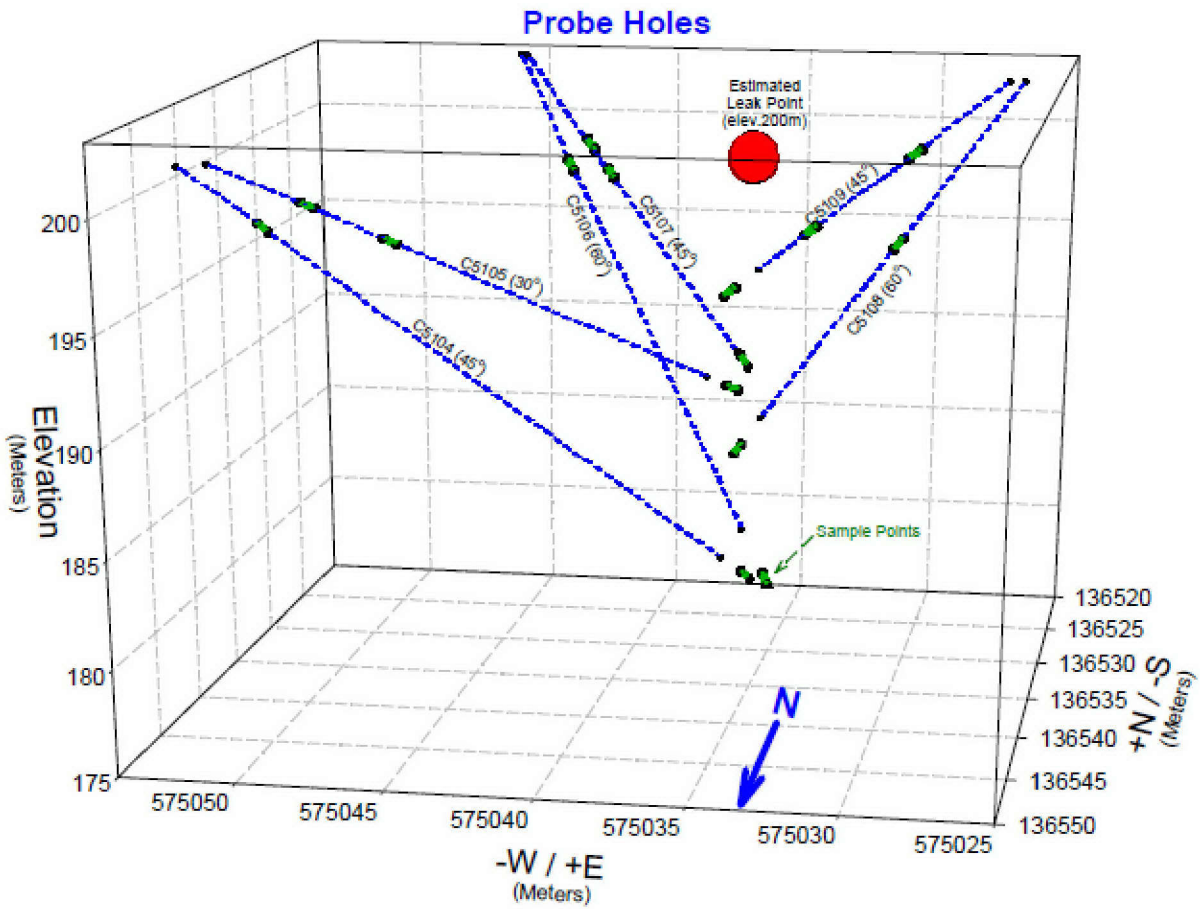
Low levels of ^{60}Co (<1 pCi/g) were found at depths from 12 to 20 m (40 to 65 ft) bgs. Cesium-137 was detected between the ground surface and 6 m (19 ft) in depth at concentrations up to 1,700 pCi/g and ^{154}Eu was detected between 3 and 5 m (11 and 16 ft) bgs at a maximum concentration of 400 pCi/g. The log report states that the profile of the gamma log between 3 and 5 m (11 and 16 ft) bgs is suggestive of a point source of contamination such as a pipeline and may be waste inside a near-by pipeline. No significant ^{137}Cs activity was observed below the base of the tank.

5.2.2.2 UPR-200-E-82 Direct Pushes. From October 2004 to June 2006, 20 vertical direct pushes were pushed and logged to depths of 9 or 18 m (30 or 60 ft) bgs in a rough circle approximately 37 m (120 ft) in diameter that surrounded the location of unplanned release (UPR-200-E-82) near diversion box 241-C-152 (Figure 4-4). The boreholes were placed further from the leak than the 1969 auger holes to determine the extent of contamination. Logging surveys were conducted with three detectors: neutron moisture, gross gamma and spectral gamma.

The moisture surveys identified several zones typically above 9 m (30 ft) with moisture content greater than 10%, many were very thin zones with moisture content greater than 20%. Note that moisture content is considered percent moisture by volume (i.e., volume fraction) and is identified as percent in this report. The moisture content below 9 m (30 ft) is typically less than 8%, except for one zone in borehole C4431 at 11 m (37 ft) that approaches 9%. The rapid-scan gamma surveys encountered only background activity from the natural radionuclides. No surveys encountered ^{137}Cs or any other anthropogenic radionuclide at concentrations approaching the targeted minimum detection threshold of 10 pCi/g (RPP-34644, *Small Diameter Geophysical Logging at the 241-C-152 Diversion Box*).

Because vertical direct push logs showed little or no gamma activity, three pairs of slant direct pushes (six boreholes) were completed at locations northwest, southeast, and northeast of the Gunite cover (Figure 5-1). Logging surveys were conducted with two detectors: NaI (scintillation) gross gamma, and neutron moisture. The gamma activities in all borehole indicate low activity, (count rate levels are at or near the natural background activity), except for C5109 which encountered one zone with elevated count rate. However, the moisture surveys show significant variations with depth. The paired boreholes have similar distribution profiles. Except for the pair (C5108, C5109) which show the most difference between the depth range (elevation): 194 to 199 m (636 to 653 ft). The moisture content is higher near the surface and significantly dryer 6 m (20 ft) bgs in all boreholes. The dry zones are where the boreholes extend below the protective Gunite barrier that was placed over diversion box 241-C-152 (RPP-34643, *Small Diameter Slant-Hole Logging at the 241-C-152 Diversion Box*).

Figure 5-1. UPR-200-E-82 Slant Hole Locations, Drive Angle and Direction



5.2.2.3 Borehole 299-E27-22. Borehole 299-E27-22 (C4124) was drilled using the Becker hammer method between August 21 and September 02, 2003 and completed as a RCRA groundwater monitoring well. The borehole is located just north of the C Farm (Figure 4-4).

Borehole 299-E27-22 was completed to establish a groundwater monitoring location and as an uncontaminated site near WMA C for comparison with other contaminated sites (PNNL-14656, *Borehole Data Package for Four CY 2003 RCRA Wells 299-E27-4, 299-E27-21, 299-E27-22, and 299-E27-23 at Single-Shell Tank, Waste Management Area C, Hanford Site, Washington*). Spectral gamma ray logs were run on September 8, 2003 from ground surface to 81 m (266 ft) bgs. A slight amount of ^{137}Cs near the minimum detection level (MDL, 0.2 pCi/g), was found sporadically throughout the borehole.

5.2.3 Phase 1.5 Geophysical Logging

Phase 1.5 logging was performed for UPR-81 and UPR-86.

5.2.3.1 UPR-81 Direct Pushes. From April 2008 to June 2008, five vertical direct push boreholes were drilled and logged to assess the nature and extent of contamination near the 241-CR-151 Vault (Figure 4-6). The investigation included geophysical logging from total depth to surface on five of the boreholes utilizing a sodium–iodide scintillation gross gamma detector and a neutron moisture probe. Gamma and moisture logging results for push holes C6391, C6393, C6395, C6397, and C6399 are presented in RPP-38406, Small Diameter Geophysical Logging for UPR-200-E-81, and RPP-38927, Completion Report for the 241-CR-151 Vault (UPR-200-E-81) Direct Push Characterization and Sampling. Two of the five boreholes (C6397 and C6399) showed only background activity from the natural radionuclides. Gamma activity, above background levels, was encountered in three boreholes (C6391, C6393, and C6395), with the highest activity occurring at shallow depths. The maximum depth of the gamma-emitting contamination was encountered in borehole C6393 at 13 m (44 ft) bgs. Borehole C6393 also contained the highest gamma activity. The maximum depth of gamma-emitting contamination was less than 4 m (12 ft) bgs in the other two boreholes (C6391 and C6395). The maximum gamma activity encountered was 45,000 pCi/g of 137Cs at 1 m (3 ft) bgs in borehole C6393. The neutron moisture surveys for these boreholes all had unique profiles. However, a high-moisture zone was present at the top of each borehole that extends from the surface to depths of 8 to 14 m (25 to 45 ft) bgs and all five of the boreholes had a moisture peak at approximately 41 m (135 ft) bgs.

5.2.1.1 UPR-86 Direct Pushes. From November 2007 to March 2008, nine direct push boreholes were installed near the southwest corner of WMA C to assess the nature and extent of a 1971 pipeline leak. These boreholes were logged with neutron moisture and gross gamma tools. The logging results showed that eight of the nine boreholes had only background activity. One borehole showed a maximum gamma activity of 40,000 pCi/g of ^{137}Cs.

5.2.4 Phase 2 Geophysical Logging

This section provides a summary of the geophysical logging results for Phase 2 of the WMA C RFI. Geophysical logging for direct push soil investigations was completed using slim-hole BGO spectral gamma scintillation detector for spectral and gross gamma logs and a neutron moisture tool for soil moisture logs at:

- Investigation Group A + B
- Investigation Group C + D
- Investigation Site E
- Investigation Group F + G
- Investigation Group H + I
- Investigation Site J
- Investigation Group L1 + L2
- Investigation Group P
- Investigation Site Q
- Investigation Site R
- Investigation Site U.

The gross gamma results were calibrated to the industry standard of equivalent ^{226}Ra in a scale of 2 to 5 pCi/g. The neutron moisture results are evaluated using a scale of 0 to 30% moisture by volume (%).

C Farm drywells specified by the work plan (RPP-PLAN-39114) (Sites L and M) were also re-logged to identify changes in drywell measurements since 1997. Drywell logging included measurements using the SGLS, NMLS, radionuclide assessment system (RAS), and handheld neutron moisture logging (HHNM). RAS and HHNM were completed as part of retrieval monitoring activities and are included in retrieval logging summaries compiled to support retrieval data reports (RDR). To date RDRs have been completed for drywells in the vicinity of the 200-series tanks and Tanks C-103, C-104, C-106, C-108, C-109, and C-110. As indicated in Section 4, the SGLS and RAS systems detect spectral and gross gamma emitting radioactive isotopes; most commonly ^{137}Cs, ^{60}Co, and ^{154}Eu, are detected in WMA C. The spectral gamma survey data also detect naturally occurring radionuclides (e.g., K, U, and Th). The NMLS and HHNM detect soil moisture.

Site M locations correlate with many of the other investigation sites/groups where direct push investigations were completed around the 100-series SSTs:

- Investigation Group A + B
- Investigation Site E
- Investigation Site J
- Investigation Group L1 + L2
- Investigation Site U.

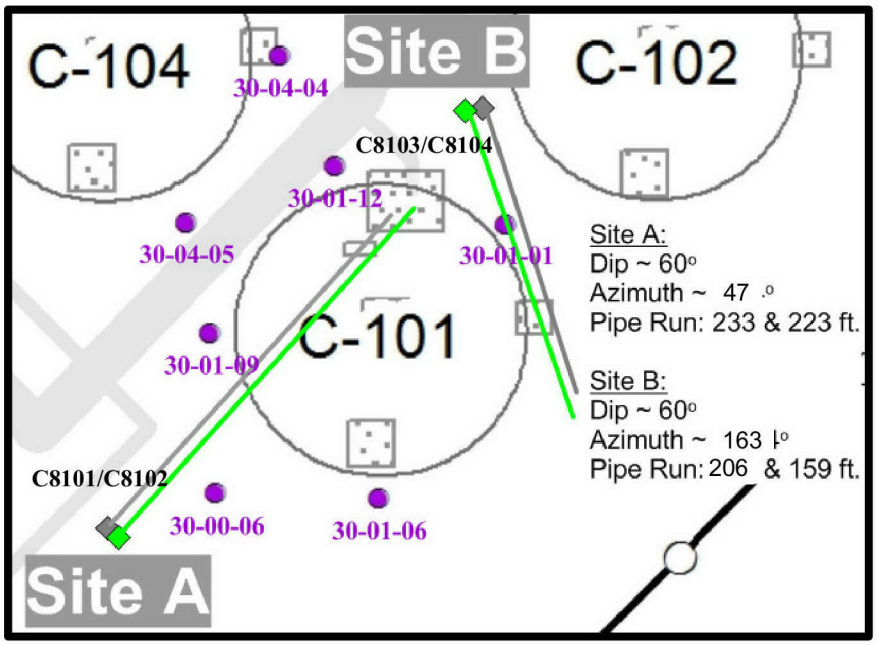
As such, the results of Site M are briefly discussed in the following sections in context of the associated sites/groups, as well as in the Site M section.

Groundwater wells in the vicinity of WMA C that were selected for geophysical logging in Phase 2 are included in the work plan as Site W.

Investigation Group A + B

Direct push and drywell geophysical logging events were completed to assess the extent of contamination near Tank C-101 (Figure 5-2). Low levels of ^{137}Cs were detected in the near surface of the direct push location. Drywell logging results for 30-01-09 showed no change from the baseline conducted in 1997. A peak ^{137}Cs value of 518 pCi/g was noted at 8.7 m (28.5 ft) bgs.

Figure 5-2. Group A + B Direct Push and Drywell Location Map



Direct Push Logging

Group A + B consisted of two angle push pairs, C8101/C8102 and C8103/C8104 respectively; oriented as shown in Figure 5-2. Spectral gamma, gross gamma, and neutron moisture logs were completed for the C8101 and C8103 push holes and neutron moisture logs were completed for the C8102 and C8104 push holes.

Table 5-6 contains a summary of the logging results for Group A + B. The "Flag Isotopes" column refers to other radionuclides that may have been noted by the analyst. Site A (C8101) showed ^{137}Cs at the surface, with a maximum of 2.2 pCi/g. Moisture values ranged from 2.5 to 15%. Site B (C8103) also showed ^{137}Cs near the surface with a maximum of 30 pCi/g. Moisture values ranged from 2 to 18%.

Table 5-6. Group A + B Logging Results

Borehole	Hole Depth (m)	Hole Depth (ft)	^{137}Cs (pCi/g) Max Detection	^{137}Cs Max Detected Depth	Flag Isotopes Other than Naturals and ^{137}Cs
C8101	70.7	233	2.2 pCi/g at surface	2 ft	None
C8102	68.0	223	N/A	N/A	N/A
C8103	62.8	206	30 pCi/g at 0.7 ft	8 ft	None
C8104	48.5	159	N/A	N/A	N/A

Drywell Logging

Drywell logging was completed as part of Site M. Four drywells were re-logged in the vicinity of Group A + B. Drywells 30-00-01 and 30-01-09 were re-logged in 2010 and drywells 30-04-04 and 30-04-05 were logged in support of retrieval operations in 2012/2013 using the RAS.

Groundwater Monitoring Well Logging

No groundwater wells are present in the vicinity of Investigation Group A + B.

Investigation Group C + D

Direct Push Logging

Direct push logging was completed at five locations associated with Investigation Group C + D:

- Site C: C8105 - Spectral gamma and moisture logging
  C8106 – Moisture logging and sampling

- Site D: C8763, C8765, C8766, C8767 - Spectral gamma and moisture logging.

Site C consisted of an angle push under Tank C-203 to investigate UPR-200-E-137, and support the Site D investigation. Site D consisted of four vertical pushes in the direct vicinity of the 200-series tanks (Figure 5-3). The four pushes were advanced to over 61 m (200 ft) bgs. Retrieval infrastructure, subsurface infrastructure, and topography prevented the possibility of closer investigation sites.

The Site C angle push showed ^{137}Cs was observed from the surface to 2 m (6 ft) of pipe run with a maximum reading of 18 counts per second and gross gamma levels < 4 pCi/g. There are clear indications of moisture zones at 28 m (92 ft) (pipe run) and several from 2 to 9 m (5 to 28 ft) (pipe run) in C8105. Moisture values range from 3 to 27%.

The Site D direct push gamma results showed ^{137}Cs concentrations <10 pCi/g near the surface in the boreholes logged. Cesium-137 was not detected below a depth of ~1.5 m (5 ft). Variations in subsurface moisture observed at each borehole are consistent with changes in soil texture and correlate well with the Hanford soil units.

Drywell Logging

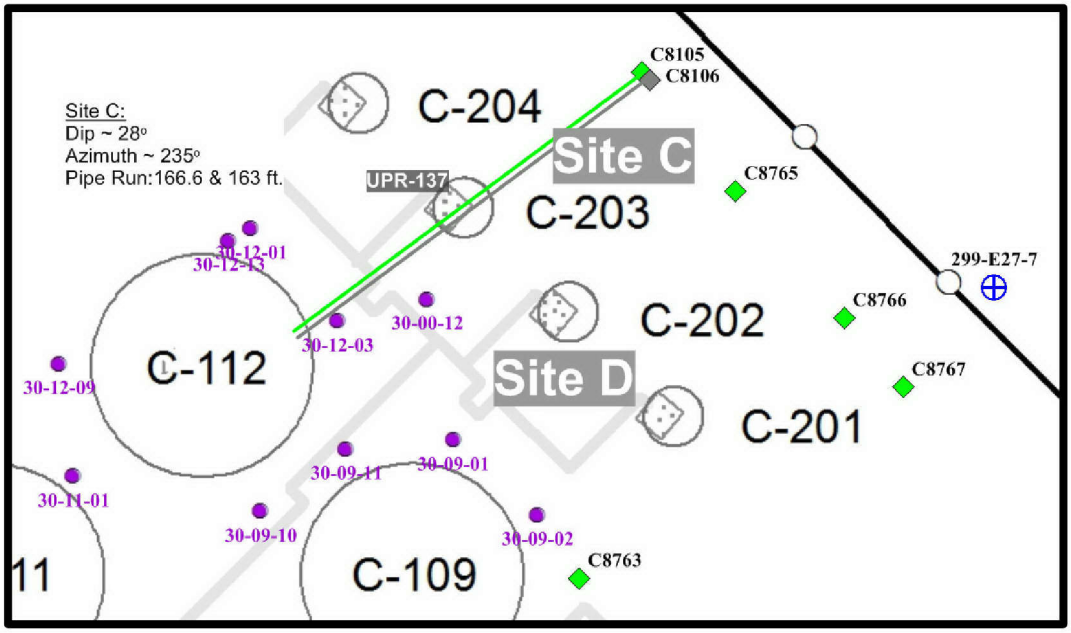
Drywells 30-09-01, 30-09-02, 30-09-10, 30-09-11, 30-12-01, 30-12-03, and 30-12-13 are included as part of Site M and are associated with Investigation Group C + D. Spectral gamma logging of these drywells was completed using the SGLS system in July and December of 2010.

Groundwater Well Logging

Groundwater well 299-E27-7 was logged using the SGLS in January of 2008 to a depth of 73 m (238 ft). It is located due east of the 200-series tanks just outside the fenceline. Logging results

for this well indicate ^{60}Co, ^{235}U, and ^{238}U were detected between 30 and 50 m (98 and 164 ft) bgs.

Figure 5-3. Investigation Group C + D Geophysical Logging Location Map



Investigation Site E

Direct Push Logging

Direct push logging at Site E consisted of a single vertical push hole adjacent to Tank C-106 (C7671). This location was intended to investigate the presence of ^{60}Co between Tanks C-109 and C-106 (Figure 5-4). However, ^{60}Co was not detected in the direct push spectral gamma logging results for this location. Cesium-137 was detected at the surface with a value of 281 pCi/g.

Moisture values ranged from 2 to 20%, with the latter value occurring at the base of the tank, likely due to the soil boundary between the backfill and the H1 layer.

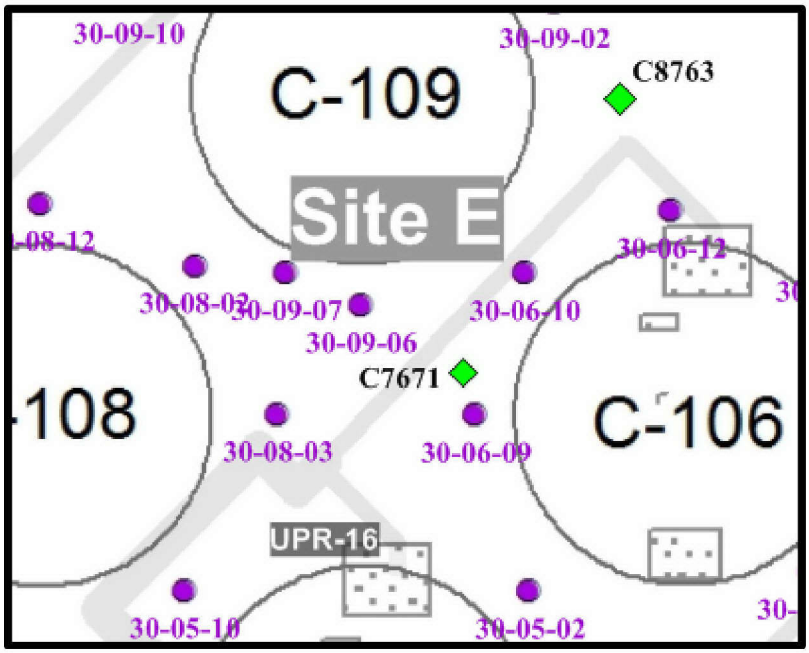
Drywell Logging

Drywells 30-09-02, 30-09-10, 30-09-11, 30-12-01, 30-12-03, and 30-12-13 are included as part of Site M and are associated with Site E. Spectral gamma logging of these drywells was completed in July and December of 2010.

Groundwater Well Logging

No groundwater wells are present in the vicinity of Site E.

Figure 5-4. Site E Direct Push and Drywell Location Map



Investigation Group F + G

Direct Push Logging

Direct push logging at Site F consisted of one vertical push location adjacent to the C-801 Building chemical drain. Site F was assessed for the presence of PUREX based wastes. Site G consisted of one vertical push location between C-801 Building and Tank C-103 to assess the presence of ^{60}Co (Figure 5-5).

At Site F (C7471), ^{137}Cs was detected from the surface to 1.5 m (5 ft) bgs, with a maximum detection of 3.6 pCi/g at 0.3 m (1 ft) bgs. At Site G, ^{137}Cs was observed from 0.15 to 0.6 m (0.5 to 2 ft) bgs, with a maximum value of 55 pCi/g at 0.3 m (1 ft) bgs in C7465 and from 0.15 to 0.6 m (0.5 to 2 ft) bgs, with a maximum value of ~6 pCi/g at 0.3 m (1 ft) bgs in C7467. No ^{137}Cs was observed below 1.5 m (5 ft) bgs in Investigation Group F + G.

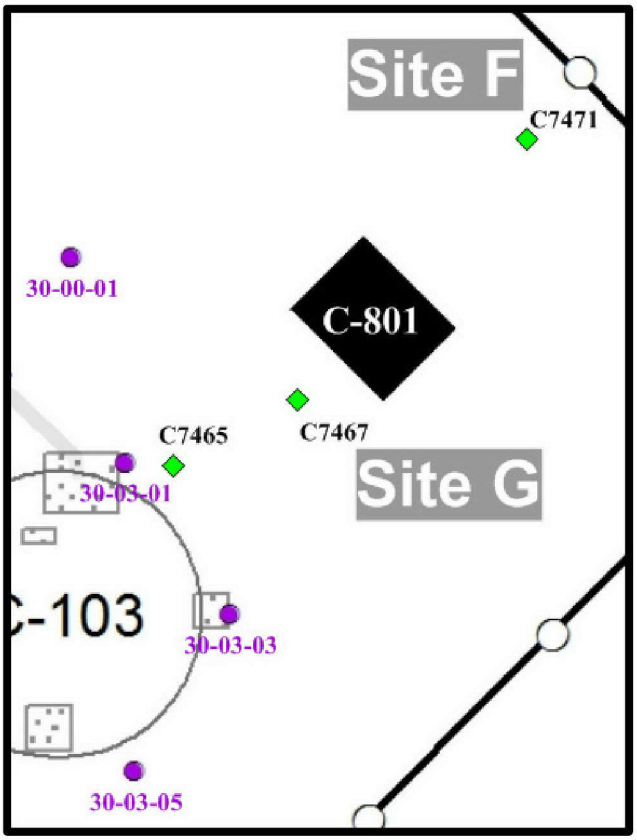
Drywell Logging

Drywell logging was completed as part of Site M. Four drywells were logged in the vicinity of Site G: 30-00-01, 30-03-01, 30-03-03, and 30-03-05.

Groundwater Well Logging

No groundwater wells are present in the vicinity of Investigation Group F + G.

Figure 5-5. Investigation Group F + G Direct Push and Drywell Location Map



Investigation Group H + I

Direct Push Logging

Direct push logging at Investigation Group H + I consisted of two vertical pushes in the vicinity of UPR E-91 and UPR-E-115 (Figure 5-6). At Site H (C7679), ^{137}Cs was not observed and there were no significant findings. Moisture variations range from 2 to 26%. At Site I (C7681), ^{137}Cs was not observed and there were no significant findings. Moisture variations range from 2 to 26%.

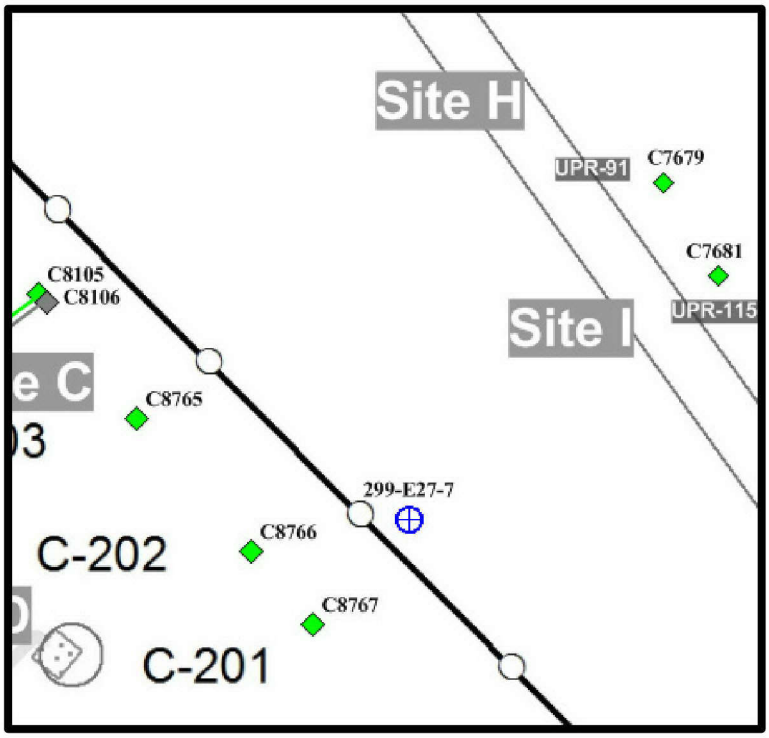
Drywell Logging

No drywells are present in the vicinity of Investigation Group H + I.

Groundwater Well Logging

Groundwater well 299-E27-7 is located over 43 m (140 ft) southwest of Investigation Group H + I and is associated with Investigation Group C + D.

Figure 5-6. Investigation Group H + I Direct Push and Drywell Location Map



Investigation Site J

Direct Push Logging

Direct push logging consisted of one angled push location for Site J. One angle push was completed to the southwest of Tank C-104, trending northeast under Tank C-104 (C8099) (Figure 5-7). Cesium-137 was observed at the surface, with a maximum of 5.8 pCi/g.

Additionally, one vertical push was completed to 10.97 m (36 ft) bgs between Tanks C-104 and C-105 (C7469). This push was not a part of Phase 2 activities but was completed to support retrieval activities. At this location, ^{137}Cs was detected from the surface to total depth with a maximum detection of 43,000,000 pCi/g of ^{137}Cs was detected at 10.67 m (35 ft) bgs. Moisture values range from 2.3 to 17%. Note that Site X, which was part of Phase 2, was planned for this area; however was not completed due to retrieval activities. Information obtained from borehole C7469 represents information that would have been obtained from Site X. The log report and plot for C7469 is reported in RPP-RPT-43725*, Small Diameter Geophysical Logging for C Tank Farm Leak Assessment of Tank 241-C-105*.

Drywell Logging

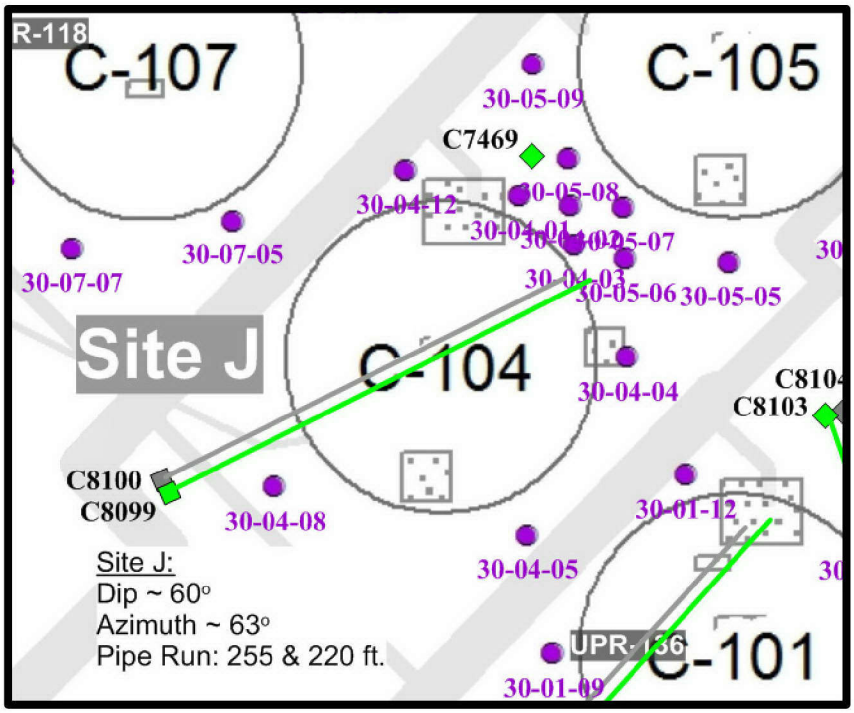
Drywell logging was completed as part of Site M. Four drywells were logged in the vicinity of Site J as part of the Phase 2 investigation: 30-04-01, 30-05-06, 30-05-07, and 30-05-08. Additionally, log data are available for drywells associated with Tank C-104 as part of the

retrieval monitoring program. RPP-RPT-56085, *241-C-104 Tank Waste Retrieval Project Final Report of Drywell Monitoring Data*, provides a geophysical logging summary of the results pursuant to retrieval monitoring of Tank C-104.

Groundwater Well Logging

No groundwater wells are present in the direct vicinity of Site J.

Figure 5-7. Site J Direct Push and Drywell Location Map



Investigation Group L1 + L2

Direct Push Logging

The work plan identified two vertical push locations, which consisted of two exploratory and two sampling push holes, L1 and L2 (Figure 5-8). Push hole C7465 (Site L1), located adjacent to and north of Tank C-103 detected ^{137}Cs from the surface to 2 m (6 ft) bgs, with a maximum concentration of 53 pCi/g. No ^{137}Cs was detected below 2 m (6 ft) bgs). C7669 (Site L2), located adjacent to and west of Tank C-103 detected ^{137}Cs at a maximum concentration of 11 pCi/g at a depth of ~0.15 m (0.5 ft) bgs. No ^{137}Cs was detected below 2 m (6 ft) bgs.

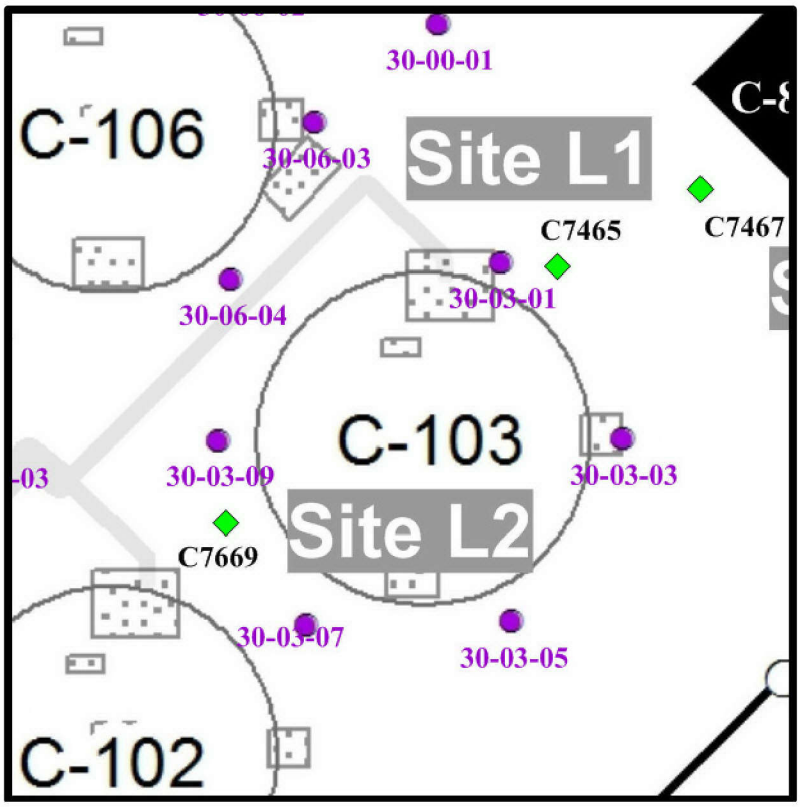
Drywell Logging

Geophysical drywell logging was completed as part of Site M. Drywells 30-03-01, 30-03-03, 30-03-5, 30-03-07, 30-03-09, 30-06-03, and 30-06-04 are associated with Investigation Group L1 and L2.

Groundwater Well Logging

No groundwater wells are present in the direct vicinity of Investigation Group L1 and L2.

Figure 5-8. Group L1 & L2 Direct Push and Drywell Location Map



Investigation Site M

Site M was intended as a "catch all" for repeat geophysical logging of drywells within the vicinity of the 100-series tanks as part of Phase 2 investigations. Figure 4-3 shows the location of the drywells. Following are summaries from log data reports for each of the drywells logged as part of the Phase 2 investigation efforts. No significant changes were observed in repeat logs for these drywells.

Moisture logs were obtained for selected wells using NMLS or handheld neutron probes. Drywells 30-00-12, 30-04-03, 30-04-05, 30-04-08, 30-08-03, 30-08-12 were selected for Phase 2 logging, but were not accessible for the SGLS (Section 4.4.2).

30-00-01 (299-E27-56, A6681)

Cesium-137 was detected almost continuously from ground surface to 6.3 m (20.5 ft) bgs, intermittently from 6.9 to 13.6 m (22.5 to 44.5 ft) bgs and continuously from 13.6 to 20.3 m (45.5 to 66.5 ft) bgs, with a maximum concentration of ~16 pCi/g at ground surface. Cobalt-60 was not detected in the primary log but was detected in the repeat log run at 19.7 m (64.5 ft) bgs. The ^{60}Co that existed in the depth interval from 17.8 to 20 m (58.5 to 67 ft) bgs in 1997 has generally decayed below the 2010 MDL. A single detection of ^{60}Co is observed at 19.7 m (64.5 ft) bgs slightly above the MDL of 0.1 pCi/g. No significant changes have occurred since 1997. No significant moisture variations were noted.

30-01-09 (299-E27-58, A6683)

In drywell 30-01-09, ^{137}Cs was detected almost continuously from ground surface to 11 m (37 ft) bgs and intermittently to 29.7 m (97.5 ft) bgs, with a maximum concentration of ~518 pCi/g at 8.7 m (28.5 ft) bgs (HRLS). Because the HRLS had not been used before, potential changes in the high rate interval could not be assessed. No changes were observed for ^{137}Cs in the remainder of the drywell since 1997. Cobalt-60 detected in 1997 appears to have decayed below the MDL and was not detected. Further investigations of the spectra from 1997 data of the ^{154}Eu and ^{152}Eu detections indicate that the 1997 detections were not valid peaks.

30-03-01 (299-E27-74, A6699)

Cesium-137 was detected from ground surface to 25.8 m (84.5 ft) bgs, 29.4 m (96.5 ft) bgs, from 30.3 to 30.9 m (99.5 to 101.5 ft) bgs, and from 37.2 to 38 m (122 to 124.5 ft) bgs. A maximum concentration of ~ 287 pCi/g was measured at 0.46 m (1.5 ft) bgs. Comparisons with the 1997 data indicate no significant change except from 13 to 14 m (44 to 46 ft) bgs where there is a possible increase. Cobalt-60 was detected from 29 to 33 m (95 to 107 ft) bgs, 34 and 35 m (111.5 and 113.5 ft) bgs, and from 36.7 to 37.6 m (120.5 to 123.5 ft) bgs. A possible increase in ^{60}Co is indicated over the detected intervals but is not definitive. Additional monitoring of this interval in the future is recommended.

30-03-03 (299-E27-75, A6700)

Cesium-137 was detected in this drywell. Cesium-137 was detected continuously from ground surface to 12.04 m (39.5 ft) bgs and intermittently from 16 to 22 m (53 to 73 ft) bgs, with a maximum concentration of ~ 151 pCi/g at 2.13 m (7 ft) bgs. No significant changes have occurred since 1997. Detections of ^{137}Cs from 14 to 23 m (45 to 74 ft) bgs in 2010 are interpreted to be the result of the enhanced detection system rather than migration of contaminants. The 2010 handheld moisture data ranged from 5 to 10%.

30-03-05 (299-E27-76, A6701)

Cesium-137 was detected from ground surface to 8.7 m (28.5 ft) bgs, intermittently from 9 to 9.9 m (29.5 to 32.5 ft) bgs, continuously from 11 to 14 m (35 to 44.5 ft) bgs, 17 to 23 m (54 to 75.5 ft) bgs, intermittently from 25 to 27 m (80.5 to 88.5 ft) bgs and continuously from 29 to 30 m (95.5 to 99.5 ft) bgs. A maximum concentration of ~ 35 pCi/g was measured at 0.15 m (0.5 ft) bgs. Comparisons of the 1997, 2009 and 2010 data indicate no evidence of change.

30-03-07 (299-E27-77, A6702)

Cesium-137 was detected almost continuously from ground surface to total logged depth of the drywell. A maximum concentration of ~61 pCi/g was measured at 2.9 m (9.5 ft) bgs. No significant changes have occurred since 1997.

30-03-09 (299-E27-78, A6703)

Cesium-137 was detected from ground surface to 20 m (66 ft) bgs, and intermittently to the bottom of the drywell. A maximum concentration of approximately 47 pCi/g was measured at 2 m (7 ft) bgs. Comparisons with the 1997 data indicate no significant change. Cobalt-60 was detected from 24 to 28 m (78 to 90.5 ft) bgs with a maximum concentration of ~0.4 pCi/g measured at 24 m (78.5 ft) bgs. Comparisons with the 1997 data indicate no significant change. After review of the spectra, there appears to be no supporting energy peaks for the ^{152}Eu and ^{154}Eu detected in 1997, nor were they detected in 2010.

30-04-01 (299-E27-115, A6735)

Cesium-137 was detected almost continuously from ground surface to the total logged depth of the drywell. A maximum concentration of approximately 49 pCi/g was measured at 0.3 m (1 ft) bgs. Comparisons with the 1997 data indicate no significant change.

30-04-04 (299-E27-79, A6704) and 30-04-05 (299-E27-80, A6705)

These drywells were re-logged in support of Tank C-104 retrieval. Gross gamma and neutron probe moisture data for drywells 30-04-04 and 30-04-05 show no evidence of any significant changes in moisture content or gamma activity since 1997. Peak gamma activity concentrations of ~100 pCi/g between ground surface and 1.5 m (5 ft) bgs and ~10 pCi/g between 1.5 and 6 m (5 and 20 ft) bgs in drywell 30-04-04 and ~50 pCi/g at 4 m (12 ft) bgs in drywell 30-04-05. In general the neutron-neutron moisture logging data show variation in moisture content from 2 to 9% over the first 12 m (40 ft) with the remainder of the deeper readings between 2 and 4% for these drywells (RPP-RPT-56085).

30-05-02 (299-E27-70, A6695)

Cesium-137 was detected almost continuously from ground surface to 27 m (88.5 ft) bgs, intermittently from 28 to 36 m (92.5 to 117 ft) bgs, and almost continuously from 36 to 39 m (119.5 to 127.5 ft) bgs. A maximum concentration of ~ 762 pCi/g was measured at 0.5 m

(1.5 ft) bgs. Comparisons with the 2004 and 1997 data indicate no significant change. Cobalt-60 was detected at 22.8, 23.3, and 35.5 m (75, 76.5, and 116.5 ft) bgs with a maximum concentration of approximately of 0.1 pCi/g at 23 m (75 ft) bgs. Cobalt-60 detected in 1997 and 2004 from 23 to 25 m (75 to 83 ft) bgs has apparently decayed below the 2010 MDL. Europium-154 detected at ground surface in 1997 has apparently decayed below the 2010 MDL. Moisture data were acquired from the interval of ground surface to 39 m (127.25 ft) bgs. Moisture content ranges from 3 to 11% with a peak of 10% between 3 and 5 m (10 and 15 ft) bgs.

30-05-06 (299-E27-119, A6739)

Cesium-137 was detected almost continuously from ground surface to the total logged depth of the drywell. A maximum concentration of ~18 pCi/g was measured at 0.3 m (1 ft) bgs. Comparisons with the 1997 data indicate no significant change. Comparison of 1997 and 2010 data with RLS data acquired in 1993 indicate similar profiles. Radiation assessment logging system data acquired in 1993, suggested ^{60}Co was detected discontinuously from 5 to 16 m (16 to 51 ft) bgs at less than 0.3 pCi/g. The ^{60}Co was mostly observed from 14 to 15 m (45 to 50 ft) bgs. There was no evidence of ^{60}Co in the 1997 or 2010 log data. A detection of ^{235}U in 1997 at ground surface was determined to be erroneous based on inspection of the spectrum, and was removed from the data set.

30-05-07 (299-E27-118, A6738)

Cesium-137 was detected almost continuously from ground surface to 20 m (66.5 ft) bgs, with a maximum concentration of ~19,800,000 pCi/g at 11 m (37.5 ft) bgs measured using the HRLS with an internal tungsten shield. No significant changes have occurred since 1997. Cobalt-60 detected in 1997 at 8.69 m (28.5 ft) bgs and 19 to 20.3 m (65 to 66.5 ft) bgs has decayed below the 2010 MDL. However, it likely exists in the high activity zone below 11 m (35 ft) bgs. Europium-154, ^{152}Eu, and ^{235}U, detections in 1997, were determined to be invalid and were removed from the data set. Handheld neutron moisture logs show moisture between 5 and 10% except between 10 and 13 m (34 and 42 ft) bgs. The detector was influenced by high gamma activity between at this depth and does not reflect the true moisture content.

30-05-08 (299-E27-117, A6737)

Cesium-137 was detected continuously from ground surface to 15 m (48 ft) bgs, with a maximum concentration of ~104 pCi/g at 0.3 m (1 ft) bgs. No significant changes have occurred since 1997. Cobalt-60 was detected almost continuously from 10 to 12 m (35 to 39.5 ft) bgs, with a maximum concentration of ~0.3 pCi/g at 12 m (38 ft) bgs. No significant changes have occurred since 1997. Cobalt-60 concentrations that were detected in 1997 at some depth locations have decayed below the MDL of the 2011 SGLS. Europium-154 was detected continuously from 4 to 6 m (14 to 18 ft) bgs, with a maximum concentration of ~7.8 pCi/g at 5 m (16.5 ft) bgs. No significant changes have occurred since 1997. Handheld neutron moisture logs were obtained in 2011 to a depth of ~15 m (48 ft) bgs. The logs showed moisture content between 3 and 7%.

30-06-02 (299-E27-72, A6697)

Cesium-137 was detected from ground surface to 4 m (14 ft) bgs, intermittently from 6.4 to 18.4 m (21 to 60.5 ft) bgs, and intermittently from 35 m (114 ft) bgs to the total logged depth of the drywell. A maximum concentration of ~8 pCi/g was measured at 0.15 m (0.5 ft) bgs. Comparisons with the 2004 and 1997 data indicate no significant change. Moisture data were acquired using the NMLS from the interval of ground surface to 37 m (122 ft) bgs. Moisture content varies from 3 to 12% with peaks over 10% at ~3 and 15 m (10 and 48 ft) bgs.

30-06-03 (299-E27-84, A6709)

Cesium-137 was detected continuously from ground surface to 14 m (46.5 ft) bgs, and from 15 to 21 m (48 to 67.5 ft) bgs, at 21, 22, 23, and at 30 m (69, 71.5, 74, and at 98 ft) bgs, with a maximum concentration of ~61 pCi/g at 0.15 m (0.5 ft) bgs. No significant changes have occurred since 1997. Europium-154 was detected at ground surface with a concentration of ~0.9 pCi/g. Although not detected in the 1997 baseline, the ground surface measurement may be influenced by a distant surface source unrelated to the drywell. Moisture data were acquired using the NMLS from the interval of ground surface to 30 m (98 ft) bgs. Moisture content varies from 3 to 13% with peaks over 9% at ~14 and 28 m (46 and 92 ft) bgs.

30-06-04 (299-E27-73, A6698)

Cesium-137 was detected continuously from ground surface to 17 m (56.5 ft) bgs and intermittently throughout the remainder of the drywell. A maximum concentration of approximately 1500 pCi/g was measured at the ground surface. Comparisons with the 2004 and 1997 data indicate no significant change. Cobalt-60 was detected at the bottom of the borehole in 2010 with an approximate concentration of 0.1 pCi/g and at 20 m (92 ft) bgs (repeat run). Cobalt-60 detected in 1997 and 2004 between 25 and 28 m (83 and 93 ft) bgs has apparently decayed below the 2010 MDL. Europium-154 was detected at the ground surface with a concentration of ~3 pCi/g. Moisture data were acquired using the NMLS from the interval of ground surface to 40 m (130 ft) bgs. Moisture content varies from 2 to 15% with a peak over 10% at ~13 m (44 ft) bgs.

30-06-09 (299-E27-85; A6710)

Cesium-137 was detected from ground surface to 18.44 m (60.5 ft) bgs, intermittently from 20 to 27 m (64 to 89.5 ft) bgs, and continuously from 29 to 30 m (96.5 to 98.5 ft) bgs. A maximum concentration of ~ 64.7 pCi/g was measured at ground surface. Comparisons of SGLS data indicate no significant change in ^{137}Cs. Cobalt-60 detected at 8.2, 8.4, and 22.7 m (27, 27.5, and 74.5 ft) bgs at less than 0.2 pCi/g in 1997 has apparently decayed below the MDL. A detection of ^{235}U in 1997 at ground surface was determined to be erroneous, based on inspection of the spectrum, and has been removed from the data set. Moisture data were acquired using the NMLS from the interval of ground surface to 30 m (98 ft) bgs. Moisture content varies from 2 to 10% with peaks of ~10% at ~3, 4, and 12 m (9, 12 and 38 ft) bgs.

30-06-10 (299-E27-71; A6696)

Cesium-137 was detected almost continuously from ground surface to 5 m (17 ft) bgs, intermittently from 6.1 to 12 m (20 to 38.5 ft) bgs, almost continuously from 13 to 17 m (43 to 56 ft) bgs, intermittently from 17.98 to 20.27 m (59 to 66.5 ft) bgs, at 24, 30, and 38 m (78, 98, and 124.5 ft) bgs, and continuously from 38.7 to 39.2 m (127 to 128.5 ft) bgs. A maximum concentration of ~ 5.1 pCi/g was measured at 0.8 m (2.5 ft) bgs. Comparisons of all SGLS data indicate no significant change in ^{137}Cs.

Table 5-7 shows changes in the ^{60}Co contamination profile from 1997 to 2011.

Table 5-7. Drywell 30-06-10 Geophysical Logging Summary

Date	Depth (ft)	Comment
1997	86-117	Baseline
1999	86-124	^{60}Co contamination increase from 112 to 124 ft
2004	86-129	^{60}Co below the MDL from 90 to 96 ft; ^{60}Co increase from 121 to 129 ft
2011	86-129	^{60}Co increase from 86 to 90 ft and at 93 ft; ^{60}Co generally below MDL from 90 to 98 ft; Stable from 98 to 129 ft

Lateral and downward migration of ^{60}Co has been observed in this drywell since 1997 that extends to at least the bottom of the drywell at 39 m (129 ft) bgs. In 2011, a further influx of contamination is indicated from 26 to 27 m (86 to 90 ft) bgs and at 28 m (93 ft) bgs, suggesting ongoing migration near the top of the plume from a source in the vicinity of the drywell. Contamination below 30 m (98 ft) bgs appears to have stabilized although it is not known if contamination has migrated below the bottom of the drywell where migration could be occurring. Europium-154 detected at ground surface in 1997 has apparently decayed below the MDL. Moisture data were acquired using the NMLS from the interval of ground surface to 39 m (128 ft) bgs. Moisture content varies from 3 to 13% with peaks of ≥10% between 2 and 4 m (8 and 14 ft) bgs, at 11 m (37 ft) bgs, and between 12.5 and 13 m (41 and 44 ft) bgs.

30-06-12 (299-E27-86; A6711)

Cesium-137 was detected almost continuously from ground surface to 10 m (31 ft) bgs, intermittently from 10.4 to 12 m (34 to 40.5 ft) bgs, almost continuously from 13 to 19 m (43 to 61.5 ft) bgs, intermittently from 19 to 23 m (63 to 74 ft) bgs, and at 30 and 30.2 m (98.5 and 99 ft) bgs. A maximum concentration of ~19.7 pCi/g was measured at 0.15 m (0.5 ft) bgs. Comparisons with the 1997 data indicate no significant change. Cobalt-60 was detected at 6, 27.3, 27.8, and 29.3 m (20, 89.5, 91, and 96 ft) bgs. Comparison with the 1997 data shows an increase of ^{60}Co concentrations at depths between 27 and 29 m (89 and 96.5 ft) bgs. Cobalt-60 detected in 1997 from 6 to 7 m (19.5 to 22 ft) bgs has decayed below the MDL, except at 6 m (20 ft) bgs. Moisture data were acquired using the NMLS from the interval of ground surface to

30 m (99 ft) bgs. Moisture content varies from 3 to 15% with peaks of >10% at 14 and 24 m (46 and 78 ft) bgs.

30-08-02 (299-E27-94; A6719)

Cesium-137 was detected continuously from ground surface to 7 m (23 ft) bgs, intermittently from 7 to 11 m (24 to 36 ft) bgs, almost continuously from 14 to 17 m (46 to 57 ft) bgs, and at 30 and 30.2 m (98 and 99 ft) bgs, with a maximum concentration of ~1,380 pCi/g at 6 m (21 ft) bgs as measured by the HRLS. The HRLS data cannot be directly compared with prior SGLS data at this depth interval because the measurement range of the SGLS was exceeded. However, comparisons of 1997, 2004, and 2010 SGLS data at other depth locations indicate an increase of ^{137}Cs concentrations from 14 to 17 m (46 to 57 ft) bgs. Cobalt-60 was detected almost continuously from 14 to 24 m (47 to 80 ft) bgs with a maximum concentration measured at ~6.8 pCi/g at 19 m (61 ft) bgs. Comparisons of 1997 and 2004 data (after decay to a common date) indicate a significant increase of ^{60}Co concentrations from 14 to 23 m (47 to 78 ft) bgs. Between 2004 and 2010, a decrease in concentration beyond what can be attributed to decay alone occurred from 14 to 18 m (47 to 58 ft) bgs. Cobalt-60 also increased at between 18 and 24 m (58 and 78 ft) bgs. Moisture data were acquired using the NMLS from the interval of ground surface to 30 m (99 ft) bgs. Moisture content varies from 3 to 15% with peaks of ≥9% from the surface to 4 m (13 ft) bgs at 11 m (36 ft) bgs.

30-09-01 (299-E27-96, A6721)

Cesium-137 was detected continuously from ground surface to 11, 15, and 16 m (37.5, 50.5, and 52 ft) bgs and from 29 m (95 ft) bgs to the total logged depth of the borehole. A maximum concentration of ~30.3 pCi/g was measured at the ground surface. Comparisons with the 1997 data indicate no significant change. Cobalt-60 was detected at 28 and 29 m (92 and 95.5 ft) bgs in 2010 with a maximum concentration of ~0.09 pCi/g was measured at 29 m (95 ft) bgs. Cobalt-60 detected in 1997 between 27 and 30 m (89 and 97.5 ft) bgs have decayed below the MDL.

30-09-02 (299-E27-97; A6722)

Cesium-137 was detected almost continuously from ground surface to 4 m (13.5 ft) bgs, 14.6 to 14.9 m (48 to 49 ft) bgs, and 16.3 to 17 m (53.5 to 55 ft) bgs, with a maximum concentration of ~2 pCi/g at 3 m (11 ft) bgs. No significant changes have occurred since 1997. Cobalt-60 was detected continuously from 16 to 18 m (51 to 58 ft) bgs, and at 23 and 23.3 m (75.5, and 76.5 ft) bgs, with a maximum concentration of ~ 1.5 pCi/g at 16.2 m (53.5 ft) bgs. The ^{60}Co concentrations appear to increase from 17 to 17.4 m (54 to 57 ft) bgs and possibly at 23 m (76 ft) bgs as compared to the 1997 data. This profile may suggest a lateral and downward influx of contamination since 1997 from a relatively distant source. Cobalt-60 contamination that existed between 27 and 30 m (90 and 97 ft) bgs in 1997 has decayed below the MDL.

30-09-06 (299-E27-98; A6723)

Cesium-137 was detected almost continuously from ground surface to 30 m (98 ft) bgs, with a maximum concentration of ~ 598 pCi/g at ground surface. No significant changes have occurred since 1997. Cobalt-60 was detected continuously from 23 to 26 m (77 to 85 ft) bgs, with a maximum concentration of ~ 1.5 pCi/g at 25 m (81.5 ft) bgs. An increase in ^{60}Co concentrations was observed since the 1997 baseline. Moisture data were acquired using the NMLS from the interval of ground surface to 30 m (99 ft) bgs. Moisture content varies from 2 to 10% with a peaks of 10% at ~2 m (8 ft) bgs.

30-09-07 (299-E27-135; A6754)

Cesium-137 was detected almost continuously from ground surface to 12 m (39 ft) bgs and intermittently from 15.6 to 16.2 m (51 to 53 ft) bgs, with a maximum concentration of ~7 pCi/g at ground surface. No significant changes have occurred since 1997. Cesium-137 detected from 15.5 to 16.2 m (51 to 53 ft) bgs is interpreted to be the result of the enhanced detection system rather than migration of contaminants. Cobalt-60 was detected almost continuously from 22.86 to 25.30 m (75 to 83 ft) bgs, with a maximum concentration of ~1.8 pCi/g at 24.23 m (79.5 ft) bgs. An increase in ^{60}Co concentrations since the 1997 baseline was observed from 23 to 35 m (75 to 83 ft) bgs. A possible increase was noted in May 2007 during monitoring using the RAS. Other boreholes in the area have indicated changes in ^{60}Co concentrations since 1997. These boreholes include 30-08-02, 30-09-06, 30-06-10, 30-06-12, and 30-09-02. A detailed evaluation of the subsurface contamination is recommended for this area to determine if any interrelationships exist. Moisture data were acquired using the NMLS from the interval of ground surface to 37 m (122 ft) bgs. Moisture content varies from 3 to >15% with a peak of >15% between 8 and 13 m (25 and 41 ft) bgs; The presence of grout is suggested as indicated by the large increase in volumetric moisture and drop in ^{40}K concentration at this depth.

30-09-10 (299-E27-99; A6724)

Cesium-137 was detected almost continuously from ground surface to 20 m (67 ft) bgs, and 22 to 30 m (73 to 98 ft) bgs, with a maximum concentration of ~158 pCi/g at 0.8 m (2.5 ft) bgs. No significant changes have occurred since 1997. Cobalt-60 was detected at 18 m (58.5 ft) bgs with a concentration of ~0.1 pC/g. This detection is a slight increase from the 1997 data, since decay of the 1997 data suggests that the concentration should be below the current MDL.

30-09-11 (299-E27-100, A6725)

Cesium-137 was detected from ground surface to 6 m (19 ft) bgs, at 7 and 7.5 m (23 and 24.5 ft) bgs, from 13.5 to 14.2 m (44.5 to 46.5 ft) bgs, at 24.2 m (79.5 ft) bgs and from 28.4 to 30 m (93 to 98.5 ft) bgs, with a maximum concentration of ~3 pCi/g at 0.3 m (1 ft) bgs. No significant changes have occurred since 1997.

30-12-01 (299-E27-107, A6732)

Cesium-137 was detected almost continuously from ground surface to 6 m (18 ft) bgs and intermittently from 9 to 19 m (29 to 61 ft) bgs. A maximum concentration of ~1.8 pCi/g was measured at the ground surface. Comparisons with the 1997 data indicate no significant change. Detections of ^{137}Cs from 17 to 19 m (55 to 61 ft) bgs in 2010 are interpreted to be the result of the enhanced detection system rather than migration of contaminants. Cobalt-60 was detected at 13 m (43 ft) bgs in 2010 with a concentration of ~0.09 pCi/g. Cobalt-60 was detected in 1997 between 13 and 14.5 m (43 and 47.5 ft) bgs, and has apparently decayed below the MDL. Moisture data were acquired using the NMLS from the interval of ground surface to 30 m (97 ft) bgs. Moisture content varies from 2 to 9% with peaks at 11 and 13 m (36 and 44 ft) bgs.

30-12-03 (30-12-03)

Cesium-137 was detected in this drywell intermittently from ground surface to 17 m (55 ft) bgs, with a maximum concentration of approximately 9 pCi/g at ground surface. Comparisons of ^{137}Cs concentration suggest no significant change since 1997. Moisture data were acquired using the Tank Farm's Handheld Moisture Gauge from the interval of ground surface to 21 m (68 ft) bgs. Moisture content varies from 1 to 9% with a peak at 8 m (25 ft) bgs.

30-12-09 (299-E27-109, A6734)

Cesium-137 was detected from ground surface to 0.2 m (0.5 ft) bgs, and continuously from 2 to 3 m (7.5 to 10.5 ft) bgs with a maximum concentration of ~0.7 pCi/g at ground surface. No significant changes have occurred since 1997.

30-12-13 (299-E27-125, A6745)

Cesium-137 was detected almost continuously from ground surface to 10 (34 ft) bgs and from 13 to 14 m (44 to 46 ft) bgs. A maximum concentration of approximately 6.1 pCi/g was measured at 3 m (10 ft) bgs. Cobalt-60 was detected continuously from 10.5 to 11.3 m (34.5 to 37 ft) bgs and at 14 m (45 ft) bgs in 2010. A maximum concentration of ~0.2 pCi/g was measured at 11 m (36.5 ft) bgs. Europium-154 was detected at 11 to 11.1 m (36 to 36.5 ft) bgs with a concentration of ~0.6 pCi/g. Comparisons with the 1997 data indicate no significant change in ^{137}Cs, ^{60}Co or ^{154}Eu. A zone of greater than 40% dead time was encountered in 1997 from 2.7 to 3 m (9 to 10 ft) bgs. HRLS spectra acquired in 1999 indicate no specific radionuclide. The 2010 spectra indicated ^{137}Cs concentrations that are too low for the measured dead time. The dead time may be caused by a remote source of ^{137}Cs, such as from a pipeline. The driller's log records hitting a "water line" at approximately 3 m (11 ft) in depth. Moisture logging was conducted using the Handheld Moisture Gauge, from the interval of ground surface to ~36 m (119 ft) bgs. Moisture content varies from 1 to ~8% with peak moisture content between 6 and 11 m (20 and 36 ft) bgs. High moisture content between ground surface and 4.88 m (16 ft) bgs is due to grouting of the drywell casing.

Investigation Group P (P1 through P5)

Direct Push Logging

Two additional vertical direct push holes (C6403 and C6405) in Sites P1 and P3 were installed and logged to further investigate UPR-81. Several other holes were pushed for sampling, but were not logged. Figure 5-9 shows the location of the Phase 2 push holes. Logging surveys were conducted with a BGO spectral gamma scintillation detector and a neutron moisture probe. A peak ^{137}Cs concentration of 1,200,000 pCi/g was detected at 15.24 m (50 ft) bgs in C6403 and a peak concentration of 11 pCi/g was detected in C6405. Borehole C6403 was installed after the adjacent sampling borehole encountered high levels of contamination. The gamma activity encountered in C6403 exceeded the linear response range of the BGO detector system. The NaI and Green GM detectors were run in this borehole to measure the high levels of ^{137}Cs.

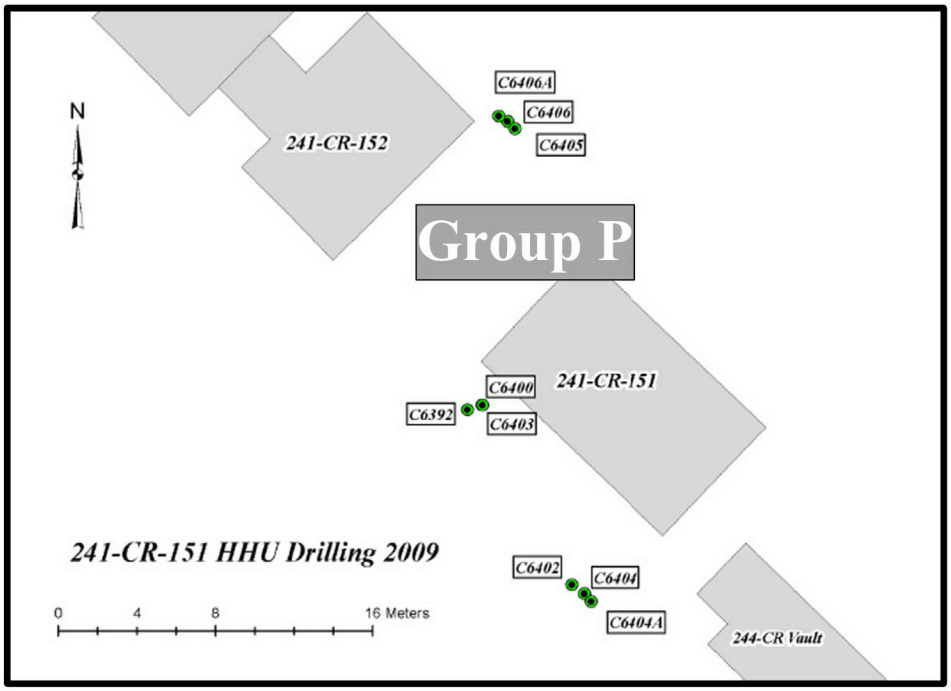
Drywell Logging

No drywells are present in the vicinity of Investigation Group P.

Groundwater Well Logging

No groundwater wells are present in the vicinity of Investigation Group P.

Figure 5-9. Location of Phase 2 Direct Pushes for Group P



Investigation Site Q

Direct Push Logging

Four direct push holes, placed to a depth of ~60.96 m (200 ft) bgs, were logged to further investigate UPR-82 (C7940, C7941, C7942 and C7943) (Figure 5-10). A maximum ^{137}Cs concentration of 16 pCi/g was detected at the surface. Soil moisture content ranged from 3 to 10%, with peak moisture content at about 3 m (11 ft) bgs.

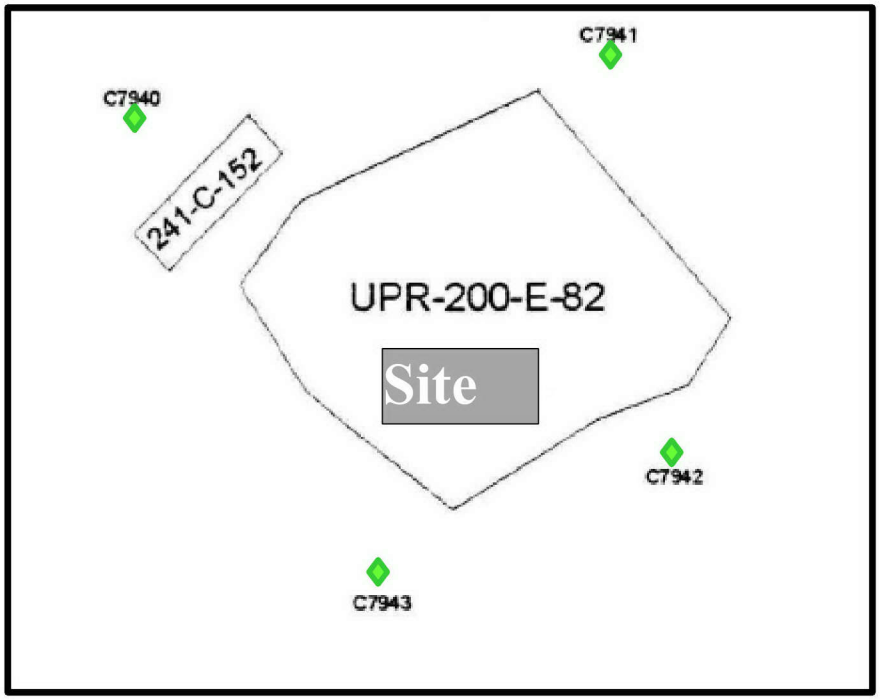
Drywell Logging

No drywells are present in the vicinity of Site Q.

Groundwater Well Logging

No groundwater wells are present in the vicinity of Site Q.

Figure 5-10. Location of Phase 2 Direct Pushes for Site Q



Investigation Site R

Direct Push Logging

One vertical push hole (C7667) was installed and logged to a depth of 67.67 m (222 ft) bgs to investigate a potential release from the C-301 Catch Tank (Figure 5-11). The maximum ^{137}Cs concentration was 722 pCi/g at 4.1 m (13.5 ft) bgs; the true ^{137}Cs levels are higher due to remote signal and non-uniform distribution. Moisture values ranged from 2 to 25%, with peaks >20% at ~9 and 12 m (28 and 40 ft) bgs.

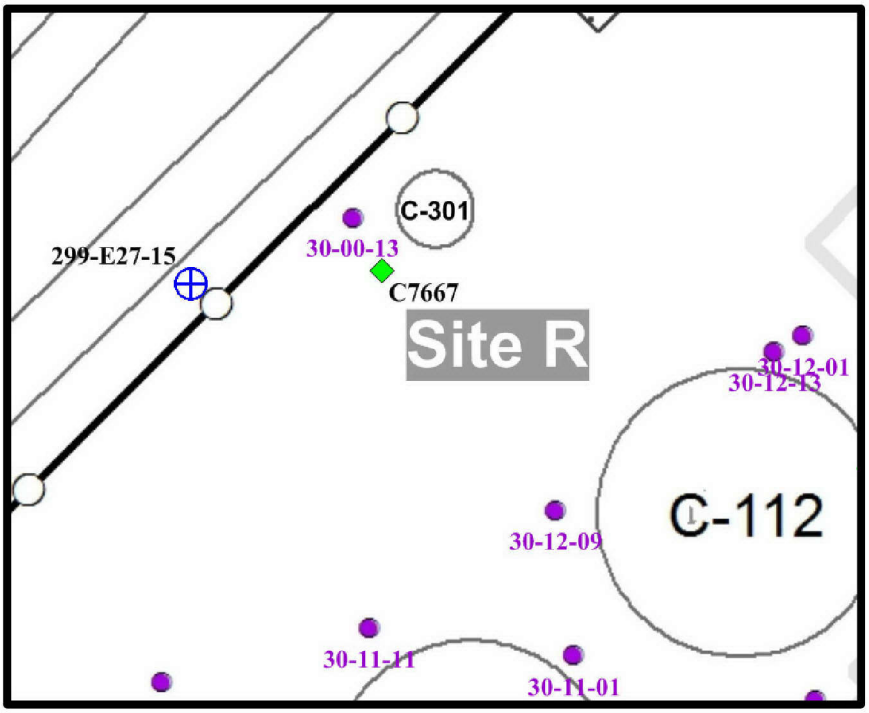
Drywell Logging

Drywell logging was completed as part of Site M. Drywell 30-00-13 is in the vicinity of Site R.

Groundwater Well Logging

Groundwater well 299-E27-15 (C5852), in the vicinity of Site R was not available for logging as part of the Phase 2 investigations.

Figure 5-11. Site R Direct Push and Drywell Location Map



Investigation Site U

Direct Push Logging

One angle push hole (C7675) was installed and logged to a depth of 67 m (222 ft) bgs at Site U. A maximum ^{137}Cs concentration of 9 pCi/g was detected at 0.3 m (1 ft) bgs. Moisture values ranged from 2 to 20%, with a peak at ~12 m (38 ft) bgs.

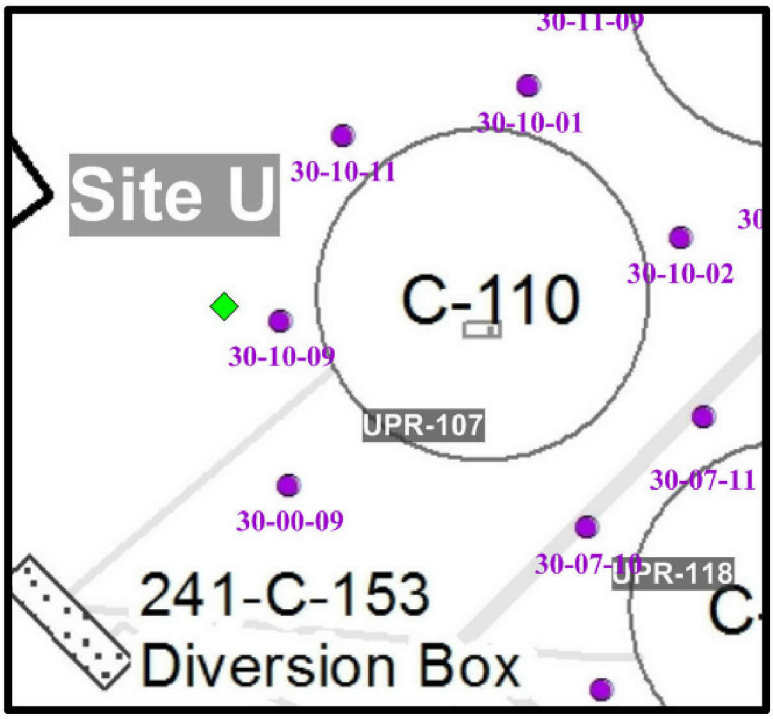
Drywell Logging

Geophysical drywell logging was part of Site M. Drywells associated with Site U were not logged. Approval was received in the September 20, 2011 work plan meeting (Appendix I) and was documented in the approved RPP-PLAN-39114, Rev. 2 (Section 4.4.2).

Groundwater Well Logging

No groundwater wells are present in the vicinity of Site U.

Figure 5-12. Site U Direct Push and Drywell Location Map



Investigation Site W

Site W is for re-logging of groundwater wells associated with WMA C (Figure 4-17). Originally five wells were indicated; however, three of the wells were not suitable or were not accessible

for logging: 299-E27-12, 299-E27-13, and 299 E27-15. Borehole 299-E27-14 (A4812) was logged in March 2007 using the SGLS and borehole 299-E27-4 was logged in August, 2003. Borehole 299-E27-14 was logged to a depth of 82 m (270 ft) bgs. Cesium-137 was detected from 1.2 to 2.1 m (4 to 7 ft) bgs with a maximum concentration of 1.2 pCi/g at 2 m (6 ft) bgs. Cobalt-60 was detected from 74 to 80 m (244 to 261 ft) bgs, from 39.62 to 45.72 m (130 to 150 ft) bgs, and sporadically (7 of 54 depth intervals) from 49 to 66 m (162 to 216 ft) bgs with maximum concentrations of 0.3 pCi/g at 76 m (250 ft) bgs, 0.1 pCi/g at 43 m (142 ft) bgs, and 0.1 pCi/g at 49 m (162 ft) bgs. Borehole 299-E27-4 was logged to a depth of 94 m (309 ft) bgs. Cesium-137 was the only man-made radionuclide detected in this borehole. Cesium-137 was detected at a few sporadic locations in the borehole near its MDL of approximately 0.2 pCi/g.

In addition, to the five groundwater wells identified for Phase 2 investigations, borehole 299-E27-7 was logged in support of Investigation Group C + D. Spectral gamma logging system LDRs for 299-E27-7 and other groundwater boreholes in C Farm discussed in Section 5.4 (299-E27-21, 299-E27-22, 299-E27-23, 299-E27-24 and 299-E27-155) are included in Appendix T.

5.3 SGE RESULTS

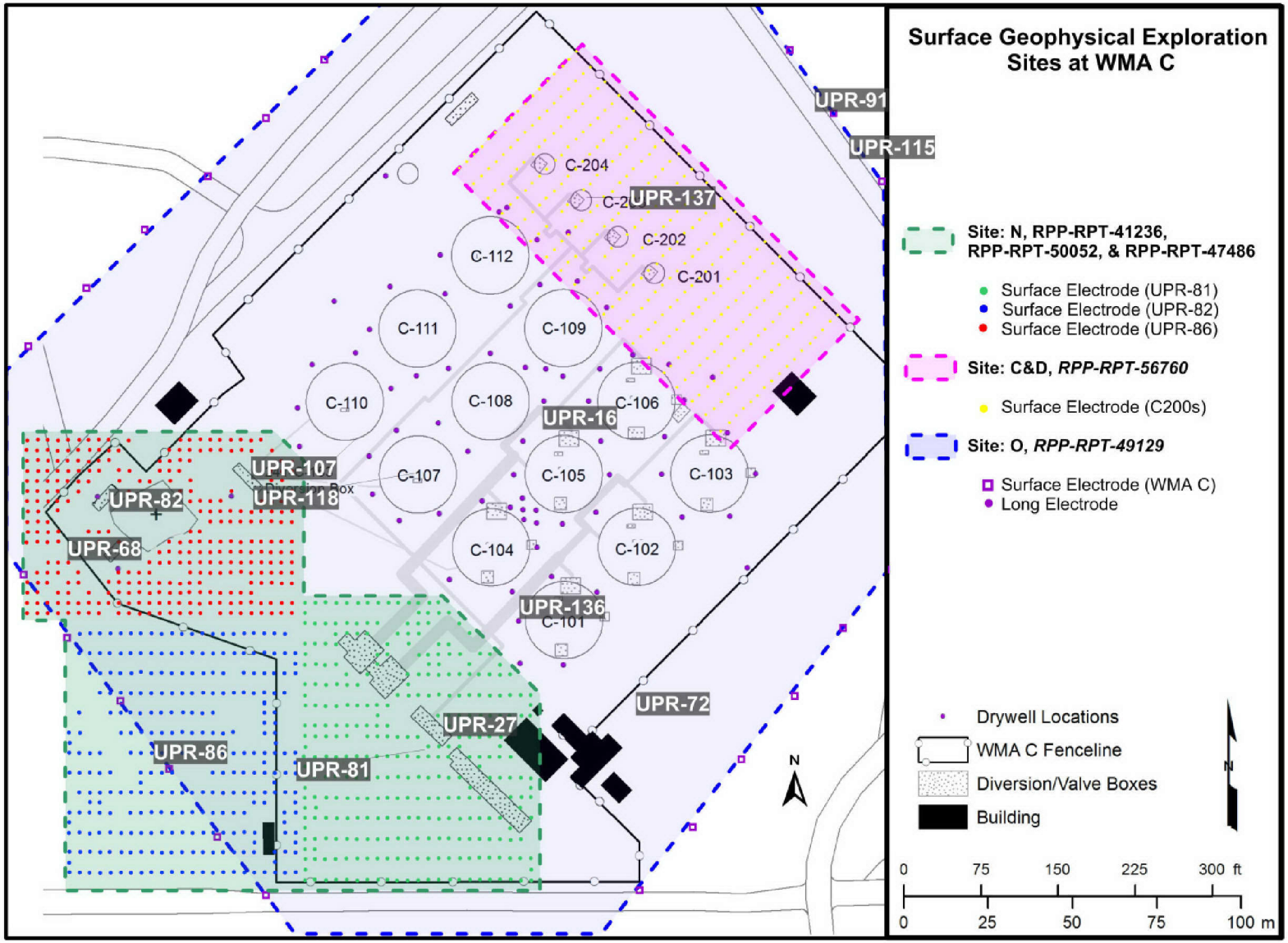
As indicated in Section 4, four investigation sites comprised of three general areas were identified for subsurface characterization using SGE. Investigation Group C+D, Site N, and Site O. This section presents results of the SGE characterization surveys for each of these locations. Figure 5-13 demonstrates the coverage areas associated with each of the three sites.

5.3.1 Investigation Group C+D: UPR-200-E-137 including Tanks C-203, C-201, C-202, and C-204

Site C is defined by the work plan (RPP-PLAN- 39114, Rev. 2) as a UPR (UPR-200- E-137) associated with Tank C-203. The UPR associated with a transfer to Tank C-203 was estimated at approximately 1,520 L (400 gal) of high level PUREX waste. Site D is comprised of the remaining 200-series tanks: C-201, C-202, and C-203 which exhibited level losses of 2,082 L (550 gal), 1,703 L (450 gal), and 1,325 L (350 gal), respectively (HNF-EP-0182). The current leak loss assessment for the all of the 200-series tanks at WMA C (RPP-ENV-33418, Rev. 2) determined that the observed liquid level decreases could be accounted for through evaporation processes. The objective of the SGE analysis of Investigation Group C+D was to determine if the 200-series actually leaked and refine the associated conceptual models.

A three-dimensional electrical resistivity imaging (ERI) investigation was completed as part of the SGE program in the vicinity of the 200-series tanks at WMA C in the summer of 2013. The survey area encompassed the 200-series tanks and UPR-200-E-137, as well as the area within the C Farm boundary directly northeast of the 200-series tanks. The coverage area extended to groundwater monitoring well 299-E27-7 in the northeast, where geophysical logging detected ^{60}Co in the soil column at a depth of approximately 40 m (131 ft) bgs. The survey results are presented in RPP-RPT-56760, *Three-Dimensional Surface Geophysical Exploration of the 200-Series Tanks at the 241-C Tank Farm*.

Figure 5-13. Investigation Group C+D and Sites N and O for SGE at WMA C



The survey included electrical current transmission and voltage measurements on 318 surface electrodes, within a grid layout, 41 depth electrodes, and one groundwater monitoring well acting as a long electrode. The surface electrode and depth electrode data from the survey were combined to produce a resistivity inversion model for the 200-series tanks area. The results indicated a low resistivity target in the region between boreholes C8765, C8766, and C8767 and the monitoring well 299-E27-7, on the northeast edge of the survey area. This conductive target extended from an elevation of approximately 166 m (545 ft) above MSL to down below the water table, at an elevation of 122 m (400 ft) above MSL. It is postulated that the constrained shape of this anomaly was a result of limited resolution at depth, and the anomaly is more likely continuous throughout this depth. The increased moisture content associated with the H2 sedimentary unit is likely the cause of the decreased resistivity at this depth. The anomaly occurs in the direct vicinity of the placed depth electrodes, and falls off with distance from the electrodes, suggesting the response is a result of limited resolution. Geophysical logging completed at each depth electrode location demonstrates the increase in moisture content with no associated increase in gross gamma signature. Based on the available data, the signature observed near well 299-E27-7 is not likely from the 200-series tanks.

Additional low resistivity regions were observed between the 100- and 200-series tanks and to the northwest of Tank C-106. Figures 5-14 and 5-15 display a plan view of the distribution of resistivity in the 200-series tanks survey area, through a series of depth slices and a three-dimensional representation of the tank farm, respectively. Two contours of low resistivity values are highlighted in the three-dimensional representation:

- Opaque value (dark blue) representing 3 Ohm-meter (Ohm-m)
- Transparent value (light blue) representing 10 Ohm-m.

A two-dimensional vertical slice was extracted from the three-dimensional inverse model along a profile through the boreholes C8765, C8766, and C8767, adjacent to the groundwater monitoring well 299-E27-7 (Figure 5-14). Additional resolution is provided to the inverse modeling by the inclusion of the depth electrodes.

5.3.2 Site N: UPR-200-E-81, UPR-200-E-82, and UPR-200-E-86

As defined by RPP-PLAN-39114, Site N is comprised of three unplanned release sites in the southwest corner of WMA C:

1. Unplanned release site UPR-200-E-81 is associated with a transfer line break near diversion box 241-CR-151. The release occurred in October of 1969 and was comprised of approximately 136,000 L (36,000 gal) of PUREX coating waste.

2. Unplanned release site UPR-200-E-82 is associated with a line break near diversion box 241-C-152. The release occurred in December of 1969 and was comprised of approximately 10,000 L (2,600 gal) of B Plant IX waste.

Figure 5-14. Summary of Inversion Model Results for the 200-Series Tank Survey Area

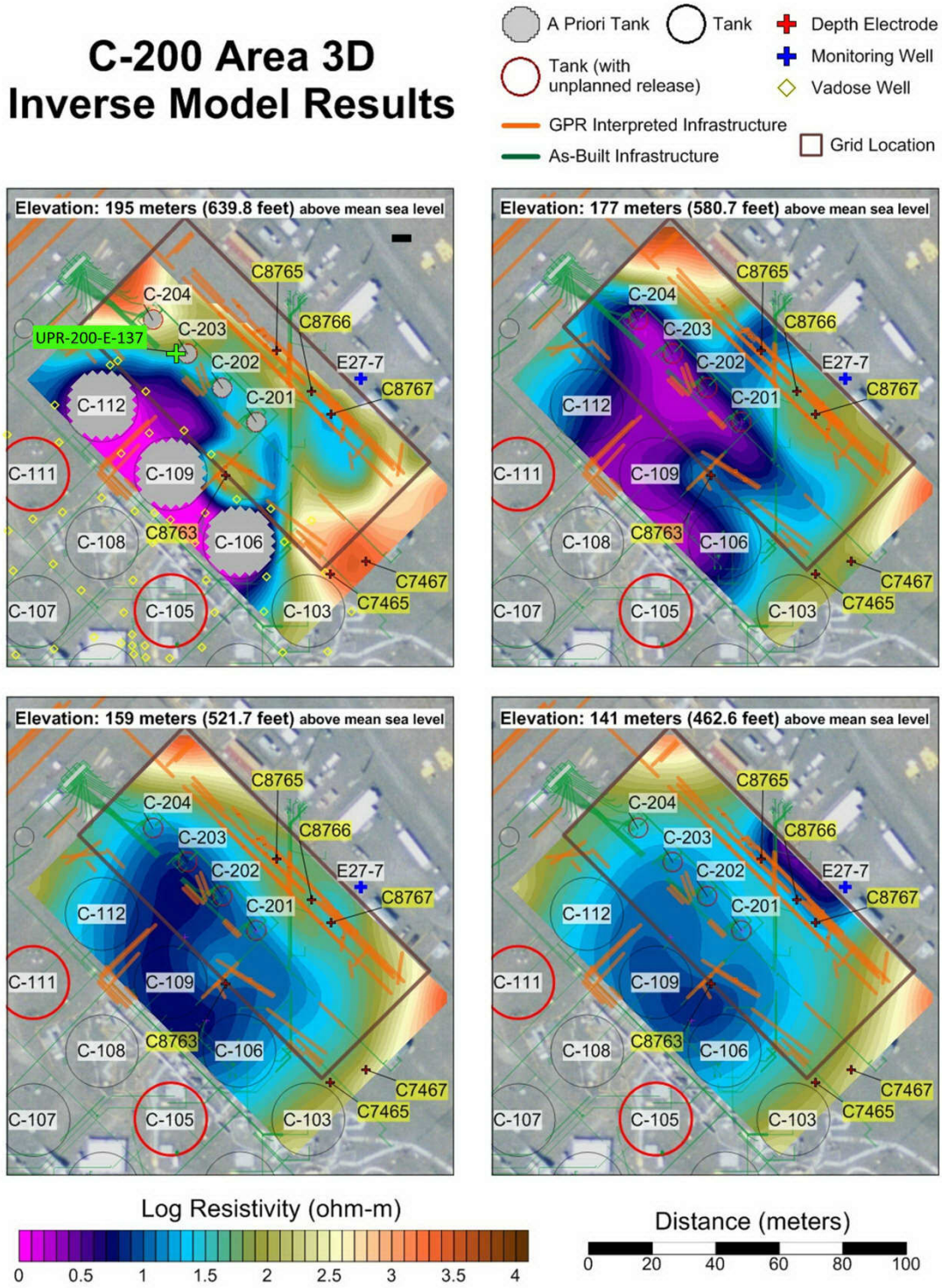


Figure 5-15. Three-Dimensional ERI Results for 3 and 10 Ohm-m Contours, Plan View

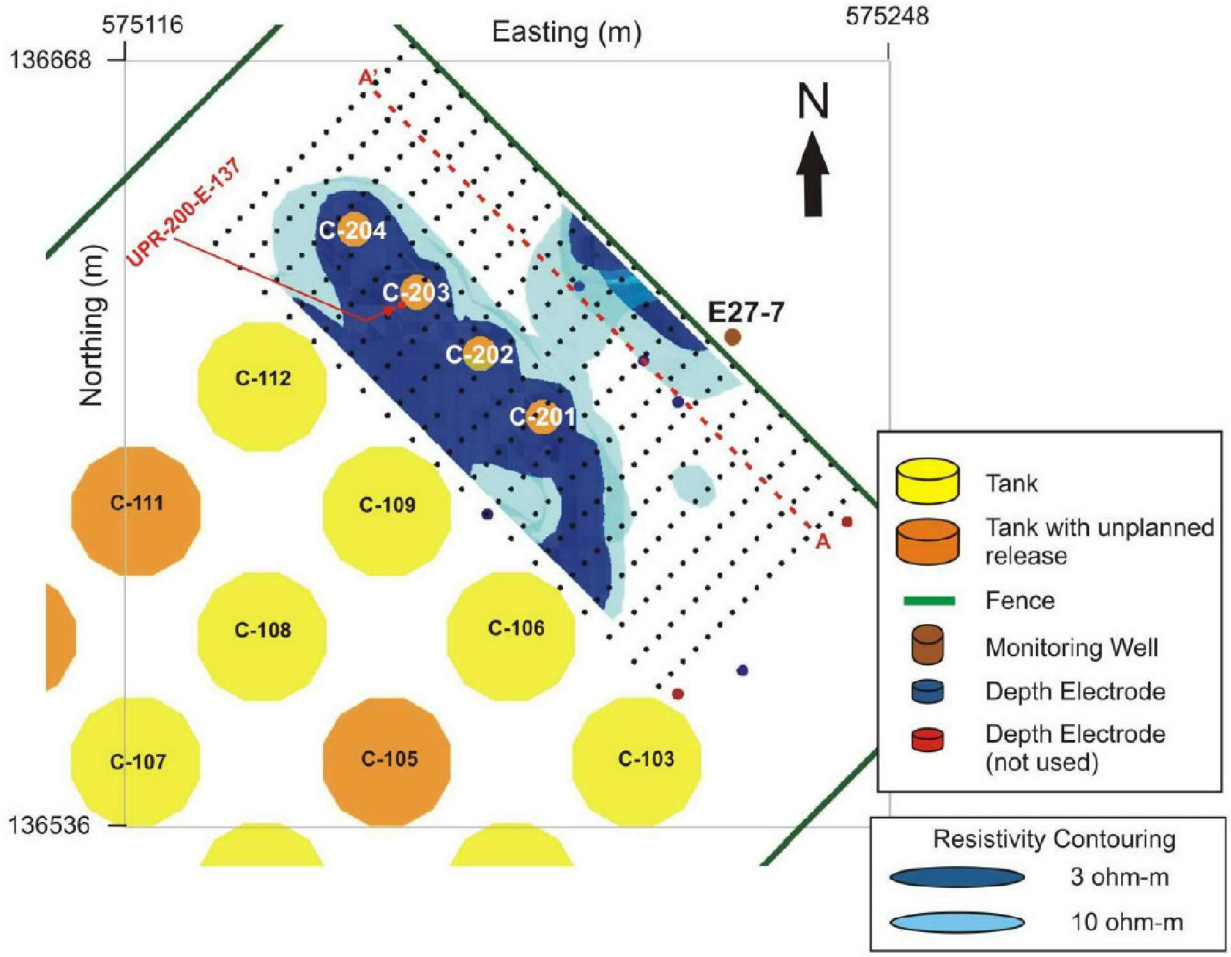
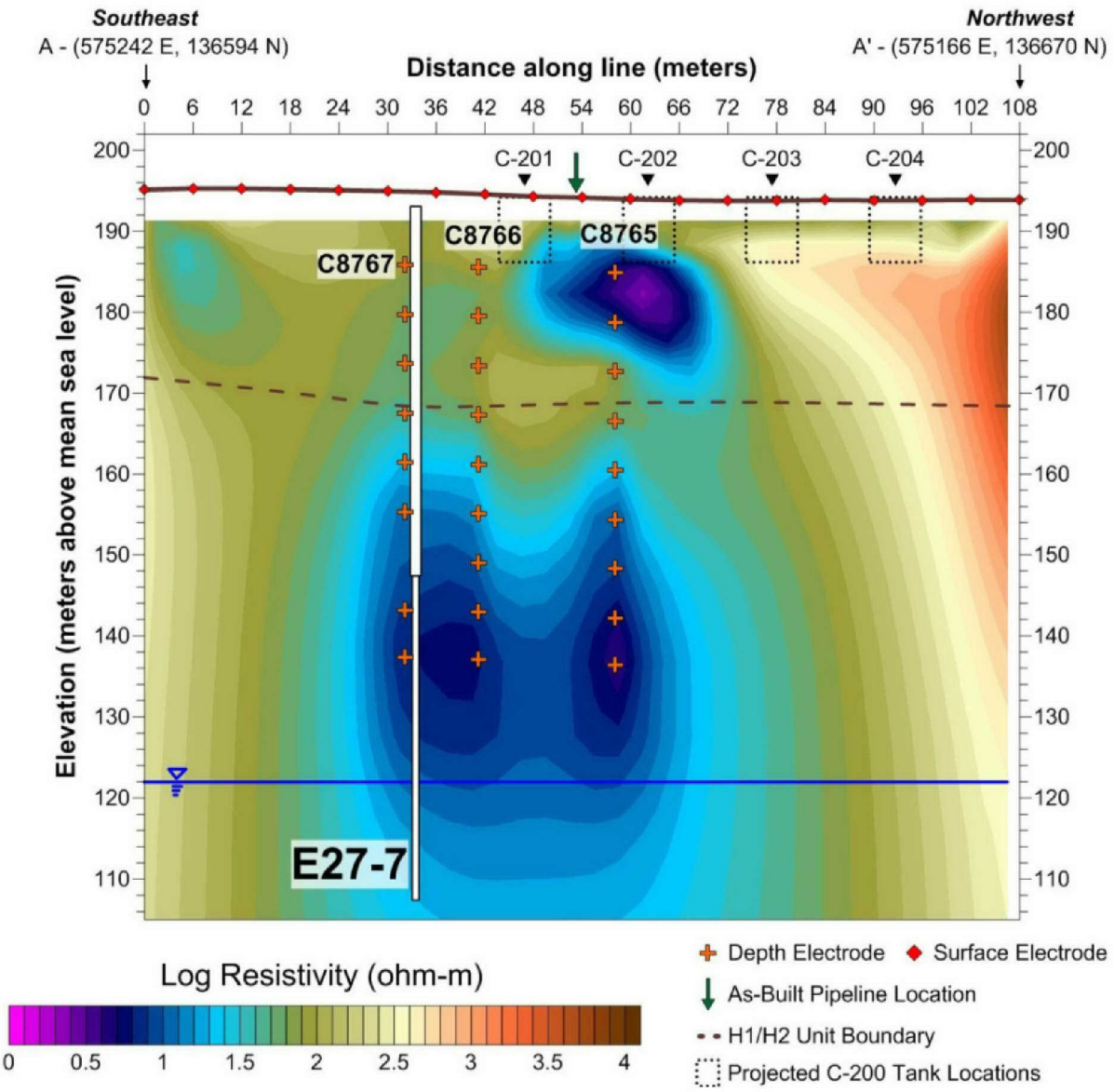


Figure 5-16. Three-Dimensional ERI Results Cross Sectional View Looking Southwest



Note: The location is shown in Figure 5-16 as a red dashed line A-A'.

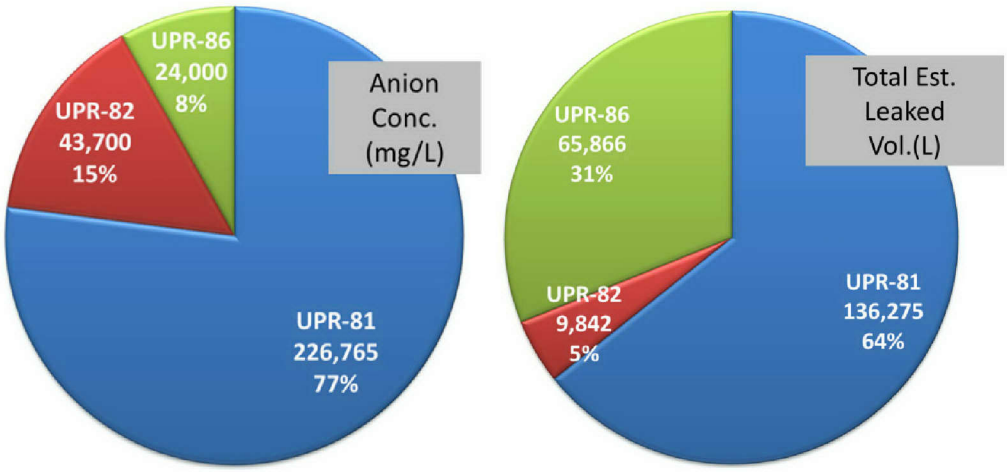
3. Lastly, the unplanned release site UPR-200-E-86 is associated with the C Farm 812 transfer line. The release occurred in February of 1971 and was comprised of approximately 66,000 L (17,000 gal) of process waste.

The objective of the SGE investigation at Site N was to define plume extents at each of the three UPR locations, and refine the associated conceptual models. Figure 5-16 shows the relative anion concentrations and release volumes associated with the wastes from each UPR.

Each of the three Site N locations have a limited amount of subsurface infrastructure, but are relatively clear of infrastructure when compared to areas beneath the tanks. Because subsurface infrastructure (e.g., pipelines, buried utilities) can interfere with instrument readings, confidence in the interpretation of results is higher in areas with less infrastructure.

Based on anion concentrations and release volumes (Figure 5-17), it was predicted that UPR-200-E-81 would have the most resolvable target of the three areas investigated. Correspondingly, with less release volume and lower concentration of anions released, UPR-200-E-86 was predicted as a less observable target. Lastly, UPR-200-E-82, with the lowest release volume but a relatively high concentration of anions (Figure 5-17), was expected to have some measureable response to SGE investigation.

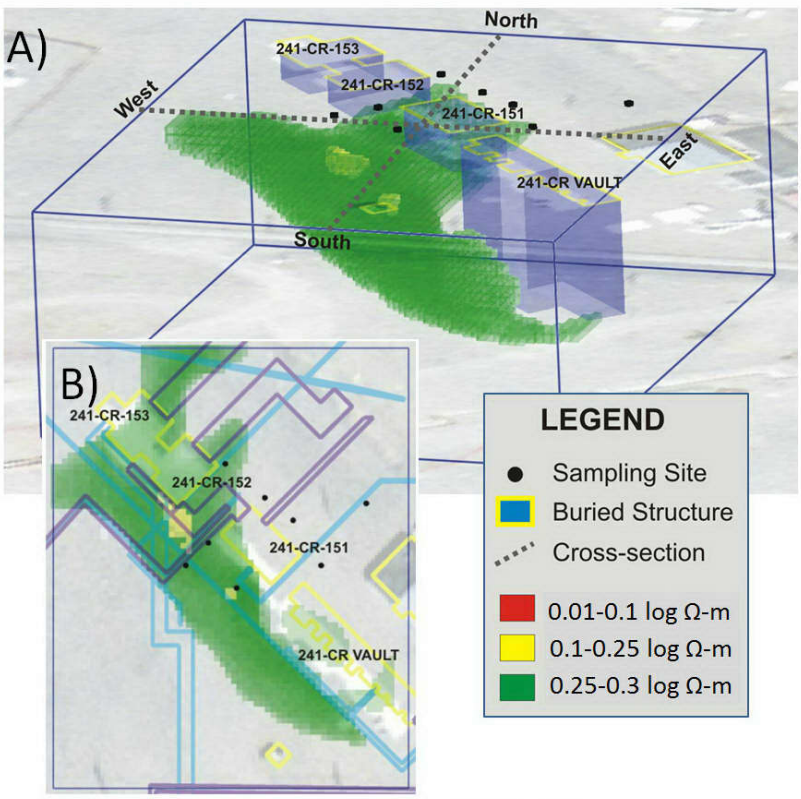
Figure 5-17. Relative Anion and Volume of Releases for UPRs at Site N.



5.3.2.1 UPR-200-E-81. RPP-RPT-41236, *Surface Geophysical Exploration of UPR 200-E-81 Near the C Tank Farm*, reports the results of a three-dimensional ERI survey acquired at UPR-81. The data were acquired using 332 surface electrodes (located at the ground surface) and two pairs of discrete depth electrodes located near UPR-200-E-81. The four depth electrodes were placed in the vicinity of the UPR to improve the target resolution in the complex area below the localized surface infrastructure.

Results of the data processing analyses and comparisons of greater than 50 separate inverse models identified a series of plausible model results. Overall the best model took into account the *a-priori* information (i.e., the approximated effects of the known infrastructure in the vicinity) and resulted in an acceptable root mean square value. The *a-priori* approach incorporates both the known dimensions and estimated resistivity for specific regions in the model domain that approximate buried infrastructure while solving for the best fitting solution within adjacent model layers that are based on actual field measured data. Results from the preferred model exhibit low resistivity areas in the vicinity of diversion boxes 241-CR-151 and 241-CR-152 (Figure 5-18).

Figure 5-18. Three-Dimensional ERI Model Results for UPR-200-E-81, Incorporting A-priori Infrastructure Effects



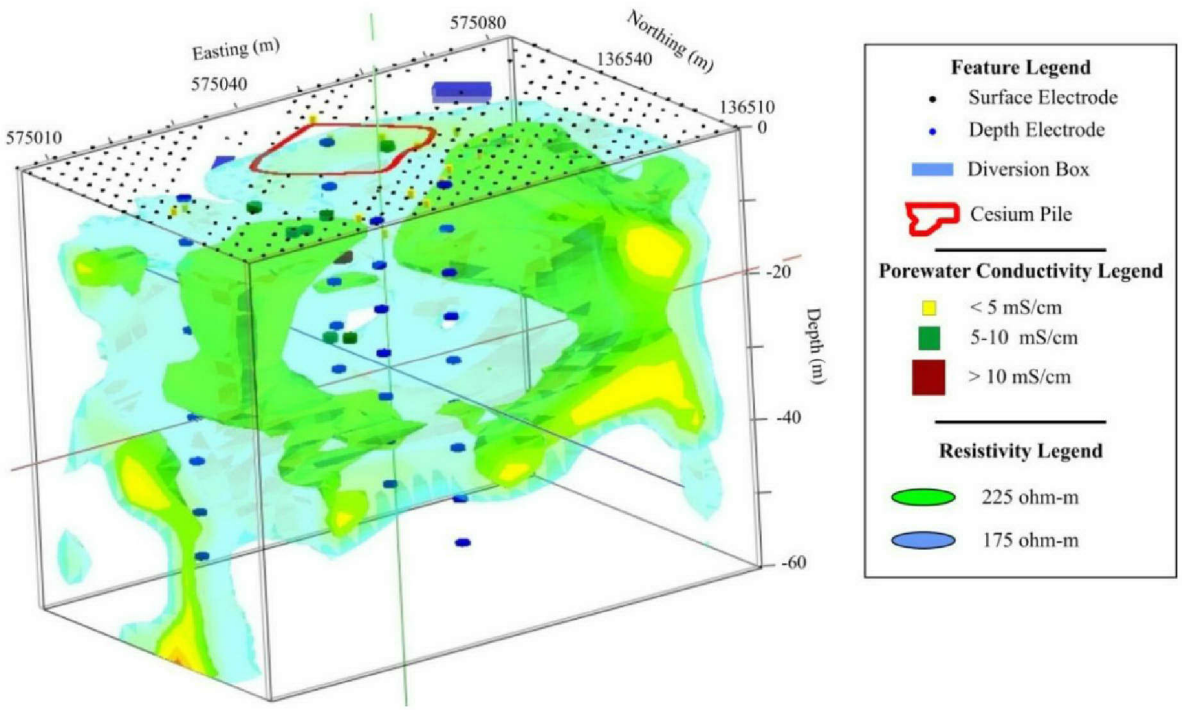
Note: A) Oblique View; B) Plan View

5.3.2.2 UPR-200-E-82. RPP-RPT-50052, *Surface Geophysical Exploration of UPR-200-E-82 Near the C Tank Farm*, reports the results of a three-dimensional ERI survey conducted at the UPR-82 release site within the C Farm. The survey focused on imaging the extents of the past release directly beneath the cesium pile. The survey included a concentrated three-dimensional analysis, with measurements on 303 surface electrodes placed within a grid and 35 depth electrodes in five boreholes, and a two-dimensional survey with three profile lines extending outside of the UPR-200-E-82 and C Farm. The results of the three-dimensional model showed a general distribution of high electrical resistivity values beneath the UPR-200-E-82 release, with

values approximately two orders of magnitude higher than other sites where a discernable feature was noted in the resistivity data.

Figure 5-19 shows a three-dimensional rendering of the resistivity results, demonstrating a resistive subsurface. Confirmation from soil analytical data also showed low porewater electrical conductivity values, with a maximum of 12 mS/cm, and typical values less than 5 mS/cm. Other waste sites at Hanford, where resistivity analysis has been extremely successful in identifying contamination, display much higher porewater electrical conductivity (EC). The conclusion from the combined interpretation of porewater EC and electrical resistivity geophysics, therefore, is that there is no indication of a continuing source of groundwater contamination from this unplanned release.

Figure 5-19. Three-Dimensional ERI Results for UPR-200-E-82

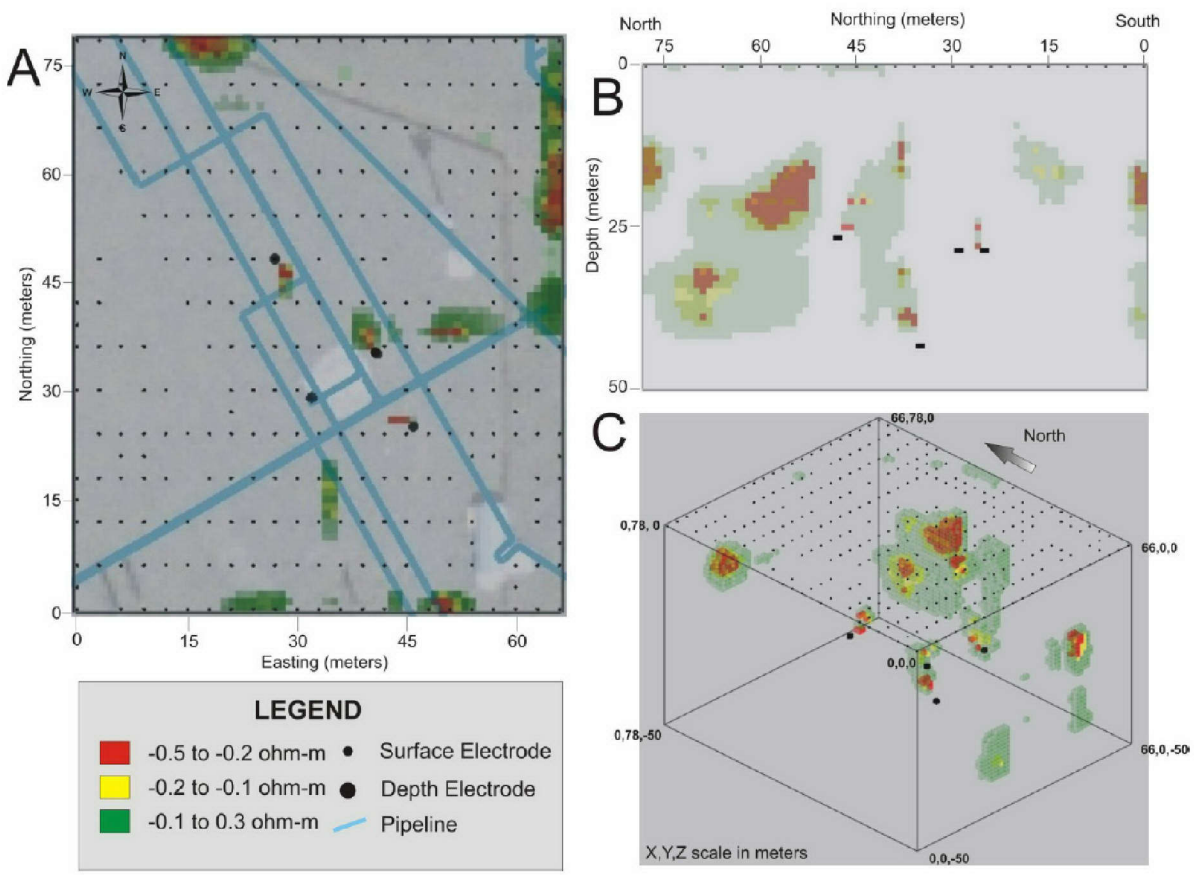


Note: Contours are presented at 175 and 225 Ohm-m, oblique view

5.3.2.3 UPR-200-E-86. RPP-RPT-47486, *Surface Geophysical Exploration of UPR-200E-86 Near the C Tank Farm*, reports the results of a three-dimensional ERI survey conducted at the UPR-200-E-86 release site. The data were acquired at 301 surface electrodes (located at the ground surface) and five depth electrodes. The depth electrodes were used to improve the target resolution in the area below the localized surface infrastructure. The data were inverse modeled with a multi-threaded algorithm capable of handling large domains, called RES3DINVx64. The use of a multi-threaded code allows faster modeling times over single threaded codes.

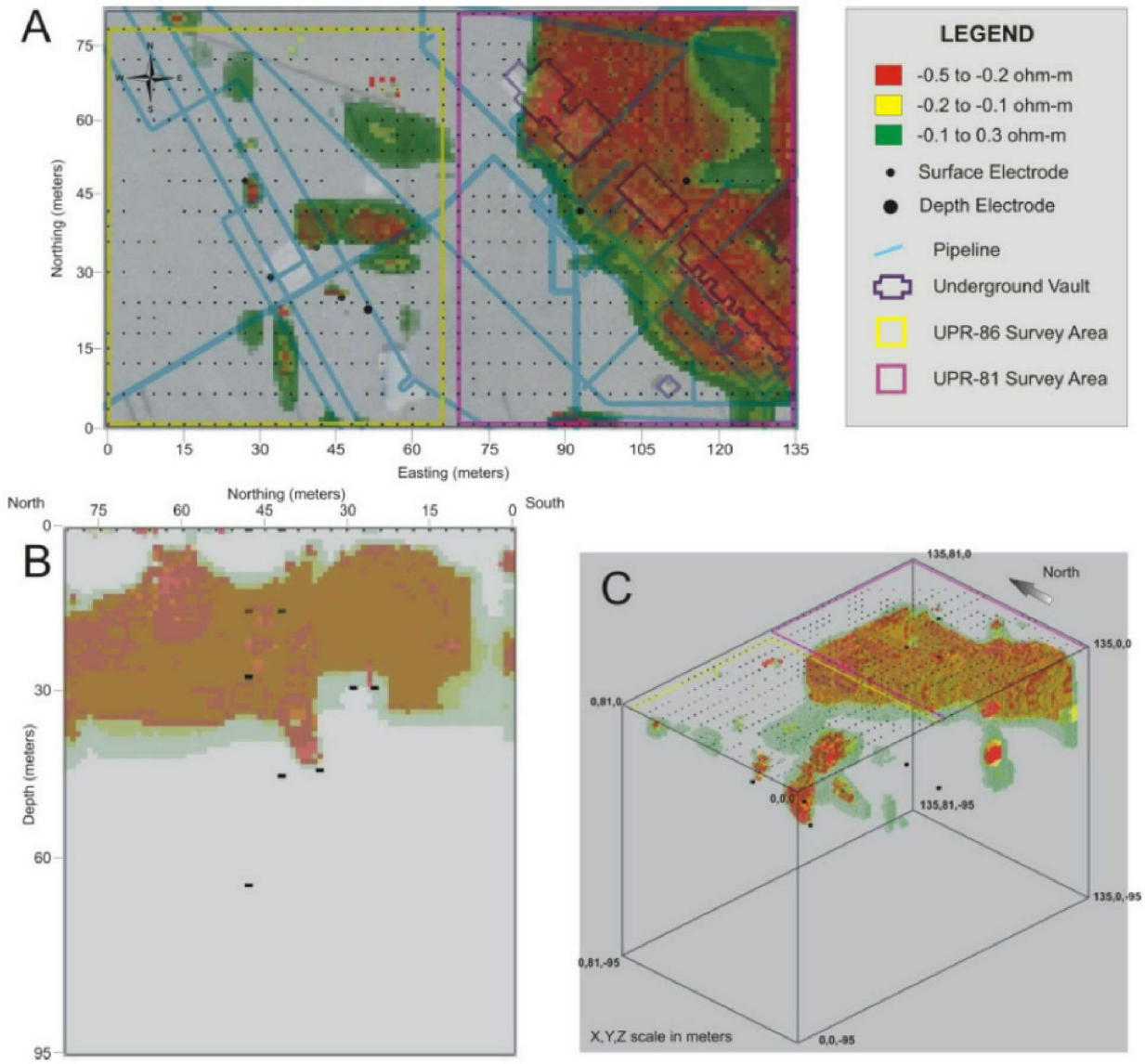
Results from the analyses of more than 30 separate inverse models showed that the area beneath UPR-200-E-86 was relatively resistive despite the approximately 66,000 L (17,000 gal) projected release. Small isolated conductive targets are seen in the area, which may be more reminiscent of noise than actual subsurface features (Figures 5-20). When the data from the adjacent UPR-200-E-81 site was combined with the UPR-200-E-86 data and both areas inverse modeled together, stark differences in the distribution of electrical resistivity were observed (Figure 5-21). The UPR-200-E-81 site is much more electrically conductive, despite having released only about twice as much (136,000 L [36,000 gal]) to the subsurface. The findings of the resistivity survey combined with the soil sampling analyses from boreholes surrounding the release site suggest that the 66,000 L (17,000 gal) release estimate may have been an over estimate, alternatively the composition of the waste and estimated volume of the release may have been below the sensitivity of the three-dimensional ERI methodology.

Figure 5-20. Three-Dimensional ERI Results for UPR-200-E-86



(A) Plan View, (B) Side View, looking East, (C) Oblique View, looking Northeast.

Figure 5-21. Three-Dimensional SGE Results for Both UPR 81 and UPR 86



Note: A) Plan View, B) Profile Looking from East to West, C) Oblique View Looking from the Southwest.

5.3.3 Site N SGE Performance Summary

The electrical resistivity imaging of each of the Site N UPR locations performed as expected based on the estimated waste stream associated with the individual releases (Figure 5-22). The text below evaluates the performance of SGE analysis compared to expected contaminant behavior based on release volumes and concentrations.

UPR-200-E-86 – The targets identified for UPR-200-E-86 are uncertain. There was great variability in the model results associated with UPR-200-E-86. At approximately 66,000 L (17,000 gal), the UPR-200-E-86 site release volume was approximately half of the clearly identified UPR-200-E-81 release, but the concentration was considerably more dilute with anion values estimated at up to 10 times less than the UPR-200-E-81 release.

UPR-200-E-81 – In each model completed for UPR-200-E-81 a target was identified. At approximately 136,000 L (36,000 gal), the UPR-200-E-81 release was the greatest volume and greatest anion concentration of the three sites. As such, it should have the greatest likelihood of being detected with the greatest contrast to background conditions.

UPR-200-E-82 – No clear target was identified. At approximately 10,000 L (2,600 gal), the UPR-200-E-82 release was the smallest volume release of the three Site N locations. However, the anion concentration was the second highest at approximately 44,000 mg/L. The SGE results demonstrate values slightly less resistive than background, suggesting there may be some increased moisture or variation in soil mineralogy relative to the dry background hanford soils. But there was no evidence of decreased resistvity due to the presence of a suburface release.

The age of the release, relative volume, and relative concentrations, in conjunction with a uncertain historical documentation contribute to the uncertainty of these results.

5.3.4 Site O: Full Farm WMA C

As defined by RPP-PLAN-39114, Rev. 2, Site O is comprised of the entirety of WMA C with the objective to obtain a three-dimensional vision of suspected releases.

Table 3-2 identifies waste releases that are associated with WMA C. The greatest recorded releases within WMA C are associated with Tanks C-101, C-104, and C-108. Note that the latter two are associated with cascade line releases.

A long electrode ERI survey was implemented in 2006 and results were provided in RPP-RPT-31558, *Surface Geophysical Exploration of C Tank Farm at the Hanford Site*. In 2011, the results were reprocessed taking advantage of advancements in computer processing abilities (RPP-RPT-49288, *C Farm Surface Geophysical Exploration-Reprocessing*).

The survey instrumented 69 drywells within the tank farm, eight groundwater wells outside the tank farm, one buried electrode recently installed in the west end of the tank farm, and four surface electrode arrays outside of the farm.

Figure 5-22. Summary of SGE Results for Site N, Including Target Waste Stream Components

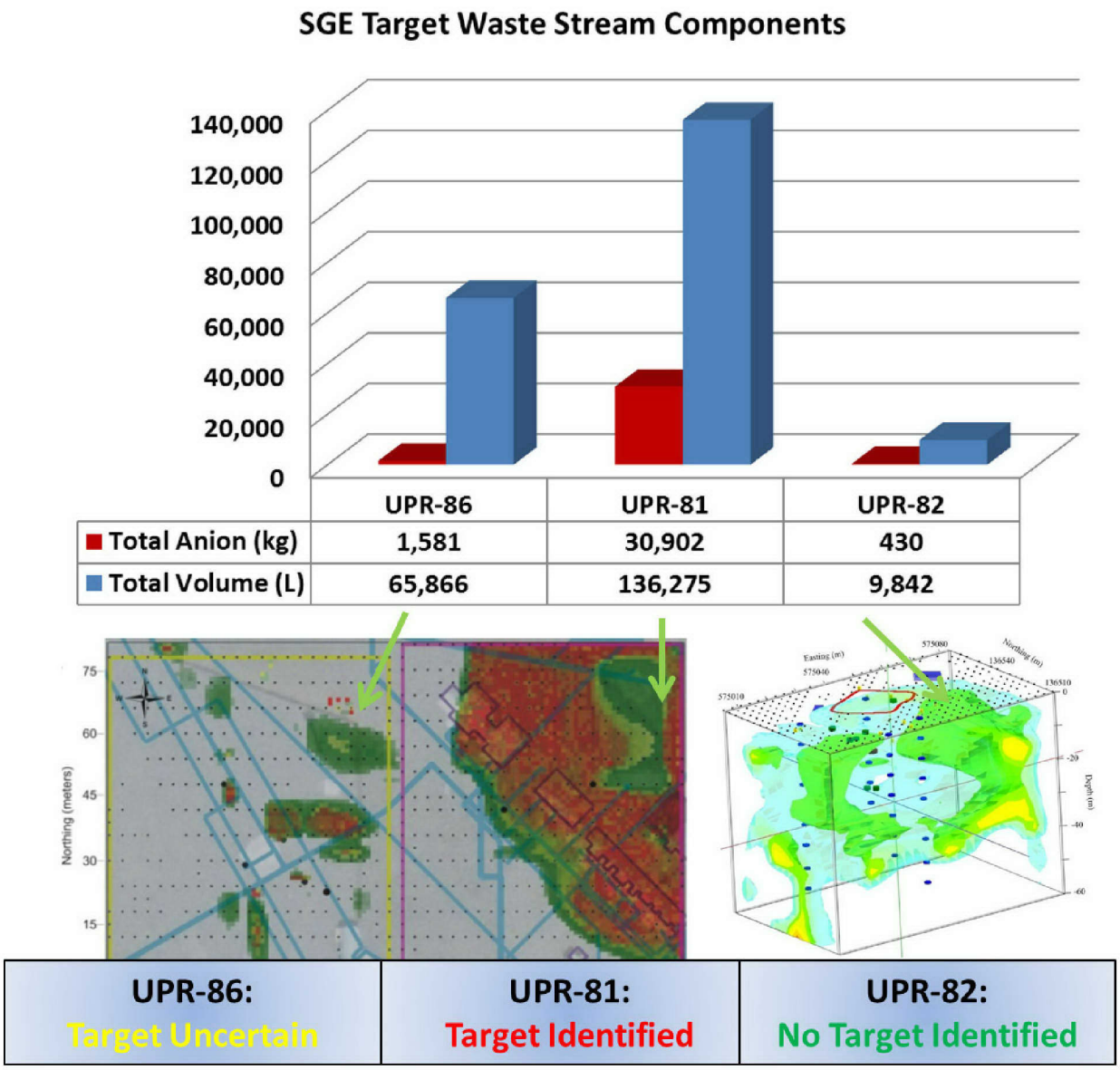
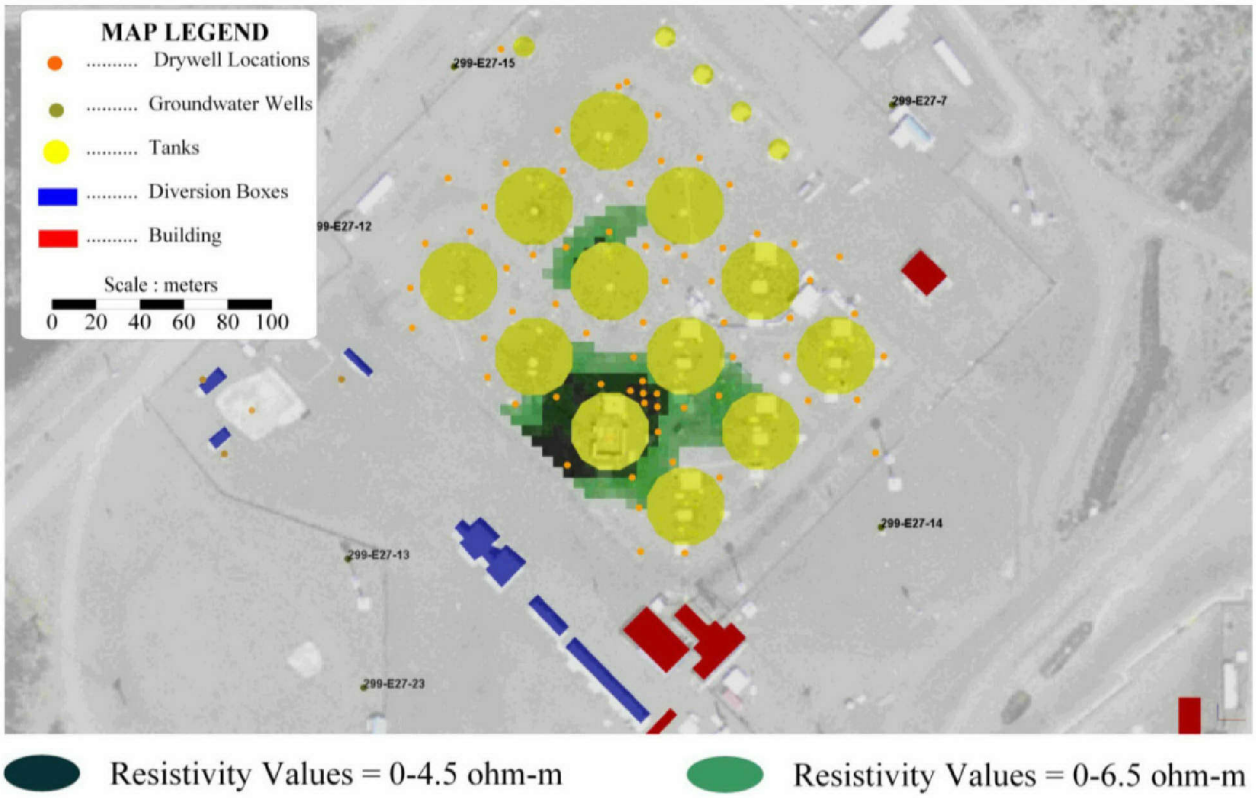


Figure 5-23. Three-Dimensional SGE Results for 3 and 10 Ohm-m Contours, Plan View



The four surface electrode arrays were located outside of the farm and were oriented parallel to the perimeter of the C Farm fenceline. The four surface arrays provided limited coverage, but were deployed in an effort to investigate areas near the tank farm fenceline for targeting future characterization activities. The limited coverage data collection strategy was used to collect data in support of near-term planned characterization while limiting resources required for multiple tank farm entries.

The initial analysis of C Farm survey identified areas of low resistivity which are most likely associated with increased soil moisture or inorganic salt concentration. Additionally, the investigation identified specific areas of low-resistivity values within the C Farm that can be correlated with current interpretations of historical data. Specifically, the well to well data indicated a low-resistivity region near Tanks C-104 and C-105, along with a smaller low-resistivity zone near Tank C-108 (Figure 5-23). This is in contrast to the results provided in 2011 (Figures 5-24 and 5-25), which indicates an anomaly specific to Tank C-101 and no significant anomaly at Tank C-104.

Figure 5-24. Results of the 2011 Reprocessed Long Electrode ERI Survey, Plan View

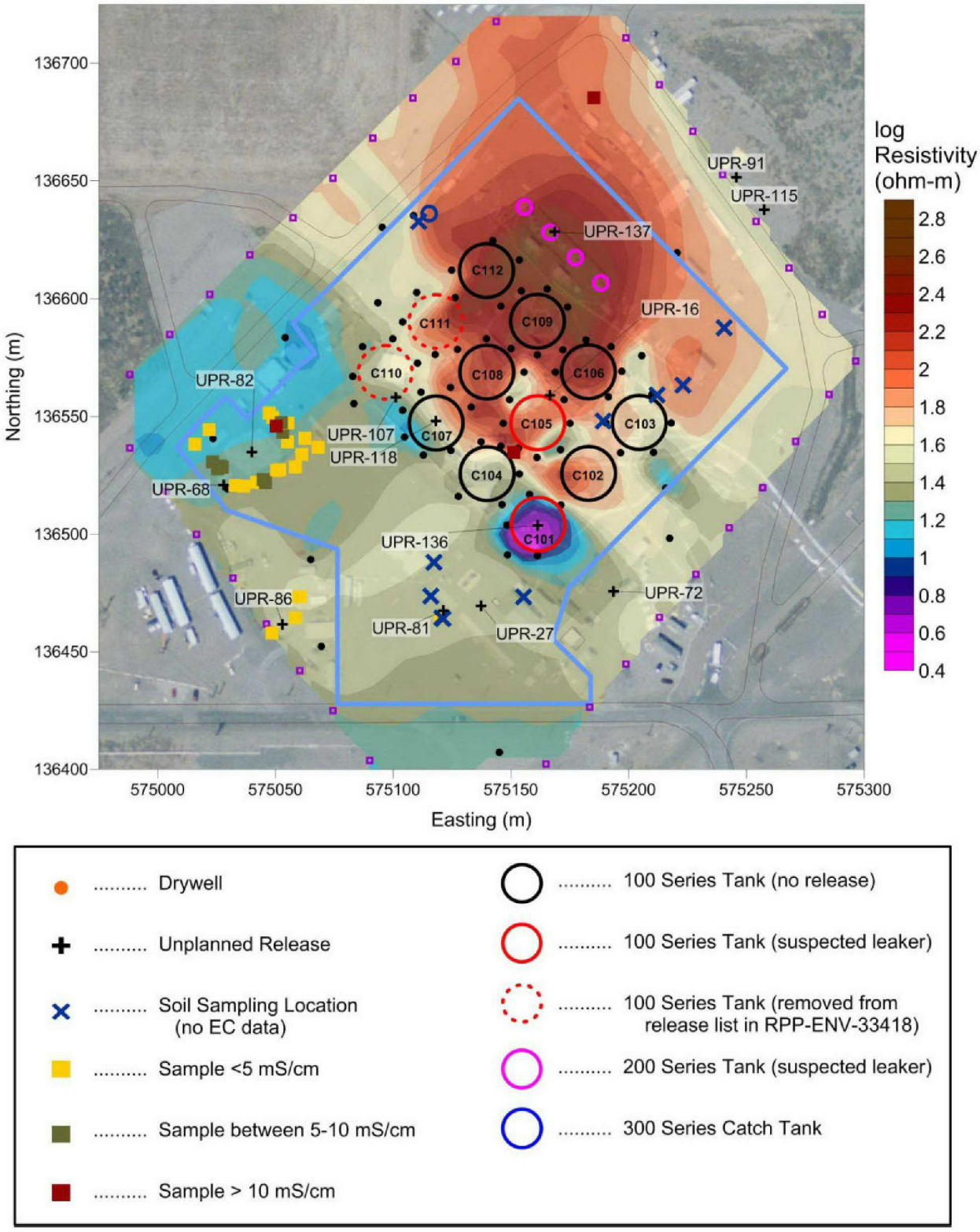


Figure 5-25. Results of the 2011 Reprocessed Long Electrode ERI Survey, Plan, and Cross Section Views

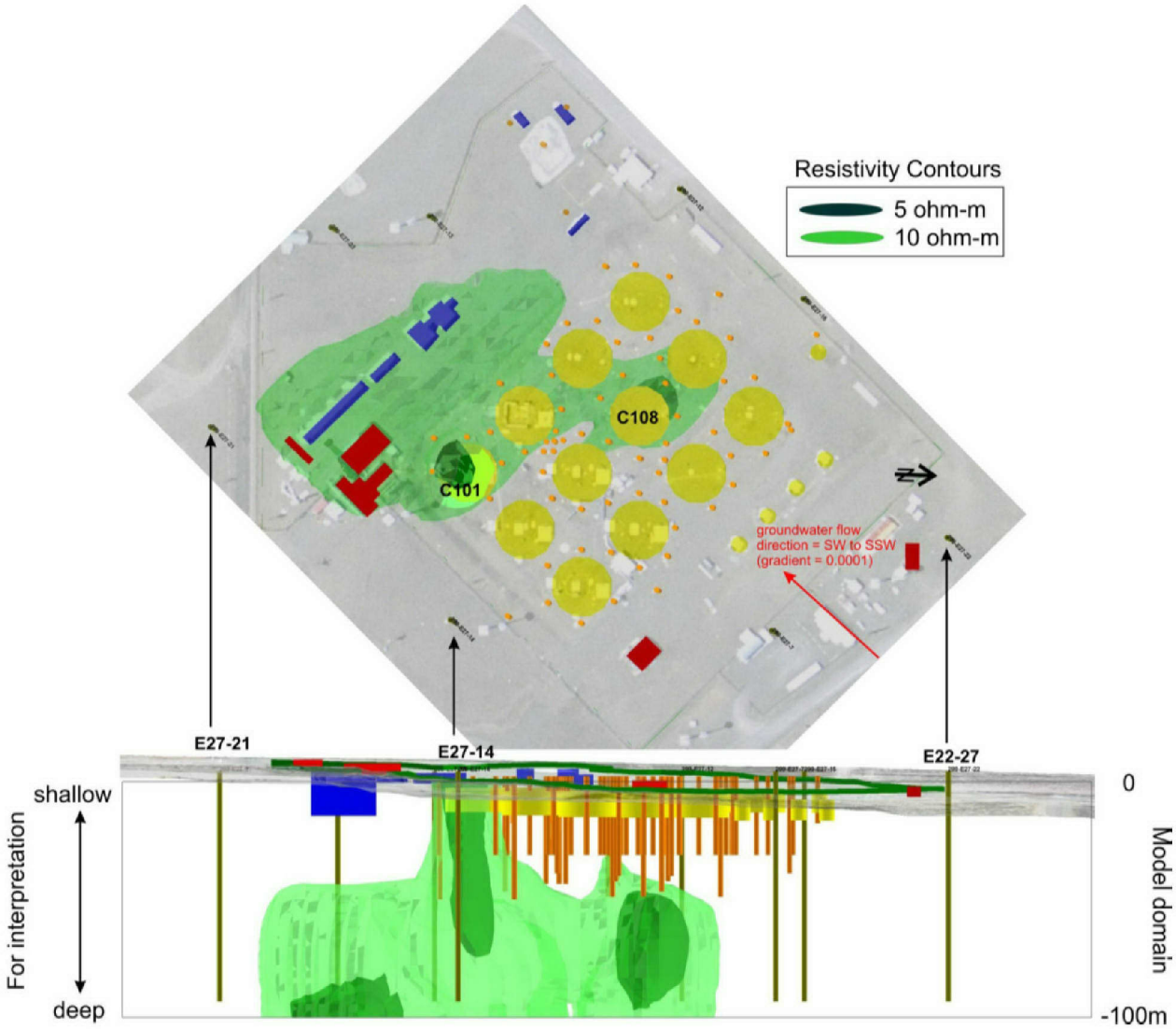
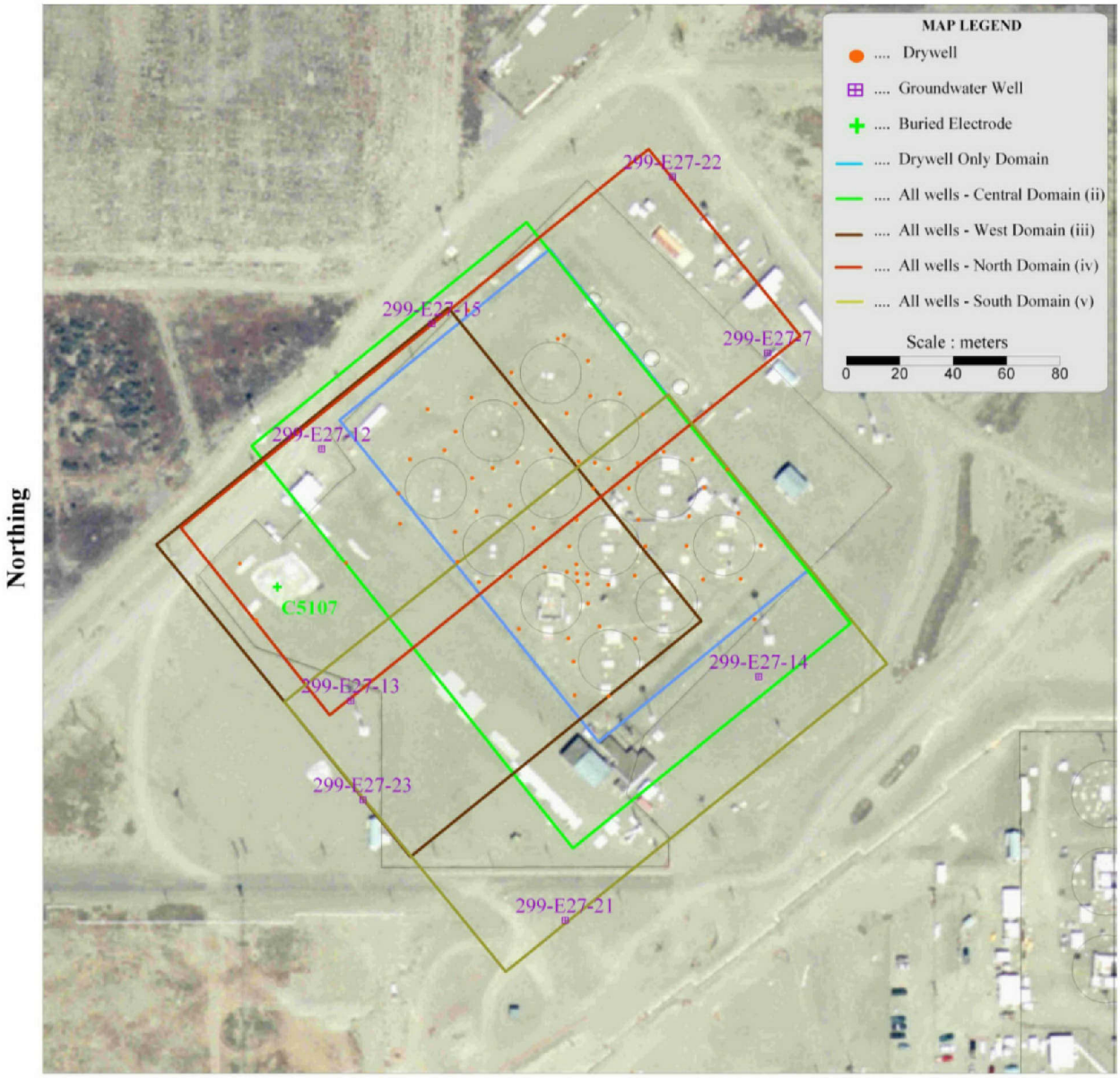


Figure 5-26. 2006 SGE Analysis Subdomains for Long Electrode ERI Modeling of WMA C, Plan View



The 2006 analysis was limited to the available computer processing capabilities at that time. Recent advancements in computer processing have facilitated the ability to complete the analysis in a more technically correct approach. The 2006 modeling analysis broke the survey area into multiple overlapping sub-domains, and the results were presented by combining the smaller subdomain results to represent the larger domain. This approach can skew target locations depending on the number of, and relative locations of, the sub domains. Figure 5-23 identifies the relative locations of the subdomains used in the 2006 model. Note that domain "iv" does not incorporate the area surrounding Tanks C-104 and C-101. Because of the shape and positioning of this domain, when it was included the final 2006 results, the anomaly now thought to be located at Tank C-101, was skewed to the west and shown at Tank C-104. The 2011 analysis was completed using a single model that incorporated the entirety of the survey area into one domain. As such, these results represent the best available model of this data set to date.

The results presented in Figures 5-24 and 5-25 clearly indicate an anomaly at Tank C-101, as well as directly adjacent to Tanks C-103, C-105, and C-108. The latter results are not as conductive or as extensive as the Tanks C-101 results, however they do correlate well with the results of coincident gamma logging and soil sample results, where low values of ^{60}Co were historically detected (WRPS-56461-VA). There is also an anomaly due west of the farm shown in blue near the cesium pile (UPR-200-E-82). The black dots in Figure 5-24 represent the drywell locations used to acquire this data set. This anomaly is most likely an artifact of the inversion modeling given the very limited resoluiton in the area. Figure 5-25, appears to confirm results from UPR-200-E-81, associated with the CR Vault (blue) also demonstrating decreased resistivity with depth.

5.3.5 Integrated SGE Results for WMA C

In general, the SGE campaigns at WMA C have performed as expected. The results of the individual sites have been combined into a single interpretation as presented in Figure 5-27. This figure was generated by aligning and shifting the different relative data sets and limiting the displayed contour intervals to 1, 3, and 10 Ohm-m, respectively. This provides an overall summary of the low resistivity level extents at WMA C.

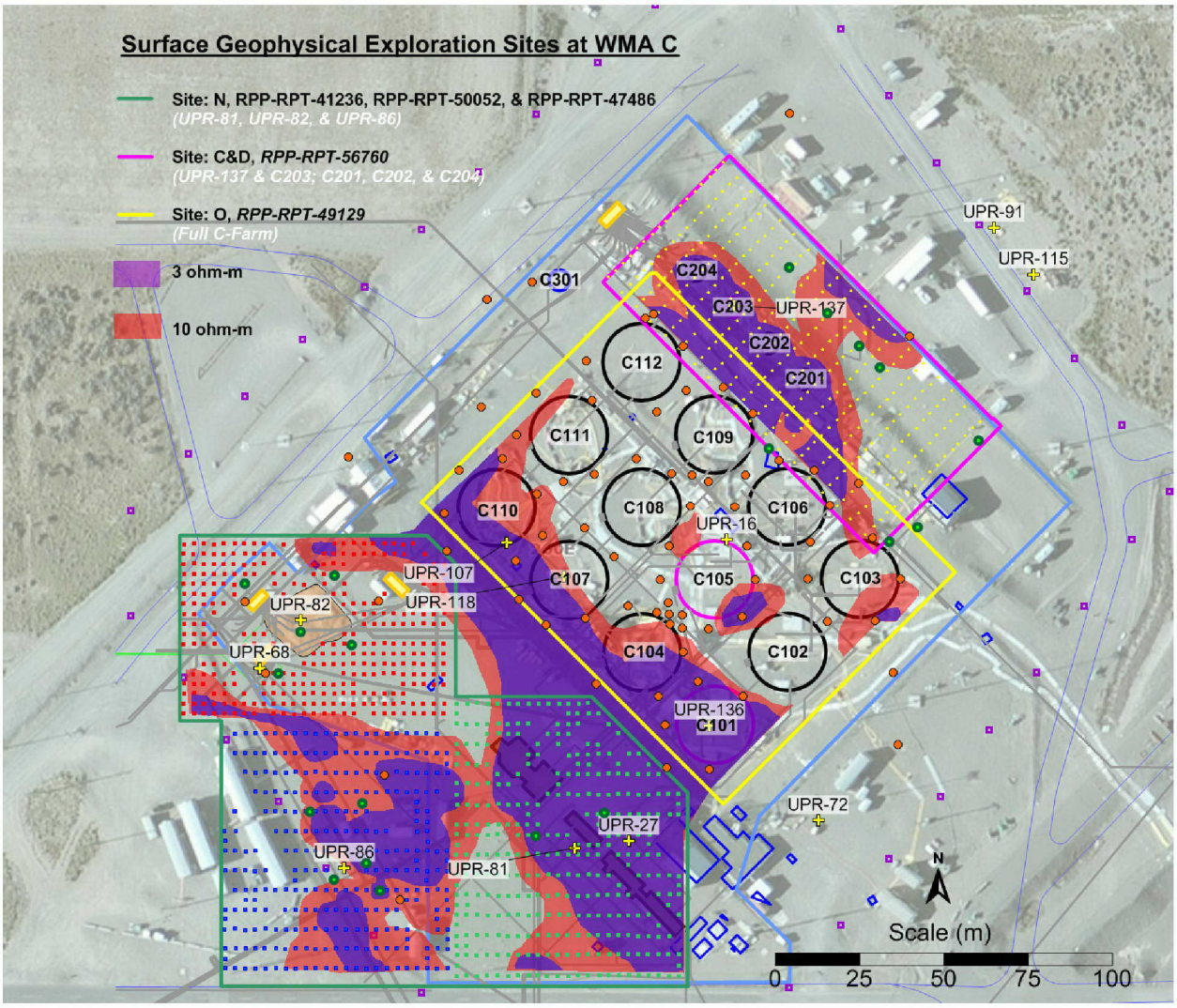
The locations of the surface electrodes are shown for each area, with the long electrode locations shown as orange dots in the vicinity of the tanks, and the depth electrode locations shown as green dots. Displaying the electrode locations provides a qualitative example of survey resolution for each investigation area. As such, areas with sparcely populated electrode locations have greater uncertainty then the areas with dense electrode placement. Additionally, unless supported by depth electrodes, resolution decreases with depth. The vicinity between the southwestern edge of the tank farm and UPR-200-E-82 has the greatest uncertainty, and may well be an extraploation of nearby anomalies.

The two investigation areas with the greatest signatures are UPR-200-E-81 (CR Vault transfer line) and UPR-200-E-136 (Tank C-101). Additionally, signatures identified adjacent to Tanks C-108, C-105 and C-103 correlate very well with known ^{60}Co contamination. The anomaly in the direct vicinity of the 200-series tanks is most likely due to subsurface infrastructure, with the exception of the area at the northeastern boundary of the survey area. This anomaly occurs at

depth and correlates well to gamma results obtained from well 299-E27-7 (WRPS-56991-VA). However, it should be noted that this anomaly may be a result of limited coverage at depth. The anomaly is only present near the depth electrodes, and resistivity surface coverage varies laterally with depth. It should also be noted that the direct push logging completed when the depth electrodes were installed does not indicate any increases in gamma specific to this zone of interest. This anomaly warrants further investigation only if the outcome is anticipated to change planned closure activities.

It is important to note that the results presented for the ERI data are the best models based on the statistical evaluation of the data and known occurrances. All results are subject to change based on inclusion of additional information.

Figure 5-27. Integrated ERI Results for All of WMA C, Plan View



5.4 SUMMARY OF GROUNDWATER CONTAMINATION

This section provides a summary of Hanford Site groundwater contamination relevant to WMA C. As identified in Section 2.4.6.3, groundwater monitoring is conducted in the WMA C area to meet both RCRA and CERCLA requirements. The RCRA groundwater monitoring program for WMA C was initiated in 1989 and is currently being monitored under a RCRA interim status groundwater quality assessment monitoring program described in DOE/RL-2009-77. Wells in and around WMA C are also sampled as part of the CERCLA monitoring for the 200-BP-5 OU. The 12 wells that are monitored in the WMA C area are shown on Figure 5-28. All of these wells are screened in the unconfined aquifer.

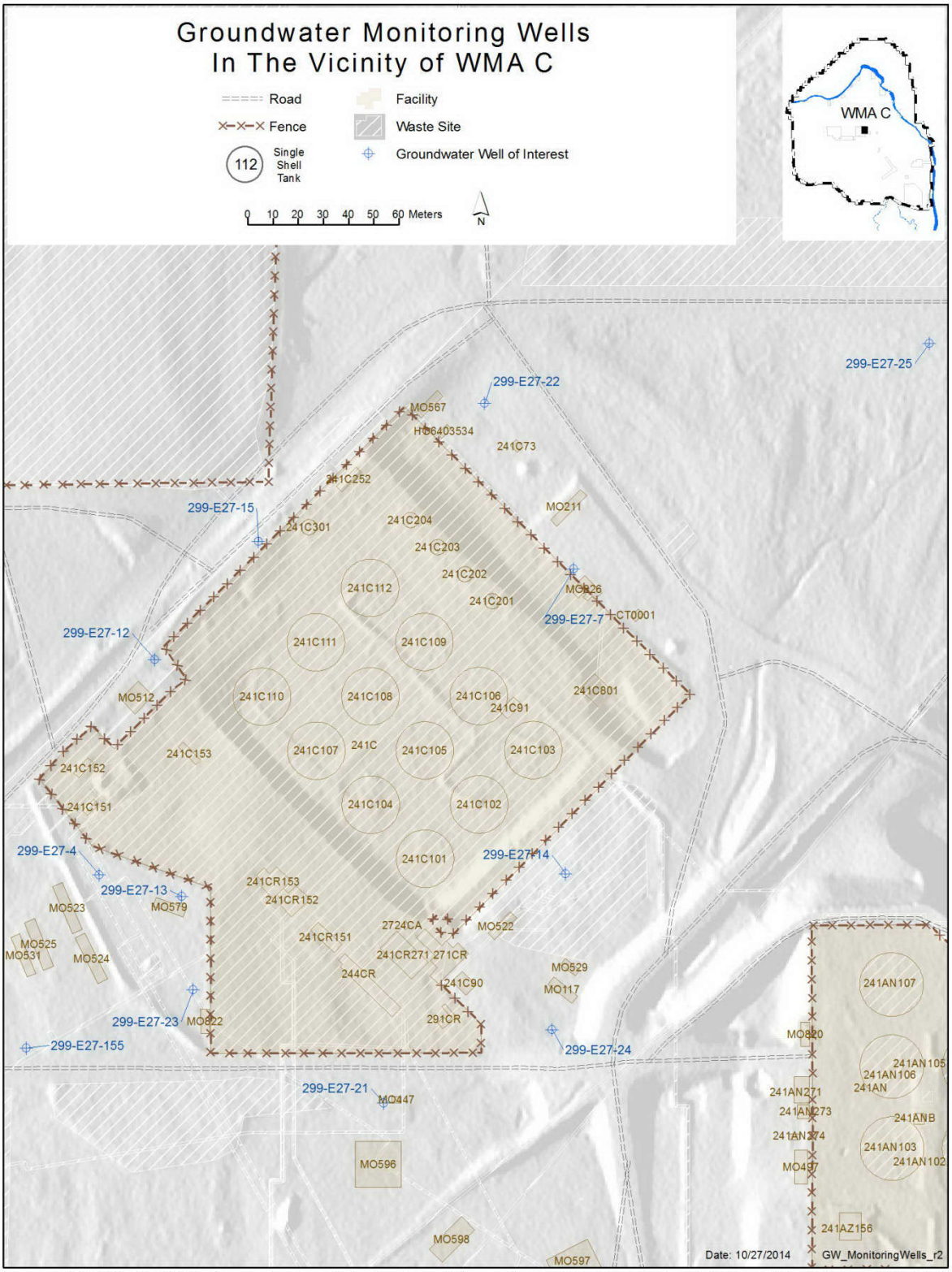
DOE/RL-2014-32 reported cyanide as the only dangerous waste constituent impacting groundwater in the C Farm area. Additionally, DOE/RL-2014-32 identified three plumes exceeding the national primary drinking water standard in the groundwater beneath WMA C: nitrate, ^{129}I, and ^{99}Tc. Two of the three plumes, nitrate and ^{129}I, are regional plumes from multiple regional sources. Note that due to the recently identified shift in the groundwater flow direction in the vicinity of WMA C, the movement of the contaminant plumes identified and tracked for WMA C can be expected to shift in the future, to reflect the change in flow direction. However, as discussed in Section 2 due to the very low gradient in the vicinity, the flow rate is slow.

Additionally, Section 2.4.5 of this report identifies sources of enhanced recharge to the soil column and the preferential pathways in the vadose zone to groundwater. It is the consensus that the primary sources of groundwater contamination in the WMA C include discharges to cribs and trenches near the PUREX facility; discharges throughout the 200 East Area; and from WMA C sources (e.g., tank leaks and unplanned releases).

To provide supplemental information for the WMA C RFI effort and the ongoing investigations into potential contributions to current and future groundwater contamination from sources in the vadose zone RPP-RPT-58297, *Screening-Level Evaluation of Groundwater Monitoring Data Collected in Vicinity of WMA C*, was prepared. This report provides a screening-level evaluation of groundwater data from the 12 wells around WMA C and was based on sampling and analysis data collected over the 10-year period from January 2004 through December 2013. The primary objective of the evaluation was to identify a set of groundwater constituents of interest that report concentrations greater than comparison values developed for protection of human health (MCLs and risk-based standards) in the vicinity of WMA C. These constituents of interest would have the potential to be cancer risk or noncancerous hazard drivers.

This evaluation was a high-level evaluation intended to provide information to support the WMA C RFI process as well as the baseline risk assessment for the groundwater aquifer conducted to support the 200-BP-5 groundwater OU. It should be noted that the constituents of interest identified in RPP-RPT-58297 are not necessarily those that will be identified as risk drivers in the baseline risk assessment for the 200-BP-5 OU.

Figure 5-28. Groundwater Monitoring Wells in the Vicinity of WMA C



Source: RPP-RPT-58297, *Screening-Level Evaluation of Groundwater Monitoring Data Collected in Vicinity of WMA C*.

From the 55 constituents reviewed as part of the screening-level evaluation, only seven constituents were considered likely to be of interest for assessing the potential for cancer risks or noncancerous hazards or investigating potential groundwater contamination sources at WMA C. The seven constituents of interest for the WMA C data set are cyanide, nitrate, sulfate, nickel, vanadium, ^{129}I, and ^{99}Tc. Of these, ^{129}I, nickel, and vanadium do not appear to be correlated with releases from WMA C (DOE/RL-2011-118). Cyanide, nitrate, sulfate, and ^{99}Tc appear to be correlated with a release from WMA C, with declining concentrations.

Appendix U provides the concentration trend plots for each constituent of interest in each well that were included in RPP-RPT-58297. These plots are provided to assist the following discussion on each constituent of interest. Additionally, Appendix U includes cross-sections of the WMA C area along with showing vadose zone soil concentrations for these groundwater constituents of interest. These cross sections also identify the last 2013 concentration for the constituents of interest in the wells around WMA C area. These figures and information provided on soil analysis in the vadose zone indicate that these constituents of interest are not pervasive in the vadose zone. Table 5-8 summarizes the exceedances that occurred in Phase 2 for the constituents of interest. Note that cyanide was not detected above background at any investigation sites and ^{129}I and vanadium were only detected and above background concentrations, respectively, at Site P with respect to all Phase 2 analysis. It should be noted that the geologic interpretation provided in these cross sections is consistent with the interpretations provided in RPP-RPT-56356, *Development of Alternative Digital Geologic Models of Waste Management Area C* (i.e., Alternative Geologic Model 1 [modified] with water level data from June 2013).

Table 5-8. Summary of Phase 2 Exceedances for the Constituents of Interest

Analyte	A+B	C	E	F+G	H+I	J	L1+L2	P	R	U
Cyanide	*Not detected in soil*									
Nitrate	D			D	S		D	D		D
Sulfate	S,D				S					
Nickel			D				D	D		D
Vanadium								S,D		
Iodine-129								S		
Technetium-99	D			D			D	S,D	D	D

D = exceeds background or detected without background in deep soil (> 5 m [15ft])
S = exceeds background or detected without background in shallow soil (≤ 5 m [15ft])

5.4.1 Groundwater Constituents of Interest

This section provides information on each constituent of interest:

- Cyanide
- Nitrate
- Sulfate
- Nickel
- Vanadium
- Iodine-129
- Technetium-99

Relevant information from specific groundwater annual reports and RPP-RPT-58297 are summarized below for each of these constituents.

5.4.1.1 Cyanide. Cyanide has been detected in all of the monitoring wells adjacent to WMA C, except 299-E27-25. During 2013, cyanide was only found above detection limits (e.g. 4 µg/L) in three wells (299-E27-14, 299-E27-23 and 299-E27-24). The cyanide results for these wells were all significantly below the 200 µg/L drinking water standard (i.e., federal MCL). By the end of 2013 the cyanide concentrations in two of the wells were below the detection limit. The highest concentration, 13.9 µg/L, in 2013 was in well 299-E27-24, which is screened across the bottom of the aquifer, in December 2013. During 2013 the cyanide concentration in this well ranged between 8.64 and 13.9 µg/L.

Cyanide was previously observed in the WMA C groundwater at much higher concentrations than recently observed. The highest historic groundwater concentrations reported (44.6 µg/L) have been associated with upgradient well 299-E27-7, although the results have been highly variable. Results from well 299-E27-14 have been lower but more consistent, with a general upward trend from 2007 to 2011, followed by a general downward trend through the end of 2013.

The extent of cyanide contamination and the rate of migration are reported on a quarterly basis under the RCRA groundwater monitoring. For the fourth quarter of 2013, the rate of migration was estimated to range between 0.03 and 0.6 m (0.11 and 2 ft)/day in a southeast to south-southeast flow direction (SGW-56777). Detectable levels of cyanide are not considered to be significantly farther south or south west of wells 299-E27-23 or 299-E27-24. A small area of elevated cyanide at depth to the southeast of well 299-E27-155 is also inferred (SGW-56515, Figure 8 and Section 4.3).

As identified in RPP-RPT-58297, cyanide concentrations above the 0.48 µg/L Method B noncancerous HQ of 0.1 screening level were measured in 11 of the 12 wells in the vicinity of WMA C, however, in most of these wells concentrations were predominantly below the 90th percentile background level of 8.4 µg/L. Comparison of upgradient and downgradient trends indicates that there was a local release of cyanide from WMA C. Persistent cyanide detections above background were observed only at three wells along the east perimeter of WMA C

(299-E27-7, 299-E27-14, and 299-E27-24). In recent years concentrations in these wells have generally been declining.

Cyanide is associated with some of the tank wastes in WMA C. Tanks C-108, C-109, C-111, and C-112 are reported to have had cyanide-bearing waste inventory. As discussed in DOE/RL-2009-77, the source of cyanide may be related to past releases from WMA C.

5.4.1.2 Nitrate. Nitrate concentrations in four WMA C wells exceeded the drinking water standard of 45 mg/L during 2013. These wells are 299-E27-14, 299-E27-21, 299-E27-24 and 299-E27-25. Well 299-E27-14, located on the southeast side of WMA C, had the greatest concentration (110 mg/L) from the December 2013 sampling event.

The nitrate plume in the WMA C area extends throughout the 15.5 m (50.9 ft) thick aquifer. Two wells are screened at the bottom of the aquifer (299-E27-24 and 299-E27-155). The nitrate concentration in well 299-E27-24 has been stable, ranging between 68.2 and 72.2 mg/L since December 2010 when the well was installed. Nitrate concentrations in well 299-E27-155 decreased from 50.5 to 24 1 mg/L between September 2012 and December 2013. Of the four wells screened at the top of the aquifer (299-E27-12, 299-E27-13, 299-E27-14, and 299-E27-15), only 299-E27-14 had concentrations exceeding the drinking water standard of 45 mg/L. The wells northwest, north and northeast of WMA C which have longer screen intervals than those screened near the top of the aquifer (wells 299-E27-4, 299-E27-22 and 299-E27-25) show mixed nitrate trends. Nitrate is trending down at well 299-E27-4, but is stable at well 299-E27-25. At well 299-E27-22, located between the other two wells, concentrations are trending down, but increased in September 2013. Nitrate concentrations at wells southwest and south of WMA C continue to be elevated relative to nitrate concentrations seen in wells north and northwest of WMA C, through 2013 (DOE/RL-2014-32 and SGW-56515).

Three of the four wells with nitrate concentrations exceeding the drinking water standards are to the south to southeast of WMA C (299-E27-14, 299-E27-21, and 299-E27-24). The source of elevated nitrate at well 299-E27-25 may be associated with unplanned releases associate with discharges to the 216-B-2 Ditches (DOE/RL-2011-118, Section 3.4.1.7).

As identified in RPP-RPT-58297, nitrate concentrations above the 11,360 µg/L Method B noncancer HQ of 0.1 screening level were measured in all 12 wells in the vicinity of WMA C, however, in recent years persistent detections above the 90th percentile background value of 26,871 µg/L were reported predominantly in six wells located along the south and east perimeters of the area (wells 299-E27-23, 299-E27-21, 299-E27-24, 299-E27-14, 299-E27-7, and 299-E27-25). Nitrate concentrations in these wells appear to be steady or gradually increasing. Comparison of upgradient and downgradient trends indicates that there was a local release of nitrate from WMA C. The highest concentrations were consistently reported in well 299-E27-14, where the concentration at the end of 2013 was 110,000 µg/L.

5.4.1.3 Sulfate. As of the December 2013 sampling (SGW-56777), the most significant sulfate concentrations at WMA C continue to be at wells 299-E27-14, 299-E27-24, and 299-E27-25. Results from these wells exceeded the secondary drinking water standard of 250 mg/L through 2013. The remainder of the wells range from 53 to 185 mg/L.

The greatest sulfate concentrations downgradient of WMA C are at wells 299-E27-14 and 299-E27-24. Trends in sulfate and nitrate concentrations in these two wells, relative to those observed in upgradient wells, continue to suggest a past release of contaminants containing elevated nitrate and sulfate to the groundwater from within WMA C. Well 299-E27-14 is screened across the upper part of the aquifer, and well 299-E27-24 is screened across the bottom of the aquifer. Data from these wells suggest that these contaminants have migrated vertically through the aquifer (DOE/RL-2014-32).

Sulfate concentrations at well 299-E27-25 had been slowly increasing since this well was installed and began being sampled. Specifically, the concentrations increased from 227 mg/L to 292 mg/L. The December 2013 result at well 299-E27-25 saw a minor decrease, dropping to 282 mg/L. The trend at well 299-E27-25 appears to mimic the past trend at well 299-E27-10, located near the 216-B-2 Ditches. The comparable sulfate trends between these wells and historical southward groundwater flow direction indicate that these wells are likely being impacted by past releases from the 216-B-2 Ditches (DOE/RL-2011-01, *Hanford Site Groundwater Monitoring Report for 2010*, Section 9.1.10.3).

As identified in RPP-RPT-58297, sulfate concentrations near or above the 250,000 µg/L secondary drinking water standard were persistently observed in four wells located along the east perimeter of WMA C (299-E27-24, 299-E27-14, 299-E27-7, and 299-E27-25). Sulfate concentrations in these wells appear to be steady or slightly declining. Comparison of upgradient and downgradient trends again indicates that there was a local release of sulfate from WMA C. The highest concentrations at the end of 2013 were 296,000 µg/L and 282,000 µg/L in wells 299-E27-24 and 299-E27-25, respectively.

5.4.1.4 Nickel. As identified in RPP-RPT-58297, nickel concentrations above the 32 µg/L Method B noncancer HQ of 0.1 screening level were measured in four wells in the vicinity of WMA C (299-E27-4, 299-E27-15, 299-E27-23, and 299-E27-25). Nickel concentrations in these wells have generally fluctuated around the screening level value over the 10-year period. The highest nickel concentrations were observed in well 299-E27-4, where concentrations spiked to levels above the 100 µg/L drinking water standard (i.e., state maximum contaminant level) in 2009 and 2013. These spiked concentrations do not reflect general trends and appear to reflect well screen degradation based on the investigation associated with similar findings at wells 299-E33-337 and 299-E33-339 (DOE/RL-2011-118). It should also be noted that this well is located upgradient from WMA C (groundwater flow in the area is to the south and east).

5.4.1.5 Vanadium. As identified in RPP-RPT-58297, vanadium appears to be pervasive and persistent in the unconfined aquifer in the vicinity of WMA C. Vanadium concentrations above the 8 µg/L Method B noncancer HQ of 0.1 screening level were measured in all 12 wells. Concentration fluctuations were observed in all of the wells but there does not appear to be a discernable trend in overall vanadium concentrations in this area. Comparison of upgradient and downgradient trends does not indicate any local releases of vanadium in the WMA C vicinity.

5.4.1.6 Iodine-129. As reported in DOE/RL-2014-32, all 12 wells at WMA C had ^{129}I levels exceeding drinking water standard (1 pCi/L) and are associated with past migration of greater

^{129}I activity to the east/southeast. The levels at WMA C ranged from 2.5 to 7.5 pCi/L. Iodine-129 levels detected near WMA C have been relatively consistent over the past two decades.

As identified in RPP-RPT-58297, ^{129}I is pervasive and persistent in the unconfined aquifer in the vicinity of WMA C. Concentrations were above the drinking water standard in all 12 wells over the entire 10-year period. Concentration fluctuations were observed in all of the wells but there does not appear to be a discernable decline in overall ^{129}I concentrations in this area. Comparison of upgradient and downgradient trends does not indicate any local releases of ^{129}I in the WMA C vicinity.

5.4.1.7 Technetium-99. Seven of the 12 WMA C monitoring wells have had ^{99}Tc concentrations exceeding the 900 pCi/L drinking water standard at times or consistently during 2012 and the first three quarters of 2013. Results for four other wells (299-E27-12, 299-E27-15, 299-E27-22 and 299-E27-25) have never exceeded the drinking water standard. These wells have been and/or are considered upgradient wells (SGW-56515).

Currently activity is trending sharply upwards in well 299-E27-21, south of WMA C. Concentrations have also been increasing in wells 299-E27-24 and 299-E27-14, southeast of WMA C. The activity at well 299-E27-14 exhibited a decrease starting in September 2013, which is inconsistent with the continued increase at well 299-E27-21.

Three wells to the west of WMA C (299-E27-4, 299-E27-23 and 299-E27-155) had decreasing ^{99}Tc activity during 2012 and the first three quarters of 2013. Well 299-E27-23 had had the greatest activity of all WMA C wells for the 6 years up through 2012, and is currently showing a sharp downward trend. The pattern of decline in concentration in the wells to the southwest, and increase in the two wells to the south and southeast appears to be associated with the change in flow direction and rate (SGW-56515).

As discussed in SGW-56515, the higher levels of ^{99}Tc at wells 299-E27-21 and 299-E27-23, without significant levels of nitrate (see discussion of nitrate in next subsection) indicate that nitrate was probably removed from the waste stream stored in WMA C. During the PUREX process, nitrate began to be recycled to reduce operating costs. One potential waste stream, the PUREX supernate, provides a good relationship between the original waste concentrations and concentrations in groundwater at these wells (SGW-56515, Section 4.4).

An anomalous spike was observed in upgradient well 299-E27-7 in 2001-2002, but the concentrations have remained at low levels since 2003. No specific source has been identified for the spike.

As identified in RPP-RPT-58297, ^{99}Tc concentrations above the 900 pCi/L drinking water standard were observed in seven wells located along the south perimeter of WMA C. Since 2012, concentrations have declined in four of these wells (299-E27-4, 299-E27-155, 299-E27-13, and 299-E27-23) but have increased in the other three wells (299-E27-21, 299-E27-24, and 299-E27-14). Well 299-E27-23 has had the highest ^{99}Tc concentrations historically, reaching a peak of 26,000 pCi/L in 2012, but the concentrations in this well have steadily declined in recent years, reaching 4,400 pCi/L in December 2013. The trends in ^{99}Tc concentration show apparent

plume movement toward the east beginning in 2012, as evidenced by a sharp increase in concentration in well 299-E27-21. At the end of 2013, the ^{99}Tc concentration in well 299-E27-21 was 21,000 pCi/L. Less sharp increases in concentration were also observed beginning in 2012 in wells 299-E27-14 and 299-E27-24, which are located to the east of well 299-E27-12, and in December 2013 the concentrations in these two wells were 7,300 pCi/L and 4,800 pCi/L, respectively. Comparison of upgradient and downgradient trends indicates that there was a local release of ^{99}Tc from WMA C.

5.5 BIOTA SAMPLING

Small mammals were collected and analyzed for radionuclides and chemicals, including metals, organics, and polychlorinated biphenyl (PCB) congeners during the Phase 2 investigation. The purpose of the effort was to assess exposure to contaminants that may have originated from WMA C. Investigating transport pathways and potential exposures was expected to inform potential impacts to biological resources during facility decommissioning and corrective measure selection activities.

Field collection of small mammals was initiated in March 2011 to support the RPP-PLAN-39114, *Phase 2 Facility Investigation/Corrective Measures Study Work Plan for Waste Management Area C.* The work plan specified collections of samples in the habitats and perimeter area near WMA C (Figures 5-29 and 5-30). Traps were opened for collection and checked daily until sufficient sample masses were obtained from each of the study grids or until low-capture success rates were determined not likely to yield a sufficient sample mass in a reasonable amount of time for all analyses prescribed. All trap maintenance such as resetting, baiting, or relocating was also performed daily. The target sample mass needed to meet the minimum requirements for all analyses was only obtained from within Habitat A. Poor trapping success in Habitats B and C prompted the need to cease field sampling events before enough mass was obtained for all planned analyses. Traps in Habitat A were closed on April 11, 2011, after the target total collection mass had been obtained. Trap Areas B and C were closed on April 14, 2011, because of low trapping success.

A total of 21 small mammals were prepared for analysis. Specimens captured and not selected for sampling were surveyed for gross beta/gamma radiation and marked using non-toxic permanent marker to document the number of recapture events. Specimens captured and selected for analytical sampling were immediately euthanized, surveyed for radioactivity, double-bagged, labeled, placed in a cooler, and transported back to locked storage for dissection and subsample processing steps. Specimens were thoroughly homogenized in a laboratory-grade blender, bottled, digested, and shipped to analytical laboratories for analysis. Organic and radiological constituents were reported in whole animal (including skin and viscera), whereas metal analyses were performed on the liver/kidney. Whole animals were briefly rinsed in deionized water, and the dissection tools and blender were decontaminated consistent with the *Sampling and Analysis Instruction* within RPP-PLAN-39114, Rev. 1B.

Figure 5-29. WMA C Small Mammal Trapping Areas

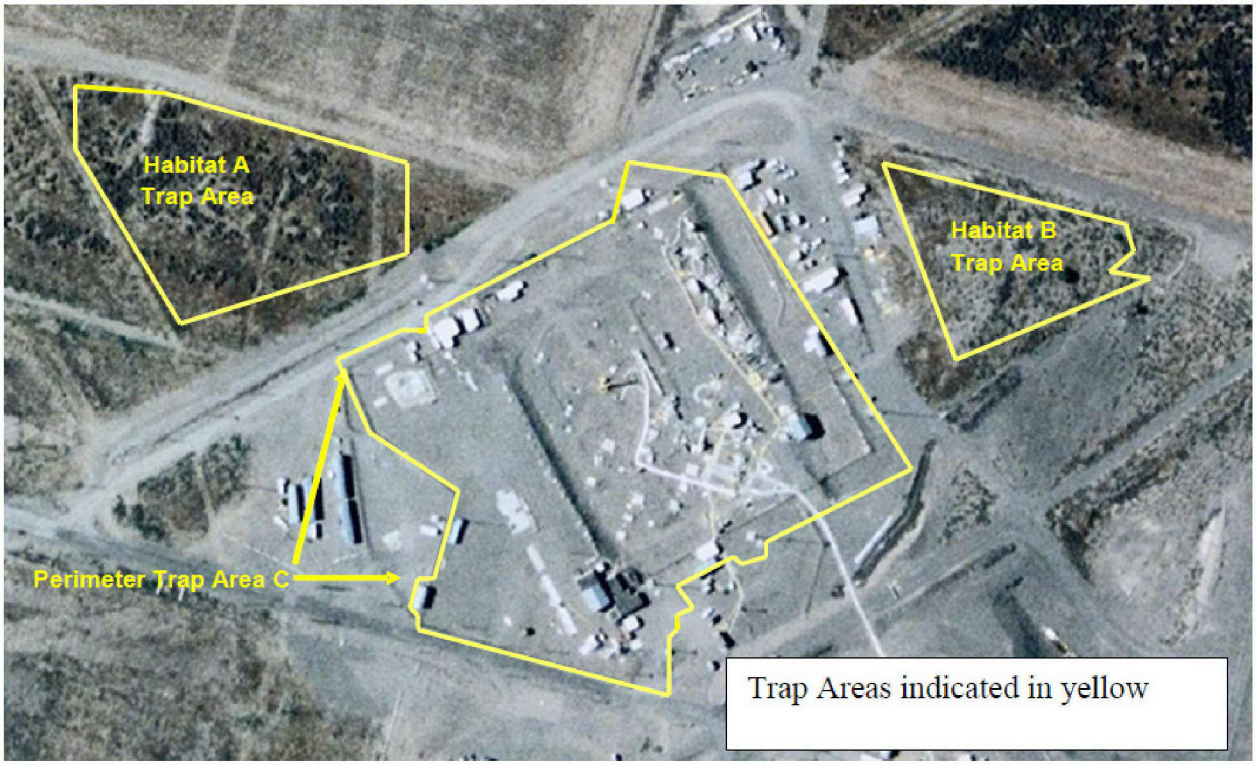
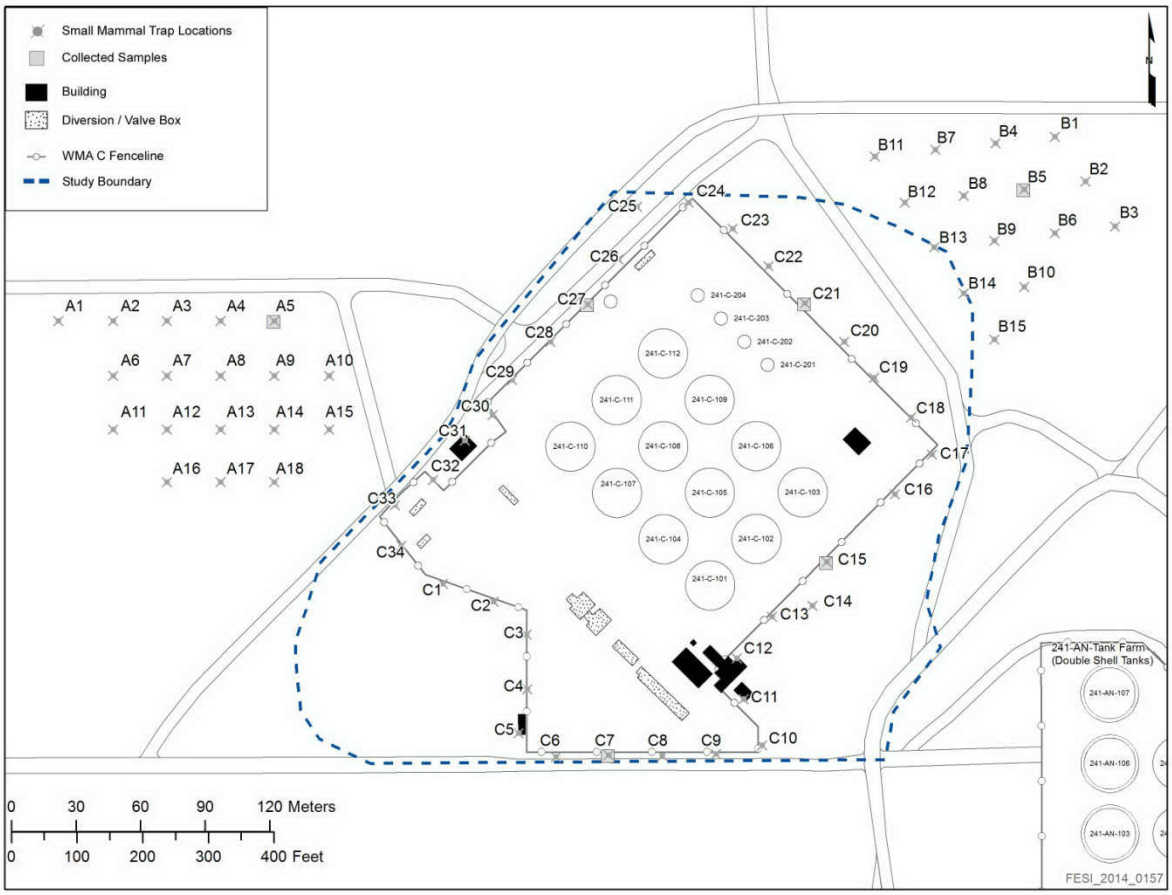


Figure 5-30. WMA C Small Mammal Trap Grid Locations



5.5.1 Small Mammal Analytical Data

Small mammal samples were analyzed for select metals, radionuclides and organic constituents. Of the 51 non-PCB congener analytes measured, only 12 were detected. Table 5-9 presents a summary of analytical results for small mammal tissue by constituent.

PCB congener analysis was also performed for two composite small mammal samples from WMA C. Of the 109 PCB congeners analyzed, 70 congeners were detected. Detected concentrations of PCB congeners are provided in Table 5-10.

Given the limited number of analytes detected in small mammal tissues, the small sample size, unspecified exposure route, and lack scientific information on tissue-based toxicity values, results of the small mammal sampling are limited in use for risk assessment and should be considered as information only. Neither co-located soil or nor vegetation samples were collected at the time of sampling, therefore no uptake factors can be inferred from these results. Due to the limited quantity and utility of these data, they are not recommended for incorporation in the risk assessment effort.

Table 5-9. Summary of Non-PCB Analytes Measured in Small Mammal Tissue

Class	Analyte	CAS ID	Number of Samples	Number of Detects	Maximum Detected Result	Units	Frequency of detection
Detected Analytes							
INORGANIC	Barium	7440-39-3	6	1	2.79	µg/kg	16.7%
INORGANIC	Copper	7440-50-8	6	2	4.03	µg/kg	33.3%
INORGANIC	Manganese	7439-96-5	6	2	5.03	µg/kg	33.3%
INORGANIC	Zinc	7440-66-6	6	2	41.8	µg/kg	33.3%
ORGANIC	Aroclor-1260	11096-82-5	3	2	2.2	µg/kg	66.7%
RAD	Americium-241	14596-10-2	2	1	0.017	pCi/g	50.0%
RAD	Gross beta	12587-47-2	3	3	47	pCi/g	100.0%
RAD	Plutonium-239/240	PU-239/240	2	1	0.13	pCi/g	50.0%
RAD	Radium-226	13982-63-3	2	2	120	pCi/g	100.0%
RAD	Total Radiostrontium	SR-RAD	2	1	7.9	pCi/g	50.0%
RAD	Uranium-233/234	13966-29-5	2	2	0.11	pCi/g	100.0%
RAD	Uranium-238	U-238	2	1	0.11	pCi/g	50.0%
Analytes Not Detected							
INORGANIC	Arsenic	7440-38-2	6	0	NA	µg/kg	0
INORGANIC	Cadmium	7440-43-9	5	0	NA	µg/kg	0
INORGANIC	Chromium	7440-47-3	7	0	NA	µg/kg	0
INORGANIC	Lead	7439-92-1	6	0	NA	µg/kg	0
INORGANIC	Mercury	7439-97-6	6	0	NA	µg/kg	0
INORGANIC	Molybdenum	7439-98-7	6	0	NA	µg/kg	0
INORGANIC	Nickel	7440-02-0	6	0	NA	µg/kg	0
INORGANIC	Selenium	7782-49-2	6	0	NA	µg/kg	0

Table 5-9. Summary of Non-PCB Analytes Measured in Small Mammal Tissue

Class	Analyte	CAS ID	Number of Samples	Number of Detects	Maximum Detected Result	Units	Frequency of detection
ORGANIC	Aldrin	309-00-2	4	0	NA	µg/kg	0
ORGANIC	Aroclor-1016	12674-11-2	3	0	NA	µg/kg	0
ORGANIC	Aroclor-1221	11104-28-2	3	0	NA	µg/kg	0
ORGANIC	Aroclor-1232	11141-16-5	3	0	NA	µg/kg	0
ORGANIC	Aroclor-1242	53469-21-9	3	0	NA	µg/kg	0
ORGANIC	Aroclor-1248	12672-29-6	3	0	NA	µg/kg	0
ORGANIC	Aroclor-1254	11097-69-1	3	0	NA	µg/kg	0
ORGANIC	Benzo(a)pyrene	50-32-8	3	0	NA	µg/kg	0
ORGANIC	Chlordane	57-74-9	4	0	NA	µg/kg	0
ORGANIC	Dichlorodiphenyldichloroethane	72-54-8	4	0	NA	µg/kg	0
ORGANIC	Dichlorodiphenyldichloroethylene	72-55-9	4	0	NA	µg/kg	0
ORGANIC	Dichlorodiphenyltrichloroethane	50-29-3	4	0	NA	µg/kg	0
ORGANIC	Dieldrin	60-57-1	4	0	NA	µg/kg	0
ORGANIC	Endrin	72-20-8	4	0	NA	µg/kg	0
ORGANIC	Gamma-BHC (Lindane)	58-89-9	4	0	NA	µg/kg	0
ORGANIC	Heptachlor	76-44-8	4	0	NA	µg/kg	0
ORGANIC	Heptachlor epoxide	1024-57-3	4	0	NA	µg/kg	0
ORGANIC	Hexachlorobenzene	118-74-1	3	0	NA	µg/kg	0
ORGANIC	Pentachlorophenol	87-86-5	3	0	NA	µg/kg	0
RAD	Cesium-134	13967-70-9	2	0	NA	pCi/g	0
RAD	Cesium-137	10045-97-3	2	0	NA	pCi/g	0
RAD	Cobalt-60	10198-40-0	2	0	NA	pCi/g	0

Table 5-9. Summary of Non-PCB Analytes Measured in Small Mammal Tissue

Class	Analyte	CAS ID	Number of Samples	Number of Detects	Maximum Detected Result	Units	Frequency of detection
RAD	Europium-152	14683-23-9	2	0	NA	pCi/g	0
RAD	Europium-154	15585-10-1	2	0	NA	pCi/g	0
RAD	Europium-155	14391-16-3	2	0	NA	pCi/g	0
RAD	Gross alpha	12587-46-1	3	0	NA	pCi/g	0
RAD	Plutonium-238	13981-16-3	2	0	NA	pCi/g	0
RAD	Thorium-228	14274-82-9	3	0	NA	pCi/g	0
RAD	Thorium-230	14269-63-7	3	0	NA	pCi/g	0
RAD	Thorium-232	TH-232	3	0	NA	pCi/g	0
RAD	Uranium-235	15117-96-1	2	0	NA	pCi/g	0

Table 5-10. PCB Congener Concentrations Detected in Small Mammal Composite Tissues

Homologue Group	Analyte	CAS ID	Number of Samples	Number of Detects	Maximum Detected Result	Units	Frequency of Detection
Diclorobiphenyl	PCB4	13029-08-8	2	1	0.00717	µg/kg	50%
Diclorobiphenyl	PCB6	25569-80-6	2	1	0.00607	µg/kg	50%
Diclorobiphenyl	PCB8	34883-43-7	2	2	0.0372	µg/kg	100%
Diclorobiphenyl	PCB9	34883-39-1	2	1	0.00224	µg/kg	50%
Diclorobiphenyl	PCB11	2050-67-1	2	2	0.0785	µg/kg	100%
Diclorobiphenyl	PCB12/13	PCB12/13	1	1	0.0028	µg/kg	100%
Diclorobiphenyl	PCB15	2050-68-2	2	2	0.015	µg/kg	100%
Triclorobiphenyl	PCB16	38444-78-9	2	1	0.0252	µg/kg	50%
Triclorobiphenyl	PCB17	37680-66-3	2	1	0.028	µg/kg	50%

Table 5-10. PCB Congener Concentrations Detected in Small Mammal Composite Tissues

Homologue Group	Analyte	CAS ID	Number of Samples	Number of Detects	Maximum Detected Result	Units	Frequency of Detection
Triclorobiphenyl	PCB18/30	PCB18/30	2	2	0.0574	µg/kg	100%
Triclorobiphenyl	PCB19	38444-73-4	2	1	0.00513	µg/kg	50%
Triclorobiphenyl	PCB20/28	PCB20/28	2	2	0.105	µg/kg	100%
Triclorobiphenyl	PCB21/33	PCB21/33	2	2	0.0555	µg/kg	100%
Triclorobiphenyl	PCB22	38444-85-8	2	1	0.031	µg/kg	50%
Triclorobiphenyl	PCB25	55712-37-3	2	1	0.00662	µg/kg	50%
Triclorobiphenyl	PCB26/29	PCB26/29	1	1	0.0141	µg/kg	100%
Triclorobiphenyl	PCB27	38444-76-7	2	1	0.00338	µg/kg	50%
Triclorobiphenyl	PCB31	16606-02-3	2	2	0.0811	µg/kg	100%
Triclorobiphenyl	PCB32	38444-77-8	2	1	0.0212	µg/kg	50%
Triclorobiphenyl	PCB37	38444-90-5	2	1	0.0117	µg/kg	50%
Tetraclorobiphenyl	PCB40/41+	PCB40/41/71	1	1	0.0116	µg/kg	100%
Tetraclorobiphenyl	PCB42	36559-22-5	2	1	0.00469	µg/kg	50%
Tetraclorobiphenyl	PCB44/47+	PCB44/47/65	2	2	0.0263	µg/kg	100%
Tetraclorobiphenyl	PCB45/51	PCB45/51	1	1	0.00615	µg/kg	100%
Tetraclorobiphenyl	PCB48	70362-47-9	2	1	0.00628	µg/kg	50%
Tetraclorobiphenyl	PCB49/69	PCB49/69	1	1	0.0157	µg/kg	100%
Tetraclorobiphenyl	PCB50/53	PCB50/53	1	1	0.00412	µg/kg	100%
Tetraclorobiphenyl	PCB52	35693-99-3	2	2	0.0295	µg/kg	100%
Tetraclorobiphenyl	PCB56	41464-43-1	2	1	0.00383	µg/kg	50%
Tetraclorobiphenyl	PCB60	33025-41-1	2	1	0.00535	µg/kg	50%
Tetraclorobiphenyl	PCB61/70+	PCB61/70/74/76	2	2	0.0285	µg/kg	100%
Tetraclorobiphenyl	PCB64	52663-58-8	2	1	0.00774	µg/kg	50%

Table 5-10. PCB Congener Concentrations Detected in Small Mammal Composite Tissues

Homologue Group	Analyte	CAS ID	Number of Samples	Number of Detects	Maximum Detected Result	Units	Frequency of Detection
Tetraclorobiphenyl	PCB66	32598-10-0	2	2	0.0178	µg/kg	100%
Pentaclorobiphenyl	PCB83/99	PCB83/99	2	2	0.0686	µg/kg	100%
Pentaclorobiphenyl	PCB86/87+	PCB86/87/97+	1	1	0.00538	µg/kg	100%
Pentaclorobiphenyl	PCB90/101+	PCB90/101/113	1	1	0.00613	µg/kg	100%
Pentaclorobiphenyl	PCB95	38379-99-6	2	1	0.00472	µg/kg	50%
Pentaclorobiphenyl	PCB105	32598-14-4	2	2	0.0351	µg/kg	100%
Pentaclorobiphenyl	PCB114	74472-37-0	2	1	0.00157	µg/kg	50%
Pentaclorobiphenyl	PCB118	31508-00-6	2	2	0.134	µg/kg	100%
Hexaclorobiphenyl	PCB128/166	PCB128/166	2	2	0.0216	µg/kg	100%
Hexaclorobiphenyl	PCB129+	PCB129/138/160+	2	2	0.451	µg/kg	100%
Hexaclorobiphenyl	PCB130	52663-66-8	2	1	0.00307	µg/kg	50%
Hexaclorobiphenyl	PCB133	35694-04-3	2	1	0.00436	µg/kg	50%
Hexaclorobiphenyl	PCB137	35694-06-5	2	2	0.00935	µg/kg	100%
Hexaclorobiphenyl	PCB146	51908-16-8	2	2	0.042	µg/kg	100%
Hexaclorobiphenyl	PCB147/149	PCB147/149	1	1	0.0044	µg/kg	100%
Hexaclorobiphenyl	PCB153/168	PCB153/168	2	2	0.72	µg/kg	100%
Hexaclorobiphenyl	PCB156/157	PCB156/157	2	2	0.0365	µg/kg	100%
Hexaclorobiphenyl	PCB158	74472-42-7	2	2	0.0159	µg/kg	100%
Hexaclorobiphenyl	PCB167	52663-72-6	2	2	0.00855	µg/kg	100%
Hexaclorobiphenyl	PCB170	35065-30-6	2	2	0.12	µg/kg	100%
Heptaclorobiphenyl	PCB171/173	PCB171/173	2	2	0.0152	µg/kg	100%
Heptaclorobiphenyl	PCB172	52663-74-8	2	2	0.025	µg/kg	100%
Heptaclorobiphenyl	PCB177	52663-70-4	2	2	0.0439	µg/kg	100%

Table 5-10. PCB Congener Concentrations Detected in Small Mammal Composite Tissues

Homologue Group	Analyte	CAS ID	Number of Samples	Number of Detects	Maximum Detected Result	Units	Frequency of Detection
Heptaclorobiphenyl	PCB178	52663-67-9	2	2	0.0401	µg/kg	100%
Heptaclorobiphenyl	PCB180/193	PCB180/193	2	2	0.424	µg/kg	100%
Heptaclorobiphenyl	PCB183/185	PCB183/185	2	2	0.0877	µg/kg	100%
Heptaclorobiphenyl	PCB187	52663-68-0	2	2	0.152	µg/kg	100%
Heptaclorobiphenyl	PCB189	39635-31-9	2	1	0.00525	µg/kg	50%
Heptaclorobiphenyl	PCB190	41411-64-7	2	2	0.0197	µg/kg	100%
Octaclorobiphenyl	PCB194	35694-08-7	2	2	0.108	µg/kg	100%
Octaclorobiphenyl	PCB195	52663-78-2	2	2	0.0271	µg/kg	100%
Octaclorobiphenyl	PCB196	42740-50-1	2	2	0.0102	µg/kg	100%
Octaclorobiphenyl	PCB198/201	PCB198/201	2	2	0.0585	µg/kg	100%
Octaclorobiphenyl	PCB200/201	40186-71-8	2	1	0.00153	µg/kg	50%
Octaclorobiphenyl	PCB202	2136-99-4	2	2	0.0149	µg/kg	100%
Octaclorobiphenyl	PCB203	52663-76-0	2	2	0.0369	µg/kg	100%
Nanoclorobiphenyl	PCB206	40186-72-9	2	1	0.0164	µg/kg	50%
Decaclorobiphenyl	PCB209	2051-24-3	2	1	0.00448	µg/kg	50%

5.6 NATURE AND EXTENT EVALUATION OF VADOSE ZONE SOIL CONTAMINATION

The purpose of this section is to collectively evaluate the vadose zone soil data obtained from field efforts (i.e., sample analysis, logging, and SGE) at WMA C, along with information about known waste release areas and groundwater constituents of interest. The evaluation process included:

- Identifying a subset of waste constituents known as Select Constituents (Section 5.6.1)
- Reviewing waste release information (Section 5.6.2)
- Identifying field investigation/waste release areas of interest (Section 5.6.3)

Collectively, these data were evaluated to identify potential correlations and observations and to generate conclusions as to the nature and extent of contamination at WMA C, as possible. Section 5.6.4 presents the observed contaminant correlations with respect to the field investigation/waste release areas of interest. Section 5.6.5 presents an overall summary of the nature and extent of vadose zone soil contamination for WMA C and identifies any potential data gaps pertaining to the evaluation.

5.6.1 Select Constituents

For Phase 2 RFI efforts, 230 constituents in soil were analyzed and of these, 122 constituents were detected above background or were detected and had no established background value. Results for constituents detected above background or detected in the absence of a background comparison value are herein referred to as exceedances. Section 5.1 provides a detailed summary of the vertical extent of exceedances for these 122 constituents at each sampling location and the spatial distribution of these exceedances in and around WMA C.

In order to focus the comprehensive discussion of nature and extent of contamination, "select constituents" were identified from the122 constituents having exceedances. Select constituents were defined as:

- Contaminants of interest in the vadose zone that are known to be affected by geochemical processes (e.g., ion exchange)

- Constituents that have waste inventory information

- Constituents evaluated using more than one field measurement technology (i.e., from logging and sampling efforts, such as ^{60}Co[1], ^{137}Cs, and ^{154}Eu)

- Groundwater constituents of interest.

[1] Cobalt-60 is relatively mobile in the subsurface and serves as a surrogate for contaminants of concern such as ^{99}Tc, which is difficult to detect in the vadose zone with logging methods in cased boreholes.

Known groundwater contaminants identified as select constituents for soil evaluation include cyanide, nitrate, sulfate, nickel, vanadium, ^{129}I, and ^{99}Tc (Section 5.4).

5.6.1.1 Geochemical Processes. A number of waste release constituents are known to be influenced by geophysical processes. Key geochemical interactions and how they pertain to indications of contamination (e.g., soil moisture or anion concentrations) or contaminant behavior (e.g., vertical migration) were reviewed to identify select constituents for detailed discussion.

In general, tank waste is consider caustic (in excess of 1,000,000 free hydroxide), which in-turn impacts geochemical processes that occur when this waste is released to the underlying soil. In particular, when waste containing high concentrations of dissolved sodium (in excess of 4,000,000) contact the soil, the sodium exchanges with calcium, which is one of the most dominant cations present in vadose zone soil. When a waste release has moved through an area, it is expected that the naturally present calcium would be removed from the soil. For this reason, sodium and calcium, were identified as select constituents based on their exchange capacity. Other common cations and anions were selected to potentially enhance discussions (e.g., potassium).

Additionally, IX in the vadose zone can significantly impact the mobility of some contaminants (e.g., cesium) in vadose zone sediments. For example, ^{137}Cs is generally quite immobile in the vadose zone. When a large amount of sodium has leaked from a tank, it displaces the cesium from the soil, thus allowing the cesium to be free to move with porewater and travel significant distances. As the concentration of sodium is reduced, cesium once again binds tightly with the soil. Cesium-137 was identified as a select constituent because it is a primary contaminant of interest and because of its geochemical interaction with sodium.

Overall, tank waste contaminants released to the vadose zone exhibit a wide range of mobility behaviors. For instance, some tank waste contaminants have been strongly retarded by adsorption and precipitation reactions (e.g., europium), while others have remained mobile (e.g., technetium, and nitrate). Others show variable, waste-specific behaviors that are closely tied to the changing composition of porewater in soil (e.g., strontium, chromium, and uranium). The change in oxidation state can affect chromium and heat exchange from tank waste can also cause secondary mineral precipitation in the soil to have neutralized the high concentrations of base (OH^-) (Brown and Serne 2008, "Deep Vadose Zone Characterization at Hanford Site: Accomplishments from the Last Ten Years"). Chromium, europium, nitrate, ^{90}Sr, and ^{99}Tc were identified as select contaminants due to their associations with tank waste and their impacted mobility due to geochemical processes.

5.6.1.2 Waste Inventory Information. Another factor that was considered in identifying select constituents was waste inventory information. RPP-PRT-42294, *Hanford Waste Management Area C Soil Contamination Inventory Estimates,* Rev. 1, identifies the most current soil inventory estimates. These inventories are estimated by multiplying the waste release volume by the contaminant concentration in the solution released to the soil. The concentration of the solution is based on process knowledge of the waste composition at the time the release occurred. For some major releases, historical records confirm the waste loss event and provide a strong

technical basis for leak volume and inventory estimates. However, for many releases little data is available and there are varying degrees of uncertainty or differences in the available data.

Table 5-11 identifies the 75 constituents for which waste inventory information is available. It should be noted that only a subset of these constituents were analyzed in RFI samples, as prescribed by the DQO. Chloride, potassium, and tributyl phosphate were identified as select constituents based on their waste inventory information and their association with waste types managed at WMA C. Three constituents, ^{137}Cs, ^{60}Co, and ^{154}Eu, have soil inventory values and also report logging and analytical results from Phase 2 investigation locations. However, there are no soil inventory values for cyanide and vanadium, which have been identified as groundwater constituents of interest.

Table 5-11. Constituent Inventories in the Hanford Soil Inventory Model

Chemicals				Radionuclides					
Ag	Cr	Mn	Pb	Ac-227	Cm-244	I-129	Pu-240	Sm-151	U-233
Al	F	Na	PO4	Am-241	Co-60	Nb-93m	Pu-241	Sn-126	U-234
Bi	Fe	NH3	Si	Am-243	Cs-134	Ni-59	Pu-242	Sr-90	U-235
Butanol	Fe(CN)6	Ni	SO4	Ba-137m	Cs-137	Ni-63	Ra-226	Tc-99	U-236
Ca	Hg	NO2	TBP	C-14	Eu-152	Np-237	Ra-228	Th-229	U-238
CCl4	K	NO3	U-Total	Cd-113m	Eu-154	Pa-231	Ru-106	Th-232	Y-90
Cl	La	NPH	Zr	Cm-242	Eu-155	Pu-238	Sb-125	U-232	Zr-93
CO3				Cm-243	H-3	Pu-239	Se-79		

Reference: RPP-26744, *Hanford Soil Inventory Model, Rev. 1.*
TBP = tribuytl phosphate

5.6.1.3 Summary of Soil Exceedances by Select Constituents. Based on groundwater constituents of interest, geochemical processes, and waste inventory information along with those constituents that have comparable logging and sampling results, 20 constituents were identified as select constituents. Table 5-12 identifies the 20 select constituents and additionally identifies the type of waste it is associate with in WMA C. In addition to the 20 select constituents, pH is considered a key measurement for characterizing waste releases and is discussed in subsequent sections.

Table 5-12. Select Constituents and Associated WMA C Waste Type

Select Constituent	Associated Process	Associated Waste Type Identified
		BL, CW, HS, IX, Misc., OWW, PSN, PSS, RSN, TFeCN, TH*
Chromium	Reprocessing waste chemical	Not identified in Best Basis Inventory
Calcium	Reprocessing waste chemical	All

Table 5-12. Select Constituents and Associated WMA C Waste Type

Select Constituent	Associated Process	Associated Waste Type Identified
		BL, CW, HS, IX, Misc., OWW, PSN, PSS, RSN, TFeCN, TH*
Nickel	Fission product	All
Sodium	Reprocessing waste chemical	All
Uranium	Residual product	All
Vanadium	Reprocessing waste chemical/contaminate	Not identified in Best Basis Inventory
Cesium-137	Fission product	All
Cobalt-60	Fission product	All
Europium-154	Fission product	All
Strontium-90	Fission product	All
Potassium-40	Fission product	Not identified in Best Basis Inventory; Potassium is in All
Sulfate	Reprocessing waste chemical	All
Nitrate	Reprocessing waste chemical	All
Cyanide	Reprocessing waste chemical	Not identified in Best Basis Inventory
Iodine-129	Fission product	All
Tributyl Phospate	Reprocessing waste chemical	Not identified in Best Basis Inventory
Chloride	Reprocessing waste chemical	All
Potassium	Reprocessing waste chemical	All
Thorium-230	Product	Not identified in Best Basis Inventory
Techetium-99	Fission product	All

*Waste types identified in Table 3-2 of this report.

Four of the 20 select constituents (chloride, cyanide, potassium, and TBP) were not detected or were detected below background at all locations during the Phase 2 soil investigation. Appendix V provides Phase 2 summary information for the remaining 16 select constituents. Extent of occurrence for select constituents in soil across WMA C is summarized below. Results are reported in terms of exceedances encountered by investigation site/group.

- Nitrate was reported above background in eight samples at WMA C. The maximum concentration (198,000 µg/kg) was reported at Investigation Group F+G at a depth of 38 m (126 ft) bgs.

  The distribution of concentrations above background is as follows:

  - Shallow soil only (≤ 5 m [15 ft] bgs): Investigation Group H+I.

- Deep soil only (>5 m [15 ft] bgs): Investigation Groups A+B, F+G, L1+L2, P, and Site U

- Shallow and Deep (both): *none.*

Nitrate results for all other locations were less than background or were below detection.

- Sulfate was reported above background in three samples collected during Phase 2. The maximum concentration was 592,000 µg/kg from Investigation Group A+B at a depth of 4.3 m (14.2 ft) bgs (shallow).

  Sulfate exceeded background in Phase 2 WMA C soils as follows:

  - Shallow only: Investigation Group H+I.
  - Deep only: *none*
  - Shallow and Deep (both): Investigation Groups A+B.

  Results for all other locations were less than background or were below detection.

- Calcium was reported above background in three samples from WMA C. The maximum concentration was 32,200,000 µg/kg from Investigation Group A+B at a depth of 11 m (36 ft) bgs (deep).

  Calcium exceeded background in Phase 2 WMA C soils as follows:

  - Shallow only: Site C and Investigation Group F+G
  - Deep only: Investigation Group A+B
  - Shallow and Deep (both): *none.*

  Calcium results for all other locations were less than background or were below detection.

- Chromium, a dangerous waste constituent, was reported above background in 29 samples from nine Investigation Sites/Groups. The maximum concentration of chromium was 44,500 µg/kg from Site U at a depth of 48 m (158 ft) bgs (deep).

  Chromium exceeded background in Phase 2 WMA C soils as follows:

  - Shallow only: *none*
  - Deep only: Investigation Groups A+B, F+G, H+I, L1+L2, and Sites C, E, and J
  - Shallow and Deep (both): Investigation Groups H+I, P, and Site U.

  Chromium was not reported above background at Site R.

- Nickel, a dangerous waste constituent, was reported above background in nine samples from four Investigation Sites/Groups, in deep soils (>5 m [15 ft] bgs) only. The

maximum concentration was 30,600 J µg/kg from Investigation Group P at a depth of 8 m (26 ft) bgs (deep).

Nickel exceeded background in Phase 2 WMA C soils as follows:

- Shallow only: *none*
- Deep only: Investigation Groups L1+L2, P, and Investigations Sites E and U
- Shallow and Deep (both): *none.*

Nickel results for all other locations were less than background or were below detection.

- Sodium was reported above background in nine samples from two Investigation Sites/Groups. The maximum concentration was 1,930,000 µg/kg from Investigation Group P at a depth of 5 m (15 ft) bgs (shallow).

  Sodium exceeded background in Phase 2 WMA C soils as follows:

  - Shallow only: *none*
  - Deep only: Site E
  - Shallow and Deep (both): Investigation Group P.

  Sodium results for all other locations were less than background or were below detection.

- Uranium was reported above background in 44 samples from three Investigation Sites/Groups. All results were reported as non-detects. The maximum concentration was 101,000 U at Investigation Group P from a depth of 5 m (15 ft) bgs (shallow).

  Uranium exceeded background in Phase 2 WMA C soils as follows:

  - Shallow only: *none*
  - Deep only: *none*
  - Shallow and Deep (both): Investigation Groups F+G, L1+L2, P.

  Uranium results for all other locations were less than background or were below detection.

- Vanadium was reported above background in two samples from Group P. The maximum concentration was 110,000 M µg/kg at a depth of 5 m (15 ft) bgs (shallow).

  Vanadium exceeded background in Phase 2 WMA C soils as follows:

  - Shallow only: *none*
  - Deep only: *none*
  - Shallow and Deep (both): Investigation Group P.

  Vanadium results for all other locations were less than background or below detection.

- Cesium-137 was reported above background in 34 samples from eight Investigation Sites/Groups. The maximum concentration was 73.1 pCi/g from Investigation Group P at a depth of 5 m (15 ft) bgs (shallow).

  Cesium-137 exceeded background in Phase 2 WMA C soils as follows:

  - Shallow only: Investigation Groups A+B, L1+L2, and Sites C, E, J, and U
  - Deep only: *none*
  - Shallow and Deep (both): Investigation Groups F+G and P.

  Cesium-137 results for Investigation Group H+I and Site R were less than background or below detection.

- Cobalt-60 was reported above background in 138 samples across all locations and depths. However, all results were reported as non-detects. The maximum reported concentration was 3.13 U pCi/g from Investigation Group P at a depth of 2 m (7 ft) bgs (shallow).

- Europium-154 was reported above background in 146 samples across all locations and depths. However, all results were reported as non-detects. The maximum reported concentration was 9.45 U pCi/g from Investigation Group P at a depth of 3 m (11 ft) bgs (shallow).

- Iodine-129 was detected in one sample at a concentration of 0.808 B pCi/g from Investigation Group P at a depth of 2 m (6 ft) bgs (shallow). Iodine-129 results for all other locations and depths were below detection. Note that ^{129}I contamination in groundwater is present throughout the east half of the 200 East Area and are believed to be from liquid waste facilities in the northern portion of the 200-PO-1 OU (DOE/RL-2011-01).

- Potassium-40 was reported above background in 26 samples from nine Investigation Sites/Groups. The maximum concentration was 31 pCi/g from Investigation Groups A+B at a depth of 24.8 m (81.4 ft) bgs (deep).

  Potassium-40 exceeded background in Phase 2 WMA C soils as follows:

  - Shallow only: *none*
  - Deep only: Investigation Groups F+G, P, and Sites E, J, R, and U
  - Shallow and Deep (both): Investigation Groups A+B and H+I.

  Potassium-40 was less than background or below detection at Site C and Investigation Group L1+L2.

- Strontium-90 was reported above background in 141 samples from all Investigation Sites/Groups. The maximum concentration was 141 pCi/g from Investigation Group P at a depth of 3 m (11 ft) bgs (shallow). Some results exceeding background were reported as non-detects.

Strontium-90 exceeded background in Phase 2 WMA C soils as follows:

- Shallow only: *none*
- Deep only: Sites R, and U
- Shallow and Deep (both): Investigation Groups A+B, E, F+G, H+I, P, and Investigation J.

- Technetium-99 was detected in 16 samples from six Investigation Sites/Groups. The maximum reported value was a non-detect result of 76 BYUJ pCi/g from Investigation Group L1+L2 at a depth of 35 m (115 ft) bgs (deep), however, the highest detected value was 53.5 Y pCi/g from Site U at a depth of 39 m (129 ft) bgs (deep).

  Technetium-99 was detected in Phase 2 WMA C soils as follows:

  - Shallow only: *none*
  - Deep only: Investigation Groups A+B, F+G, L1+L2 and Sites R and U
  - Shallow and Deep (both): Investigation Group P.

  Technetium-99 was below detection at all other investigation sites/groups and depths.

- Thorium-230 was detected in 29 samples from seven Investigation Site/Groups. The maximum concentration was 1.85 B pCi/g from Investigation Group H+I at a depth of 0.2 m (0.5 ft) bgs (shallow).

  Thorium-230 was detected in Phase 2 WMA C soils as follows:

  - Shallow only: Site E
  - Deep only: *none*
  - Shallow and Deep (both): Investigation Groups A+B, F+G, H+I, L1+L2, P, and Site U.

  Thorium-230 was below detection at all other investigation sites/groups and depths.

As identified in addition to soil analysis, ^{137}Cs, ^{60}Co, and ^{154}Eu results were also obtained though geophysical logging. Surface radiological surveys performed for ongoing worker protection at WMA C were compiled to evaluate potential areas of contamination (Figure 5-31). In addition, geophysical logging results for a depth of 0.6 m (2 ft) bgs for ^{137}Cs and ^{154}Eu were mapped to estimate the horizontal extent of contamination associated with presumed leaking tanks (Figure 5-32). Appendix W presents these results from all phases supporting the RFI effort including logging information from groundwater well, as possible. Figures in Appendix W show the extent (vertical depth) to which these constituents occur, as well as, the maximum concentrations in both shallow and deep soil. These figures show that ^{137}Cs contamination is widespread and tends to be more at shallower depths. However, the figures also show that ^{137}Cs contamination is also at quite deep depths: specifically 41 m (135 ft) bgs around Tanks C-104 and C-105; 30 m (100 ft) bgs around Tank C-103; and at depths around 61 m (200 ft) bgs in groundwater wells, both to the southwest and northeast of WMA C). Additionally, these figures

show that ^{60}Co and ^{154}Eu concentrations also occur at WMA C but not as predominately as ^{137}Cs. The extent of these contaminants is both seen in shallow and deep soil; however, ^{60}Co appears more to be more associated with shallow soil and ^{154}Eu appears to be more associated with shallow soil.

5.6.2 Waste Release Information

As described in Section 3, there have been several large waste releases associated with WMA C. Table 5-13 presents the waste releases and volumes, including chemical and radiochemical inventory information, of these releases to the soil. As noted in Section 3 also several key documents associated with leak assessments and inventories are undergoing revision and may not present consistent information. For this reason, Table 5-13 presents data from both sources to capture the range of reported values. At time of publication of the RFI, both leak assessment and contaminant inventory estimate documents are being revised to reflect the most up-to-date information in a consistent manner.

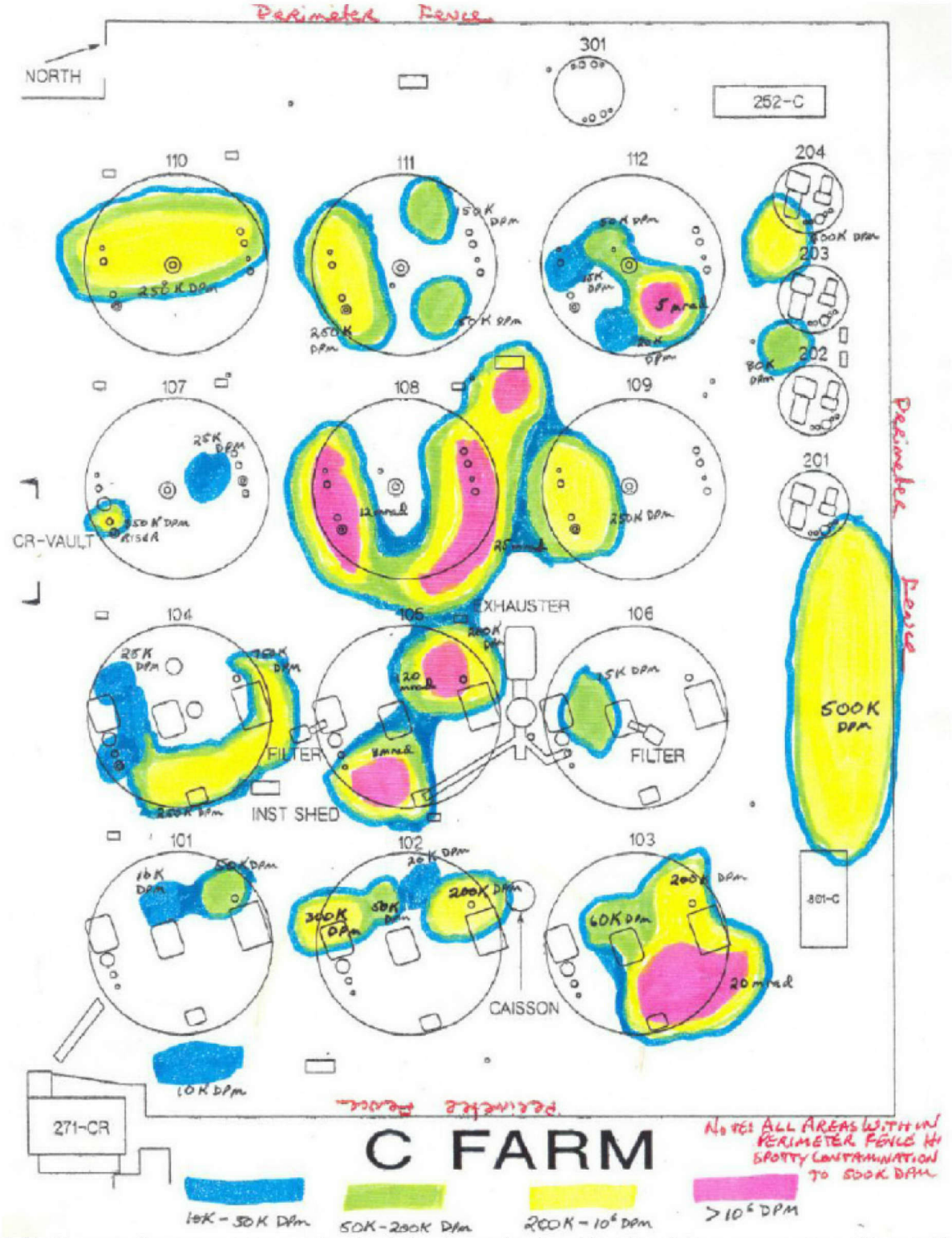
The most current contaminated soil inventory for the various waste releases is also presented in tabular form in Appendix X (RPP-RPT-42294, Rev. 1). Appendix X also includes figures that display the waste release volumes and the inventories associated with the select constituents. Table 5-12, which presents the select constituents, shows that many of the select constituents are associated with all waste types in WMA C. Appendix X also indicates that many of the select constituents represent the larger fraction of the soil contamination from the release.

5.6.3 Field Investigation/Waste Release Areas of Interest

WMA C, which is approximately 4 hectares (9 acres) in size, has been investigated with over 180 field locations (e.g., drywells, borings). As identified in Section 4, the boundary of the Phase 2 field investigation was approved through the DQO process. The spatial boundary of the Phase 2 study is approximately 7 hectares (16 acres) (Figure 4-1). The vertical (depth) boundary defined in the DQO was 61 m (200 ft) bgs. Note that the vertical depths of all field investigation locations, including pre-RFI, Phase 1 and Phase 1.5 locations, ranged from approximately 9 to 73 m (30 to 240 ft) bgs: early pushes around UPR-200-E-82 were shallower (i.e., 9 m [30 ft] bgs for Pre-RFI efforts); drywells were typically 100 ft bgs; and direct pushes were typically sampled to around 61 m (200 ft) bgs.

As previously indicated, all areas investigated in WMA C were either areas of known contamination or areas where contamination was expected. Table 5-14 identifies the field activities deployed to investigate the 16 specific areas within WMA C. Several of these investigation areas are in very close proximity to each other and are associated with the same waste release event. For this reason, some of these areas are grouped for discussion in Section 5.6.4 (e.g., Tanks C-104 and C-105).

Figure 5-31. C Farm Radioactivity Surface Survey Map*



*This C Farm surface survey status map is a sketch showing results of weekly radioactivity survey reports as of January 2010. The sketch is posted at the C Farm entrance for worker protection.

Figure 5-32. Near Surface Spectral Gamma Activity in C Farm

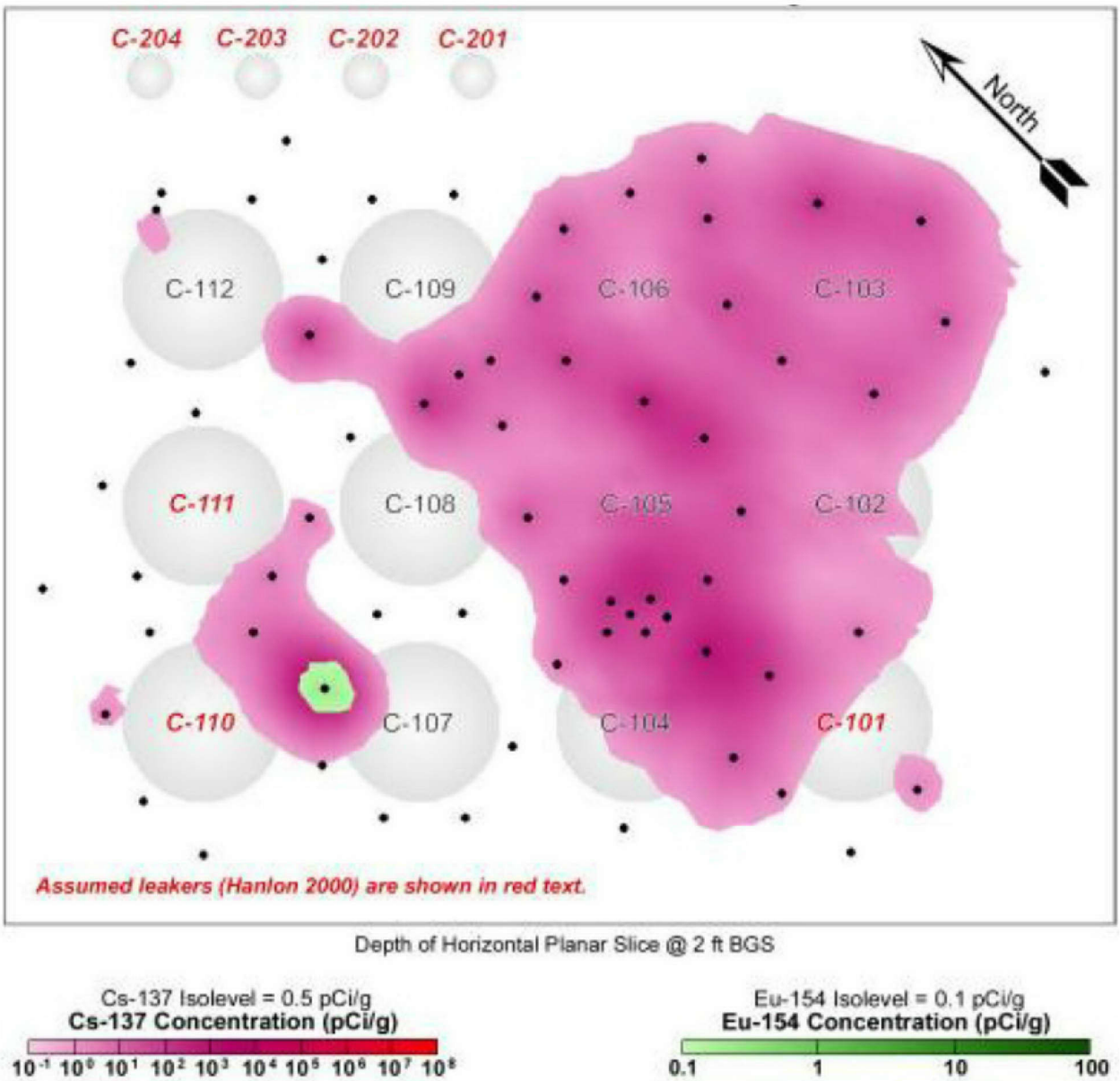


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Table 5-13. Select Waste Releases From and Around Each 241-C Farm Tank*

Tank/ UPR	Waste Release Volume (gal)	Chemical Component of Release (kg)	Radiochemical Component of Release (Ci)	^{60}Co (Ci)	^{137}Cs (Ci)	^{99}Tc (Ci)	Basis
C-101	37,000 20,000	NA 950	NA 8,480	0.17 0.202	800 4,260	0.22 1.12	Estimated waste release volume based on an assumed CW waste type and drywell readings. According to surface level measurements there was a waste release of up to ~37,000 gal, likely a combination of a CW release from the spare inlet and condensate (depending on condenser operation).
C-104	28,000 0	NA NA	NA NA	1.3 NA	80 NA	0.03 NA	Cascade line leak next to Tank C-104. Tank C-104 was filled to 560,000 gal of CW waste in 1965. No transfer was identified; however, the surface level decreased to the spare inlet elevation of ~532,000 gal resulting in a possible 28,000-gal release.
C-105	2,000 2,000	NA 2,000	NA 8,260	0.08 0.306	2,500 4,150	0.8 1.51	Release range from 40 to 2,000 gal (<2,000 gal) of P1 supernate (PSN). Cascade line release and possible tank leak.
C-108	18,000 0	NA NA	NA NA	0.8 NA	50 NA	0.02 NA	Cascade line leak; Tank C-108 filled to 568,000 gal of CW-HS waste in 1965; decreased in surface level to 532,000 gal through a transfer to Tank C-102; waste loss assumed to be 18,000 gal based on ^{60}Co and soil moisture determinations. Waste volume based on CW waste composition.
C-110	2,000 2,000	NA 11,000	NA 850	0.3 0.00619	300 350	0.11 0.114	No observed liquid level decrease and less than 1,000 pCi/g ^{137}Cs activity in drywell.
C-111	0 0	NA NA	NA NA	NA NA	NA NA	NA NA	Waste level decrease attributed to evaporation.

Table 5-13. Select Waste Releases From and Around Each 241-C Farm Tank*

Tank/ UPR	Waste Release Volume (gal)	Chemical Component of Release (kg)	Radiochemical Component of Release (Ci)	^{60}Co (Ci)	^{137}Cs (Ci)	^{99}Tc (Ci)	Basis
C-112	7,000 0	NA NA	NA NA	0.33 NA	20 NA	0.0075 NA	Transfer line leak from diversion box 252-C to Tank C-112. Line leak likely prior to 1974; waste type in Tank C-112 was CW-IX; 7,000 gal based on ^{60}Co plume and 5% soil moisture content above background.
C-201	0 550	NA 250	NA 507	NA 0.0405	NA 43	NA 0.0107	Surface level discrepancy likely due to evaporation.
C-202	0 450	NA 210	NA 415	NA 0.0331	NA 35.2	NA 0.00877	Surface level discrepancy likely due to evaporation.
C-203	0 400	NA 200	NA 392	NA 0.0313	NA 33.2	NA 0.00829	Surface level discrepancy likely due to evaporation.
C-204	0 350	NA 170	NA 333	NA 0.0266	NA 28.2	NA 0.00704	Surface level discrepancy likely due to evaporation.
UPR-200-E-81	36,000 36,000	NA 62,000	NA 1,850	0.36 11.5	350 350	0.11 0.112	Volume: 36,000 gal ^{137}Cs: 350 Ci

Table 5-13. Select Waste Releases From and Around Each 241-C Farm Tank*

Tank/ UPR	Waste Release Volume (gal)	Chemical Component of Release (kg)	Radiochemical Component of Release (Ci)	^{60}Co (Ci)	^{137}Cs (Ci)	^{99}Tc (Ci)	Basis
UPR-200-E-82	2,600 2,100	NA 990	NA 8,900	0.4 0.293	5,500 4,400	3.0 2.07	Volume: 2,600 gal ^{137}Cs is 5,500 Ci (sample concentration times volume). 1969 ^{137}Cs conc. = 4.28 Ci/gal For other analytes, the leak inventory values for radiological constituents are based on the activity per unit leak volume for the analyte in HDW P2 wastes times the ratio of the 1969 concentration for ^{137}Cs to the ^{137}Cs concentration in HDW for P2 waste, times the updated volume.
UPR-200-E-86	17,000 17,000	NA 3,700	NA 22,800	0.7 0.733	11,500 11,500	2.9 2.85	Volume: 17,000 gal Maximum, Based on mass balance estimate. Estimate appears to be high based on waste site investigations. ^{137}Cs is 11,500 Ci (1971 sample concentration times the updated volume).

*Cesium-137 and ^{60}Co values are approximations decayed to January 1, 2001.

CW = cladding waste, aluminum clad fuel
HS = Hot Semiworks strontium purification waste (1961-1968)
IX = ion exchange
P1 = Plutonium Uranium Extraction high level waste (1956-1962), also referred to as PSN waste type
NA = Not available or not applicable

Reference: RPP-ENV-33418, *Hanford C-Farm Leak Assessments Report: 241-C-101, 241-C-110, 241-C-111, 241-C-105 and Unplanned Waste Releases*, Rev. 1. Information in blue is from RPP-RPT-42294, *Hanford Waste Management Area C Soil Contamination Inventory Estimates,* Revision 1.

Table 5-14. Areas Investigated in WMA C

Area Investigated	Field Efforts[a]
Tank C-101	• Group A + B Direct Push Logging • Group A + B Analytical • Drywell Logging (30-01-01, 30-01-01, 30-01-06, and 30-01-09) • Site O SGE
Area between Tanks C-103 and C-106	• Group L1 + L2 Direct Push Logging • Group L1 + L2 Analytical • Drywell Logging (30-00-01, 30-03-01, 30-03-03, 30-03-05, 30-03-07, 30-03-09, 30-06-02, 30-06-03, 30-06-04, 30-06-09, 30-06-10, and 30-06-12) • Site O SGE
Tank C-103 and C-801 Building and the building's chemical drain	• Group F + G Direct Push Logging • Group F + G Analytical • Drywells Logging (30-03-01, 30-03-03, 30-03-05, 30-03-07, and 30-03-09) • Site O SGE
Tank C-104	• Site J Direct Push Logging • Site J Analytical • Site M Drywell Logging (30-04-01, 30-04-02, 30-04-03, 30-04-04, 30-04-05, 30-04-08, 30-04-12, and 30-05-06) • Site O SGE
Tank C-105	• C4297 Analytical and Logging • C7469 Direct Push Logging • Drywell Logging (30-05-02, 30-05-07, and 30-05-08)
Area between Tanks C-106 and C-109	• Site E Direct Push Logging • Site E Analytical • Site M Drywell Logging (30-00-01, 30-06-02, 30-06-03, 30-06-04, 30-06-09, 30-06-10, 30-06-12, 30-09-01 ,30-09-02, 30-09-06, 30-09-10, and 30-09-11) • Site O SGE
Tank C-108	• Drywell Logging (30-05-10, 30-07-01, 30-07-02, 30-08-02, 30-08-03, 30-08-12, and 30-09-07)
Tank C-110	• Site U Direct Push Logging • Site U Analytical • Site M Drywell Logging (30-00-09, 30-10-01, 30-10-02, 30-10-09, and 30-10-11) • Site O SGE
Tank C-111	• Drywell Logging (30-11-01, 30-11-05, 30-11-06, 30-11-09, and 30-11-11)
Tank C-112	• Drywell Logging (30-00-12, 30-12-01, 30-12-03, 30-12-09, and 30-12-13)
200-series tanks	• Group C + D Direct Push Logging • Site C Analytical • Group C + D SGE

Table 5-14. Areas Investigated in WMA C

Area Investigated	Field Efforts[a]
UPR-200-E-81	• Phase 1.5 and Phase 2 Site P Direct Push Logging • Phase 1.5 and Phase 2 Site P Analytical • Site N SGE
UPR-200-E-82	• Pre-RFI Tanaka Analytical Locations 5 and 10 • Phase 1 Direct Push Logging • Phase 1 Analytical • Site Q Direct Push Logging • Site N SGE
UPR-200-E-86	• Phase 1.5 Direct Push Logging • Phase 1.5 Analytical • 299-E27-20 (Site Z) Analytical • Site N SGE
UPR-200-E-91 and UPR-200-E-115	• Group H + I Direct Push Logging • Group H + I Analytical • Site O SGE
Area near C-301 Catch Tank	• Site R Direct Push Logging • Site R Analytical • Site O SGE

[a]Approximately 70 drywells were logged in WMA C, not all are listed in this table.

Based on information presented in Sections 5.1 through 5.4 and Section 3, waste releases and subsequent contaminant distributions of select constituents are collectively evaluated and presented for the following field investigation/waste release areas:

- UPR-200-E-81
- Tank C-101
- Tanks C-104 and C-105
- Tank C-108 and C-109

These areas have some of the largest documented waste releases, ranging from 18,000 gals to 37,000 gals. Characterization results for these areas are presented in Section 5.6.4 along with supporting information from UPR-200-E-82 and UPR-200-E-86, 200-series tanks, and the Cesium Loadout Facility.

5.6.4 Discussion on Field Investigation/Waste Release Areas of Interest

The purpose of this section is to present the combined information collected for the following areas, in which some specific correlations, observations, and conclusions could be made:

- UPR-200-E-81 (Section 5.6.4.1)
- Tank C-101 (Section 5.6.4.2)

- Tanks C-104 and C-105 (Section 5.6.4.3)
- Tanks C-108 and C-109 (Section 5.6.4.4)

Discussions on each waste release area include the following information, as available:

- Time of the release
- Amount of waste released
- Waste type released
- Inventory information associated with the release
- Field result highlights and correlations

A brief synopsis of each leak event from RPP-ENV-33418, Rev. 2A is provided for each waste release area of interest. Additionally, inventory information associated with the waste release is provided for each area of interest from the most current soil contamination inventory report (RPP-RPT-42294, Rev. 1).

5.6.4.1 UPR-200-E-200-E-81. As per RPP-ENV-33418, Rev. 2A, UPR-200-E-81 was the result of a leak in an underground transfer pipeline located northeast of the 244-CR Vault near diversion box 241-CR-151. The leak occurred at the weld connection between the carbon steel and stainless steel on one of the lines. The estimated 36,000 gallons of waste leaked from the pipeline in October 1969 consisted of PUREX coating waste (i.e., CW). The pipeline near the diversion box was located at a depth of about 10 ft bgs. Radiation levels of 5 R/hr at 6 m (20 ft) were measured. Backfill was placed over the liquid, which reduced the levels to a maximum of 3 R/hr at 0.3 m (1 ft), above about 46 cm (18 in.) of backfill and clean gravel. In November 1969 a stainless steel bypass line was installed around the location of the leak. The original lines had a carbon steel segment from diversion box 241-151-CR to Tank C-102.

Waste Release Inventory Information

The estimated volume of the pipeline leak was 36,000 gal, consisting of 62,000 kg of chemical waste and 1,850 Ci of radiochemical waste. Appendix X identifies the specific constituents associated with the waste release event. The select constituents contributing most to the release inventory near UPR-200-E-81 included:

- Nitrate, 23,600 kg approximately 38% from the chemical portion of the release
- Sodium, 20,700 kg approximately 33% from the chemical portion of the release
- Cesium-137, 350 Ci approximately 19% from the radiochemical portion of the release
- Strontium-90, 299 Ci approximately 16% from the radiochemical portion of the release

Results from Field Efforts

As discussed in Section 4, a number of direct push holes have been pushed, logged, and sampled in the vicinity of UPR-200-E-81 during 2008 and 2009. During Phase 2, soil samples were collected at Investigation Group P to evaluate the extent of releases from UPR-200-E-81. Additionally SGE investigations and analyses were performed in this vicinity. Results of field characterization efforts are summarized by activity.

Vadose Zone Soil Analysis

- This area (Investigation Group P) has the highest number of constituents with concentrations above background or detected for those constituents with no background levels, 84 out of 122 constituents.

- Of the 20 select constituents, 14 had concentrations above background or detected for those constituents with no background (i.e., exceedances).

- Eight of the select constituents had both the greatest frequency of exceedances and the maximum results from all investigation groups/sites.

  - Cesium-137, 73 pCi/g at 6 m (15 ft) bgs
  - Cobalt-60, 3 pCi/g at 2 m (7 ft) bgs
  - Europium-154, 9 pCi/g at 3 m (11 ft) bgs
  - Iodine-129, 0.8 pCi/g at 2 m (6 ft) bgs
  - Sodium, 1,930,000 µg/kg at 6 m (15 ft) bgs
  - Strontium-90, 141 pCi/g at 3 m (11 ft) bgs
  - Uranium, 101,000 µg/kg at 6 m (15 ft) bgs
  - Vanadium, 110,000 at 6 m (15 ft) bgs

- Additionally, Investigation Group P reported nickel as the maximum result (30,600 µg/kg at 8 m [26 ft] bgs) of all investigation groups/sites at WMA C.

- Sitewide maximum results reported at Investigation Group P occurred at depths at or shallower than 8 m (26 ft) bgs.

- Maximum nitrate and ^{99}Tc concentrations for Investigation Group P were observed at about 6 and 12 m (20 and 40 ft) bgs in pushes C6392 and C6404 on the south and southeast side of diversion box 241-CR-151.

- pH was greater than 8.5 from 2 to 18 m (6 to 60 ft) bgs and also at 41 m (133 ft) bgs.

- Exceedances of select constituents occurred in samples from 2 to 52 m (6 to169 ft) bgs (deepest depth sampled was 52 m [169 ft] bgs).

- Exceedances of select constituents occurred in backfill, H1, and H2.

- Investigation Group P showed the highest number of groundwater constituents of interest with exceedances (five of the seven constituents: nitrate, nickel, ^{99}Tc, vanadium, and ^{129}I).

  - Iodine-129 and vanadium were only detected and above background, respectively at Investigation Group P.

Geophysical Logging

- Two of the boreholes (C6397 and C6399) showed only background activity from the natural radionuclides. The maximum depth of the gamma-emitting contamination in boreholes C6397 and C6399 was less than 4 m (12 ft) bgs.

- Gamma activity, above background levels, was encountered in three boreholes (C6391, C6393, and C6395) with the highest activity occurring at shallow depths (45,000 pCi/g for ^{137}Cs at 0.9 m [3 ft] bgs for C6393). The maximum depth of the gamma-emitting contamination was encountered in borehole C6393 at 13 m (44 ft) bgs as was the highest gamma activity.

- A ^{137}Cs peak occurred in borehole C6405 at 15 m (50 ft) bgs, 1,200,000 pCi/g. Additionally, gamma activity encountered at adjacent borehole C6403 exceeded the linear response range for the detector.

- Three increased moisture zones extend from surface (0.5 ft bgs) to depths of 8 to 14 m (25 to 45 ft) bgs and around 41 m (135 ft) bgs in the area of UPR-200-E-81.

Surface Geophysical Exploration

- UPR-200-E-81 presented one of the most likely targets for SGE to be a successful tool given the high volume and high volume of ionic constituents like nitrate. As such, UPR-200-E-81 demonstrated the greatest SGE response for all of the Site N UPR sites (UPR-200-E-81, 82, and 86).

- SGE results identify a clear resistivity plume in the vicinity of diversion box 241-CR-151, between 3 to about 9 m (10 to about 30 ft) bgs. This is consistent with the components of the waste release.

It appears that logging, direct push, and SGE results are consistent with the estimated 36,000 gal line leak and a CW release. Contamination has been determined to be at the surface (0.2 m [0.5 ft] bgs) all the way to 52 m (169 ft) bgs; however maximum concentrations for select constituents seemed to occur to a depth of 8 m (26 ft) bgs. The maximum ^{137}Cs concentration occurred to a depth of 15 m (50 ft) bgs, 1,200,000 pCi/g 13 m (43 ft) bgs (Appendix W). The soil contamination inventory for the release event in this area for ^{137}Cs was 350 Ci (RPP-RPT-42294, Rev. 1).

5.6.4.2 Tank C-101. Tank C-101 was classified as a confirmed leaking tank in 1968 with a leak volume of 20,000 gal (HNF-EP-0182). RPP-ENV-33418, Rev. 2A identified that the waste surface level measurements from 1965 through 1969 (when Tank C-101 waste was pumped down to a waste depth of approximately 102 cm [40 in.]) showed an unaccounted surface level measurement decrease of approximately 34 cm (13.5 in.) (approximately 37,000 gal). Evaporation calculations reported in RPP-ENV-33418, Rev. 1 indicated that given the high heat and high temperature of PUREX high-level (1956 to 1962) (PSN) waste, up to 85 gal/day of supernate could have evaporated from the tank over this time period, potentially accounting for

all of the liquid level decrease over 4 years. However, if as expected, a condenser was operating during that time, supernate would have condensed back into the tank and the evaporation rate may have been negligible. Some condensers were reported to have leaked and condensate may have been released from the condenser pit to the soils.

Supernate may also have been released through the cascade or spare inlet line. Liquid level measurements indicate that the tank was filled above the cascade outlet with PSN waste from the 244-CR Vault from 1965 to 1969. High levels of total gamma activity were detected when the drywells were constructed in 1970. Most of the gamma activity decayed away following a ^{106}Ru decay curve and less than 1,000 pCi/g of ^{137}Cs gamma activity was observed in 1997 SGLS measurements. If 37,000 gal of PSN waste was released, much greater ^{137}Cs activity would be expected compared to what was observed. It is likely that the waste released was not PSN but was mostly PUREX CW and/or condensate.

Per RPP-ENV-33418, Rev. 2A, the release may have spread over a soil volume of approximately 400,000 ft^3.

Waste Release Inventory Information

Although RPP-ENV-33418, Rev. 2A identifies the estimated leak volume to be 37,000 gal, the most current contaminated soil inventory report (RPP-RPT-42294, Rev. 1) indicated that the leak volume was 20,000 gal. RPP-RPT-42294 other leaks assessment and inventory document are being revised to present up-to-date, consistent information.

Inventory data from RPP-RPT-42294 indicated that the 20,000 gal leak consisted of 950 kg of chemical waste and 8,480 Ci of radiochemical waste. Appendix X identifies the specific constituents associated with the waste release event. The select constituents contributing most to the release inventory near Tank C-101 included:

- Sodium, 333 kg, approximately 35% from the portion of the chemical release
- Nitrate, 251 kg, approximately 26% from the portion of the chemical release
- Sulfate, 65.5 kg, approximately 7% from the portion of the chemical release
- Cesium-137, 4,260 Ci, approximately 50% from the portion of the radiochemical release.

Results from Field Efforts

Characterization of Investigation Group A+B conducted in 2011 consisted of two angle pushes oriented under and adjacent to Tank C-101. Drywell logging, in the vicinity of Tank C-101, was conducted to support leak assessment reevaluations. SGE was also performed in the area (i.e., overall WMA C coverage, Site O). Results of the field characterization efforts near Tank C-101 are summarized by activity below.

Vadose Zone Soil Analysis

- Of the 20 select constituents, 10 had exceedances.

- One of the select constituents, sulfate, had both the greatest frequency of exceedances and the maximum results from all investigation groups/sites (592,000 µg/kg at 4 m [14 ft] bgs).

- Additionally, one constituent, ^{40}K, had the maximum result (31 pCi/g at 25 m [81 ft] bgs) from all investigation groups/sites.

- Maximum results for ^{137}Cs, ^{60}Co, and ^{154}Eu are as follows:

  – Cesium-137, 27.7 pCi/g at the surface (which was also the extent of ^{137}Cs at this investigation group)

  – Cobalt-60, 0.16 pC/g at 119 ft bgs (extent of 60Co was 52 m [170 ft] bgs)

  – Europium-154, 0.31 pCi/g at the surface (extent of 154Eu was 52 m [170 ft] bgs).

- Maximum ^{99}Tc concentrations for Investigation Group A+B was 16 pCi/g at 11 m [36 ft] bgs.

- There were no exceedances of Nitrate at Group A+B.

- pH was greater than 8.5 from the surface (0.15 m [0.5 ft] bgs) to the deepest depth of 42 m (137 ft) bgs.

- Exceedances of select constituents occurred in surface to 52 m (170 ft) bgs (deepest depth sampled was 52 m [170 ft] bgs).

- Exceedances of select constituents occurred in backfill, H1, and H2.

- Investigation Group A+B had three groundwater constituents of interest with exceedances (nitrate, ^{99}Tc, and sulfate).

Direct Push Logging

- Site A (C8101) showed ^{137}Cs at the surface, with a maximum value of 2.2 pCi/g. Moisture values ranged from 2.5 to 15%.

- Site B (C8103) also showed ^{137}Cs near the surface with a maximum value of 30 pCi/g. Moisture values ranged from 2 to 18%.

- No additional detects were identified in the direct push logging results.

Drywell Logging

- High levels of total gamma activity were detected when the drywells were constructed in 1970. Most of the gamma activity decayed away following a ^{106}Ru decay curve and less than 1,000 pCi/g of ^{137}Cs gamma activity was observed in 1997 logging measurements.

- No indication of downward migration was observed in historical drywell total gamma trend plots between 1975 and 1995.

- Logging was completed at drywell 30-01-09 (299-E27-58; A6683) in August of 2010. ^{137}Cs was detected almost continuously from ground surface to 11 m (37 ft) bgs and intermittently to 30 m (97.5) ft bgs, with a maximum concentration of approximately 518 pCi/g at 8.7 m (28.5 ft) bgs. Drywell logging at this location showed no change from baseline conducted in 1997.

Surface Geophysical Exploration

- The SGE results show a low resistivity anomaly extending deep below Tank C-101. The resistivity anomaly results may indicate the presence of elevated salts such as nitrate or sodium (indicating a waste source) or may indicate higher moisture regions below the tank.

Data suggest that the low resistivity area beneath Tank C-101 extends to groundwater and additionally confirms that a large release may have occurred near Tank C-101. The low resistivity region appears to be reasonably consistent with a 37,000 gal release volume estimate. Based on curies of ^{137}Cs released to the soil from Tank C-101 (4,260 Ci, approximately 50% from the portion of the radiochemical release), it appears that ^{137}Cs contamination has migrated laterally and vertically from the area (i.e., analytical and logging concentrations have a maximum concentration of 518 pCi/g at 8.7 m [28.5 ft] bgs).

The Nez Perce Tribe have identified that by 1979 only a zone of high gamma remained approximately at about 35 ft bgs (^{137}Cs peak). They have additionally identified that based on the stratigraphic dip, it is expected that contamination in the area would move vertically and laterally to the northeast and that Tank C-101 is the source of ^{60}Co contamination outside the C Farm fenceline and at well 299-E27-14 (ERWM 2009)

Note that Tank C-101 was retrieved using modified sluicing, which commenced on December 10, 2012 and ended on September 1, 2013. Although large volumes of water and supernatant were added to the tank during sluicing operations there was no indication of a leak during retrieval from the HRR leak detection monitoring system or other monitoring systems used (RPP-57570, *Retrieval Completion Certification Report for Tank 241-C-101*).

5.6.4.3 Tanks C-104/C-105. For many years, Tank C-105 was classified as a "sound" tank (HNF-EP-0182). However a high activity of ^{137}Cs (greater than approximately 10^7 pCi/g) was observed in drywell 30-05-07 near the base of the tank when it was drilled in 1974. The drywell activity has been attributed to a cascade line leak and potentially a tank leak. After further field

investigation and review in 2010, the tank was reclassified as an "assumed leaker" (RPP-ASMT-46452, *Tank 241-C-105 Leak Assessment Completion Report*).

RPP-ENV-33418, Rev. 2A, concluded that the activity around Tank C-105 originated from several different sources. Probable sources of waste releases to the soil include: releases from the cascade line between Tanks C-104 and C-105, a leak near the base of Tank C-105, releases from spare inlet nozzles, and condenser leaks and leaks from pipeline V103. The soil between Tanks C-104 and C-105 was excavated to a depth of at least 5 m (16 ft) in 1967 when pipeline V103 was installed. Because of transfers of waste in and out of the tank, a liquid level decrease indicating the time of release could not be determined. Gamma activity was first observed when drywell 30-05-07 was installed in 1974. Liquid level decreases between 1963 and 1967 were attributed to evaporation, but a leak may also have contributed to liquid level decreases. A tank leak or cascade line release may also have occurred during the first quarter of 1968 when the tank received PSN waste and was filled above the cascade line.

Tank C-104 is currently classified as a "sound" tank (HNF-EP-0182); however, drywell 30-04-03 shows a ^{137}Cs peak at about 7 m (23 ft) bgs and ^{60}Co readings from 7 to 15 m (23 to 50 ft) bgs. This drywell is close to the cascade line between Tanks C-104 and C-105. It is thought that there was a release in 1965 when Tank C-104 was overfilled to 560,000 gal of CW waste. The surface level decreased to the spare inlet elevation of approximately 532,000 gal resulting in a possible 28,000-gal release. The waste released is assumed to be CWP1.

Waste Release Inventory Information:

At time of publication of this RFI, the current version of the soil contamination inventory report (RPP-RPT-42294, Rev. 1) has inventory information for the Tank C-105 release but not for Tank C-104. The report is being revised and will contain information about Tank C-104 in a future revision. For the purposes of this section, only Tank C-105 inventory information is presented.

The estimated volume of the release at Tank C-105 was 2,000 gal, consisting of 2,000 kg of chemical waste and 8,260 Ci of radiochemical waste. Appendix X identifies the specific constituents associated with the waste release event. The select constituents contributing most to the release inventory from Tank C-105 included:

- Sodium, 333 kg approximately 35% from the portion of the chemical release
- Nitrate, 251 kg approximately 26% from the portion of the chemical release
- Sulfate, 66 kg approximately 7% from the portion of the chemical release
- Cesium-137, 4260 Ci approximately 50% from the portion of the radiochemical release.

Results from Field Efforts

Several investigation efforts were conducted around Tanks C-104 and C-105 during Phase 1, Phase 2, and to support retrieval operations (Table 5-14). The investigations are comprised of:

- Angle pushes at Site J, under Tank C-104

- Borehole C4297, adjacent to the cascade overflow pipeline between Tanks C-104 and C-105 and a few feet from pipeline V103

- Logging at borehole C7469, between Tanks C-104 and C-105

- Drywell logging in the area

- SGE characterization of Site O, comprising the entirety of WMA C.

The following is an overall summary of the information.

Vadose Zone Soil Analysis

C4297

- Technetium-99 concentrations ranged from -8.48 pCi/g to 8.42 pCi/g, with the maximum concentration occurring at depth of 42 m (137 ft) bgs.

- Cobalt-60 concentrations of about 0.5 pCi/g were observed at depths of 12 to 18 m (40 to 60 ft) bgs.

- The maximum nitrate concentration of 19.5 µg/g was reported at a depth of 42 m (137 ft) bgs.

- Sodium was measured in 39 samples from C4297 at concentrations ranging from 8.26 µg/g to 131 µg/g. The maximum concentration of sodium (131 µg/g) was reported at a depth of 13.9 m (45.5 ft) bgs where elevated pH (9.43) was present. The highest concentrations of sodium (ranging from 32.4 µg/g to 131 µg/g) were located below the tank, within the soil interval between 12.4 and 18 m (40.8 and 60 ft) bgs.

- The highest concentrations of ^{137}Cs (ranging from 3 pCi/g to 31.4 pCi/g) were reported in shallow soils (backfill) at depths ranging from 0.8 to 4 m (2.5 to 12 ft) bgs. All results for ^{137}Cs in deep soils (≥ 5 m [15 ft] bgs) were reported as below detection or below the limit of quantitation.

- pH was elevated (i.e., 8 to 9.3) between 12 and 16 m (40 and 52 ft) bgs.

Site J

- Of the 20 select constituents, 6 had exceedances.

- Maximum results for ^{137}Cs, ^{60}Co, and ^{154}Eu are as follows:

  – Cesium-137, 5.71 pCi/g at the surface (which was also the extent of ^{137}Cs at this investigation group)

  - Cobalt-60, 0.101 pCi/g at the surface (extent of ^{60}Co was 53 m [173 ft] bgs)

  - Europium-154, 0.165 pCi/g at 39 ft bgs (extent of ^{154}Eu was 53 m [173 ft] bgs).

- Technetium-99 and nitrate had no exceedances at Site J.

- pH was greater than 8.5 for all depths sampled at Site J, from the surface to the depth of 53 m (173 ft) bgs.

- Exceedances of select constituents occurred at the surface to 53 m (173 ft) bgs (Deepest depth sampled was 53 m [173 ft] bgs).

- Exceedances of select constituents occurred in backfill, H1, and H2.

- Site J had no groundwater constituents of interest with exceedances.

Logging at C4297

- Logging indicated gamma activity between 3 and 5 m (11 and 16 ft) bgs, which is suggests a point source of contamination such as a pipeline or waste inside a nearby pipeline.

- Low levels (<1 pCi/g) of ^{60}Co were found at depths from 12 to 20 m (40 to 65 ft) below ground surface.

- Cesium-137 was detected between the ground surface and 6 m (19 ft) in depth at concentrations up to 1,700 pCi/g

- Europium-154 was detected between 3 and 5 m (11 and 16 ft) bgs at a maximum concentration of 400 pCi/g.

Direct Push Logging

- One angle push was completed as part of Site J under Tank C-104 (C8099).

  - Cesium-137 was observed at the surface, with a maximum of 5.8 pCi/g, and at a depth of 4.9 to 5.1 m (16 to 17 ft) bgs with a maximum of 2.2 pCi/g.

  - Gamma activity starting at about 6 m (20 ft) bgs (near the cascade line) and increasing in activity to near the base of the tank.

  - No additional detects were reported.

  - Moisture values range from 2.3 to 17%.

- One vertical push, C7469, was completed to 11 m (36 ft) bgs between Tanks C-104 and C-105.
  - Levels detected by the gross gamma logging tool indicated values exceeding the detection range greater than 68,000 pCi/g.
  - A second tool, with a greater range, was implemented and values up to 43,000,000 pCi/g of ^{137}Cs were detected at 11 m (35 ft) bgs.
  - Detect values increased with depth beginning at approximately 18 ft bgs.

Drywell Logging

- Cesium-137 was detected at 30-04-01 almost continuously from ground surface to the total logged depth of the drywell. A maximum concentration of approximately 49 pCi/g was measured at 0.3 m (1 ft) bgs. Comparisons with the 1997 data indicate no significant change.

- Drywell 30-04-03 shows a ^{137}Cs peak at about 7 m (23 ft) bgs and ^{60}Co readings from 7 to 15 m (23 to 50 ft) bgs. This drywell is close to the cascade line between Tanks C-104 and C-105 (RPP-ENV-33418).

- Peak gamma activity concentrations of approximately 100 pCi/g between ground surface and 2 m (5 ft) bgs and approximately 10 pCi/g between 2 and 6 m (5 and 20 ft) bgs in drywell 30-04-04 and approximately 50 pCi/g at 4 m (12 ft) bgs in drywell 30-04-05. Comparisons with the 1997 data indicated no significant change.

- Cobalt-60, ^{154}Eu, and ^{152}Eu were not detected in drywells 30-04-05 and 30-04-04. Cobalt-60 detected in 1997 appears to have decayed below the detection level. Further investigations of the 1997 data for ^{154}Eu and ^{152}Eu detections indicated that the 1997 detections were not valid peaks.

- Cesium-137 was detected almost continuously from ground surface to the total logged depth of the drywell. A maximum concentration of approximately 18 pCi/g was measured at 0.3 m (1 ft) bgs. Comparisons with the 1997 data indicate no significant change. Comparison of 1997 and 2010 data with RLS data acquired in 1993 indicate similar profiles.

- Radiation assessment logging system data acquired in 1993, suggested ^{60}Co was detected discontinuously from 5 to 16 m (16 to 51 ft) bgs at less than 0.3 pCi/g. The ^{60}Co was mostly observed from 14 to 15 m (45 to 50 ft) bgs. There was no evidence of ^{60}Co in the 1997 or 2010 log data.

- Drywell 30-05-07 is of particular interest. Cesium-137 was detected almost continuously from ground surface to 20.3 m (66.5 ft) bgs, with a maximum concentration of approximately 19,800,000 pCi/g at 11.4 m (37.5 ft) bgs measured using the HRLS with an internal tungsten shield. No significant changes have occurred since 1997. Cobalt-60 detected in 1997 at 9 m (28.5 ft) bgs and 19.8 to 20.3 m (65 to 66.5 ft) bgs has decayed below the detection limit. However, it likely exists in the high activity zone below 11 m (35 ft) bgs. Europium-154, ^{152}Eu, and ^{235}U, detections in 1997, were determined to be invalid and were removed from the data set. Handheld neutron moisture logs show moisture between 5 and 10% except between 10 and 13 m (34 and 42 ft) bgs. The detector was influenced by high gamma activity between at this depth and does not reflect the true moisture content.

- Cesium-137 was detected continuously at 30-05-08 from ground surface to 15 m (48 ft) bgs, with a maximum concentration of approximately 104 pCi/g at 0.3 m (1 ft) bgs. No significant changes have occurred since 1997. Cobalt-60 was detected almost continuously from 10 to 12 m (35 to 39.5 ft) bgs, with a maximum concentration of approximately 0.3 pCi/g at 12 m (38 ft) bgs. Cobalt-60 concentrations that were detected in 1997 at some depth locations have decayed below the detection limit. Europium-154 was detected continuously from 4 to 5 m (14 to 18 ft) bgs, with a maximum concentration of approximately 7.8 pCi/g at 5 m (16.5 ft) bgs. No significant changes have occurred since 1997.

- Log data were available for drywells associated with Tank C-104 as part of the retrieval monitoring program. The results showed no evidence of any significant changes in either moisture content or gamma activity during and after retrieval operations (RPP-RPT-56085).

Surface Geophysical Exploration

- SGE results associated with Tank C-104 do not conclusively identify a target. While the most recent version presents an area of low resistivity compared to other parts of the farm, there is no clear indication of the presence of a low resistivity plume. The results presented in the initial model erroneously estimated a plume at Tank C-104.

Data suggest that a large area of contamination between Tanks C-104 and C-105 may have originated from the cascade line connecting these two tanks. It is possible that one or both of these tanks may have been a source of a waste release, but the depth and location of the suspected origin of the contamination suggest that the most likely source of the released waste was the cascade line. Contamination appears to have migrated downward and eastward of Tank C-104 to a depth of at least 41 m (135 ft) bgs.

As indicated, high ^{137}Cs concentrations were detected in one drywell 30-05-07, nearby in direct push hole C7469. Sorption theory suggests that ^{137}Cs would be expected to migrate about the same horizontal distance in all directions in the soil. This theory seems to be supported by the observation that the ^{137}Cs activity levels were much lower and nearer to the waste surface or tank

spare inlet ports for all other drywells. Even in C4297, only 3 m (9 ft) away from drywell 30-05-07, significantly lower gamma activity was measured well above the tank bottom.

It has been identified that the ^{137}Cs contamination extends under the tank and may be at higher concentrations than those measured in drywells. A ^{137}Cs plume estimate assuming this condition (Figure 5-33) was presented in a letter from the Nez Perce Tribe to DOE and a presentation in November 2010 (ERWM 2009 and ERWM 2010). The Nez Perce estimate assumes that the ^{137}Cs plume under Tank C-105 is mostly at a concentration of 10^8 pCi/g, the peak concentration observed in SX Farm drywell and borehole measurements (Appendix C) and at 10^7 pCi/g around the perimeter of the plume. This model results indicates an estimated 20,500 gallon release (88,000 Ci of ^{137}Cs at a concentration of 4.3 Ci/gal, 25,500 Ci decayed to 2001).

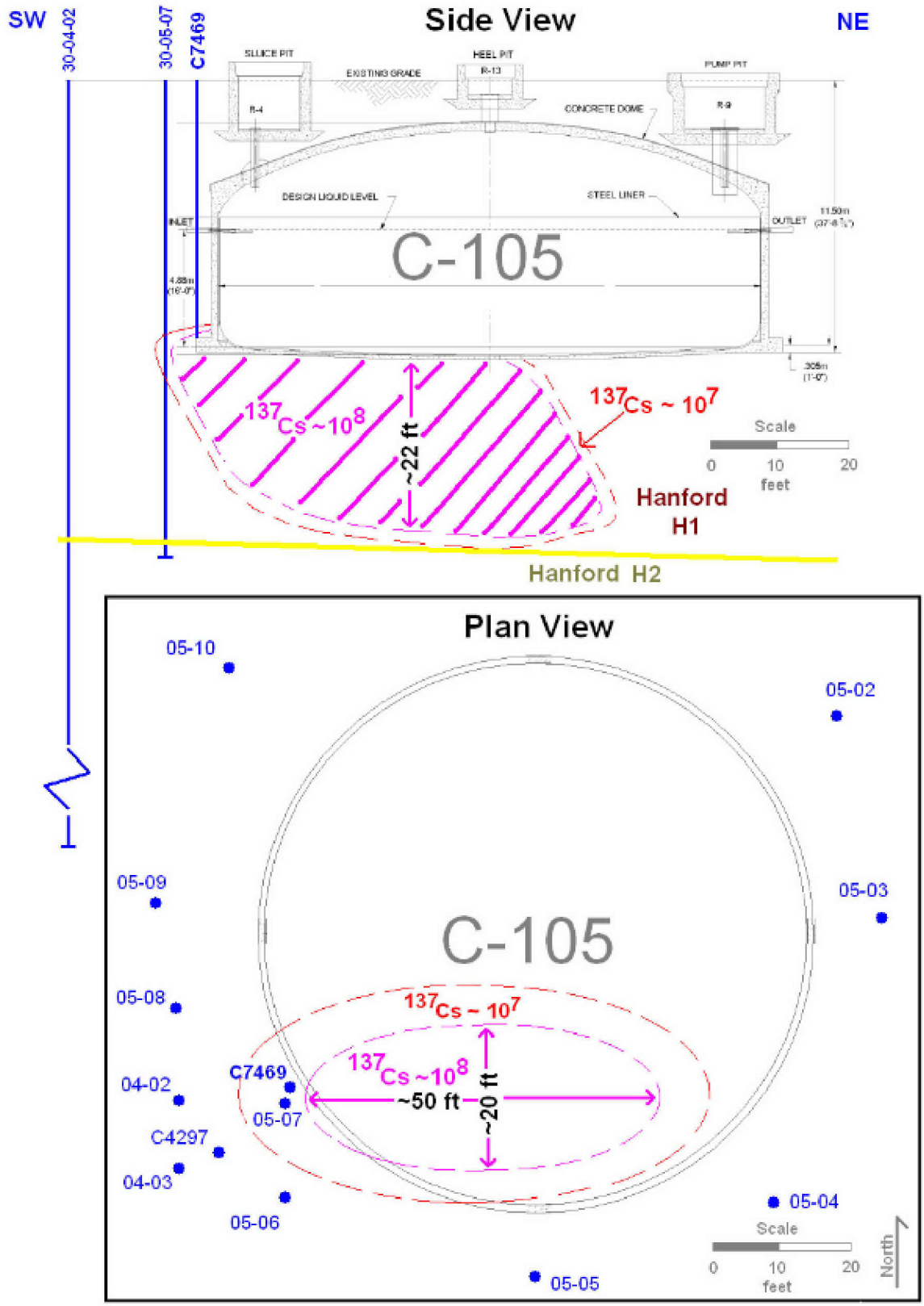
Ultimately, analytical and logging results identify that there is a ^{137}Cs and ^{60}Co contamination in the vicinity of Tanks C-104 and C-105 in both shallow and deep soil. This contamination is to be expected since 4,260 Ci of ^{137}Cs has been estimated to be released to the soil from the Tank C-105 release (i.e., approximately 50% from the portion of the radiochemical release).

It should be noted that the waste retrieval operations for Tank C-105 began in June 2014 and are ongoing. To date, there has been no indication of a tank leak during retrieval. Because Tank C-105 is an assumed leaker, the primary waste retrieval technology currently being deployed is venturi vacuum with supernate or water. The second technology deployed is high-pressure water spray. Both of these technologies are deployed via the mobile arm retrieval system vacuum (MARS-V) waste retrieval technology.

Tank C-104 has undergone two waste retrieval campaigns; the first was modified sluicing, which removed ~98% of the initial waste inventory; a second campaign comprised of chemical dissolution (caustic cleaning) with a subsequent heel water wash resulted with a waste residual of 255 ft^3 (RPP-CALC-54284, *Post-Hard Heel Retrieval Camera/CAD Modeling System Waste Volume Estimate for Tank 241-C-104*). Tank C-104 modified sluicing waste retrieval campaign began January 8, 2010 and was completed on May 9, 2011. The caustic cleaning retrieval operations began on June 14, 2012 and reached the limits of technology on August 17, 2012. Prior to retrieval, the best estimate of waste volume was ~259,000 gal (34,600 ft^3). After retrieval operations were completed, over 99+% of the initial waste volume was removed from Tank C-104.

5.6.4.4 Tank C-108. Tank C-108 was classified as a "sound" tank (HNF-EP-0182) and was removed from service in 1976. RPP-ENV-33418 (Rev. 2A) also states that Tank C-108 appears to be sound, as previously classified. However, the report also notes that drywells in the area show ^{137}Cs near the tank at 22 ft bgs (probably inside the cascade line) and ^{60}Co plumes that appear to extend from the tank bottom and migrate out and downward. Although the leak detection monitoring results show no indication of a tank leak or other releases to the soil during retrieval, drywell logging indicates continued migration of the ^{60}Co in the soil.

Figure 5-33. Nez Perce Plume Concept for Tank C-105 Leak



RPP-ENV-33418 (Rev. 2A) additionally identifies that Tank C-108 was filled to 568,000 gal of CW-HS waste in 1965 and that there was a decrease in surface level to 532,000 gal through a transfer to Tank C-102. The waste loss was assumed to be 18,000 gal based on ^{60}Co and soil moisture determinations, and the waste volume based on CW waste composition. Waste releases from the tank spare inlet nozzles or pipeline leaks may have also occurred. It should also be noted that the Nez Perce Tribe also agrees that there is a waste release associated with Tank C-108 (Figure 5-34).

Waste Release Inventory Information

The estimated volume of the release was 18,000 gal. At this time the current version of the soil contamination inventory report (RPP-RPT-42294, Rev. 1) does not have inventory information for this waste release. The report is being updated and will contain information about Tank C-108 in a future revision.

Results from Field Efforts

Data in this area consist of Site E (analytical and logging), drywell logging in the general area, and SGE analysis (i.e., overall WMA C).

Vadose Zone Soil Analysis

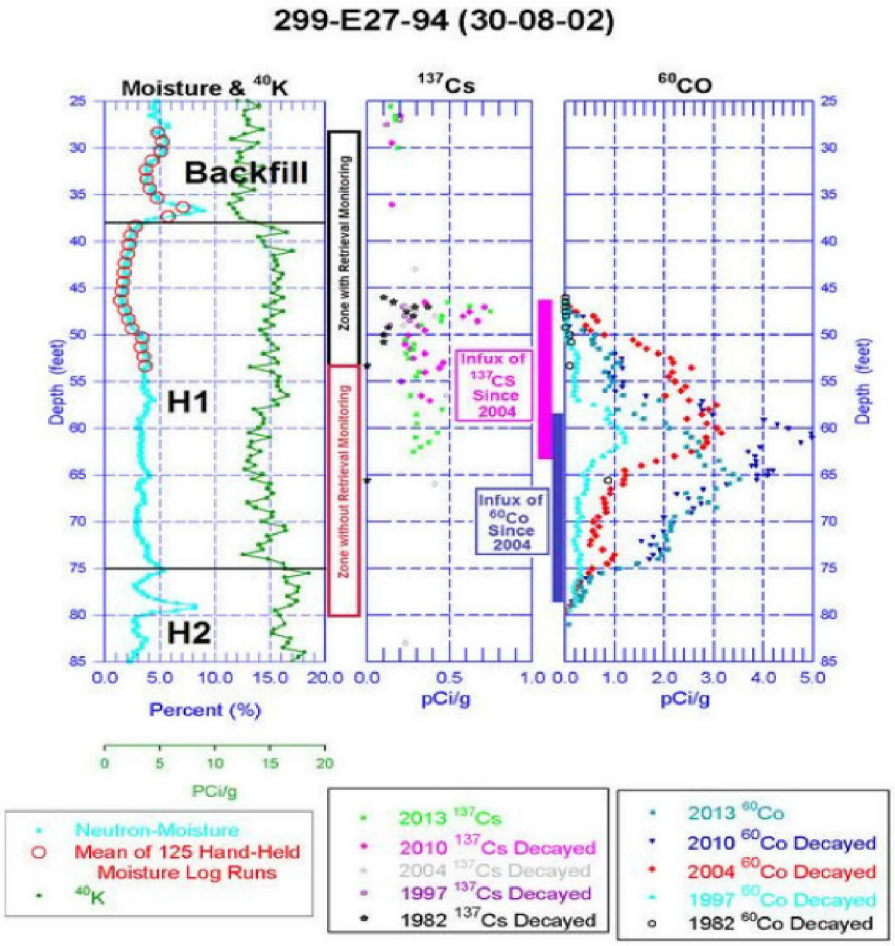
- Of the 20 select constituents, 9 had exceedances.
- Site E had the highest frequency of exceedances for chromium (33.3% of samples) and nickel (22.2% of samples) across all Phase 2 locations at WMA C; however, neither constituent was reported as a maximum concentration.
- Maximum results for ^{137}Cs, ^{60}Co, and ^{154}Eu are as follows:
  - Cesium-137, 5.13 pCi/g at the surface (which was also the extent of ^{137}Cs at this investigation site)
  - Cobalt-60, 0.384 pC/g at 6 ft bgs (extent of ^{60}Co was 37 m [123 ft] bgs)
  - Europium-154, 1.24 pCi/g at 6 ft bgs (extent of ^{154}Eu was 37 m [123 ft] bgs).
- There were no exceedances of ^{99}Tc or nitrate at Site E.
- Exceedances of select constituents occurred in surface to 37 m (123 ft) bgs (Deepest depth sampled was 37 m [123 ft] bgs).
- Exceedances of select constituents occurred in backfill, H1, and H2.

Figure 5-34. Email Regarding Leak Classification for Tank C-108

From: "Stan Sobczyk" <stans@nezperce.org>
Subject: C-108 retrieval leak
Date: September 2, 2014 at 11:41:59 AM PDT
To: "Todds email" <toddmrtn@gmail.com>

Currently, tank 241-C-108, located in Waste Management Area (WMA) C, has been retrieved and is classified as a non-leaking tank. However, we believe that there is evidence that this tank should be classified as a leaking tank and may have continued to leak during retrieval operations. A ^{60}Co vadose zone plume extends from the base of tank C-108 to the area between tanks 241-C-106 and 241-C-109 and is projected out to well 299-E27-7 where ^{60}Co has been detected at depths between 133 and 158 ft. Migration of radionuclides, in the down-dip direction, from tank C-108 have been observed in this area since 1974 over a span of at least 37 years.

Spectral gamma logging measurements (SGLS) in 1982, 1997, 2004, 2010 and 2013 indicate changes in the subsurface activity of ^{60}Co in drywell 30-08-02 that are inconsistent with radioactive decay. DOE-EM/GJ777-2004 didn't suggest an "apparent change" in ^{137}Cs activities while indicating an ongoing change in ^{60}Co activities for SGLS data collected in 2004 when compared to 1997. SGLS data collected in 2010 indicate that ^{137}Cs activities have doubled from levels (~ 0.3 pCi/g) observed in 1982, 1997 and 2004 in the interval from 47 to 50 ft. SGLS data from 2010 indicate recent movement of low levels (< 0.5 pCi/g) of ^{137}Cs to depths between 51 and 57 ft when compared to 2004 SGLS data. SGLS data from 2013 indicate continued movement of low levels of ^{137}Cs to depths between 57 and 62 ft when compared to 2010 SGLS data. This influx of ^{137}Cs below the base of the tank, since 2004, is most likely related to a leak from tank C-108. The timing of the ^{137}Cs influx is contemporaneous with the tank C-108 retrieval operations that started in December 2006 and ended in March 2012. ^{60}Co contamination increased between log depths 50 to 76 ft between 1997 and 2010. Between 2010 and 2013, ^{60}Co activities apparently decreased in the interval between log depths of 55 to 65 ft.



- Site E had no groundwater constituents of interest with exceedances.

- pH was greater than 8.5 for all depths sampled at Site E, from the surface to 37 m (123 ft) bgs.

Drywell Geophysical Logging

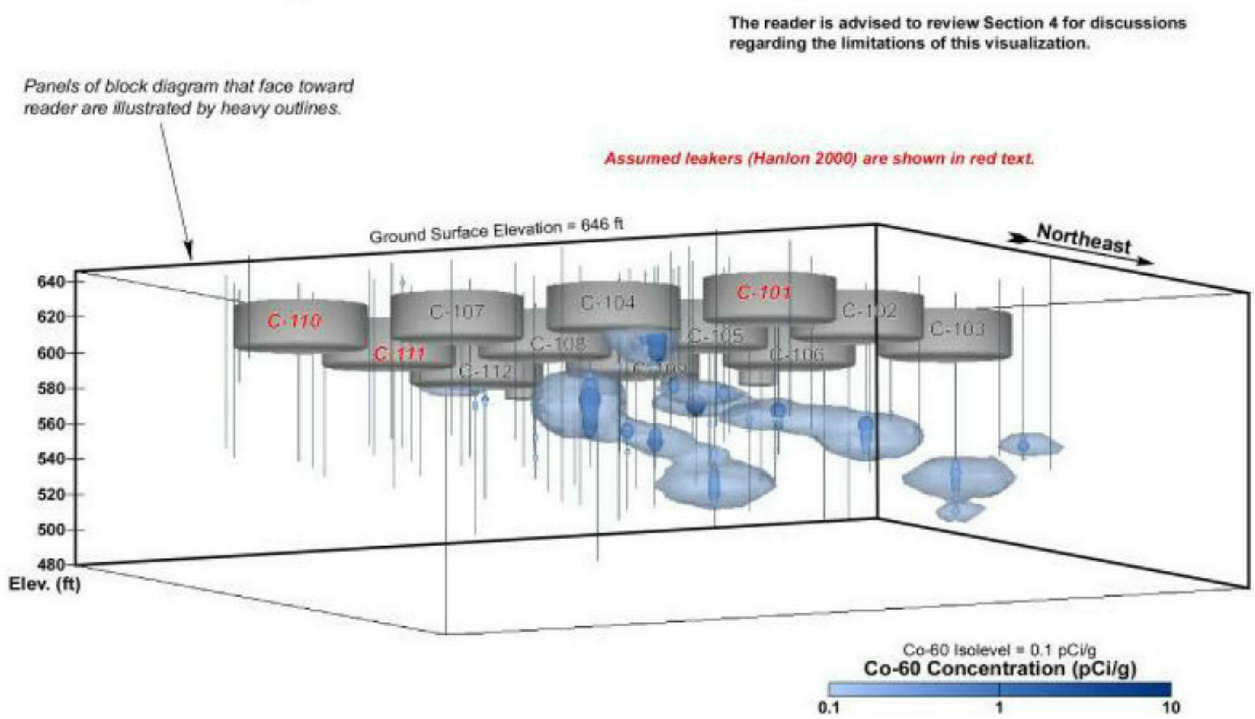
- Drywells show that ^{137}Cs and ^{154}Eu appear to have migrated from the cascade level near Tank C-108 at 7 m (22 ft) (probably inside the cascade line) to a peak at 7 m (23 ft) bgs (^{137}Cs, 1,000 pCi/g)

- No gamma activity was detected from approximately 8 to 15 m (25 to 50 ft) bgs.

- Cobalt-60 was consistently detected in the vicinity of Tanks C-108, C-109, C-106, and C-103 from around 15 m (50 ft) bgs and occurred progressively deeper with distance from Tank C-108 (i.e., 37 m [120 ft] bgs). Specifically, ^{60}Co seems to originate from a source in the vicinity of drywell 30-08-02, moved down to about 24 m (80 ft) bgs, and then moved laterally to the east, past drywells 30-09-07 and 30-09-06 to the vicinity of 30-06-10, where it migrated downward to below 37 m (120 ft) bgs. Figure 5-35 depicts the observed ^{60}Co plume beneath C Farm.

- The general interpretation is that contamination originates in the vicinity of Tank C-108, with "stair step" migration to the east (downward in the vicinity of 30-08-02, laterally past drywells 30-09-07 and 30-09-06, and downward in the vicinity of 30-06-10).

Figure 5-35. C Farm Cobolt-60 Activity Visualization



Direct Push Geophysical Logging

- Borehole C7671 (Site E) adjacent to and west of Tank C-106 detected a maximum ^{137}Cs concentration of 218 pCi/g at a depth of 0.6 m (2 ft) bgs.

Surface Geophysical Exploration

- SGE results show a low resistivity plume adjacent to Tanks C-108, C-105, and C-103.

- The low resistivity plume appears to loosely correlate with the geophysical logging ^{60}Co detect locations in the vicinity.

Based on evaluation of the data, it appears that the contamination beneath Tank C-108 possibly incorporates a larger area, that including Tanks C-103, C-106 and C-109 as indicated by direct pushes associated with these area. Additionally, continued movement of contamination beneath the Tank C-108 could indicate that there may have been other waste releases and additional solutions (water) released.

Per RPP-ENV-33418, Rev. 2A, ^{137}Cs appears to have migrated from the cascade level to a peak at 23 ft bgs, and ^{60}Co, detected at 15 m (50 ft) bgs, extends to a depth of 24 m (80 ft) bgs. Historical gamma logs since 1976, and more current log data, indicate continued migration of ^{60}Co from 15 to 37 m (50 to 120 ft) bgs. It is thought that up to four "pulses" of activity or ^{60}Co movement have been observed in the 34 intervening years. This suggests a source may be continuing to "feed" the plume. A cascade line would have leaked a limited amount and the source would have ceased after the overfill event in 1965. It was suggested that the narrow peak of ^{137}Cs and ^{154}Eu probably indicated residual waste in the cascade line. The ^{137}Cs activity (less than 100 pCi/g) in drywells around these tanks was attributed to surface spills, indicated by the elevation of the measurements. The ^{60}Co activity observed from 24 to 38 m (78 to 125 ft) bgs in drywells around these tanks could also attributed to releases from another or other tanks. The activity may also be migration from a known surface release near Tank C-108.

During the retrieval of Tank C-108, which was completed in March 2012, drywell moisture monitoring and HRR monitoring were performed for leak detection. Although large volumes of supernate and other liquids were introduced to the tank during retrieval operations and liquid was recirculated in the tank to remove the remaining hard heel, no evidence of a leak during retrieval was detected by the drywell monitoring or the HRR leak detection system (RPP-RPT-52449, *Single-Shell Tank 241-C-108 Hard Heel Retrieval Completion Report* and RPP-RPT-55709, *241-C-108 Tank Waste Retrieval Project Final Report of Drywell Monitoring Data*). These reports support the previous evaluations that the tank appears to be sound.

5.6.4.5 Highlights from Other Waste Release Areas. The following are some brief highlights that could be gleamed from the following locations: UPR-200-E-86, UPR-200-E-82, 200-series tanks, C-301 Catch Tank, and Cesium Loadout Facility.

UPR-200-E-86

UPR-200-E-86 resulted from a transfer line release (leakage) of waste that connected between the 244-AR Vault and diversion box 241-151-C. The waste release comprised of PUREX sludge supernate (PSS) and was discovered on February 25, 1971. The transfer line was a direct buried line, about 2 m (8 ft) below grade. The leak appeared to have occurred at a carbon steel – stainless steel weld. Per RPP-ENV-33418, Rev. 2A, the maximum volume the soil would hold is 4,000 gal.

The estimated volume of the unplanned release was 17,000 gal, consisting of 3,700 kg of chemical waste and 22,800 Ci of radiochemical waste. Appendix X identifies the specific consistuents associated with the waste release event and the below summarizes highest components from the select constituents:

- Sodium, 1,220 kg, approximately 33% from the portion of the chemical release
- Nitrate, 734 kg, approximately 20% from the portion of the chemical release
- Sulfate, 65.5 kg, approximately 8% from the portion of the chemical release
- Cesium-137, 11,500 Ci, approximately 51% from the portion of the radiochemical release.

Only one of the nine locations logging, C5959 during Phase 1.5 showed above background limits (40,000 pCi/g of ^{137}Cs, at approximately 8ft bgs). Cesium-137, ^{60}Co, ^{154}Eu, ^{99}Tc and ^{230}Th were reported as below detection for all other samples analyzed from UPR-200-E-86 during Phase 1.5. The maximum concentration for ^{40}K was 23.4 pCi/g at a depth of 35 m (115 ft) bgs (deep) from borehole C5958. With respect to SGE, only a few small low resistivity anomalies were identified in the vicinity.

UPR-200-E-82

UPR-200-E-82 is associated with a leak in a transfer line going from Tank C-105 to B Plant that was discovered in December 1969 about 11 m (35 ft) south of diversion box 241-152-C. Waste from the pipe line leak migrated to the surface and the site was covered with 0.6 m (2 ft) of backfill (ARH-1945). A Gunite cap was installed over the release site, but not for 20 years after the leak. It was assumed that the loss of waste was from a joint connecting two pipes at an angle near diversion box 241-C-152 about 3 m (11 ft) bgs (RHO-CD-673).

It is thought that 2,100 to 2,600 gal of PSN waste (RPP-35484*)* was released in the area, consisting of 990 kg of chemical waste and 8,900 Ci of radiochemical waste. Appendix X identifies the specific constituents associated with the waste release event and the below summarizes highest components from the select constituents:

- Sodium, 330 kg, approximately 33% from the portion of the chemical release
- Sulfate, 146 kg, approximately 15% from the portion of the chemical release

- Nitrate, 91 kg, approximately 9% from the portion of the chemical release
- Cesium-137, 4,400 Ci, approximately 51% from the portion of the radiochemical release.

Based on results in the area, it has been concluded that the pipeline leak was either of low volume and not a source of groundwater contamination for the waste management area, or actions taken to control exposure to the spill have resulted in it being diluted and/or flushed into the underlying groundwater.

200-Series Tanks

RPP-ENV-33418 Rev. 2A states liquid level decreases in the 200-series tanks were attributed to evaporation. Previous tank leak assessments concluded the liquid level decreases had to be due to a tank leak because there was assumed to be no point of air entry into the tanks other than through breather air filters. Previous leak assessments also concluded that intrusions in Tank C-203 from 1973 through 1980 may have masked a larger tank leak.

Additionally, it should be noted that depleted uranium is known to have been stored in the 200-series tanks. Uranium-235 and ^{238}U were detected in the vadose zone at concentrations of about 2 and 20 pCi/g, respectively at 30 m (100 ft) bgs in borehole 299-E27-7, approximately 61 m (200 ft) northeast of the tanks; however, uranium and uranium isotopes were not detected in samples from the direct push location by the 200-series tanks (i.e., Site C). Overall, uranium was not detected very infrequently in and around WMA C (Appendix Q). None of the less, as discussed in the April 19 meeting (Appendix A in RPP-ENV-33418, Rev. 2A), transfer lines from the 200-series tanks appear to be the most likely source for uranium and cyanide in well 299-E27-7.

Another potential source for soil contamination in the region, north of the 200-series tanks, is UPR-200-E-91; a 3 hectares (7 acres) area located adjacent to the northeast corner of the C Farm. In 1991 contaminated soils were scraped and removed from the area. The WIDS entry for UPR-200-E-91 states, "contaminated soil releases occurred overtime, due to radioactive particles migrating out of the adjacent 241-C Tank Farm. At one time water from an equipment decontamination station, located inside the Tank Farm, seeped downhill into this area" (italics in parentheses added).

The angle direct push holes (Site C) were placed to investigate the area under Tank C-203 in an attempt to characterize potential leaks/releases near the tank. No subsurface gamma activity was detected in the angle push; however the samples from the surface at this location had ^{137}Cs detections, with a maximum of 7 pCi/g. Logging also indicated several moisture peaks of between 10% and 25% between 1 and 4 m (4 and 14 ft) bgs and at ~12 m (40 ft) bgs. Similar results were observed in vertical direct push holes in the vicinity of the 200-series tanks. It should be noted that analysis of samples and logging from the angle pushes would not likely be able detect small shallow releases from the spare inlets.

SGE results show a low resistivity region north of the 200-series tanks that extends to the groundwater. The deep anomaly in the direct vicinity of the 200-series tanks is most likely due to subsurface infrastructure, with the exception of the area at the northeastern boundary of the

survey area. This anomaly occurs at depth and correlates with gamma results obtained from borehole E27-7 (RPP-RPT-56760). It has been speculated that low resistivity north of the 200-series tanks may be from contamination migrating from the direction of Tanks C-108 and C-109. It is also possible that the anomaly, at the northeastern boundary of the surface area, is a result of limited coverage at depth. Resistivity surface coverage varies laterally with depth and the low resistivity is only present near the depth electrodes. It should also be noted that direct push logging completed when the depth electrodes were installed does not indicate any increases in gamma specific to this zone of interest.

C-301 Catch Tank

As identified in the work plan (RPP-PLAN-39114), leaks from ancillary equipment were observed and recorded when sufficient fluid reached the surface from the buried, but near-surface, sources. The primary parts of the ancillary equipment system responsible for the surface spills appear to be the collection points for fluids being transferred around the tank farm (e.g., diversion boxes, valve pits, and catch tanks). Numerous pipes feed into these collection points. The pipes were frequently attached, detached, and reattached as part of normal operations because the permanent pipelines would become clogged or unusable. Plugging of underground pipelines resulted in waste escaping containment, especially transfer and cascade lines.

Additionally, if waste leaked into a diversion box, it generally drained by gravity to nearby unlined concrete catch tanks where any spilled waste was stored and then pumped to SSTs (DOE/RL-92-04). Catch tanks including C-301 has a 36,000-gal capacity 20-ft radius by 20.25-ft tall reinforced-concrete interior painted with two coats of Amercoat Paint (INDC-356-VOL3, *Construction Hanford Engineer Works U.S. Contract Number W-7412-ENG-1 Du Pont Project 9536 History of the Project Volume III*, page 923 and W-72903, *Hanford Engineer Works – Bl'd. #241-TUB 20'-0" Catch Tank Arrangement and Concrete*).

Direct pushes at Site R were sampled and logged to assess a potential waste release from the C-301 Catch Tank. Characterization data obtained through the field effort yielded less than expected contamination levels (i.e., minimal soil background exceedances). Nitrate and ^{137}Cs were not detectable in samples at this site and ^{99}Tc was only detected in one sample at 12 m (40 ft) bgs (6.5 pCi/g). Cobalt-60, ^{90}Sr, and ^{154}Eu concentration were all not detectable at very low levels above background. Additionally, the maximum ^{137}Cs concentration from logging was 722 pCi/g at 4 m (13.5 ft) bgs; however, it is thought that the true ^{137}Cs levels are higher due to remote signal and non-uniform distribution. This ^{137}Cs was the primary contamination found at this site. Moisture values ranged from 2 to 25%, with peaks >20% at ~9 and 12 m (28 and 40 ft) bgs.

Cesium Loadout Facility

The Cesium Loadout Facility is located in the northeastern portion inside WMA C. The C-801 Building was used from 1961 through 1968 to load cesium and occasionally technetium onto casks containing IX material (Interoffice memo 7G400-03-SMM-003, "Shipments of Cesium-137 and Strontium-90 from the Hanford Site [1961 through 1977]"). A cask would be staged in

the C-801 Building and connected to waste transfer piping at a shielded enclosure within the C-801 Building. Tank waste (PUREX P1 and P2 [1963-1967 high-level waste]) was transferred from Tank C-103 through underground piping to a valve pit located inside the C-801 Building. The tank waste would then flow into the cask, the target radionuclide would be absorbed by the IX material, and then waste would flow back to Tank C-102.

There are two drywells associated with this facility. One drywell is located inside the tank farm fence near the north wall of the C-801 Building and another drywell located outside of the tank farm fence (H-2-4573, *Engineering Flow Diagram, C-Farm Cesium Loadout Facility,* and H-2-4565, *Plot Plan – Roads Drawing Schedule, Cesium Loadout Facility*). This drywell is located ~23 m (75 ft) north of the C-801 Building; outside the tank farm fence (DOE/RL-88-30, Rev. 20, page 1158). Per RPP-ENV-33418, Rev. 2A, it is thought that PUREX (P1 and P2) waste types along with decontamination solutions may have been discharged to this drywell as a result of operations conducted at the C-801 Building.

This area is of interest because from the various data collected for WMA C and based on the stratigraphic dip in the vadose zone, it appears that soil contamination from the waste releases associated with the 100-series tanks (identified in Section 5.6.4) is migrating towards this area.

5.6.5 Overall WMA C Vadose Zone Contamination

A significant amount of work has been performed to characterize contamination in the vadose zone within and around WMA C. The area shows evidence of widespread shallow and deep contamination and a discontinuity between soil constituents and groundwater contamination, and there continues to be a limited understanding of the linkage between sources and contaminants at WMA C. In general, contamination has been found from the surface to depths of approximately 73 m (240 ft) bgs. It is difficult to make specific correlations because the various waste releases have occurred in near proximity and in an area of up to 7 hectares (16 acres).

Several observations could be made from the Phase 2 RFI characterization efforts. For instance, gamma logging showed higher gamma spectra near the soil surface and near locations of suspected waste loses, confirming that waste had entered the soil and that many gamma emitting radionuclides did not show significant mobility. Moisture logging showed layers of higher moisture interspersed with lower moisture. These observations were consistent with expectations. Although the SGE campaign did not determine conclusively whether individual 200-series tanks leaked, it did identify that soil anomalies in the area suggested the presence of moisture (e.g., UPR-200-E-81).

For the most part, sampling did not show high concentrations of mobile constituents in any specific depth range. A number of observations should be noted:

- Many sampling locations showed concentrations of mobile constituents somewhat above background (37 out of 45 constituents), suggesting that for the most part that mobile constituents had migrated through the region, to greater depths.

- Increased concentrations of some mobile contaminants above background were found in samples from all depths.

- As the Phase 2 RFI characterization was proceeding, the groundwater sampling program was finding additional evidence that waste from the WMA C tank system had reached groundwater (Section 5.4).

- Information collected in and near other tank farms suggested that geologic layers in the soil were providing significant lateral movement of water and mobile contaminants. In at least some parts of WMA C, there appears to be lateral movement within the vadose zone.

As identified, Phase 2 sampling efforts did not represent a random statistical sampling scheme at WMA C. The Phase 2 investigation targeted locations where contamination was expected to be found based on historic records of waste losses. Results of the Phase 2 investigation confirm the expectation that a number of immobile waste constituents remain near sources of waste releases. Mobile constituents have moved into the vadose zone to varying depths as a result of the waste release and geochemical processes. In addition to vertical movement of the contamination, lateral migration has occurred. Although there may be a preferential direction in some parts of the tank farm, spreading in other directions due to smaller lenses of less permeable soil cannot be ruled out.

With respect to data gaps, only Site X could not be accessed during the field investigation (as per Section 4). Specifically, Site X, which was to be located near the Tank C-105, was added to Revision 2 of the work plan to better define the area of contamination associated with a historic waste loss from Tank C-105. The goal of the investigation was to gain information about a contamination under the tank, which was thought to be accomplished with an angled direct push under the tank. However, based on the available information already collected from WMA C, it is not certain if this additional field information is needed, or if it will be of value. The area continues to be difficult to access and it is thought that modeling may provide any additional information, if needed. Therefore, no further field characterization is recommended at this site.

Additionally as identified, direct pushes at Site R were completed to assess a potential waste release from the catch tank. Characterization data obtained through the field effort yielded less than expected contamination levels (i.e., minimal soil background exceedances). It is understood that additional information may be required to make retrieval and closure decisions for C-301 Catch Tank, beyond the scope of the characterization covered in this RFI; however, it is believed that no further soil characterization around the C-301 Catch Tank is needed.

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6. CONTAMINANT FATE AND TRANSPORT

This section describes both current and anticipated efforts for evaluating the fate and transport of selected contaminants of potential concern at WMA C. The initial focus of this effort will be to evaluate the possible impacts of contaminants expected to remain in tanks and equipment after closure. The completed evaluation will include analysis of the impacts of contaminants in the vadose zone and the underlying groundwater at WMA C. This section also describes the approaches that will be used to identify contaminants of potential concern and to model the movement of those contaminants in the environment. Factors affecting the fate and transport of contaminants, modeling methods, and uncertainties are also discussed.

As described in Section 1.1, a performance assessment (the WMA C IPA) is being prepared pursuant to requirements of HFFACO Action Plan Appendix I and DOE O 435.1. Fate and transport evaluation activities are common to both the performance assessment required by the WMA C soil corrective action process and by DOE O 435.1 and are being performed as a part of the IPA. The discussions in this section summarize the IPA work activities and results that support the soil corrective action process.

6.1 PRIMARY AND SECONDARY SOURCES

Current and future contamination at WMA C results from past and future releases of contaminants from two types of sources: primary and secondary.

6.1.1 Primary Sources – Waste Inventory in Tanks and Ancillary Equipment

Primary sources of contamination in WMA C include the residual wastes in the SSTs and ancillary equipment, transported through pipelines and from processes at separation facilities during operations. Tank and pipeline residuals remain in place, and are expected to remain following closure of WMA C. Section 3.6 of this RFI report contains a summary of waste characteristics and associated inventories from primary sources, based on information contained in RPP-RPT-42323, Rev. 2. RPP-RPT-42323 provides inventory estimates for waste residuals that are assumed to remain in C Farm tanks and ancillary equipment after retrieval is completed. The estimates are based on knowledge of tank farm inventories as of September 1, 2014. Current knowledge includes waste volume measurements and estimates, analysis of tank samples, and process knowledge estimates of tank waste composition, as well as analysis of tank waste residuals for tanks retrieved as of September 1, 2014. Projected residual estimates are the assumed amount of waste and the composition of waste that will remain in tanks and ancillary equipment after retrievals are completed. Detailed summaries of current inventories and projected residual estimates in tanks and ancillary equipment after closure are provided in Appendices B through D of RPP-RPT-42323, Rev. 2. An updated version of this report that considers the current state of retrieval at WMA C is in preparation.

6.1.2 Secondary Sources – Contaminant Inventory Released to Vadose Zone

Secondary sources include environmental media, such as soil and groundwater that have been impacted by the releases from primary sources. Liquid wastes were discharged through unplanned releases from tank leaks and overfills, unplanned releases to the ground surface, and planned releases to engineered structures such as the French drains. Information about the formation of and contaminant inventory associated with secondary sources is presented in Section 3.7 of this document. The release estimates were developed and documented in Revision 2A of RPP-ENV-33418. RPP-ENV-33418 was prepared in accordance with the process and conditions outlined in RPP-RPT-32681, *Process to Assess Tank Farm Leaks in Support of Retrieval and Closure Planning*. A summary of waste release volumes and inventories of selected constituents is provided in Table 3-5 of this RFI report.

The secondary sources retain sufficient levels of contaminants such that they will act as continuing sources of contamination to the soil, groundwater, or air. The nature and extent of contamination associated with secondary sources (i.e., contaminated environmental media) are discussed in Section 5 of this document.

6.2 APPROACH TO THE ASSESSMENT OF CONTAMINANT FATE AND TRANSPORT

This section provides an overview of the approach to and methodologies being used for the assessment of contaminant fate and transport from sources at WMA C. The content of the WMA C performance assessment (the IPA) is driven in large part by the regulatory requirements outlined in HFFACO Action Plan Appendix I and DOE O 435.1.

Section 2.5 of HFFACO Action Plan Appendix I states:

> *Ecology, as the lead agency for SST system closure, EPA, and DOE have elected to develop and maintain as part of the SST system closure plan <u>one performance assessment</u> for the purposes of evaluating whether SST system closure conditions are protective of human health and the environment for <u>all contaminants of concern</u>, both radiological and non-radiological. DOE intends that this performance assessment (PA) will document by reference relevant performance requirements defined by RCRA, HWMA, Clean Water Act, Safe Drinking Water Act, and the Atomic Energy Act of 1954 (AEA) and any other performance requirements that might be ARARs under CERCLA. <u>The PA is of larger scope than a risk assessment</u> required solely for non-radiological contaminants. The PA is expected to provide a single source of information that DOE can use to satisfy potentially duplicative functional and/or documentation requirements. <u>A PA will be developed for each WMA</u> and will incorporate the latest information available. These PAs will be approved by Ecology and DOE pursuant to their respective authorities. For Ecology approval means incorporation by reference, into the Site-Wide Permit through the closure plans.*

> *As individual components are retrieved or characterized, or other component closure activities are completed, the resulting component characterization information will be incorporated into the WMA PA to determine its relative risk compared to the entire WMA performance. In doing this, the Parties will be able to make interim closure decisions for individual components. Initially, the WMA PA will be based on assumptions and available data describing component characterization information. As each WMA proceeds toward closure, its respective PA will be updated to address all pertinent new results and findings – and will, as a minimum, incorporate the following results as they become available: actual volumes of tank waste residuals left after retrieval, results of leak investigations, new geologic and ancillary equipment waste characterization information, and the results of new barrier and tank residual stabilization and fill performance studies and tests. Final WMA closure decisions will be made after all components are retrieved and/or characterized, and all other component closure activities have been completed and a final WMA PA is completed.*

Note: Underlining is added to emphasize key points influencing the scope of the IPA.

Based on the regulatory requirements outlined above, the closure performance assessment (the IPA) for WMA C will contain two major components: (1) a baseline risk assessment, and (2) an assessment of long-term risk associated with contamination assumed to remain in WMA C primary sources under anticipated closure actions. The long-term risk assessment will include an analysis of the fate and transport of contaminants from secondary sources as a scoping analysis as described in Section 6.4.

An extended discussion of the regulatory requirements and other elements of the assessment context are presented in RPP-RPT-41918, *Assessment Context for Performance Assessment for Waste in C Tank Farm Facilities after Closure.*

6.2.1 Assessment of Baseline Risk Based on Site Characterization Data

The WMA C IPA includes a baseline risk assessment that evaluates human and ecological risks associated with current conditions at WMA C. The baseline risk assessment, which is summarized in Section 7, presents the risks from releases of hazardous substances to the environment in the absence of any actions to control or mitigate these releases. A baseline risk assessment must be completed at contaminated waste sites prior to remediation activities to establish a need for action. A baseline risk assessment is also used to determine cleanup levels and assess the performance of remedial actions against the cleanup levels.

6.2.1.1 Assessment of Direct Contact Exposure Impacts. A discussion of the approach to and methodology for the assessment of direct contact exposure impacts is provided in Section 7. Within this assessment, soil concentrations are evaluated against a variety of direct contact exposures using reasonably anticipated future land use scenarios.

WMA C will be under Federal ownership for the foreseeable future, and managed as an industrial area with restricted access and various institutional controls. Reasonably anticipated future land used scenarios include the following:

- Industrial Worker
- Industrial Worker under MTCA Method C
- Construction Worker
- Maintenance/Surveillance Worker
- Trespasser (Adult/Youth).

The baseline risk assessment provides additional information for risk management through the evaluation of a residential scenario and the evaluation of a resident under MTCA Method B. Additionally, Native American Scenarios (Harris, 2004; Harris, 2008; Ridolfi, 2007) are included to support risk-informed decisions

6.2.1.2 Assessment of Groundwater Impacts. Soil concentrations for groundwater protection are calculated for non-radiological constituents using the WAC 173-340-747 "Fixed Parameter Three-Phase Partitioning Model." Soil concentrations protective of groundwater are back calculated from a protective groundwater concentration. The protective groundwater concentration is multiplied by a dilution factor that represents the reduction of soil leachate concentration caused by mixing the aquifer, and then a standard linear equilibrium soil/water partitioning equation is used to calculate a soil concentration corresponding to the adjusted groundwater concentration.

Soil concentrations of non-radiological contaminants in soil are compared to the WAC 173-340-747 groundwater protection values in Section 7.1 of this RFI report. The fixed parameter three-phase equation is based on conservative, simplifying assumptions about the release and transport of contaminants in the subsurface.

As a part of the WMA C IPA, the site specific numerical model(s) being developed to support the evaluation of human health and environmental impacts from residual wastes assumed to remain in tanks and equipment after closure will also be used to evaluate the potential impacts of soil contamination on groundwater. Results of these analyses will be included in anticipated updates of the baseline risk assessment (RPP-RPT-58329).

6.2.2 Assessment of Human Health and Environmental Impacts from Residual Wastes Left in Tanks and Equipment

The second component of the WMA C IPA is an initial assessment of long-term performance of WMA C assuming implementation of anticipated closure actions. This analysis addresses the requirements of HFFACO Action Plan Appendix I and DOE O 435.1. This long-term performance assessment will evaluate potential human health and environmental impacts that could be associated with contaminants that are assumed to remain in WMA C primary sources under anticipated closure actions. This assessment will also include evaluation of potential impacts of secondary sources of contamination as part of a scoping analysis.

6.2.2.1 Performance Objectives and Measures. The performance objectives and measures for the analysis of tank waste residuals comprise a combination of DOE O 435.1, RCRA closure requirements, and Ecology requirements, as shown in Table 6-1. Water resources protection and soil concentration performance objectives are determined from State and EPA regulations. All pathways, air pathway, radon release, water resources protection, and hypothetical inadvertent intrusion are areas for performance objectives determined from DOE O 435.1. Details of the performance objectives are presented in RPP-RPT-41918.

Table 6-1. Exposure Scenarios, Performance Objectives and Measures, and Points of Assessment for the WMA C Performance Assessment.

Exposure Scenario	Performance Objective and Measures	Point of Assessment	
		Operational and Active Institutional Control Periods [e]	Post-Institutional Control Period
All pathways	25 mrem/yr [a]	Facility boundary	100 m [c]
Air pathway	10 mrem/yr [a]	Facility boundary	100 m [c]
Radon	20 pCi/m^2/s	Flux rate at facility surface	Flux rate at facility surface
	0.5 pCi/L [b]	Facility boundary	100 m [c]
Water Resources	Ecology requirements on concentration	At the source and 100 m [cd]	100 m [c]
Chemical Toxicity	Ecology and RCRA Closure requirements on risk	At the source and 100 m [cd]	100 m [c]
Soil Concentrations	Ecology MTCA requirements	Soil concentrations in the first 15 ft below ground surface	Not applicable
Intruder	100 mrem/yr Chronic [a, f]	Not applicable	Facility
	500 mrem Acute [a, f]	Not applicable	Facility

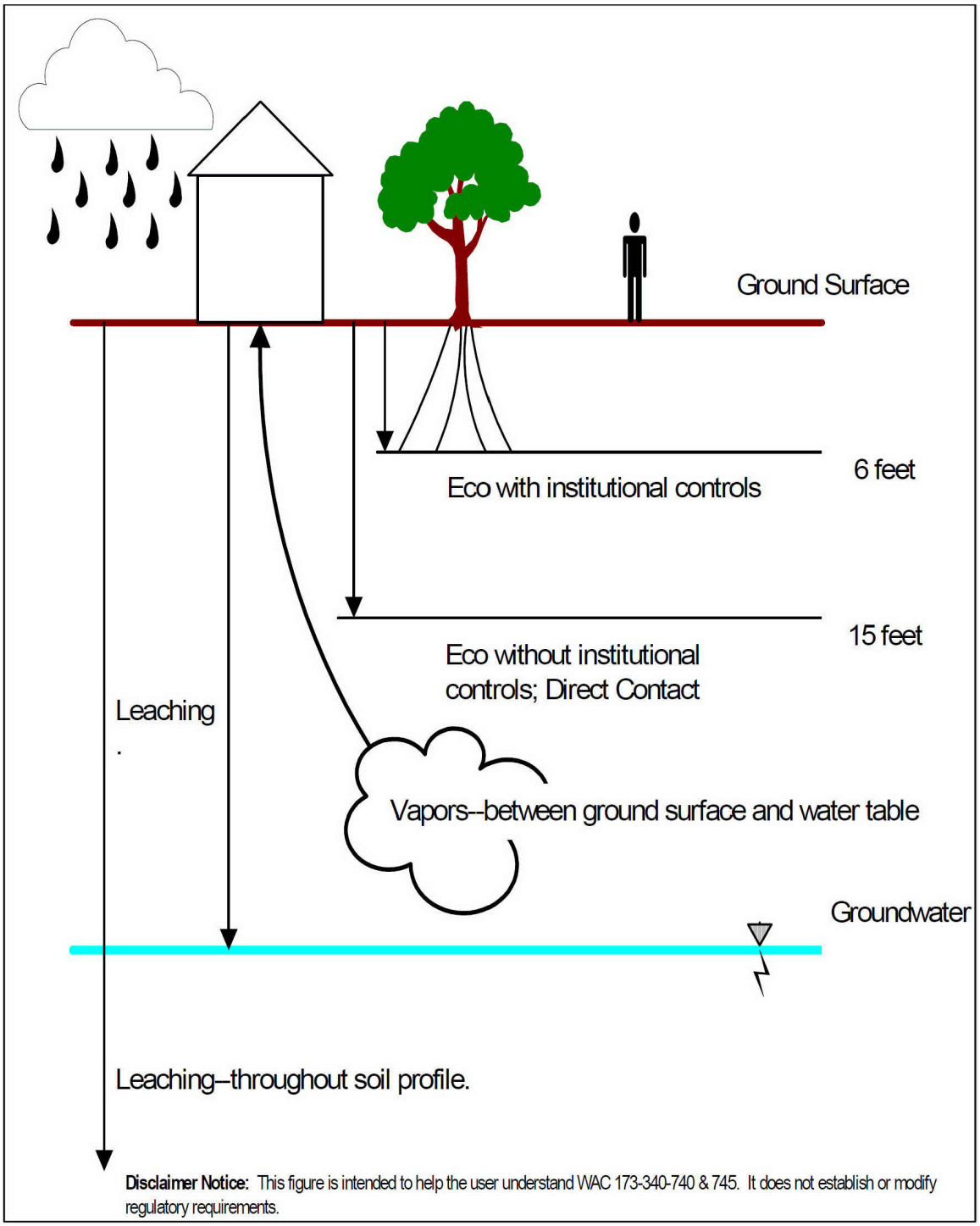
[a] Excluding radon in air (DOE O 435.1).
[b] Alternate radon Performance Objective (DOE O 435.1).
[c] The point of highest projected dose or concentration beyond a 100- meter buffer zone surrounding the disposed waste per DOE O 435.1.
[d] Concentrations found in tank residuals, ancillary equipment, and soils, will be compared against the standard MTCA three-phase model for hazardous constituents.
[e] The active institutional control period includes final closure.
[f] Performance Measure (DOE O 435.1).

6.2.2.2 Point of Assessment and Timing Assumptions. The TC&WM EIS Record of Decision for landfill closure of SSTs was published in the Federal Register on December 13, 2013. The presumed landfill closure of WMA C is assumed to occur at year 2020, at which time the tanks are assumed to be filled with grout and covered with a final closure cover. The post-closure care of the site is driven by both WAC-173-303-610 (7), "Post-closure Care and Use of Property," and WAC-173-303-610 (8), "Post-closure Plan; Amendment of Plan," along with DOE O 435.1. The point of assessment and timing assumptions are consistent with the requirements of DOE O 435.1 and the HFFACO. It is assumed for the purposes of the IPA that institutional control and societal memory are retained for the following 100 years, based on the standard DOE O 435.1 requirement for inadvertent human intrusion. It should be noted that WAC 173-303-610 has post-closure care extending 30 years after closure; however, Ecology can "...extend the post-closure care period applicable to the dangerous waste management unit or facility if it finds that the extended period is necessary to protect human health and the environment" (WAC-173-303-610 (7)(b)(ii)). The points of compliance differ between WAC-173-340 and DOE O 435.1. The points of compliance under WAC 173-340-740 are given in Figure 6-1 for soils. The point of compliance under DOE O 435.1 (radionuclides) for all pathways and groundwater protection analyses is 100 m (30.5 ft) from the down-gradient boundary of WMA C. To ensure consistency in the modeling analysis, hazardous chemicals will also be evaluated at this point. The concentrations used for compliance are the peak concentrations in groundwater at that distance from WMA C, calculated across a spatial plane at 100 m (31 ft) down gradient of the C Farm fenceline.

6.2.2.3 Assessment Period. Neither WAC-173-303-610 nor WAC-173-340-740 provide a compliance time period for evaluating dangerous waste left at a waste site. DOE O 435.1 requires that a performance assessment assume a compliance time period of 1,000 years after closure. Longer timeframes (10,000 years) are included in the analysis per U.S. Nuclear Regulatory Commission (NRC) guidance (NUREG-1854, *NRC Staff Guidance for Activities Related to U.S. Department of Energy Waste Determinations – Draft Final Report for Interim Use,* Section 4.1.1.1) and as a sensitivity and uncertainty analysis component per DOE O 435.1 to provide information to decision makers about potential long-term doses, but doses after 1,000 years need not be directly compared with performance objectives for compliance with the DOE Order. The closed WMA C is assumed to remain under institutional control for a period of 100 years after closure, at which time control and memory of C Farm is assumed to be lost. This assumption is applied solely for the purpose of evaluation of compliance with inadvertent human intrusion criteria in DOE O 435.1, and does not represent a DOE intent to release C Farm in the future (DOE P 454.1, *Use of Institutional Controls*).

6.2.2.4 Modeling Approach. As stated in Section 6.2.1.2 the default method for evaluating dangerous waste impacts to groundwater is WAC-173-340-747(a) "Fixed Parameter Three-Phase Partitioning Model." However, under WAC-173-340-747(8), "Alternative Fate and Transport Models," are allowed for the evaluation of dangerous waste impacts to groundwater, provided the fate and transport modeling meets the requirements listed under WAC-173-340-747(8). Both methods will be used to evaluate the impacts of dangerous waste, which remains in WMA C after closure, on groundwater. This section briefly describes the modeling approach. This approach was presented to Ecology, EPA, NRC, and the stakeholders during the Numerical Modeling working session held in January 2011.

Figure 6-1. Point of Compliance for Soils under WAC 173-340-740 and -745



Source: Figure 7 from Ecology Focus Sheet 01-09-071

The IPA modeling analysis of waste residual inventories is being conducted using complementary approaches, including both deterministic and probabilistic approaches for simulating contaminant releases to groundwater. Deterministic analyses use detailed

representations of the geological system that are implemented in the Subsurface Transport Over Multiple Phases (STOMP[1]) computer model, so that influences of relevant features and processes on water flow and radionuclide transport in groundwater can be evaluated. However, the model for evaluating flow requires significant computational time, limiting its ability to fully address parameter uncertainties using Monte Carlo analyses. As a result, the deterministic analyses are augmented using probabilistic analyses for an abstracted model of the groundwater system. The abstracted model, implemented in GoldSim[2], will use probability density functions to represent the uncertainty in input parameters and demonstrate their influence on contaminant transport predictions. Consistency between the probabilistic GoldSim-based system model and the physically-based STOMP model is achieved through an abstraction process, in which the STOMP flow fields are used as inputs to the GoldSim-based model. This approach assures consistency between the flow field calculated using STOMP and the flow field needed by GoldSim.

The abstraction approach assures that, for a specific set of input parameters for flow, the flow field in both models is consistent, differing only in the discretization of the two models. This approach is extended to support probabilistic analyses as follows. A set of STOMP analyses are conducted for a discrete set of combinations of input parameters, selected to span the range of values in the input parameters. The outputs from these flow analyses are used to construct a response surface representation of the flow for the full range of input parameters. This response surface is constructed by interpolating between the STOMP-calculated flow rates to give an approximation to the flow field for the full range of input parameters. The response surface is then used in the probabilistic analyses by sampling the input parameters, and using the response surface to represent the flow field for the sampled input parameters. The focus of the work to date has been on developing a credible set of deterministic analyses that will be extended to probabilistic analyses in FY 2015. The full ranges of input parameters that will be used in the probabilistic analysis are yet to be defined.

6.3 CONCEPTUAL MODEL(S) OF CONTAMINANT FATE AND TRANSPORT

The National Research Council in *Conceptual Models of Flow and Transport in the Fractured Vadose Zone* (National Research Council 2001) defines a conceptual model as "… an evolving hypothesis identifying the important features, processes, and events controlling fluid flow and contaminant transport of consequence at a specific field site in the context of a recognized problem." Furthermore, Dr. Eileen Poerter (Colorado School of Mines), while giving the 2006 Darcy Lecture for the National Groundwater Association, recommended using "multiple working hypotheses" (alternative conceptual models) when studying complex geohydrologic systems. This section provides an overview of the alternative conceptual models supporting the DQO process for the Phase 2 characterization data needed for the WMA C CMS. As more data are collected during the Phase 2 characterization activities, these conceptual models will be updated and revised as necessary.

[1] STOMP is copyright by Battelle Memorial Institute, Richland, Washington.
[2] GoldSim is copyright by GoldSim Technology Group, Issaquah, Washington.

As described in Section 3.3 of RPP-PLAN-39114, Rev. 2, multiple alternative conceptual site models were developed to identify the important features and processes controlling contaminant transport at WMA C. These models address the contaminant inventory and release mechanisms; the subsequent migration, including driving forces, that move contaminants; and the subsurface stratigraphy through which the contaminants move.

Five primary conceptual models were developed and described as part of the FIR for WMA C (RPP-35484) and the DQO report for the Phase 2 characterization activities (RPP-RPT-38152). This set of models includes input from the Nez Perce Tribe.

These five conceptual models are as follows:

- Alternative 1: Phase 1 Conceptual Model (Alternative 1 Model)
- Expanded Phase 1 Conceptual Model Accounting for Additional Recharge (Additional Recharge Model)
- Alternative 2: Movement of Contaminants Down Stratigraphic Dip Conceptual Model (Lateral Flow Model)
- Alternative 3: Preferential Pathways Conceptual Model (Preferential Pathways Model)
- Alternative 4: Unknown Leak Event Conceptual Model (Unknown Leak Model).

These conceptual models are illustrated in Figures 6-2 through 6-6 and are briefly described below. A complete discussion of the development of each model is provided in Section 9.3 of RPP-RPT-41918.

These conceptual models were factored into the selection of Phase 2 sampling locations as described in RPP-PLAN-39114, Rev. 2. It was expected that high concentrations of mobile contaminants (i.e., ^{99}Tc, nitrate) chemicals would be found in the vadose zone at the direct push sites. This was not the case. This may indicate sample locations were not placed within a footprint of a contaminant plume (i.e., the difficulty of sampling 4 to 7 hectares [9 to 16 acres] with a 5.1 cm [2 in.] direct push). However, high concentrations of ^{99}Tc in groundwater have been found just south of WMA C in groundwater wells 299-E27-23, 299-E27-155, 299-E27-21, and 299-E27-4. This suggests the ^{99}Tc plume may have already reached the groundwater before the sampling took place. As part of the IPA, a scoping analysis will be conducted to evaluate the potential impacts of multiple variables on the movement of contaminants to the groundwater. Using numerical models, all five conceptual models will be compared to the WMA C Phase 2 RFI findings to see if one or more of them account for the contaminant distribution(s) found. Based on the outcome of the scoping analysis, the numerical model(s) may be modified as required to better fit the observed contaminant distributions. The resulting numerical model(s) that will be evaluated in the WMA C IPA are expected to include elements of one or more of the five conceptual models.

Figure 6-2. Alternative 1: Phase 1 Conceptual Model

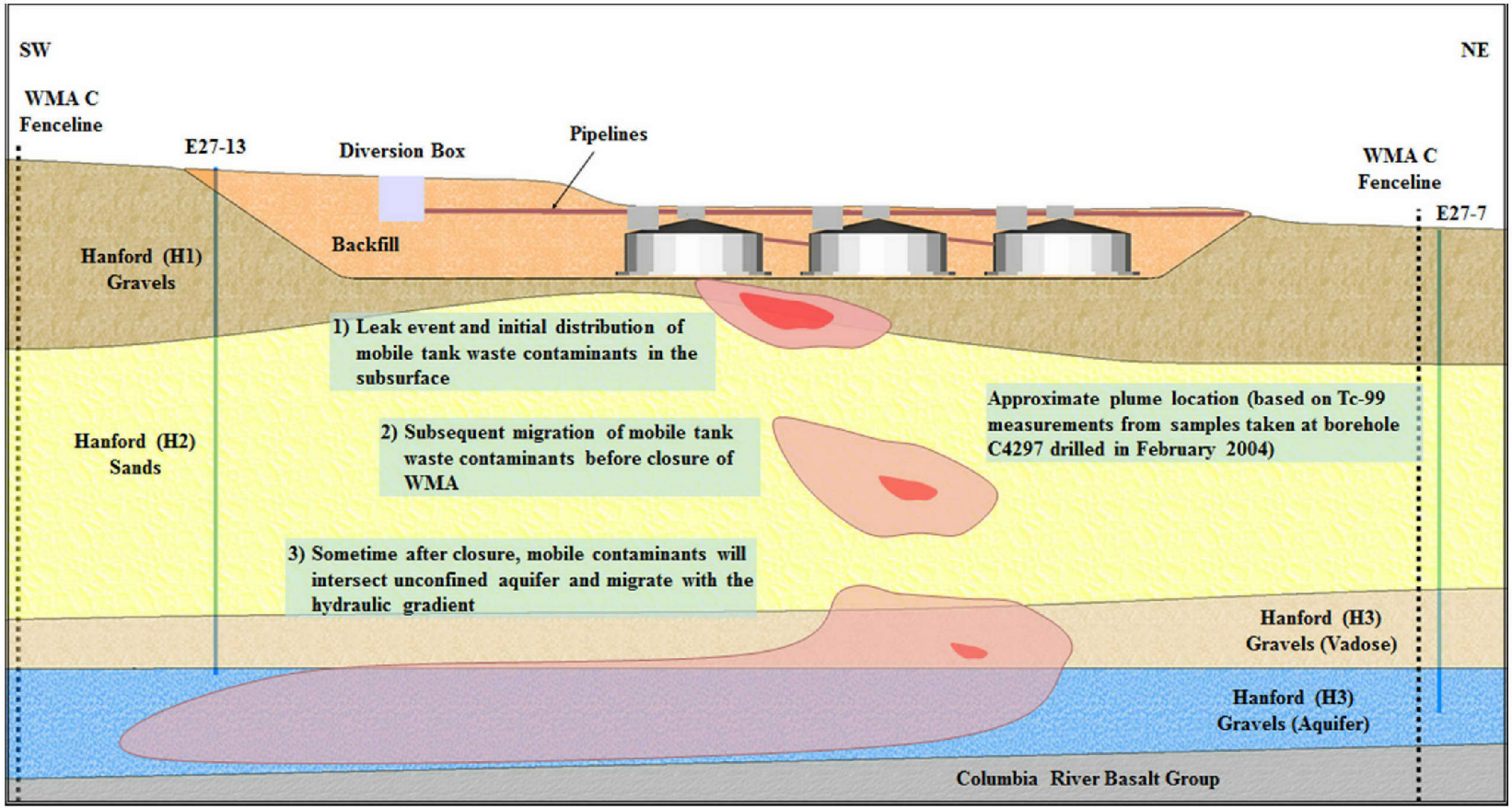


Figure 6-3. Expanded Phase 1 Conceptual Model Accounting for Additional Recharge

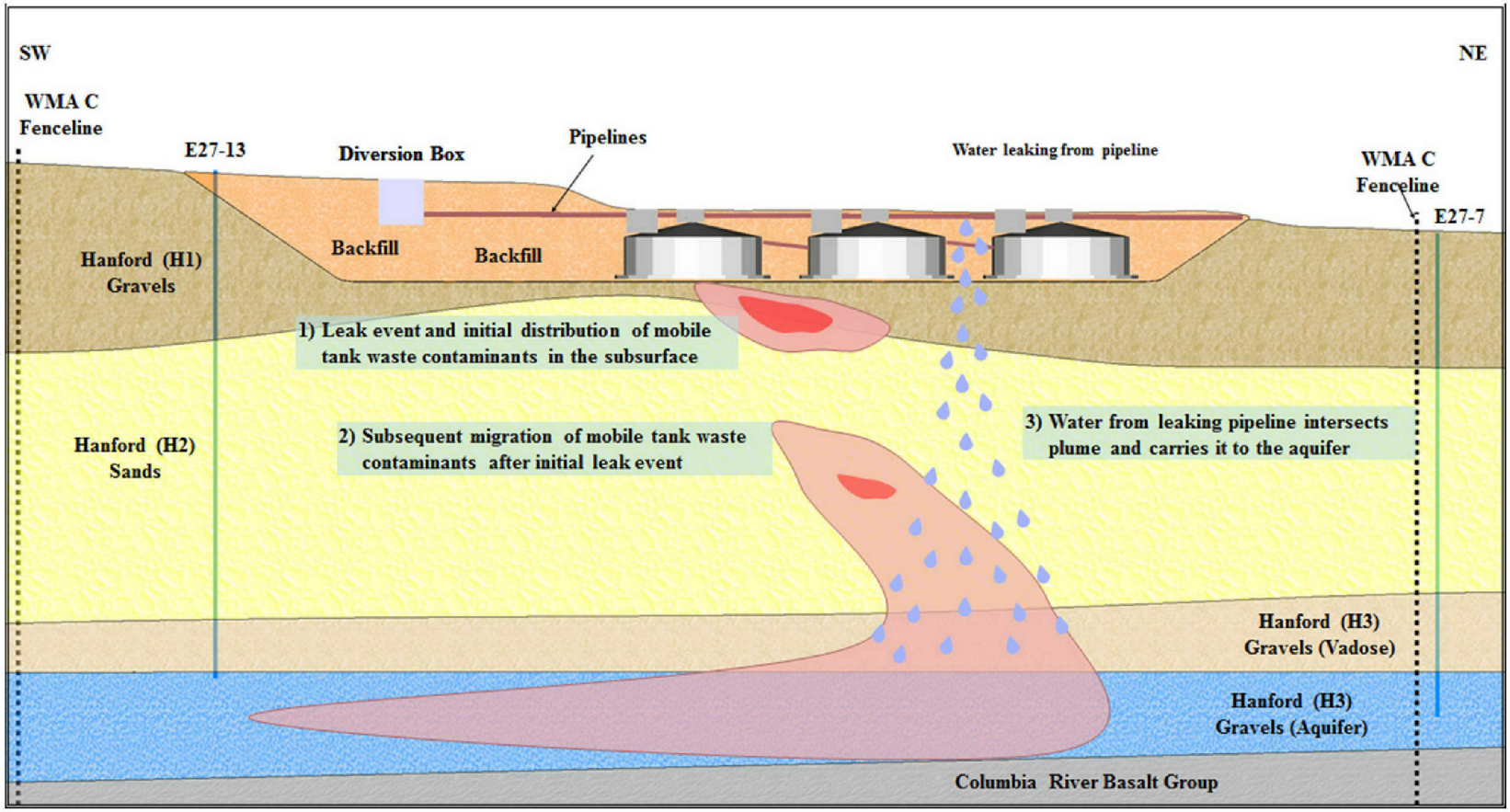


Figure 6-4. Alternative 2: Movement of Contaminants Down Stratigraphic Dip Conceptual Model

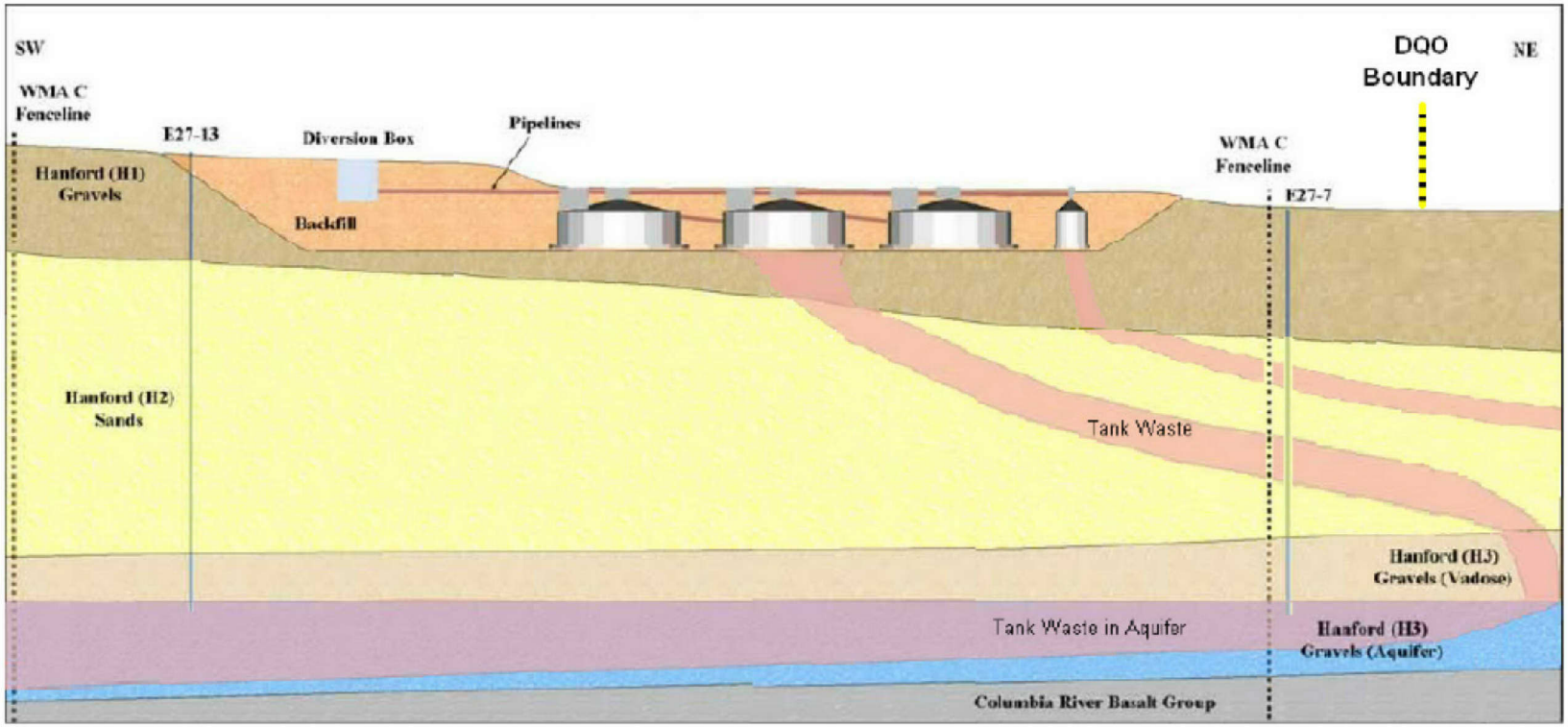


Figure 6-5. Alternative 3: Preferential Pathways Conceptual Model

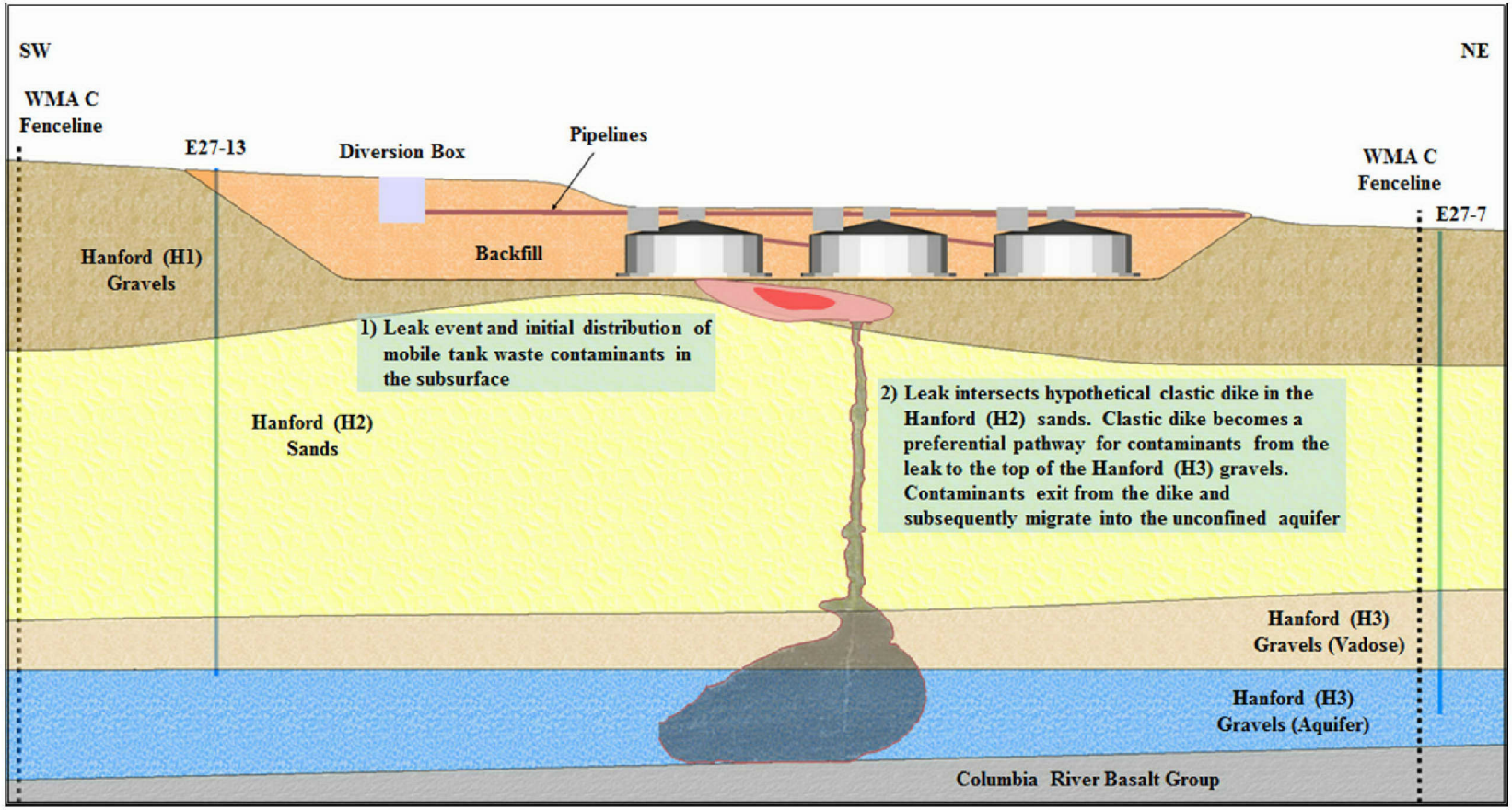
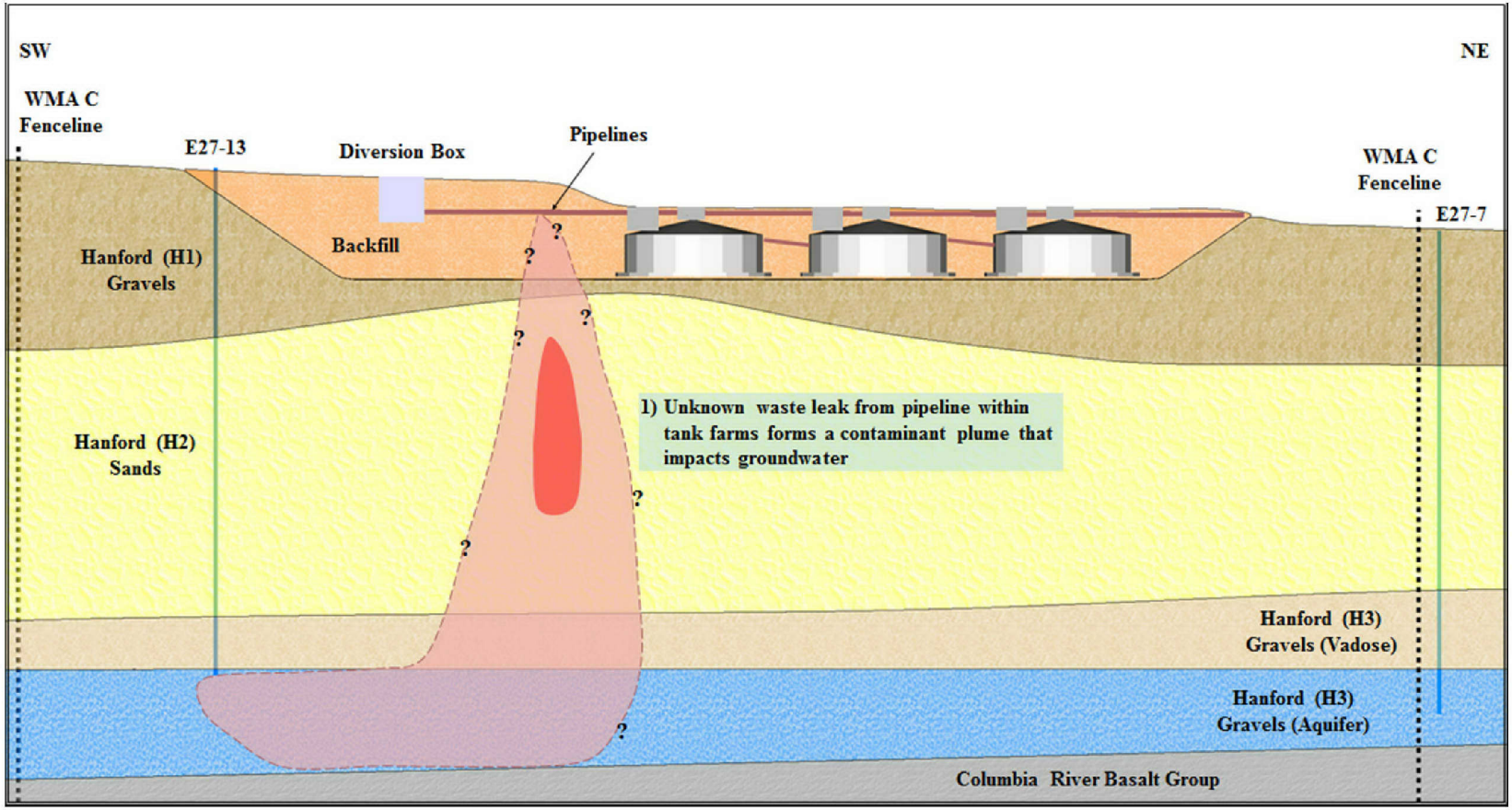


Figure 6-6. Alternative 4: Unknown Leak Event Conceptual Model



6.3.1 Alternative 1 Model and Initial Numerical Model Alternatives

The Alternative 1 Model contains the framework for the base WMA C conceptual model; the remaining four primary conceptual models incorporate variations on selected elements of the Alternative 1 Model. This base conceptual model reflects information gained during the Phase 1 investigation of WMA C.

Ultimately, the WMA C conceptual models will inform the development of one or more numerical models that will be run as a part of the WMA C IPA to generate estimates of long-term performance of the closed WMA C. Initial development of the numerical models is already underway and is discussed in Section 6.3.1.2. The numerical model(s) incorporate additional information gained during the Phase 2 characterization and will incorporate information that becomes available as the scoping analysis is performed to evaluate the different model elements.

6.3.1.1 Alternative 1 Model. The Alternative 1 Model (Figure 6-2) assumes an initial leak event. In the modeled scenario, the leaked waste fluids increase the moisture content of the soils and change the local geochemical conditions. The waste fluids are distributed through a local volume of the vadose zone until the moisture conditions are restored to the pre-leak conditions. Due to the unsaturated flow and lateral migration processes that affect the distribution of the excess moisture, the waste contacts an expanded vadose zone volume relative to the initial volume occupied by the released waste.

As identified in Section 5.6, chemical reactions take place between the tank waste fluid and the vadose zone soil and water system as the fluids are re-distributed in the vadose zone. Some of the important reactions include neutralization of the high pH conditions typical of tank waste fluids and precipitation or sorption of reactive contaminants onto soil surfaces in the surrounding sediments. Specific contaminants can show variable distribution in the vadose zone volume contacted by the waste, depending on their reactivity. Maximum outward/downward movement typically occurs with non-reactive and mobile constituents (e.g., ^{99}Tc and nitrate).

After the initial waste fluid release and distribution in the vadose zone, vertical and lateral migration continues. Now migration is driven by local recharge conditions, and chemical reactions can continue, depending on the ambient conditions. The model incorporates a general observation that only non-reactive to slightly reactive contaminants (primarily nitrate and ^{99}Tc, with ^{60}Co, chromium, and uranium to a lesser extent, if present) migrate. The exception to this observation is at Tank SX-108, where high sodium concentrations in the tank waste have been observed to lead to enhanced ^{137}Cs mobility (RPP-7884, *Field Investigation Report for Waste Management Area S-SX*).

6.3.1.2 Initial Numerical Model Alternatives. Two numerical (digital) geologic models, for the general area of WMA C, will be used in the long-term assessment of the performance for closure at WMA C. The development of these models is summarized in RPP-RPT-56356. Over the past 15 years, the geologic strata underlying WMA C has been characterized in conjunction with soil sampling and borehole logging for radionuclides and hazardous waste constituents. The borehole and geologic logging has been used to identify the elevations of tops of the

geologic units in the vicinity of WMA C. This information has been used to create two alternative geologic models of WMA C.

The first digital geologic model (Geologic Model I) is primarily based on interpretations by WRPS and its subcontractors that consider the following sources of information.

- Geologic interpretations of geophysical logs in selected drywells, boreholes, direct pushes, and groundwater wells in the vicinity of WMA C by Kent Reynolds of Energy*Solutions*, Inc. These interpretations are summarized in FS-NW-LT-5367, "Submittal of C Farm Geology/Geophysics *[sic]* Review, Task 26," a letter report prepared by Energy*Solutions* for WRPS in 2010. This project letter report was provided in its entirety in Appendix A of RPP-RPT-56356.

- Geologic interpretations from more recent direct push completion reports that contain information on interpreted elevations of tops of geologic units from geophysical logs of direct push locations developed after completion of Letter Report FS-NW-LT-5367. These interpretations were also provided to WRPS by Kent Reynolds of Energy*Solutions*, Inc.

- Geologic interpretations provided for selected groundwater wells in the vicinity of WMA C that were not included in the Energy*Solutions* 2010 report. For these specific wells, the information came from other published reports identified in Section 3.1 of RPP-RPT-56356.

The second geologic model (Geologic Model II) is primarily based on the interpretations made by Dr. Stanley Sobczyk of the Environmental Restoration & Waste Management Program of the Nez Perce Tribe. Dr. Sobczyk provided a spreadsheet to WRPS in July 2013 containing basic data and information associated with his interpretations of the tops of the same geologic units in many of the drywells, boreholes, direct pushes, and groundwater wells identified in Letter Report FS-NW-LT-5367 for the WMA C area. In constructing this digital geologic model, the information supplied by the Nez Perce Tribe was supplemented with tops of the geologic units provided in the Hanford Site GeoContacts Database[3] for other selected wells used in the Geologic Model I. These wells are located outside of WMA C. The original sources of the interpretations for these wells are cited in Section 3.1 of RPP-RPT-56356.

6.3.2 Additional Recharge Model

The groundwater monitoring data from wells south of WMA C, and near the fencelines of other tank farms, indicate that some tank waste has reached the aquifer in specific locations. High, and variable, ^{99}Tc concentrations in particular are noted. Thus, the Alternative 1 Model must be expanded to account for these observations. Enhanced recharge, from a variety of events or

[3] The Hanford Site GeoContacts Database is maintained and updated via the CH2M HILL Plateau Remediation Company Environmental Program and Strategic Planning – Risk and Data Integration Task. Contact for authorized access is provided by William Webber at William_D_Webber@rl.gov.

processes, as described in Section 2.4, is needed to account for the observation of specific contaminants in the groundwater. The Additional Recharge Model incorporates enhanced recharge encountering tank waste in the vadose zone with subsequent transportation of tank waste to the unconfined aquifer (Figure 6-4).

6.3.3 Lateral Flow Model

This alternative conceptual model (Figure 6-3) was proposed by the Nez Perce Tribe, and was developed by Dr. Stan Sobczyk. Dr. Sobczyk correlated transport of ^{60}Co from spectral gamma measurements at WMA C with stratigraphic dip to the northeast in this area. This model includes primarily vertical migration through the backfill and H1 gravels, with primarily lateral migration through the H2 sands following stratigraphic dip, followed by primarily vertical migration through the lower H2 and H3 gravels until reaching the groundwater. Once reaching the groundwater, the tank waste is denser and sinks in the aquifer.

6.3.4 Preferential Pathways Model

This alternative model (Figure 6-5) addresses the possibility of the effect of preferential pathways as a factor in water movement and waste transport in the vadose zone. The two features most frequently proposed for this at the Hanford Site are poorly constructed wells and clastic dikes. Poorly constructed wells are expected to be associated with larger void spaces and, thus, allow for a greater migration rate. As noted in Section 2.4, almost all C Farm drywells reach bottom well above the groundwater, having depths of around 31 m (100 ft) bgs. Therefore, it is unlikely a drywell within WMA C could provide a preferential pathway all the way to groundwater. Nearby groundwater monitoring wells could have provided a pathway all the way to the aquifer by allowing contaminants to move vertically downward between the casing and the surrounding media. While a clastic dike can possibly increase the flow rate, they are very small scale features and the cross-sectional area of the intersection of a clastic dike with a large segment of leaked waste would be small, if they are a factor at WMA C.

6.3.5 Unknown Leak Model

Figure 6-6 accounts for the possibility of an undetected leak from a waste pipeline that might have occurred within the tank farm. The movement of contaminants could follow one of the previous transport model alternatives.

6.4 SCOPING ANALYSIS FOR ALTERNATIVE CONCEPTUAL MODELS FOR PAST RELEASES

Because of the uncertainty associated with past waste releases at WMA C, the analysis of impacts of past waste releases from WMA C will use a two-step approach. The first step will be to perform a scoping analysis of impacts of past waste releases that will attempt to identify key elements of the various alternative conceptual models that could have played a role in the impacts to groundwater from releases from WMA C. The results of this scoping analysis will

provide a basis for the evaluation of potential future impacts from past waste releases using the site-specific model(s) of WMA C.

This planned evaluation of releases will initially make of use of the numerical models of WMA C that will be used for the tank residuals, introduced in Section 6.3.1.2 and further described in Section 6.5, based on the STOMP code. These initial digital models will be used to perform a set of scoping simulations that will examine the uncertainties on key model parameters that could influence the observed groundwater impacts of past tank leaks in the vicinity of tanks. The digital model(s) of WMA C will be modified as appropriate to account for large influxes of waste liquids or anthoprogenic water that have occurred in the past. The key factors that will need to be evaluated include:

- The potential effects of additional anthropogenic recharge during the period of operations. This set of scoping calculations examines the key element(s) postulated to occur under the Additional Recharge Model modified to account for the effects of additional recharge.

- The possible role of heterogeneities in the hydraulic properties of vadose zone sediments in causing lateral flow and transport. This set of scoping calculation examines the key element(s) postulated to occur under the Lateral Flow Model modified to account for the effects of movement down the stratigraphic dip in the vadose zone sediments.

- The potential effects of preferential pathways in the downward migration of past leaks and losses to groundwater. This set of scoping calculations examines the key conceptual model element(s) postulated to occur under the Preferential Pathways Model modified to account for the effects of movement down preferential pathways in the vadose zone sediments.

- The possible impacts of the uncertainties in the estimated timing of leaks, leak volumes, and estimated inventories. This set of scoping calculations examines the key conceptual model element(s) postulated to occur under the Unknown Leak Model modified to account for the effects of the uncertainty in waste releases to the vadose zone sediments.

Prior to defining the number and range of model cases to consider in the scoping analysis, this evaluation will examine:

- Estimates of the timing of leaks, leak volumes, and leaks inventories available in the current version of RPP-RPT-42294, *Hanford Waste Management Area C Soil Contamination Inventory Estimates*. An update of this data package is expected to be completed by the end of December 2014.

- Historic groundwater monitoring measurements, interpreted groundwater plumes, and estimated arrival of key contaminants of concern as possible metrics to consider in the scoping.

- Possible ranges of effective recharge and hydraulic properties.

The results of the WMA C scoping analysis will be used to define a set of model simulations that will be used to evaluate and project into the future the potential effects of past waste releases at WMA C. Results of the projected impacts of waste releases at WMA C will be combined with results from complimentary modeling efforts being undertaken as part of the 200-BP-5 OU groundwater remedial investigation to evaluate possible impacts from sources at and up gradient from WMA C. The results of both these sets of analyses will eventually be combined and compared to the predicted impacts from residual waste assumed to remain in the C Farm tanks and equipment after closure, which will be evaluated in the IPA process. These combined results will be summarized in a single document.

Planning for FY 2015 and 2016 includes the following scoping analysis-related activities.

- Perform scoping analysis of impacts of past waste releases.
- To support WMA C IPA working sessions related to impacts of past leaks, prepare presentations that summarize the combined results of the WMA C scoping analysis and the 200-BP-5 OU remedial investigation modeling work.
- Prepare a technical document that summarizes the results of the WMA C scoping analysis, the results of 200-BP-5 OU remedial investigation modeling work, and the combined results of the forward predictions of past leaks and impacts of residual waste assumed to remain in the C Farm tanks and equipment after closure.

6.5 CURRENT IMPLEMENTATION OF NUMERICAL MODELS FOR EVALUATING CONTAMINANT FATE AND TRANSPORT FOR TANK RESIDUALS

DOE/RL-2011-50, Rev. 0, contains the description of the generalized models, conditions, and parameters applicable to the Hanford Site vadose zone, which were refined and augmented for the WMA C IPA evaluation (e.g., RPP-RPT-44042; RPP-RPT-42323, and RPP-RPT-46088). The site-specific conceptual model components for the WMA C IPA evaluation are as follows:

- Model domain and boundary conditions (Section 6.5.1)
- Hydrogeologic information (Sections 6.5.2 and 6.5.3)
- Contaminant inventory (Section 6.5.4)
- Vadose zone flow and transport (Section 6.5.5)
- Recharge (Section 6.5.5.1)
- Groundwater flow and transport (Section 6.5.6)

Although the model domain and boundary conditions are not generally regarded as conceptual model elements, they are included in the list above to emphasize the fundamental nature of boundary conditions used in the modeling. The evaluation adopted modeling assumptions and parameter estimates appropriate for the WMA C site-specific conditions to determine the impacts to groundwater resulting from post-retrieval residual waste remaining in tanks and ancillary

equipment, in accordance with DOE O 435.1 requirements. Table 6-2 provides a summary of key elements and parameters for the conceptual model components.

Table 6-2. Summary of Key Elements and Denominator Case Parameters Associated with Site-Specific Model Components for WMA C[a]

Model Domain and Boundary Conditions	Rectangular Prism: 737.9 m (2,421 ft.) × 795.3 m (2,609 ft.) × 116 m (381 ft.) Prescribed flux across the top (recharge); no-flow along vertical side boundaries in the vadose zone; prescribed flux and head along the up-gradient and down-gradient vertical side boundaries in the aquifer, respectively; no-flow along the bottom of the model (aquifer). The prescribed volumetric water flux boundary condition is calculated to maintain mass conservation in the aquifer independent of recharge.

Geologic Setting	The WMA C cross-section includes the following anthropogenic or natural units that occur from surface to groundwater (RPP-RPT-56356, *Development of Alternative Digital Geologic Models of Waste Management Area C*, Rev. 0):
	• WMA C Backfill
	• Hanford formation H1 (gravel-dominated, generally identified as gravel or very coarse sand)
	• Hanford formation H2 Sand (sand-dominated facies generally identified as fining upward sequences of gravel, sandy/gravel to sand to very fine sand)
	• Hanford formation H3 (coarse-grained open framework gravel to sandy gravel; in the vicinity of WMA C is often referred to as undifferentiated H3/Cold Creek unit/Ringold Formation)
	• In Geologic Model II, the H2 Sand includes following two additional subunits:
	  o H2 Coarse (gravel/coarse-grained facies that underlies the H2 fines)
	  o H2 Silty Sand – (a silty sand unit that is only observed in deep groundwater wells, and a mappable unit may not be readily identified).

Groundwater Domain and Characteristics	WMA C post-closure water table elevation ~119.5 m NAVD88 and average hydraulic gradient ~0.00001 m/m Aquifer area along northwest cross-section boundary = 6,151.04 m^2 Aquifer area along southeast cross-section boundary = 13,997.55 m^2 Average aquifer area along all aquifer cross-sections = 9,439.56 m^2 Prescribed flux along northwest cross-section boundary (saturated K = 3,000 m/d); 3,000 m/d × 0.1000E-04 × 365.25 d/yr = 0.109575E+02 m/yr; 0.109575E+02 m/yr × 9,439.56 m^2 / 6,151.04 m^2 = 0.16816E+02 m/yr Prescribed head along southeast cross-section boundary = 119.495 m Groundwater thickness is ~12 m (39 ft) in the aquifer; groundwater concentrations evaluated for upper 5 m (16 ft) of the aquifer (rationale for aquifer depth presented in Section 6.5.6).
Source Term/ Inventory	WMA C Denominator Case inventory for ^{99}T, total uranium, and chromium (RPP-RPT-42323, *Hanford C-Farm Tank and Ancillary Equipment Residual Waste Inventory Estimates*): The total radionuclide inventory (Ci) is decayed to January 1, 2020.

Table 6-2. Summary of Key Elements and Denominator Case Parameters Associated with Site-Specific Model Components for WMA C[a]

<table>
<tr><td></td><td>
<table>
<tr><th>Source</th><th>Technetium-99 (Ci)</th><th>Total Uranium (kg)</th><th>Chromium (kg)</th></tr>
<tr><td>241-C-101</td><td>4.34E-02</td><td>5.16E+02</td><td>7.23E+00</td></tr>
<tr><td>241-C-103</td><td>4.48E-02</td><td>4.91E+01</td><td>2.38E+00</td></tr>
<tr><td>241-C-104</td><td>1.73E-01</td><td>7.50E+02</td><td>1.74E+00</td></tr>
<tr><td>241-C-106</td><td>1.64E-01</td><td>2.70E+00</td><td>3.78E+00</td></tr>
<tr><td>241-C-108</td><td>3.96E-02</td><td>9.84E+01</td><td>5.14E-01</td></tr>
<tr><td>241-C-109</td><td>7.50E-03</td><td>2.44E+01</td><td>1.51E-01</td></tr>
<tr><td>241-C-110</td><td>5.77E-02</td><td>2.60E+00</td><td>3.49E+00</td></tr>
<tr><td>241-C-201</td><td>2.63E-03</td><td>1.11E+02</td><td>1.22E+01</td></tr>
<tr><td>241-C-202</td><td>2.50E-03</td><td>9.88E+01</td><td>9.09E+00</td></tr>
<tr><td>241-C-203</td><td>2.32E-03</td><td>3.26E+02</td><td>2.60E+00</td></tr>
<tr><td>241-C-204</td><td>3.18E-03</td><td>2.43E+02</td><td>1.36E+00</td></tr>
<tr><td>241-C-102</td><td>3.56E-03</td><td>2.93E+02</td><td>1.13E+01</td></tr>
<tr><td>241-C-105</td><td>9.43E-01</td><td>2.39E+02</td><td>2.42E+00</td></tr>
<tr><td>241-C-107</td><td>4.02E-02</td><td>2.49E+02</td><td>2.07E+01</td></tr>
<tr><td>241-C-111</td><td>5.49E-02</td><td>5.38E+02</td><td>1.25E+01</td></tr>
<tr><td>241-C-112</td><td>2.00E-01</td><td>2.45E+03</td><td>7.33E+00</td></tr>
<tr><td>241-C-301</td><td>3.00E-02</td><td>5.93E+02</td><td>1.62E+01</td></tr>
<tr><td>CR-Vault</td><td>5.45E-02</td><td>1.08E+03</td><td>2.94E+01</td></tr>
<tr><td>Pipelines</td><td>4.61E-02</td><td>9.12E+02</td><td>2.49E+01</td></tr>
</table>

Diffusion controlled release from the grouted tanks and advection controlled release from the pipelines along with equilibrium sorption-desorption processes (i.e., K_d control).
</td></tr>
<tr><td>Vadose Zone Hydrogeology and Fluid Transport</td><td>Hydrogeologic properties for WMA C models derived and described in RPP-RPT-46088, Flow and Transport in the Natural System at Waste Management Area C, Rev. 1.

Aquifer Hydraulic Conductivity Horizontal to Vertical Anisotropy 10:1; Vadose Zone Hydraulic Conductivity Anisotropy allowed to vary as a function of the moisture content in accordance with the Polmann model (Polmann 1990, Application of Stochastic Methods to Transient Flow and Transport in Heterogeneous Unsaturated Soils).

Aquifer and Vadose Zone Dispersion Horizontal to Vertical Anisotropy 10:1

K_d-control for radionuclide transport</td></tr>
</table>

Table 6-2. Summary of Key Elements and Denominator Case Parameters Associated with Site-Specific Model Components for WMA C[a]

	Phase	Recharge on Surface (mm/yr [in./yr])			
		Natural Vegetation	Tank Farm Disturbed Surface	Non-Tank Farm Disturbed Surface*	Surface Barrier
Recharge	Pre-operations	3.5 [0.14]	NP	NP	NP
	Operations	3.5 [0.14]	100 [3.9]	22 [0.87]/63 [2.5]	NP
	First 100-years Post-Closure	3.5 [0.14]	NP	3.5 [0.14]	0.5 [0.02]
	Early Post-Closure (100 to 500 years)	3.5 [0.14]	NP	3.5 [0.14]	0.5 [0.02]
	Late Post- Closure (after 500 years)	3.5 [0.14]	NP	3.5 [0.14]	3.5 [0.14]
	Disturbed areas that allow vegetation are assigned 22 mm/yr [0.87 in. /yr]. Disturbed areas that are reworked such that vegetation does not grow are assigned 63 mm/yr [2.5 in. /yr].[b]				
Sorption Characteristics	Contaminant	Geologic Unit K_d (mL/g) Value			
		H1	H2*	H3	Backfill
	^{99}Tc(VII)	0.0	0.0	0.0	0.0
	U(VI), all isotopes	0.35	0.6	0.49	0.28
	Chromium	0.0	0.0	0.0	0.0

[a]The basis for the elements and parameter selection provided in the individual model components sections.
[b]Applies to all surfaces of this unit.
NAVD88, *North American Vertical Datum of 1988*, National Geodetic Survey, U.S. Department of Commerce.
NP = not present

The following subsections for the individual conceptual model components provide the basis, rationale, and references for the values. These parameters represent the values selected for use in the model from the ranges of plausible parameter values. These values may differ for parameter estimates from other Hanford Site modeling efforts that were performed for different purposes, different areas of the Hanford Site, or at different scales.

6.5.1 Model Domain and Boundary Conditions

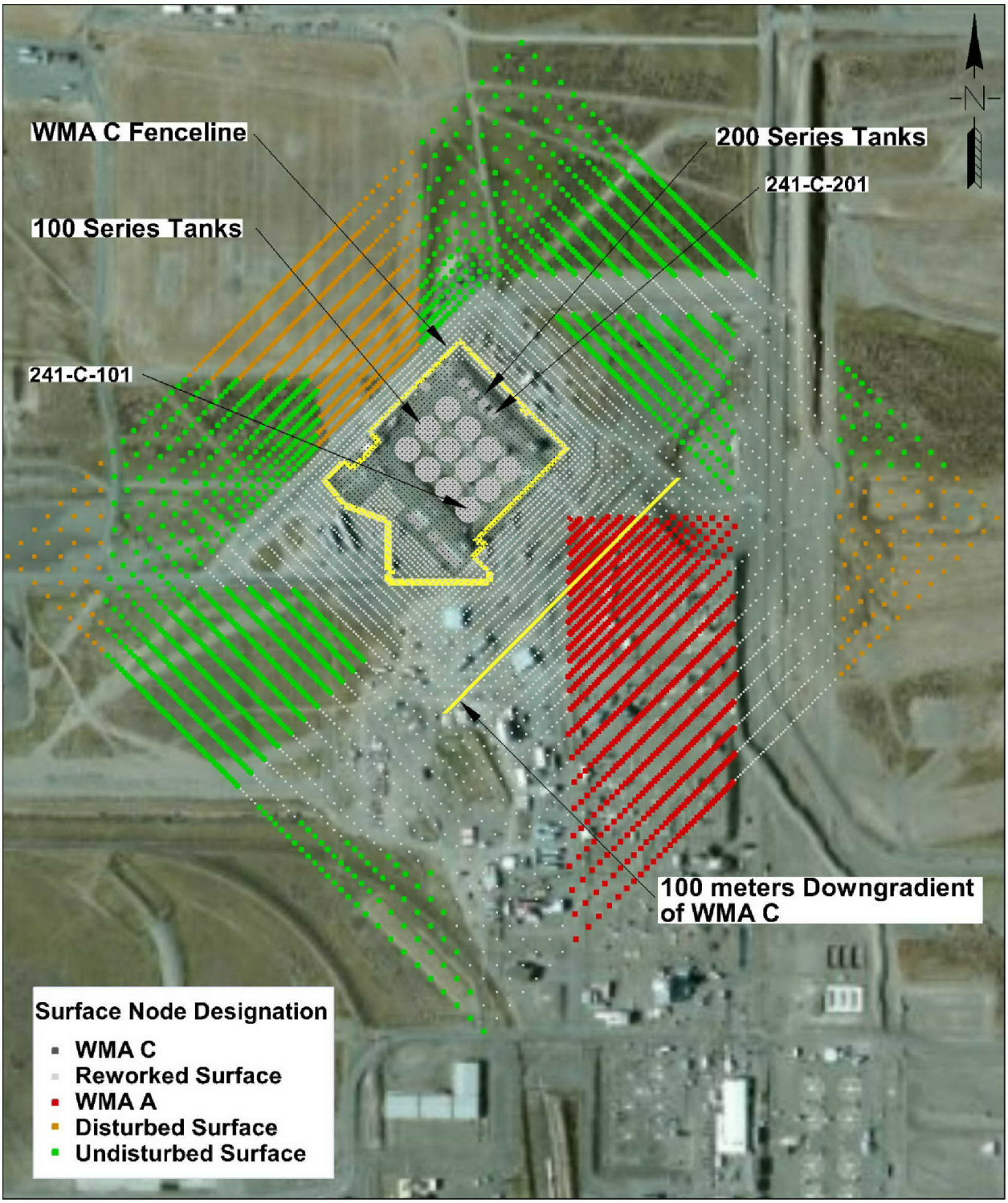
The model domain and boundary conditions establish both a framework and limiting conditions for the numerical model. The model domain for flow and transport in the vadose zone is represented numerically in three-dimensional space with one of the horizontal axes aligned in the general direction of groundwater flow. Aligning an axis with the general direction of groundwater flow allows concentrations to be calculated more easily down gradient of the waste sites. The numerical model adapts the physical elements of the conceptual model to a Cartesian grid and also assigns numerical values to the parameters used in algorithms to represent the physical and geochemical systems and processes.

The WMA C model domain is 738 m (2,421 ft) northwest to southeast by 795 m (2,609 ft) southwest to northeast by 116 m (381 ft), vertically, extending about 12 m (49 ft) below the water table. The southwestern and northwestern boundaries of the model are 574,656.09 m (1,885,354.63 ft), 136,454.41 m (447,685.07 ft), and 575,218.45 m (1,887,199.64 ft), 137,016.78 m (449,530.12 ft), respectively (Lambert Coordinate system easting, NOAA Manual NOS NGS 5, *State Plane Coordinate System of 1983*). The southeastern and northeastern boundaries are 575,177.86 m (1,887,066.47 ft), 135,932.64 m (445,973.23 ft), and 575,740.22 m (1,888,911.48 ft), 136,495.00 m (447,818.24 ft), respectively. The vertical base elevation of the model is nominally 95 m (312 ft) (NAVD88, *North American Vertical Datum of 1988*), although the bottom and top of the model domain vary spatially according to the top of basalt elevation and surface relief, respectively (RPP-RPT-56356).

The horizontal node spacing varies between 3 and 20 m (10 and 66 ft) to optimize the discretization in the areas attempting to approximate the slopes associated with construction of WMA C and the 100-series tanks without overwhelming the available computational resources. The vertical spacing in the vadose zone ranged between 1 and 1.3 m (3 and 4.1 ft) except around the water table where the spacing decreased to 0.5 m (1.6 ft) to minimize the impact of the capillary fringe above the water table. The total number of nodes in the modeled rectangular prism equals 736,653.

During the pre-operational phase (prior to year 1944), the number of active nodes equals 640,565 with 96,088 inactive. During the operational phase (year 1945 to year 2020) and post-closure period (after 2020) phase, the number of active nodes equals 637,543 with 99,110 inactive, the increase in inactive nodes attributed to the inactivation of the tank and ancillary equipment nodes within the WMA C excavation. Figure 6-7 shows the plan view distribution of the calculation node and Table 6-3 presents the pattern of the spacing of the finite difference cells.

Figure 6-7. Plan View of WMA C Performance Assessment Model Domain Showing the Horizontal Distribution and Surface Type of the Irregularly-Spaced Calculation Nodes



Note: The resolution increases in the area of WMA C.

Table 6-3. Horizontal and Vertical Spacing of the Finite Difference Cells in the Three-Dimensional WMA C Flow and Transport Model Domain

West to East Spacing; Southeastern Boundary Coordinate = 574656 m (Lambert Coordinate System[a] Easting)						
4@ 20.00 m	2@ 16.00 m	2@ 12.00 m	2@ 10.00 m	2@ 8.00 m	2@ 6.00 m	7@ 4.50 m
1@ 3.70 m	6@ 3.80 m	2@ 3.85 m	14@ 3.80 m	2@ 3.85 m	6@ 3.80 m	1@ 3.00 m
7@ 4.50 m	3@ 6.00 m	4@ 8.00 m	10@ 10.00 m	2@ 12.00 m	1@ 16.00 m	9@ 20.00 m
South to North Spacing; Southwestern Boundary Coordinate = 136454 m (Lambert Coordinate System[a] Northing)						
8@ 20.00 m	3@ 16.00 m	2@ 12.00 m	4@ 10.00 m	3@ 8.00 m	2@ 6.00 m	11@ 4.50 m
4@ 4.00 m	8@ 3.80 m	1@ 3.90 m	15@ 3.80 m	1@ 3.00 m	11@ 4.50 m	2@ 6.00 m
2@ 8.00 m	3@ 10.00 m	3@ 12.00 m	4@ 16.00 m	6@ 20.00 m		
Vertical Spacing; Bottom Elevation = 95 m (NAVD88[b])						
1@ 5.00 m	2@ 4.00 m	1@ 3.00 m	1@ 2.00 m	2@ 1.50 m	1@ 1.25 m	1@ 1.00 m
1@ 0.75 m	3@ 0.50 m	1@ 0.75 m	12@ 1.00 m	40@ 1.25 m	4@ 1.00 m	19@ 1.25 m

[a]NOAA Manual NOS NGS 5, State Plane Coordinate System of 1983.
[b]North American Vertical Datum of 1988, National Geodetic Survey, U.S. Department of Commerce.

Note: The sequences read left to right. The number preceding the "@" symbol indicates the number of columns (west to east), rows (south to north), or vertical layers (bottom to top) that have the length indicated by the distance following it.

A specified-flux boundary condition was applied at the surface to simulate recharge. Recharge rates varied spatially and temporally along the upper boundary depending on site conditions, the location and physical dimensions of WMA C, and the time of WMA C operations and surface conditions simulated (RPP-RPT-44042). The bottom boundary of the unsaturated (vadose) zone is the water table, and the bottom of the model (aquifer) was defined as a vertical no flow boundary condition. Boundary conditions at the sides of the model domain were assumed to be no flow in the vadose zone and prescribed flux and prescribed head in the aquifer on the up-gradient and down-gradient boundaries, respectively. The boundary condition in the aquifer on the up-gradient boundary was assumed to be prescribed flux calculated on the basis of the hydraulic conductivity and gradient, and independent of recharge. The prescribed flux boundary condition value includes a factor to account for the fact that the thickness of the unconfined aquifer varies because of the uneven surface of the underlying basalt. To account for the non-uniform aquifer thickness, the nominal flux rate calculated as the product of the hydraulic conductivity and gradient (denominator case values of 3,000 m (9,843 ft)/day and 1.0E-05 m/m, respectively) was proportioned according to the ratio of the average aquifer area throughout the model domain (9,440 m^2 [101,611 ft^2]) and the aquifer area along the southwest-northwest

boundary (6,151 m^2 [66,209 ft^2]) where the prescribed flux is applied. The aquifer area refers to the area perpendicular to the direction of groundwater flow.

6.5.2 Hydrogeologic Framework

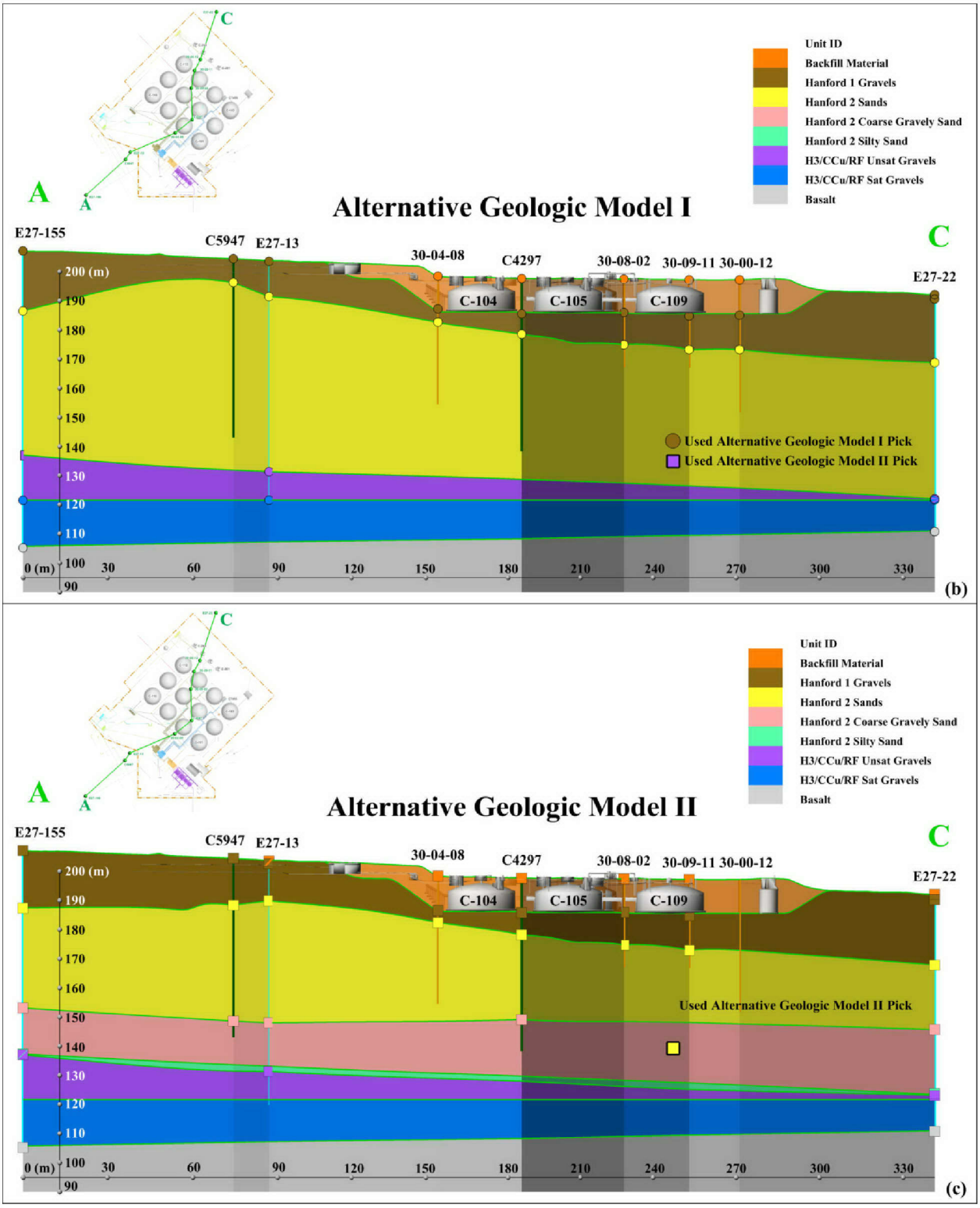
The general geology of WMA C and in the region is presented in detail in RPP-RPT-46088. In discussions associated with the 2009 to 2011 IPA working sessions and additional discussions with regulators in 2013 and 2014, two alternative geological models have been proposed. Both of these models have been carried forward into the IPA, as a means to explore the performance implications of the alternative conceptualizations, as noted in Section 6.3.1.2. This section provides a brief summary of these alternative models; details on the basis for their development are provided in RPP-RPT-56356.

As part of the WMA C RFI effort, the geologic strata underlying WMA C have been characterized in conjunction with soil sampling and borehole logging for radionuclides and hazardous waste constituents. The borehole and geologic logging has been used to identify the elevations of the tops of the geologic units in the vicinity of WMA C. Specifically, ^{40}K, uranium, and thorium data from geophysical logs was used to map the tops of the different geologic units at WMA C (RPP-RPT-56356). Two alternative numerical geologic models were developed based on this data.

The difference between the two alternative models relates primarily to whether or not a sandy gravel facies followed by a silt layer exist at the bottom of the H2 subunit in the vicinity of WMA C. The ^{40}K, uranium, and thorium data (i.e., a lower gross gamma and ^{40}K count) indicate that there is a coarsening of the sand at the bottom of the H2, turning more into sandy gravel. Underlying this sandy gravel facies is a silty sand unit with a strong ^{40}K peak and occasional strong natural uranium peak. The difficulty in making this determination is that there are few direct pushes or drywells that go deep enough in which there are both good geophysical logs and geologic logs (with drill cuttings). For the most part, only the nearby groundwater wells go deep enough. The drill cuttings from nearby groundwater wells indicate that there was definite fining of the sands along with some silty sands found at the vertical location as indicated by the ^{40}K, uranium, and thorium data in the geophysical logs, but a competent silt layer was not observed. Geologic Model I does not include the sandy gravel and underlying silty sand unit, while Geologic Model II does include them. The significance is that the presence of these layers could cause increased lateral movement in the vadose zone. A series of fence diagrams showing the differences between the two models within WMA C is given in RPP-RPT-56356. The fence diagram for both these models running southwest to northeast through the center of WMA C is given in Figure 6-8.

The geological setting information presented here is a summary and synopsis of the information presented in RPP-RPT-46088 and RPP-RPT-56356. General information about the hydrogeologic setting of WMA C is also provided in Section 2 of this document.

Figure 6-8. Fence Diagram of Alternative Geologic Models to be Used in WMA C



The vadose zone at WMA C is ~80 to 100 m (262 to 328 ft) thick, and there is ~68 m (233 ft) between the base of WMA C and the present day water table. WMA C lies within the gravel-dominated H1 unit in the vadose zone. The stratigraphic units recognized in the WMA C area include:

- Recent (Holocene) backfill material (~10 m [33 ft] thick)
- Hanford formation unit H1 – Gravel-dominated sequence (H1 unit) (~10 to 30 m [33 to 98 ft] thick)
- Hanford formation unit H2 –
  - H2 Sand-dominated sequence (H2 unit) (~45 to 70 m [148 to 230 ft] thick)
  - H2 Coarse subunit (gravel/coarse-grained facies that underlies the H2 sands)
  - H2 Silty sand subunit (silty sand lower permeability laminations/lenses)
- Hanford formation unit H3 – gravel-dominated sequence (H3 unit or H3/CCu/HF) (~0 to 20 m [0 to 66 ft] thick)
- CRBG.

The base of the aquifer is the underlying basalt surface. The undifferentiated lower sands and gravels associated with the H3/CCu/RF (Unit A) that comprise the aquifer sediments are simply categorized as saturated H3 sediments in the model. The thickness of the uppermost aquifer beneath WMA C is approximately 12 m (39 ft). The model results provided represent concentrations in the upper 5 m (16 ft) of the aquifer. The 5 m (16 ft) vertical interval corresponds to the well screen length of a conceptual groundwater monitoring well.

6.5.3 Development of the Numerical Hydrogeologic Model

The base hydrogeologic conceptual model developed for the WMA C IPA (RPP-RPT-46088 and RPP-RPT-56356) provides the information basis and data necessary to prepare the three-dimensional geologic inputs used in the three-dimensional numerical model. Each node in the numerical model represents a unique set of horizontal (x and y) coordinates and vertical (z) elevation. A node is assigned the hydrogeologic properties associated with the hydrostratigraphic unit (HSU) identified in the RPP-RPT-56356 geologic models as existing in the space represented by the node coordinates and elevation.

Figure 6-9 shows the geologic interpretation prepared by WRPS staff and identified as Geologic Model I as interpolated onto the numerical grid used in the fate and transport model. Figure 6-10 shows some internal cross-sections of the geology to illustrate the shape and layering of the hydrogeologic units. Figures 6-11 and 6-12 show the geologic interpretation prepared with input from technical staff of the Nez Perce Tribe and identified as Geologic Model II. Geologic Model II includes the separation of the H2 sand unit into three distinct subunits: the H2 sand, the H2 gravelly sand, and the H2 fine or silty sand. Explanation of the basis and the development of the two geologic interpretations are presented in RPP-RPT-56356.

Figure 6-9. The Interpolated Numerical Three-Dimensional Post-Closure Geologic Model I

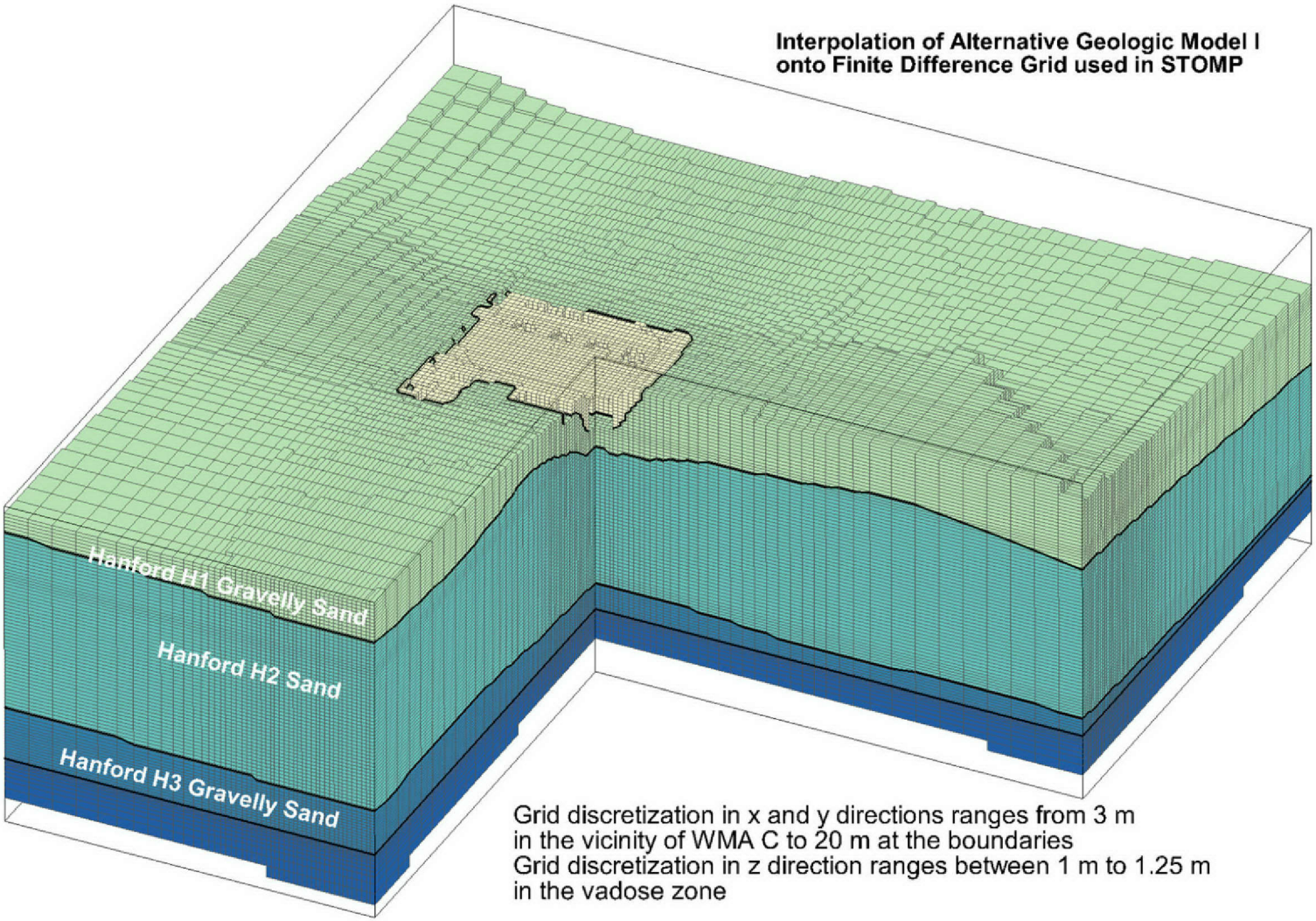


Figure 6-10. Diagram of the Interpolated Numerical Three-Dimensional Post-Closure Geologic Model I

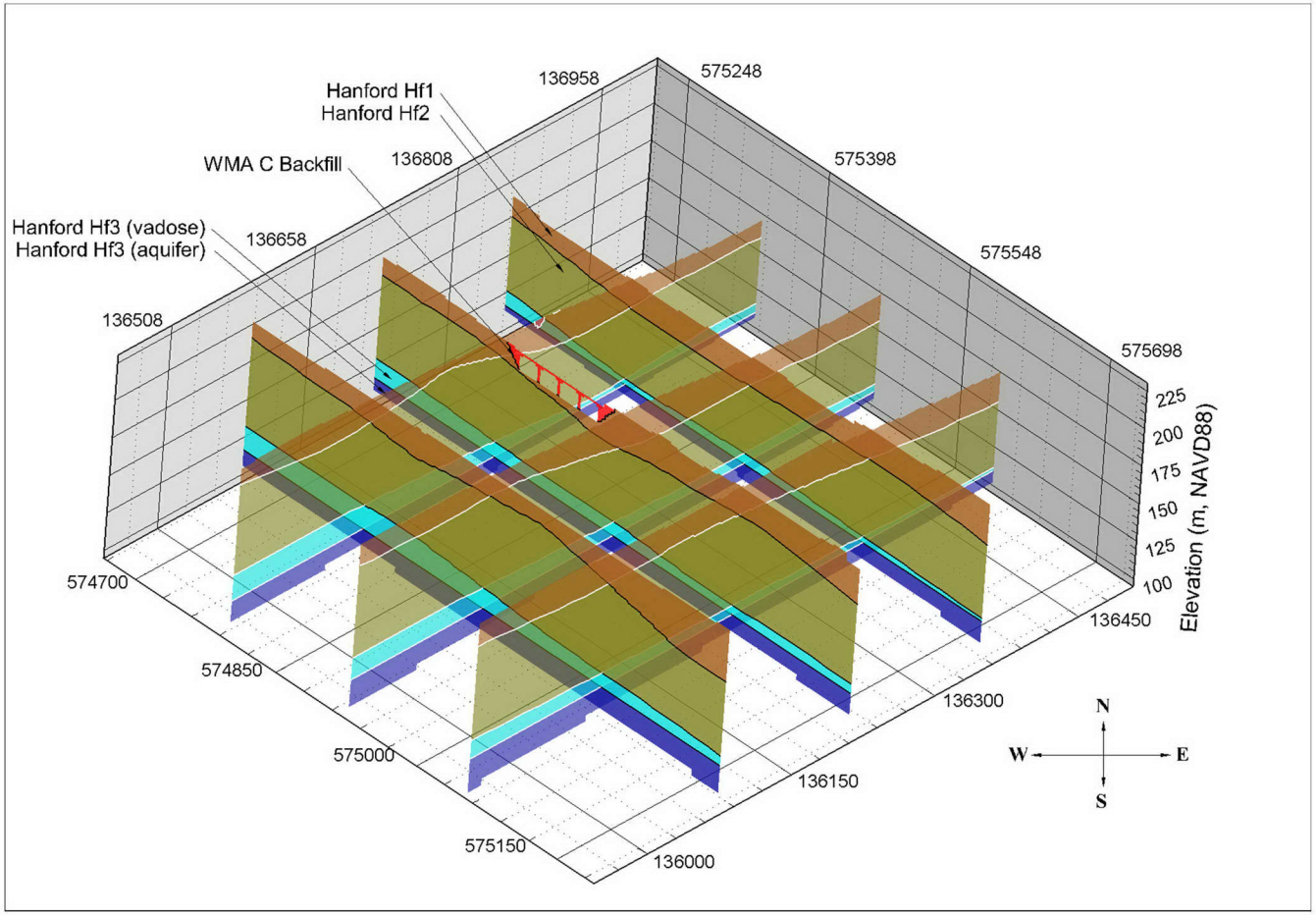


Figure 6-11. The Interpolated Numerical Three-Dimensional Post-Closure Geologic Model II

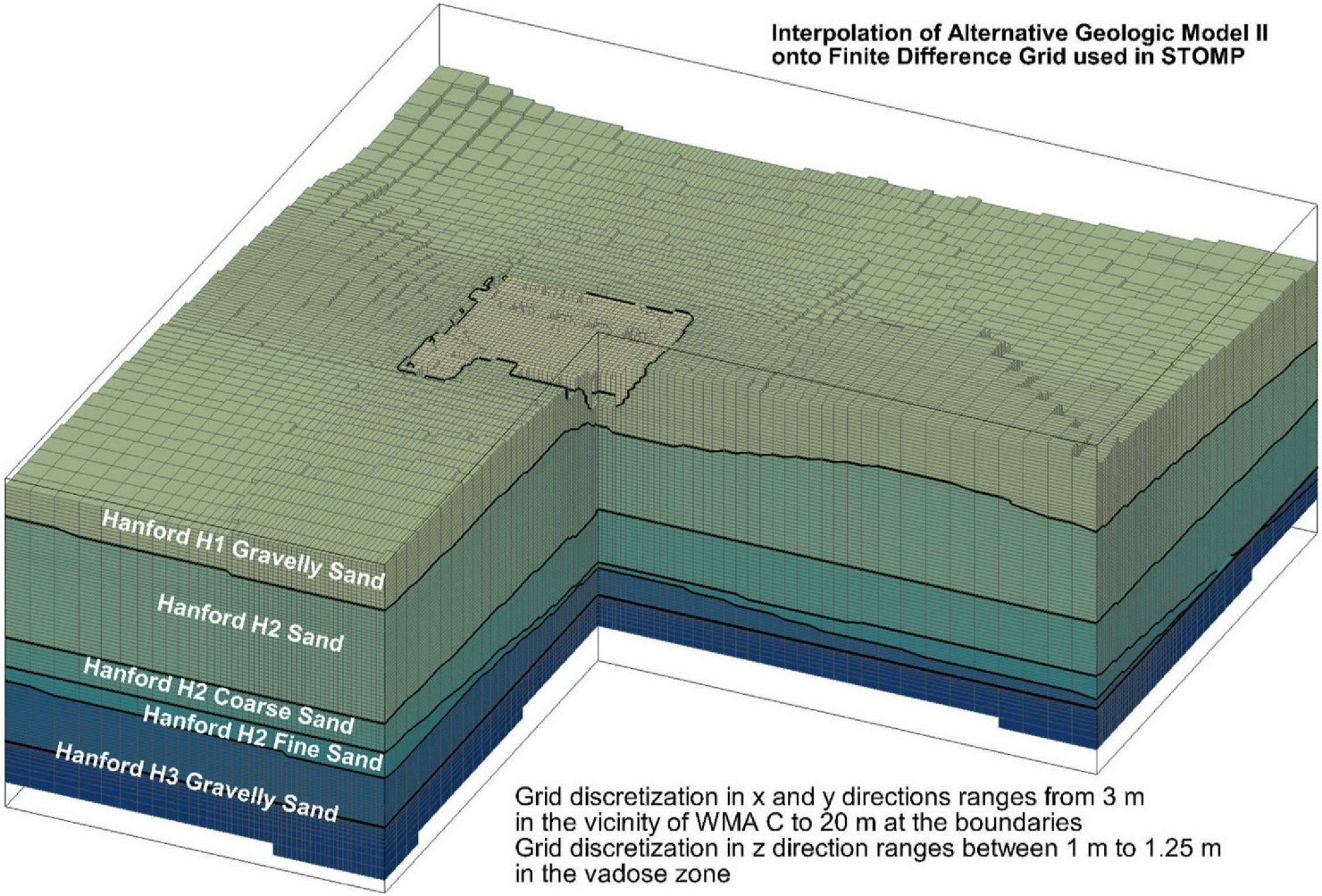
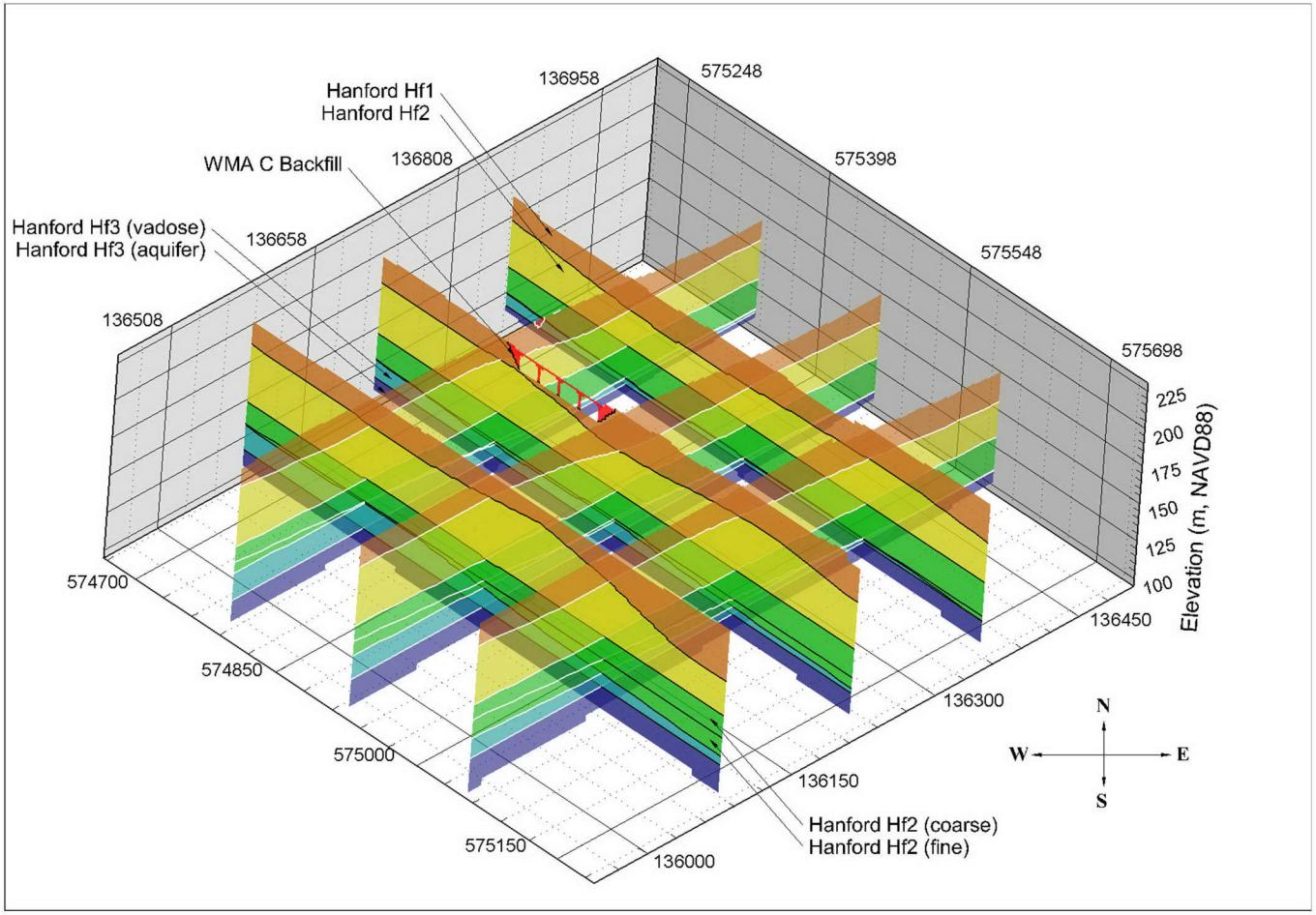


Figure 6-12. Diagram of the Interpolated Numerical Three-Dimensional Post-Closure Geologic Model II



6.5.4 Contaminant Inventory

The radionuclide inventory information presented here is a summary and synopsis of the information presented in RPP-RPT-42323, Rev. 2. The source term conceptual model component defines the characteristics of the inventory and release of residual waste from the tanks, ancillary equipment, and pipelines. As discussed in RPP-RPT-42323, a conservative or bounding bias is built into the inventory estimating process, generally resulting in larger than likely inventory estimates. This report presents the basis for chemical and radiological inventory estimates for residual waste remaining in C Farm SSTs and associated transfer equipment after tank waste is retrieved. The inventory estimates presented in Table 6-4 are derived from the values presented in RPP-RPT-42323 (Appendices B-1, C-3, and C-5), with the radionuclides decayed to January 1, 2020. These values are subject to revision as additional information is obtained.

Table 6-4. Post-Retrieval Residual Waste Inventory for WMA C Tanks, Ancillary Equipment, and Pipelines

Source	Technetium-99 (Ci)	Total Uranium (kg)	Chromium (kg)
241-C-101	4.34E-02	5.16E+02	7.23E+00
241-C-102	3.56E-03	2.93E+02	1.13E+01
241-C-103	4.48E-02	4.91E+01	2.38E+00
241-C-104	1.73E-01	7.50E+02	1.74E+00
241-C-105	9.43E-01	2.39E+02	2.42E+00
241-C-106	1.64E-01	2.70E+00	3.78E+00
241-C-107	4.02E-02	2.49E+02	2.07E+01
241-C-108	3.96E-02	9.84E+01	5.14E-01
241-C-109	7.50E-03	2.44E+01	1.51E-01
241-C-110	5.77E-02	2.60E+00	3.49E+00
241-C-111	5.49E-02	5.38E+02	1.25E+01
241-C-112	2.00E-01	2.45E+03	7.33E+00
241-C-201	2.63E-03	1.11E+02	1.22E+01
241-C-202	2.50E-03	9.88E+01	9.09E+00
241-C-203	2.32E-03	3.26E+02	2.60E+00
241-C-204	3.18E-03	2.43E+02	1.36E+00
241-C-301	3.00E-02	5.93E+02	1.62E+01
CR-Vault	5.45E-02	1.08E+03	2.94E+01
Pipelines	4.61E-02	9.12E+02	2.49E+01

A summary of waste release volumes and inventories of selected constituents associated with past waste releases are provided in Table 3-5 cited in Section 3.7.

6.5.5 Vadose Zone Flow and Transport

The vadose zone hydrogeology and transport information presented here is a summary and synopsis of the information presented in RPP-RPT-46088. RPP-RPT-46088 includes detailed discussion and description of the data available and the methods used to develop the parameters, distributions, and percentile values that are not included here. This section represents a brief summary and synopsis of the information contained in the data packages. The hydrogeologic framework for the vadose zone is summarized in Section 6.5.2 and is not repeated here.

6.5.5.1 Current and Future Recharge Conditions. Natural recharge can vary greatly, depending on factors such as climate, vegetation, surface condition, and soil texture. Studies conducted at the Hanford Site suggest that recharge rates can range from less than 0.1 mm (0.0039 in.)/yr on a variety of soil and vegetative combinations to greater than 130 mm (5.12 in.)/yr on bare basalt outcrops or bare, gravel-covered waste sites ("Variations in Recharge at the Hanford Site," Gee et al. 1992). Data from experimental sites such as the Field Lysimeter Test Facility and the prototype Hanford barrier (crib B-57) suggest that recharge through gravels can range from 15 to 70% of precipitation, with the lower amount occurring under vegetated conditions [PNNL-11367, Hanford Prototype-Barrier Status Report: FY 1996; PNL-10285, Estimated Recharge Rates at the Hanford Site; and "Estimating Recharge Rates for a Groundwater Model Using a GIS" (Fayer et al. 1996)]. With a long-term annual average precipitation of 160 mm (6.30 in.), the higher percentage translates into a recharge rate of ~100 mm (4 in.)/yr and was observed on sandy gravels that were kept free of vegetation (PNNL-14744, Recharge Data Package for the 2005 Integrated Disposal Facility Performance Assessment). Drainage is ~70 mm (2.75 in.)/yr from bare sand and ~100 mm (4 in.)/yr from sandy gravel under Hanford Site climatic conditions. There has been no direct measurement of recharge on tank farm gravels, which are known to contain a larger amount of fines compared to clean gravels. Thus, it is likely that the tank farms experience a recharge rate that ranges between that observed for bare sand and the rate for clean gravels (i.e., 70 to 100 mm [3 to 4 in.]/yr).

The magnitude of recharge for soils at the Hanford Site varies as a function of the soil type, condition of the vegetation cover, and soil integrity (e.g., disturbed versus undisturbed). The range of recharge values reported in RPP-RPT-44042 represents distinct populations of data based on lysimetry and isotopic measurements, and interpretation, and in some instances extrapolation, by Hanford Site subject matter experts. The natural background recharge rates represent a population for natural vegetated conditions. The range of values for operational conditions represents a population of recharge rates for vegetation-free disturbed soil. Table 6-5 presents a summary of the denominator case recharge rates applied to the different surface types, and Table 6-6 presents a summary of the values included in the sensitivity analysis cases.

Table 6-5. Denominator Case Recharge Rate (Net Infiltration) Estimates for Surface Conditions during the Pre-Construction, Operational, and Post-Closure Periods

Period	WMA C Region and Surface Condition	Denominator Case Value of Recharge Rate (mm/yr)
Pre-Operational period (before 1944)	Undisturbed region (Rupert sand with vegetation)	3.5
Operational period (1945 to 2020)	Undisturbed region (Rupert sand with vegetation)	3.5
	WMA C Surface region (Gravel without vegetation)	100
	Surface region that covers part of WMA A-AX southeast of WMA C (Gravel without vegetation)	100
	Disturbed revegetated region (Rupert sand with vegetation)	22
	Disturbed unrevegetated region (Rupert sand with no vegetation)	63
Early post-closure (2020 to 2520)	Undisturbed region (Rupert sand with vegetation)	3.5
	WMA C Surface region (Surface barrier with vegetation)	0.5
	WMA A Surface region (Surface barrier with vegetation beginning in 2050)	0.5
	Disturbed revegetated region (Rupert sand with vegetation beginning in 2050 with vegetation recovery completed in 2080)	3.5
	Disturbed unrevegetated region (Rupert sand with no vegetation until vegetation recovery begins in 2050 and completes in 2080)	3.5
Late post-closure (2520 to 3020 and beyond)	Undisturbed region (Rupert sand with vegetation)	3.5
	WMA C Surface region (Surface barrier with vegetation)	3.5
	Surface region that covers part of WMA A-AX (Degraded surface barrier with vegetation begins in 2550)	3.5
	Disturbed revegetated region (Rupert sand with vegetation recovery completed in 2080)	3.5
	Disturbed unrevegetated region (Rupert sand with vegetation recovery completed in 2080)	3.5

Table 6-6. Recommended Denominator and Sensitivity Cases Proposed for Recharge Rates over Time Periods Considered in the WMA C IPA

	Pre-Hanford Prior to Waste Management Area Construction (mm/yr)	Operational Period to Site Closure (mm/yr)	Site Closure to End of Institutional Control (100 Yrs after Site Closure) (mm/yr)	End of Institutional Control to End Barrier Design Life (500 Yrs after Site Closure) (mm/yr)	End of Barrier Design Life to End of Analysis (10,000 Yrs after Site Closure) (mm/yr)
Denominator	3.5	100	0.5	0.5	3.5
Sensitivity Case 1	3.5	100	0.5	0.5	1.0
Sensitivity Case 2	3.5	40	0.5	0.5	1.0
Sensitivity Case 3[a]	3.5	140	0.5	100	100
Sensitivity Case 4	5.2	100	0.5	0.5	5.2

[a] Recharge values selected for this case during the post-institutional control period would reflect a total failure of the engineered surface barrier and the high recharge rates for bare soils assumed during the historical period of operations.

The final design for the surface barrier for WMA C at closure has not been developed, but it is expected to function comparably to a Modified RCRA Subtitle C Barrier. Summary of data collected over 13 years at the Prototype Hanford Barrier (PNNL-17176, *200-BP-1 Prototype Hanford Barrier Annual Monitoring Report for Fiscal Years 2005 Through 2007*; DOE/RL-93-33, *Focused Feasibility Study of Engineered Barriers for Waste Management Units in the 200 Areas*) indicates that infiltration through the prototype is much less than 0.1 mm (0.0039 in.)/yr, and evaluations of the design using lysimeter data indicate that the barrier is capable of limiting recharge to this amount even with a complete lack of vegetation (Fayer and Gee 2006, "Multiple-Year Water Balance of Soil Covers in a Semiarid Setting"). However, for IPA simulations involving WMA C with a functioning surface barrier, a denominator case recharge rate of 0.5 mm (0.0196 in.)/yr is assumed, which is consistent with the drainage design specification in DOE/RL-93-33.

At the end of 500 years, the surface barrier performance is assumed to degrade to permit an infiltration rate of 3.5 mm (0.03 in.)/yr and maintain that infiltration rate for the remainder of the simulation for the denominator case. No quantifying data are available for specifying the performance of the barrier top after its design life. According to PNNL-13033, *Recharge Data Package for the Immobilized Low-Activity Waste 2001 Performance Assessment*, the erosion of the silt loam layer and deposition of dune sand on the barrier is not likely to alter the barrier performance significantly. The value of 3.5 mm (0.03 in.)/yr corresponds to the recharge in an undisturbed area, which indicates that native vegetation is assumed to reclaim the land.

Although the side slopes and berm are likely to function and perform differently than the surface of the barrier, they are included as part of the barrier surface. The impact of the side slopes on the overall recharge rate is expected to be relatively minor. The sandy gravel/gravelly sand barrier side slope and berm are assumed eventually to resemble a Burbank loamy sand, and if that assumption is valid, then PNNL-16688, *Recharge Data Package for Hanford Single-Shell Tank Waste Management Areas,* indicates that the long-term recharge rate for that soil type is 1.9 mm (0.075 in.)/yr, which is less than the value of 3.5 mm (0.03 in.)/yr used in the analysis for the degraded barrier surface.

6.5.5.2 Hydraulic and Transport Properties. Table 6-7 lists the upscaled composite-fitted van Genuchten-Mualem (van Genuchten 1980, "A Closed-form Equation for Predicting the Hydraulic Conductivity of Unsaturated Soils"; Mualem 1976, "A New Model for Predicting the Hydraulic Conductivity of Unsaturated Porous Media"; EPA/600/2-91/065, The RETC Code for Quantifying the Hydraulic Functions of Unsaturated Soils) parameters for the various strata at the WMA C site. A stochastic model of variable moisture or tension-dependent anisotropy provides the framework for upscaling small-scale measurements to the effective (upscaled) properties for the large-scale vadose zone (Polmann 1990, Application of Stochastic Methods to Transient Flow and Transport in Heterogeneous Unsaturated Soils). The upscaling processes factor the inherent spatial variability that occurs on different scales in heterogeneous media into the field scale parameter estimates (Ye et al. 2005, "Stochastic analysis of moisture plume dynamics of a field injection experiment"; Yeh et al. 2005, "Estimation of effective unsaturated hydraulic conductivity tensor using spatial moments of observed moisture plume"). Specific upscaled flow parameters include moisture retention and saturated and unsaturated hydraulic conductivity. Upscaled transport parameters include bulk density, diffusivity, sorption

coefficients, and macrodispersivity. Detailed discussion of the Polmann (1990) model and the derivation of the upscaled parameters are presented in RPP-RPT-46088.

Table 6-7. Composite van Genuchten-Mualem Parameters for Various Strata at the WMA C Site Used in the Denominator Case Evaluations of Geologic Models I and II

Strata	Number of Samples	θ_s	θ_r	α (1/cm)	n	ℓ^c	Fitted K_s (cm/s)
Backfill	10	0.1380	0.0100	0.0210	1.374	0.5	5.60E-04
H1 (gravel-dominated)	11	0.2126	0.0032	0.0141	1.3730	0.5	2.62E-04
H2 (sand-dominated)	12	0.3819	0.0443	0.0117	1.6162	0.5	9.88E-05
H2 - gravel/coarse sand subunit[a]	N/A	0.3526	0.1034	0.0083	2.0028	0.5	6.19E_05
H2 - silty-sand subunit[a]	N/A	0.3310	0.0956	0.0149	2.0258	0.5	2.85E-05
H3 (gravel-dominated)	8	0.2688	0.0151	0.0197	1.4194	0.5	5.15E-04

[a] Hydraulic properties of these units are only used in numerical model simulation of Geologic Model II. As an initial estimate of these properties, the hydraulic properties associated with the 25th and 75th percentile realizations of unsaturated hydraulic conductivity curves developed in WCH-515 (2013) for the H2 sand unit were considered to be representative of the H2 gravel/coarse sand and the H2 silty sand subunits.

N/A = not applicable

For the Geologic Model II evaluation, the H2 gravel/coarse sand subunit was assumed to be more transmissive and the H2 silty sand less transmissive than the H2 sand. Therefore, as an estimate of these properties, the hydraulic properties associated with the 25th and 75th percentile realizations of unsaturated hydraulic conductivity curves developed in WCH-515 for the H2 sand unit were considered representative of the H2 gravel/coarse sand and the H2 silty sand subunits, respectively.

The effective transport parameter (i.e., macrodispersivity, bulk density, and diffusivity) estimates used in the denominator case and sensitivity cases are presented. Because of natural variability, the transport parameters are all spatially variable. The purpose is similar to the upscaled flow parameters, to evaluate the effect of such variability on the large-scale transport process. Effective bulk density (ρ_b) estimates are needed to calculate retardation factors for different species. The average ρ_b, E[ρ_b] estimates for various strata at WMA C are presented in Table 6-8. These estimates are derived from bulk density values listed in RPP-RPT-46088. The Gelhar and Axness model ("Three-dimensional Analysis of Macrodispersion in a Stratified Aquifer" [Gelhar and Axness 1983]) provides a method to estimate values of macrodispersivity, which according to "Solute Transport in Heterogeneous Porous Formations" (Dagan 1984) reaches a constant, asymptotic value after the solute travels a few tens of correlation scales (~50 cm [19.7 in.]) of the hydraulic conductivity field (RPP-RPT-46088). The estimated values of macrodispersivity applicable to the scale of the WMA C IPA model for the denominator case are shown in Table 6-9.

Table 6-8. Effective Bulk Density ($E[\rho_b]$, g/cm^3) Estimates for Various Strata at WMA C Used in the Denominator Case Evaluations of Geologic Models I and II

Strata	$E[\rho_b]$
Backfill	2.13
H1 (gravel-dominated)	2.07
H2 (sand-dominated)	1.76
H2 - gravel/coarse sand-dominated[a]	1.88
H2 - silty sand-dominated[a]	1.94
H3 (gravel-dominated)	1.94

[a] Effective bulk densities of these units are only used in numerical model simulation of Alternative Geologic Model II.

Table 6-9. Macrodispersity Estimates for Various Strata at WMA C Used in the Denominator Case Evaluations of Geologic Models I and II

Strata	A_L (cm)	A_T (cm)
Backfill	~150	15
H1 (gravel-dominated)	~100	10
H2 (sand-dominated)	~150	15
H2 - gravel/coarse sand-dominated[a]	~150	15
H2 - silty sand-dominated[a]	~150	15
H3 (gravel-dominated)	~150	15

[a] Macrodispersivities of these units are only used in numerical model simulation of Geologic Model II.

It is assumed that the effective, large-scale diffusion coefficients for all strata in the vadose zone at the WMA C site are a function of volumetric moisture content, θ, and can be expressed using the Millington-Quirk (Millington and Quirk 1961, "Permeability of Porous Solids") empirical relation:

$$D_e(\theta) = D_0 \frac{\theta^{10/3}}{\theta_s^2} \tag{4-1}$$

Where:

$D_e(\theta)$ = the effective diffusion coefficient of an ionic species
D_0 = the effective diffusion coefficient for the same species in free water
θ = the localized volumetric moisture content.

The tortuosity formulation in the Millington-Quirk model is based on theoretical considerations absent from other empirical models, and accounts for the ranges of moisture contents present in the vadose zone around WMA C. The molecular diffusion coefficient for all species in pore water is assumed to be 2.5×10^{-5} cm^2/sec (WHC-SD-WM-EE-004, *Performance Assessment of Grouted Double-Shell Tank Waste Disposal at Hanford*), which is consistent with and representative of values used in other Hanford performance assessments.

6.5.6 Groundwater Flow and Transport

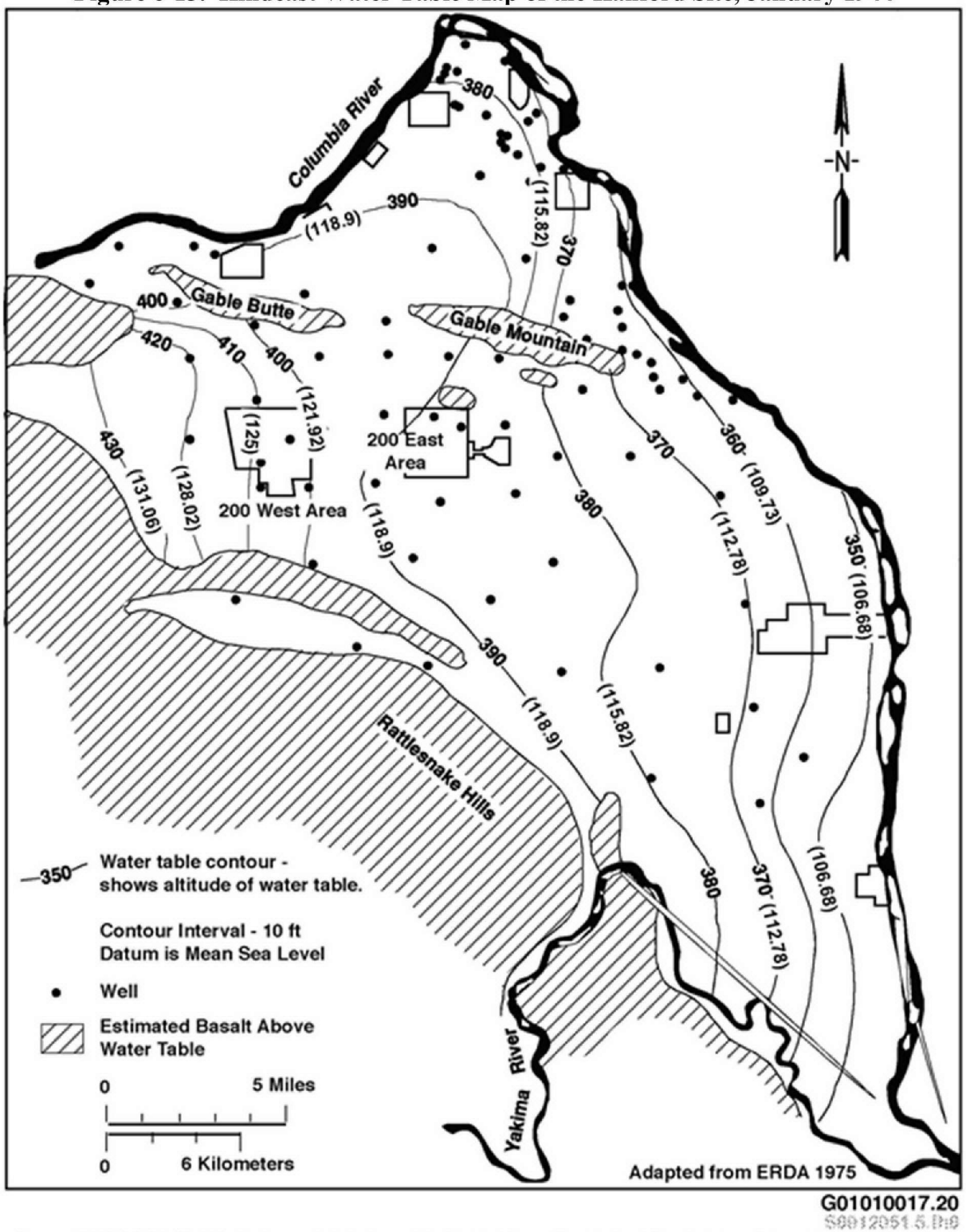
The groundwater in the aquifer system in the vicinity of WMA C have been studied extensively as part of the site characterization as discussed in RPP-RPT-46088 and Section 2.0 of this RFI report. The groundwater conceptual model for WMA C includes the uppermost unconfined aquifer system that exists within a channel eroded by the cataclysmic floods of the Pleistocene. Discussion of groundwater aspects of the hydrogeologic framework of WMA is summarized in Section 6.5.2 and is not repeated here.

6.5.6.1 Current and Future Anticipated Groundwater Flow Conditions. Groundwater flow beneath WMA C has been difficult to measure historically because the hydraulic gradient is very small and the hydraulic conductivity is very large in this region of the Hanford Site. In the future, the gradient is expected to be generally from northwest to southeast. The horizontal saturated hydraulic conductivity for the aquifer is estimated to be 3,000 m/day (9,842.52 ft/day), and the vertical anisotropy ratio of 0.1. The basis of the hydraulic properties is presented in RPP-RPT-46088. The aquifer, identified as H3 – aquifer, is separated from that portion of the H3 above the water table, reflecting the distinctly different saturation conditions.

The water table in the unconfined aquifer is expected to continue declining because the large discharges of operational liquid to the ground at B Pond system and other large discharge sites in the 200 East Area have ceased. The hydraulic heads around WMA C are expected to continue declining slowly until they stabilize around year 2030 at 120 m (392 ft) (CP-47631). This stabilization leads to a long-term hydraulic gradient value of about 0.00001, which is close to the one observed prior to start of Hanford Site operations, as estimated from Figure 6-13 (adapted from Figure 2-8 in WHC-EP-0645). Changes in hydraulic gradient are only expected to occur within the first 10 to 50 years of the post-closure simulation period, which, according to the screening analysis (Section 6.6 of this RFI report), is before the mobile radionuclides reach the water table. Thus the hydraulic gradient is assumed to be stable for this analysis.

6.5.6.2 Hydraulic and Transport Properties. Table 6-10 presents a summary of the aquifer hydraulic parameters for the H3 – aquifer used for the denominator case.

Figure 6-13. Hindcast Water Table Map of the Hanford Site, January 1944



Source: WHC-SD-ER-TI-003, *Geology and Hydrology of the Hanford Site: A Standardized Text for Use in Westinghouse Hanford Company Documents and Reports*.

ERDA 1975 = ERDA-1538, *Final Environmental Statement, Waste Management Operations, Hanford Reservation, Richland, Washington*.

Table 6-10. Soil Hydraulic Properties for Aquifer Soil Type used for Denominator Case at WMA C

Aquifer Soil Type	Total Porosity	Saturated Moisture Content	Horizontal Saturated Hydraulic Conductivity[a] (m/day)	Longitudinal Dispersivity[b] (m)	Aquifer Hydraulic Gradient (m/m)	Average Aquifer Water Flux ($m^3/yr/m^2$)
H3 (aquifer)	0.25	0.25	3000	10.5	0.00001	10.96

Source: RPP-RPT-46088, *Flow and Transport in the Natural System at Waste Management Area C*.

[a] Vertical Saturated Hydraulic Conductivity assumed equal to 1/10 of the Horizontal Saturated Hydraulic Conductivity.

[b] Transverse dispersivity assumed to be equal to 1/10 of the longitudinal dispersivity.

6.6 CONTAMINANTS OF POTENTIAL CONCERN IDENTIFICATION APPROACH AND RESULTS

This section discusses the approach to identifying COPCs for both the baseline risk assessment and the impacts analysis of waste residuals assumed to remain in WMA C tanks and equipment after closure of WMA C. This section also provides the results of these data evaluation efforts.

6.6.1 Identification of COPCs for Consideration in the Baseline Risk Assessment

This subsection provides a summary of the process used to identify contaminants of potential concern for the baseline risk assessment.

6.6.1.1 Screening Based on Phase 2 Soil Characterization Data. RPP-RPT-57218 presents a detailed description of the computation of exposure point concentrations (EPCs) for both radiological and non-radiological analytes based on selected soil characterization data collected as part of the Phase 2 RFI at WMA C. The results of these EPC calculations are being used in the WMA C baseline risk assessment.

As a part of the EPC calculational process, RPP-RPT-57218 summarizes (1) a COPC identification considered in the evaluation; (2) organization and preliminary evaluation of site characterization data based on exposure scenarios; (3) data reduction and screening of analytical data to identify analytes for which the EPCs will be computed.

This methodology and the results of the COPC identification are summarized in Section 5 and 8 of RPP-RPT-57218. The initial Phase 2 data set processed contained 25,595 records with 365 analytes. Data reduction steps and application of exclusion criteria eliminated 3,697 and 6,019 records, respectively. The weight-of-evidence screen eliminated 7,591 records. In total, the screenings removed 17,307 records and 283 analytes. Therefore, the EPCs were calculated for 82 analytes by utilizing 8,288 records. The baseline risk assessment based on the EPCs is summarized in Section 7.0 of this RFI.

6.6.1.2 Screening Based on Groundwater Monitoring Data. As identified in Section 5.4, RPP-RPT-58297 provides a screening-level evaluation of groundwater data from 12 wells that monitor contaminants in the unconfined aquifer in the vicinity of WMA C. A summary of the results from this initial screening level is also provided in Section 7.7 of this document.

6.6.2 Identification of COPCs for Impact Assessment of Residual Waste Left in Tanks and Ancillary Equipment

Contaminants of potential concern were identified for the long-term assessment of the performance of a closed WMA C using two evaluations: 1) inventory, and 2) groundwater pathway, which are described in the following sections.

6.6.2.1 Inventory Evaluation. The approach taken for including specific radionuclides and chemicals in the long-term performance assessment of waste residuals model, based on the evaluation of the inventory-related information, is discussed below.

- All radionuclides and chemicals for which WMA C tank inventory information is available in the BBI (and official Tank Waste Information Network System) database are considered. The BBI contains inventory estimates for 46 radionuclides and 24 chemicals.

- The BBI list contains some very short-lived radionuclides (half-lives less than three years), such as ^{90}Y, ^{106}Ru, ^{125}Sb, ^{134}Cs, ^{137m}Ba, and ^{242}Cm. These six radionuclides were removed because either they were assumed to decay to negligible concentrations or their parents were already included in the IPA calculations.

- In order to calculate the radon flux, the ^{222}Rn was included along with intermediate parent ^{230}Th that would form during the decay from ^{234}U. In addition, ^{210}Pb was included as it is the decay product of ^{222}Rn. The initial mass of all three radionuclides (^{230}Th, ^{222}Rn, and ^{210}Pb) is assumed to be zero at closure. This resulted in a total of 43 radionuclides being considered in the system model.

- The number of chemicals that were considered in the system model is based on evaluation of the available toxicity values. If the chemical (that is tracked in the BBI) was found to have no known toxicity value, then it was identified for removal. The following chemicals and aqueous species were identified for no further consideration on this basis: Bi, Ca, Cl, K, La, Na, PO_4, Si, SO_4, CO_3, and Zr. This resulted in a total of 12 chemicals being evaluated for the system model.

Following the identification of the radionuclides and chemicals listed in the BBI, an additional evaluation was conducted to find any supplemental analytes that were not included in the BBI but may be of interest for the IPA evaluations. For this, the residual inventory estimates for retrieved tanks were obtained from RPP-RPT-42323, Table D-1. The analytes identified in RPP-RPT-42323, Table D-1 were reduced by 1) eliminating analytes not required to be sampled in RPP-23403, *Single-Shell Tank Component Closure Data Quality Objectives*, and 2) analytes already evaluated in the BBI list. The remaining analytes were evaluated further and excluded based on their inventory, toxicity, and mobility using the following exclusion criteria in the following order:

- Chemicals without known toxicity information were excluded

- Chemicals with nominal inventories less than 0.1 kg (0.22 lb) at each retrieved tank were eliminated because such small numbers were judged to have insignificant effect on the system performance

- Chemicals with K_d values greater than 3 mL/g were excluded because their arrival times at the water table would be beyond the 10,000-year evaluation time period under future recharge conditions.

The exclusion criterion applied to supplemental radionuclides was

- Radionuclides that have half-lives less than 3 years were excluded, and
- Radionuclides that are not directly related to Hanford Site operations were excluded.

Based on this evaluation, following six chemical supplemental analytes were included in the system model: boron, cobalt, cyanide, selenium, tin, and tributyl phosphate (organic). No additional radionuclides were included.

In summary, the total number of radionuclides considered in the system model are 43 while the total number of chemicals are 18, leading to a total number of 61 species evaluated in the IPA.

6.6.2.2 Groundwater Pathway Evaluation. The purpose of a groundwater pathway evaluation is to identify those contaminants that are not sufficiently mobile to impact groundwater within the compliance and sensitivity-uncertainty timeframes. These contaminants are then omitted from further groundwater impact analysis. Because of the long timeframes associated with conducting STOMP-based numerical model runs, identification of only relevant COPCs can help expedite the modeling evaluation process.

The identification process does not consider radioactive decay and applies the maximum possible recharge value identified for each modeled time period (Table 6-11). Contaminant arrival time is evaluated for a range of K_d values. Any calculated breakthrough to groundwater of the hypothetical contaminants within 1,000 and 10,000 years is considered to indicate that any radionuclide or hazardous chemical with that K_d value (or less) could reach groundwater within the compliance and sensitivity-uncertainty timeframes, respectively. Contaminants with K_d values greater than the identified maximums are omitted from further denominator case and sensitivity-uncertainty groundwater impact analysis.

Table 6-11. Long-Term Recharge Rates Associated With the Different Modeling Periods Used in the Groundwater Pathway Evaluation of Arrival Times

Modeling Period	Duration	Surface Condition of Waste Management Area C	Arrival Time Analysis Recharge Rate (mm/yr)
Pre-construction Period	Steady state	Undisturbed natural conditions	5.2
Operational Period	1945 – 2020	Disturbed bare gravel surface	140
Early Post-closure Period	2020 – 2520	Evapotranspiration surface barrier	1
Late Post-closure Period	2520 – 12020	Evapotranspiration barrier reverts to natural conditions	5.2

The identification of K_d value thresholds is based on any non-zero impact to groundwater, obtained by using vadose zone properties associated with the maximum transport rates for each geologic unit and the maximum net infiltration rate present during the five different simulation periods, regardless of its location relative to the tank residuals. The application of these parameter values is a conservatism accepted for the identification process, which is recognized as an acceptable expedient in DOE G 435.1-2, and conducted per the EPA guidance to use simple methods and conservative or simplified assumptions (EPA/540/F-95/041).

On the basis of the model evaluation results, radionuclides and hazardous chemicals with K_d values greater than a particular value can be identified for no further evaluation because they do not arrive in groundwater within the 1,000-year compliance timeframe or the 10,000-year sensitivity-uncertainty timeframe. The identification process results indicate that radionuclides with K_d values greater than or equal to 0.3 mL/g do not arrive in groundwater within 1,000 years and can be omitted from further evaluation with respect to compliance. Those with K_d values greater than or equal to 3 mL/g do not arrive in groundwater within 10,000 years and can be omitted from further evaluation with respect to sensitivity-uncertainty (Table 6-12).
A list of eliminated COPCs from the combined use of the inventory and groundwater pathway evaluations and the reason for their elimination in the COPC identification process is provided in Table 6-13.

Table 6-12. Contaminant Inventory and Mobility Arrival Time Identification Evaluation Results

	Years to First Arrival					
	Distribution Coefficient (mL/g)					
Location	0.1	0.2	0.3	0.6	2.0	3.0
Water Table	547	975	1,430	2,740	8,750	DNA
100 m from WMA C	695	1,080	1,575	3,029	9,680	DNA

Contaminant transport starts year 2030 and contaminant release concludes year 2031.

DNA = Did Not Arrive in 10,000 years

Table 6-13. COPC Excluded from Further Consideration

Analyte Name	Exclusion Rationale	Half-life
Radionuclides		
Thorium-228	Naturally-occurring background radiation; half-life less than three years	1.91 yrs
Thorium-230	Naturally-occurring background radiation	77,000 yrs
Non-radionuclides		
1, 1, 2-Trichloroethylene (Trichloroethene)	Inventory less than 0.1 kg	--
2-Butanone(MEK)	Inventory less than 0.1 kg	--
2-Propanone (Acetone)	Inventory less than 0.1 kg	--
4-Methyl-2-pentanone (MIBK) (Hexone)	Inventory less than 0.1 kg	--
Acetate	No toxicity information available	--
Ammonium	Inventory less than 0.1 kg	--

Table 6-13. COPC Excluded from Further Consideration

Analyte Name	Exclusion Rationale	Half-life
Antimony	K_d value greater than 3 mL/g	--
Aroclor-1016	Inventory less than 0.1 kg	--
Aroclor-1221	Inventory less than 0.1 kg	--
Aroclor-1232	Inventory less than 0.1 kg	--
Aroclor-1242	Inventory less than 0.1 kg	--
Aroclor-1248	Inventory less than 0.1 kg	--
Aroclor-1254	Inventory less than 0.1 kg	--
Aroclor-1260	Inventory less than 0.1 kg	--
Arsenic	K_d value greater than 3 mL/g	--
Barium	K_d value greater than 3 mL/g	--
Beryllium	K_d value greater than 3 mL/g	--
Bromide	No toxicity information available	--
Cadmium	K_d value greater than 3 mL/g	--
Cerium	No toxicity information available	--
Copper	K_d value greater than 3 mL/g	--
Europium	No toxicity information available	--
Formate+A2	No toxicity information available	--
Glycolate	Inventory less than 0.1 kg	--
Lithium	K_d value greater than 3 mL/g	--
Magnesium	Essential Nutrient	--
Molybdenum	K_d value greater than 3 mL/g	--
m-Xylene	Inventory less than 0.1 kg	--
Neodymium	No toxicity information available	--
Niobium	No toxicity information available	--
Oxalate	No toxicity information available	--
o-Xylene	Inventory less than 0.1 kg	--
Palladium	No toxicity information available	--
Percent water	Water quality parameter	--
Phosphorus	K_d value greater than 3 mL/g	--
Polychlorinated Biphenyls (high risk)	Inventory less than 0.1 kg	--
Praseodymium	No toxicity information available	--

Table 6-13. COPC Excluded from Further Consideration

Analyte Name	Exclusion Rationale	Half-life
Rhodium	No toxicity information available	--
Rubidium	No toxicity information available	--
Ruthenium	No toxicity information available	--
Samarium	No toxicity information available	--
Silver	K_d value greater than 3 mL/g	--
Sulfide	No toxicity information available	--
Sulfur	No toxicity information available	--
Tantalum	No toxicity information available	--
Tellurium	No toxicity information available	--
Thallium	K_d value greater than 3 mL/g	--
Thorium	No toxicity information available	--
Titanium	No toxicity information available	--
Tungsten	No toxicity information available	--
Vanadium	K_d value greater than 3 mL/g	--
Xylene (m & p)	Inventory less than 0.1 kg	--
Xylenes	Inventory less than 0.1 kg	--
Yttrium	No toxicity information available	--
Zinc	K_d value greater than 3 mL/g	--

6.7 CONTAMINANT FATE AND TRANSPORT SUMMARY

An initial evaluation of performance of the primary sources of contaminants (i.e. residual waste left in a closed WMA C) will use projected estimates of volumes and inventories for selected tanks based on either Hanford Tank Waste Operations Simulator Model (RPP-RPT-39908, *Hanford Tank Waste Operations Simulator Model (HTWOS) Version 3.0 Verification and Validation Report)* or BBI estimates. As the initial version of the IPA is completed, calculations will not able to account for:

- Final inventories for wastes left in three retrieved SSTs (C-101, C-107 and C-112) that will be developed from waste residual sampling and analyses

- Final volumes and inventories for waste left in three SSTs (C-102, C-105 and C-111) that are in the process of being retrieved

- Final volumes and inventories for waste left in the 244-CR Vault tanks, the C-301 Catch Tank, and other ancillary equipment where retrieval has not been initiated.

Based on progress to date with un-retrieved tanks, it is anticipated that final volumes for the unretrieved tanks may be above final volumes assumed in the initial set of analyses. In fiscal year 2015, the IPA effort will be evaluating additional sensitivity cases that will examine, as bounding inventory case, the volume and concentration for waste remaining in these unretrieved tanks based on the BBI at the time that this information is finalized for the first version of the IPA.

Eventually, once retrieval of these SSTs and other ancillary equipment has been completed and final inventories have been estimated based on waste residual sampling and analysis, the impacts from these final volumes and inventories will need to be evaluated. Analysis of final closure volumes and inventories will not be included in the initial version of the IPA but will be considered in the next iteration of the IPA.

The analysis of impacts of secondary contaminant sources (i.e. past waste releases) from WMA C has begun with a completion of a baseline risk assessment (RPP-RPT-58329). The baseline risk assessment, which is summarized in Section 7, presents the risks from releases of hazardous substances to the environment under current conditions in the absence of any actions to control or mitigate these releases. Within this initial assessment, soil concentrations were evaluated against a variety of direct contact exposures using reasonably anticipated future land used scenarios. This assessment also performed a limited evaluation of soil concentrations for non-radiological constituents for groundwater protection are calculated using the WAC 173-340-747, "Fixed Parameter Three-Phase Partitioning Model."

As a part of the WMA C IPA, the site specific numerical model(s) being developed to support the evaluation of human health and environmental impacts from residual wastes left in tanks and ancillary equipment after closure will also be used to evaluate the potential impacts of soil contamination for radiological and non-radiological constituents on groundwater. Results of these analyses will be included in anticipated updates of the baseline risk assessment (RPP-RPT-58329) and associated sections of this RFI report.

Because of the uncertainty associated with past waste releases at WMA C, the analysis of impacts of past waste releases from WMA C will use a two-step approach. The first step will be a scoping analysis of impacts of past waste releases. This scoping analysis will attempt to identify key elements of the various alternative conceptual models that could have play a role in the impacts to groundwater from releases from WMA C that have been observed. This analysis will make use of the existing numerical models that have developed for the tank residual analysis with necessary modifications to account for key elements of the four alternative conceptual models. Once completed, the results of the scoping analysis will provide feedback about modifications that may be needed to the numerical model(s) such that they better approximate the behavior of waste releases in the past as we move forward with IPA analysis of the long-term impacts of both primary and secondary sources that will remain at WMA C after closure.

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7.0 SUMMARY OF HUMAN HEALTH AND ECOLOGICAL RISK ASSESSMENT

This section summarizes both the human health risk assessment (HHRA) and the screening level ecological risk assessment (SLERA) that have been performed for WMA C. The HHRA provides an analysis of baseline human health risks that will be used to determine the need for remedial action at WMA C. The HHRA will also identify radiological and nonradiological COPCs that may be retained for further evaluation in the CMS. The SLERA will determine the potential for adverse ecological impact resulting from exposure to nonradiological and radiological contaminants released to the environment through past site operations. A high-level groundwater screening evaluation was performed as part of the baseline risk assessment (RPP-RPT-58329) to provide preliminary information that can be used in conjunction with additional groundwater evaluations.

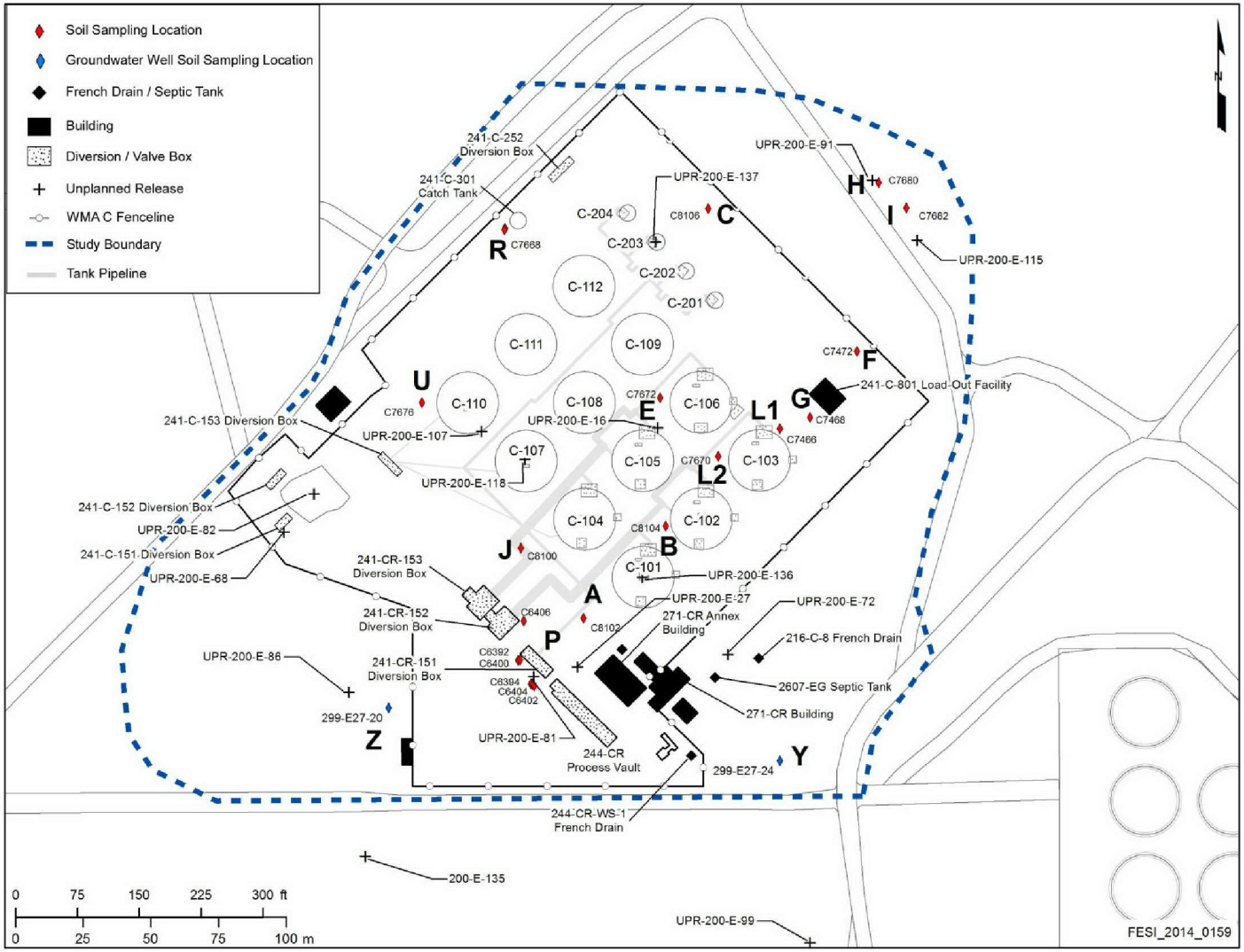
The contamination in the groundwater underlying WMA C is being addressed under the CERCLA. WMA C, a RCRA regulated unit, is identified as an area of interest within the 200-BP-5 groundwater OU. A quantitative baseline risk assessment and evaluation of remedial alternatives for the groundwater underlying the WMA C area of interest is evaluated within the 200-BP-5 groundwater OU remedial investigation/feasibility study (DOE/RL-2009-127, *Remedial Investigation/Feasibility Study for the 200-BP-5 Groundwater Operable Unit).*

Section 7.1 summarizes the analytical data used in the HHRA and SLERA. Section 7.2 summarizes the methods and results for the baseline HHRA and Section 7.3 summarizes the methods and results of the SLERA for WMA C. The groundwater screening evaluation is summarized in Section 7.4.

7.1 ANALYTICAL DATA PROCESSING

As identified in Section 4, soil samples at WMA C were collected and analyzed in accordance with RPP-RPT-38152, RPP-PLAN-39114, and RPP-PLAN-38777. The soil characterization data consists of analytical results from soil samples collected from 14 sampling locations (A, B, C, E, F, G, H, I, J, L1/L2, P, R, and U) within WMA C. The data were obtained from the HEIS database. Figure 7-1 presents the final sampling locations in relation to existing surface features in and around WMA C. The final sampling locations were established based on geophysical surveys and facility walk-downs conducted prior to deployment of the sampling equipment to the sample site.

Figure 7-1. Final Sampling Locations with Respect to Physical Features



The WMA C Phase 2 characterization soil data used in the baseline risk assessment is evaluated in RPP-RPT-57218. The document provides a detailed description of the data processing and reduction steps applied to the WMA C soil data following the extraction from the HEIS database, the methodology used to calculate analyte-specific 95% UCL values, and the logic applied to compute exposure point concentrations for detected analytes in the data set.

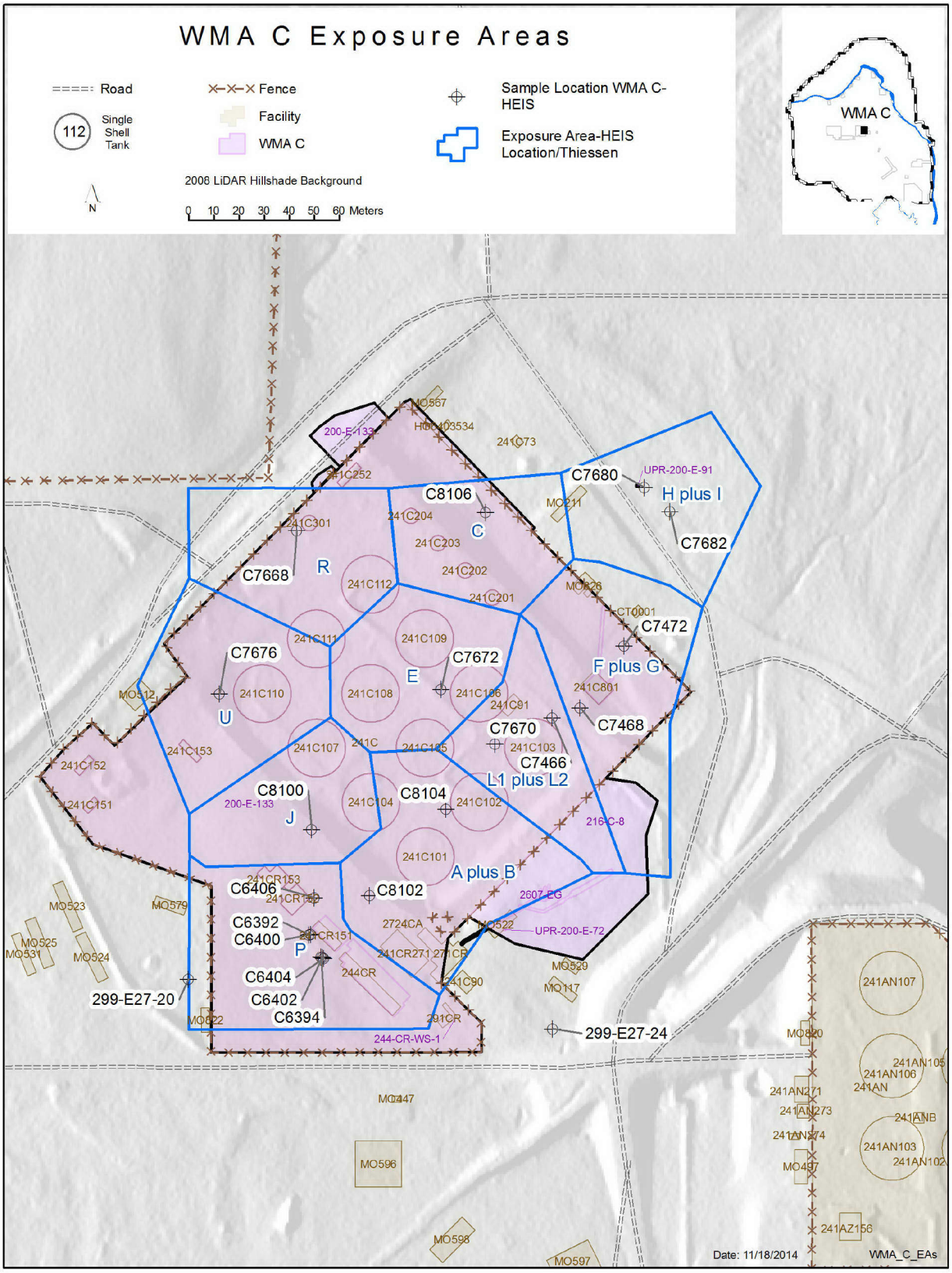
For the purposes of the baseline risk assessment, several of the soil borings were grouped into a single exposure area based on the Phase 2 characterization objectives. Phase 2 site characterization data collected from 14 sampling locations was grouped into 10 primary exposure areas. The exposure area, the general locations within WMA C, and the Phase 2 characterization objectives are identified in Table 7-1. Figure 7-2 depicts the exposure areas within WMA C.

Table 7-1. Identification of Exposure Areas

Exposure Area	General Location Within WMA C*	Phase 2 Characterization Objective
A+B	Area near Tank C-101	Characterize releases from Tank C-101
C	Area near 200-series tanks	Determine if C-200s actually leaked, and determine if any C-200 tank leaked during retrieval
E	Area between Tanks C-106 and C-109	Assess cobalt-60
F+G	Area near Tank C-103 and C-801 Building, and C-801 Building chemical drain	Assess releases of PUREX Plant waste, cesium-137, technetium-99, and cobalt-60
H+I	Area northeast of UPR-200-E-91 and UPR-200-E-115	Assess surface exposures, and assess cobalt-60 and surface release conceptual site models
J	Area near Tank C-104	Assess suspected release
L1+L2	Area between Tanks C-103 and C-106	Updated logging data for cobalt-60 and cesium-137, uranium, and moisture and assess potential release
P	Area near UPR-200-E-81	Characterize release
R	Area near C-301 Catch Tank	Assess potential catch tank release
U	Area near Tank C-110	Characterize Tank C-110 release

*See Figure 7-2

Figure 7-2. Exposure Areas within WMA C



Under MTCA cleanup regulations (WAC 173-340-740, "Unrestricted Land Use Soil Cleanup Standards"), the point of compliance for soil cleanup levels based on the direct contact pathway is defined as the zone extending from the ground surface to 5 m (15 ft) bgs. A deep vadose zone (> 5 m [15 ft] bgs) exposure scenario may also be evaluated to screen for sites that pose a potential risk from inadvertent exposure through deep vadose zone excavation activities and to allow institutional controls to be established at those sites to control access to deep vadose zone contamination. The HHRA and SLERA were evaluated for shallow vadose zone soil (0 to 5 m [0 to 15 ft] bgs) for each exposure area.

7.2 HUMAN HEALTH RISK ASSESSMENT

DOE is required to assess human and ecological risk under CERCLA, RCRA, NEPA, and DOE orders. The "National Oil and Hazardous Substances Contingency Plan" (NCP) (40 CFR 300), specifically requires a site-specific baseline risk assessment to be performed at the Hanford Site (40 CFR 300.430[d][4]). Therefore, a site-specific HHRA was conducted as a part of the baseline risk assessment for WMA C. The WMA C soil risk assessment is documented in RPP-RPT-58329.

The baseline risk assessment provides information to:

- Estimate potential human health and ecological risks associated with WMA C if no remedial action occurs.
- Identify areas that pose no unacceptable risk to human health or the environment, and thus require no further action.
- Identify areas that pose unacceptable risk to human health or the environment, and thus require remedial action.
- Develop a list of COPCs that contribute to unacceptable risk to human health or the environment.

The technical approach for the risk assessment is consistent with the EPA guidance for performance of HHRAs at CERCLA or RCRA sites. Remedial action goals related to chemical cancer risk and hazards may be based on MTCA screening models in WAC 173-340. Therefore, in addition to the quantitative CERCLA-compliant HHRA, this approach includes a separate risk assessment methodology consistent with the WAC 173-340 regulations.

7.2.1 Identification of COPCs

The identification of COPCs is a two-step process that identifies the radiological and nonradiological analytes evaluated in the baseline risk assessment. This process includes the application of data reduction and exclusion criteria, followed by a weight of evidence screening. Table 3-2 in RPP-RPT-58329 identifies the final radiological and nonradiological COPCs for each exposure area.

7.2.1.1 Data Reduction and Exclusion Criteria. The analytical data processing and reduction steps evaluate data qualification flags, analytes reported by multiple analytical methods, and duplicate results. After the data have been processed, exclusion criteria are applied to identify a subset of analytes to be carried forward into the next step of the baseline risk assessment for exposure point concentration (EPC) computation. Analytes that meet the exclusion criteria are eliminated from further consideration. The following were excluded:

- Radionuclides that have half-lives less than 3 years and that are not significant daughter products
- Naturally occurring radionuclides that are not directly related to Hanford Site operation or processes
- Water quality or soil physical property measurements
- Essential nutrients (minerals) (calcium, magnesium, potassium, and sodium)
- Analytes without known toxicity information.

7.2.1.2 Weight of Evidence. Analytes that have not been detected in any of the samples collected are eliminated from further consideration. After the data reduction and exclusion criteria screen, a total of 110 analytes were identified that were not detected in the WMA C Phase 2 soil samples. Any analyte that is detected at least once within the WMA C Phase 2 soil data set is carried forward for EPC computation.

7.2.2 Exposure Assessment

The exposure assessment identifies the population that may be exposed, the routes by which these receptors may become exposed, and the magnitude, frequency, and duration of potential exposures. The exposure assessment was performed in two steps: 1) development of a conceptual site model, and 2) quantification of exposure point concentrations and pathway-specific intakes

7.2.2.1 Development of Conceptual Site Model. An exposure pathway can be described as the physical course that a COPC takes from the point of release to a receptor. The route of exposure is the means by which a COPC enters a receptor. For an exposure pathway to be complete, all of the following components must be present:

- A source
- A mechanism of chemical or radionuclide release and transport
- An environmental transport medium
- An exposure point
- An exposure route
- A receptor or exposed population.

In the absence of any one of these components, an exposure pathway is considered incomplete and, therefore, creates no risk or hazard. Figure 7-3 schematically presents five components of the conceptual site model for the HHRA.

Human Exposure Scenarios and Receptors

The estimation of exposure requires numerous assumptions to describe potential exposure situations. Upper bound exposure assumptions are used to estimate reasonable maximum exposure (RME) conditions to provide a bounding estimate of exposure. WMA C exposure scenarios are described in RPP-RPT-47479, *Exposure Scenario for the Waste Management Area C Performance Assessment*. RPP-RPT-47479 describes the potential exposure pathways for characterizing human health risk at WMA C.

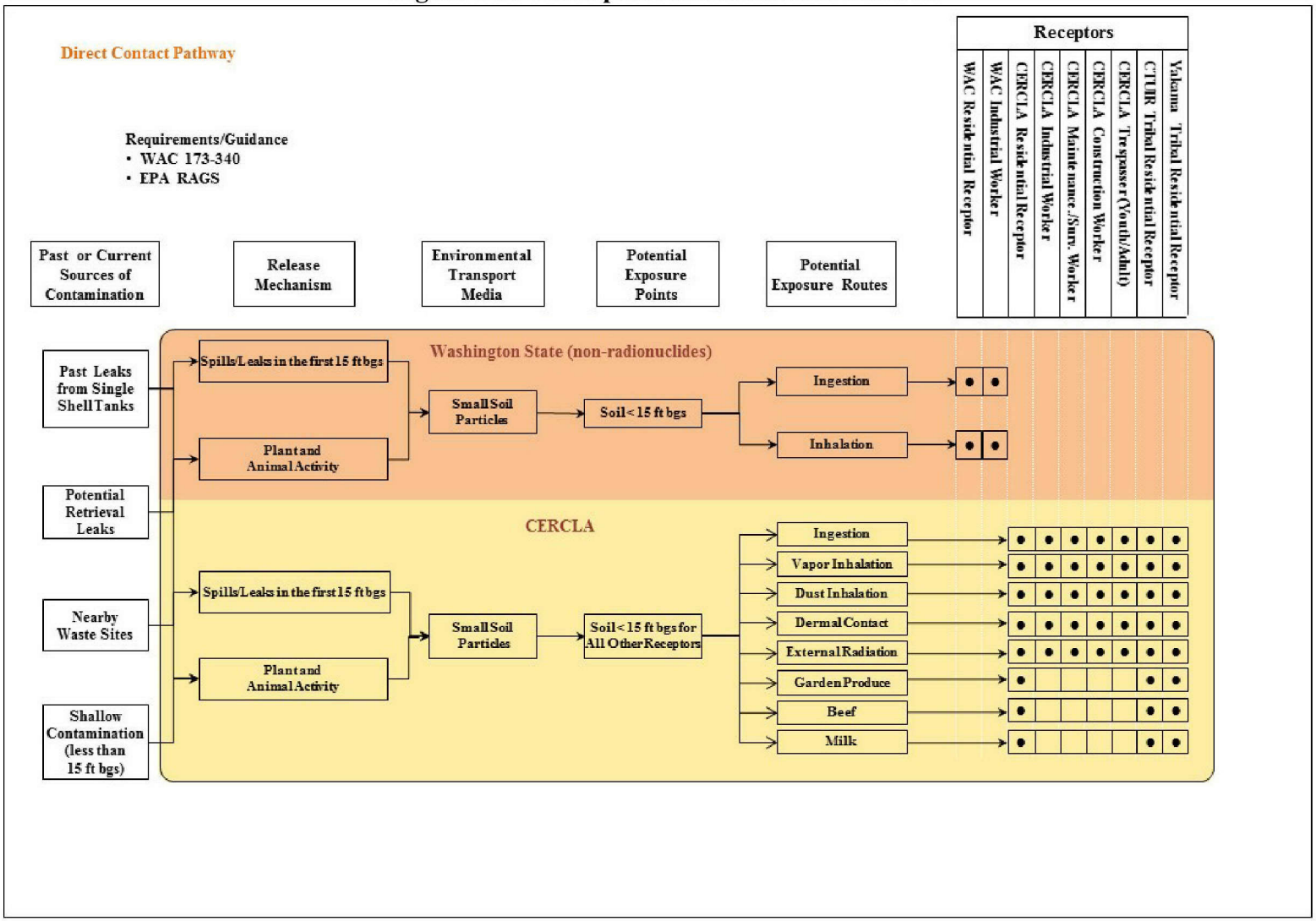
All current land use activities associated with the Central Plateau are industrial in nature. It is assumed that the Inner Area of the Central Plateau will be under Federal ownership in perpetuity, and managed as an industrial area with restricted access and institutional controls. However, in addition to evaluation under an industrial use scenario, the consequences of institutional control failures will be evaluated with several unrestricted land use scenarios.

Based on the current understanding of future land use scenarios for the WMA C, the most plausible receptor scenario for characterizing human health risks has been identified as an adult industrial worker. In addition, an adult construction worker, an adult maintenance/surveillance worker, a trespasser adult and a trespasser youth receptor scenarios are also selected to represent reasonably anticipated future land use scenarios and provide risk information on the consequences of future institutional control failures. These receptors may come in contact with contaminated media while working at the Site.

In addition to above RME scenarios, the baseline risk assessment provides additional information for risk management through the evaluation of a residential receptor. The residential scenario is used to evaluate unrestricted land use and determine if remedial alternatives are necessary in the absence of any engineering or institutional controls.

Additionally, several local and regional Native American Tribes have ancestral ties to the Hanford Reach of the Columbia River and surrounding lands, including portions of the Hanford Site. As part of the CERCLA process for identifying exposed individuals, the DOE has requested that each Tribe provide an exposure scenario that reflects their traditional activities. At this time, the Confederated Tribes of the Umatilla Indian Reservation (CTUIR) (Harris and Harper 2004, *Exposure Scenario for CTUIR Traditional Subsistence Lifeways*) and the Yakama Nation (Ridolfi, Inc. 2007, *Yakama Nation Exposure Scenario for Hanford Site Risk Assessment*) have provided scenarios. Therefore, risk assessments were performed for both CTUIR and Yakama Nation scenarios. DOE requested and invited the Native American perspectives included in this baseline risk assessment to ensure fair consideration of differing views and to inform the decision making process. DOE respects those views and has considered them for the purposes of preparing this RFI.

Figure 7-3. Conceptual Site Model for WMA C



CERCLA Adult Industrial Worker Scenario

The industrial worker is selected as the receptor to represent potential exposures from the industrial land use scenario similar to that experienced in the Inner Area of the Central Plateau. This receptor could potentially be exposed to contaminants in the shallow vadose zone and under this scenario, is expected to be at the site for 250 days per year for 25 years (EPA 2012). Exposure pathways evaluated for the industrial worker scenario include:

- External gamma radiation from radionuclides in the shallow vadose zone
- Incidental ingestion of shallow vadose zone soil
- Inhalation of airborne contaminated dust or volatile emissions from soil
- Dermal exposure from nonradiological COPCs.

WAC Adult Industrial Worker Scenario - Based on MTCA Method C Standard

Typically, soil concentrations of nonradiological COPCs are evaluated against the soil cleanup levels, established in the 2007 WAC 173-340-745 to identify COPCs that do not meet the soil cleanup standards. However, during this baseline risk assessment, instead of comparing soil concentration to their respective cleanup levels, an additional risk assessment was performed for nonradiological COPCs by utilizing the equations (rearranged to solve for risk) and exposure assumptions presented in MTCA (WAC 173-340-745[5][b], "Soil Cleanup Standards for Industrial Properties"; WAC 173-340-750[4][b], "Cleanup Standards to Protect Air Quality"). The exposure frequency for the industrial worker under WAC 173-340-745 is 146 days per year over a duration of 20 years. The exposure pathways evaluated for the MTCA Method C industrial worker scenario include:

- Incidental soil ingestion
- Inhalation of vapors and dust in ambient air.

MTCA Standard Method C default assumptions were utilized during this risk assessment.

Construction Worker Scenario

Under reasonably anticipated future land use scenarios, construction workers could potentially be exposed to contaminants in the shallow vadose soil up to 5 m (16 ft) bgs. The construction worker is assumed to have short-term exposure to contaminants in soil performing trenching and excavation activities on the Central Plateau. Under this scenario, construction workers are assumed to be on the job eight hours per day, 30 days per year over a one year period. Exposure pathways evaluated for the construction worker scenario include:

- External gamma radiation from radionuclides in the soil
- Incidental ingestion of contaminated soil
- Inhalation of airborne contaminated dust or volatile emissions from soil
- Dermal exposure to nonradiological COPCs.

This exposure scenario assumes that drinking water is obtained from a source other than the groundwater beneath WMA C.

Maintenance/Surveillance Worker Scenario

This scenario assumes that adult maintenance/surveillance workers (authorized users) could potentially be exposed to contaminants in the shallow vadose soil up to 5 m (16 ft) bgs within the Inner Area of the Central Plateau. The scenario assumes that exposure to contaminants in soil occurs while performing waste site surveillance activities such as walk downs and visual inspections as well as activities such as mowing the grass, clearing brush, and general site maintenance. Exposure pathways evaluated for the maintenance/surveillance worker scenario include:

- External gamma radiation from radionuclides in the soil
- Incidental ingestion of contaminated soil
- Inhalation of airborne contaminated dust or volatile emissions from soil
- Dermal exposure to nonradiological COPCs.

This exposure scenario assumes that drinking water is obtained from a source other than the groundwater beneath WMA C.

Adult and Older Youth Trespasser Scenario

The trespasser exposure scenario for radiological and nonradiological contaminants is used to represent reasonably anticipated future land use conditions. This scenario assumes that older youth and adults could trespass within the Inner Area of the Central Plateau and could potentially be exposed to the shallow vadose zone soil. The scenario assumes that exposure to surface soil occurs from infrequent unauthorized off-road activities such as dirt bike riding, mountain bike riding, or hiking. The exposure pathways for adult and older youth trespasser include:

- External gamma radiation from radionuclides in the soil
- Incidental ingestion of contaminated soil
- Inhalation of airborne contaminated dust or volatile emissions from soil
- Dermal exposure to nonradiological COPCs.

This exposure scenario assumes that drinking water is obtained from a source other than the groundwater beneath the site.

CERCLA Residential Scenario

The residential scenario for radiological and nonradiological contaminants represents the "all pathways" exposure scenario for this risk assessment. The potentially exposed population for this exposure scenario includes adult and child residents. The exposure pathways for residential receptor include:

- External gamma radiation from radiological COPCs in the soil
- Incidental ingestion of soil for both radiological and nonradiological COPCs
- Inhalation of airborne contaminated dust or volatile emissions from soil
- Dermal exposure to nonradiological COPCs
- Fruits, vegetables and grain consumption pathways for radiological COPCs
- Meat consumption pathway for radiological COPCs
- Milk consumption pathway for radiological COPCs.

Residential Scenario - Based on MTCA Method B Standard
Typically, soil concentrations of nonradiological COPCs are evaluated against the soil cleanup levels established in in WAC 173-340-740 to identify COPCs that do not meet the soil cleanup standards under unrestricted land use. However, instead of comparing soil concentrations to their cleanup standards, a risk assessment was performed for nonradiological COPCs based on the equations (rearranged to solve for risk) and exposure assumptions presented in MTCA Standard "Unrestricted Land Use Soil Cleanup Standards," "Method B Soil Cleanup Levels for Unrestricted Land Use" (WAC 173-340-740(3)) and Standard "Cleanup Standards to Protect Air Quality," "Method B Air Cleanup Levels" (WAC 173-340-750(3)). The exposure pathways evaluated for MTCA Method B residential scenario include:

- Soil ingestion pathway for residential child
- Inhalation of vapors and dust in ambient air from soil for child and adult.

Residential adult and child were considered for carcinogenic and noncarcinogenic COPCs, respectively for the inhalation pathway. MTCA Standard Method B default assumptions were utilized for this risk assessment.

Native American Tribal Scenarios
Several local and regional Native American Tribes have ancestral ties to the Hanford Reach of the Columbia River and surrounding lands. DOE has requested that each Tribe provide an exposure scenario that reflects their traditional activities. At this time, the CTUIR and the Yakama Nation have provided scenarios. Therefore, risk assessments were performed for both Tribal scenarios. However, these assessments were performed for information purposes. No conclusion will be drawn based on those results.

7.2.2.2 Exposure Point Concentrations. OSWER 9285.6-10, *Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites,* is the most recent EPA guidance for EPC calculations, and ProUCL 4.00.05[1] serves as the companion software package for this guidance. ProUCL 4.00.05 contains rigorous parametric and nonparametric statistical methods (including bootstrap methods) that can be applied to data sets with or without non-detect results (results reported below detection limits).

ProUCL was used to calculate EPCs for the analytes that passed through the COPC screening processes. Figure 3-2 in RPP-RPT-58329 explains the rationale for selection of EPCs. EPC values were calculated for each analyte from each exposure area and are used in the next step of quantifying exposures.

7.2.2.3 Quantification of Potential Exposures. The magnitude of human exposure to chemicals in environmental media is usually described in terms of the average daily intake, which is defined as the amount of contaminants in contact with exchange surfaces of the body (e.g., skin, lungs, gastrointestinal tract). Exposure that is normalized over time and body weight is termed "intake" (expressed as milligrams of chemical per kilogram body weight per day [mg/kg-day]). The intake equations for ingestion of soil, inhalation of dust or vapors, and dermal

[1] ProUCL software was developed by Lockheed Martin Environmental Services, Las Vegas, Nevada, under a contract with the U.S. Environmental Protection Agency, Office of Research and Development

contact are presented in RPP-RPT-58329. The exposure parameters used to calculate intake for nonradiological risk are presented in RPP-RPT-58329 Appendix A, Attachment A-1.
The human health radiological dose and risk assessment for radiological COPCs was conducted utilizing the RESidual RADioactivity computer code (RESRAD)[2] Version 6.5 (ANL 2009, *RESRAD for Windows*). Developed by Argonne National Laboratory for DOE, the RESRAD model is typically used to estimate the potential dose and risk to the average member of the critical group for unrestricted land use based on site-specific and generic parameters. The model calculates direct dose, inhalation dose, and ingestion doses from air, water, produce, meat, milk, fish and aquatic foodstuffs, and incidental ingestion of contaminated soils. RESRAD input parameters are presented in RPP-RPT-58329, Appendix A, Attachment A-2.

7.2.3 Toxicity Assessment

The toxicity assessment evaluates the relationship between the magnitude of exposure to a contaminant at the WMA C and the likelihood of adverse health effects to potentially exposed populations. The HHRA provides, where possible, a numerical estimate of the increased likelihood of adverse health effects associated with contaminant exposure. Toxicity assessments for both nonradiological and radiological COPCs are summarized below.

7.2.3.1 Toxicity Assessment for Nonradiological COPCs. The toxic effects of a chemical generally depend not only upon the inherent toxicity of the chemical and the level of exposure (intake), but also on the route of exposure (oral, inhalation, or dermal) and the duration of exposure. Thus, a full description of toxic effects of a chemical includes a listing of what adverse health effects the chemical may cause, and how the occurrence of these effects depend upon intake, route, and duration of exposure. Toxicity values for nonradiological COPCs are presented in RPP-RPT-58329, Appendix B, Table B-1.

Reference Doses for Noncancer Effects
Toxicity values describing the dose response relationship for noncancer effects is the reference dose (RfD) value. For noncarcinogenic effects, the body's protective mechanisms must be overcome before an adverse effect is manifested. If exposure is high enough and these protective mechanisms (or thresholds) are exceeded, adverse health effects can occur. The EPA attempts to identify the upper bound of this tolerance range in the development of noncancer toxicity values. The EPA uses the apparent toxic threshold value, in conjunction with uncertainty factors based on the strength of the toxicological evidence, to derive RfD values. For the inhalation pathway, noncancer reference values are expressed in terms of the reference concentration (RfC), having the units of mg of chemical/m^3 of air.

Slope Factor for Cancer Effects
The dose response relationship for cancer effects is expressed as a cancer slope factor that converts estimated intake directly to excess lifetime cancer risk (ELCR). Slope factors (SF) are expressed in units of risk per level of exposure (or intake). The data used for estimating the dose response relationship are taken from the lifetime animal studies or human occupational or epidemiological studies where excess cancer risk has been associated with exposure to the

[2] RESRAD software was developed by Argonne National Laboratory Environmental Assessment Division, Argonne, Illinois, under a contract with the U.S. Department of Energy

chemical. For the inhalation pathway for CERCLA receptors, cancer toxicity values are expressed in terms of the inhalation unit risk (IUR), having the units of (µg chemical/m^3 volume in air)$^{-1}$. However, for the inhalation pathway for the WAC receptors, cancer toxicity values are expressed in terms of the inhalation SF, having the units of mg of chemical/kg of body weight per day)$^{-1}$.

Toxicity Values

Analyte specific toxicity values (cancer slope factors and noncancer RfDs) are determined using the following recommended reference hierarchy as described in OSWER Directive 9285.7-53, *Human Health Toxicity Values in Superfund Risk Assessments:*

- Tier 1 – The EPA Integrated Risk Information System (IRIS)
- Tier 2 – The EPA Provisional Peer Reviewed Toxicity Values
- Tier 3 – Other Toxicity Values (California Environmental Protection Agency, the Agency for Toxic Substances and Disease Registry, Health Effects Assessment Summary Tables).

When Tier 1, Tier 2, or Tier 3 toxicity values are not available for a COPC, the toxicity values from the National Center for Environmental Assessment are used. These values can be found in the Risk Assessment Information System (ORNL 2014).

7.2.3.2 Toxicity Assessment for Radiological COPCs. To estimate radiological risk, the RESRAD code utilizes Federal Guidance Report No. 13 risk coefficient values. The risk coefficients derived in Federal Guidance Report No. 13 are based on methods and models that take into account the age- and gender-dependence of radionuclide intake, metabolism, dosimetry, radiogenic risk, and competing causes of death in estimating the excess cancer risk from low-level exposures to radionuclides in the environment. These risk coefficient slope factors are presented in units per picocuries per gram (pCi/g) (internal pathways) or risk per year per pCi/g (external pathways). The dose coefficient factors and risk coefficient factors for radiological COPCs are presented in RPP-RPT-58329, Appendix B, Table B-2.

7.2.4 Risk Characterization Approach

Risk characterization determines whether soil concentrations are protective of human health. Risk characterization is completed by combining the results of the exposure assessment (estimated chemical intakes) with the results of the dose-response assessment (toxicity values established in the toxicity assessment) to provide quantification of excess cancer risk and noncancer hazard. The methods for risk characterization used in the HHRA evaluation are based upon guidance provided in EPA's RAGs (EPA 1989) and WAC 173-340.

7.2.4.1 Risk Characterization Methods. Both carcinogenic risk and noncarcinogenic hazard evaluations were performed for nonradiological COPCs. RPP-RPT-58329, Appendix C includes nonradiological risk assessments for the receptor scenarios presented in Section 7.2.2.1.

Non-radiological Carcinogenic Risk Characterization

The potential for cancer risk is evaluated by estimating the ELCR. This risk is the incremental increase in the probability of developing cancer during one's lifetime in addition to the

background probability of developing cancer. For each COPC, risk is calculated by multiplying the average intake of the chemical, by the slope factor for the chemical/route.

$$Risk = Intake \times SF$$

Where:

Risk = Cancer Risk (unitless)
Intake = Daily intake of chemical (mg/kg-day)
SF = Cancer Slope Factor $(mg/kg\text{-}day)^{-1}$

For inhalation exposure, the carcinogenic risk is calculated by multiplying the exposure concentration of the chemical by the inhalation unit risk for the chemical.

$$Risk = EC \times IUR$$

Where:

Risk = Cancer Risk (unitless)
EC = Exposure Concentration ($\mu g/m^3$)
IUR = Inhalation Unit Risk $(\mu g/m^3)^{-1}$

Synergistic or antagonistic interactions might occur between cancer-causing contaminants and other chemicals, information is generally lacking in the toxicological literature to predict quantitatively the effects of these potential interactions. Therefore, cancer risks are treated as additive within an exposure route in this assessment. This is consistent with EPA guidelines on chemical mixtures (EPA/630/P-03/001F, *Risk Assessment for Carcinogens*).

Radiological Carcinogenic Risk Characterization

As mentioned previously, RESRAD 6.5 was used to perform the radiological risk assessments for each exposure area. Radiological COPCs have carcinogenic toxicity values. Therefore, RESRAD 6.5 was used to calculate cumulative ELCRs for each exposure area. RPP-RPT-58329, Section 3.5 and Appendix D include the results of the radiological risk assessment.

Noncarcinogenic Risk Characterization

The potential for noncancer hazards is evaluated by comparing the intake for a constituent to the level of intake that is recognized as unlikely to result in adverse noncarcinogenic health effects. For each COPC, the noncancer hazard is calculated by dividing the intake of the constituent over the RfD for the chemical/route. This comparison results in a noncancer hazard quotient (HQ).

$$HQ = \frac{Intake}{RfD}$$

Where:

HQ = hazard quotient (unitless)
Intake = daily chemical intake (mg/kg-day)
RfD = noncancer reference dose (mg/kg-day)

For inhalation exposure, the noncancer hazard is calculated by dividing the exposure concentration by the reference concentration. Since exposure occurs simultaneously to more than one chemical, HQ values may be summed, resulting in an overall hazard index (HI).

$$HQ = \frac{EC}{RfC \times 1{,}000\ \mu g/mg}$$

Where:

EC = exposure concentration ($\mu g/m^3$)
RfC = noncancer reference concentration (mg/m^3)

Consideration of Background in Risk Assessment

EPA 540-R-01-003, *Guidance for Comparing Background and Chemical Concentrations in Soil for CERCLA Sites,* provides national policy considerations for application of background data in risk assessment and remedy selection. This policy recommends an approach that addresses site-specific background issues in the risk characterization. A background risk assessment was performed for the residential receptor scenario by utilizing Hanford Site background values for nonradiological COPCs.

7.2.4.2 Risk Criteria. For the purpose of the risk characterization step, the potential for unacceptable human health risk is identified using the following risk thresholds:

- For carcinogenic risk, the ELCR values are compared to the "target range" of 10^{-6} to 10^{-4} (EPA 1991) that is generally used by regulatory agencies. The ELCR values within or exceeding this target range require a risk management decision that includes evaluating site-specific characteristics and exposure scenario factors to assess whether remedial action is warranted.

  - For nonradiological COPCs, the total ELCR for each exposure area is compared with respect to the MTCA cumulative risk threshold of 1×10^{-5}. When the cumulative ELCR for nonradiological analytes exceeds 10^{-5}, those individual analytes with a risk greater than 10^{-6} are identified as major risk contributors for the exposure area. Under MTCA Method C standard, the cumulative risk threshold is 1×10^{-6}. When the cumulative ELCR for non-radiological analytes exceeds 10^{-6}, those individual analytes with a risk greater than 10^{-7} are identified as major risk contributors

  - For radiological COPCs, when the total cumulative ELCR exceeds 10^{-4}, those individual COPCs with a risk greater than 10^{-6} (those analytes that contribute greater than 1% of total cumulative ELCR) are identified as major risk contributors for the exposure area.

- For non-carcinogenic risk, an HI (the sum of the ratios of the chemical intake to the RfDs for all COPCs) greater than 1 indicates that potential exists for adverse health effects associated with exposure to the COPCs. When the HI exceeds 1, those individual COPCs

that contribute greater than 1% of total HI are identified as major hazard contributors for the exposure area.

7.2.5 Summary of Risk Estimates by Exposure Scenario

This section summarizes the results for both nonradiological and radiological constituents for the following receptor scenarios – (1) Industrial worker; (2) Construction worker; (3) Maintenance/Surveillance worker; (4) Adult Trespasser; (5) Youth Trespasser; (6) Residential Receptor; (7) CTUIR; and (8) Yakama Nation.

7.2.5.1 Summary of Results for the CERCLA Industrial Worker Scenario. The total ELCRs for five exposure areas (A+B, C, E, L1+L2, and P) are greater than the EPA upper risk threshold of 1 x 10^{-4}. Two major risk contributors, ^{137}Cs and ^{126}Sn are retained as radiological COPCs for further evaluation in the RCRA CMS. No hazards were identified for noncancer effects (i.e., HI < 1). Table 7-2 provides a summary of the cancer risk and noncancer hazards. RPP-RPT-58329, Appendix C, Attachment C-1 and Appendix D, Attachment D-1 includes the results of the industrial worker scenario for nonradiological and radiological risk assessments, respectively.

Table 7-2. Summary of Total Risk Characterization Results for the CERCLA Industrial Worker Exposure Scenario

Exposure Area	Carcinogenic Risk - Radiological		Carcinogenic Risk - Nonradiological		Hazard - Nonradiological	
	ELCR	Risk Drivers	ELCR	Risk Drivers	HI	Noncancer Hazard Drivers
A+B	5 x 10^{-4}	Cs-137, Sn-126	1 x 10^{-6}	--	0.05	--
C	6 x 10^{-4}		6 x 10^{-6}		0.1	
E	2 x 10^{-4}		2 x 10^{-6}		0.05	
F+G	4 x 10^{-5}	--	1 x 10^{-6}		0.03	
H+I	8 x 10^{-5}		1 x 10^{-6}		0.05	
J	3 x 10^{-5}		2 x 10^{-6}		0.3	
L1+L2	1 x 10^{-4}	Cs-137, Sn-126	1 x 10^{-6}		0.04	
P	2 x 10^{-4}	Cs-137	1 x 10^{-6}		0.05	
R	8 x 10^{-7}	--	2 x 10^{-6}		0.1	
U	8 x 10^{-5}		2 x 10^{-6}		0.1	

RPP-RPT-58329, Table 3-3
-- = COPC was not identified

7.2.5.2 Summary of Results for the Industrial Worker Scenario under MTCA Method C. The total ELCRs for three exposure areas (C, P, and U) are greater than the MTCA Method C risk threshold of 1 x 10^{-6}. Arsenic was identified as the risk contributor at those three exposure areas. The ELCR based on the background concentration for arsenic is equal to or greater than the ELCRs for each exposure area. Therefore, arsenic was retained for further evaluation. The HI for any exposure area did not exceed the target HI of 1. Table 7-3 provides a summary of the cancer risk and noncancer hazards. RPP-RPT-58329, Appendix C, Attachment C-2 includes the risk assessment results for the industrial worker scenario under MTCA Method C.

Table 7-3. Summary of Total Risk Characterization Results for the Industrial Worker Exposure Scenario under MTCA Method C

	Carcinogenic Risk - Nonradiological		Hazard - Nonradiological	
Exposure Area	**ELCR**	**Risk Drivers**	**HI**	**Noncancer Hazard Drivers**
A+B	4 x 10^{-7}	--	0.03	--
C	2 x 10^{-6}	Arsenic	0.05	
E	9 x 10^{-7}	--	0.06	
F+G	4 x 10^{-7}		0.01	
H+I	6 x 10^{-7}		0.03	
J	9 x 10^{-7}		0.04	
L1+L2	5 x 10^{-7}		0.03	
P	1.2 x 10^{-6}	Arsenic	0.03	
R	7 x 10^{-7}	--	0.04	
U	1.1 x 10^{-6}	Arsenic	0.05	
Background Evaluation – Arsenic				
ELCR			2 x 10^{-6}	

RPP-RPT-58329, Table 3-4
-- = COPC was not identified

7.2.5.3 Summary of Results for the Construction Worker Scenario. The total ELCRs for nonradiological and radiological COPCs for each exposure area are less the EPA upper risk threshold of 1 x 10^{-4}. Noncancer hazards were identified as less than the target HI of 1. Table 7-4 provides a summary of the cancer risk and noncancer hazards. RPP-RPT-58329, Appendix C, Attachment C-3 and Appendix D, Attachment D-2 includes the results of the construction worker scenario for nonradiological and radiological risk assessments, respectively.

Table 7-4. Summary of Total Risk Characterization Results for the Construction Worker Exposure Scenario

Exposure Area	Carcinogenic Risk - Radiological		Carcinogenic Risk - Nonradiological		Hazard - Nonradiological	
	ELCR	Risk Drivers	ELCR	Risk Drivers	HI	Noncancer Hazard Drivers
A+B	8×10^{-6}	--	3×10^{-8}	--	0.04	--
C	1×10^{-5}		2×10^{-7}		0.07	
E	4×10^{-6}		6×10^{-8}		0.03	
F+G	7×10^{-7}		3×10^{-8}		0.02	
H+I	2×10^{-6}		4×10^{-8}		0.04	
J	4×10^{-7}		6×10^{-8}		0.2	
L1+L2	2×10^{-6}		3×10^{-8}		0.04	
P	2×10^{-6}		4×10^{-8}		0.04	
R	8×10^{-9}		4×10^{-8}		0.05	
U	1×10^{-6}		6×10^{-8}		0.04	

RPP-RPT-58329, Table 3-5
-- = COPC was not identified

7.2.5.4 Summary of Results for the Maintenance/Surveillance Worker Scenario. The total ELCRs for five exposure areas (A+B, C, E, L1+L2, and P) are greater than the EPA upper risk threshold of 1×10^{-4}. Two major risk contributors, ^{137}Cs and ^{126}Sn are retained as radiological COPCs for further evaluation in the CMS. Noncancer hazards were identified at less than the target HI of 1. Table 7-5 provides a summary of the cancer risk and noncancer hazards. RPP-RPT-58329, Appendix C, Attachment C-4 and Appendix D, Attachment D-3 includes the results of the maintenance/surveillance worker scenario for nonradiological and radiological risk assessments, respectively.

Table 7-5. Summary of Total Risk Characterization Results for the Maintenance/ Surveillance Worker Exposure Scenario

Exposure Area	Carcinogenic Risk - Radiological		Carcinogenic Risk - Nonradiological		Hazard - Nonradiological	
	ELCR	Risk Drivers	ELCR	Risk Drivers	HI	Noncancer Hazard Drivers
A+B	5×10^{-4}	Cs-137, Sn-126	1×10^{-6}	--	0.05	--
C	6×10^{-4}		6×10^{-6}		0.1	
E	2×10^{-4}		3×10^{-6}		0.05	
F+G	4×10^{-5}	--	1×10^{-6}		0.03	
H+I	8×10^{-5}	--	1×10^{-6}		0.06	
J	3×10^{-5}	--	2×10^{-6}		0.3	

Table 7-5. Summary of Total Risk Characterization Results for the Maintenance/ Surveillance Worker Exposure Scenario

Exposure Area	Carcinogenic Risk - Radiological		Carcinogenic Risk - Nonradiological		Hazard - Nonradiological	
	ELCR	Risk Drivers	ELCR	Risk Drivers	HI	Noncancer Hazard Drivers
L1+L2	1×10^{-4}	Cs-137, Sn-126	1×10^{-6}		0.05	
P	2×10^{-4}	Cs-137	1×10^{-6}		0.06	
R	8×10^{-7}	--	2×10^{-6}		0.1	
U	7×10^{-5}	--	3×10^{-6}		0.1	

RPP-RPT-58329, Table 3-6
-- = COPC was not identified

7.2.5.5 Summary of Results for the Trespasser Adult Scenario. The total ELCRs for each exposure area are less than the EPA upper risk threshold of 1×10^{-4}. Noncancer hazards were identified at less than the target HI of 1. Table 7-6 provides a summary of the cancer risk and noncancer hazards. RPP-RPT-58329, Appendix C, Attachment C-5 and Appendix D, Attachment D-4 includes the results of the adult trespasser scenario for nonradiological and radiological risk assessments, respectively.

Table 7-6. Summary of Total Risk Characterization Results for the Adult Trespasser Exposure Scenario

Exposure Area	Carcinogenic Risk - Radiological		Carcinogenic Risk - Nonradiological		Hazard - Nonradiological	
	ELCR	Risk Drivers	ELCR	Risk Drivers	HI	Noncancer Hazard Drivers
A+B	5×10^{-5}	--	1×10^{-7}	--	0.01	--
C	7×10^{-5}		8×10^{-7}		0.01	
E	2×10^{-5}		2×10^{-7}		0.01	
F+G	5×10^{-6}		1×10^{-7}		0.01	
H+I	9×10^{-6}		2×10^{-7}		0.01	
J	4×10^{-6}		3×10^{-7}		0.04	
L1+L2	1×10^{-5}		1×10^{-7}		0.01	
P	2×10^{-5}		2×10^{-7}		0.01	
R	2×10^{-8}		2×10^{-7}		0.01	
U	9×10^{-6}		3×10^{-7}		0.01	

RPP-RPT-58329, Table 3-7
-- = COPC was not identified

7.2.5.6 Summary of Results for the Trespasser Youth Scenario. The total ELCR for nonradiological and radiological COPCs in shallow vadose zone soil at Exposure Areas A+B, and C are greater than the EPA upper risk threshold of 1×10^{-4}. Table 7-7 provides a summary of the cancer risk and noncancer hazards. RPP-RPT-58329, Appendix C, Attachment C-6 and Appendix D, Attachment D-5 includes the results of the youth trespasser scenario for nonradiological and radiological risk assessments, respectively.

Table 7-7. Summary of Total Risk Characterization Results for the Youth Trespasser Exposure Scenario

Exposure Area	Carcinogenic Risk - Radiological		Carcinogenic Risk - Nonradiological		Hazard - Nonradiological	
	ELCR	Risk Drivers	ELCR	Risk Drivers	HI	Hazard Drivers
A+B	1×10^{-4}	Cs-137, Sn-126	2×10^{-7}	--	0.04	--
C	2×10^{-4}		1×10^{-6}		0.08	
E	6×10^{-5}	--	3×10^{-7}		0.04	
F+G	1×10^{-5}		2×10^{-7}		0.04	
H+I	2×10^{-5}		3×10^{-7}		0.05	
J	6×10^{-6}		5×10^{-7}		0.25	
L1+L2	3×10^{-5}		3×10^{-7}		0.04	
P	4×10^{-5}		4×10^{-6}		0.05	
R	1×10^{-7}		4×10^{-7}		0.05	
U	2×10^{-5}		4×10^{-7}		0.05	

RPP-RPT-58329, Table 3-8
-- = COPC was not identified

For radiological COPCs, the total ELCRs Exposure Areas A+B, and C are greater than the EPA upper risk threshold of 1×10^{-4}. The major risk contributors to the total cumulative ELCRs are ^{137}Cs and ^{126}Sn. Therefore, both are retained as radiological COPCs for further evaluation in the CMS.

For nonradiological COPCs, the total ELCR for Exposure Areas A+B, and C are less than the WAC 173-340-745 cumulative risk threshold of 1×10^{-5}. No major nonradiological risk contributor was identified. The HIs for noncancer effects did not exceed the acceptable target HI of 1.

7.2.5.7 Summary of Results for the CERCLA Residential Scenario. For nonradiological COPCs, the ELCR for six exposure areas (C, E, F+G, H+I, P and R) are greater than the cumulative risk threshold of 1 x 10^{-5}. The HI exceeded the target HI of 1 for eight exposure areas (A+B, C, H+I, J, L1+L2, P, R and U). A background risk and hazard assessment was performed on the primary nonradiological risk and hazard drivers. The background risk was equal to or greater than the ELCRs for each exposure area, and background HI was greater than the HIs for each exposure area. Therefore, no nonradiological risk contributors were retained.

For radiological COPCs, the ELCR for nine exposure areas (A+B, C, E, F+G, H+I, J, L1+L2, P, and U) are greater than the upper risk threshold 1 x 10^{-4}. Cesium-137, ^{60}Co, ^{63}Ni, ^{79}Se, ^{90}Sr, and ^{126}Sn were identified as major risk contributors at various exposure areas. Therefore, they are retained as radiological COPCs for further evaluation. Table 7-8 provides a summary of the cancer risk and noncancer hazards. RPP-RPT-58329, Appendix C, Attachments C-7 and C-8 include the results of the adult and child residential scenario risk assessments for nonradionuclides. RPP-RPT-58329, Appendix D, Attachment D-6 includes the results of the residential scenario risk assessments for radionuclides.

Table 7-8. Summary of Total Risk Characterization Results for the CERCLA Residential Exposure Scenario

Adult						
	Carcinogenic Risk - Radiological		Carcinogenic Risk - Nonradiological		Hazard - Nonradiological	
Exposure Area	ELCR	Risk Drivers	ELCR	Risk Drivers	HI	Noncancer Hazard Drivers
A+B	2 x 10^{-3}	Cs-137, Se-79, Sn-126, Sr-90	3 x 10^{-6}	--	0.1	--
C	2 x 10^{-3}	Cs-137, Sn-126, Sr-90	1 x 10^{-5}	Arsenic	0.3	
E	1 x 10^{-3}	Cs-137, Se-79, Sn-126, Sr-90	4 x 10^{-6}	--	0.1	
F+G	2 x 10^{-4}		3 x 10^{-6}		0.06	
H+I	4 x 10^{-4}	Se-79, Sn-126	4 x 10^{-6}		0.2	
J	3 x 10^{-4}	Cs-137, Se-79, Sr-90	6 x 10^{-6}		0.2	
L1+L2	5 x 10^{-4}	Cs-137, Ni-63, Se-79, Sn-126, Sr-90	3 x 10^{-6}		0.1	
P	2 x 10^{-3}	Co-60, Cs-137, Se-79, Sn-126, Tc-99	4 x 10^{-6}		0.2	
R	7 x 10^{-6}	--	4 x 10^{-6}		0.2	
U	4 x 10^{-4}	Cs-137, Se-79, Sn-126, Sr-90	5 x 10^{-6}		0.2	

Table 7-8. Summary of Total Risk Characterization Results for the CERCLA Residential Exposure Scenario

Background Evaluation – Arsenic						
Total ELCR			1×10^{-5}			
Child						
Exposure Area	**Carcinogenic Risk - Radiological**		**Carcinogenic Risk - Nonradiological**		**Hazard - Nonradiological**	
	ELCR	**Risk Drivers**	**ELCR**	**Risk Drivers**	**HI**	**Noncancer Hazard Drivers**
A+B	--		7×10^{-6}	--	1.4	Arsenic, Cobalt, Iron, Vanadium
C			4×10^{-5}	Arsenic	2.5	Arsenic, Cobalt, Iron
E			9×10^{-6}	--	1.1	Arsenic, Cobalt, Lithium
F+G			6×10^{-6}		0.6	--
H+I			9×10^{-6}		1.5	Arsenic, Cobalt, Iron, Vanadium
J			1.4×10^{-5}	Arsenic	2.0	Arsenic, Boron, Cobalt, Iron
L1+L2			7×10^{-6}	--	1.3	Arsenic, Cobalt, Iron, Vanadium
P			9×10^{-6}		1.6	
R			1×10^{-5}		1.7	Arsenic, Cobalt, Iron
U			1×10^{-5}	Arsenic	1.6	
Background Evaluation – Nonradiological COPCs						
Nonradiological Risk			**Noncancer Hazard**			
Total ELCR	5×10^{-5}		**HI**	3.0		

Table 3-9 and 3-10, RPP-RPT-58329
-- = COPC was not identified

7.2.5.8 Summary of Results for the WAC Residential Scenario under MTCA Method B

The ELCR for each exposure area is greater than the cumulative risk threshold of 1 x 10^{-5}. The HI exceeded the target HI of 1 for nine exposure areas (A+B, C, E, H+I, J, L1+L2, P, R and U). A background risk and hazard assessment was performed on the primary risk and hazard drivers. The background risk was equal to or greater than the ELCRs for each exposure area, and the background HI was greater than the HIs for each exposure area. Therefore, no risk contributors were retained for further evaluation for WMA C. Table 7-9 provides a summary of the cancer risk and noncancer hazards. RPP-RPT-58329, Appendix C, Attachment C-9 includes the risk assessment results for the residential scenario under MTCA Method B.

Table 7-9. Summary of Total Risk Characterization Results for the Residential Exposure Scenario under MTCA Method B

Exposure Area	Carcinogenic Risk - Nonradiological		Hazard - Nonradiological	
	ELCR	Risk Drivers	HI	Noncancer Hazard Drivers
A+B	6 x 10^{-6}	--	1.4	Arsenic, Cobalt, Iron, Vanadium
C	3 x 10^{-5}	Arsenic	2.4	Arsenic, Cobalt, Iron
E	8 x 10^{-6}	--	1.1	Arsenic, Cobalt, Iron, Lithium
F+G	5 x 10^{-6}		0.6	--
H+I	8 x 10^{-6}		1.5	Arsenic, Cobalt, Iron, Vanadium
J	1 x 10^{-5}	Arsenic	1.6	Arsenic, Cobalt, Iron
L1+L2	6 x 10^{-6}	--	1. 3	Arsenic, Cobalt, Iron, Vanadium
P	8 x 10^{-6}		1.5	
R	9 x 10^{-6}		1.6	Arsenic, Cobalt, Iron
U	1 x 10^{-5}	Arsenic	1.5	
Background Evaluation – Nonradiological COPCs				
Total ELCR	3 x 10^{-5}		**HI**	2.3

Table 3-11, RPP-RPT-58329
-- = COPC was not identified

7.2.5.9 Summary of Results for the Tribal Exposure Scenario.

Table 7-10 provides a summary of the CTUIR cancer risks and noncancer hazard for each exposure area. RPP-RPT-58329, Appendix C, Attachments C-10 and C-11 include the intake and risk calculation for all ten exposure areas under the CTUIR adult and child receptor scenarios, respectively. RPP-RPT-58329, Appendix D, Attachment D-7 includes the results of the maximum radiological dose and risk assessments over a period of 1,000 years under the CTUIR scenario.

Table 7-10. Summary of Total Risk Characterization Results for the CTUIR Exposure Scenario

Adult			
	Carcinogenic Risk - Radiological	**Carcinogenic Risk - Nonradiological**	**Hazard - Nonradiological**
Exposure Area	**ELCR**	**ELCR**	**HI**
A+B	7×10^{-3}	3×10^{-5}	0.6
C	8×10^{-3}	2×10^{-4}	1.1
E	3×10^{-3}	1×10^{-4}	0.5
F+G	8×10^{-4}	3×10^{-5}	0.3
H+I	1×10^{-3}	4×10^{-5}	0.7
J	2×10^{-3}	6×10^{-5}	0.9
L1+L2	2×10^{-3}	3×10^{-5}	0.6
P	7×10^{-3}	4×10^{-5}	0.7
R	3×10^{-5}	5×10^{-5}	0.7
U	2×10^{-3}	6×10^{-5}	0.7
Child			
	Carcinogenic Risk - Radiological	**Carcinogenic Risk - Nonradiological**	**Hazard - Nonradiological**
Exposure Area	**ELCR**	**ELCR**	**HI**
A+B	--	1×10^{-5}	2.9
C		8×10^{-5}	5.2
E		2×10^{-5}	2.2
F+G		1×10^{-5}	1.5
H+I		2×10^{-5}	3.2
J		3×10^{-5}	4.1
L1+L2		1×10^{-5}	2.7
P		2×10^{-5}	3.2
R		2×10^{-5}	3.5
U		3×10^{-5}	3.3

RPP-RPT-58329, Table 3-12

-- = COPC was not identified

Table 7-11 provides a summary of the Yakama Nation cancer risks and noncancer hazard for each exposure area. RPP-RPT-58329, Appendix C, Attachments C-12 and C-13 include the intake and risk calculation for all ten exposure areas under the Yakama adult and child receptor Tribal scenarios, respectively. RPP-RPT-58329, Appendix D, Attachment D-8 presents the

results of the maximum radiological dose and risk assessments over a period of 1,000 years under the Yakama Nation Tribal scenario.

Table 7-11. Summary of Total Risk Characterization Results for the Yakama Nation Exposure Scenario

Adult			
	Carcinogenic Risk - Radiological	**Carcinogenic Risk - Nonradiological**	**Hazard - Nonradiological**
Exposure Area	**ELCR**	**ELCR**	**HI**
A+B	8×10^{-3}	2×10^{-5}	0.3
C	9×10^{-3}	9×10^{-5}	0.6
E	4×10^{-3}	2×10^{-5}	0.3
F+G	1×10^{-3}	1×10^{-5}	0.2
H+I	2×10^{-3}	2×10^{-5}	0.3
J	2×10^{-3}	3×10^{-5}	0.4
L1+L2	2×10^{-3}	2×10^{-5}	0.3
P	7×10^{-3}	2×10^{-5}	0.3
R	2×10^{-5}	2×10^{-5}	0.4
U	2×10^{-3}	3×10^{-5}	0.4
Child			
	Carcinogenic Risk - Radiological	**Carcinogenic Risk - Nonradiological**	**Hazard - Nonradiological**
Exposure Area	**ELCR**	**ELCR**	**HI**
A+B	--	1×10^{-5}	2.9
C		8×10^{-5}	5.2
E		2×10^{-5}	2.4
F+G		1×10^{-5}	2.8
H+I		2×10^{-5}	3.2
J		3×10^{-5}	3.4
L1+L2		1×10^{-5}	2.7
P		2×10^{-5}	3.2
R		2×10^{-5}	3.5
U		3×10^{-5}	3.2

RPP-RPT-58329, Table 3-13
-- = COPC was not identified

7.2.6 Summary of Groundwater Protection Evaluation

Evaluation of a groundwater protection pathway for radionuclides and nonradiological COPCs is used to determine if vadose zone contamination may impact groundwater. Radiological contaminants in the vadose zone will be evaluated using models developed in support of the WMA C Performance Assessment. Therefore, no evaluation was performed for radiological COPCs in the vadose zone in the baseline risk assessment.

Nonradiological COPCs in the vadose zone were evaluated using the WAC 173-340-747(4) fixed-parameter three-phase partitioning model (hereinafter referred to as the three-phase model) cleanup levels. Documentation of the cleanup level calculations is provided in ECF-HANFORD-10-0442, *Calculation of Nonradiological Soil Concentrations Protective of Groundwater Using the Fixed Parameter 3-Phase Equilibrium Partitioning Equation for the 100 Areas and 300 Area*.

The evaluation of soil COPC concentrations protective of groundwater compares maximum detected concentrations and EPCs for each nonradiological COPC to corresponding soil cleanup levels, based on the three-phase model. COPCs for which maximum detected concentrations were greater than the cleanup levels were then evaluated against background concentrations (DOE/RL-92-24). The results of the evaluation of soil concentrations protective of groundwater is summarized in RPP-RPT-58329 Table 3-14.

Five COPCs (arsenic, cadmium, nitrate, beta-BHC, and lindane) were identified as exceeding their corresponding three-phase model soil cleanup levels and background levels. Protection of groundwater underlying WMA C will be evaluated in the future using a more representative site-specific model developed to support the WMA C Performance Assessment. Final decisions regarding those COPCs will be taken following the development of protective soil concentrations based on the representative site-specific model.

7.2.7 Uncertainty Analysis

The methodology used in this risk assessment is consistent with EPA risk assessment guidance documents and cleanup regulations (WAC 173-340). However, due to the many assumptions that must be made about exposure and toxicity, there is uncertainty associated with every risk assessment. Assumptions built into the risk assessment, in general, overestimate rather than underestimate potential risks, but occasionally can result in underestimating risk. Uncertainty is inherent in the selection of input parameters and in every step of the risk assessment process. Risk assessment of contaminated sites must not be viewed as yielding single value, invariant results. Rather, the results of risk assessment are estimates that span a range of possible values, and must be understood only in light of the assumptions and methods used in the evaluation.

The results of the HHRA conducted for WMA C are presented in terms of the potential for adverse effects based upon a number of conservative assumptions. The tendency to be conservative is an effort toward ensuring that the results of the assessment are protective of human health. Uncertainty can be found in all phases of the risk assessment: in the analytical data, the exposure assessment, the toxicity assessment, and the risk characterization.

The sources of uncertainty are summarized in RPP-RPT-58329.

Current baseline conditions are represented by soil sample analysis data collected from 14 biased sampling locations within the WMA C. No systematic or random samples were collected. In addition, the soil sample data set from 14 biased sampling locations were further divided into 10 exposure units. Therefore, the results of the HHRA are based on biased samples and are potentially overly conservative.

Calculating UCLs for EPCs (OSWER 9285.6-10) recommends using a 95% UCL on the mean for estimating EPCs. RPP-RPT-57218, describes the methodology for calculating the EPCs for detected analytes. The uncertainty from a relatively small sample size (i.e., less than five) requires a greater amount of conservatism during the estimation of mean, while a large sample size requires less conservatism during the estimation of mean. Therefore, maximum detected concentrations were selected as the EPCs for small sample size. For either case, a conservative bias to overestimate potential exposure has been incorporated into the risk estimates. The uncertainty associated with the statistical analysis of environmental data is low, with little introduction of bias.

The exposure assumptions developed for each exposure scenario represent a RME. For estimating the RME, 95 percentile values (or upper-bound estimates of national averages) are generally used for exposure assumptions, and exposed populations and exposure scenarios are also selected to represent upper-bound exposures. In general, these assumptions are intended to be conservative and yield an over-estimate of the true risk or hazard.

The toxicological database was also a source of uncertainty. EPA has outlined some of the sources of uncertainty as defined in the risk assessment guide (EPA/540/1-89/002) and in the human health toxicity values (Cook 2003). For example, a source of uncertainty may result from the extrapolation of high to low doses and from animals to humans.

In the risk characterization, the assumption was made that the total risk of developing cancer from exposure to COPCs is the sum of the risk attributed to each individual contaminant. Likewise, the potential for the development of noncancer adverse effects is the sum of the HQs estimated for exposure to each individual contaminant. This approach, in accordance with EPA guidance, did not account for the possibility that COPCs act synergistically or antagonistically.

7.3 SCREENING LEVEL ECOLOGICAL RISK ASSESSMENT

A SLERA is a process for evaluating the likelihood that releases of chemicals from contaminated media may adversely affect ecological receptors. This SLERA will determine the potential for adverse ecological impacts resulting from exposure to nonradiological and radiological COPCs released to the environment through past site operations at WMA C. This SLERA provides information that is intended for use to determine: 1) whether ecological risks at the site are negligible, 2) if further information and evaluation are necessary to better define potential ecological risk at the site, or 3) determine if mitigation should be done without further evaluation.

The SLERA was prepared primarily in accordance with the framework developed using the tiered process outlined in CHPRC-00784, *Tier 1 Risk-Based Soil Concentrations Protective of Ecological Receptors at the Hanford Site*. The framework was based on the steps outlined in EPA 540-R-97-006, *Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments: Interim Final*, hereafter referred to as ERAGS, and the ecological evaluation procedure presented in WAC 173-340-7490 through WAC 173-340-7493 ("Model Toxics Control Act—Cleanup," "Terrestrial Ecological Evaluation Procedures;" "Exclusions from a Terrestrial Ecological Evaluation;" "Simplified Terrestrial Ecological Evaluation Procedures;" and "Site-Specific Terrestrial Ecological Evaluation Procedures"). This tiered process allows the incorporation of more sophisticated ecological risk assessment methods and increasing levels of ecological site-specific and site relevant information to provide soil screening levels (SSL) that are more representative of Hanford Site conditions. The framework for this evaluation consists of the following progressively more site-specific tiers:

- Characterization of the Ecological Setting – This section evaluates site ecological settings and the potential for habitat for terrestrial receptors, as well as review of the potential for certain sensitive species for the regional area (Section 7.4).

- Selections of Contaminants of Potential Ecological Concerns (COPEC) – During this step, COPECs were selected for soil (Section 7.5). The selection of COPECs utilized the soil characterization sampling results collected from 14 sampling locations (A, B, C, E, F, G, H, I, J, L1/L2, P, R, and U) within 10 EUs.

- Tiered Assessments – Tiered based risk assessments were conducted based on the framework presented in CHPRC-00784. Generic screening and Tier 1 screenings were performed as a part of the tiered based risk assessments.

  - Generic screening (Section 7.5.1) – During the generic screen, the maximum detected concentration of each COPEC was divided to its corresponding literature-derived generic SSLs to calculate HQ. If the HQs for the COPECs are less than 1, those COPECs were not retained for further evaluation. When the HQs for the COPECs are greater than 1, those COPECs are retained for Tier 1 screening.

  - Tier 1 screening (Section 7.5.2) – Based on toxicity reference values (TRV), two types of screening were performed during Tier 1 screening. During the first screen, the maximum detected concentration of each COPEC was compared to its corresponding screening benchmark (referred as no observed adverse effect level [NOAEL]). The COPECs with maximum concentrations less than the NOAELs were considered to pose negligible risk and therefore, were eliminated from further consideration. COPECs with maximum concentrations equal or greater than the NOAEL were retained for second Tier 1 screening.

    During the second screen, sampling results for remaining COPECs were divided by their corresponding screening benchmark, based on lowest observed adverse effect level (LOAEL) to calculate HQ. If the HQs for the COPECs are less than 1, those

COPECs were not retained for further evaluation. When the HQs are the COPECs are greater than 1, scientific management decision points (SMDP) were considered before retaining them.

- Preliminary SMDP (Section 7.6) – Potential risks identified through the direct comparison of maximum detected concentration for COPECs within each exposure area to SSLs were considered in the context of size of the site relative to the home range of wildlife receptors.

- Uncertainty Analysis (Section 7.7) – This section addresses potential sources of uncertainty in the SLERA and discusses how assumptions used in the analyses may affect the conclusions.

- Summary of SLERA (Section 7.8) – This section summarizes an evaluation of ecological risks within WMA C.

7.4 CHARACTERIZATION OF ECOLOGICAL SETTING

This section summarizes the ecology of the Hanford Site (Section 4.5 of PNNL-6415), emphasizing plant and animal activities that may affect exposure pathways. PNNL-6415 details both the terrestrial and aquatic ecology of the Hanford Site and presents extensive listings of plant and animal species, while this section considers only terrestrial ecological effects because all SSTs are not located near significant aquatic ecological systems.

As mentioned previously, WMA C is part of the SST system in the 200 East Area of the Hanford Site and is one of the first four tank farms built at the Hanford Site in 1944. The area within WMA C consists primarily of undeveloped land within the fence line of the 200 East Area. Chemical processing facilities, decommissioned nuclear reactors, and supporting facilities occupy only about 6% of the Hanford Site. Most of the Hanford Site has not experienced tillage or agricultural grazing since the early 1940s.

The Hanford Site is characterized as a shrub-steppe ecosystem that is adapted to the mid-latitude semiarid climate of the region. These ecosystems are typically dominated by a shrub overstory with a grass understory. In the early 1800s, dominant plants in the area consisted of large sagebrush (*Artemisia tridentata*) and an understory consisting of perennial Sandberg's bluegrass (*Poa sandbergii*) and bluebunch wheatgrass (*Pseudoregneria spicata*). Other species included threetip sagebrush, bitterbrush, gray rabbitbrush, spiny hopsage, bluebunch wheatgrass, needle-and-thread grass, Indian rice grass, and prairie June grass.

With the advent of settlement, livestock grazing and agricultural production contributed to colonization of non-native vegetation species that currently dominate portions of the landscape. Although agriculture and livestock production were the primary subsistence activities at the turn of the century, these activities ceased when the Hanford Site was designated in 1943. No farming has occurred on the Hanford Site since the government took control of the Site. The dominant non-native species, cheatgrass, is an aggressive colonizer and has become well

established across the Site. Over the past decade, several knapweed species also have become persistent invasive species in areas not dominated by shrubs. Range fires that historically burned through the area during the dry summers eliminated fire-intolerant species (e.g., big sagebrush) and allowed more opportunistic and fire-resistant species to establish. Of the 590 species of vascular plants recorded for the Hanford Site, approximately 20% are non-native. Wildfires are frequent on the Hanford Site. Three large wildfires in the past two decades have burned over 15% of the site.

Currently, no plant species on the Hanford Site are federally listed as threatened or endangered under the *Endangered Species Act of 1973*. Plant species listed as threatened or endangered by Washington State include the awned halfchaff sedge (*Lipocarpha aristulata*), grand redstem (*Ammannia robusta*), lowland toothcup (*Rotala ramosior*), and persistentsepal yellowcress (*Rorippa columbiae*). These plant species are restricted to wetlands in the riparian zone of the Columbia River (PNNL-6415).

Even though wildlife use of the disturbed and developed areas is expected to be reduced as these areas are less attractive and provide fewer of the needs of wildlife than do natural habitats, these areas are frequented by wildlife. Common species include large animals like Rocky Mountain elk (*Cervus elaphus*) and mule deer (*Odocoileus hemionus*); predators such as coyote (*Canis latrans*), bobcat (*Lynx rufus*), and badger (*Taxidea taxus*); and herbivores including deer mice (*Peromyscus maniculatus*), harvest mice (*Riethrodontonomys megalotis*), ground squirrels (*Spermophilus* spp.), voles (*Lemmiscus curtatus, Microtus* spp.), and black-tailed jackrabbits (*Lepus californicus*). The most abundant mammal on the Hanford Site is the Great Basin pocket mouse (*Perognathus parvus*). Other nonburrowing animals including cottontails (*Sylvilagus nutalli*), jackrabbits, snakes, and burrowing owls (*Athene cunicularia*), which may use abandoned burrows of other animals.

No species that regularly frequent the Hanford Site are listed as threatened or endangered under the *Endangered Species Act of 1973*. Species listed as threatened or endangered by Washington State include the burrowing owl (*Athene cunicularia*), Merriam's shrew (*Sorex merriami*), and Washington ground squirrel (*Urocitellus washingtoni*). However, no species are known or expected to occur onsite because of the highly developed nature of the area.

As mentioned previously, WMA C is located in the northeast corner of the Inner Area of the Hanford Site 200 East Area. The boundary of the Inner Aarea is defined by waste disposal decisions already in place and anticipated future decisions that will require continued waste management and containment of residual contamination (DOE/RL-2009-81 Figure 2*;* DOE/RL-2009-10, *Hanford Site Cleanup Completion Framework*). Future land use for the Inner Area of the Central Plateau will be industrial and will remain under federal ownership and control. Public access to the Hanford Site is restricted. No food is grown at the Hanford Site. The area within WMA C is covered by fill material with a gravel surface. It is actively managed to preclude nuisance colonization by plants and associated communities of animals. Herbicides and pesticides are used on a regular basis to control plant growth and fences are placed around the perimeter to keep larger animals out. Without a source of food within the WMA, smaller animals are less likely to enter.

7.5 IDENTIFICATION OF CONTAMINANTS OF POTENTIAL ECOLOGICAL CONCERN

Analytical results from the 10 WMA C exposure areas are described in Section 7.1.1 and were obtained from the HEIS database. The analytical data processing and reduction steps evaluate data qualification flags, analytes reported by multiple analytical methods, and duplicate results. After the data has been processed, exclusion criteria are applied to identify a subset of COPECs to be carried forward. The following were excluded:

- Radionuclides that have half-lives less than 3 years and that are not significant daughter products
- Naturally occurring radionuclides that are not directly related to Hanford Site operation or processes
- Essential nutrients (minerals) (calcium, magnesium, potassium, and sodium)

Analytes that have been analyzed for but not detected in any sample (collected from appropriate locations with adequate detection limits) were eliminated as COPECs. All analytes detected at least once in an exposure area were identified as COPECs. Table 4-1, RPP-RPT-58329 identifies the COPECs for each exposure area. The results of the screening level ecological risk assessment are included in RPP-RPT-58329, Appendix E.

7.5.1 Generic Screening Levels

Generic screening levels for plants, soil invertebrates, birds, and mammals are obtained from existing published and accepted sources including, EPA (Ecological soil screening levels [EcoSSL]), Washington State Department of Ecology (Ecological Indicator Soil Concentrations), Oak Ridge National Laboratory Screening-Level Benchmarks, and the DOE Biota Concentrations Guides. Generic Screening Values are not specific to the Hanford Site; rather, they represent conservative, literature-based screening values. Because of their inherent conservatism, Generic Screening Levels are intended to differentiate between COPECs that clearly present no risk and those for which additional evaluation may be warranted. Generic screening levels for plants, soil invertebrates, birds, and mammals are obtained from following existing published and accepted sources:

- EPA (EcoSSLs)
- Ecology (Ecological Indicator Soil Concentrations), found in Ecology Publication 94-06, *Model Toxics Control Act Regulation and Statue,* Table 749-3
- Oak Ridge National Laboratory Screening-Level Benchmarks
- DOE Biota Concentrations Guides for radionuclides that are presented in DOE-STD-1153-2002, *A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota*

Table 6-1 of CHPRC-00784, Rev. 1 presents the literature published screening values for plants, soil invertebrates, birds, and mammals, Hanford Site background concentration and the literature-derived generic screening values for 113 out of 137 COPECs considered for the Hanford Site. The literature-derived generic screening levels for COPECs are determined by

- Identifying readily available SSLs for terrestrial plants, soil invertebrates, birds, and mammals extracted from published regulatory agency and related sources.
- Deriving the most conservative (i.e., lowest) SSL for each COPEC from the readily available SSLs for terrestrial plants, soil invertebrates, birds, and mammals.
- Selecting the higher value between the most conservative SSL for each COPEC and its corresponding Hanford Site background concentration.

7.5.1.1 Generic Screening Process. The generic screening process represents the first two steps of the 8-step EPA process presented in ERAGS (EPA 540-R-97-006). 1) The most conservative literature derived generic SSLs were identified for each contaminant. 2) The maximum detected concentration for each COPEC within each exposure area were compared against the Generic Screening Levels established to identify contaminants that poses no ecological risk and thereby require no further evaluation. Contaminants that require additional evaluation are evaluated by calculating a preliminary HQ. The preliminary HQ is obtained by the following equation:

$$Preliminary\ HQ = \frac{Max\ Detected\ Concentration}{Generic\ Screening\ Level}$$

A contaminant was retained as a COPEC and subject to a Tier 1screening in the SLERA if the preliminary HQ exceeded 1.0. RPP-RPT-58329, Appendix E, Attachments E-1 and E-2 included the results of generic screening for nonradiological and radiological COPECs, respectively. Table 4-2, RPP-RPT-58329 identifies nonradiological COPECs with HQs greater than 1 for each exposure area. For radiological COPECs the maximum detected concentration was divided by the generic SSL. The ratios are then summed to calculate the sum of fraction (SOF). RPP-RPT-58329, Table 4-3 identifies radiological COPECs with a SOF greater than 1.

7.5.2 Tier 1 Assessment

Tier 1 assessment was performed for COPECs that were retained during the generic screening. Under Tier 1 assessment, the maximum detected concentrations for retained COPECs were compared against Tier I SSLs. Tier 1 SSLs were developed to reflect Hanford-specific conditions using information obtained from the literature. Overall guidance for the development of tiered values is presented in ERAGS (EPA 540-R-97-006). Tier 1 SSLs for wildlife were back-calculated from TRVs using a wildlife exposure model. The TRVs used were based on both NOAELs and LOAELs. The Tier 1 values for wildlife are more site-specific than the Generic Screening Levels, because they incorporate exposure factors for wildlife species that

occur at the Hanford Site. Tier 1 SSLs for plants and soil invertebrates are not available (CHPRC-00784). CHPRC-00784, Rev. 1 details the development of Tier 1 SSLs.

7.5.2.1 Problem Formulation. The problem formulation includes the development of an ecological conceptual site model that evaluates potential exposure pathways and identifies the representative species used to assess ecological risk to those and other similar species. Figure 7-4 presents a conceptual site model for Hanford Site terrestrial habitats to establish a relationship between the contaminant sources and transport mechanisms, evaluates potential exposure pathways, and identifies the representative species that were used to assess ecological risk. The medium of concern for WMA C is shallow vadose zone soil 0 to 5 m (0 to 16 ft). With consideration of the ecological setting, land use, and COPEC release mechanisms know at the Hanford Site areas, the following ecological exposure pathways considered the most plausible are: soil and food web/chains. The information necessary for evaluating effects via dermal exposure is generally unavailable. Also, the information necessary for evaluating effects via inhalation is not generally available. Two exposure pathways - incidental ingestion of soil and ingestion of contaminated food/prey were considered during the exposure assessment.

7.5.2.2 Ecological Exposure Assessment. Screening level ecological exposure assessment involves identification of representative ecological receptors and estimation of chemical intake based on the exposure to COPECs detected in the soil. Figure 7-5 presents a food web model for the Hanford Site terrestrial receptors based upon an understanding of the ecology of the area and documented in WMP-20570.

Previous investigations have identified the following entities and their associated organizational level, for consideration during the ERAs within the terrestrial portion of the Hanford Site:

- Terrestrial plants—community level
- Terrestrial invertebrates—community level
- Herbivorous birds—population level
- Herbivorous mammals—population level
- Insectivorous birds—population level
- Insectivorous mammals—population level
- Omnivorous birds—population level
- Omnivorous mammals—population level
- Carnivorous birds—population level
- Carnivorous mammals—population level
- Reptiles and amphibians[3]

[3] Although part of the food web for the upland environment, effects data for reptiles and amphibians are limited. Therefore, SSLs were not developed for this trophic guild.

Figure 7-4. Conceptual Ecological Conceptual Site Model for Hanford Site Terrestrial Habitats

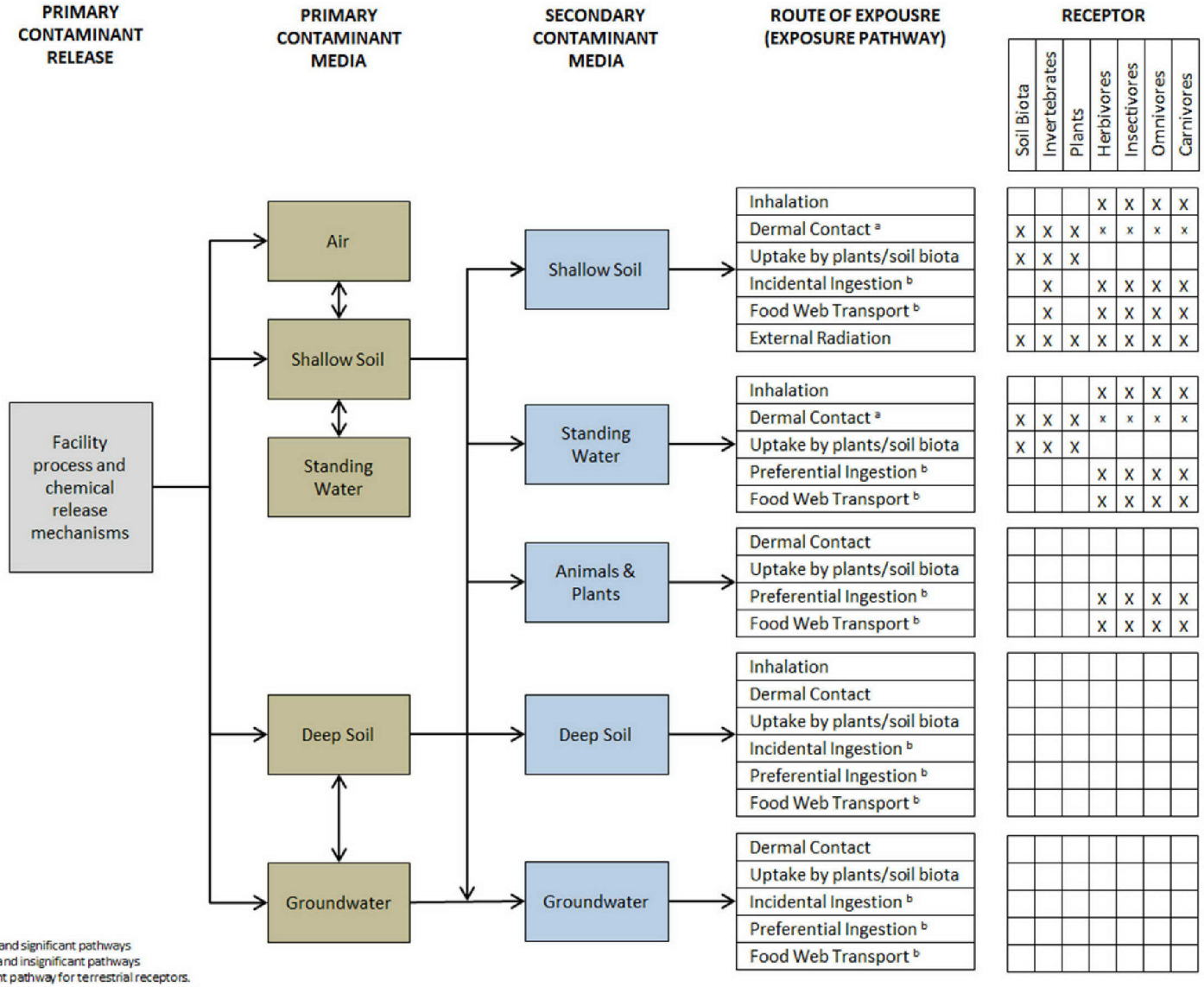
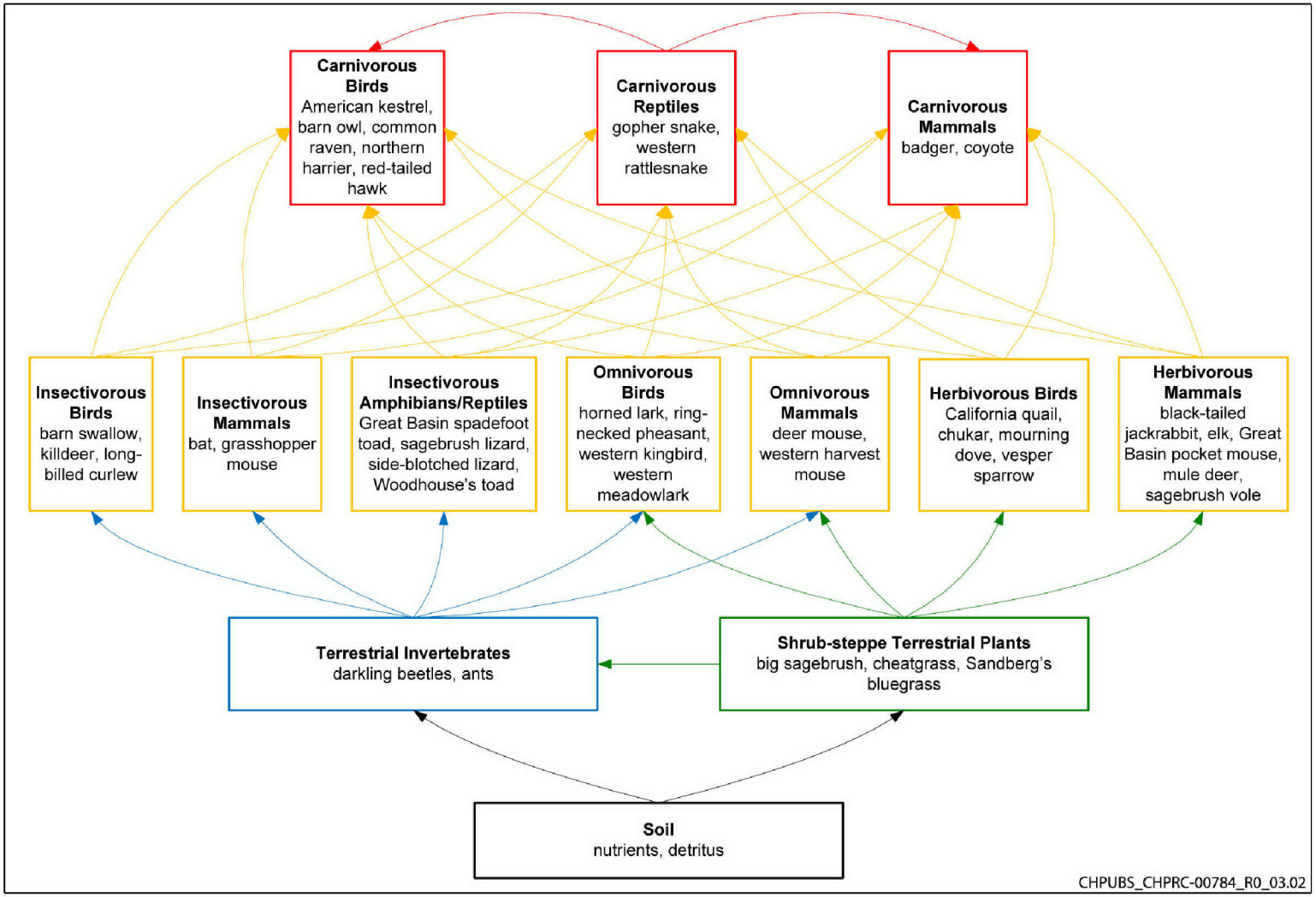


Figure 7-5. Hanford Site Terrestrial Food Web



To calculate Tier 1 values, the following representative Hanford area receptor species common to the terrestrial portion of the Hanford Site were selected for each of the trophic guilds. Consistent with EPA 540-R-97-006, EPA/630/R-95/002F, *Guidelines for Ecological Risk Assessment,* and WAC 173-340-7493, the following factors – species that have ecological relevance, are of societal value, are susceptible to chemical stressors at the site, and allow risk managers to meet policy goals, were used to select representative receptor species.

- Herbivorous birds—California quail (*Callipepla californica*)
- Herbivorous mammals—Great Basin pocket mouse (*Perognathus parvus*)
- Insectivorous birds—killdeer (*Charadrius vociferus*)
- Insectivorous mammals—northern grasshopper mouse (*Onychomys leucogaster*)
- Omnivorous birds—western meadowlark (*Sturnella neglecta*)
- Omnivorous mammals—deer mouse (*Peromyscus maniculatus*)
- Carnivorous birds (raptors)—red-tailed hawk (*Buteo jamaicensis*)
- Carnivorous mammals—badger (*Taxidea taxus*)

During the next step, the exposures were calculated based on the intake of soil and food by the representative receptors to the COPECs presents in the soil. Section 3.2 of the CHPRC-00784, Rev. 1, report presented the methodologies used to quantify nonradiological and radiological intake for Birds and Mammals. In this SLERA, no actual analytical data exists for chemical concentrations in food from soil. For the purposes of exposure estimation, partitioning of constituents from environmental media to prey was estimated from literature values and models. The models presented in the EPA EcoSSLs methodology (OSWER Directive 9285.7-55) were used preferentially for estimation of bioaccumulation into biota from soil. Consistent with the approach employed for the EcoSSLs, regression-based models (if available) and median BAFs from the source selected by EPA were used. In the absence of applicable bioaccumulation models, a default value of 1 was assumed (as in the case of boron uptake to small mammals). In all cases, it was assumed that tissue uptake occurs under steady state conditions. Tier 1 values for nonradiological COPECs were calculated assuming 100% site use.

Exposure to radionuclides differs from chemical exposure. For the purposes of developing Tier 1 values, radionuclide exposure was estimated based on the internal and external radiation exposure models incorporated into DOE-STD-1153-2002. Tier 1 values for 22 radionuclides were calculated for eight representative species (four bird and four mammal species - California quail, western meadowlark, killdeer, red-tailed hawk, Great Basin pocket gopher, deer mouse, grasshopper mouse, and badger) common to the terrestrial portion of the Hanford Site, based on the modified exposure assumptions. Tier 1 values for radionuclides were calculated assuming 100% site use.

7.5.2.3 Screening Level Ecological Effects Assessment. The ecological effects assessment consists of an evaluation of available toxicity or other effects information that can be used to interpret the significance of the exposures to COPECs relative to potential adverse effects to ecological receptors. The effects data used to calculate Tier 1 values was based exclusively on literature derived single-chemical toxicity data.

For nonradiological COPECs, both NOAEL and LOAEL based TRVs for birds and mammals were obtained from various sources and focus was given to the most recent sources and those derived or endorsed by EPA and Ecology. The primary literature source for TRVs was EcoSSLs. Other sources include:

- Other available literature—primarily ES/ER/TM-86/R3, *Toxicological Benchmarks for Wildlife: 1996 Revision*

- NOAEL and LOAEL values selected for chemicals and reported in the EPA Integrated Risk Information System

- NOAEL and LOAEL values presented in Wildlife Toxicity Assessments developed by USACHPPM

There are a number of uncertainties associated with literature –based effects data for plants and soil invertebrates. Therefore literature-based effect values were not attempted, and no Tier 1 SSLs were derived for plants and soil invertebrates (CHPRC-00784, Rev. 1).

For radiological COPECs, more receptor-specific SSLs for wildlife (animals) were developed using RESRAD-BIOTA for Windows, Version 1.5 (ANL 2009) with Level 3 assumptions. Values were established for eight species representing feeding guilds at the site. However, Hanford Site-specific tissue residue of radionuclides was insufficient for developing models so values from relevant published literature were used (Beresford et al. 2008, "Derivation of Transfer Parameters for Use Within the ERICA Tool and the Default Concentration Ratios for Terrestrial Biota").

7.5.2.4 Ecological Risk Characterization. The risk characterization step of the SLERA integrates the results of the exposure and toxicity assessments into a quantitative description of excess risks. Risk is not directly evaluated. Instead, exposure and effects data are used to calculate Tier 1 values that represent COPEC concentrations in soil that are associated with minimal likelihood of adverse effects (i.e., risk).

Tier 1 values for both nonradiological and radiological COPECs for community level and population level receptors that are common to and representative of the Central Plateau Area. These Tier 1 values are developed using approaches consistent with EPA risk assessment protocols (EPA 910/R-97/005, *EPA Region 10 Supplemental Ecological Risk Assessment Guidance for Superfund*; EPA 540-R-97-006; and EPA/630/R-95/002F) and Ecology Publication 94-06. Table 6-13 of CHPRC-00784, Rev. 1 report presents the Tier 1 SSLs for both non-radiological and radiological analytes.

7.5.3 Results of Tier I Screening

Tier 1 assessment was performed for COPECs that were retained during the generic screening. Under Tier 1 assessment, the maximum detected concentrations for retained COPCs were compared against Tier I SSLs by calculating a HQ. The HQ was obtained by dividing the

maximum detected concentration of the COPEC by the appropriate Tier I SSL, as represented by the following equation:

$$HQ = \frac{Maximum\ Detected\ Concentration}{Tier\ 1\ SSL}$$

As mentioned previously, two Tier 1 SSLs for each COPEC were derived based on the corresponding NOAEL and LOAEL, respectively. Table 7-12 summarizes the results of the Tier 1 screening for nonradiological COPECs when the HQs are greater than 1.0.

Table 7-12. Results of Tier 1 Screening for Nonradiological COPECs

Exposure Area	COPEC	Maximum Detected Concentration (mg/kg)	SSL_{NOAEL} (mg/kg)	HQ = Maximum Detected Concentration / SSL_{NOAEL}	SSL_{LOAEL} (mg/kg)	HQ = Maximum Detected Concentration / SSL_{LOAEL}
E	Cadmium	3.26	0.9	**3.62**	2	**1.6**
P	Vanadium	110.00	16	**6.88**	31	**3.5**
	Zinc	305.00	67	**4.55**	68	**4.5**
R	Cadmium	3.47	0.9	**3.86**	2	**1.7**

HQ values less than 1.0 indicate that adverse effects associated with exposure to a given analyte are unlikely (ERAGS [EPA 540-R-97-006]). These analytes were not considered to present a significant risk and were excluded from further evaluation. An HQ greater than or equal to 1.0 indicates data are insufficient to exclude the potential for risk, but does not indicate that risks are actually present; therefore, these COPECs were carried forward for further evaluation.

The results of the Tier 1 assessment show that the HQs for cadmium within Exposure Areas E and R, and HQs for vanadium and zinc within Exposure Area P area greater than 1.0.

All soil sampling results for cadmium within Exposure Areas E and R are approximately two times higher than its corresponding Tier 1 SSL based on LOAEL of 2 mg/kg. It should be noted that the LOAEL value for cadmium was selected based on the SSL for representative insectivorous bird—killdeer. It should be noted that the Tier 1 SSLs for all other representative ecological receptors based on their corresponding LOAELs are greater than the maximum concentration of cadmium for both exposure areas.

One sampling result (110 mg/kg) for vanadium at Exposure Area P is greater than its corresponding literature derived generic SSL value of 85.1 mg/kg. This sample was detected at a depth between 4 to 5 m (14 to 16 ft) bgs. However, all soil sampling results for vanadium are greater than its corresponding Tier 1 SSL based on LOAEL of 31 mg/kg. It should be noted that like cadmium, the LOAEL value for vanadium was selected for representative insectivorous bird—killdeer. It should be noted that the Tier 1 SSLs for all other representative ecological receptors based on their corresponding LOAELs are greater than the maximum concentration of vanadium at Exposure Area P.

One sampling result (305 mg/kg) for zinc at Exposure Area P is five times higher than its corresponding Tier 1 SSL based on LOAEL of 68 mg/kg. It should be noted that like cadmium and vanadium, the LOAEL value for zinc was selected based on the SSL for representative insectivorous bird—killdeer. It should be noted that the Tier 1 SSLs for all other representative ecological receptors based on their corresponding LOAELs are greater than the maximum concentration of zinc at Exposure Area P.

The maximum detected concentration for each radiological COPEC was divided by the Tier 1 SSL based on the LOAEL to determine the HQ. The HQs for all radiological COPECs were summed to calculate the SOF. If the SOF was greater than 1.0, a SMDP was considered before retaining them. Table 7-13 summarizes the results of the Tier 1 screening for radiological COPECs.

The results of the Tier 1 assessment for radiological COPECs show that SOF for Exposure Area P is greater than 1.0.

Table 7-13. Results of Tier 1 Screening for Radiological COPECs

Exposure Area	COPEC	Maximum Detected Concentration (pCi/g)	SSL_{LOAEL} (pCi/g)	HQ = Maximum Detected Concentration/ SSL_{LOAEL}	Sum-of-the-Fractions
P	Am-241	2.2	4.84E+03	4.55E-04	2.4E+00
	Co-60	0.83	805	1.03E-03	
	Cs-137	73.1	9.24E+02	7.91E-02	
	H-3	308	420	7.33E-01	
	I-129	0.81	NA	NC	
	Ni-63	85	NA	NC	
	Np-237	1.5	7880	1.90E-04	
	Pu-239	10.7	6.27E+03	1.71E-03	
	Pu-241	39.9	NA	NC	
	Se-79	8.7	NA	NC	
	Sr-90	141	9.10E+01	1.55E+00	
	Tc-99	24	5360	4.48E-03	
	U-233	2.6	NA	NC	
	U-234	1.4	6370	2.20E-04	
	U-235	0.043	4360	9.86E-06	
	U-238	0.88	5150	1.71E-04	

7.5.4 Scientific Management Decision Point

Within the process for conducting ecological risk assessments, several decision points occur at which risk managers, risk assessors, and other stakeholders agree on a path forward with respect

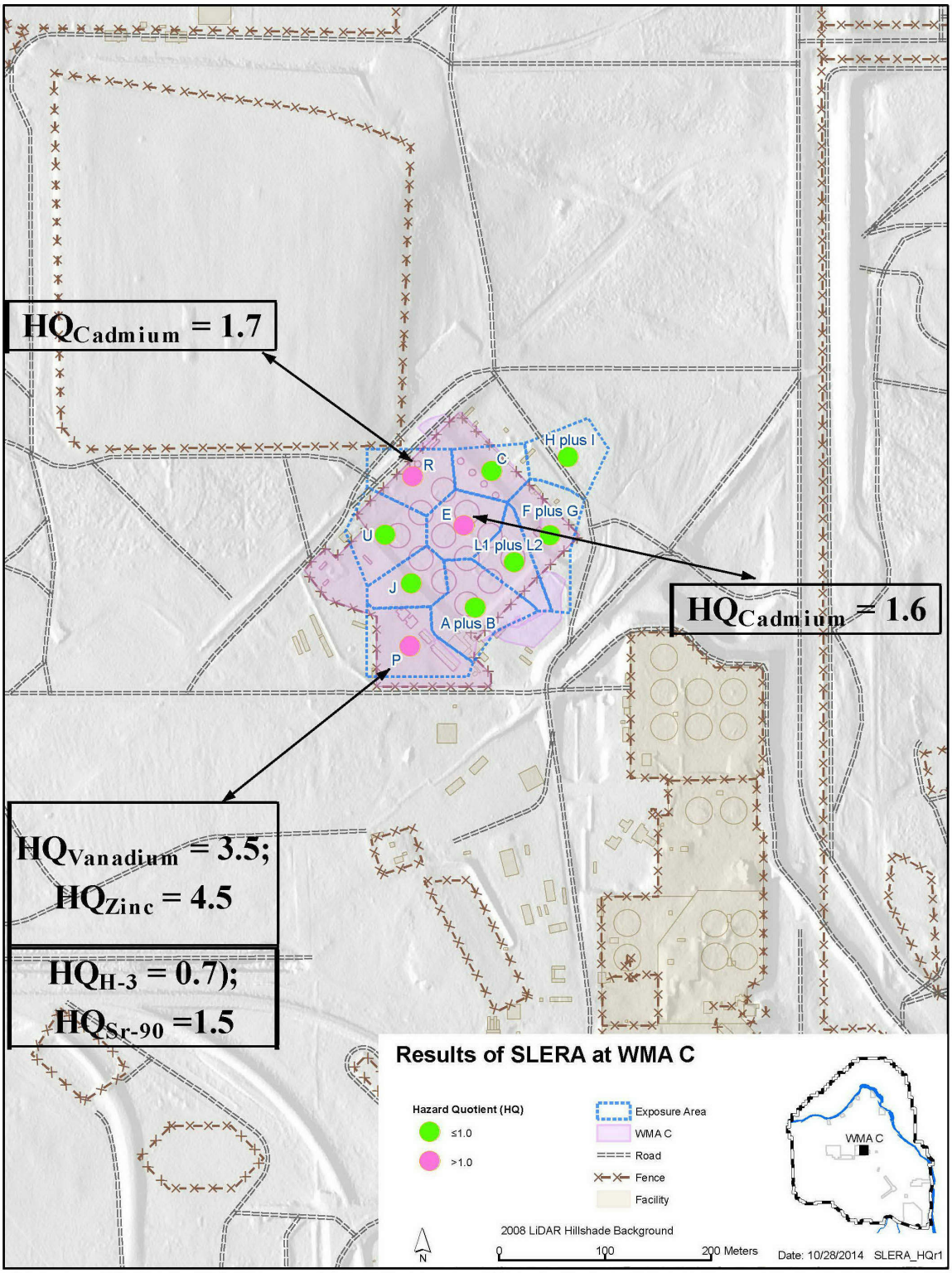
to ecological risk associated with a site. Typical variations include the following risk assessment outcomes:

- No unacceptable potential risks to ecological receptors (for example, risks are sufficiently low and below risk based thresholds such as SSLs).
- Potential for risks to ecological receptors, but the risks do not warrant the evaluation of remedial alternatives in the CMS because of a number of considerations.
- Potential for risks to ecological receptors, but there is uncertainty in one or more components of the ERA that warrant the evaluation of remedial alternatives in the CMS.
- Need to evaluate remedial alternatives in the CMS based on the protection of another receptor or exposure pathway (for example, human health) that would address potential ecological risks.
- Potential for risk to ecological receptors warranting evaluation of remedial alternatives in the CMS.

To confidently achieve one of the risk assessment outcomes, a number of factors and supporting information were considered in the conclusion of the risk assessment to assist risk management decisions. These outcomes were considered within the context of other exposure pathways and receptors evaluated at the same site. One of the factors that was considered to interpret the results of the risk characterization and determine if the site requires evaluation of remedial alternatives in the CMS include the identification of specific receptors that have the potential for adverse health effects (feeding guild [plants, insects, or omnivorous, herbivorous, insectivorous, or carnivorous wildlife], proportion of receptors affected, likelihood of population- or community-level effects, home range of the receptors at risk relative to the area exceeding risk-based thresholds).

Figure 7-6 shows the location and concentration of COPECs reported with an HQ greater than 1.0. During development of the evaluation, the factors above were evaluated and resulted in a recommendation, as part of the SMDP, that no nonradiological COPECs be carried forward into the CMS for evaluation of remedial alternatives.

Figure 7-6. Results of SLERA with Unacceptable Risk



As discussed in the technical support documents for ecological values in soil for wildlife (CHPRC-00784), the values used to calculate SSLs are based on the assumption that the size of the waste site inhabited by a receptor is the same size as the area used by the animal, for example, its home range, breeding range, or feeding/foraging range. In other words, the SSLs assume that a wildlife receptor is exposed 100% of the time to the contaminants in a waste site. This ratio of the area of contamination to the home range is known as an AUF. Therefore, an evaluation was performed for killdeer (most sensitive receptor at WMA C) based on area of exceedance relative to the ratio of receptor home range area of unaffected habitat to the area affected within the home range. The SSLs for killdeer utilizing during Tier I screening were calculated by assuming a AUF of 1. The killdeer is assumed to be exposed to the contaminants present within WMA C for 100% of the time. However, based on Sanzenbacher and Haig 2002, *Regional Fidelity and Movement Patterns of Wintering Killdeer in an Agricultural Landscape*, mean home range size for killdeer is 7.73 ±3.19 square kilometers (km^2). The size of WMA C is around 0.04 km^2. Therefore, the AUF for killdeer is less than 0.01. That means, the killdeer will utilize less than 1% for its food sources from WMA C. The SSLs based on AUF of 0.01 for all three nonradiological COPECs (cadmium, vanadium, and zinc) will be 100 times higher as compared to the SSLs developed based on an AUF of 1 during Tier 1 screening. Under such circumstances, the maximum detected concentrations for all three nonradiological COPECs will be much lower as compared to their SSLs based on AUF of 0.01. The home range evaluation for the killdeer resulted in a recommendation, as part of the SMDP, that no nonradiological COPECs be carried forward for further evaluation in the CMS.

The results of Tier 1 assessment for radiological COPECs identified unacceptable ecological risk is present at Exposure Area P. In section 7.2.5, the results of human health risk characterization also identified unacceptable radiological risk at Exposure Area P for industrial worker, maintenance/ surveillance worker and residential receptors. Therefore, based on the results of human health risk assessment, remedial action will be initiated at Exposure Area P to address the unacceptable risk associated with the radiological COPCs. Remedial action to be initiated under the HHRA will address all of the contamination associated with the radiological COPECs. Therefore, no radiological COPEC was retained for further evaluation.

7.5.5 Uncertainties Associated with the SLERA

There are a number of uncertainties inherent in the analysis tools used for this SLERA and SSLs values that are derived in CHPRC-00784, Rev. 1. However, uncertainties must be taken into consideration when interpreting the data presented in the previous sections and when making risk management decisions based on the conclusions of this risk characterization. Section 4 of the CHPRC-00784 revision 1 presented a more detailed description of the uncertainties encountered during the derivation of the generic and Tier 1 SSLs. Therefore, uncertainties associated with the development of SSLs are not described in this section. This section of this report summarized the uncertainties associated with the sampling results used during the SLERA.

Chemicals that were not detected in any samples were not selected as COPECs regardless of their detection limits. A non-detect could occur at any concentration below its detection limit and, possibly, above its screening-level concentration. This presents uncertainties in the SLERA in cases where the detection limit of the chemical is greater than its screening-level

concentration. These screening-level concentrations were derived to provide very conservative risk screening values. Therefore, these values are often lower than standard method detection limits.

The quantitative evaluation of chemical concentrations in soil included surface soil from the 0 to 5 m (0 to 15 ft) depth range. Ecology uses a standard point of compliance in soil of 5 m (15 ft) for demonstrating protection of ecological receptors (WAC 173-340-7490[4][b], "Terrestrial Ecological Evaluation Procedures"). This depth range may overestimate the depth to which many terrestrial receptors would be exposed. MTCA (WAC 173-340) identifies the biologically active zone as 2 to 5 m (6 to 15 ft) (WAC 173-340). Evaluation of data that extends beyond the biologically active zone could either overestimate or underestimate risk.

No toxicological data or background values were available for some COPECs or were limited for some COPEC/receptor combinations. Therefore, SSLs could not be calculated for all receptors or COPECs. Exclusion of COPECs from SSL development may not adequately address aggregate risk at a site, although remedial alternatives protective of receptors with SSLs may also be protective of receptors lacking sufficient toxicity data. In addition, the absence of SSLs for plants and soil invertebrates can be addressed through site-specific bioassays, which are a component of Tier 2.

Bioavailability and toxicity of metals are functions of many factors including soil pH, with metals (e.g., aluminum, iron, lead, mercury) generally being more bioavailable and toxic at low pHs (OSWER Directive 9285.7-55, *Guidance for Developing Ecological Soil Screening Levels*). Because the range of pH values in soil associated with plant and soil invertebrate toxicity values within the published literature include values substantially lower than those present throughout most of the Hanford Site, the resulting SSLs for plants and soil invertebrates may not accurately represent toxicity. Because metals are more bioavailable at lower pH, the SSLs may overestimate concentrations in Hanford Site soil that would be toxic to plants and soil invertebrates; therefore, risk estimates may be overly conservative. Further, oxidized environments (upland or well-aerated soils like those at the Hanford Site) promote the precipitation of ferric-oxide compounds, which are not available to plants for uptake. Thus, the SSLs more accurately reflect the actual bioavailability of potential contaminants within the Hanford Site soil than they do the SSLs developed using published data from laboratory studies and other sites.

As is typical in an SLERA, a finite number of samples of environmental media are used to develop the exposure estimates. The maximum measured concentration provides a conservative estimate for sessile biota or those with a limited home range. The most realistic exposure estimates for mobile species with relatively large home ranges and for species populations (even those that are sessile or have limited home ranges) are those based upon an estimate of central tendency of chemical concentrations in each medium to which these receptors are exposed. This is reflected in the wildlife dietary exposure models contained in EPA/600/R-93/187, *Wildlife Exposure Factors Handbook*. It is possible, however, that receptors could spend additional time foraging at a nearby waste site and thus be exposed to analytes from more than one site. Assuming an AUF of 1 will likely result in a conservative estimate of exposure due to offsite foraging that would likely be conducted in uncontaminated areas.

A major source of uncertainty in the SLERA is associated with the estimation of receptor exposure to COPECs. Generally, the models used to estimate exposures from soil and prey were created to represent a worst-case scenario of possible risks to the receptor groups, and thus, many conservative assumptions were incorporated into the models. For example, the models assume a 100% area use factor. In addition, the bioavailability of chemicals was based on values and models taken from the scientific literature. COPECs to which receptors are exposed are assumed to be present in their most bioavailable and toxic chemical form found in the environment. Availability and chemical form are affected by factors such as pH, moisture, temperature, microbial activity, and interaction with other chemicals, and in many cases, chemicals are present in less bioavailable/toxic forms in the environment. Given the relatively conservative nature of the toxicity values in terms of chemical bioavailability and form, it is likely that the potential for adverse effects was overestimated.

7.6 SUMMARY OF SCREENING LEVEL ECOLOGICAL RISK ASSESSMENT

The purpose of this SLERA for the WMA C was to determine the potential for adverse ecological impacts resulting from exposure to nonradiological and radiological contaminants released to the environment through past site operations related to the WMA C. It was prepared primarily in accordance with the framework developed using the tiered process outlined in CHPRC-00784.

As a part of the SLERA, data reduction and weight of evidence screenings were performed to identify both nonradiological and radiological COPECs by utilizing the soil characterization sampling results collected from 14 sampling locations (A, B, C, E, F, G, H, I, J, L1/L2, P, R, and U) within 10 exposure areas.

Two tiered risk assessments were conducted – Generic Screening and Tier 1 Screening. Under the generic screen, the maximum detected concentration of each COPEC was divided to its corresponding literature derived generic SSLs to calculate HQ. If the HQs for the COPECs are less than 1, those COPECs were not retained for further evaluation. When the HQs are the COPECs are greater than 1, those COPECs are retained for Tier 1 screening.

Due to two TRV values (NOAEL and LOAEL) for non-radiological COPECs, two types of Tier 1 SSLs values were selected for nonradiological COPECs and therefore, two screens were performed. During the first screen, the maximum detected concentration of each COPEC was compared to its corresponding NOAEL. COPECs with maximum concentrations equal or greater than the NOAEL were retained for second Tier 1 screening. During the second screen, the maximum detected sampling results for remaining COPECs were divided by their corresponding LOAEL to calculate HQ. If the HQs for the COPECs are less than 1, those COPECs were not retained for further evaluation. When the HQs are the COPECs are greater than 1, SMDPs were considered before retaining them. Table 7-12 summarizes the results of Tier 1 screening for nonradiological COPECs. The results of Tier 1 assessment showed that the maximum detected concentrations for cadmium within Exposure Areas E and R; and maximum detected concentrations for vanadium and zinc within Exposure Area P are two to five times

higher than their corresponding SSLs based on LOAEL. Therefore, HQs for cadmium within Exposure Areas E and R and HQs for vanadium and zinc within Exposure Area P are greater than 1. The LOAEL values for all three nonradiological COPECs were selected based on the SSL for representative insectivorous bird—killdeer. Killdeer is sensitive to all three nonradiological COPECs - cadmium, vanadium and zinc. It should be noted that the maximum detected concentrations for cadmium, vanadium and zinc within each exposure area are less than their corresponding Tier 1 SSLs for all other representative ecological receptors. Therefore, killdeer was identified as the only sensitive species among eight representative species, selected for the Hanford Site.

It should be noted that during the development of Tier 1 SSLs, it was assumed that a wildlife receptor is exposed 100% of the time to the contaminants in a waste site. That means, killdeer is exposed 100% of the time to the contaminants presented with WMA C. However, based on literature, the mean home range size for killdeer is 7.73 ±3.19 km^2. The size of WMA C is around 0.04 km^2. Based on the ratio of the size of WMA C area to the home range size, the killdeer will utilize less than 1% for its food sources from WMA C. The SSLs based on AUF of 0.01 for all three nonradiological COPECs (cadmium, vanadium and zinc) will be 100 times higher as compared to the SSLs utilized during Tier 1 screening. Therefore, the maximum detected concentrations for all three nonradiological COPECs will be much lower as compared to their SSLs based on AUF of 0.01. Therefore, none of the COPECs were retained for further evaluation.

For radiological COPECs, Tier 1 SSLs were derived based their LOAELs. The ratios of maximum detected concentration to SSLs based on LOAELs were summed to calculate the SOF for each exposure area. Table 7-13 summarizes the results of Tier 1 screening for radiological COPECs. The results identified presence of unacceptable ecological risk at exposure area. The results of human health risk characterization also identified unacceptable radiological risk at Exposure Area P for industrial worker, maintenance/surveillance worker and residential receptors. Therefore, remedial action will be initiated at Exposure Area P to address the unacceptable risk associated with the radiological COPCs. Remedial action to be initiated will address all of the contamination associated with the radiological COPECs. Therefore, no radiological COPECs were retained for further evaluation.

7.7 GROUNDWATER SCREENING EVALUATION

The primary purpose of the groundwater screening evaluation is to support the ongoing investigation into potential contributions to current and future groundwater contamination from sources in the vadose zone within WMA C. This is considered a high-level evaluation and is intended to provide an initial basis of information that can be used in conjunction with additional groundwater evaluations. The groundwater screening level evaluation at WMA C is documented in RPP-RPT-58297, *Screening-Level Evaluation of Groundwater Monitoring Data Collected in Vicinity of WMA C*. Protectiveness of human health is evaluated by comparing groundwater contaminant concentrations to existing federal or state MCLs or nonzero MCLGs. Groundwater contaminant concentrations are compared to MTCA "Groundwater Cleanup Standards" to determine whether maximum contaminant concentrations exceed an HI greater than 0.1.

It should be noted that contamination in the groundwater underlying WMA C is being addressed under CERCLA. WMA C, a RCRA-regulated unit, is identified as an area of interest within the 200-BP-5 groundwater OU. A quantitative baseline risk assessment and evaluation of remedial alternatives for groundwater underlying the WMA C area of interest are scheduled to be completed as part of the 200-BP-5 groundwater OU RI/FS (DOE/RL-2009-127, *Remedial Investigation/Feasibility Study for the 200-BP-5 Groundwater Operable Unit*).

7.7.1 Groundwater Data Set

The groundwater data set used for the identification of analytes of interest consists of sampling and analysis data collected over a 10-year period, between January 2004 and December 2013, from 12 monitoring wells located in the vicinity of WMA C. A list of the wells is provided in Table 7-14. The location of the wells is shown in Figure 7-7. All of the wells are screened in the unconfined aquifer and are sampled to fulfill requirements of RCRA and AEA. The wells listed in Table 7-14 are the same as the wells identified in the 200-BP-5 groundwater OU RI/FS for evaluation of the WMA C area of interest (DOE/RL-2009-127).

The analytical data for these 12 wells reside in, and were downloaded for this evaluation from, the HEIS database. A total of 40,505 records were obtained from HEIS, and a total of 310 analytes were included in the data set prior to analytical data processing.

Table 7-14. Groundwater Monitoring Wells Used for Identification of Analytes of Interest at WMA C

Well Name			
299-E27-12	299-E27-15	299-E27-22	299-E27-25
299-E27-13	299-E27-155	299-E27-23	299-E27-4
299-E27-14	299-E27-21	299-E27-24	299-E27-7

7.7.2 Analytical Data Processing

The groundwater data set obtained from HEIS included the following types of information:

- Analytical results from both unfiltered and filtered samples.
- Data qualification and data validation flags, including rejected results.
- Results for a given analyte reported by more than one analytical method.
- Parent and field duplicate sample results.

The analytical data were processed to remove unusable results and identify one set of results per sampling location and date of sample collection. Filtered samples, laboratory and data validation flags, analytes reported by multiple analytical methods, and duplicate samples were removed. The data processing steps and the numbers of records associated with each step are presented in Figure 7-8. After analytical data processing using the steps described in Section 7.3.2, the data set contained 25,738 records and 300 analytes.

Figure 7-7. Groundwater Monitoring Wells in the vicinity of WMA C

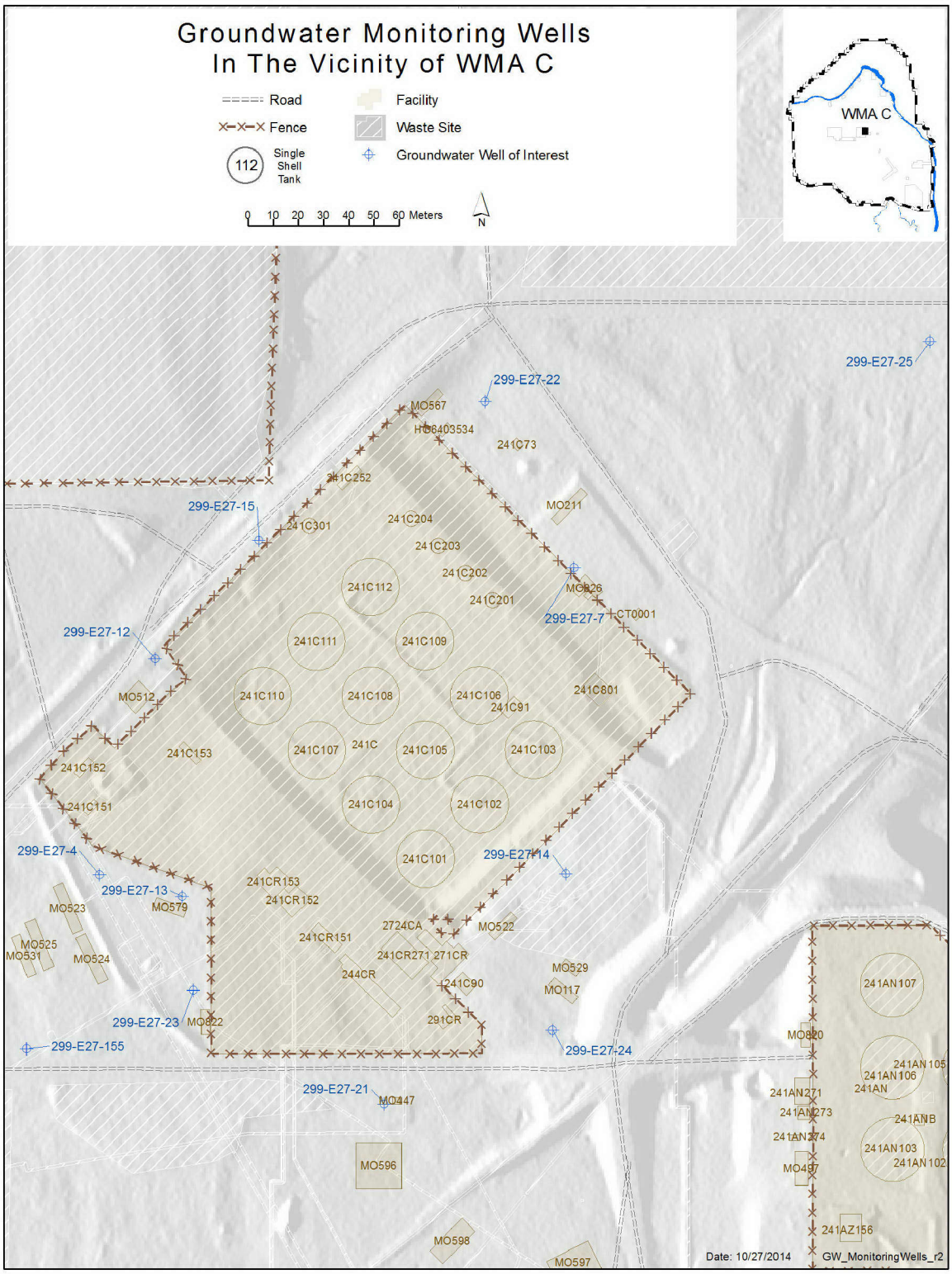
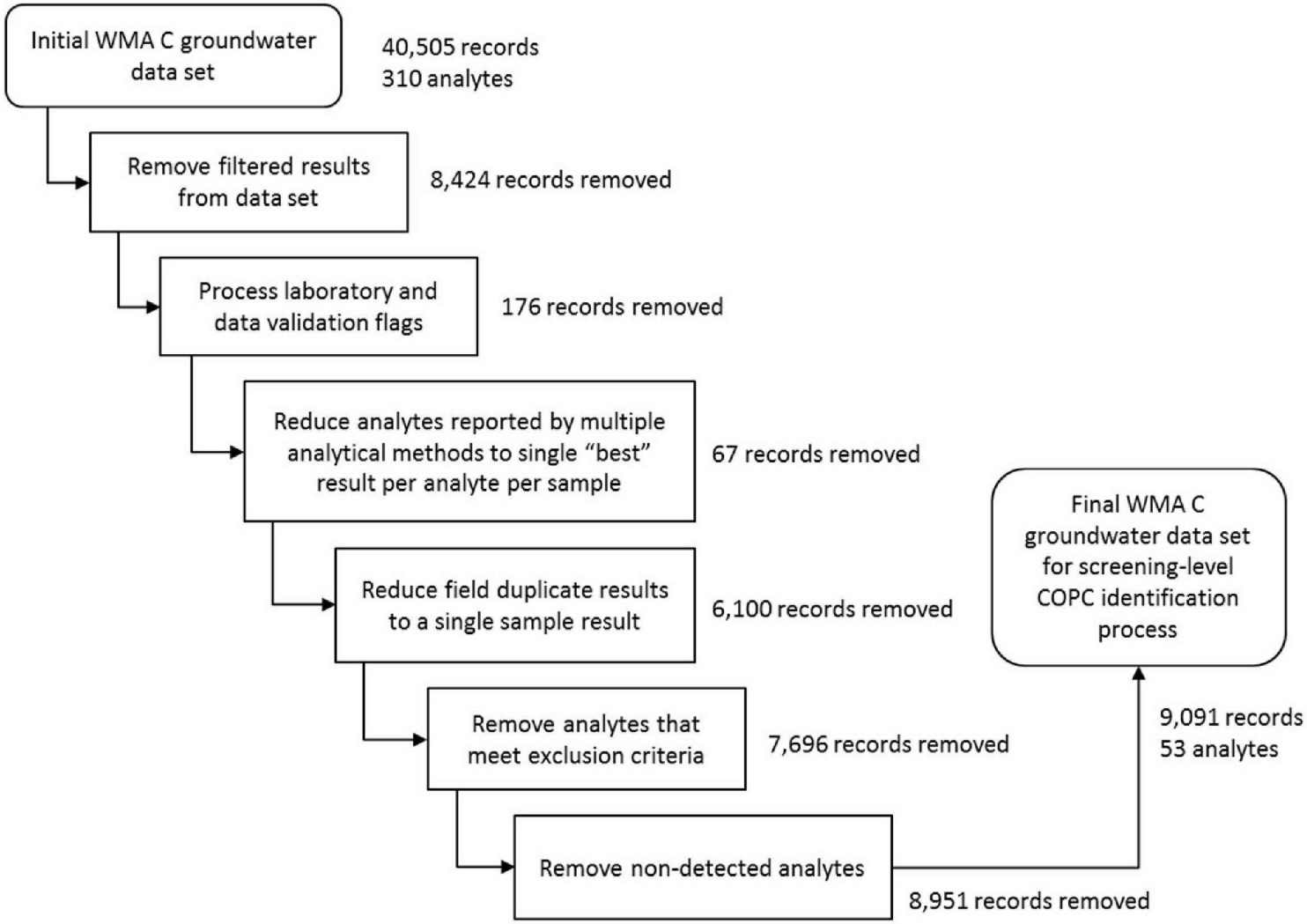


Figure 7-8. Analytical data Processing for the WMA C Groundwater Data Set



7.7.3 Identify Groundwater Comparison Values and Background Concentrations

The following subsections describe the derivation of the applicable or relevant and appropriate requirement (ARAR)-based groundwater comparison values and groundwater background concentrations used in identifying groundwater analytes of interest.

7.7.3.1 ARAR-Based Groundwater Comparison Values. For purposes of this evaluation, the groundwater comparison values are the lowest of the available chemical-specific ARARs for protection of human health.

Following are the sources of groundwater comparison values from federal regulations:

- 40 CFR 141, "National Primary Drinking Water Regulations", MCLs, Secondary MCLs, and nonzero MCLGs established under the *Safe Drinking Water Act of 1974*.

Following are the sources of groundwater comparison values from Washington State regulations:

- WAC 173-340-720, "Groundwater Cleanup Standards."

- WAC 246-290-310, "Group A Public Water Supplies," "Maximum Contaminant Levels (MCLs) and Maximum Residual Disinfectant Levels (MRDLs)."

Derivation of groundwater cleanup levels in accordance with the MTCA cleanup regulations (WAC 173-340-720, "Groundwater Cleanup Levels") is provided in ECF-100NPL-10-0462, *Calculation of Standard Method B Groundwater Cleanup Levels for Potable Groundwater for the 100 Areas and 300 Area Remedial Investigation/Feasibility Study Reports*.

7.7.3.2 Groundwater Background Concentrations. For certain analytes (e.g., arsenic), measured background concentrations in the Hanford Site unconfined aquifer are greater than the ARAR-based comparison value. In such cases, detected concentrations above the comparison value do not necessarily indicate the presence of site-related contamination. The process for identifying analytes of interest therefore uses comparisons to both background concentrations and ARAR-based values to distinguish between probable site-related contamination and natural background conditions.

The program of sampling, analysis, screening, and statistical interpretation used to establish Hanford Site background concentrations is presented in DOE/RL-96-61, *Hanford Site Background: Part 3, Groundwater Background*. In this study, historical Hanford Site groundwater data (and new data collected specifically for the study) were screened to eliminate samples and/or constituents that may have been affected by Hanford Site activities.

7.7.4 Contaminants of Interest Screening Process

After extracting and processing the groundwater analytical data as described in Section 7.3.2, and then identifying comparison values and background concentrations as described in

Section 7.3.3, a multi-step screening process is used to identify groundwater analytes of interest. The process involves the following steps:

- Apply exclusion criteria.
- Identify non-detected analytes.
- Identify analytes with maximum detected concentrations less than action values.
- Identify analytes with maximum detected concentrations greater than action values.

These four steps are performed using the combined (12 well) data set and result in the identification of groundwater analytes of interest for the data set as a whole. As a final step, the data sets for the individual monitoring wells are evaluated to determine which wells report detected concentrations of COPCs greater than their respective comparison values.

7.7.4.1 Apply Exclusion Criteria. Analytes that meet one or more exclusion criteria are eliminated as analytes of interest. Analytes that do not meet exclusion criteria are carried forward to the next step of the process. The exclusion criteria are as follows:

- Water quality parameters.
- Essential nutrients (minerals).
- Naturally occurring radionuclides associated with background radiation.
- Radionuclides that have half-lives of less than three years and that are not significant daughter products.
- Analytes without comparison values or known toxicity information.

Of the 300 analytes in the processed data set, a total of 74 analytes met the exclusion criteria and were eliminated from further consideration as COPCs. The excluded analytes are listed in RPP-RPT-58297, Table 5-1. The table provides sampling dates, minimum and maximum detected concentrations, minimum and maximum MDLs, and the basis for exclusion for each analyte.

7.7.4.2 Identify Nondetected Analytes. A total of 173 analytes were not detected in any groundwater samples in the 10-year, 12-well data set and were eliminated from further consideration as COPCs. The non-detected analytes are listed in RPP-RPT-58297, Table 5-2. The table provides sampling dates, minimum and maximum MDLs, the ARAR-based comparison value and its basis, and the ratio of the minimum MDL to the comparison value.

The minimum MDL/comparison value ratio was used to identify analytes with MDLs that did not achieve the comparison value. A total of 48 analytes were not detected and were reported with all MDLs greater than their respective comparison values, indicating the analytical method used was unable to detect the analyte at or below the comparison value. These analytes included 2 herbicides, 8 pesticides, 22 SVOCs, and 16 VOCs.

7.7.4.3 Identify Analytes with Maximum Detected Concentrations Less than Action Levels. A total of 39 analytes were detected at least once and had maximum detected concentrations less than their respective comparison values. These analytes were eliminated from further consideration as COPCs. A list of these analytes is provided in Table 5-3, RPP-RPT-58297. The table provides sampling dates, minimum and maximum MDLs, minimum and maximum detected concentrations, the ARAR-based comparison value and its basis, and number of detections that exceed the comparison value. Also provided are the 90th percentile Hanford Site groundwater background concentration, the number of detections that exceed the background value, and the ratio of the maximum detected concentration to the comparison value.

7.7.4.4 Identify Analytes with Maximum Detected Concentrations Greater than Action Levels. A total of 14 analytes were detected at least once and had maximum detected concentrations greater than their respective comparison values. These analytes were carried forward for further consideration as COPCs. A list of these analytes is provided in RPP-RPT-58297, Table 5-4. The table provides sampling dates, minimum and maximum MDLs, minimum and maximum detected concentrations, the ARAR-based comparison value and its basis, and the number of detections that exceed the comparison value. Also provided are the 90th percentile Hanford Site groundwater background concentrations and the number of detections that exceed the background value.

7.7.5 Summary of Analytes of Interest

Based on the uncertainty evaluation, a total of seven analytes with maximum detected concentrations greater than their respective comparison values are identified as screening-level groundwater analytes of interest. These analytes are sulfate, vanadium, nickel, nitrate, ^{129}I, ^{99}Tc, and cyanide. Table 7-15 provides a summary indicating the analytes of interest detected at concentrations above their respective comparison values in each of the 12 groundwater monitoring wells. A location map depicting each well's analytes of interest is provided in Figure 7-9. For additional information, refer to Section 5.4 and Appendix U.

7.8 CONCLUSION OF THE RISK ASSESSMENTS

A HHRA and SLERA were performed for WMA C, using Phase 2 soil characterization data (RPP-PLAN-39114). The methodology used to calculate RME using 95% UCL EPCs are based on ProUCL 4.00.05, and are documented in RPP-RPT-57218. Risk and hazards were calculated for a range of exposure scenarios that include reasonably anticipated future land use scenarios, as well an evaluation of a residential receptor for risk management information. Additionally, risk was calculated using Tribal scenarios based on assumptions provided by the CTUIR and Yakama Nation.

The SLERA was prepared primarily in accordance with the framework developed using the tiered process outlined in CHPRC-00784. The tiered process allows the incorporation of more sophisticated risk methods and increasing levels of ecological site-specific and site relevant information to provide SSLs that are more representative of Hanford Site conditions.

Contaminant concentrations in groundwater were compared against groundwater comparison values protective of human health and background concentrations. The groundwater screening is a high-level evaluation intended to provide an initial basis of information that can be used in conjunction with additional groundwater evaluations. A quantitative risk assessment and evaluation of remedial alternatives for groundwater underlying the WMA C area of interest are scheduled to be completed as part of the 200-BP-5 groundwater OU RI/FS (DOE/RL-2009-127).

7.8.1 Conclusion for Soil Risk Assessment

The contaminants present in soil within WMA C that are the largest contributors to calculated risk are radionuclides. Cancer risk associated with radionuclides within the top 5 m (15 ft) of soil are in the 10^{-4} range, based on the industial worker exposure scenario. Risks associated with the primary radionuclide risk drivers are no greater than 2×10^{-4}. An adult industrial worker represents reasonably anticipated future land use conditions. In addition, an adult construction worker, an adult maintenance/surveillance worker, a trespasser adult and a trespasser youth receptor scenarios are also selected to represent reasonably anticipated future land use conditions. Cancer risk associated witht the maintenance/surveillance worker scenario are similar to the industrial worker scenario. Cancer risk associated with the youth trespasser scenario range from approximatly three to eight times lower than the industrial worker scenario. Cancer risk associated with the industrial worker scenario based on MTCA Method C, the construction worker, the adult trespasser scenarios were orders of magnitude lower than the industrial woker scenario, and did not exceed the risk threshold of 10^{-4}. Cancer risk associated with radionuclides range from 1×10^{-3} to 7×10^{-4} based on the adult residential exposure scenario. The residential scenarios do not represent reasonably anticipated future land use.

Five exposure areas (A+B, C, E, L1+L2, and P) reported an exceedance of 1×10^{-4} based on the industrial worker exposure scenario and maintenance/surveillance worker scenario. Two expousre areas (A+B and C) reported an exceedance of 1×10^{-4} based on the youth trespasser exposure scenario. The two major contributors, ^{137}Cs and ^{126}Sn were retained as radiological COPCs for further evaluation in the CMS.

Based on the residential exposure scenarios, nine exposure areas (A+B, C, E, F+G, H+I, J, L1+L2, P, and U) contain contaminants that are greater than the upper risk threshold of 1×10^{-4}. Cesium-137, ^{60}Co, ^{63}Ni, ^{79}Se, ^{90}Sr, and ^{126}Sn were identified as major risk contributors.

For nonradiologcal COPCs, cancer risks and noncancer hazards indices fell below the acceptable risk value of 1×10^{-5} for multiple contaminants and multiple pathways (WAC 173-340-708[5], "Human Health Risk Assessment Procedures"); based on the reasonably anticipated land use scenarios. Based on the adult and child residential exposure scenarios and the residential exposure scenario evaluated under MTCA Method B, cancer risk and hazards did not excced background.

7.8.2 Conclusion for Screening Level Ecological Risk Assessment

The purpose of the SLERA for the WMA C was to determine the potential for adverse ecological impacts resulting from exposure to nonradiological and radiological contaminants released to the

environment through past site operations. It was prepared primarily in accordance with the framework developed using the tiered process outlined in CHPRC-00784.

It should be noted that during the development of Tier 1 SSLs, it was assumed that a wildlife receptor is exposed 100% of the time to the contaminants in a waste site. Therefore, a killdeer is expected to be exposed 100% of the time to the contaminants present in WMA C. However, based on literature, the mean home range size for killdeer is 7.73 ±3.19 km^2. The size of WMA C is approximately 0.04 km^2. Based on the ratio of the size of WMA C area to the home range size, the killdeer will utilize less than 1% for its food sources from WMA C. SSLs based on AUF of 1% will result in much higher SSL for killdeer as compared to their maximum detected concentrations. Therefore, none of the COPECs were retained for further evaluation.

For radiological COPECs, Tier 1 SSLs were derived based their LOAELs. The ratios of maximum detected concentration to SSLs based on LOAELs were summed to calculate the SOF for each exposure area. The results identified the presence of unacceptable ecological risk at exposure area. The results of human health risk characterization also identified unacceptable radiological risk at Exposure Area P for an industrial worker, maintenance/surveillance worker and residential receptors. Therefore, remedial action will be initiated at Exposure Area P to address the unacceptable risk associated with the radiological COPECs. Remedial action to be initiated will address all of the contamination associated with the radiological COPECs. Therefore, no ecological COPECs were retained for further evaluation.

7.8.3 Conclusion for Groundwater Screening Evaluation

The purpose of the groundwater screening evaluation was to identify a set of groundwater analytes of interest underlying WMA C that have the potential to be cancer risk or noncancer hazard drivers. The evaluation was based on sampling results collected over a 10-year period from 12 groundwater monitoring wells that monitor contaminants in the unconfined aquifer in the vicinity of WMA C. A total of 40,505 records were obtained from the HEIS database, and a total of 310 analytes were included in the data set prior to analytical data evaluations. After data processing, application of an exclusion criteria screening process, and removal of non-detected analytes, the data set contained 9,524 records and 55 analytes. These 55 analytes were carried forward for screening against human health-protective comparison values.

Seven analytes were considered likely to be of interest for assessing protection of human health or investigating potential groundwater contamination sources at WMA C. The seven analytes of interest for the WMA C data set as a whole are ^{129}I, ^{99}Tc, nickel, vanadium, cyanide, nitrate, and sulfate.

7.8.4 Data Gaps

The evaluation of groundwater protection is used to determine if vadose zone contamination may impact groundwater. Nonradiological COPCs in the vadose zone were evaluated using WAC 173-340-747(4) fixed-parameter three-phase partitioning model. No evaluation was performed for radiological COPCs in the vadose zone in the baseline risk assessment.

Data gaps will be address as part of the analyses being conducted in support of the HFFACO Appendix I performance assessment. The WMA C Performance Assessment will use a site-specific model to evaluate nonradiological and radiological COPCs in the vadose zone.

Table 7-15. Analytes of Interest at Groundwater Monitoring Wells in the Vicinity of WMA C

Well Name	Analyte of Interest (Comparison Value)						
	Iodine-129 (1 pCi/L)[a]	Technetium-99 (900 pCi/L)[a]	Cyanide (0.48 µg/L)[b]	Nickel (32 µg/L)[b]	Nitrate (11,360 µg/L)[b]	Sulfate (250,000 µg/L)[a]	Vanadium (8.0 µg/L)[b]
299-E27-12	●		●		●		●
299-E27-13	●	●	●		●		●
299-E27-14	●	●	●		●	●	●
299-E27-15	●		●	●	●		●
299-E27-155	●	●	●		●		●
299-E27-21	●	●	●		●		●
299-E27-22	●		●		●		●
299-E27-23	●	●	●	●	●		●
299-E27-24	●	●	●		●	●	●
299-E27-25	●			●	●	●	●
299-E27-4	●	●	●	●	●		●
299-E27-7	●		●		●	●	●

a. Federal maximum contaminant level
b. Method B groundwater screening level (hazard quotient = 0.1 noncancer hazard value).

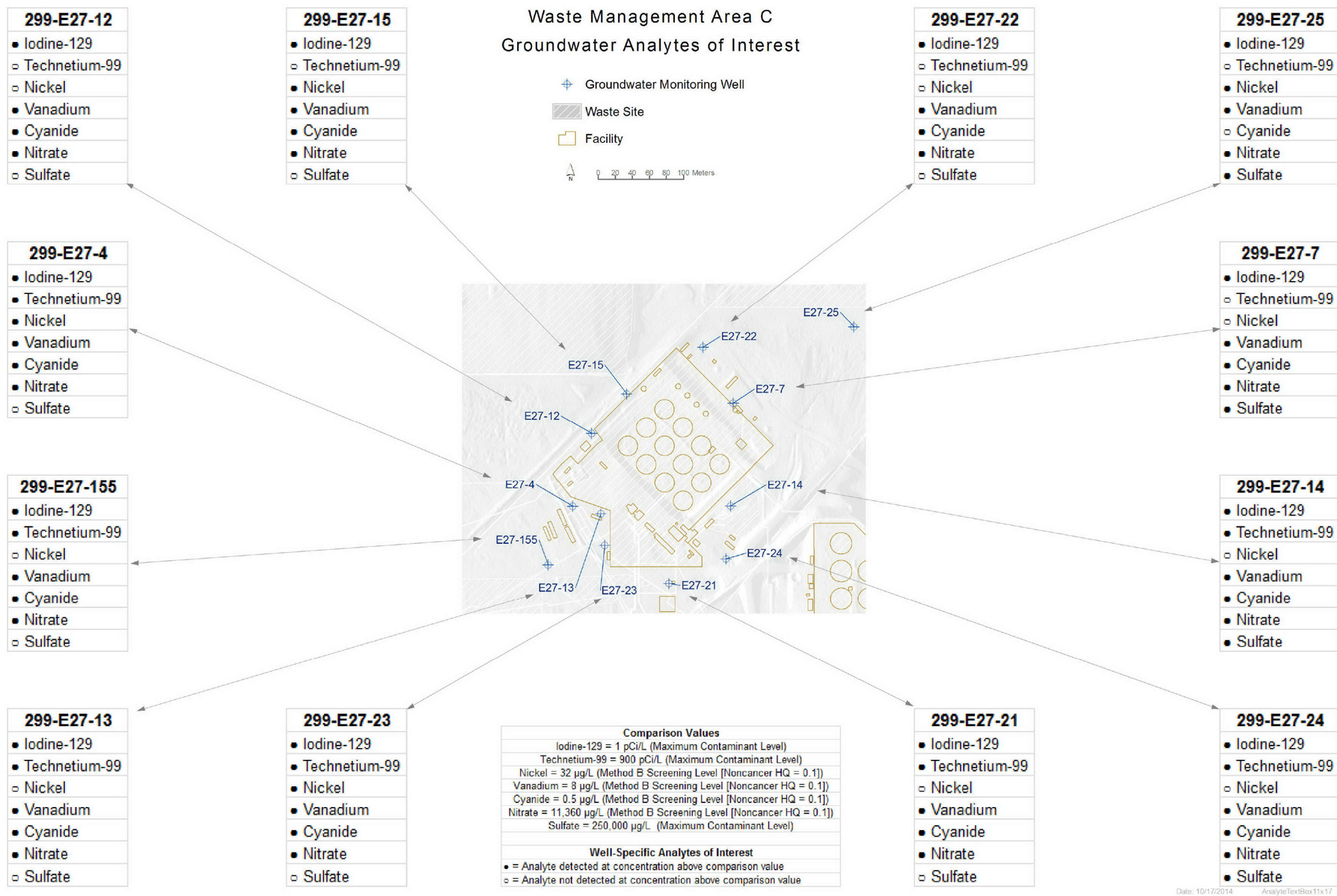



Figure 7-9. Well-Specific Analytes of Interest in the Vicinity of WMA C (2004 through 2013)