# DOCUMENT RELEASE AND CHANGE FORM

Prepared For the U.S. Department of Energy,
Assistant Secretary for Environmental Management
By Washington River Protection Solutions, LLC., PO Box 850, Richland, WA 99352
Contractor For U.S. Department of Energy, Office of River Protection, under Contract DE-AC27-08RV14800

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This document provides the DOE O 435.1, Radioactive Waste Management performance assessment analysis for Waste Management Area C. The performance assessment is required by DOE O 435.1 for closing U.S. Department of Energy (DOE)-operated facilities that will manage radioactive waste generated during departmental activities as low-level waste. The fundamental objective of this performance assessment is to support the closure of tanks and ancillary equipment within Waste Management Area C that will contain residual levels of radioactive wastes left at closure.

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**RPP-ENV-58782, Rev. 0**

# Performance Assessment of Waste Management Area C, Hanford Site, Washington

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Abstract: This document provides the DOE O 435.1, Radioactive Waste Management performance assessment analysis for Waste Management Area C. The performance assessment is required by DOE O 435.1 for closing U.S. Department of Energy-operated facilities that will manage radioactive waste generated during departmental activities as low-level waste. The fundamental objective of this performance assessment is to support the closure of tanks and ancillary equipment within Waste Management Area C that will contain residual levels of radioactive wastes left at closure.

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# Performance Assessment of Waste Management Area C, Hanford Site, Washington

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| Rev. 0 | 30-Sep-2015 | S. Mehta et. al | Updates to Draft B in response to review comments provided by DOE-HQ through the Low-Level Waste Disposal Facility Federal Review Group (LFRG). |

# EXECUTIVE SUMMARY

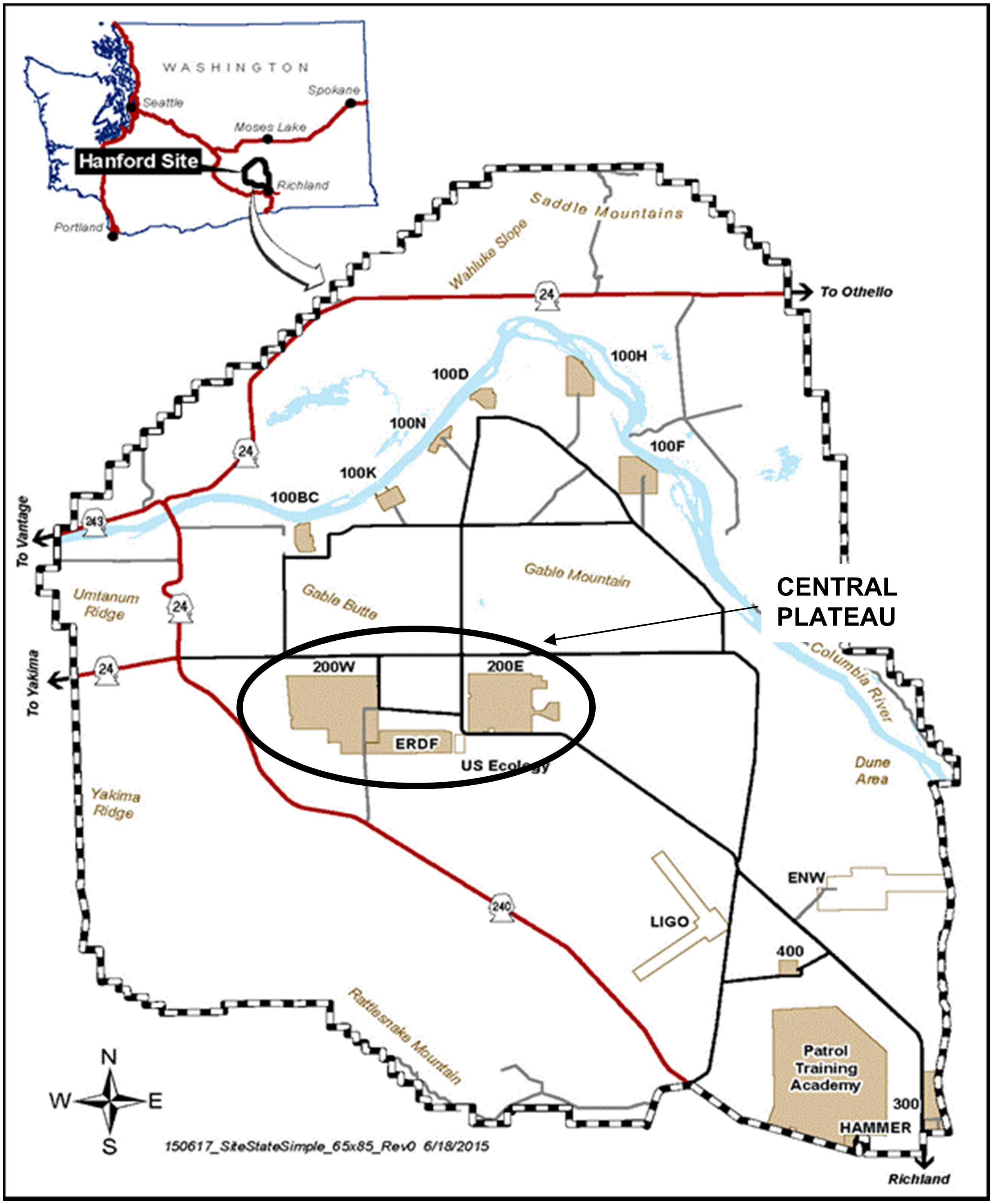
The U.S. Department of Energy, Office of River Protection (DOE-ORP) is pursuing closure on the single-shell tank (SST) Waste Management Area (WMA) C under Federal requirements and forthcoming State-approved closure plans and permits in accordance with the Hanford Federal Facility Agreement and Consent Order (HFFACO) (Ecology et al. 1989), Action Plan, Appendix I. Waste Management Area C is located in the 200 East Area of the Central Plateau at the Hanford Site in southcentral Washington (Figure ES-1) and is one of 12 tank farms grouped into 7 WMAs (A-AX, B-BX-BY, C, S-SX, T, TX-TY, and U) containing 149 SSTs and ancillary equipment built from 1943 to 1964 (see Figure ES-2).

This document provides the DOE O 435.1, Radioactive Waste Management performance assessment (PA) analysis for WMA C. The PA is required by DOE O 435.1 for closing U.S. Department of Energy (DOE)-operated facilities that will manage radioactive waste generated during departmental activities as low-level waste. The fundamental objective of this PA is to support the closure of tanks and ancillary equipment within WMA C that will contain residual levels of radioactive wastes left at closure.

Waste Management Area C is located in the east central portion of the 200 East Area in land that is designated to be Industrial-Exclusive. In general, the WMA C boundary is represented by the fenceline surrounding the 241-C Tank Farm (C Farm) (Figure ES-3). The WMA C facility contains twelve 100-series tanks and four 200-series tanks (see Figure ES-3). The 100-series tanks are 23 m (75 ft) in diameter, have a 5-m (15-ft) operating depth, and have an operating capacity of 2,006,000 L (530,000 gal) each. The 200-series tanks are 6 m (20 ft) in diameter with a 7.32-m (24-ft) operating depth and an operating capacity of 208,000 L (55,000 gal) each. The tanks sit below grade with at least 2 m (7 ft) of soil cover to provide shielding from radiation exposure to operating personnel. Tank pits are located on top of the tanks and provide access to the tanks, pumps, and associated monitoring equipment. To support the transfer and storage of waste within WMA C SSTs, there is a complex waste transfer system of pipelines (transfer lines), diversion boxes, vaults, valve pits, and other miscellaneous structures. These miscellaneous features of the tank farm are referred to in this document by the general term "ancillary equipment and components."

Closure of the individual SSTs and WMA C in its entirety occurs in three major steps: 1) SST waste retrieval, 2) filling the tanks with grout for stabilization, and 3) surface cover barrier placement. The final state of a tank farm that is considered in the PA is therefore a set of grouted tanks with associated ancillary equipment containing residual wastes that remain at the end of retrieval, covered by a modified Resource Conservation and Recovery Act of 1976 (RCRA) Subtitle C surface cover, residing in the native geological setting.

**Figure ES-1. Hanford Site and its Location in Washington State.**



ENW = Energy Northwest

LIGO = Laser Interferometer Gravitational Wave Observatory

ERDF = Environmental Restoration Disposal Facility

HAMMER = Volpentest Hazardous Materials Management and Emergency Response (HAMMER) Federal Training Center

**Figure ES-2. Hanford Site Tank Farms.**

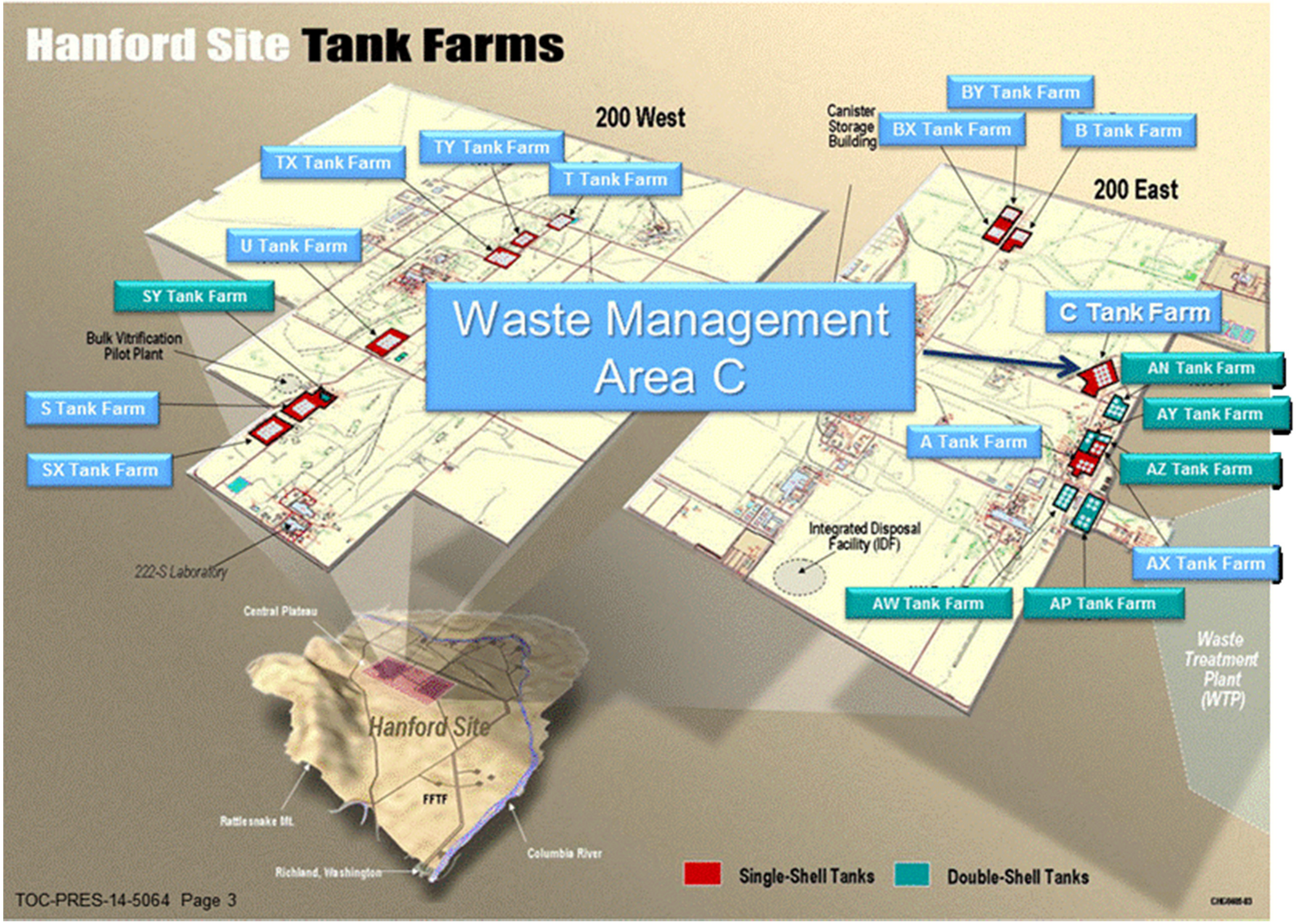
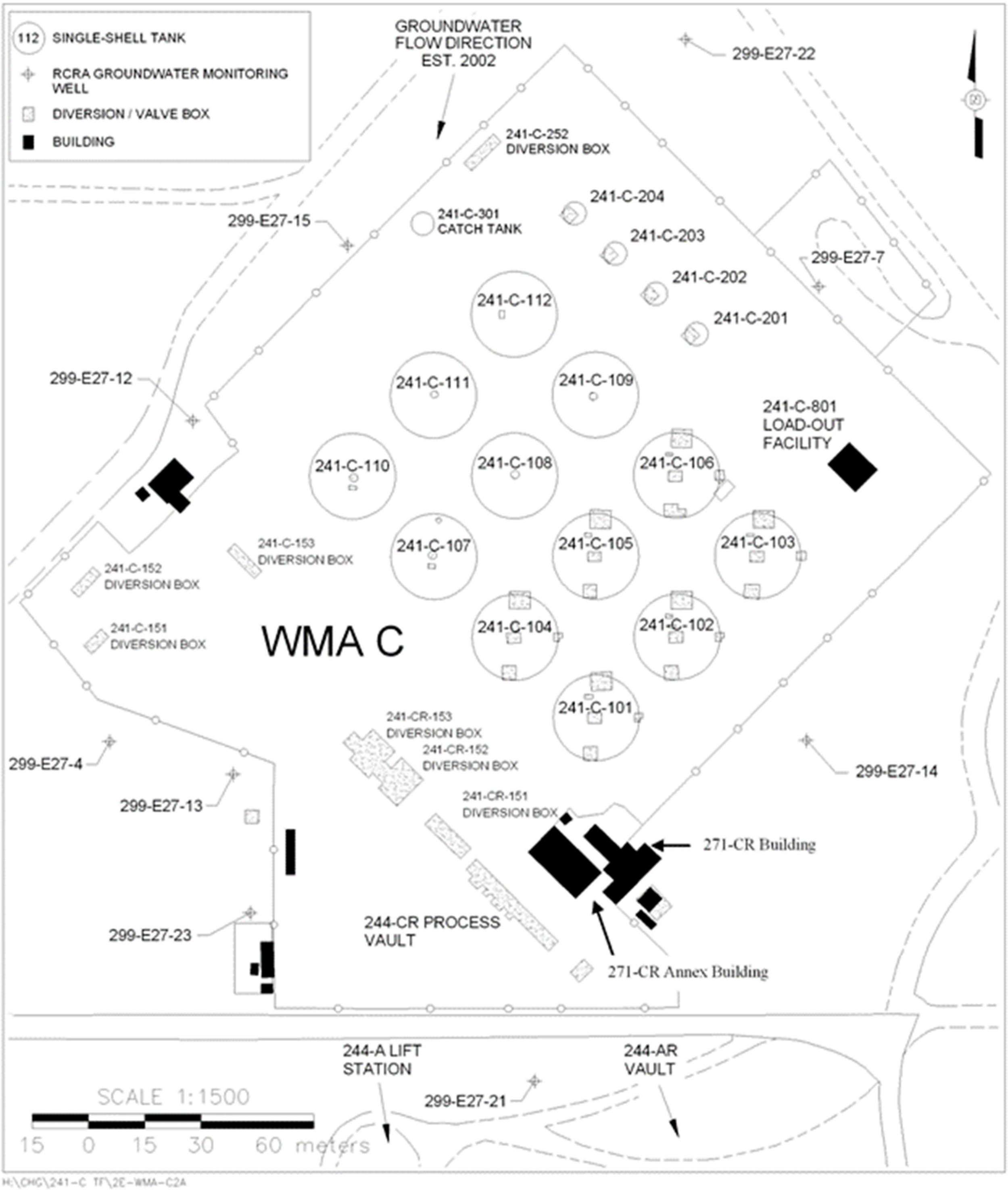


Figure ES-3. Location of Facilities at Waste Management Area C and Surrounding Area.



RCRA = Resource Conservation and Recovery Act of 1976

WMA = Waste Management Area

The safety concept for this system is composed of a set of safety functions of manmade as well as natural components that act together to provide the long-term performance of a closed facility required in closure regulations. The safety functions represent multiple and redundant barriers, so that the loss of one or some of the safety functions continues to result in adequate performance of the overall system. A schematic depiction of these safety functions for the closed WMA C is provided in Figure ES-4. The manmade components of the system that influence contaminant migration include a closure surface barrier, and the distribution of waste in the subsurface tanks and ancillary equipment. The natural components of the system that influence contaminant migration are the several underlying, nearly-horizontal stratigraphic layers within the vadose zone and the unconfined aquifer.

The WMA C PA has been structured to evaluate the behavior of the closed tank farm under a variety of potential future conditions. An analysis case has been defined in which the safety functions evolve in an expected manner without unusual behavior or unanticipated disruption; this is termed the “base case.” The base case is the main analysis used to compare against the performance objectives, but is not the sole analysis for such comparisons. In addition, a set of deterministic sensitivity analyses have been conducted that show the effects when the safety functions are degraded compared to their expected behavior as defined in the base case. The specific safety functions examined in this way relate to the various physical components of the disposal system that included model evaluations of groundwater impacts with the following:

- Higher than expected infiltration rates; these may be the result of a number of potential effects, ranging from unexpectedly poor performance of the cover, through changes in land use with irrigation on top of the facility

- Changes in the effectiveness of the tanks and infill grout to act as barriers, by assuming that the hydraulic conductivity of the tanks increases at times earlier than expected

- Changes in the leachability of the residual wastes, by assuming that the material would dissolve instantly and completely upon contact with water

- Bounding inventories for unretrieved tanks

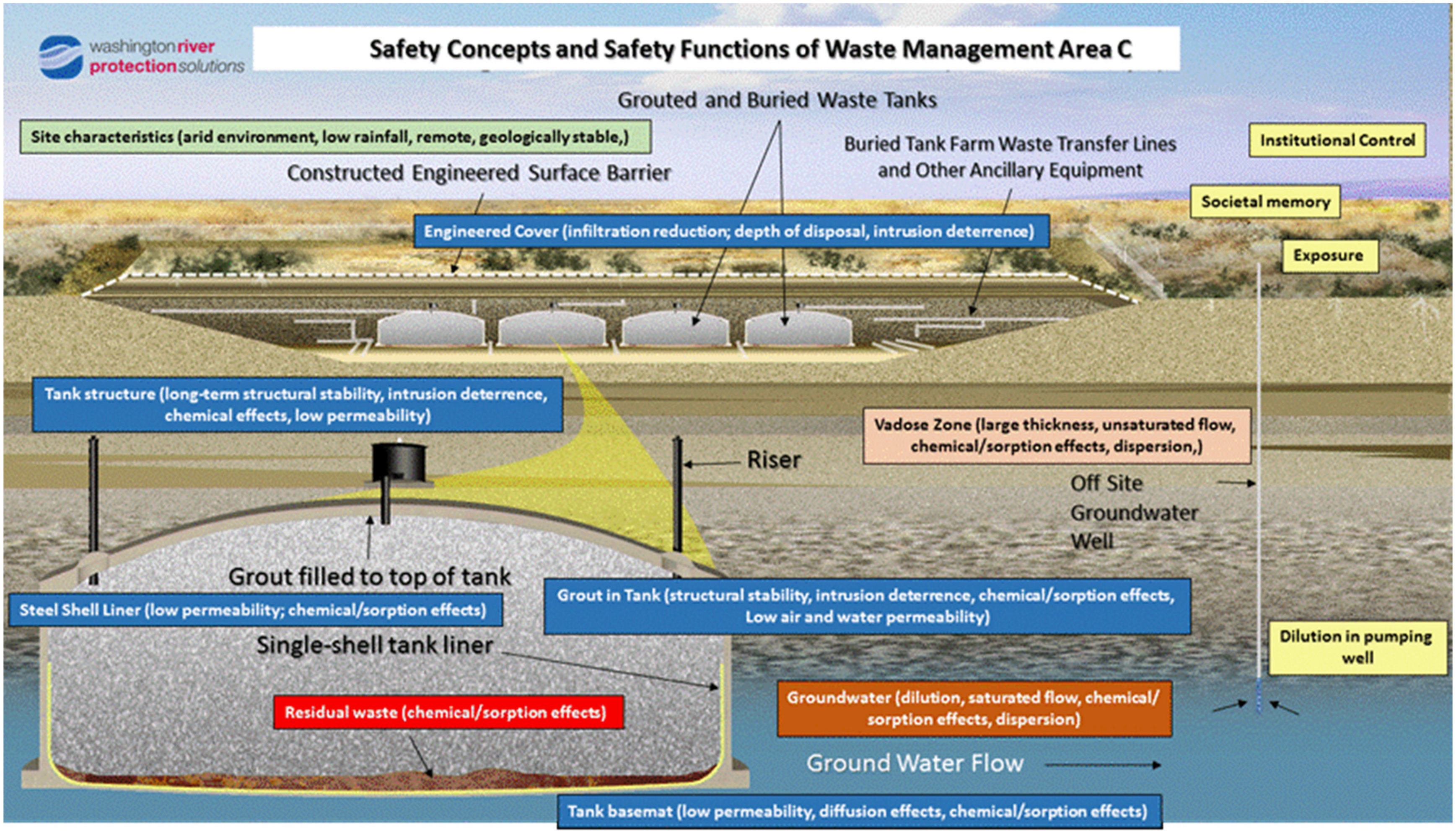
- Alternative conceptualizations of the stratigraphy of the vadose zone

- Alternative assumptions about dilution in the aquifer.

In addition to these deterministic analyses of the effect of the safety functions, a probabilistic analysis of the base case was conducted to show the effects of parameter uncertainty on the performance of the system. A number of parameters were assigned probability density functions, the PA was run probabilistically, and uncertainty estimates in dose were evaluated.

Consequently, the PA includes a base case representing the expected behavior of the disposal system, alternative cases representing degraded safety functions, and uncertainty analyses that represent the effects of parameter uncertainty. These three elements of the PA represent the uncertainties in the post-closure performance of the closed WMA C that will support closure decisions.

Figure ES-4. A Schematic Depiction of the Safety Functions for a Closed Waste Management Area C.



A closure date of year 2020 has been assumed for the WMA C PA. In the post-closure assessment, four time periods have been considered: (1) a 100-year institutional control period when the engineered surface cover works to its design capability, resulting in effectively 0.5 mm/yr recharge rate under the base of surface cover system; (2) a 400-year post-institutional control period (from 100 years to 500 years after closure) within which the surface cover remains intact; (3) the time period from 500 years after closure up to the DOE O 435.1-defined compliance time period of 1,000 years after closure, during which the surface cover barrier function is assumed to be fully degraded at the start of the time period (assuming a design life of 500 years after closure); and (4) the post-compliance period (beyond 1,000 years after closure) up to 10,000 years after closure for the purpose of evaluating uncertainty and sensitivity on dose estimates.

Residual inventory estimates used in this PA were determined based on information and conditions as of September 2014. Inventory estimates were developed for 1) residuals in retrieved tanks with post-retrieval sampling, 2) residuals in retrieved tanks without post-retrieval sampling, 3) residuals in tanks undergoing retrieval and 4) post-retrieval residual inventory estimates for ancillary equipment, including C-301 catch tank, 244-CR vault tanks, and sumps, pits, diversion boxes, and waste transfer pipelines. All radionuclides left in tanks and ancillary equipment at WMA C at closure with half-lives greater than 3 years and non-negligible inventories were included in the PA. In addition, few radionuclides were included that are decay progeny of radionuclides in the inventory to complete the decay chain. A total of 43 radionuclides are evaluated in the WMA C PA.

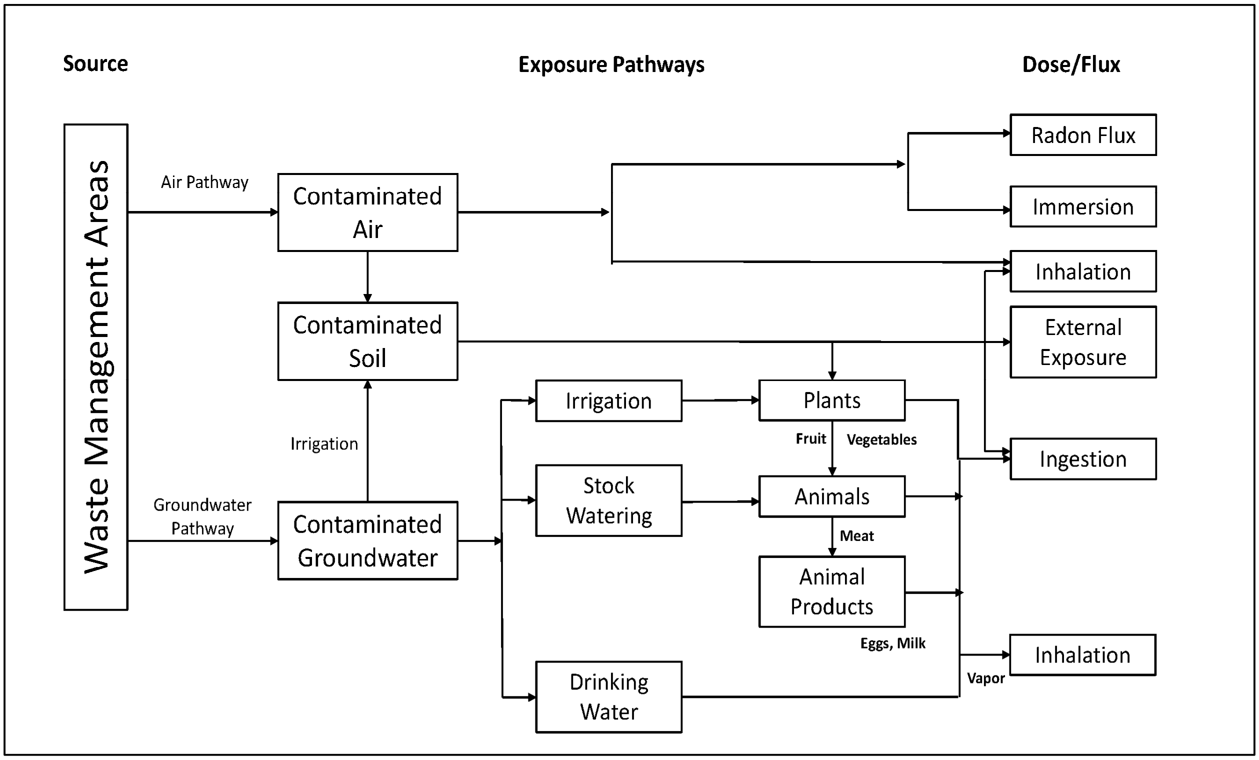
Radiological contaminant releases from the grout inside the tanks and 244-CR vault are controlled by diffusion processes while the grout is assumed to remain intact. In the base case, the tank structure and infill grout placed into the tanks were assumed to be intact for the entire period of analysis. This assumption is supported by an evaluation of the degradation rate of cementitious materials at Hanford. Because all waste transfer lines will likely be disposed in place without the emplacement of infill grout within individual pipelines, the PA considered contaminant release from wastes within the pipelines using a combination of advection and diffusion release mechanisms.

The various pathways of possible exposure evaluated in the WMA C PA are illustrated in Figure ES-5. The major pathways for contamination entering the environment are the groundwater pathway, the air pathway, and an inadvertent intruder pathway (through drill cuttings brought to the surface). The groundwater pathway evaluates the effect of moisture from rain and snowfall entering the subsurface, contacting waste, and carrying dissolved contaminants through the vadose zone to the unconfined aquifer. Therefore, a primary focus of the PA is estimating the groundwater dose to a hypothetical member of the public (i.e., receptor) who:

- Consumes contaminated groundwater, leafy vegetables, and produce that were irrigated with contaminated groundwater, and

- Consumes milk and meat from animals that in turn consume contaminated water and fodder that was irrigated with contaminated groundwater (Figure ES-5).

**Figure ES-5. Overview of the Dose Calculations for Exposure Along the Groundwater Pathway and Air Pathway for the Waste Management Area C Performance Assessment.**



WMA = Waste Management Area

During the compliance and post-compliance periods, the receptor is assumed to reside 100 m downgradient of the WMA C fenceline. The surface water pathway is not a possible exposure pathway for the disposal facility because surface water is not present near WMA C, and is too limited on the Hanford Site Central Plateau in quantity to be used domestically.

All-pathway dose calculations have been performed by evaluating the long-term release of radionuclides from the closed WMA C along the groundwater and atmospheric pathways. The groundwater pathway analysis is the most complex and included the following.

(a) An initial three-dimensional screening analysis to identify radionuclides that cannot provide calculable groundwater contamination over the duration of the simulation and thus can be screened out from further calculations. Using conservative recharge rates and hydraulic properties it was determined that radionuclides with a $K_d > 0.1$ mL/g require no detailed analysis for the 1,000-year compliance time frame, and radionuclides with a $K_d > 1.5$ mL/g require no detailed analysis for the 10,000-year post-compliance period. As a result of the screening, radionuclides with $K_d > 1.5$ mL/g are excluded from further consideration in the groundwater pathway calculations.

(b) A three-dimensional flow and transport analysis for the base case with the parameter values set at their expected values. This involved determining the appropriate boundary conditions under steady-state conditions that are expected in the future. No breakthrough of contaminant was observed within the 1,000-year compliance time period at the 100-m downgradient compliance location in the saturated zone. The first breakthrough of non-retarded contaminants occurred after 1,500 years after closure.

(c) One-dimensional abstraction models for performing uncertainty analyses and multiple parameter sensitivity analyses. For the uncertainty analysis, including evaluation of the coupled effects of uncertainty in source term, engineered system, and natural system, a PA abstraction model was developed. A full uncertainty analysis using the Monte Carlo sampling methodology was undertaken by developing stochastic inputs and performing multi-realization simulations. Uncertainties in the dose estimates are calculated for the compliance and post-compliance time periods.

(d) A suite of sensitivity analyses to evaluate the performance of the system when the safety functions are degraded compared to their expected behavior.

The PA results of the all-pathways, atmospheric, radon flux, inadvertent intruder, and groundwater (water resources) protection analyses are shown in Table ES-1 for the compliance and post-compliance periods. Only the peak values of the effective dose equivalent or peak concentrations are compared to the standards. Releases to groundwater and air were evaluated against performance objectives for the all-pathways analysis required by DOE O 435.1. The all-pathways analysis combines the groundwater pathway analysis and the air pathway analysis for the base case, as discussed in Section 6.

As illustrated in Figure ES-6, the peak dose for the all-pathways analysis in the compliance period is associated with the air pathway, with the peak dose of $4 \times 10^{-3}$ mrem/yr dominated by tritium resulting from upward gaseous diffusive flux from the residual waste. The peak calculated dose occurs in the institutional control period, between 10 and 20 years after closure. This peak dose occurs during the period of institutional control, and cannot, strictly speaking, be regarded as a dose to a member of the public. Instead, the dose during this time period would represent a potential dose to a worker at the compliance boundary. This calculated dose does not consider the active monitoring measures that are anticipated during institutional control. The all-pathways dose remains low, approximately $4 \times 10^{-5}$ mrem/yr, for about 800 years after closure, but shows a rapid increase near the end of the compliance time period due to breakthrough of $^{99}$Tc at 100 m downgradient of the facility along the groundwater pathway. The peak dose within the sensitivity/uncertainty analysis time period (1,000 to 10,000 years after closure) occurs at about 1,500 years after closure, and results primarily from a peak in $^{99}$Tc groundwater concentration at 100 m downgradient of the facility. The peak total dose within the sensitivity/uncertainty analysis time period is 0.1 mrem/yr. The peak dose remains over two orders of magnitude below the performance objective of 25 mrem/yr during the sensitivity/uncertainty analysis period.

### Table ES-1. Comparison of Performance Objectives and Measures with the Waste Management Area C Performance Assessment Results for the Compliance and Post-Compliance Periods.

| Performance Objective and/or Measure | Standard | Performance Assessment Results | |
|---|---|---|---|
| | | Compliance Period (2020–3020)[a] | Post-Compliance Period (3020–12020)[a] |
| **All Pathways** (DOE O 435.1 Chg 1) | 25 mrem/yr EDE | 4E-3 mrem/yr | 0.17 mrem/yr |
| **Atmospheric** (40 CFR 61, Subpart H) | 10 mrem/yr EDE | 4E-3 mrem/yr | 2E-5 mrem/yr |
| **Atmospheric** (40 CFR 61, Subpart Q) | 20 $pCi.m^{-2}.s^{-1}$ radon flux (at surface of disposal facility) | 2E-4 $pCi.m^{-2}.s^{-1}$ | 7E-3 $pCi.m^{-2}.s^{-1}$ |
| **Acute Inadvertent Intruder** (DOE O 435.1 Chg 1) | 500 mrem EDE[b] | 36 mrem | 11.1 mrem |
| **Chronic Inadvertent Intruder** (DOE O 435.1 Chg 1) | 100 mrem/yr EDE[b] | 8.2 mrem/yr [f] | 7E-02 mrem/yr[g] |
| **Groundwater Protection (water resources)** (40 CFR 141) | Beta-gamma dose equivalent ≤ 4 mrem/yr | 5E-4 mrem/yr | 0.13 mrem/yr[c] |
| | Gross alpha activity concentration (excluding radon and uranium) ≤ 15 pCi/L | 0 pCi/L | 1E-10 pCi/L[d] |
| | Combined Ra-226 and Ra-228 concentration ≤ 5 pCi/L | 0 pCi/L | 7E-7 pCi/L[d] |
| | Uranium concentration ≤ 30 µg/L | 0 µg/L | 0.05 µg /L[d] |
| | Sr-90 concentration ≤ 8 pCi/L[e] | Not applicable | Not applicable |
| | H-3 concentration ≤ 20,000 pCi/L | 0 pCi/L | 1E-10 pCi/L[d] |

[a] Compliance at 100 m downgradient of Waste Management Area C except for inadvertent intruder scenarios.

[b] Not applicable for post-compliance time period.

[c] Beta-gamma dose equivalent ≤ 4 mrem/yr (based on Federal MCL) and calculated as ($C_{Peak}$/MCL) × 4 mrem/yr. For Tc-99, which contributes almost the entire dose, $C_{Peak}$ = 30 pCi/L and MCL = 900 pCi/L, so the equivalent dose is calculated to be 0.1 mrem/yr.

[d] Concentrations less than 1E-10 pCi/L are essentially zero.

[e] Not applicable; Sr-90 was screened out during evaluation of the groundwater pathway due to its relatively short half-life and its low mobility in the subsurface.

[f] Peak dose based on assumed inadvertent intrusion into a waste transfer line at 100 years following loss of institutional control using a rural pasture exposure scenario. Peak dose occurs at 100 years after closure.

[g] Peak dose based on assumed inadvertent intrusion into a waste transfer line after 1,000 years following loss of institutional control using a suburban garden exposure scenario. Peak dose occurs at 1,000 years after closure.

EDE = effective dose equivalent MCL = maximum contaminant level

References:

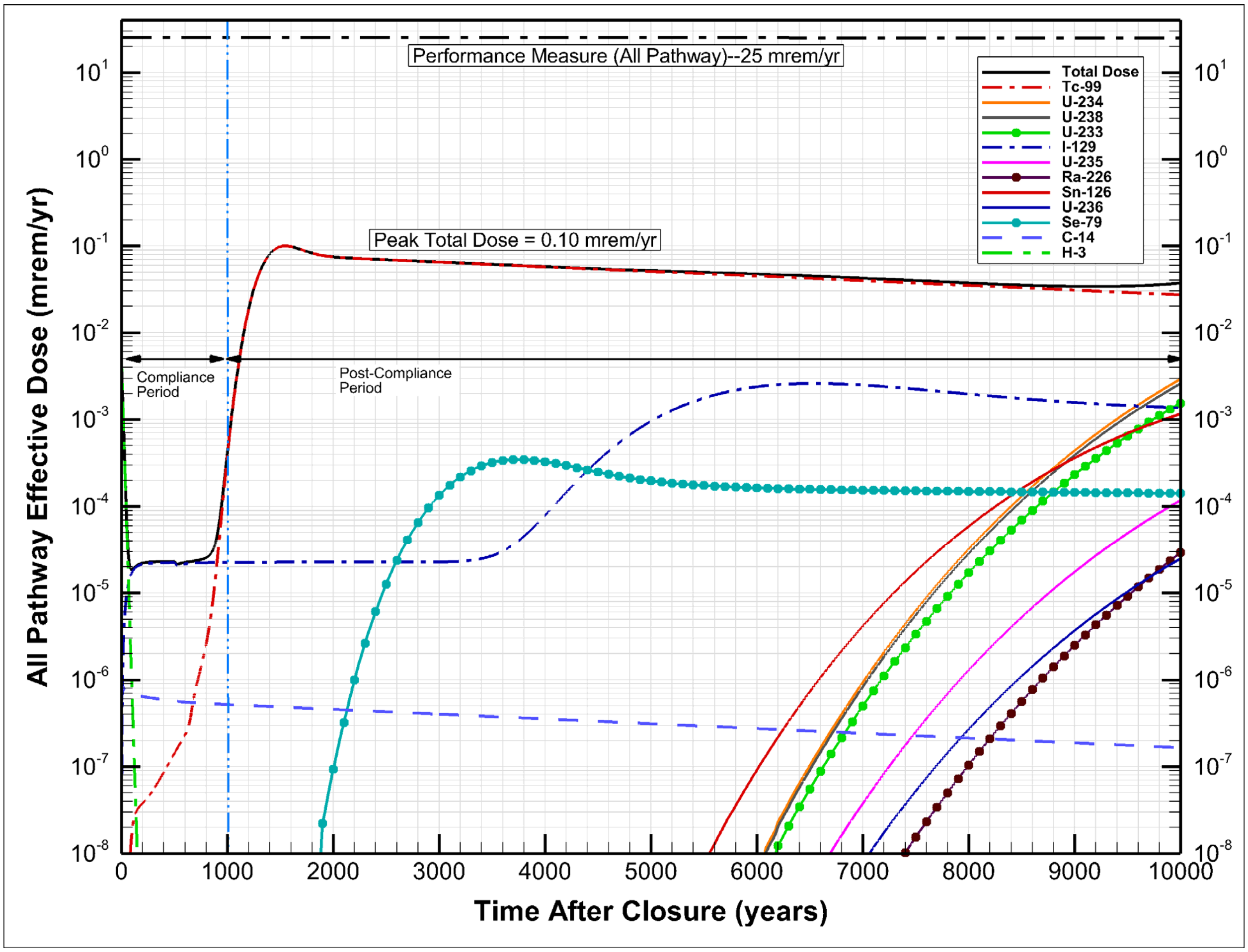
40 CFR 61, "National Emission Standards for Hazardous Air Pollutants," Subpart H—National Emission Standards for Emissions of Radionuclides Other Than Radon From Department of Energy Facilities, Code of Federal Regulations, as amended.

40 CFR 61, "National Emission Standards for Hazardous Air Pollutants," Subpart Q—National Emission Standards for Radon Emissions From Department of Energy Facilities, Code of Federal Regulations, as amended.

40 CFR 141, "National Primary Drinking Water Regulations," Code of Federal Regulations, as amended.

DOE O 435.1, 2001, Radioactive Waste Management, Change 1, U.S. Department of Energy, Washington, D.C.

**Figure ES-6. All-Pathways Dose Results for Base Case that Includes Air and Groundwater Pathway Contributions at the Maximum Point of Concentration. The DOE O 435.1 compliance time (1,000 years) is shown as a vertical blue dashed line, and the compliance dose (25 mrem/yr) is shown as the black horizontal dashed line. Note the logarithmic vertical axis.**



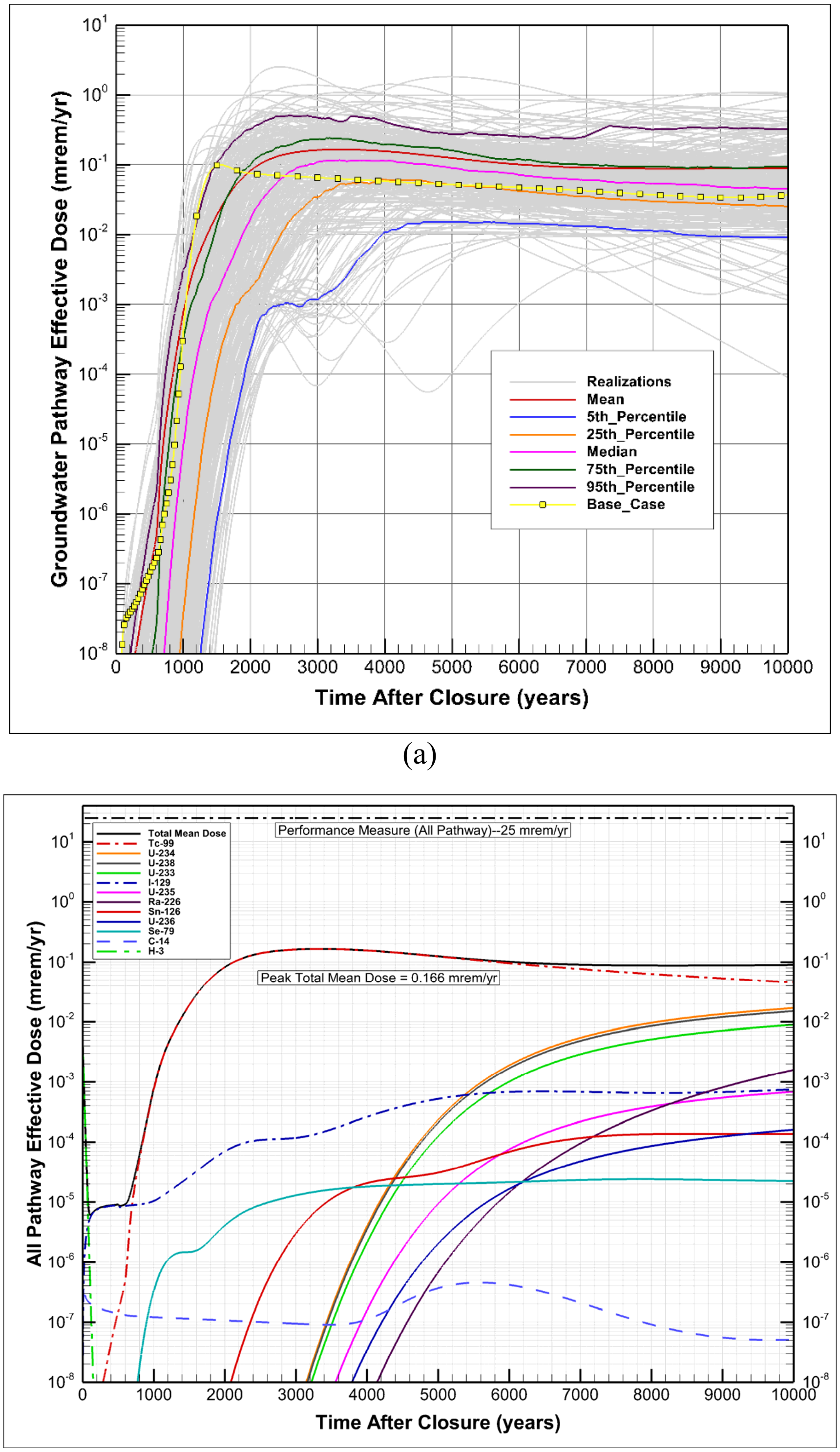
Reference: DOE O 435.1, 2001, Radioactive Waste Management, U.S. Department of Energy, Washington, D.C.

In the uncertainty analysis performed with the system-level model based on GoldSim©[1] (see Figure ES-7, the highest calculated groundwater dose in the compliance period was about 0.07 mrem/yr, and the highest calculated peak dose in the sensitivity/uncertainty analysis period was 2.5 mrem/yr, as discussed in Section 10.6. The most influential parameters that affect the peak dose in the groundwater pathway are the vadose zone hydraulic properties and Darcy flux in the saturated zone (see Section 8.1.4.4 for details).

---

[1] GoldSim© simulation software is copyrighted by GoldSim Technology Group LLC of Issaquah, Washington (see http://www.goldsim.com).

**Figure ES-7. Results of Uncertainty Analysis Based on 300 Realizations of System Model Based on GoldSim© (a) Groundwater Pathway Dose Results and (b) All-Pathways Dose Results.**



(a)

(b)

GoldSim© simulation software is copyrighted by GoldSim Technology Group LLC of Issaquah, Washington (see http://www.goldsim.com).

Among the sensitivity cases with degraded safety functions, the maximum deviation from the base case was a factor of 4.8 higher than the base case, which occurred for the sensitivity case which assumed the bounding $^{99}$Tc inventory in the unretrieved tanks. For this case, there is no change in the time dependence of the results compared to the base case; the peak occurs in the sensitivity/uncertainty time period, and the concentration in the compliance time period is small. This case represents an assumption that no further retrieval of $^{99}$Tc from tanks will be possible.

In the parameter uncertainty analysis, for the entire range of input parameters, even including the extreme of the sampled inputs, the disposal system met the performance objectives. A summary of these results show the robustness of the PA to uncertainties in the input parameters used in the model.

For the air pathway, only the radionuclides $^{14}$C, $^{3}$H, and $^{129}$I are considered as they are the only volatile radionuclides considered for air pathway dose calculations. Potential releases into the gaseous pathway were evaluated and compared to the DOE O 435.1 performance objective of 10 mrem/yr for doses from airborne contamination. The results of the analyses were orders of magnitude below the performance objective, as shown in Table ES-1.

Releases of radon from the facility were evaluated and compared to the 20 pCi/m$^{2}$/s radon flux performance objective in DOE O 435.1. The inventory of $^{226}$Ra (the parent of $^{222}$Rn) in WMA C residual waste is small, and initial radon fluxes are very low compared to the performance objectives. Ingrowth of $^{226}$Ra from decay of the $^{238}$U decay chain leads to increasing radon fluxes at longer times. However, the fluxes remain many orders of magnitude below the performance objective at all times, as presented in Section 10.3.

Doses associated with hypothetical inadvertent human intrusion were calculated for all sources in WMA C (see Section 9.0) and compared to the acute and chronic performance measures in DOE O 435.1. However, the calculated doses do not take account of the likelihood of intrusion into the various sources, and there are significant differences between them. The tank domes were constructed of reinforced concrete, which are still in good condition and will likely provide a very substantial barrier to a drilling intrusion. Furthermore, upon closure the tanks will be filled with grout, which will add a second, very significant barrier to drilling intrusion. As a result of these barriers, intrusion into grouted tanks is not regarded as a credible event, as the tank domes and infill grout form very substantial and long-lasting barriers to the intrusion. Consequently, while the potential doses from intrusion into a tank are the highest calculated, the likelihood of occurrence of intrusion into a tank is regarded as very small. As a result, the intrusion analyses for tanks should be regarded as informational, and should not be compared to the performance measures.

By contrast, barriers are much less robust or nonexistent for pipelines and other ancillary equipment, and as a result the primary potential for intrusion is considered to be into ancillary equipment. The most likely intrusion event for ancillary equipment would be intrusion into one of the waste transfer lines within the area of WMA C (see Section 9). Doses resulting from this type of intrusion event were used for comparison with performance measures for acute and chronic exposure.

The PA results indicate that the performance objectives and measures for the all-pathways dose, the air pathway dose, the radon flux, and groundwater protection are met for both the 1,000-year compliance time period (2020 to 3020) and the post-compliance period (3020 to 12020). For all of the sensitivity analyses and uncertainty analyses evaluated, the disposal system met the performance objectives. This result demonstrates the robustness of the PA to alternative assumptions with respect to the behavior of the safety functions and input parameters.

Calculated doses for the acute and chronic exposure scenarios from a potential intrusion into a waste transfer pipeline remain below the DOE O 435.1 performance measure for the time period evaluated beyond 100 years after closure. The acute scenario dose is dominated by $^{137}$Cs and $^{239}$Pu, while chronic scenario doses are dominated by $^{90}$Sr, $^{137}$Cs and $^{239}$Pu. The total dose generally shows a steep decline compared to the timescales evaluated in the PA due to short half-lives of $^{90}$Sr and $^{137}$Cs, but becomes stable once long-lived $^{239}$Pu becomes the dominant dose contributor. The dominant exposure conditions for the assessment were from the acute scenario, which had higher doses than the chronic exposure scenario at 100 years after closure. At longer times (greater than about 500 years after closure), the acute scenario also produced higher calculated doses for the intrusion into waste transfer pipelines, mainly because long-lived $^{239}$Pu plays a more important role in the dose calculation.

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## Acronym or Abbreviation

| | |
|---|---|
| 1-D | one-dimensional |
| 2-D | two-dimensional |
| 3-D | three-dimensional |
| AEA | Atomic Energy Act of 1954 |
| ALARA | As Low As Reasonably Achievable |
| ARAR | Applicable or relevant and appropriate requirement |
| ASR | alkali-silica reaction |
| BBI | Best-Basis Inventory |
| bgs | below ground surface |
| BP | before present |
| BRA | Baseline Risk Assessment |
| CA | composite analysis |
| CAD | computer-aided design |
| CCMS | camera/CAD modeling system |
| CCU | Cold Creek unit |
| CDF | cumulative distribution function |
| CERCLA | Comprehensive Environmental Response, Compensation, and Liability Act of 1980 |
| CFR | Code of Federal Regulations |
| CHPRC | CH2M HILL Plateau Remediation Company |
| CMS | corrective measures study |
| COPC | constituent of potential concern |
| CPGWM | Central Plateau Groundwater Model |

| | |
|---|---|
| CRBG | Columbia River Basalt Group |
| C-S-H | calcium silicate hydrate |
| D&D | Demolition and Decommissioning |
| DAS | Disposal Authorization Statement |
| DCF | dose conversion factor |
| DDI | distilled de-ionized |
| DI | deionized |
| DKPRO | Radioactive Decay (DK) and Processing (PRO) code |
| DOE | U.S. Department of Energy |
| DOE-ORP | U.S. Department of Energy, Office of River Protection |
| DNFSB | Defense Nuclear Facilities Safety Board |
| DQO | data quality objectives |
| DWS | drinking water standard |
| Ecology | State of Washington Department of Ecology |
| EDS | energy dispersive spectroscopy |
| EHM | equivalent homogeneous media |
| EIS | Environmental Impact Statement |
| EMCF | Environmental Model Calculation File |
| EMMA | Environmental Model Management Archive |
| EMSL | Environmental and Molecular Sciences Laboratory |
| EPA | U.S. Environmental Protection Agency |
| ERDF | Environmental Restoration Disposal Facility |
| ETF | Effluent Treatment Facility |
| FEPs | Features, Events, and Processes |

| | |
|---|---|
| FFTF | Fast Flux Test Facility |
| FLTF | Field Lysimeter Test Facility |
| FR | Federal Register |
| H3/CCu/RF | H3, CCU and Ringold Formation |
| HCP | Final Hanford Comprehensive Land-Use Plan |
| HDW | Hanford Defined Waste (Model) |
| HEIS | Hanford Environmental Information System |
| Hf | Hanford formation |
| HFFACO | Hanford Federal Facility Agreement and Consent Order |
| HFSUWG | Hanford Future Site Uses Working Group |
| HISI | Hanford Information Systems Inventory |
| HLAN | Hanford local area network |
| HLW | high-level waste |
| HMS | Hanford Meteorological Station |
| HSU | hydrostratigraphic unit |
| HTWOS | Hanford Tank Waste Operations Simulator |
| HWIS | Hanford Well Information System |
| HWMA | Hazardous Waste Management Act |
| ICRP | International Commission on Radiological Protection |
| IDF | Integrated Disposal Facility |
| ILAW | immobilized low-activity waste |
| IPA | Appendix I Performance Assessment |
| K-U-T | potassium, uranium, thorium |
| LANL | Los Alamos National Laboratory |

| | |
|---|---|
| LERF | Liquid Effluent Retention Facility |
| LFRG | Low-Level Waste Disposal Facility Federal Review Group |
| LHS | Latin hypercube sampling |
| LIGO | Laser Interferometer Gravitational Wave Observatory |
| LLW | low-level waste |
| MCL | maximum contaminant level |
| MMI | Modified Mercalli Intensity (scale) |
| NAVD88 | North American Vertical Datum of 1988 |
| NCRP | National Council on Radiation Protection |
| NEPA | National Environmental Policy Act of 1969 |
| NRC | U.S. Nuclear Regulatory Commission |
| NRIZ | normal residential intrusion zone |
| OECD | Organisation for Economic Co-operation and Development |
| OFM | Office of Financial Management |
| ORIGEN2 | Oak Ridge Isotope Generation and Depletion Code 2 |
| OU | operable unit |
| PA | performance assessment |
| PFP | Plutonium Finishing Plant |
| PHB | Prototype Hanford Barrier |
| PNNL | Pacific Northwest National Laboratory |
| PoCal | Point of Calculation |
| PUREX | Plutonium Uranium Extraction (facility) |
| RCA | RCRA Closure Analysis |
| RCC | Retrieval Completion Certification |

| | |
|---|---|
| RCRA | Resource Conservation and Recovery Act of 1976 |
| RCW | Revised Code of Washington |
| REDOX | Reduction-Oxidation (facility) |
| RETC | RETention Curve |
| RFI | RCRA facility investigation |
| RI/FS | remedial investigation/feasibility study |
| ROD | Record of Decision |
| RPPDF | River Protection Project Disposal Facility |
| RSD | relative standard deviation |
| SALDS | State-Approved Land Disposal Site |
| SD | standard deviation |
| SEM | scanning electron microscopy |
| SGE | Surface Geophysical Exploration |
| SI | saturation index |
| SNF | spent nuclear fuel |
| SPFT | single-pass flow-through |
| SST | single-shell tank |
| SSTIP | Single-Shell Tank Integrity Project |
| SST PA | DOE/ORP-2005-01, Initial Single-Shell Tank System Performance Assessment for the Hanford Site |
| STOMP | Subsurface Transport Over Multiple Phases (computer code) |
| TC&WM | Tank Closure and Waste Management |
| TEDF | Treated Effluent Disposal Facility |
| TIC | Total inorganic carbon |
| TOC | Total organic carbon |

| | |
|---|---|
| TSD | treatment, storage and disposal |
| TWINS | Tank Waste Information Network System |
| TWRS | Tank Waste Remediation System |
| UCL | upper confidence limit |
| UPR | unplanned release |
| USACE | U.S. Army Corps of Engineers |
| UST | underground storage tank |
| WAC | Washington Administrative Code |
| WIR | waste incidental to reprocessing |
| WMA | Waste Management Area |
| WRPS | Washington River Protection Solutions, LLC |
| WTP | Waste Treatment Plant |

**Waste Types**

| | |
|---|---|
| 1C | First cycle $BiPO_4$ decontamination waste |
| 1CFeCN | Ferrocyanide sludge from in-plant scavenging of T-Plant 1C waste (without coating waste) |
| 2C | Second cycle $BiPO_4$ decontamination waste |
| AR | Water washed PUREX sludge (1967-1976) |
| $BiPO_4$ | bismuth phosphate |
| BL | B Plant strontium processing wastes and miscellaneous wastes |
| BNW | research waste from Battelle Northwest |
| CW | cladding (coating) waste from Plutonium Uranium Extraction (PUREX) or Reduction Oxidation (REDOX) Plants |
| CWP1 | PUREX aluminum cladding waste (1956-1960) |

| | |
|---|---|
| CWP2 | PUREX aluminum cladding waste (1961-1972) |
| CWR1 | Reduction-Oxidation (S Plant) aluminum cladding waste |
| CWZr1 | PUREX/REDOX zirconium cladding waste (1968-1972) |
| HS | 201-C Hot Semiworks waste (1961-1968) |
| IX | cesium denuded waste from ion exchange process in B Plant |
| MW1 | $BiPO_4$ Metal Waste (1944-1949) |
| OWW3 | PUREX organic wash waste (1968-1972) |
| PFeCN | Ferrocyanide sludge from tributyl phosphate (TBP) in-plant scavenged supernate and co-disposed TBP sludge |
| 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 |
| SRR | Strontium recovery waste (1969-1985) |
| TBP | tributyl phosphate |
| TBP (UR) | Tributyl phosphate/Uranium Recovery Waste (1952-1957) |
| TFeCN | Ferrocyanide waste from 244-CR vault treatment of TBP waste |
| TH | Thorium process waste from PUREX Plant |
| TH1 | Thoria process waste (1966) |
| TH2 | Thoria process waste (1970) |

# 1.0 INTRODUCTION

The U.S. Department of Energy, Office of River Protection (DOE-ORP) is pursuing closure on the single-shell tank (SST) Waste Management Area (WMA) C under Federal requirements and forthcoming State-approved closure plans and permits in accordance with the Hanford Federal Facility Agreement and Consent Order (HFFACO) (Ecology et al. 1989), Action Plan, Appendix I. Waste Management Area C is located in the 200 East Area of the Central Plateau at Hanford and is one of 12 tank farms grouped into 7 WMAs (A-AX, B-BX-BY, C, S-SX, T, TX-TY, and U) containing 149 SSTs and ancillary equipment built from 1943 to 1964 (see Figure 1-1).

This document provides the DOE O 435.1, Radioactive Waste Management performance assessment (PA) (see section 1.1 for PA definition) analysis for WMA C. The PA is required by DOE O 435.1 for closing U.S. Department of Energy (DOE)-operated facilities that will manage generated radioactive waste as low-level waste (LLW) which was produced during departmental activities. The fundamental objective of this PA is to support the closure of tanks and ancillary equipment within WMA C that will contain residual levels of radioactive wastes left at closure.

The potential radiological dose to receptors from releases from a closed facility like WMA C is typically evaluated with a PA that examines the following: 1) the release of radionuclides from that facility, 2) the transport of those radionuclides through the environment, and 3) the exposure to humans to environmental concentration levels of constituents of potential concern (COPCs) that are released. In addition, the analysis also evaluates the exposure to potential receptors who inadvertently intrude into the residual waste left in the facility.

The PA process provides the technical basis for subsequent decision documents to demonstrate compliance with the performance objectives outlined in DOE G 435.1-1, Implementation Guide for Use with DOE M 435.1-1, Radioactive Waste Management Manual, Chapter IV – Low-Level Waste Requirements. The WMA C PA project made use of an inter-agency scoping process during the development/planning phases of the PA effort, which resulted in a collaborative understanding of the WMA C PA modeling approaches and assumptions.

This document follows as much as possible the general outline and content guidelines that are identified in the Draft Radioactive Waste Management Disposal Authorization Statement Technical Basis Documentation (DOE-STD-XXX) and those presented in the June 2014 working session. The purpose of this section, Section 1 Introduction, is to provide a general overview of the PA process for WMA C including high-level assumptions, the relationship of this PA with previous PA documents, and background information on the WMA C facility and regulatory requirements. This information is presented in the following subsections:

- General Approach (Section 1.1)
- Regulatory Context (Section 1.2)
- General Facility Description (Section 1.3)

- A Safety Concept and Safety Functions for Closed Waste Management Area C (Section 1.4)

- Land Use and Institutional Control Assumptions (Section 1.5)

- Waste Management Area C History and Plan for Closure (Section 1.6)

- Previous Performance Assessments and Overlapping Analyses (Section 1.7)

- Summary of Key Assessment Assumptions (Section 1.8).

The remainder of the document is comprised of the following sections:

- Assessment Context (Section 2)
- Site and Facility Characteristics (Section 3)
- Screening Approaches (Section 4)
- Waste Characteristics (Section 5)
- Analysis of Performance (Section 6)
- Results of Analysis (Section 7)
- Uncertainty and Sensitivity Analysis (Section 8)
- Inadvertent Intruder Analysis (Section 9)
- Performance Evaluation and Interpretation of Results (Section 10)
- Quality Assurance (Section 11)
- Preparers (Section 12)
- References (Section 13).

Additional information supporting this document is contained in Appendices A through H.

## 1.1 GENERAL APPROACH

A Performance Assessment assesses the long-term fate and transport of contamination in the environment and provides DOE with a reasonable assurance that in this case, the residual radioactive waste left in tanks and ancillary equipment within the closed WMA C will meet defined performance objectives and measures for the protection of human health and the environment into the future.

This PA will satisfy part of the requirements outlined in Appendix I of the HFFACO. Appendix I of the HFFACO Action Plan contains language that broadened the scope of a "performance assessment." 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</u>

> concern, both radiological and nonradiological. 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. The PA is of larger scope than a risk assessment required solely for nonradiological 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. A PA will be developed for each WMA 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 in the scope of the HFFACO Action Plan Appendix I "performance assessment."

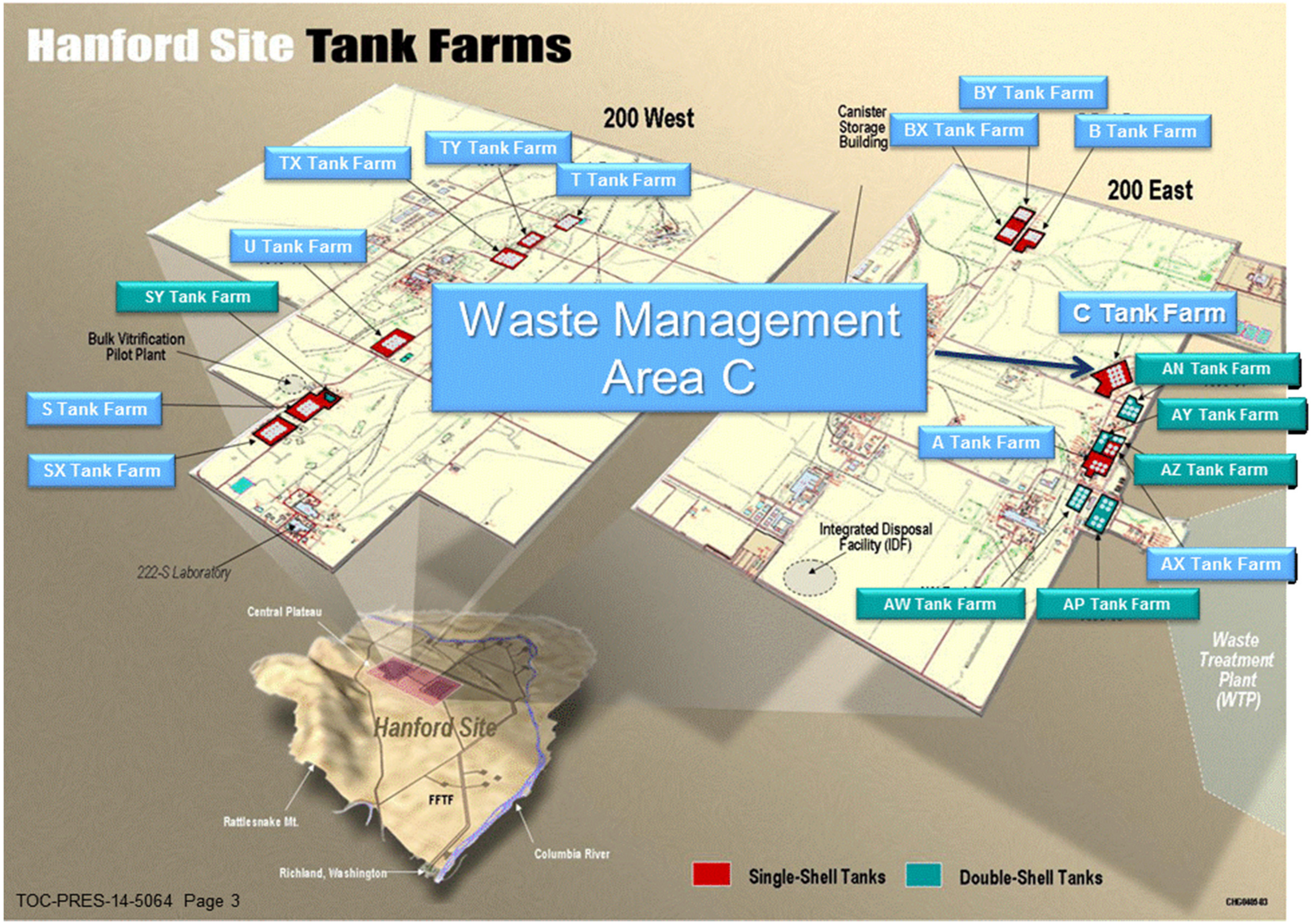
To distinguish between the two terms and avoid confusion, the term "performance assessment" will be used in this document in the following manner:

- The broadened scope of the HFFACO Action Plan Appendix I analysis, which includes non-radiological contaminants, will be referred to as the "Appendix I Performance Assessment" (IPA)

- The simpler "performance assessment" (PA) will refer solely to the DOE O 435.1 definition of performance assessment for radionuclides.

Appendix I of the HFFACO Action Plan describes the waste retrieval and closure process that is to be implemented for the Hanford Site SST system. The four components of the IPA are illustrated in Figure 1-2.

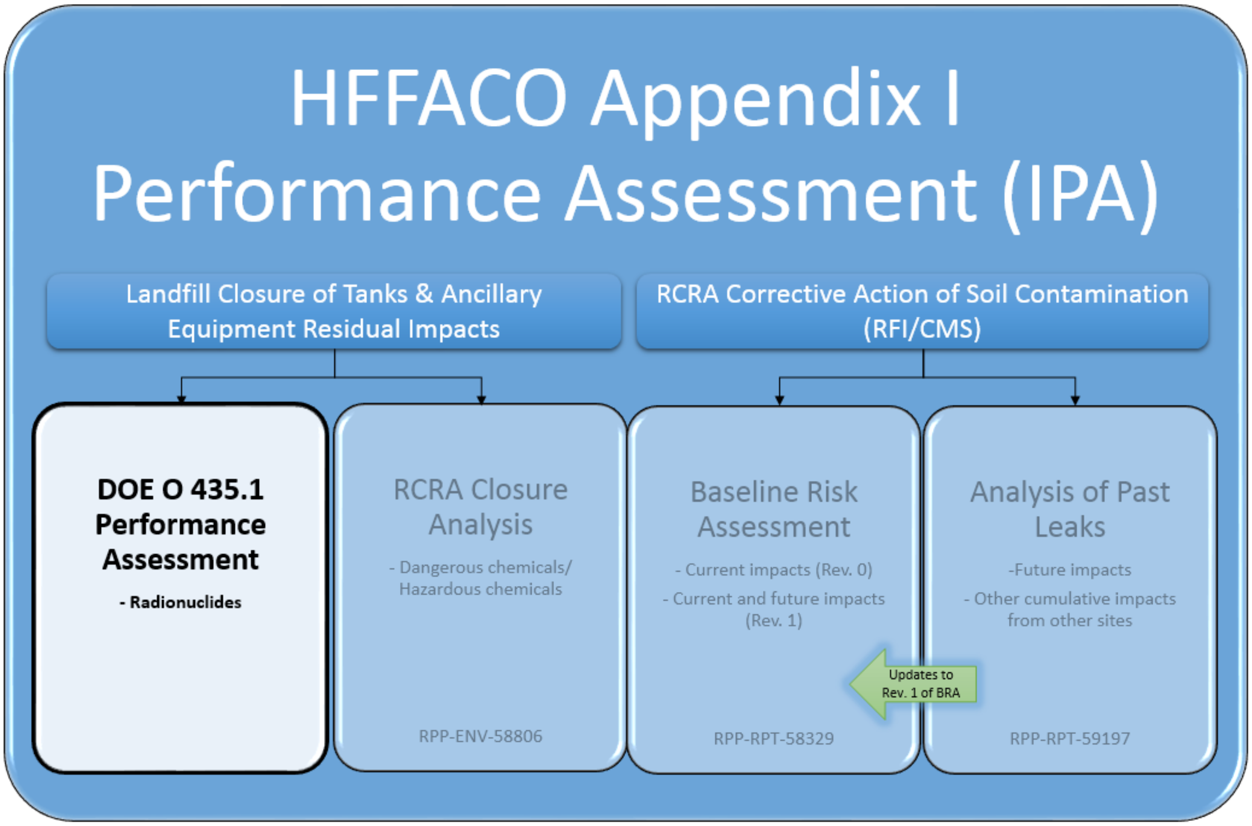
**Figure 1-1. Hanford Site Tank Farms.**



FFTF = Fast Flux Test Facility

Reference: TOC-PRES-14-5064-VA, “Waste Management Area C Performance Assessment (PA) Current Status.”

**Figure 1-2. The Components of the Appendix I Performance Assessment.**



BRA = Baseline Risk Assessment
HFFACO = Hanford Federal Facility Agreement and Consent Order
RCRA = Resource Conservation and Recovery Act of 1976
RFI/CMS = RCRA facility investigation/corrective measures study

References:
DOE O 435.1, Radioactive Waste Management.
RPP-ENV-58806, "RCRA Closure Analysis of Tank Waste Residuals Impacts at Waste Management Area C, Hanford Site, Washington."
RPP-RPT-59197, "Analysis of Past Tank Waste Leaks and Losses in the Vicinity of Waste Management Area C at the Hanford Site, Southeast Washington."
RPP-RPT-58329, "Baseline Risk Assessment for Waste Management Area C."

Closure decisions for the Hanford Site SST system soils will be made through the Resource Conservation and Recovery Act of 1976 (RCRA) corrective action process. The RCRA corrective action component of the IPA is documented in RPP-RPT-58339, "Phase 2 RCRA Facility Investigation Report for Waste Management Area C," Draft A and will contain 1) a baseline risk assessment and 2) an analysis of past leaks.

- **Baseline Risk Assessment** – An evaluation of impacts to human and ecological receptors from both non-radiological and radiological contaminants in soils at WMA C under current condition, in the absence of actions to control or mitigate releases. Following guidance for RCRA Facility Investigation (RFI) and Corrective Measures Studies (CMS), a baseline risk assessment is completed at contaminated waste sites prior to remediation activities to establish a need for action. Guidance for the conduct of human health and ecological risk assessments are summarized in Sections 3.0 and 4.0 of the initial version of the baseline risk assessment (RPP-RPT-58329, "Baseline Risk Assessment for Waste Management Area C") that was prepared to support an RFI for WMA C (RPP-RPT-58339, Draft A). Revision 1 of this document will address both current and future impacts to human health and the environment.

- **Analysis of Past Leaks** – An evaluation of future impacts to human and ecological receptors from both non-radiological and radiological contaminants in soils at the closed WMA C. This evaluation of future impacts will support updates to the anticipated Revision 1 of the baseline risk assessment (RPP-RPT-58329).

The evaluation of residual waste in tanks and ancillary equipment in support of decisions for closure at WMA C is documented in two documents: 1) a RCRA Closure Analysis, and 2) a DOE O 435.1 PA.

- **RCRA Closure Analysis (RCA)** – An evaluation of hazardous chemicals and dangerous waste residual contaminants in tanks and ancillary equipment at a closed WMA C. This component of the IPA is documented in a companion report, RPP-ENV-58806, "RCRA Closure Analysis of Tank Waste Residuals Impacts at Waste Management Area C, Hanford Site, Washington."

- **DOE O 435.1 PA** – An evaluation of radioactive residual waste contaminants in tanks and ancillary equipment at the closed WMA C. This component of the IPA is the sole focus of this current document.

This PA is limited to analyses of radiological impacts of residual wastes in tanks and ancillary equipment left in the closed WMA C under DOE O 435.1. The types of analysis in the PA required by DOE O 435.1 along with their performance objectives are given in Chapter IV – Low-Level Waste Requirements of DOE M 435.1-1, Radioactive Waste Management Manual and are briefly summarized below.

- **Performance Objective Analyses.** These analyses determine if characteristics of the closed WMA C that control radionuclide releases to the surrounding environment are sufficient to satisfy long-term (1,000 years post-closure) period objectives. Prescribed objectives include dose to humans from groundwater and air contamination (all-pathways 25 mrem/yr limit and a 10 mrem/yr atmospheric release limit) and a radon flux limit (20 pCi/m$^2$/s). Of these, the groundwater pathway is the most complex, requiring numerical simulations for radionuclide release from the closed WMA C and transport to a downgradient aquifer well. In contrast, the atmospheric release and radon flux analyses can be completed with simpler numerical solutions or semi-analytic solutions, essentially as bounding calculations.

- **Performance Measures Analyses.** These analyses establish two kinds of criteria for WMA C. Criteria 1 includes radionuclide-specific concentration limits quantified with respect to dose limit for inadvertent intruders that receive dose after exhuming waste.

These analyses estimate dose from a set of algebraic equations that calculates the intensity and duration of exposure to the intruder. Criteria 2 includes an analysis that presumes a cause-and-effect relationship between inventory remaining in tanks and ancillary equipment and groundwater contamination levels after release from WMA C and employs the groundwater pathways analyses used for the all-pathways analysis.

- **Other Analyses.** Other analyses include sensitivity/uncertainty, As Low As Reasonably Achievable (ALARA), and biota analyses. Sensitivity and uncertainty analyses are completed to determine plausible ranges of environmental contamination resulting from uncertainty in parameter values and processes considered in the PA and to identify the most important parameters that influence the dose/risk at a designated point of calculation (PoCal). Both deterministic and probabilistic approaches require numerical simulations. The goal of ALARA analysis is attainment of lowest practical dose level after taking into account health and non-health (societal, environmental, technical, economic, and public policy) considerations and showing that closure at WMA C is being conducted in a manner than maintains ALARA releases of radionuclides to the public and the environment. The biota analysis is a calculation of dose to humans through contact with contaminated biota.

The WMA C PA presents a comprehensive, systematic analysis of the long-term impacts of a closed LLW facility in a semi-arid, near-surface environment. In addition to the specific analyses included in the PA itself, the PA will be used to support decisions related to waste incidental to reprocessing (WIR) that will be left at closure within tanks and ancillary equipment. DOE M 435.1-1 Chapter IIB.(2)(a)2. is the second criteria for the WIR evaluation process. This criterion states that such wastes "(w)ill be managed to meet safety requirements comparable to the performance objectives set out in 10 CFR 61 Subpart C, *Performance Objectives*." This PA will be the primary tool used to demonstrate that Title 10, Code of Federal Regulations (CFR), Part 61, "Licensing Requirements for Land Disposal of Radioactive Waste" (10 CFR 61), Subpart C—Performance Objectives, § 61.41, Protection of the General Population from Releases of Radioactivity and § 61.42, Protection of individuals from inadvertent intrusion are met. Further, the PA will be used to develop the site-specific factors related to 10 CFR 61, Subpart D—Technical Requirements for Land Disposal Facilities, § 61.55, Waste classification Class C comparison.

Closure of WMA C will require a WIR determination of the tank residuals, a DOE O 435.1 Tier I Closure Authorization/II Closure Plan submittal, and RCRA Tier 1, 2, and 3 closure plans which will be submitted as permit modifications to the Hanford Sitewide RCRA Permit (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") for hazardous waste remaining in the tanks along with soils.

The WIR determination and the decision to landfill close the tanks will be made in accordance with DOE O 435.1 and implemented through DOE M 435.1-1 Administrative Change 2, Section I.2.F.(18) and II.B.(2), which requires consultation and coordination with the Office of Environmental Management through the evaluation process. In practice, this will require the Site Manager to submit the decision document (WIR Decision Evaluation and the DOE O 435.1

Tier I and II Closure Plans) through the Deputy Assistant Secretary for Site Restoration to the Secretary of Energy for approval. The closure of the tanks will also follow a process similar to that governed by the Ronald W. Reagan National Defense Authorization Act for Fiscal Year 2005, Section 3116, which will include consultation with the U.S. Nuclear Regulatory Commission (NRC). This PA report may be updated to incorporate substantive comments received during the NRC consultation. The finalized WMA C PA will form the technical basis for the WIR determination.

In addition, in accordance with the HFFACO, the IPA will be developed to evaluate whether SST system closure conditions are protective of human health and the environment for all contaminants of concern, both radiological and non-radiological. The IPA will include the documents outlined in Figure 1-2 to satisfy relevant DOE O 435.1, RCRA and Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) performance requirements.

The decision to remediate the contaminated soil and groundwater underneath the tank farms will be made in accordance with DOE M 435.1-1 Administrative Change 2 Sections II.U.(2) and I.2.F(5), which require the Site Manager to submit the decision document, such as the Record of Decision (ROD), or any other document that serves as the authorization to dispose, to the Deputy Assistant Secretary for Site Restoration for approval.

Related assessment activities (e.g., safety assessments, risk assessments, engineering evaluations, and cost/design studies) are being evaluated in other documents related to WMA C. Although occupational doses to workers are an important area of concern for facility retrieval and closure operations, they are addressed by regulations and guidance that differ from those used in a long-term human health and environmental impacts analysis. Additionally, this document excludes the potential impacts of chemical toxicity of radiological constituents and non-radiological hazardous constituents that may be present in the residual waste left in a closed WMA C because this is part of the RCRA analysis.

### 1.1.1 Waste Management Area C Performance Assessment Scoping Process

The foundation of the WMA C IPA was established in a scoping process that was conducted with regulatory agencies and stakeholders between 2009 and 2011. As a part of the scoping process, a series of working sessions were conducted that addressed the following technical topic areas:

- Residual Inventory (Detailed conceptual models and data related to residual waste inventories left in WMA C tanks and ancillary equipment at closure) (May 5-7, 2009)

- Assessment Context/General Conceptual Models (September 1-3, 2009)

- Soil Inventory (Detailed conceptual models and data on waste inventories released to the environment from historical releases during operations) (October 27-29, 2009)

- Engineered System #1 (Detailed conceptual models and data on natural recharge and waste release) (January 26-28, 2010)

- Natural System (Detailed conceptual models and data on vadose zone and groundwater flow and transport) (May 25-27, 2010)

- Engineered System #2 (Continuation discussion of detailed conceptual models, data, and characteristics of the engineered systems) (July 27-29, 2010)

- Exposure Scenarios (Detailed conceptual models and data on human health exposure scenarios) (September 28-30, 2010)

- Vadose Zone and Groundwater Flow and Transport Modeling (Use of numerical and system-level codes and models to support the PA) (January 25-27, 2011)

- Ecological Risk Assessment (Detailed conceptual models and data related to ecosystem risk assessments) (May 17-19, 2011).

Regulatory agency members who participated in the scoping process included representatives from DOE, U.S. Environmental Protection Agency (EPA), NRC, and the State of Washington Department of Ecology (Ecology) as well as their contractors. Other participants in the working sessions include representatives of the tribal nations, representatives of the Hanford Advisory Board, other stakeholders groups, and members of the public.

The results of the WMA C IPA scoping process have been documented in a series of data package reports that were produced in the 2009 to 2011 scoping time frame. These data packages document the outcomes of working sessions held with relevant regulatory agencies and stakeholders. The purpose of these working sessions was to solicit input from the working session participants, and to obtain a common understanding concerning the scope, methods, and data to be used in the HFFACO Appendix I PA for WMA C among the participants. The listing of the current versions of each data package produced in each of the working sessions is summarized in Table 1-1. Following each working session, Ecology provided comments on each data package. Following the comment resolution, the data packages were revised incorporating those comments. Both the comments and resolution to those comments are provided as an appendix to each data package.

Between the development of these data packages and today, updated information has become available for some of the inputs, and new conceptualizations and interpretations of data have been developed. In addition, stakeholders have expressed ideas and concerns that have led to the development of additional conceptual models and sensitivity analysis cases.

Specific areas in which deviations or updates from the prior data packages occurred include the following:

- Tank inventories have been updated for retrieved tanks based on sampling of waste residuals after completion of the retrieval process

- Data on the contaminant-specific release behavior of waste residuals has been used to develop empirical approaches from modeling dissolution of the tank residuals

- Data and modeling have been conducted on degradation of the engineered barrier system to provide an improved basis for the analysis

- Two alternative models of the site stratigraphy have been implemented based on collaboration with stakeholders

- Vadose zone flow properties have been updated to better represent site-specific data

- Aquifer flow properties have been updated to reflect new data and interpretations.

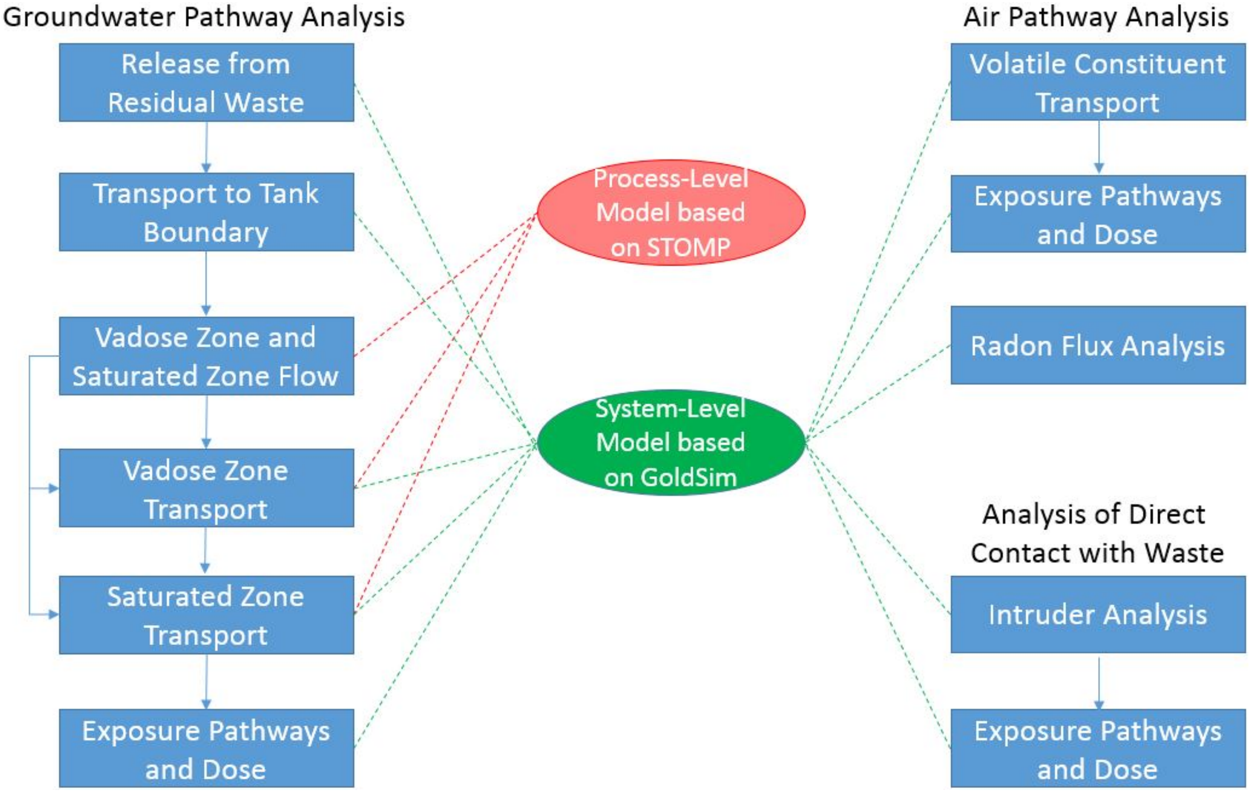
**Table 1-1. Data Packages Produced as a Part of the Waste Management Area C Performance Assessment Scoping Process.**

| Working Session Topical Area | Report Number (Year Published) | Current Revision No. | Title |
|---|---|---|---|
| **Residual Inventory** | RPP-RPT-42323 (2015) | 3 | Hanford C-Farm Tank and Ancillary Equipment Residual Waste Inventory Estimates |
| **Assessment Context** | RPP-RPT-41918 (2010) | 0 | Assessment Context for Performance Assessment for Waste in C Tank Farm Facilities after Closure |
| **Soil Inventory** | RPP-RPT-42294 (2016) | 2 | Hanford Waste Management Area C Soil Contamination Inventory Estimates |
| **Engineered System #1** | RPP-RPT-44042 (2010) | 0 | Recharge and Waste Release within Engineered System in Waste Management Area C |
| **Engineered System #2** | RPP-RPT-46879 (2011) | 2 | Corrosion and Structural Degradation within Engineered System in Waste Management Area C |
| **Natural System** | RPP-RPT-46088 (2010) | 1 | Flow and Transport in the Natural System at Waste Management Area C |
| **Exposure Scenarios** | RPP-RPT-47479 (2011) | 1 | Exposure Scenarios for the Waste Management Area C Performance Assessment |
| **Numerical Codes** | RPP-RPT-48490 (2011) | 1 | Technical Approach and Scope for Flow and Contaminant Transport Analysis in the Initial Performance Assessment of Waste Management Area C |
| **Ecosystem Risk** | RPP-RPT-49425 (2011) | 1 | Ecological Risk Assessment Approach for Hanford Waste Management Area C |

### 1.1.2 Model Development and Implementation Process

The WMA C PA effort is supported by a variety of modeling approaches, directed at various specific parts of the analysis, as shown in Figure 1-3. These include process-level models that address particular flow and transport mechanisms specific in the groundwater pathway analysis and an integrative system-level model that summarizes the entire system, from 1) contaminant release from the residual waste and environmental transport through the groundwater pathway, 2) volatile contaminant releases from the residual waste and environmental transport through the air pathways, and 3) direct contact with residual wastes in the inadvertent intruder analysis. The system-level model uses the results of these analyses in subsequent evaluations of exposure pathways and dose. While the modeling that supports the PA considers a wide range of processes contributing to contaminant transport and exposure pathways, the primary technical approach is focused on the groundwater pathway, which includes release of contaminants from the residual waste, transport through the tank structure and porous media at the site (including consideration of air, water, and solid phases of engineered media such as grout and environmental media such as unsaturated and saturated soils), and exposure of contaminants by humans using contaminated groundwater.

**Figure 1-3. Use of Subsurface Transport Over Multiple Phases and GoldSim© in the Evaluation of Parts of the Performance Assessment.**



GoldSim© simulation software is copyrighted by GoldSim Technology Group LLC of Issaquah, Washington (see http://www.goldsim.com).
Subsurface Transport Over Multiple Phases (STOMP©) is copyrighted by Battelle Memorial Institute, 1996.

The groundwater pathway analysis in this PA is focused solely on the local-scale impacts at WMA C, not on a regional scale, owing to the regulatory requirements it addresses. The groundwater impacts are evaluated at 100 m (328 ft) downgradient of WMA C, as stipulated in DOE O 435.1.

As shown in Figure 1-3, the PA model analysis makes use of a combination of process and systems models. The Subsurface Transport Over Multiple Phases (STOMP©)[1] simulator process-based code is used in the analysis of post-closure flow for both the unsaturated and saturated flow systems. These groundwater flow analyses are used in subsequent groundwater transport analyses in both STOMP© and GoldSim©[2]. The STOMP©-based process models are used deterministically to examine a range of model parameters through sensitivity analyses, whereas the GoldSim©-based system-level model is used to perform uncertainty analyses and additional sensitivity analyses to support the basis for comparisons with performance objectives under DOE O 435.1. The scope of the uncertainty analysis and sensitivity analysis cases are developed and justified on a formal approach based on the combined use of safety functions that are linked to a formal review of Features, Events, and Processes (FEPs) (see discussion of this topical area in Appendix H). These approaches have been combined with the approaches presented and developed in the 2009 – 2011 Working Sessions to produce a suite of sensitivity and uncertainty analyses that represent the basis for comparisons with performance objectives and measures. The approach establishes the safety concept for the closed WMA C facility, and leads to the identification of specific analyses that query the robustness of the disposal system.

## 1.2 REGULATORY CONTEXT

The regulatory context for tank farm closure, including requirements for the protection of human health and the environment, is complex and regulated by multiple agencies, DOE, Ecology, and EPA. The primary laws and regulations which govern cleanup and closure processes include the following:

- National Environmental Policy Act of 1969 (NEPA)

- HFFACO

- RCRA/Hazardous Waste Management Act (HWMA) (Revised Code of Washington [RCW] 70.105, "Hazardous Waste Management")

- Atomic Energy Act of 1954 (AEA)

- CERCLA.

In concert, these laws and regulations provide the overarching guidelines for the cleanup and closure processes. NEPA provides the decision-making structure for Federal agencies. The HFFACO describes closure activities, which are driven by both the requirements of 1) the AEA, as amended, regulating the radioactive portion of mixed waste and 2) RCRA/HWMA as implemented through Washington Administrative Code (WAC) 173-303, "Dangerous Waste

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[1] Battelle Memorial Institute (Battelle) retains copyright on all versions, revisions, and operational modes of the Subsurface Transport Over Multiple Phases (STOMP©) software simulator, as permitted by the U.S. Department of Energy. STOMP© is used here under a limited government use license.

[2] GoldSim© simulation software is copyrighted by GoldSim Technology Group LLC of Issaquah, Washington (see http://www.goldsim.com).

Regulations," regulating the nonradioactive dangerous portion of mixed waste. It should be noted that the various laws and regulations for closure create redundant and possibly conflicting administrative requirements. The HFFACO, in part, was established to address these issues and to also identify the need for a single IPA that will be approved by Ecology and by DOE pursuant to their authorities under RCRA and the AEA, respectively, and to ensure the actions taken for WMA closure are protective of human health for all contaminants of concern, both radiological and non-radiological.

### 1.2.1 National Environmental Policy Act of 1969

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 ROD 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 ROD stated "The tanks will be grouted and contaminated soils 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 post-closure care." The Basis for the Decision states, "DOE has determined landfill closure of the SST system, which would include corrective/mitigation actions that may require soil removal or treatment of the vadose zone, is a more appropriate approach for SST system closure than clean closure."

### 1.2.2 Hanford Federal Facility Agreement and Consent Order

The HFFACO, signed by DOE, Ecology, and EPA on May 15, 1989, is an enforceable agreement that requires DOE to clean up and dispose of radioactive and hazardous waste at the Hanford Site and close facilities that have been used to treat, store, or dispose of such waste. The HFFACO establishes work requirements (milestones), methods for resolving problems, and an action plan for cleanup that addresses priority activities. The HFFACO also recognizes the applicability of RCRA and its amendments to the Hanford Site. It incorporates a regulatory strategy that specifically places SST activities, including waste retrieval, facility cleanup, remediation, waste disposal, and closure under the HWMA.

An integrated regulatory closure process entitled "Single-Shell Tank System Waste Retrieval and Closure Process" has been developed in the HFFACO Action Plan Appendix I by DOE, in conjunction with Ecology and EPA, to streamline regulatory approval for Hanford Site tank farm closure. This integrated regulatory process uses the existing HFFACO process, action plan, and milestones; completes the HWMA closure process as negotiated by DOE and Ecology; and also recognizes that SST WMA closure and other waste site cleanup activities via compliance with Federal and State requirements need integration[3]. The process also integrates the applicable requirements of the above regulations consistent with DOE M 435.1-1 and the AEA. The agency responsible for the closure of all SST WMAs is DOE.

The HFFACO Action Plan, Appendix I, Section 2.5 establishes the need for a single IPA that will be approved by Ecology and by DOE pursuant to their authorities under RCRA and the AEA, respectively, and to ensure the actions taken for WMA closure will be protective of human health for all contaminants of concern, both radiological and non-radiological. This PA being developed per DOE O 435.1 will also undergo extensive internal DOE review and be reviewed by the NRC under a consultation agreement. Furthermore, the RCRA Closure Analysis, a separate document, will undergo extensive review by both DOE and Ecology.

### 1.2.3 Resource Conservation and Recovery Act of 1976/ Hazardous Waste Management Act

The HFFACO Appendix I, Section 2.5 designates Ecology as the lead regulatory agency for SST closure. Ecology regulates the SSTs as dangerous waste storage and treatment units under the HWMA (RCW 70.105) and WAC 173-303, which implement RCRA.

The decision under the ROD for the TC&M EIS is that the SST system will be landfill closed under the WAC regulations. Following the ROD, and in accordance with WAC 173-303-610, “Closure and Post-Closure” and WAC 173-303-640, “Tank Systems,” DOE submitted DOE/ORP-2014-02, Clean Closure Practicability Demonstration for Single-Shell Tanks to Ecology via Letter 14-ECD-0030, “Transmittal of Clean Closure Practicability Demonstration for the Single-Shell Tanks DOE/ORP-2014-02,” which demonstrated that clean closure of any portion of the SST system is impracticable. DOE will close the WMAs and perform closure and post-closure care in accordance with applicable landfill closure and post-closure requirements set forth in WAC 173-303-610 and WAC 173-303-665, “Landfills” subsection (6) “Closure and post-closure care.”

### 1.2.4 Atomic Energy Act of 1954

Under its authority of the AEA, DOE regulates the closure of its facilities containing radioactive materials. The primary mechanism for this regulation is DOE O 435.1 and the associated documents (particularly DOE M 435.1-1).

Where information regarding treatment, management, and disposal of the radioactive source, byproduct material, special nuclear material (as defined by the AEA) and/or the radionuclide component of mixed waste has been incorporated into the Hanford Site-Wide RCRA Permit, it is not incorporated for the purpose of regulating the radiation hazards of such components under the authority of this closure plan or RCW 70.105.

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[3] For the purpose of this document and HFFACO Appendix I, the terms “integrate” and “integration” mean “to coordinate for the purposes of efficiency and effectiveness.” Such terms have no effect on respective agency authority, requirements, or responsibilities (see page I-1 of HFFACO Action Plan).

### 1.2.5 Comprehensive Environmental Response, Compensation, and Liability Act of 1980

Under Appendix I of HFFACO (Ecology et al. 1989), closure decisions for SST system soils will be made through the RCRA corrective action process pursuant to Agreement Milestones M-45-55 through M-45-62 and its established process for the development of interim measures where appropriate, RCRA RFI/CMS work plans, remedial field investigations, and corrective measures studies. Ecology will also seek the involvement of EPA for the purpose of ensuring the work is consistent with future CERCLA remedial decisions, and to provide EPA and DOE a basis to evaluate the need for additional work that might be required if the closure activities were conducted under CERCLA remedial action authority. Note that the SST WMAs will be closed in close coordination with other closure and cleanup activities of the Hanford Site Central Plateau, including the CERCLA evaluations being conducted for the BP-5 and PO-1 groundwater operable units.

## 1.3 GENERAL FACILITY DESCRIPTION

The Hanford Site, a facility in the DOE nuclear waste complex, encompasses ~1,500 km$^2$ (~586 mi$^2$) northwest of the city of Richland along the Columbia River in southeastern Washington State, as shown in Figure 1-4. The Federal government acquired the Site in 1943 for the production of plutonium. Production of special nuclear materials continued until the 1980s. Since the 1990s, DOE has focused on environmental remediation of the Hanford Site.

Waste Management Area C (WMA C or the 241-C Tank Farm [C Farm]), part of the SST system, is located in the Central Plateau (see Figure 1-4), near the eastern edge of the 200 East Area. One of the first tank farms built, it was constructed in 1944 and 1945.

The WMA C facility contains twelve 100-series tanks and four 200-series tanks (see Figure 1-5). The 100-series tanks are 23 m (75 ft) in diameter, with a maximum 5 m (16-ft) depth and 2,006,000 L (530,000 gal) design capacity. The 200-series tanks are 6 m (20 ft) in diameter with a maximum 7 m (24-ft) depth and 208,000 L (55,000 gal) design capacity. Only tanks 241-C-101 (C-101) through 241-C-106 (C-106) have concrete pits. The other 100-series tanks are equipped with centrally located salt well pump pits. The tanks sit below grade with at least 2 m (7 ft) of soil cover to provide shielding from radiation exposure to operating personnel. Tank pits are located on top of the tanks and provide access to the tanks, pumps, and associated monitoring equipment.

The SSTs were constructed in place with 0.95-cm (0.375-in.)-thick carbon steel (ASTM A283 Grade C) lining the bottom and 0.64-cm (0.25-in.)-thick carbon steel lining the sides of a reinforced-concrete shell. The tanks have concave bottoms (center of tanks lower than the perimeter) and a curving intersection of the sides and bottom, where the carbon steel plate is 0.8 cm (0.3125 in.) thick. The inlet and outlet lines are located near the top of the liners. There are four inlet lines on each tank, which are also known as nozzles. Pipelines from the diversion boxes to tanks C-101, 241-C-104 (C-104), 241-C-107 (C-107), 241-C-108 (C-108), 241-C-110 (C-110), and 241-C-111 (C-111) are supported by concrete viaducts. At ~3 m (9 ft 10 in.) from the tank wall, the viaduct surface steps down and the void space between the pipes and the viaduct surface is grouted. At this point, the viaduct begins fanning out from 0.8 m (2 ft 8 in.) wide to 2.2 m (7 ft 4 in.) wide to support the spread placement of the fill lines through the tank wall. Tanks C-101, C-104, C-107, and C-110 each have one outlet line to the next tank in series. Tanks 241-C-102 (C-102), 241-C-105 (C-105), C-108, and C-111 each have one additional inlet line and one outlet line. Tanks 241-C-103 (C-103), C-106, 241-C-109 (C-109), and 241-C-112 (C-112) each have one additional inlet line from the previous tank in the series. The lines connecting each tank are also referred to as “cascade” lines since they allowed transfer of fluids between tanks using gravity flow.

To support the transfer and storage of waste within WMA C SSTs, there is a complex waste transfer system of pipelines (transfer lines), diversion boxes, vaults, valve pits, and other miscellaneous structures. These miscellaneous features of the tank farm are referred to in this document by the general term “ancillary equipment and components.”

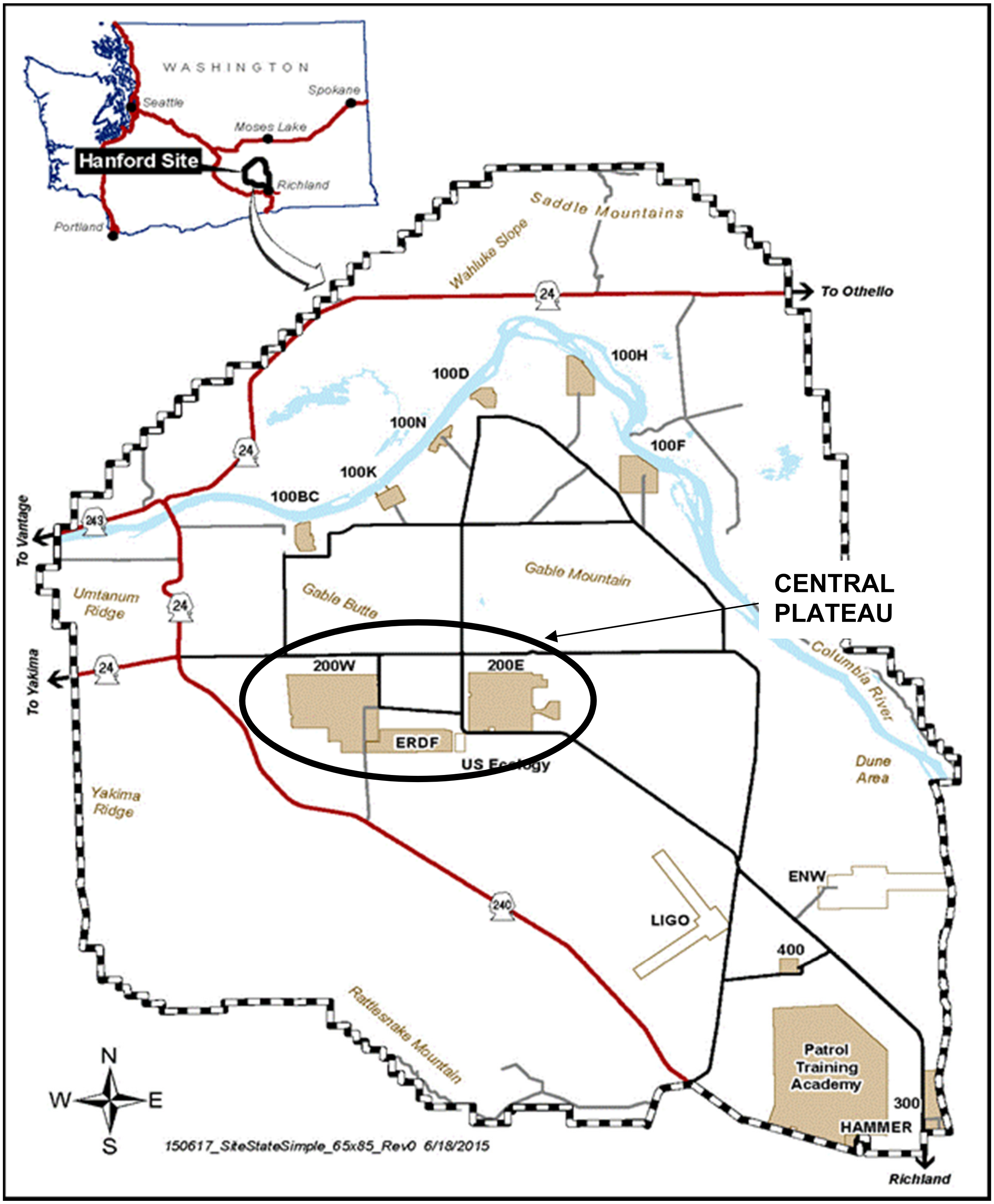
The 244-CR Process Tank Vault (244-CR vault) is located south of the tanks. The vault is a two-level, multi-cell, reinforced-concrete structure constructed below grade, which contains four underground tanks along with overhead piping and equipment. Two tanks (TK-CR-001 and TK-CR-011) have a capacity of 170,343 L (45,000 gal) each. The other two tanks (TK-CR-002 and TK-CR-003) have capacities of 55,645 L (14,700 gal) each. These sets of ancillary equipment and components are included in the DOE O 435.1 PA.

Fourteen unplanned releases (UPRs) have occurred within or near WMA C (Figure 1-6). The largest ones are associated with leaks in pipelines or diversion boxes, with releases from inlet/outlet ports of the SSTs, or with leaks from the SSTs. RPP-PLAN-39114, “Phase 2 RCRA Facility Investigation/Corrective Measures Study Work Plan for Waste Management Area C” provides more detail on these UPR sites. Impacts from the UPRs are not considered under the scope of this DOE O 435.1 PA. Potential and future impacts from the UPRs will be addressed through the RCRA Corrective Action process.

In the ROD issued December 13, 2013 (78 FR 75913), the preferred closure alternative for the tanks is Alternative 2B. Under this alternative, the tanks would be retrieved to 99% of the original inventory and filled with grout. The grout under consideration is formed from cement, fly ash, fine aggregate, sodium bentonite clay, and water to create a free-flowing material that can be used to fill the tanks after waste retrieval is completed. The grout hardens in the tanks to form a monolithic cementitious material inside the tanks. For long-term performance, the grout provides several benefits: it provides structural stability to the tank, it chemically conditions the interior of the tanks to a high pH environment, it provides a low permeability layer to limit contact of water with the residual wastes, and it provides a barrier to potential inadvertent human intrusion.

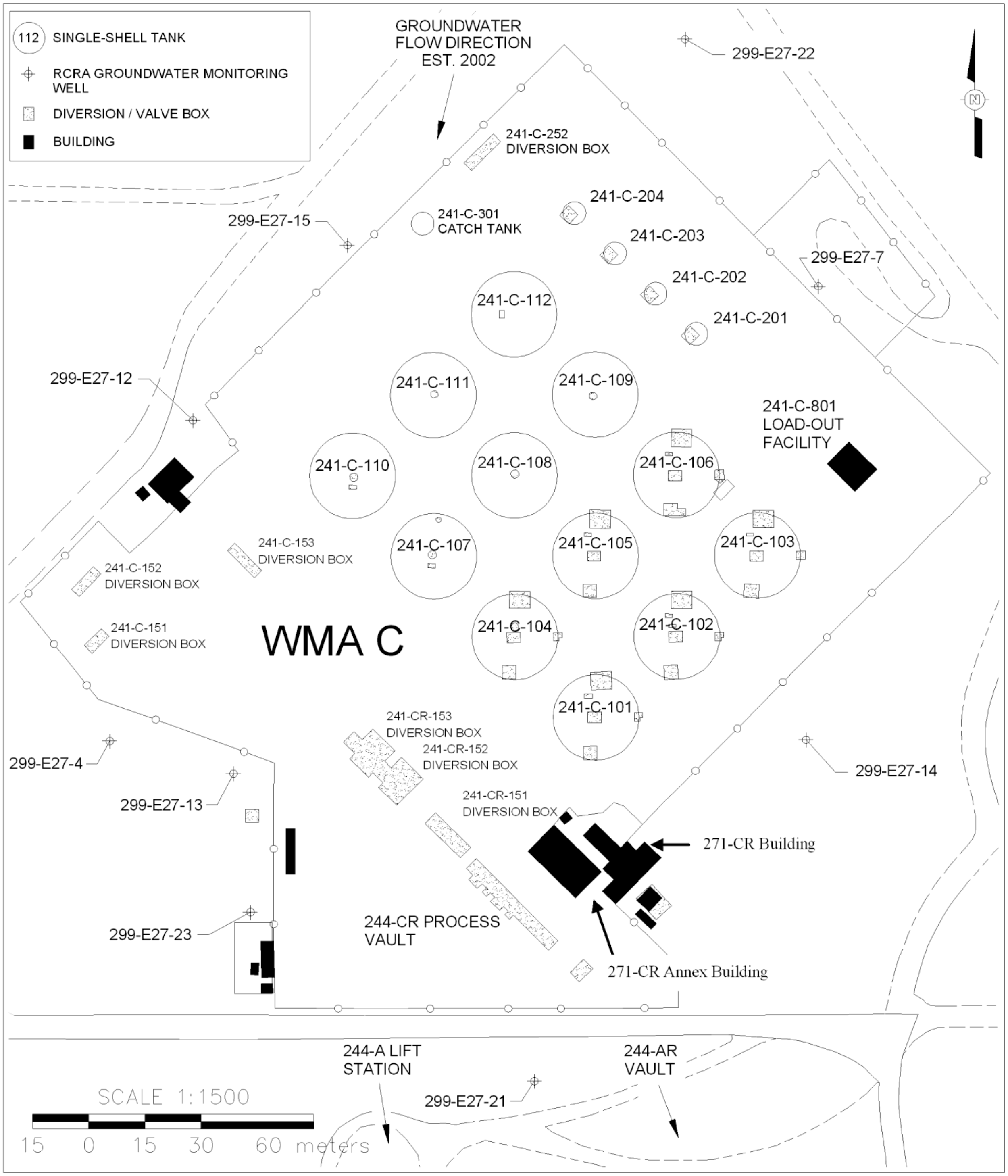
The specific formulation of the grout has not yet been established. DOE/EIS-0391 (2012) assumed the fill material for the tanks will be similar to the cold-cap grout formulation developed by the U.S. Army Corps of Engineers (USACE) for the Hanford Grout Vault Program. This formulation has low-hydration heat and is free-flowing, self-leveling, and designed to generate little or no free water during curing.

**Figure 1-4. Hanford Site and its Location in Washington State.**



ENW = Energy Northwest Columbia Generating Station
LIGO = Laser Interferometer Gravitational Wave Observatory
ERDF = Environmental Restoration Disposal Facility

**Figure 1-5. Location Map of Waste Management Area C and Surrounding Area.**



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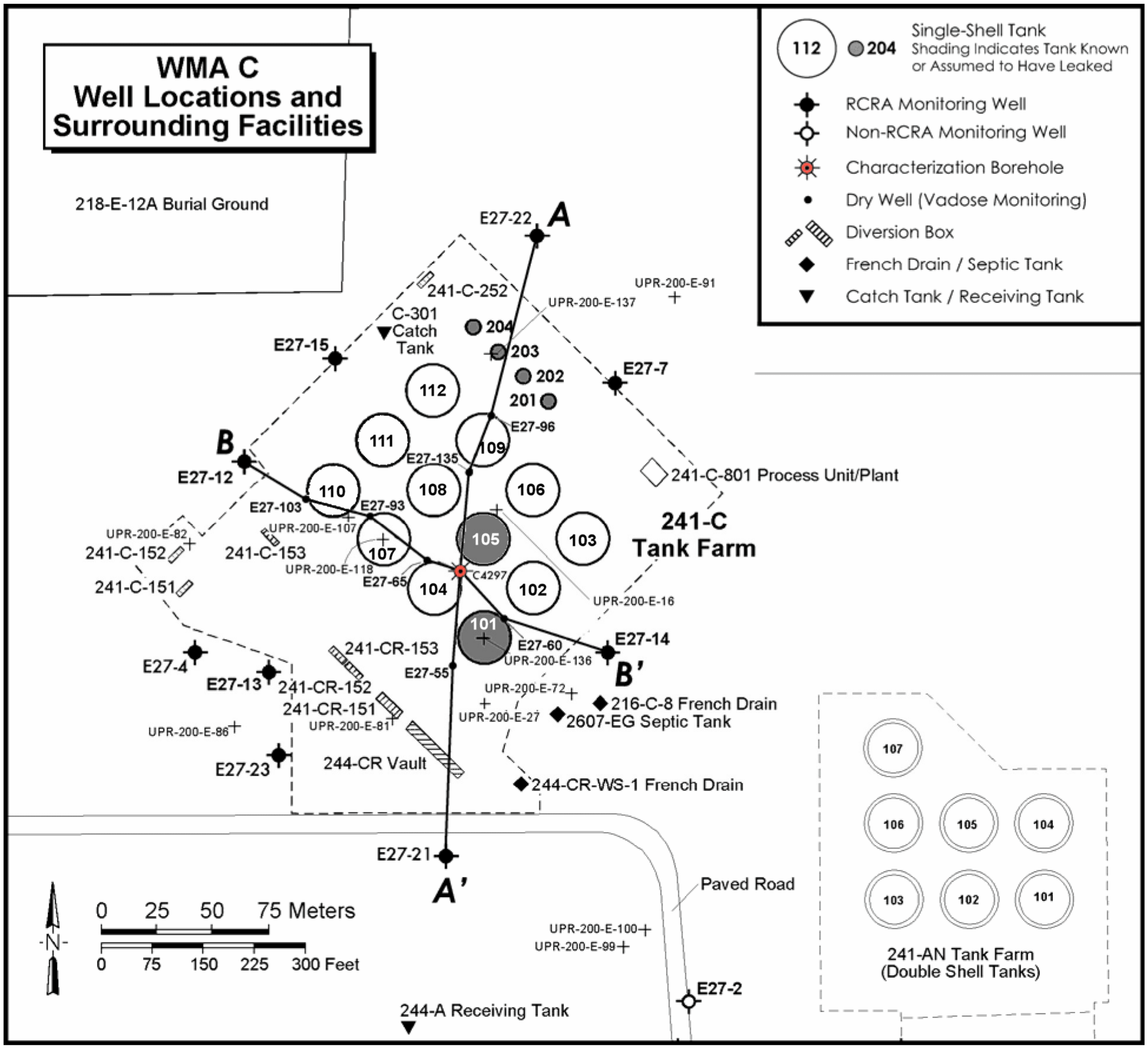
RCRA = Resource Conservation and Recovery Act of 1976 WMA = Waste Management Area

**Figure 1-6. Location Map of Unplanned Release Sites of Waste Management Area C.**



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

## 1.4 A SAFETY CONCEPT AND SAFETY FUNCTIONS FOR CLOSED WASTE MANAGEMENT AREA C

The safety concept for tank closure is composed of a set of safety functions that act together to provide the long-term performance of a closed facility required in closure regulations. The safety functions represent multiple and redundant barriers, so that the loss of one or some of the safety functions continues to result in adequate performance of the overall system. A set of safety functions for WMA C are shown in Table 1-2. A schematic depiction of these safety functions for the closed WMA C is provided in Figure 1-7. The goal of the PA is to evaluate these safety functions, to provide reasonable assurance of performance even when some of the safety functions are lost or degraded through time or disruptive events.

### Table 1-2. List of Safety Functions for the Performance Assessment of Waste Management Area C. (2 sheets)

| | | |
|---|---|---|
| I1 | Institutional control | By rule, it is assumed that control of the site will be retained for 100 years.<br>A strong potential exists that the U.S. government will retain control of the site for a much more extended period of time. |
| I2 | Societal memory | Societal memory is represented by records, deed restrictions, and other passive controls that would warn someone that additional care should be taken in the area. For a member of the public to come onsite to experience exposures to contamination from WMA C, records that the Hanford Site existed would need to be forgotten or ignored. |
| I3 | Exposure point | By rule, it is assumed a post-closure well is established 100 m downgradient at the point of highest exposure. It is highly unlikely that groundwater exposure will occur at this location, and potential wells in other locations would produce much lower impacts to a member of the public. Furthermore, the 100 m boundary for WMA C lies under the A Complex, and does not represent a realistic exposure point. Exposures are more likely to occur further downgradient. |
| EB1 | RCRA cover (permeability) | The final design cover has not yet been established, but is believed to be able to produce very low initial flow rates. Over some period of time this function may deteriorate. |
| EB2 | Steel shell (permeability) | The function of the carbon steel shell to limit flow through the tank is not currently explicitly accounted for in the performance assessment. It is assumed to be permeable at all times. The shell is part of the overall assessment of low flow through the tank for long periods of time. Its potential eventual failure is considered as part of the generic barrier failure cases. |
| EB3 | Steel shell (chemical) | The carbon steel shell will corrode over a period of time, leaving behind corrosion products of (primarily) iron oxides. These corrosion products are highly sorptive and tend to produce reducing conditions that are highly advantageous for limiting solubilities of key radionuclides, particularly technetium-99. This safety function is currently assumed to have no effect on system performance. |
| EB4 | Steel shell (structural) | The steel shell provides structural support preventing short term subsidence of the closed facility. |
| EB5 | Grout in tank (permeability) | The grout acts to limit water flow through the facility, making contaminant releases dominated by diffusion from the waste. |
| EB6 | Grout in tank (chemical) | The grout acts to condition the chemistry of the waste residuals, with sorption characteristics of high pH environments. |
| EB7 | Grout in tank (chemical) | The grout provides a passive and high pH environment for steel corrosion. This safety function is not included in the assessment since the steel shell is assumed to be permeable at all times. |
| EB8 | Grout in tank (structural) | The grout provides structural support preventing subsidence of the closed facility. |
| EB9 | Tank base mat (permeability) | The tank pad, if intact, will provide a flow-limiting layer. |
| EB10 | Tank base mat (chemical) | The concrete pad is anticipated to continue to provide a high pH environment, with associated sorption, for an extended time in the future. |

## Table 1-2. List of Safety Functions for the Performance Assessment of Waste Management Area C. (2 sheets)

| | | |
|---|---|---|
| WF1 | Residual waste (chemical) | The residual waste is recalcitrant by nature, providing limitations to the amount and contaminant release rate upon contact with water. |
| VZ1 | Water flow through vadose zone | The rate of water flow through the soil is slow, leading to long transport times in the vadose zone. |
| VZ2 | Sorption on vadose zone soils | Vadose zone soils sorb some of the constituents of potential concern, delaying their arrival at the water table. However, a number of key contaminants are not believed to sorb significantly. |
| VZ3 | Dispersion in vadose zone | Dispersion results in spreading contaminants in the vadose zone, and thereby decreasing concentrations. |
| VZ4 | Anisotropy in vadose zone | Anisotropy may increase mixing and dispersion in the vadose zone, thereby decreasing concentrations. |
| SZ1 | Water flow in saturated zone | Advective groundwater flow in the saturated zone leads to contaminant dilution. |
| SZ2 | Sorption on saturated zone soils | Saturated zone soils sorb some of the constituents of potential concern, delaying their arrival at the point of compliance. A number of key contaminants are not believed to sorb significantly. |
| SZ3 | Dispersion in saturated zone | Spreading of the plume in the saturated zone, adding dilution to the contaminant plume and lowering concentrations. |
| SZ4 | Dilution in well | Dilution is caused by mixing at a groundwater well extracting groundwater where it is usable and accessible by a member of the public. This safety function is omitted from the performance assessment to make it compatible with the groundwater protection requirements. |

RCRA = Resource Conservation and Recovery Act of 1976

WMA = Waste Management Area

A significant part of the safety concept lies in the land ownership of the Central Plateau by DOE. It is noteworthy that all of the technical calculations that are presented in the WMA C PA are predicated on the loss of the first two safety functions: loss of institutional control of the Central Plateau by DOE, followed by loss of societal memory that the Hanford Site existed. If either or both of these safety functions remain in place, the radiological impacts of releases or residual wastes from WMA C are very low and greatly delayed in time, as shown in the TC&WM EIS analyses for tank residual wastes. In the assessment context of PAs conducted under DOE O 435.1, both of these safety functions are assumed to lose functionality completely after the institutional control period of 100 years.

DOE O 435.1 introduces another administrative safety function into the analysis: the point of compliance. If the first two safety functions (institutional control and societal memory) are lost, DOE O 435.1 requires an assumption that a groundwater well is installed 100 m (328 ft) from the disposal facility fenceline in the location of peak concentration. This assumption means that relatively little credit is given for delay and dilution in the groundwater aquifer. Furthermore, since the PA evaluates impacts from groundwater use at 100 m (328 ft) downgradient of the facility fenceline, potential impacts inferred from this analysis would reflect larger potential impacts and provide an additional margin of safety than would be realized by either individuals potentially using groundwater further downgradient or individuals not using groundwater at all.

The remaining parts of the safety concept involve the use of the engineering, environmental, and hydrogeological setting to provide multiple and redundant barriers to the release and migration of residual wastes from tanks and ancillary equipment. The barriers can be divided into one of three types: structural safety functions, hydrological safety functions, and chemical safety functions. The safety concept calls for backfilling the tanks with grout, leading to a highly stable underground structural matrix. The resulting monolith of grout contained in the tank can be assumed to maintain its ability to support the soil overburden for very long periods of time. Discussion of the potential longevity of the tank structure and the emplaced grout is provided in Section 6.2.1.2 (Evaluation of Tank Stability). The hydrological safety functions are features and processes taking place in the vadose zone and unconfined aquifer that reduce the concentration of a contaminant at a PoCal, such as dispersion, adsorption, natural attenuation, and dilution with clean surrounding water. The chemical safety functions are intended to decrease the solubility and increase the sorption of key contaminants, and to provide a stable and passive chemical environment for the engineered barriers.

As discussed above, the purpose of the PA is to evaluate the safety concept in order to provide reasonable assurance of its performance. Confidence in the overall safety concept is enhanced if there is reasonable assurance of performance even in the event that one or more of the safety functions are lost or are degraded in time. It is therefore reasonable to ask which FEPs might affect a particular safety function in a way that might degrade its function, or to cause the safety function to act differently than expected.

This approach can then be used to identify a set of sensitivity analyses that can be used to explore the implications of the loss of safety functions, while at the same time exploring the implications of aggregated FEPs that might affect the safety function in similar ways. The structure of the PA for WMA C will therefore be to identify sensitivity cases and alternative models for the safety functions shown in Table 1-2, and to examine outcomes when the safety function behaves differently than expected, is degraded compared to a base case, or is lost entirely. Particular attention will be given to any FEPs identified that might affect multiple safety functions simultaneously.

## 1.5 LAND USE AND INSTITUTIONAL CONTROL ASSUMPTIONS

In September 1999, DOE issued the Final Hanford Comprehensive Land-Use Plan (HCP) EIS (DOE/EIS-0222-F, "Final Hanford Comprehensive Land-Use Plan Environmental Impact Statement"). The HCP EIS analyzed the impacts of alternatives for implementing a land-use plan for DOE's Hanford Site for at least the next 50-year planning period and lasting for as long as DOE retains legal control of some portion of the real estate. In November 1999 DOE issued its ROD establishing the HCP, which consisted of four key elements:

- A land-use map that addressed the Hanford Site as five geographic areas,

- A set of nine land-use designations that define the permissible uses for each area of the site,
- The land-use policies, and
- The implementing procedures that would govern the review and approval of future land uses.

These elements were reaffirmed in the HCP EIS Supplement Analysis (DOE/EIS-0222-SA-02, "Supplement Analysis of the Hanford Comprehensive Land-Use Plan Environmental Impact Statement") and in the amended ROD (73 FR 55824, "Amended Record of Decision for the Hanford Comprehensive Land-Use Plan Environmental Impact Statement").

The Central Plateau was designated Industrial-Exclusive by the HCP EIS to allow for continued waste management operations within the Central Plateau geographic area. The definition of Industrial-Exclusive includes treatment, storage, and disposal of all appropriate categories of wastes and related management activities. Figure 1-8 shows the Industrial-Exclusive area established by the HCP EIS within the Central Plateau.

As stated in Section 3.3.2.3.3 of the Final HCP EIS: "This [Industrial-Exclusive] designation would … allow expansion of existing facilities or development of new compatible facilities. Designating the Central Plateau as Industrial-Exclusive would be consistent with the Working Group's recommendations, current DOE management practice, other governments' recommendations, and many public stakeholder values throughout the region."

DOE/RL-2001-41, Sitewide Institutional Controls Plan for Hanford CERCLA Response Actions describes institutional controls for the current Hanford Site CERCLA response actions. This Plan originally was developed to fulfill the requirement for submittal of a Sitewide plan that describes how the DOE Richland Operations Office will implement and maintain the operable unit-specific institutional controls specified in CERCLA decision documents.

This plan includes specific discussion about each of the five categories of institutional controls including warning notices, entry restrictions, fencing, land use management, and groundwater use management on the Hanford Site for CERCLA-based remedial actions.

For all of the operational areas (i.e., including the 100, 200, and 300 Areas), this plan states: "Land use is managed according to the comprehensive land-use plan as described in DOE/EIS-0222-F and DOE/EIS-0222-SA-01and [*sic*] in compliance with DOE orders and cleanup end states as established in CERCLA decision documents."

Despite the designation of the Central Plateau, including WMA C, the assumption under DOE O 435.1 is that control of the site and institutional records (e.g., deed restrictions) associated with its designation as Industrial-Exclusive are lost or otherwise not implemented beginning 100 years after facility closure. Such events are a necessary precursor to the types of exposure scenarios and the exposure location assumed in the PA. Such assumptions do not represent an administrative intention by DOE to release the site from its Industrial-Exclusive designation, but are only assumptions made as a basis for PA under DOE O 435.1.

Figure 1-7. A Schematic Depiction of the Safety Functions for a Closed Waste Management Area C.

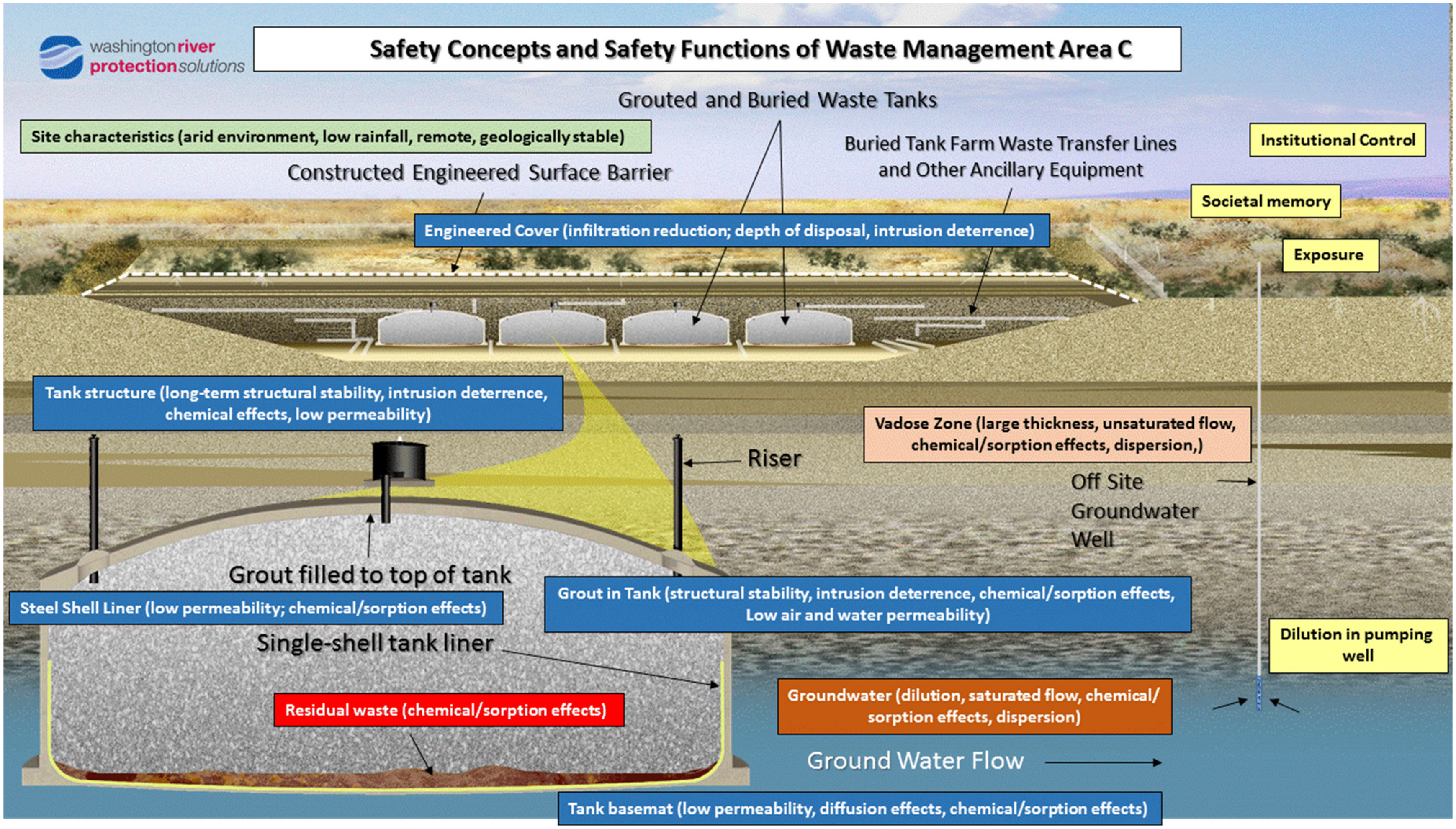
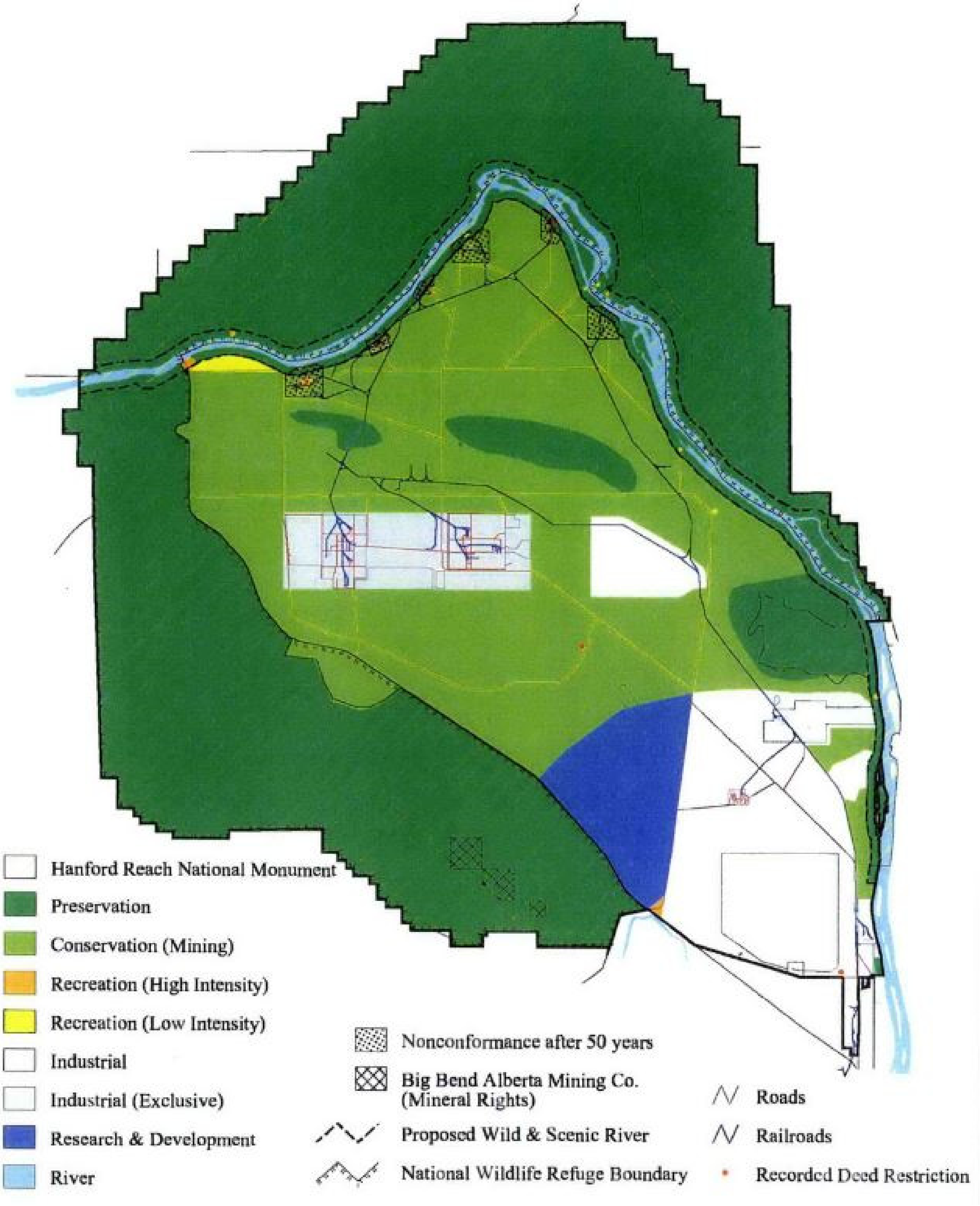


**Figure 1-8. Hanford Site, Showing Land-Use Designations Including the Hanford Reach National Monument.**



## 1.6 WASTE MANAGEMENT AREA C HISTORY AND PLAN FOR CLOSURE

### 1.6.1 History

In this section, a summary is provided of the facility history with an emphasis on those features that are important to the PA. However, this section can only provide a summary of the available information because of the long operating history of the site.

This tank farm was constructed from 1944 to 1945 and originally consisted of twelve 100-series tanks, four 200-series tanks, catch tank 241-C-301 (C-301 catch tank), four diversion boxes (241-C-151, 241-C-152, 241-C-153, 241-C-252) and interconnecting pipelines (Appendix D of RPP-7494, "Historical Vadose Zone Contamination from A, AX, and C Tank Farm Operations"). Construction of the tank farm is shown through a series of photographs (Figure 1-9). On February 10, 1945, the constructed facilities at WMA C were turned over to operations (HW-7-1388-DEL, "Hanford Engineer Works Monthly Report February 1945," page 16). However, the tanks were not utilized until March 1946 starting with the receipt of waste into the 100-series tanks and receipt of waste in the 200-series tanks in September 1947.

New facilities were constructed in WMA C in 1951 and 1952 to allow removal of the stored metal waste in tanks C-101 through C-106 as well as C-201 through C-204. New pump pits, sluice pits, and heel pits were constructed atop these 100-series SSTs for installing waste retrieval equipment through tank risers. The 244-CR vault was installed for acidification, dissolution of solids, and blending the retrieved metal waste slurries. Diversion boxes 241-CR-151, 241-CR-152, and 241-CR-153 along with concrete-encased pipelines were installed for transferring metal wastes from the SSTs to the 244-CR vault. A control room, the 271-CR building, was also constructed for operation of the 244-CR vault equipment. In 1962, building 241-C-801 was constructed to enable the recovery of $^{137}$Cs. Finally, from the 1970s through the 1990s additional pipelines and facilities were installed to support interim stabilization.

The tanks received wastes from the various chemical separations processes conducted at the Hanford Site. For a number of reasons, essentially all of the very high-activity waste streams generated during plutonium recovery operations at the Hanford Site prior to 1980 have been reprocessed. Often, these high-activity waste streams were reprocessed multiple times by physical, chemical, and thermal means. In many cases, reprocessed high-activity waste streams were commingled with lower activity wastes to produce the materials stored in the tanks. An extended summary of the waste processing activities that contributed to wastes in the tank farm is provided in Appendix B of DOE/ORP-2005-01, Initial Single-Shell Tank System Performance Assessment for the Hanford Site (SST PA).

**Figure 1-9. Photographs Showing Different Stages of the Historical Construction of Tanks and Selected Ancillary Equipment in Waste Management Area C.**

Waste retrieval activities have been ongoing since 2003. As of September 1, 2014, waste has been retrieved from 13 SSTs in C Farm (C-101, C-103, C-104, C-106, C-107, C-108, C-109, C-110, C-112, 241-C-201 [C-201], 241-C-202 [C-202], 241-C-203 [C-203], and 241-C-204 [C-204]). Waste retrieval is completed for 13 of the 16 tanks. A practicability request to forego a third technology has been submitted for tank C-102 (RPP-RPT-58676, "Practicability Evaluation Request to Forego a Third Retrieval Technology for Tank 241-C-102") and is under review, and tank C-106 is undergoing a HFFACO (Ecology et al. 1989) Appendix H Attachment 2 "Exception to Retrieval Criteria for Single-Shell Tanks" process that will "indicate the reason DOE does not believe the retrieval criteria can met" (RPP-20658, "Basis for Exception to the Hanford Federal Facility Agreement and Consent Order Waste Retrieval Criteria for Single-Shell Tank 241-C-106"). Residual tank waste constituents and/or hard heel constituents after retrieval were sampled and analyzed. Tank C-203 was not sampled, and tanks C-101, C-107 and C-112 sample results are not yet available. As of September 30, 2014, waste has been partially retrieved and waste retrieval operations are ongoing for SSTs C-102, C-105 and C-111.

### 1.6.2 Closure

Closure of the individual SSTs and WMA C in its entirety occurs in three major steps as identified in RPP-RPT-41918, "Assessment Context for Performance Assessment for Waste in C Tank Farm Facilities after Closure": 1) SST waste retrieval, 2) tank filling for stabilization, and 3) surface barrier placement. A general description of these steps follows.

1. For landfill closure of WMA C to occur, DOE must retrieve as much waste as technically possible (Ecology et al. 1989). The DOE should meet the performance objectives for the disposal of Class C LLW provided in 10 CFR 61, Subpart C. In addition, because the tank waste residual is mixed waste, it has to meet Washington State dangerous waste requirements for closure (WAC 173-303). In the HFFACO Appendix I (Ecology et al. 1989) entitled, "SST System Waste Retrieval and Closure Process," closure permits will be incorporated into the Hanford Site-Wide Permit (WA7 89000 8967).

2. The next closure action process after Ecology and DOE Headquarters approval would be to fill the tanks with grout to stabilize and immobilize the residual waste to prevent further long-term degradation of the SSTs, and to discourage intruder access as required for a near-surface disposal facility. As discussed in Section 1.3, the specific formulation of the grout has not yet been established, but the TC&WM EIS assumed the fill material for the tanks will be similar to the cold-cap grout formulation developed by USACE for the Hanford Grout Vault Program. This formulation has low-hydration heat and is free-flowing, self-leveling, and designed to generate little or no free water during curing. This assumption has been adopted for the purposes of this PA.

3. The final closure activity would be placement of an engineered surface cover. This surface cover will provide a barrier to infiltration and intrusion. The specific design of the closure cover has not been finalized, but it is likely to be based on the Modified RCRA Subtitle C Barrier concept (RPP-RPT-49701, "Waste Management Area C Closure – Conceptual Design Report").

## 1.7 PREVIOUS PERFORMANCE ASSESSMENTS AND OVERLAPPING ANALYSES

Over the years, numerous PAs relating to various disposal activities at the Hanford Site, meeting the requirements of DOE O 435.1, have been completed, including:

- WHC-EP-0645, “Performance Assessment for the Disposal of Low-Level Waste in the 200 West Area Burial Grounds”
- BHI-00169, “Environmental Restoration Disposal Facility Performance Assessment”
- WHC-SD-WM-TI-730, “Performance Assessment for the Disposal of Low-Level Waste in the 200 East Area Burial Grounds”
- WHC-SD-WM-EE-004, “Performance Assessment of Grouted Double-Shell Tank Waste Disposal at Hanford”
- PNNL-11800, “Composite Analysis for Low-Level Waste Disposal in the 200 Area Plateau of the Hanford Site”
- DOE/ORP-2000-24, Hanford Immobilized Low-Activity Waste Performance Assessment: 2001 Version.

These assessments do not directly pertain to WMA C, but represent a broad base of knowledge and activities for other facilities at Hanford and regionally relevant issues. At several sites, the nature and behavior of the general geological setting is expected to be similar.

A number of documents dealing with assessments for closing tank farms with specific relevance to WMA C have been issued. Early PAs relevant to WMA C include:

- DOE/ORP-2003-11, “Preliminary Performance Assessment for Waste Management Area C at the Hanford Site, Washington”
- RPP-13774, “Single-Shell Tank System Closure Plan.”

These older assessments were updated with current information in recent assessments that include:

- DOE/ORP-2005-01, “Initial Single-Shell Tank System Performance Assessment for the Hanford Site”
- DOE/EIS-0391, “Final Tank Closure and Waste Management Environmental Impact Statement for the Hanford Site, Richland, Washington”
- RPP-PLAN-47559, “Single-Shell Tank Waste Management Area C Pipeline Feasibility Evaluation.”

These more recent assessments provide relevant information to the IPA and are briefly summarized in the following sections.

### 1.7.1 Single-Shell Tank Performance Assessment

The SST PA (DOE/ORP-2005-01), that met the requirements of the DOE O 435.1, presented an analysis of the long-term impacts of residual wastes assumed to remain after retrieval of tank wastes and closure of the SST farms. The SST PA was intended to be a comprehensive evaluation of closure of all SST WMAs at Hanford, and included WMA C in its scope, but was not exclusively focused on it.

The reference case set of parameters and engineering assumptions evaluated in the SST PA was selected to represent a best estimate of the closed facility performance at WMA C. The SST PA also examined a range of values for parameters to support defining the expected performance range of each barrier or feature. To estimate the robustness of the selected set of barriers, alternative conceptualizations were analyzed using variations on the reference case design to establish the level of performance degradation that might occur. Additionally in the SST PA, residual tank waste impacts on groundwater, air resources, and the inadvertent intruder were shown to be limited and well below most important performance objectives for the reference case used in the analysis.

### 1.7.2 Tank Closure and Waste Management Environmental Impact Statement Analysis of Waste Management Area C

The HCP EIS and subsequent supplemental analysis (DOE/EIS-0222-F; DOE/EIS-0222-SA-01, "Hanford Comprehensive Land-Use Plan Environmental Impact Statement Supplement Analysis") and RODs [64 FR 61615, "Record of Decision: Hanford Comprehensive Land-Use Plan Environmental Impact Statement (HCP EIS)"; 73 FR 55824] designated a 5,064-hectare (12,513-acre) area within the Central Plateau of Hanford as Industrial-Exclusive. This area, which includes the 200 East and 200 West Areas, includes WMA C. The Industrial-Exclusive designation preserves DOE control of continuing remediation activities and use of the existing compatible infrastructure required to support activities such as radioactive and mixed waste treatment, storage, and disposal. Further, under this designation, DOE continues its Federal waste disposal mission. The Industrial-Exclusive designation also allows for the expansion of existing facilities or the development of new compatible facilities in support of ongoing missions.

The TC&WM EIS (DOE/EIS-0391) included in its scope an evaluation of residual wastes in WMA C. The EIS also included an evaluation of waste sources in the tank farm, including past tank leaks, retrieval leaks from the tanks, and UPRs from within the WMA C fenceline. In Federal Register notice 78 FR 75913, DOE issued the first in a series of RODs announcing its preferred alternative (Alternative 2B) for wastes contained in underground radioactive waste storage tanks evaluated in the Final TC&WM EIS, DOE/EIS-0391 (2012). Decisions announced in this ROD pertain to each of the three main areas analyzed in the EIS, i.e., tank closure, decommissioning of the Fast Flux Test Facility (FFTF), and waste management. This ROD amends the 1997 Tank Waste Remediation System (TWRS) ROD (62 FR 8693, "Record of

Decision for the Tank Waste Remediation System, Hanford Site, Richland, WA," February 26, 1997).

As a part of the ROD issued December 13, 2013 (78 FR 75913) arising from the TC&WM EIS, the preferred closure alternative for the SST WMAs was Alternative 2B. This ROD includes retrieval of 99% of the waste volume currently stored in Hanford's 177 underground storage tanks, landfill closure of the SST farm systems, and operation and maintenance of the tank farms. Tank Closure Alternative 2B considers vitrification treatment of waste from the Hanford 200 East and 200 West Area tank farms in accordance with the TWRS EIS ROD and supplemental analyses.

The end state of the tanks evaluated under Alternative 2B assumes that the individual WMAs of the SST waste system would be closed as landfill units under the requirements of WAC 173-303 and DOE O 435.1, as applicable, or decommissioned under DOE O 430.1B, Real Property Asset Management. The tanks and selected ancillary equipment would be filled with grout to immobilize residual waste, prevent long-term degradation of the tanks, and discourage inadvertent intruder access. Under Alternative 2B, removal and replacement of the top 4.5 m (15 ft) of soil was considered for the 241-BX and 241-SX Tank Farms, but no such actions are under consideration for WMA C. The ROD states that decisions on the extent of soil removal or treatment would be made on a tank farm or WMA basis through the RCRA closure permitting process. The closed tank system would be covered with an engineered Modified RCRA Subtitle C Barrier, followed by post-closure care for 100 years.

The details of the basis for the impacts analyses from WMA C for Alternative 2B within the TC&WM EIS are provided in Appendix F. Because of the importance of the TC&WM EIS in establishing the ROD for landfill closure of WMA C and other SST WMAs, the PA effort evaluated a specific sensitivity case using the current base case numerical model developed for the WMA C PA with the same residual inventories, recharge, and waste release models used for the WMA C model developed for the EIS. A comparison of results of this sensitivity case with comparable results for the WMA C-specific model used in the TC&WM EIS analysis is also described and provided in Appendix G.

### 1.7.3 Waste Management Area C Pipeline Feasibility Study

Revision 1 of RPP-PLAN-47559 provided an initial scoping analysis of the post-closure consequences of residual wastes in ancillary equipment. This analysis did not consider residual wastes in tanks. These analyses resulted in the following general conclusions:

- For the inadvertent drilling intrusion scenario, a total acute dose to the intruding receptor was well below the generally accepted performance objective for inadvertent intrusion (500 mrem for acute exposure) at closed LLW facilities under DOE O 435.1

- For groundwater, a peak chronic total dose to the receptor was well below the drinking water standard of 4 mrem/yr

- For key non-radiological contaminants assumed to be left behind in waste pipelines, human health and environmental impacts via the groundwater pathway were well below groundwater cleanup level.

## 1.8 SUMMARY OF KEY ASSESSMENT ASSUMPTIONS

This assessment has been structured as a series of sensitivity and uncertainty analyses intended to evaluate the effect of a wide range of assumptions on site evolution and alternative concepts regarding the physical behavior of the site. The alternative analyses include sensitivity cases that evaluate conditions well outside the range of the base case analysis. In all cases the calculations produced results that are below the performance measures. Therefore, none of the assumptions listed in this section are key assumptions to compliance, and there are no specific design variables that must be met in order to meet the regulatory goals of DOE O 435.1.

An extended list of key assumptions used in the PA are presented in Appendix A. Specific key assumptions are presented here that specifically relate to potential decisions regarding design features and closure of the facility.

- It has been assumed that the landfill closure of WMA C occurs in 2020, consistent with planning assumptions in the TC&WM EIS. The results of the PA are not significantly affected by alternative assumptions about closure timing.

- The engineered cover for WMA C is not yet designed, but is assumed to be similar to the Modified RCRA Subtitle C Barrier that limits infiltration through the waste primarily by evapotranspiration processes (i.e., surface barrier) based on the work done for the Hanford Prototype barrier (DOE/ORP-2008-01, RCRA Facility Investigation Report for Hanford Single-Shell Tank Waste Management Areas, Appendix C). These processes are not modeled directly, but those processes have been studied through field measurements, tracer studies, and numerical models to estimate net infiltration (PNNL-14744, "Recharge Data Package for the 2005 Integrated Disposal Facility Performance Assessment"; PNNL-14960, "200-BP-1 Prototype Hanford Barrier Annual Monitoring Report for Fiscal Year 2004"; "Multiple-Year Water Balance of Soil Covers in a Semiarid Setting" [Fayer and Gee 2006]). Instead, the recommended net infiltration rates from those reports are applied to the area under the engineered cover and are varied spatially and temporally as appropriate according to the estimated or assumed time-dependent performance of a surface barrier.

- The specific formulation of the grout has not yet been established, and site-specific measurements of the chemical influence of the grout have not been performed. The chemical effect of the grout is represented by contaminant-specific distributions of distribution coefficients ($K_d$), which have been developed from international literature on sorption of radionuclides on cementitious materials. These values are generally consistent with, or more conservative than, comparable values used for the facility-specific grout at the Savannah River F and H tank farm PAs [WSRC-STI-2007-00369, "Hydraulic and Physical Properties of Tank Grouts and Base

Mat Surrogate Concrete for FTF Closure" and WSRC-STI-2007-00607, "Chemical Degradation Assessment of Cementitious Materials for the HLW Tank Closure Project (U)"].

- Inventories of contaminants in retrieved tanks are based on post-retrieval sampling and measurements. It is assumed that the sampling results are representative of the entire waste residuals. Inventories for tanks that have not yet completed retrieval use the best estimates of post-retrieval conditions available at this time. These data have been estimated as of September 30, 2014. Additional sensitivity cases executed based on alternative inventories in the 2009 to 2011 working sessions.

# 2.0 ASSESSMENT CONTEXT

The scope of the PA must be considered within the framework of the HFFACO (Ecology et al., 1989). Appendix I of the HFFACO contains language that broadened the scope of the PA. This definition by the regulatory agencies in Section 2.5 of 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 one performance assessment for the purposes of evaluating whether SST system closure conditions are protective of human health and the environment for all contaminants of concern, 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 *[applicable or relevant and appropriate requirements]* under CERCLA. The PA is of larger scope than a risk assessment required solely for nonradiological 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. A PA will be developed for each WMA 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 WMAPA *[sic]* 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 in the scope of the HFFACO Appendix I PA.

Based on the regulatory requirements outlined above, the closure "performance assessment" as it is defined in HFFACO Appendix I will contain three major components, and is a broader analysis than "performance assessment" as it is defined in DOE O 435.1. It is therefore important to distinguish between the two to avoid confusion about the term "performance assessment." For the purposes of this report, the term "Appendix I performance assessment" (IPA) will be used to refer to the HFFACO Appendix I analysis, whereas when the simpler term "performance assessment" (PA) is used, it will refer solely to the DOE M 435.1-1 definition of "performance assessment."

The three major components of the IPA include: (1) a baseline risk assessment that evaluates human and ecological risks for current environmental contamination conditions, (2) an assessment of a closed WMA C driven by the regulatory requirements of HFFACO Appendix I for hazardous constituents, and (3) a long-term PA on the fate and transport of radionuclide tank residuals in a closed WMA C driven by the regulatory requirements of DOE O 435.1. This third component of the IPA is the topic of this report, and will be supplemented by additional documents that detail the results of other two analysis components.

The baseline risk assessment, which is the first component of the IPA, presents the risks and hazard impacts from releases of radionuclides and hazardous substances to the environment from current contamination in the absence of any actions to control or mitigate these releases. Under either the CERCLA or RCRA Corrective Action processes, a baseline risk assessment is completed at contaminated waste sites prior to remediation activities to establish a need for action. A baseline risk assessment is also used by Ecology to determine cleanup levels and assess the performance of remedial actions against the Model Toxics Control Act (RCW 70.105D, "Hazardous Waste Cleanup — Model Toxics Control Act") cleanup levels (see WAC 173-340-740, "Unrestricted Land Use Soil Cleanup Standards"; WAC 173-340-745, "Soil Cleanup Standards for Industrial Properties"; and WAC 173-340-747, "Deriving Soil Concentrations for Groundwater Protection"). An initial version of the baseline risk assessment has been prepared (RPP-RPT-58329) to support the RCRA Facility Investigation of WMA C (RPP-RPT-58339). As this version of the baseline risk assessment is updated, it will be supplemented by results of an analysis of past leaks and releases at WMA C that will include a scoping analysis and forward projection of the potential radiological and hazardous chemical impacts from past leaks and releases into the future.

The second component of the WMA C IPA will be an initial assessment of long-term impacts of hazardous chemical constituents within the residual wastes in tanks and ancillary equipment left in a closed WMA C. This component of the IPA will be documented in a companion report to this current PA.

The third component of the IPA for WMA C is the PA required for radioactive constituents of the residual wastes in tanks and ancillary equipment in a closed WMA C under DOE O 435.1. This component is the sole focus of this report.

As identified in Section 1, this PA satisfies a part of the IPA requirements outlined in Appendix I of the HFFACO Action Plan. The PA is limited to the analyses of impacts from radiological waste constituents from residual wastes in tanks and ancillary equipment, which are anticipated to be left in WMA C after closure, and is expected to satisfy those requirements under DOE O 435.1.

This section on Assessment Context includes a description of performance objectives and performance measures along with the timing and locations for points of assessment. It is comprised of the following subsections:

- Public Protection Performance Objectives and Measures (Section 2.1)
- Point of Assessment Timing and Assumptions (Section 2.2)
- Assessment Period (Section 2.3)
- Modeling Approach (Section 2.4)
- Hypothetical Inadvertent Intrusion (Section 2.5)
- Reasonable Efforts To Minimize Releases (Section 2.6).

## 2.1 PUBLIC PROTECTION PERFORMANCE OBJECTIVES AND MEASURES

An extended discussion of the full set of HFFACO Appendix I regulatory requirements and other elements of the assessment context is presented in RPP-RPT-41918. The performance objectives under HFFACO Appendix I comprise a combination of DOE O 435.1, RCRA closure requirements, and Ecology requirements. For the current report, which is focused on the requirements of DOE O 435.1, a subset of these regulatory requirements is applicable. This subset of the overall requirements is shown in Table 2-1.

## 2.2 POINT OF ASSESSMENT AND TIMING ASSUMPTIONS

As previously identified, the TC&WM EIS ROD for landfill closure of SSTs was published in the Federal Register on December 13, 2013. For the landfill closure of WMA C, site closure 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 point of assessment and timing assumptions are consistent with the requirements of DOE O 435.1 and HFFACO. It is assumed for the purposes of this PA that institutional control and societal memory are retained for 100 years after the year of closure, based on the standard DOE O 435.1 requirement for inadvertent human intrusion. The point of assessment for all-pathways (i.e., combined doses for the groundwater and air pathways) and groundwater protection analyses is 100 m (328 ft) from the downgradient fenceline of WMA C per DOE G 435.1-1, Chapter IV – Low Level Waste Requirements. In order to ensure consistency in the assessment, hazardous chemicals will also be evaluated at this point in the companion report that addresses these requirements.

The concentrations used for comparison with the performance measures for water resource protection are the peak concentrations in groundwater at that distance from the facility, calculated across a spatial plane at 100 m (328 ft) downgradient of the facility fenceline. These concentrations are strictly applicable solely to the Ecology water resources performance objectives. Doses calculated for the all-pathways (i.e., combined groundwater and air pathways) performance objective apply to a point of exposure at which people might be exposed (i.e., at the wellhead of a pumping well) at 100 m downgradient of the facility fenceline. For consistency and simplicity, the peak concentrations in groundwater calculated for comparison with water resource protection are used as the concentration in the all-pathways analyses. Since taking account of the well will only have a potential to dilute the groundwater concentrations, using peak groundwater concentrations would give similar or higher dose calculations compared to using wellhead concentrations.

**Table 2-1. Exposure Scenarios, Performance Objectives and Measures, and Points of Assessment for the Waste Management Area C Performance Assessment.**

| Exposure Scenario | Performance Objective and Measures | Point of Assessment | |
|---|---|---|---|
| | | Operational and Active Institutional Control Periods [a] | Post-Institutional Control Period |
| All-pathways [b] | 25 mrem/yr [c] | Facility boundary | 100 m (328 ft) [d] |
| Air pathway [b] | 10 mrem/yr [c] | Facility boundary | 100 m (328 ft) [d] |
| Radon [b] | 20 pCi/m$^2$/s | Flux rate at facility surface | Flux rate at facility surface |
| | 0.5 pCi/L [e] | Facility boundary | 100 m (328 ft) [d] |
| Water resources | Washington Department of Ecology requirements on concentrations of radionuclides | At the source and 100 m (328 ft) [d] | 100 m (328 ft) [d] |
| Intruder [b] | 100 mrem/yr Chronic [c, f] | Not applicable | Facility |
| | 500 mrem Acute [c, f] | Not applicable | Facility |

[a] The active institutional control period includes final closure.

[b] Chapter IV – Low-Level Waste Requirements of DOE M 435.1-1, Radioactive Waste Management Manual.

[c] Excluding radon in air.

[d] The point of highest projected dose or concentration beyond a 100 m (328 ft) buffer zone surrounding the disposed waste. Additionally, concentrations found in tank residuals will be compared against the standard Model Toxics Control Act three-phase model.

[e] Alternative radon Performance Objective.

[f] Performance Measure.

Comparison with the radon performance objective has been evaluated using the surface flux criterion in Table 2-1, applied at the top of the disposal cover.

The intruder protection objective has been applied consistent with DOE O 435.1 principles and guidance. The facility has been evaluated for credible exposure situations, taking account of the facility design and local construction and drilling practices. The closed facility is assumed to remain under institutional control for a period of 100 years after closure, at which time control and memory of the facility is assumed to be lost, and potential inadvertent human intrusion can occur.

## 2.3 ASSESSMENT PERIOD

The DOE O 435.1 compliance time period for a PA is 1,000 years after closure. Longer time frames (10,000 years) are included in the analysis per NRC draft guidance[1] (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 and measures of the DOE Order. The closed facility is assumed to remain under institutional control for a period of 100 years after closure, at which time control and memory of the facility is assumed to be lost. This assumption is applied primarily for the purpose of comparison with the performance measures related to inadvertent human intrusion in DOE O 435.1, and does not represent a DOE intent to release the facility in the future (see DOE P 454.1, Use of Institutional Controls).

## 2.4 MODELING APPROACH

This section provides an overview of the modeling approach for evaluation of 1) source-term release; 2) contaminant fate and transport along the groundwater pathway; 3) contaminant fate and transport along the air pathway; and 4) exposure and dose analysis. A schematic representation of this overall modeling approach is provided in Figure 2-1.

### 2.4.1 Source Term Release

For source-term release in the PA effort, contaminant release for the residual wastes and subsequent contaminant release for the grouted tank and ancillary equipment to the surrounding environment was performed using a system-level model based on GoldSim© using its contaminant transport module (see Figure 2-1). The source term considers processes associated with release of contaminants from residual waste into the natural environment. Separate source terms are considered for each of the twelve 100-series tanks, four 200-series tanks, C-301 catch tank, 244-CR vault, and pipelines, resulting in 19 separate source terms. The inventory used in the source term model includes the current estimate of the inventory and residual volume (see Section 3.2). Source terms for pits and diversion boxes are not explicitly considered but are incorporated as part of the pipeline source term.

Both mineral phase solubility-limited and matrix degradation rate-limited processes are considered for release of contaminant from the waste. These conceptual models are based on observations made through multi-year leaching tests and identification of mineral phases as

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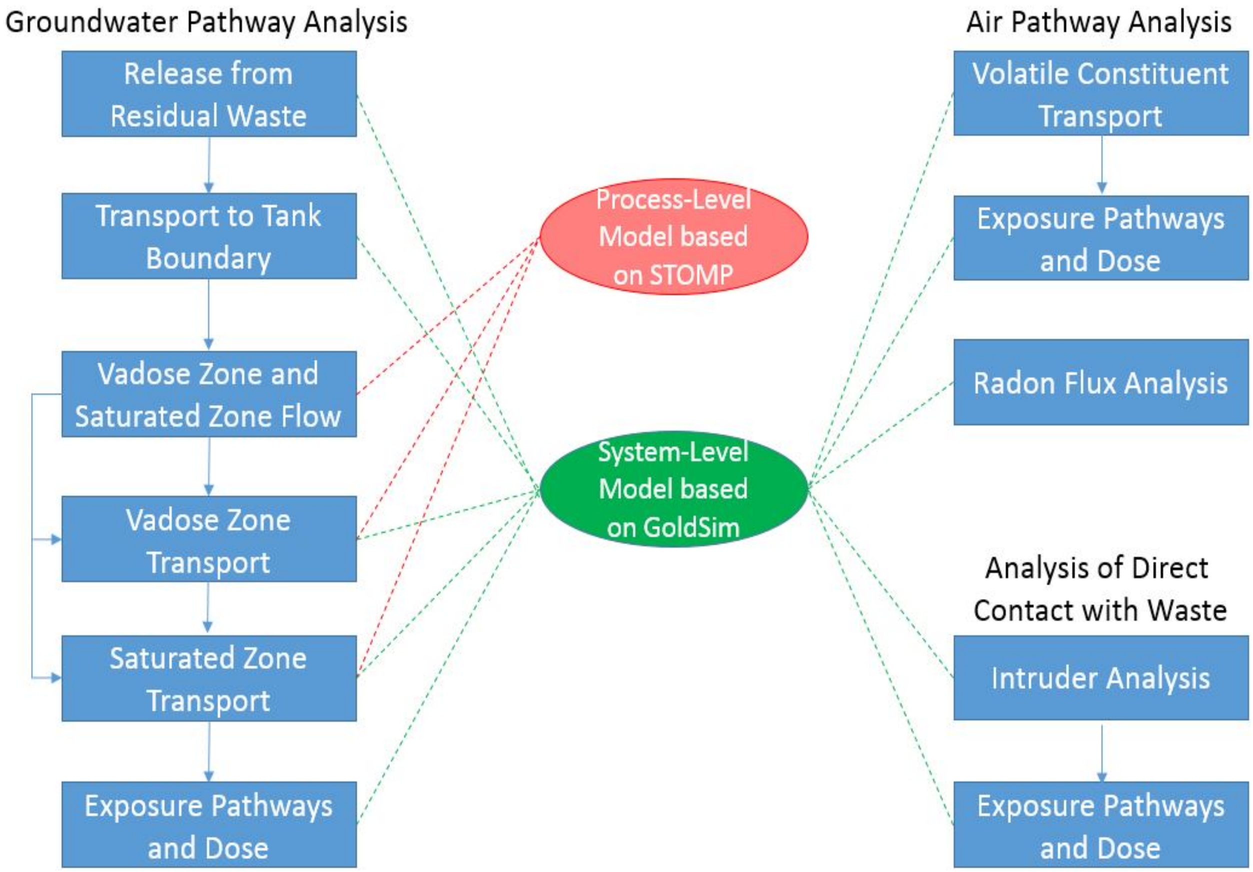
[1] On March 26, 2015, NRC issued a proposed revision to 10 CFR Part 61 and associated guidance on treatment of timeframes in performance assessment (80 FR 16082, "Low-Level Radioactive Waste Disposal"; NUREG-2175, Guidance for Conducting Technical Analyses for 10 CFR Part 61 – Draft Report for Comment). At this time these regulatory changes and associated guidance are in the public comment period, and are not completed. Consequently, they are not addressed in this report.

presented in Section 5. The following release mechanisms are considered based on experimental results:

- a matrix-degradation-rate-based release of $^{99}$Tc, and
- solubility-controlled releases of uranium.

**Figure 2-1. Schematically Overview of the Model Approach for the Waste Management Area C Performance Assessment.**



GoldSim© simulation software is copyrighted by GoldSim Technology Group LLC of Issaquah, Washington (see http://www.goldsim.com).
Subsurface Transport Over Multiple Phases (STOMP©) is copyrighted by Battelle Memorial Institute, 1996.

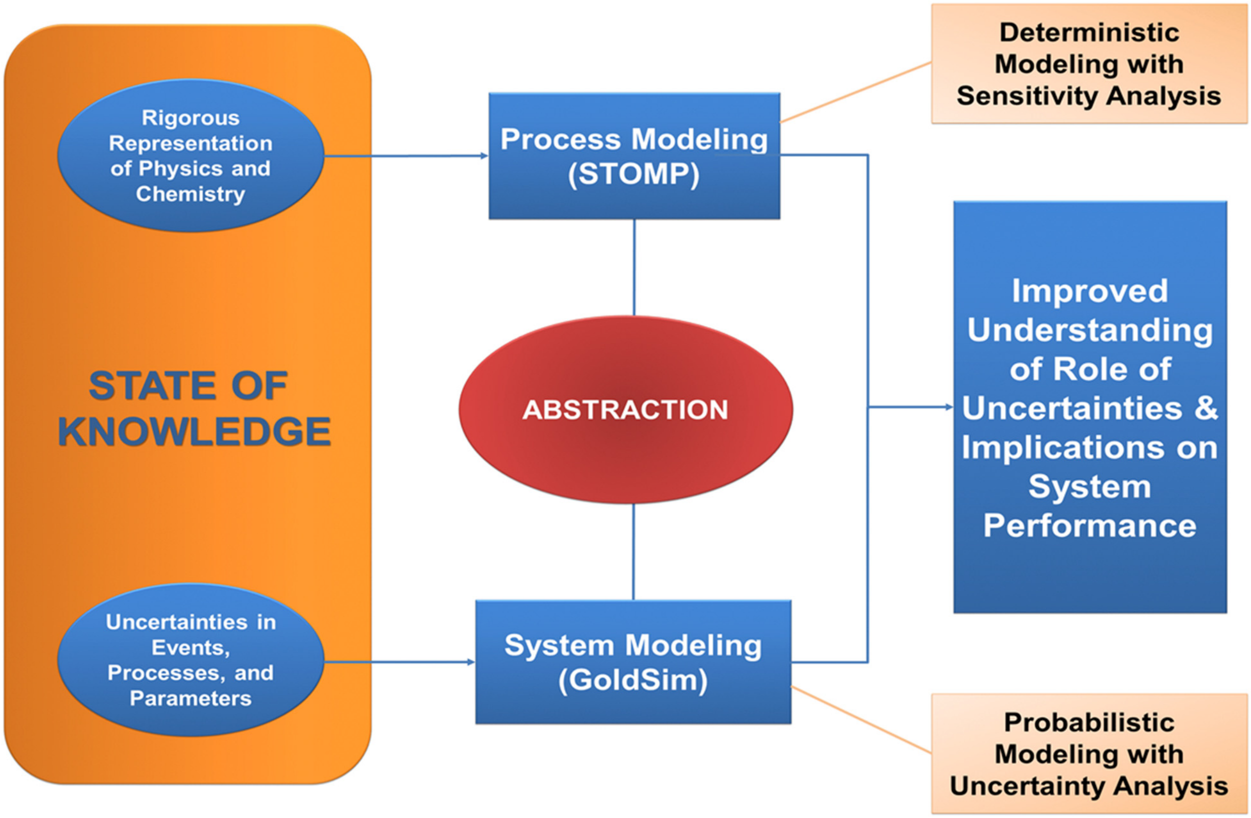
The source term processes that are considered in the post-closure period include releases of contaminants from residual waste, and their transport to the underlying vadose zone via either diffusion or advection out of the tank structures filled with grout and ancillary equipment.

The specific details of the conceptual and mathematical models of the source term release from the waste residuals into the surrounding environment as implemented in the system model based on GoldSim© are discussed in Sections 6.2.1 and 6.3.1, respectively.

### 2.4.2 Contaminant Fate and Transport along the Groundwater Pathway

For simulating contaminant fate and transport along groundwater, the PA is being conducted using complementary approaches, including both deterministic and probabilistic approaches (see Figure 2-2). Deterministic analyses use detailed representations of the geological system that are implemented in STOMP©, 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©, 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©.

**Figure 2-2. Complimentary Use of Process-Level and System-Level Models for Groundwater Pathway in the Waste Management Area C Performance Assessment.**



GoldSim© simulation software is copyrighted by GoldSim Technology Group LLC of Issaquah, Washington (see http://www.goldsim.com).
Subsurface Transport Over Multiple Phases (STOMP©) is copyrighted by Battelle Memorial Institute, 1996.

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.

### 2.4.3 Contaminant Fate and Transport along the Air Pathway

For simulating contaminant fate and transport along the air pathway, the PA evaluates gases and vapors that could travel upward from the residual inventory within tanks and ancillary equipment through the surface barrier to the ground surface using the system-level model based on GoldSim© (see Figure 2-1). The principal mechanism by which nuclides migrate from the waste to the ground surface is gaseous diffusion. For tanks, in which the residual waste is predominantly on the bottom of the tank, this means that the gases are transported through the tank infill grout, the tank dome, the soil overburden, and the surface barrier. For pipelines, the diffusion would occur through the soil overburden and the surface barrier.

Releases to the atmospheric pathway and groundwater pathway begin at the start of the simulation. The partitioning of inventory into the aqueous and gaseous phase occurs within the source-term model (in the residual waste layer). The mass partitioned into the aqueous phase is then available for transport to the underlying vadose zone, while the partitioned fraction in the gas phase is available for upward transport to the atmosphere. Although diffusive path length for the gas phase can vary based on lateral movement, in order to maximize the flux, only the shortest vertical upward path length is considered. In addition, to maximize the upward transport through the gas phase, the downward flow of water above the residual waste location is not modeled. Any physical effect of surface barrier on gaseous flux is also ignored.

Of the radionuclides contained in residual inventory at closure (Section 3), four could potentially originate as gas:

- Carbon-14 as $CO_2$ gas
- Hydrogen-3 (tritium) as $H_2$ gas
- Iodine-129 as $I_2$ gas
- Radon-222 as radon gas.

A separate calculation, specific for radon using the GoldSim© system model, is used for comparisons with the performance objective of 20 $pCi/m^{-2}/s^{-1}$ for radon flux at the surface of the disposal facility.

The specific details of the conceptual and mathematical models of the contaminant fate and transport along the air pathway as implemented in the system model based on GoldSim© are discussed in Sections 6.2.2 and 6.3.2.5, respectively.

### 2.4.4 Exposure and Dose Analysis for Comparison with Performance Objectives

For the exposure and dose analysis performed, the PA effort examined the combined doses from the groundwater and air pathways dose that resulted in the all-pathways doses using the system-level model based on GoldSim© (see Figure 2-1).

To meet the DOE O 435.1 requirements, an all-pathways farmer scenario is implemented to calculate the total effective dose equivalent for comparison to the performance objective of 25 mrem, which is the total effective dose equivalent in a year from all exposure pathways, excluding the dose from radon and progeny in air. In this scenario, calculations are performed based on predicted radionuclide transport through the groundwater pathway and atmospheric pathway, and exposure at the point of contact.

For the groundwater pathway part of the all-pathways dose analysis, the assessment assumes the individual who receives dose is a Representative Person ("ICRP Publication 101a: Assessing Dose of the Representative Person for the Purpose of the Radiation Protection of the Public" [ICRP 2006]) who resides near the WMA C tank farm and draws contaminated water from a well downgradient of WMA C. The all-pathways Representative Person is assumed to use the water to drink, irrigate crops, and water livestock. The conceptual and mathematical models for the specific implementation of the dose analysis for the groundwater pathway in the system-level model based on GoldSim© is described in Sections 6.2.3 and 6.3.3.1, respectively.

For the atmospheric transport pathway, the following three exposure routes are considered for the receptor residing 100 m (328 ft) downgradient of the facility fenceline:

- Air immersion
- Inhalation of dust
- External exposure to radiation from the contaminated ground surface.

Calculation of the dose of the air pathway for purposes of comparison with the all-pathways and air pathway performance objectives considers the effects of releases of tritium, $^{14}C$, and $^{129}I$ and specifically excludes the effects of radon and its progeny in air.

The conceptual and mathematical models for the specific implementation for the air pathway of the dose analysis in the system-level model based on GoldSim© are described in Sections 6.2.3 and 6.3.3.2, respectively.

## 2.5 HYPOTHETICAL INADVERTENT INTRUSION

To meet the DOE O 435.1 requirements, a hypothetical inadvertent intruder scenario is implemented to calculate the total effective dose equivalent for comparison to the performance measure of 500 mrem for acute exposure and 100 mrem/yr for chronic exposures. These calculations have been implemented in the system-level model based on GoldSim© (see Figure 2-1).

Calculation in the PA takes account of the potential for future human actions resulting in inadvertent intrusion into WMA C after the assumed 100-year period of institutional control.

Protection of inadvertent intruders may be accomplished through one of several strategies. The combination of strategies is intended to ensure that adequate protection of the inadvertent intruder is achieved ("Safety assessment for near-surface disposal of low- and intermediate-level radioactive waste" [Kozak 2010]). These strategies are

- Depth of disposal,
- Institutional controls,
- Control of waste concentrations, and
- Intruder barriers.

The combination of these strategies is used to minimize the likelihood of an intrusion event occurring, or to minimize the consequences of the intrusion event should it occur. The end state of WMA C contains features that support all four of these strategies for protection of the inadvertent intruder.

Controlling the depth of disposal has long been a key parameter for evaluating intrusion scenarios. The NRC, in its development of its regulation for near-surface disposal (10 CFR 61) examined a number of alternative ways in which an inadvertent human intruder might disrupt a waste trench (NUREG/CR-4370, Update of Part 61 Impacts Analysis Methodology). An underlying concept in the NRC analyses is that the number of potential types of intrusion activities that could result in an inadvertent human intrusion decreases quickly with depth, and that therefore the likelihood of an intrusion event decreases with depth. In the requirements for disposal of Class C waste established in 10 CFR 61.55, this concept was made explicit: Class C waste "must be disposed of so that the top of the waste is a minimum of 5 meters below the top surface of the cover or must be disposed of with intruder barriers that are designed to protect against an inadvertent intrusion for a least 500 years." [10 CFR 61, Subpart D, § 61.52, Land disposal facility operation and disposal site closure, subsection (a)(2)].

This concept was also made explicit in international guidance by the Nuclear Energy Agency of the Organisation for Economic Co-operation and Development (OECD) ("Shallow Land Disposal of Radioactive Waste: Reference Levels for Acceptance of Long-Lived Radionuclides" [NEA 1987]), who introduced the concept of the "normal residential intrusion zone (NRIZ)," which represented the depth of a foundation of a residential home. This zone was stated nominally to be about 3 m (10 ft) deep, but which could vary according to site-specific considerations. This approach was intended to account, to a certain extent, for the effect introduced by differing depths for excavating foundations in different locations.

The current conceptual design of the Modified RCRA Subtitle C Barrier is based on DOE/RL-93-33, Focused Feasibility Study of Engineered Barriers for Waste Management Units in the 200 Areas. The modified RCRA Subtitle C Barrier design described by DOE/RL-93-33 provides 1.7 m (5.6 ft) of depth in its basic design. However, on page 3-10 of DOE/RL-93-33, it is noted that to meet Class C depth of disposal requirements, "the thicknesses of one or more of the barrier layers (e.g., grading fill [Layer 8] or topsoil [Layers 1 and/or 2]) could be modified (i.e., increased) to conform to" a 5 m (16.4 ft) depth. Therefore, consistent with these design considerations, for the purposes of this PA, it is assumed that the modified RCRA Subtitle C barrier is designed to provide at least 5 m (16.4 ft) depth to the top-most waste zone in the closed configuration.

The closed tank farm has several additional features that will act to deter intrusion. The tank dome materials are reinforced concrete and exhibit only minor degradation (see RPP-RPT-50934, "Inspection and Test Report for the Removed 241-C-107 Dome Concrete" and RPP-RPT-58254, "Concrete Core Testing Report for the Single-Shell Tank 241-A-106 Sidewall Coring Project"), so they retain substantial strength to resist an intrusion event. Similarly, the infill grout that will be added to the tanks in the closure process will have substantial structural strength and the ability to resist intrusion. These features of the system make intrusion into tank residuals very unlikely. Furthermore, intrusion into ancillary equipment would produce similar or greater consequences to intrusion into tank waste. Consequently, the primary focus for intrusion into WMA C considers an intrusion event into ancillary equipment. Intrusion into tank wastes will be considered only as a sensitivity analysis for comparison with intrusion into ancillary equipment.

Based on these considerations, the following approach is taken to evaluating inadvertent human intrusion.

- The only credible intrusion event is a drilling event. Depth of disposal together with concrete and grout intrusion barriers limit the types of events that may be considered credible.

- The intrusion is assumed to be into the ancillary equipment rather than a tank. This type of event is more credible than a tank intrusion, since the tank dome and grout form a substantial intruder protection barrier.

- The driller is assumed to penetrate a 7.6-cm (3-in.)-diameter waste transfer pipeline that is assumed to be 5% full of waste.

- The drilling event is assumed to occur any time after 100 years post-closure.

- The acute exposure to the driller is calculated using assumptions about the duration of the drilling based on present day drilling methods at the Hanford Site.

The conceptual and calculational models for the specific implementation for the acute and chronic hypothetical inadvertent intruder scenarios in the system-level model based on GoldSim© are described in Section 9.2 and 9.3, respectively.

## 2.6 REASONABLE EFFORTS TO MINIMIZE RELEASES

DOE O 458.1, Radiation Protection of the Public and the Environment requires the application of a graded approach to consider optimization of the disposal system to keep doses to members of the public ALARA. A feature of DOE O 435.1 compared to earlier DOE Orders is the removal of specific performance objectives for ALARA based on the view that, for disposal, ALARA is a process to reduce potential doses to the public that is not amenable to numerical criteria to limit releases (National Council on Radiation Protection [NCRP] Report No. 152, "Performance Assessment of Near-Surface Facilities for Disposal of Low-Level Radioactive Waste"). Since numerical ALARA is not directly applicable to post-closure conditions of a closed disposal facility, the evaluation should instead address whether reasonable efforts have been made to minimize post-closure releases from the facility.

For WMA C, the process to minimize releases to the extent practicable is an intrinsic part of the retrieval and closure processes. The established retrieval criteria for SSTs are as defined in the HFFACO, Milestone M-045-00:

> "Closure will follow retrieval of as much tank waste as technically possible, with tank waste residues not to exceed *[10.2 $m^3$]* 360 cubic feet (cu. ft.) in each of the 100 series tanks, *[0.8 $m^3$]* 30 cu. ft. in each of the 200 series tanks, or the limit of waste retrieval technology capability, whichever is less. If the DOE believes that waste retrieval to these levels is not possible for a tank, then DOE will submit a detailed explanation to EPA and Ecology explaining why these levels cannot be achieved, and specifying the quantities of waste that the DOE proposes to leave in the tank. The request will be approved or disapproved by EPA and Ecology on a tank-by-tank basis."

When DOE completes retrieval of waste from a tank, DOE provides documentation to Ecology, known as a Retrieval Completion Certification (RCC), that DOE has completed retrieval of that tank. The RCC describes the technological approaches used to remove waste to the extent practicable. Therefore, the efforts to minimize releases from the closed facility using retrieval of waste are extensively documented and go through a regulatory review and approval process.

In addition to retrieval, releases from the facility can be minimized using design and closure methods. Alternative methods for closing the SSTs were evaluated as part of the scope of the TC&WM EIS (DOE/EIS-0391). Under the Tank Closure Alternatives, DOE evaluated each of the primary tank closure components, specifically, storage, retrieval, treatment, and disposal of tank waste and closure of the SST system. The TC&WM EIS considered a number of alternative options for retrieval, treatment, and closure of the SSTs. Specifically for residual wastes, these alternatives considered several possible approaches for SST closure, with an associated range of implications for long-term releases from the closed WMA C, as follows.

- Alternative 1: No action alternative.

- Alternative 2a: Retrieval of 99% of waste from the SSTs. The SST system would not be closed.

- Alternatives 2b, 3, and 6c: Retrieval of 99% of waste from the SSTs. Landfill closure of all SSTs under RCRA with the SSTs covered with an engineered, modified RCRA Subtitle C barrier designed to provide 500-year protection. Under these alternatives, contaminated soil would be removed down to 4.6 m (15 ft) at the 241-BX and 241-SX Tank Farms and replaced with clean soil from onsite sources. The 4.6-m (15-ft) depth would allow removal of some of the ancillary equipment prior to closure.

- Alternative 4: Retrieval of 99.9% of the waste from the SSTs. Selective clean closure of 241-BX and 241-SX Tank Farms, which means the tanks, ancillary equipment, and contaminated soil would be removed, and the remaining tank farms (including WMA C) would be closed as landfills and covered with an engineered, modified RCRA Subtitle C barrier.

- Alternative 5: Retrieval of 90% of the waste from the SSTs. The SST system would be closed as a landfill and covered with an engineered Hanford barrier, a multi-layer barrier designed to provide 1,000-year protection.

- Alternatives 6a and 6b: Retrieval of 99.9% of the waste from the SSTs. The SST system would be clean closed. Here, clean closure meant the removal or remediation of all hazardous waste such that further regulatory control under RCRA is not necessary.

Alternative 2b was selected as the preferred option in a ROD resulting from the EIS consideration of these options (78 FR 75913). By evaluating these alternatives, DOE has demonstrated reasonable efforts to minimize releases associated with the end state of WMA C.

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# 3.0 SITE AND FACILITY CHARACTERISTICS

This section provides descriptive information relevant to the WMA C site, environment, and facility to provide the basis for a conceptual model of how radionuclides and hazardous chemicals may be released following closure of the WMA. The organization of this section was taken from Performance Assessment Annotated Outline for Chapter Four given in DOE-STD-XXX, Radioactive Waste Management Disposal Authorization Statement Technical Basis Documentation Technical Standard. It is comparable to the information found in Chapter 3 "Physical Characteristics of the Study Area" in the more recent remedial investigations/feasibility studies (RI/FSs) (e.g., DOE/RL-2010-97, Remedial Investigation/ Feasibility Study for the 100-KR-1, 100-KR-2, and 100-KR-4 Operable Units, Draft A).

The assessment of radionuclide and hazardous chemical transport from WMA C and the resulting human exposure from release of those contaminants into the environment requires careful consideration of factors affecting transport processes and the potential for exposure. Topographic features and hydrogeologic characteristics strongly affect the fate and transport of contaminants potentially released from the closed site. Projected land use and population distributions affect the estimation of impacts from human exposure. Facility features control how contaminants would be released and the rate at which they are released from the facility. The waste inventory, concentration, volume, and form affect the magnitude and rate of constituent releases from the source term. Each of these topics is discussed in the following sections.

## 3.1 SITE CHARACTERISTICS

The relevant natural and demographic characteristics and data for WMA C and the surrounding area are given in this section. The purpose of this information is to provide basis for the site conceptual model and method of analysis in sufficient detail to support the PA required by HFFACO (Ecology et al. 1989) Appendix I Section 2.5. Detailed information on the topics given in this section can be found in the data packages produced for the WMA C PA scoping session meetings that took place from May 2009 through May of 2011, as well as new characterization documents that have been released since the end of the scoping sessions. References to the detailed information are provided in the summary descriptions. A listing of the scoping sessions and associated data packages are given in the Introduction and Appendix A.

### 3.1.1 Geography and Demography

This section describes the geography and demography of the Hanford Site, including a description of the use of adjacent lands, the current population database, the socioeconomics of the area, past and planned DOE activities, and the results of an investigation of future uses conducted for inclusion in the "Final Hanford Comprehensive Land-Use Plan Environmental Impact Statement" and associated ROD (DOE/EIS-0222-F, 64 FR 61615). Additional detailed information on the geography and demography of the site can be found in Revision 18 of PNNL-6415, "Hanford Site National Environmental Policy Act (NEPA) Characterization."

### 3.1.1.1 Site Location

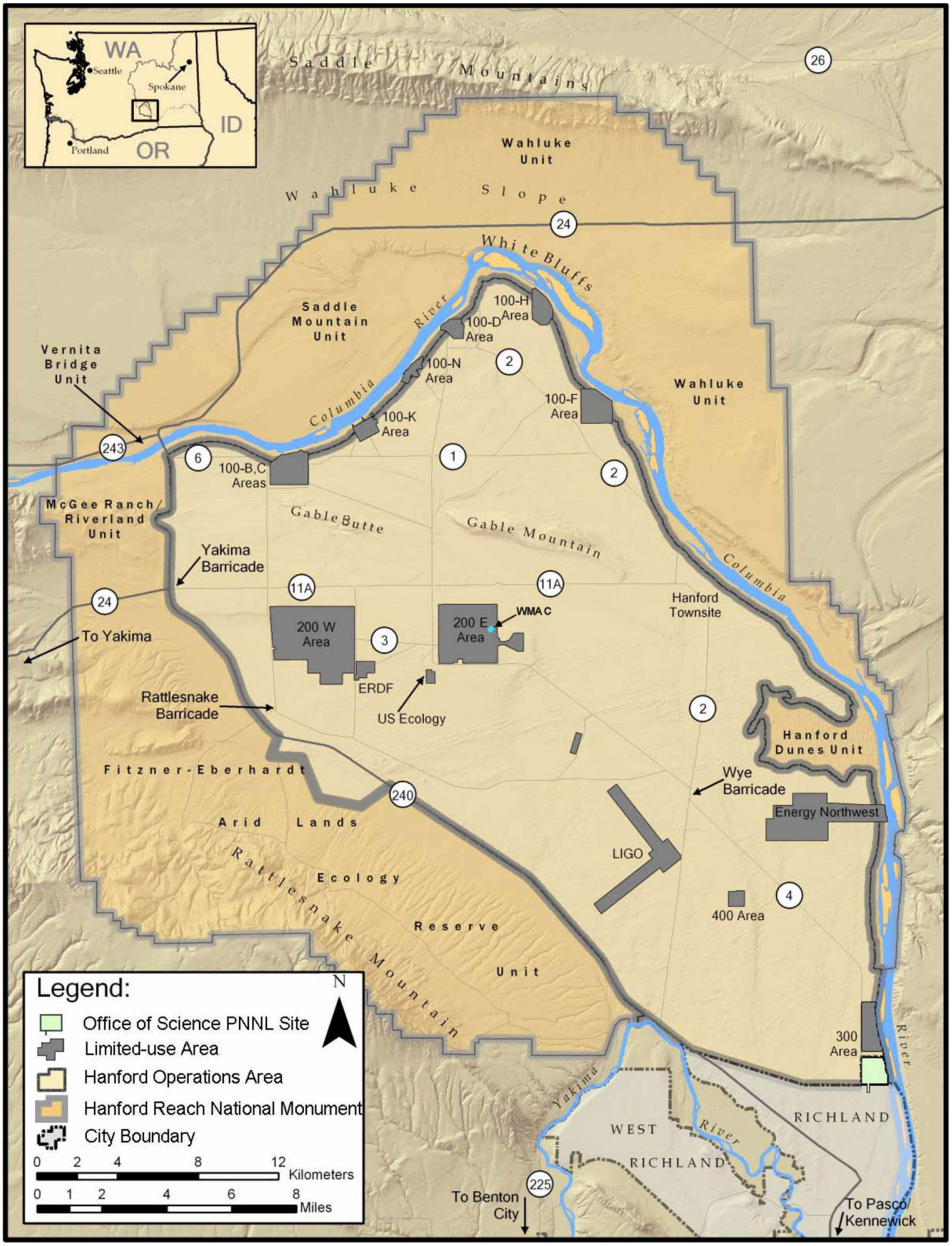
**3.1.1.1.1 Hanford Site.** The Hanford Site encompasses ~1,517 km² (~586 mi$^2$) in Benton, Franklin, and Grant Counties, located in south-central Washington State (Figure 3-1) within the semi-arid Pasco Basin of the Columbia Plateau. Nearby towns are Richland (40 km [25 mi] to the southeast) and Yakima (80 km [50 mi] to the west), with the nearby major metropolitan areas being Spokane (201 km [125 mi] to the northeast), Seattle (241 km [150 mi] to the northwest) and Portland, Oregon (~400 km [~250 mi] downstream on the Columbia River). The Hanford Site stretches ~48 km (~30 mi) north to south and ~38 km (~24 mi) east to west, immediately north-northwest of the confluence of the Yakima and Columbia Rivers, the Cities of Kennewick, Pasco, and Richland (the Tri-Cities), and the City of West Richland.

The Columbia River flows eastward through the northern part of the Hanford Site and then turns south, forming part of the eastern Site boundary. This section of the river is known as the Hanford Reach and is a free-flowing section of the Columbia River, ~82 km (~51 mi) long. It is named after a large northward bend in the river's otherwise southbound course. It is the only section of the Columbia River in the U.S. that is neither tidal nor part of a reservoir. The following seven dams are upstream of the Hanford Site and are listed from closest to furthest from Hanford: Priest Rapids, Wanapum, Rocky Island, Rocky Reach, Wells, Chief Joseph, and Grand Coulee. Other important rivers near the Hanford Site are the Yakima River to the south and southwest and the Snake River to the east. The Cascade Mountains, which are ~160 km (100 mi) to the west, have an important effect on the climate of the area.

The Yakima River runs near the southern boundary of the Hanford Site, joining the Columbia River at the City of Richland. Rattlesnake Mountain, Yakima Ridge, and Umtanum Ridge form the southwestern and western boundaries of the Site, and Saddle Mountain forms its northern boundary. The plateau of the central portion of the Hanford Site is punctuated by two small east-west ridges, Gable Butte and Gable Mountain. Lands adjoining the Hanford Site to the west, north, and east are principally range and agricultural areas.

**3.1.1.1.2 Waste Management Area C.** Waste Management Area C is one of 12 SST farms that were built from 1943 to 1962 and designed to store and transfer mixed waste generated as a part of Hanford Site operations. A complete description of WMA C is given in Section 3.2 Facility Design and Operational Features. It is located within the Hanford Site in the east central portion of the 200 East Area (Figures 3-1 and 3-2). The WMA C boundary is represented by the fenceline surrounding C Farm (Figure 3-3), which encloses an area of ~3.4 hectares (~8.5 acres). In Figure 3-3, the waste transfer pipelines emanating out of the diversion boxes have been color coded to the diversion box, thereby allow the reader to follow the pipelines and associated connections. Waste Management Area C is located 11.3 km (7 mi) west of the Columbia River, with the groundwater gradient toward the Columbia River.

**Figure 3-1. U.S. Department of Energy's Hanford Site and Surrounding Area.**



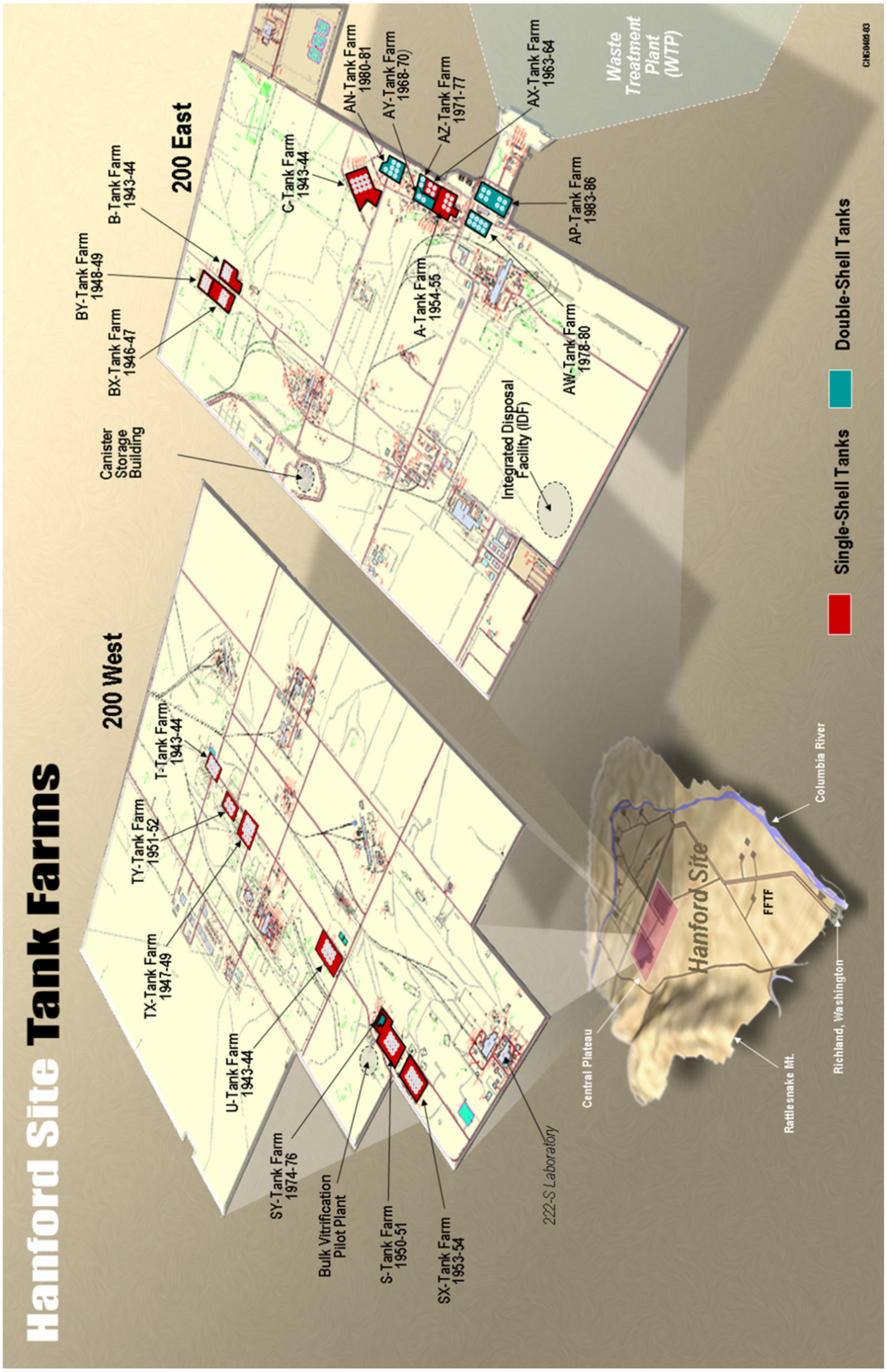
ERDF = Environmental Restoration Disposal Facility

LIGO = Laser Interferometer Gravitational Wave Observatory

PNNL = Pacific Northwest National Laboratory

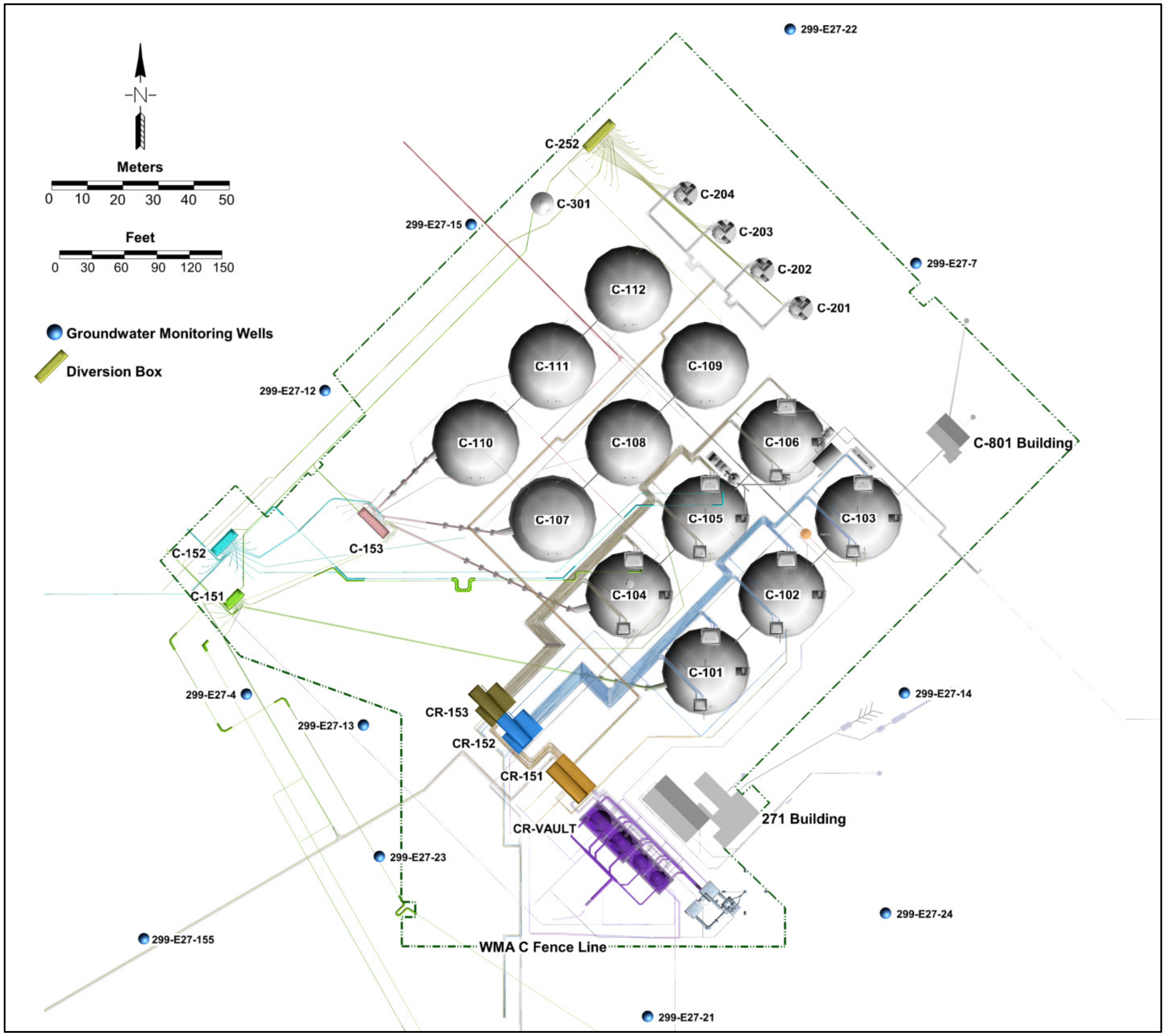
WMA = Waste Management Area

1 **Figure 3-2. Facilities in the 200 East and 200 West Areas.**
2



3
4 FFTF = Fast Flux Test Facility

**Figure 3-3. Waste Management Area C Tanks and Associated Infrastructure.**



WMA = Waste Management Area

### 3.1.1.2 Site Description

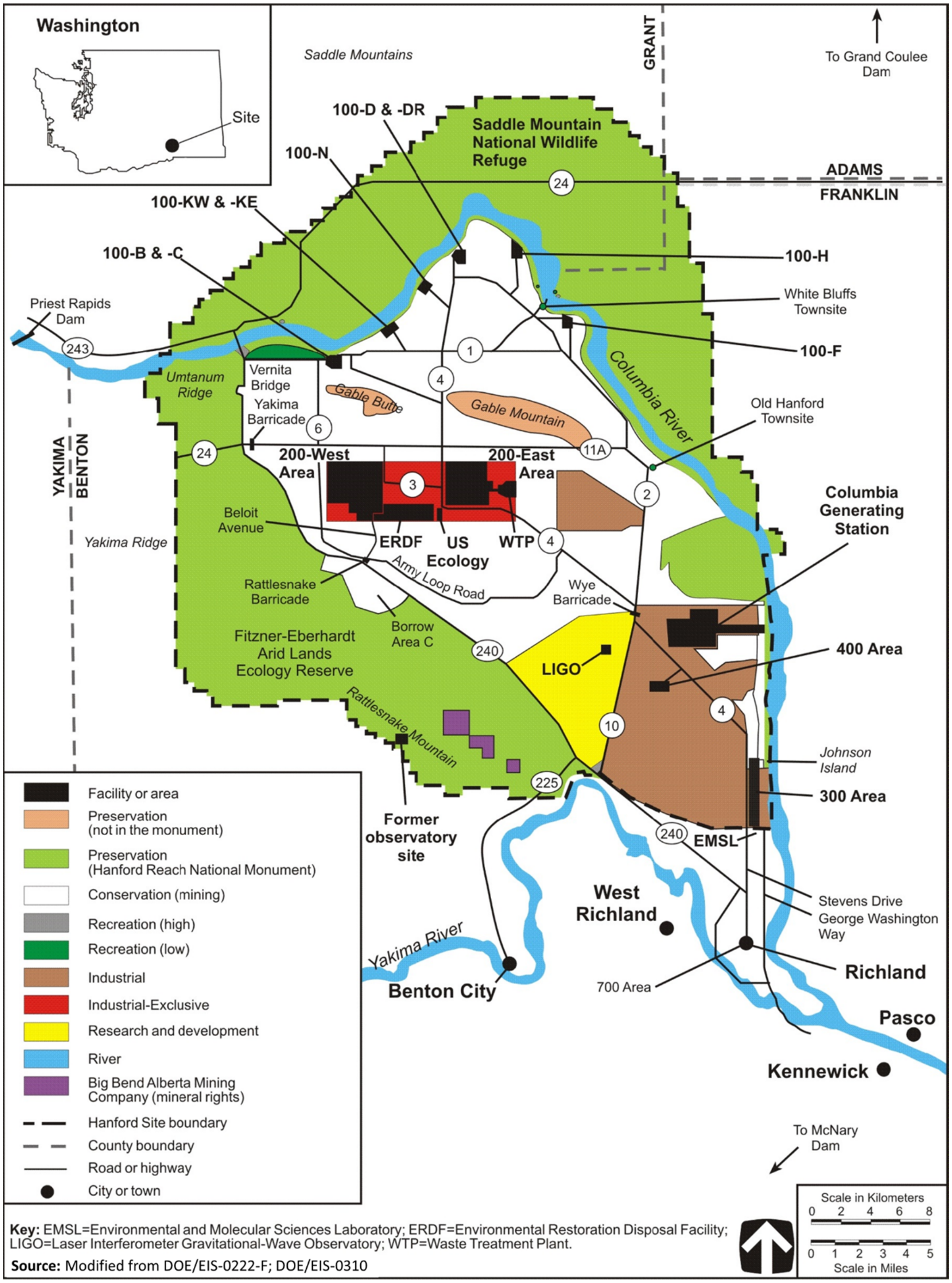
**3.1.1.2.1 Hanford Site Description.** The Hanford Site is a relatively undeveloped area of shrub-steppe (a drought-resistant, shrub and grassland ecosystem) that contains a rich diversity of plant and animal species. This area has been protected from disturbance, except for fire, over the past 60 years. This protection has allowed plant species and communities that have been displaced by agriculture and development in other parts of the Columbia Basin to thrive at the Hanford Site.

In the past, the Hanford Site was a U.S. Government defense materials production site that included nuclear reactor operation; uranium and plutonium processing; the storage and processing of spent nuclear fuel (SNF); and the management of radioactive and hazardous chemical wastes. The current mission at Hanford includes managing waste products, cleaning up the site, researching new ideas and technologies for waste disposal and cleanup, and reducing the size of the site [PNNL-20548, "Hanford Site Environmental Report for Calendar Year 2010 (Including Some Early 2011 Information)," page v.]. Present Hanford programs are diversified and include the management of radioactive waste, cleanup of waste sites and soil and groundwater contaminated by past waste releases, stabilization and storage of SNF, research into renewable energy and waste disposal technologies, cleanup of contamination, and stabilization and storage of plutonium.

Hanford is owned and used primarily by DOE, but portions of it are owned, leased, or administered by other Government agencies. Public access to the Site is limited to travel on the Route 4 and Route 10 access roads as far as the Wye Barricade, State Routes 24 and 240, and the Columbia River. By restriction of access, the public is shielded from portions of the Site formerly used for the production of nuclear materials and currently used for waste storage and disposal. Only ~6% of the land area has been disturbed and is actively used, leaving mostly vacant land with widely scattered facilities (Revision 17 of PNNL-6415, page 4.144). Figure 3-4 shows the generalized land use at Hanford as developed in the "Final Hanford Comprehensive Land-Use Plan Environmental Impact Statement" (DOE/EIS-0222-F, 64 FR 61615) and modified by the designation of the Hanford Reach National Monument (65 FR 37253, "Establishment of the Hanford Reach National Monument").

In June 2000, a Presidential proclamation (65 FR 37253) established the 78,914-hectare (195,000-acre) Hanford Reach National Monument to protect the nation's only un-impounded stretch of the Columbia River above Bonneville Dam and the largest remnant of the shrub-steppe ecosystem that once blanketed the Columbia River Basin. In 2003, DOE and the U.S. Fish and Wildlife Service began management of the monument. The U.S. Fish and Wildlife Service administered three major management units of the monument totaling ~668 $km^2$ (~258 $mi^2$). These included (1) the Fitzner/Eberhardt Arid Lands Ecology Reserve Unit, a 310-$km^2$ (120-$mi^2$) tract of land in the southwestern portion of the Hanford Site; (2) the Saddle Mountain Unit, a 129-$km^2$ (50-$mi^2$) tract of land located north-northwest of the Columbia River and generally south and east of State Highway 24; and (3) the Wahluke Unit, an 225-$km^2$ (87-$mi^2$) tract of land located north and east of both the Columbia River and the Saddle Mountain Unit.

**Figure 3-4. Generalized Land Use of the Hanford Site and Adjacent Areas.**



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

**Source:** Modified from DOE/EIS-0222-F; DOE/EIS-0310

References:

DOE/EIS-0222-F, "Final Hanford Comprehensive Land-Use Plan Environmental Impact Statement."

DOE/EIS-0310, "Final Programmatic Environmental Impact Statement for Accomplishing Expanded Civilian Nuclear Energy Research and Development and Isotope Production Missions in the United States, Including the Role of the Fast Flux Test Facility."

**3.1.1.2.2 Waste Management Area C.** This section provides a summary description of WMA C (Section 3.2 provides a complete detailed description of the WMA). Waste Management Area C is one of 12 tank farms that make up the SST system. The Hanford Site SST system consists of 149 underground SSTs and processing equipment, and was designed and constructed between 1940 and 1964 to transport and store radioactive and hazardous chemical wastes generated from reprocessing spent nuclear fuel. One of the first tank farms built, WMA C was constructed in 1944 and 1945.

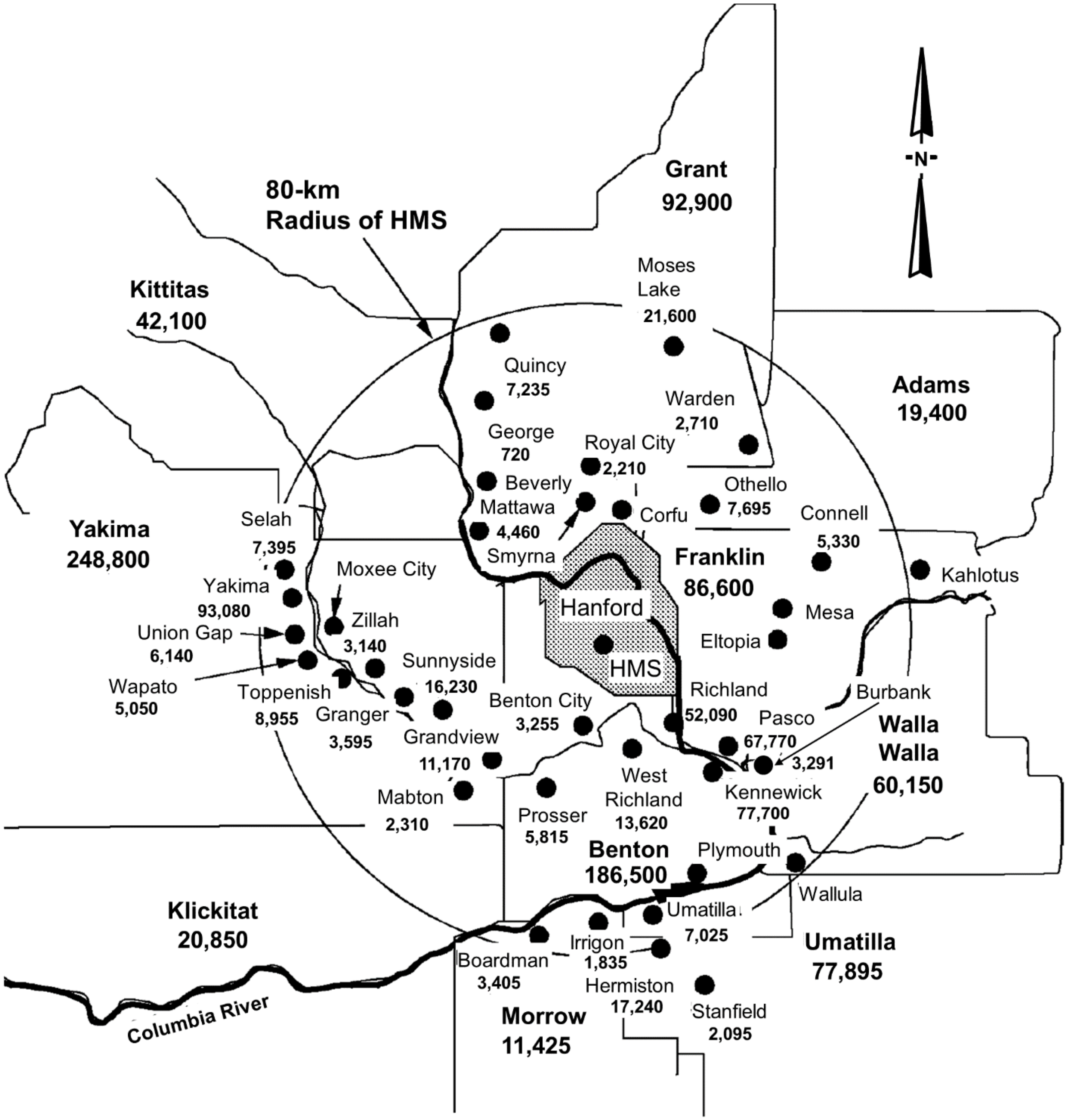
The WMA C contains twelve 100-series tanks and four 200-series tanks (see Figure 3-4). The 100-series tanks are 23 m (75 ft) in diameter, have a 5-m (15-ft) operating depth, and have an operating capacity of 2,006,000 L (530,000 gal) each. The 200-series tanks are 6 m (20 ft) in diameter with a 7.32-m (24-ft) operating depth and an operating capacity of 208,000 L (55,000 gal) each. Other specific details of these tanks are provided in Sections 1.3 and 3.2. The transfer and storage of waste within WMA C SSTs was supported by a complex waste transfer system of pipelines (waste transfer lines), diversion boxes, vaults, valve pits, and other miscellaneous structures.

Additionally, 14 UPRs have occurred within or near to WMA C. The largest ones are associated with releases from pipelines or diversion boxes, with releases from inlet/outlet ports of the SSTs, or with leaks from the SSTs. RPP-PLAN-39114 and RPP-RPT-58339 provide more detail on these UPR sites. Evaluation of these UPRs is outside the scope of the current PA analysis; but rather, will be addressed through the RCRA Corrective Action process.

**3.1.1.3 Population Distribution.** Demographic data are used within a performance assessment to help set the exposure scenarios for assessing dose/risk and to select dosimetry parameters. The population data for Washington is for April 1, 2014 from Office of Financial Management (OFM) April 1 Official Population Estimates (State of Washington Office of Financial Management, Queried 05/17/2015, [April 1 official population estimates], http://www.ofm.wa.gov/pop/april1/default.asp). The population data for Oregon are from the Population Research Center at Portland State University, which provides the official post-census estimate of population numbers for Oregon and are used to disburse State revenues to Oregon counties and cities. The estimates were published April 15, 2014 for the July 1, 2013 populations (Portland State University College of Urban & Public Affairs: Population Research Center, Queried 05/17/2015, [Population Estimates and Reports], http://www.pdx.edu/prc/population-reports-estimates).

The major population centers within an 80-km (50-mi) radius of the Hanford Site are shown in Figure 3-5, along with their estimated 2013 to 2014 populations. The 80-km (50-mi) radius is centered on the Hanford Meteorological Station (HMS), located ~1.7 km (~1.0 mi) east of WMA T in the 200 West Area, and 6.6 km (4.1 mi) west of WMA C. Portions of Benton, Franklin, Adams, Grant, Kittitas, Yakima, Klickitat, and Walla Walla Counties in Washington, and Morrow and Umatilla Counties in Oregon, lie within the 80-km (50-mi) radius. Most of the people reside in the counties of Benton and Franklin, which are two of the fastest growing counties in Washington with rates of growth during the 2000s of 23% and 58%, respectively. From 2010 to April 1, 2014, Benton and Franklin counties continue to be the fastest-growing counties in the State with rates of growth of 6.5% and 10.8%, respectively.

**Figure 3-5. Population Centers with Estimated Population within 80 kilometers (50 miles) of the Hanford Meteorological Station.**



Note: If population not listed, less than 1,000
Data: Washington State April 2014, Oregon July 2013
HMS = Hanford Meteorological Station

The largest population center within the 80-km (50-mi) radius of the site is the Tri-Cities (i.e., Richland, Kennewick, and Pasco), located ~40 km (~25 mi) to the southeast of HMS for Richland, and 56 km (35 mi) to the southeast of HMS for Kennewick and Pasco. Other major population centers include Moses Lake, 64 km (40 mi) to the north-northeast of HMS; Yakima, 69 km (43 mi) to the west of HMS; and Umatilla, 75 km (47 mi) to the south-southeast of HMS. The Washington cities of Ellensburg and Walla Walla lie just beyond the 80-km (50-mi) radius.

In 2010, ~586,500 people resided within 80 km (50 mi) of the HMS (PNNL-20631, “Hanford Site Regional Population-2010 Census”). This total represents an increase in population of 29% from 1990 to 2000 and 21% from 2000 to 2010 (PNNL-20631). Because WMA C’s location is near the center of the Hanford Site, the resident population within 16 km (10 mi) is estimated to be only 15, and 13,000 within 32 km (20 mi) (PNNL-20631). About 186,000 people, located mostly to the southwest and the southeast, live between 32 and 48 km (20 and 30 mi) from WMA C (PNNL-20631). The population has grown since 2010.

**3.1.1.4 Uses of Adjacent Lands.** This section describes the socioeconomics of the region, historical use of the land, and the expected future use of the land.

**3.1.1.4.1 Socioeconomics.** The principal driving forces of the Tri-Cities’ economy since the early 1970s are: 1) DOE and its contractors operating the Hanford Site; 2) Energy Northwest (formerly the Washington Public Power Supply System) which operates a nuclear power plant just north of Richland; and 3) the agricultural community, including a substantial food-processing component. Although DOE activities, agriculture and food processing are the dominant industries, there has been a substantial rise in the number of visitors to the Tri-Cities over the last several years resulting in tourism playing an increasing role in helping to diversify and stabilize the area’s economy. Overall tourism expenditures for 2011 were $393 million, up from $299 million in 2005. The socioeconomics of the area surrounding the Hanford Site are more fully described in Section 4.7 of PNNL-6415.

The land use classification around the Hanford Site varies from urban to rural. Most of the land south of the Hanford Site is urban, including the Tri-Cities, while much of the land to the north and east is irrigated crop land. Most of the irrigation water comes from the Bureau of Reclamation Columbia Basin Project, which uses the water behind Grand Coulee Dam (e.g., Roosevelt and Banks Reservoirs) as the primary water source. The water is transported via canals to the areas north and east of the Columbia River. The land to the west of the Hanford Site is used for irrigated agriculture near the Yakima River and dry-land farming at the higher elevations. The Columbia River is used by the cities of Richland, Pasco, and Kennewick for drinking water. It is used to transport numerous grains and other agricultural-related commodities by barge and similar means. It is also used for recreation and hydroelectric power production for the western United States.

Additionally, the Hanford Reach contains islands, riffles, gravel bars, oxbow ponds, and backwater sloughs that support some of the most productive salmon spawning areas in the Northwest, including the largest remaining stock of wild fall chinook salmon in the Columbia Basin. The loss of other spawning grounds on the Columbia and its tributaries has increased the importance of the Hanford Reach’s fisheries.

**3.1.1.4.2 Early Historical Use of the Land.** In prehistoric and early historic times, American Indians of various tribal affiliations heavily populated the Hanford Reach, and some of their descendants still live in the region. Present-day tribal members retain traditional secular and religious ties to the region, and many have knowledge of the ceremonies and lifestyles of their culture. The Washani, or Seven Drums religion, which has ancient roots, is still practiced by many American Indians. Native plant and animal foods, some of which can be found at Hanford, are used in ceremonies performed by tribal members (DOE/EIS-0310, "Final Programmatic Environmental Impact Statement for Accomplishing Expanded Civilian Nuclear Energy Research and Development and Isotope Production Missions in the United States, Including the Role of the Fast Flux Test Facility," pages 3-125).

Significant non-Indian settlement of the region began relatively late. In 1888, small irrigation companies and farmer cooperatives began to develop irrigation systems in the Columbia Basin. The agricultural economy of the region saw upswings and downswings, from agricultural price increases during World Wars I and II, drought during the 1920s, and the Great Depression during the 1930s. While, principally, non-Indian farmers lived on the adjacent private lands, members of the Wanapum Band continued to reside on portions of the future Hanford Site that remained in Federal ownership. In 1942, ~19,000 people lived in Benton and Franklin counties. Pasco was the largest population center, with ~3,900 people (WHC-MR-0293, "Legend and Legacy: Fifty Years of Defense Production at the Hanford Site"). The City of Richland had a population of ~200 people (Drummers and Dreamers [Relander 1956]).

In the early 1940s, almost all of the land that would at some time be considered part of the Hanford Site was being used for crops or grazing. More than 88% (~152,971 hectares [378,000 acres]) was sagebrush range land interspersed with volcanic outcroppings, where some 18,000 to 20,000 sheep grazed during winter and spring. Some 11% (almost 19,830 hectares [49,000 acres]) was farmland, much of it irrigable but not all under cultivation. Less than 1% (less than 809 hectares [2,000 acres]) consisted of town plots, right of ways, school sites, cemeteries, and similarly used land, most of it in or near the three small communities of Richland, Hanford, and White Bluffs (United States Army in World War II, Special Studies -- Manhattan: The Army and the Atomic Bomb [Jones 1985]).

**3.1.1.4.3 Past and Present U.S. Department of Energy Activities at the Hanford Site.** In 1943, the Hanford Engineer Works was established as one of the three original Manhattan Project sites and USACE began construction of the Hanford Site to produce plutonium for national defense. It was the first nuclear production facility in the world. The region was selected because of its remoteness and because it had abundant electrical power from Grand Coulee Dam (located ~230 mi [~370 km] upstream from the old Hanford town site), a functional railroad, clean water from the Columbia River, and available sand and gravel for construction. The USACE divided the site into a number of operational areas which are briefly summarized below (for more information on the description of each operational area, please see PNNL-6415, Revision 18 or DOE/EIS-0391).

- **100 Areas:** These areas of the Site are situated along the shore of the Columbia River in the northern portion of the Site and contain nine retired nuclear reactors. The irradiated fuel produced in the 100 Areas reactors was transported by rail to the 200 Areas.

- **200 Areas:** Fuel reprocessing, plutonium and uranium separation, plutonium finishing, and waste management including treatment, storage, and disposal activities, have been conducted in the 200 Areas. Waste from the research and development activities and fuel fabrication activities in the 300 Area, reactor operation programs conducted in the 100 Areas, and FFTF in the 400 Area is sent to the 200 Areas for storage and disposal. Waste management activities are scheduled to continue until the mid-21st century. Waste management facilities are located in the 200 Areas, which are surrounded by security fencing. The following major facilities, many of which are inactive, are located in the 200 Areas (Figure 3-2):

- Burial trenches, burial grounds, low-level waste burial grounds

- 18 underground storage tank farm areas including the 241-A, 241-AN, 241-AP, 241-AW, 241-AX, 241-AY, 241-AZ, 241-B, 241-BX, 241-BY, 241-C, 241-S, 241-SX, 241-SY, 241-T, 241-TX, 241-TY, and 241-U Tank Farms

- Very large fuel processing and recovery facilities including the B, T, U, and Z Plants, and the Reduction-Oxidation (REDOX) and Plutonium Uranium Extraction (PUREX) facilities

- Tank wastewater evaporator facilities (242-A, 242-S, and 242-T Evaporators)

- Office and warehouse buildings.

Between and just south of the 200 East and West Areas is the Environmental Restoration Disposal Facility (ERDF) (Figures 3-1 and 3-4). This facility is a trench system and will hold most of the contaminated soil and materials from facility decontamination and decommissioning and Hanford Site remediation. Washington State leases a 3.9-km$^2$ (1.5-mi$^2$) parcel located between the 200 West and 200 East Areas, which, in turn, subleases a portion of this land to U.S. Ecology, Inc., a private company, for the disposal of commercially-generated low-level radioactive waste.

- **300 Area:** This area of the Site is located just north of Richland and was the location of nuclear fuel fabrication and research and development activities.

- **400 Area:** This area of the Site is located northwest of the 300 Area. It is the location of FFTF, a 400-megawatt thermal, liquid-metal (sodium)-cooled nuclear research and test reactor owned by DOE. The facility, which operated for ~10 years, has been shut down since 1993 and is currently being deactivated.

- **600 Area:** This area of the Site includes the Hanford Reach National Monument and all the land not included in the 100, 200, 300, and 400 Areas. The Hanford Reach National Monument, established in 2000 (65 FR 37253), totals 792.6 km$^2$ (306 mi$^2$) and includes Fitzner-Eberhardt Arid Lands Ecology Reserve Unit, 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 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.

- **Former 700 Area:** This area of the Site was the original location for administrative activities for the Hanford Site and was located where the Federal Building is located today (DOE/RL-97-02, National Register of Historic Places Multiple Property Documentation Form - Historic, Archaeological and Traditional Cultural Properties of the Hanford Site, Washington). It is no longer part of the Hanford Site.

- **Former 1100 Area:** This area of the Site was the location of general stores 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 of the Site 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).

For more than 40 years, the primary mission at Hanford was associated with the production of nuclear materials for national defense. Land management and development practices at the Hanford Site were driven by resource needs for nuclear production, chemical processing, waste management, and research and development activities. The DOE developed infrastructure and facility complexes to accomplish this work, but large tracts of land used as protective buffer zones for safety and security purposes remained undisturbed. These buffer zones preserved a biological and cultural resource setting unique in the Columbia Basin region.

In the late 1980s, the primary DOE mission changed from defense materials production to environmental restoration. In 1989, DOE entered into the HFFACO (Tri-Party Agreement) with EPA and Ecology (Ecology et al. 1989).

The Hanford Site encompasses more than 2,963 waste management units and contaminated groundwater plumes that have been grouped into 75 operable units (OUs). Each OU has common characteristics such as geography, waste content, type of facility, and relationship to contaminant plumes. The grouping into designated 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").

**3.1.1.4.4 Future Hanford Land Use.** In 1992, DOE, EPA, and Ecology gathered a group of stakeholders (Hanford Future Site Uses Working Group [HFSUWG]) to study potential future uses for the Hanford Site land. This HFSUWG issued a summary ("The Future for Hanford: Uses and Cleanup, Summary of the Final Report of the Hanford Future Site Uses Working Group" [HFSUWG 1992a]) and a detailed report ("The Future for Hanford: Uses and Cleanup, The Final Report of the Hanford Future Site Uses Working Group" [HFSUWG 1992b]) of its findings. The "Final Hanford Comprehensive Land-Use Plan Environmental Impact Statement"

(DOE/EIS-0222-F) is heavily based on the work of the HFSUWG. However, DOE land use planning extends for only 50 years instead of the 100 years forecast by the HFSUWG. HFSUWG (1992a) contains the following statement about near-term use of the 200 Areas, called the Central Plateau in the report:

> "The presence of many different types of radionuclides and hazardous constituents in various volumes, forms and combinations throughout the site poses a key challenge to the Hanford cleanup. To facilitate cleanup of the rest of the site, wastes from throughout the Hanford site should be concentrated in the Central Plateau. … Waste storage, treatment, and disposal activities in the Central Plateau should be concentrated within this area as well, whenever feasible, to minimize the amount of land devoted to, or contaminated by, waste management activities. This principle of minimizing land used for waste management should specifically be considered in imminent near-term decisions about utilizing additional uncontaminated Central Plateau lands for permanent disposal of *[sic]* grout."

The report continues on the subject of future use options (HFSUWG 1992a):

> "In general, the Working Group desires that the overall cleanup criteria for the Central Plateau should enable general usage of the land and groundwater for other than waste management activities in the horizon of 100 years from the decommissioning of waste management facilities and closure of waste disposal areas."

Based on conversations of the HFSUWG, they could not agree on a definition of "general use." For the "foreseeable future," the HFSUWG developed options involving waste treatment, storage, and disposal of DOE low-level radioactive waste. The differences among the options are whether offsite waste (radioactive and/or hazardous) would be allowed to be disposed of on the Hanford Site. Finally, the report states (HFSUWG 1992a):

> "The working group identified a single cleanup scenario for the Central Plateau. This scenario assumes that future uses of the surface, subsurface, and groundwater in and immediately surrounding the 200 West and 200 East Areas would be exclusive. Surrounding the exclusive area would be a temporary surface and subsurface exclusive buffer zone composed of at least the rest of the Central Plateau. As the risks from the waste management activities decrease, it is expected that the buffer zone would shrink commensurately."

For nearer-term land use planning, the ROD (64 FR 61615) for the "Final Hanford Comprehensive Land-Use Plan Environmental Impact Statement" (DOE/EIS-0222-F) identifies near-term land uses for the Hanford Site. The ROD prescribes the use in the 200 Areas as exclusively industrial (primarily waste management) with much of the surrounding land having the use of preservation or conservation. The Hanford Reach National Monument was established along the Columbia River corridor as well as in lands at the northern and western edges of the Site (65 FR 37253). For further discussion of Hanford land uses, the reader is referred to DOE/EIS-0222-F and DOE/RL-2009-10, Hanford Site Cleanup Completion Framework.

### 3.1.2 Meteorology and Climatology

The climate of the Pasco Basin, where the Hanford Site is located, can be classified as either mid-latitude semiarid or mid-latitude desert, depending on which climatological classification system is being used. Large diurnal temperature variations are common, resulting from intense solar heating and night-time cooling. Summers are warm and dry with abundant sunshine. Daytime high temperatures in June, July, and August can exceed 40 °C (104 °F). Winters are cool with occasional precipitation that makes up ~44% of the yearly total. During the winter, outbreaks of cold air associated with modified arctic air masses can reach the area and cause temperatures to drop below –18 °C (0.4 °F). Overcast skies and fog occur during the fall and winter months.

The region's climate is greatly influenced by the Pacific Ocean and the Cascade Mountain Range to the west, and other mountain ranges to the north and east. The Pacific Ocean moderates temperatures throughout the Pacific Northwest, and the Cascade Range generates a rain shadow that limits rain and snowfall in the eastern half of Washington State. The Cascade Range also serves as a source of cold air drainage, which has a considerable effect on the wind regime on the Hanford Site. Mountain ranges to the north and east of the region shield the area from the severe winter storms and frigid air masses that move southward across Canada.

**3.1.2.1 Current Data.** Climatological data for the Hanford Site are compiled at the HMS, which is located on the Central Plateau, just outside the northeast corner of the 200 West Area and ~4 km (~2.5 mi) west of the 200 East Area. To characterize meteorological differences accurately across the Hanford Site, the HMS operates a network that currently contains 30 monitoring stations (Figure 3-6). Data are collected and processed at each station, and information is transmitted to the HMS every 15 minutes. This monitoring network has been in full operation since the early 1980s. Data from the HMS capture the general climatic conditions for the region and describe the specific climate of the Central Plateau. Meteorological measurements have been made at the HMS since late 1944. Before the HMS was established, local meteorological observations were made at the old Hanford town site (1912 through late 1943) and in Richland (1943 to 1944) (PNNL-6415). Meteorological data collected at the HMS are considered to be representative of conditions at WMA C.

**3.1.2.2 Temperature and Humidity.** Daily and monthly averages and extremes of temperature, dew point temperature, and relative humidity for 1945 through 2004 are reported in PNNL-15160, "Hanford Site Climatological Summary 2004 with Historical Data." From 1945 through 2010, the record maximum temperature was 45 °C (113.0 °F) recorded in August 1961, July 2002, and July 2006. The record minimum temperature was -30.6 °C (-23.1 °F) in February 1950. Normal monthly average temperatures ranged from a low of -0.2 °C (31.6 °F) in December to a high of 24.6 °C (76.3 °F) in July. During winter, the highest monthly average temperature at the HMS was 6.9 °C (44.4 °F) in February 1991, and the record lowest was -11.1 °C (12.0 °F) in January 1950. During summer, the record maximum monthly average temperature was 27.9 °C (82.2 °F) in July 1985, and the record minimum was 17.2 °C (63.0 °F) in June 1953. Table 3-1 provides the average monthly temperatures for the last 13 years along with average annual temperature. The bottom two rows provide the average annual temperature from 1947 to 2013, and the normal temperature which is a 30-year average from 1980 to 2010.

The normal annual relative humidity at the HMS is 54%. Humidity is highest during winter, averaging ~76%, and lowest during summer, averaging ~36%.

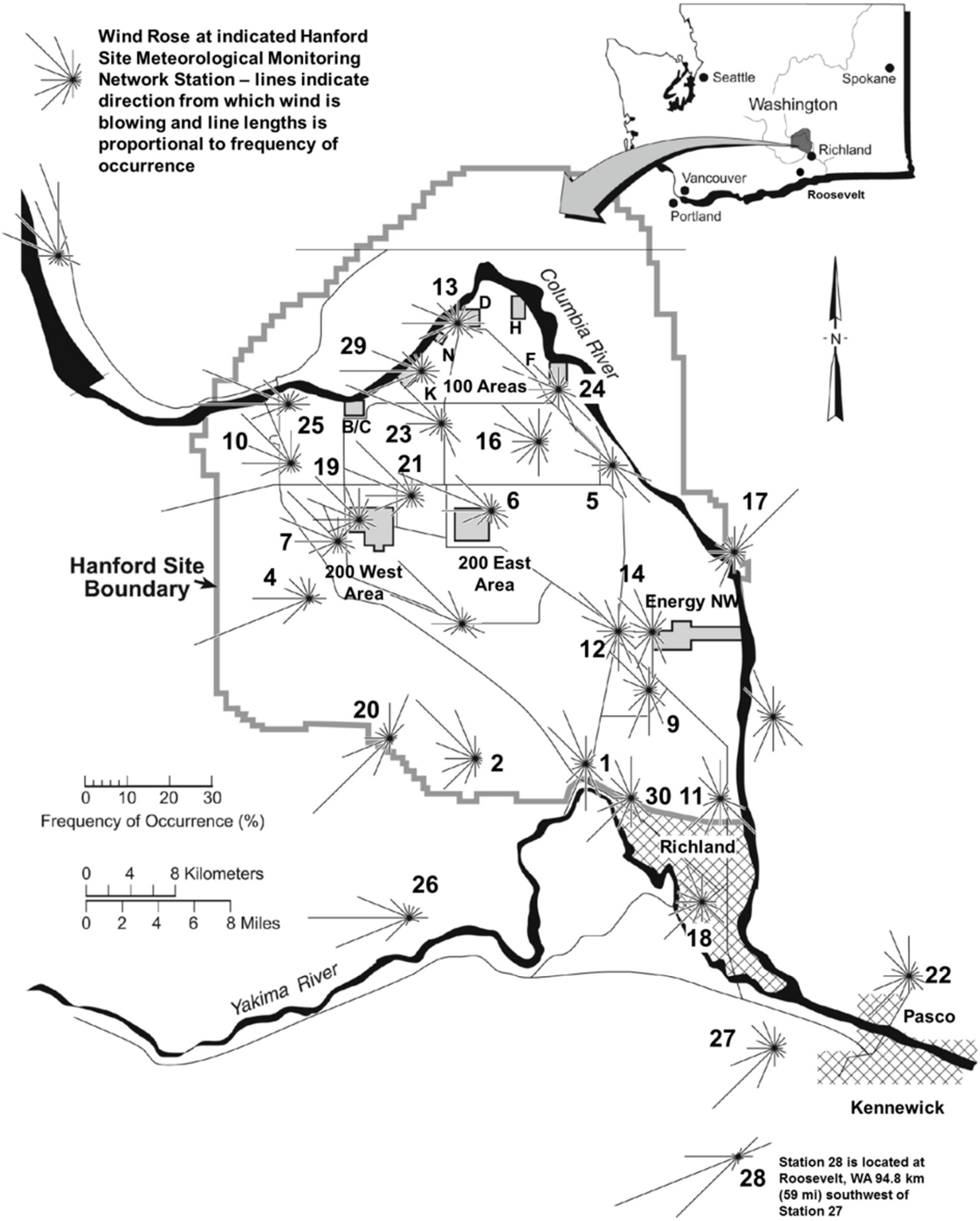
**3.1.2.3 Precipitation.** Average annual precipitation at the HMS is 17 cm (6.7 in.). During 1995, the wettest year on record, 31.3 cm (12.3 in.) of precipitation was measured; during 1976, the driest year, only 7.6 cm (3 in.) was measured. The wettest season on record was the winter of 1996-1997 with 14.1 cm (5.6 in.) of precipitation; the driest season was the summer of 1973, when only 0.1 cm (0.04 in.) of precipitation was measured. Most precipitation occurs during the late autumn and winter, with more than half of the annual amount occurring from November through February. Days with greater than 1.3 cm (0.51 in.) precipitation occur on average less than one time each year. Table 3-2 provides the monthly and average annual precipitation at HMS since 2000. The bottom two lines provide the average yearly precipitation since 1947 and normal precipitation, which is a 30-year average from 1980 to 2010.

Average snowfall ranges from 0.25 cm (0.1 in.) during October to a maximum of 13.2 cm (5.2 in.) during December and decreases to 1.3 cm (0.5 in.) during March. The record monthly snowfall of 59.4 cm (23.4 in.) occurred during January 1950. The seasonal record snowfall of 142.5 cm (56.1 in.) occurred during the winter of 1992-1993. Snowfall accounts for ~38% of all precipitation from December through February.

**3.1.2.4 Wind.** On the Hanford Site, the prevailing wind direction is from the northwest all year long. 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 ~3 m/s (~7 mi/hr), and highest during summer, averaging ~4 m/s (~9 mi/hr). Wind speeds well above average are usually associated with southwesterly winds. However, summertime drainage winds are generally northwesterly and frequently exceed 13 m/s (29 mi/hr). These winds are most prevalent over the northern portion of the Hanford Site. Figure 3-6 shows the 2010 wind roses (i.e., diagrams showing direction and frequencies of wind) measured at a height of 9 m (30 ft) for the 30 meteorological monitoring stations located at and around the Hanford Site. Figure 3-7 provides wind roses for the same stations from 1982 to 2006 (PNNL-6415).

The monthly and annual prevailing wind directions, average speeds, and peak gusts are summarized in Tables 5.1 through 5.4 of PNNL-15160. The annual average wind speed for meteorological records kept from year 1945 to 2004 is calculated to be ~3.4 m/s (7.6 mi/hr) at 15.2 m (50 ft) above the ground. During 2010, the average wind speed was 3.6 m/s (8.1 mi/hr), which was 0.2 m/s (0.4 mi/hr) above normal (PNNL-20548).

**Figure 3-6. Hanford Meteorological Monitoring Network Wind Roses in 2010 at the 9.1-meter (30-foot) Level.**



Adapted from PNNL-20548, "Hanford Site Environmental Report for Calendar Year 2010 (Including Some Early 2011 Information)."

**Table 3-1. Monthly and Average Annual Temperatures at Hanford Meteorological Station since 2000 (°C).**

| YEAR | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | ANNUAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **2000** | 0.5 | 3.7 | 7.1 | 13.0 | 16.2 | 21.1 | 24.2 | 23.3 | 17.6 | 11.2 | 1.1 | -1.2 | 11.4 |
| **2001** | 0.8 | 2.1 | 8.2 | 10.8 | 17.6 | 19.2 | 24.4 | 25.4 | 20.6 | 11.9 | 6.0 | 1.6 | 12.4 |
| **2002** | 3.1 | 3.6 | 5.8 | 11.8 | 15.6 | 22.0 | 26.4 | 24.2 | 19.1 | 10.2 | 5.0 | 2.9 | 12.4 |
| **2003** | 3.3 | 4.4 | 9.4 | 11.2 | 16.2 | 22.5 | 26.8 | 24.7 | 20.7 | 14.1 | 3.2 | 0.5 | 13.1 |
| **2004** | -1.6 | 2.8 | 9.8 | 12.7 | 16.4 | 21.3 | 26.4 | 25.5 | 18.3 | 12.5 | 4.3 | 2.2 | 12.6 |
| **2005** | -1.1 | 3.2 | 9.4 | 12.0 | 17.9 | 20.3 | 25.3 | 24.8 | 18.4 | 12.4 | 3.5 | -2.6 | 11.9 |
| **2006** | 3.6 | 2.3 | 7.2 | 11.2 | 17.0 | 21.3 | 26.7 | 23.8 | 19.3 | 11.3 | 4.4 | -1.7 | 12.2 |
| **2007** | -1.8 | 3.2 | 8.6 | 11.3 | 17.3 | 20.3 | 27.2 | 23.3 | 18.7 | 10.8 | 4.0 | 0.4 | 11.9 |
| **2008** | -2.7 | 4.8 | 6.3 | 9.3 | 17.6 | 20.1 | 25.1 | 23.7 | 18.9 | 11.3 | 5.7 | -3.9 | 11.3 |
| **2009** | -0.7 | 1.7 | 5.5 | 10.9 | 16.8 | 21.9 | 26.5 | 24.6 | 20.2 | 10.1 | 5.0 | -4.1 | 11.6 |
| **2010** | 3.3 | 5.6 | 8.3 | 11.8 | 14.4 | 19.4 | 24.8 | 23.7 | 18.8 | 12.3 | 2.6 | 0.9 | 12.2 |
| **2011** | 0.9 | 1.7 | 6.7 | 9.1 | 14.0 | 19.4 | 23.0 | 24.7 | 20.8 | 12.3 | 3.6 | -0.7 | 11.3 |
| **2012** | 0.2 | 3.2 | 7.6 | 12.7 | 16.2 | 18.9 | 25.6 | 25.4 | 19.7 | 11.6 | 5.6 | 2.4 | 12.4 |
| **2013** | -1.2 | 3.9 | 7.9 | 12.0 | 17.3 | 21.0 | 27.1 | 25.4 | 20.7 | 11.4 | 3.6 | -2.8 | 12.2 |
| **AVERAGE** | -0.4 | 3.2 | 7.4 | 11.6 | 16.6 | 20.7 | 24.9 | 24.0 | 19.1 | 11.7 | 4.5 | 0.1 | 11.9 |
| **NORMAL** | 0.8 | 3.4 | 8.1 | 11.9 | 16.7 | 20.9 | 25.1 | 24.3 | 19.1 | 11.7 | 4.7 | -0.5 | 12.2 |

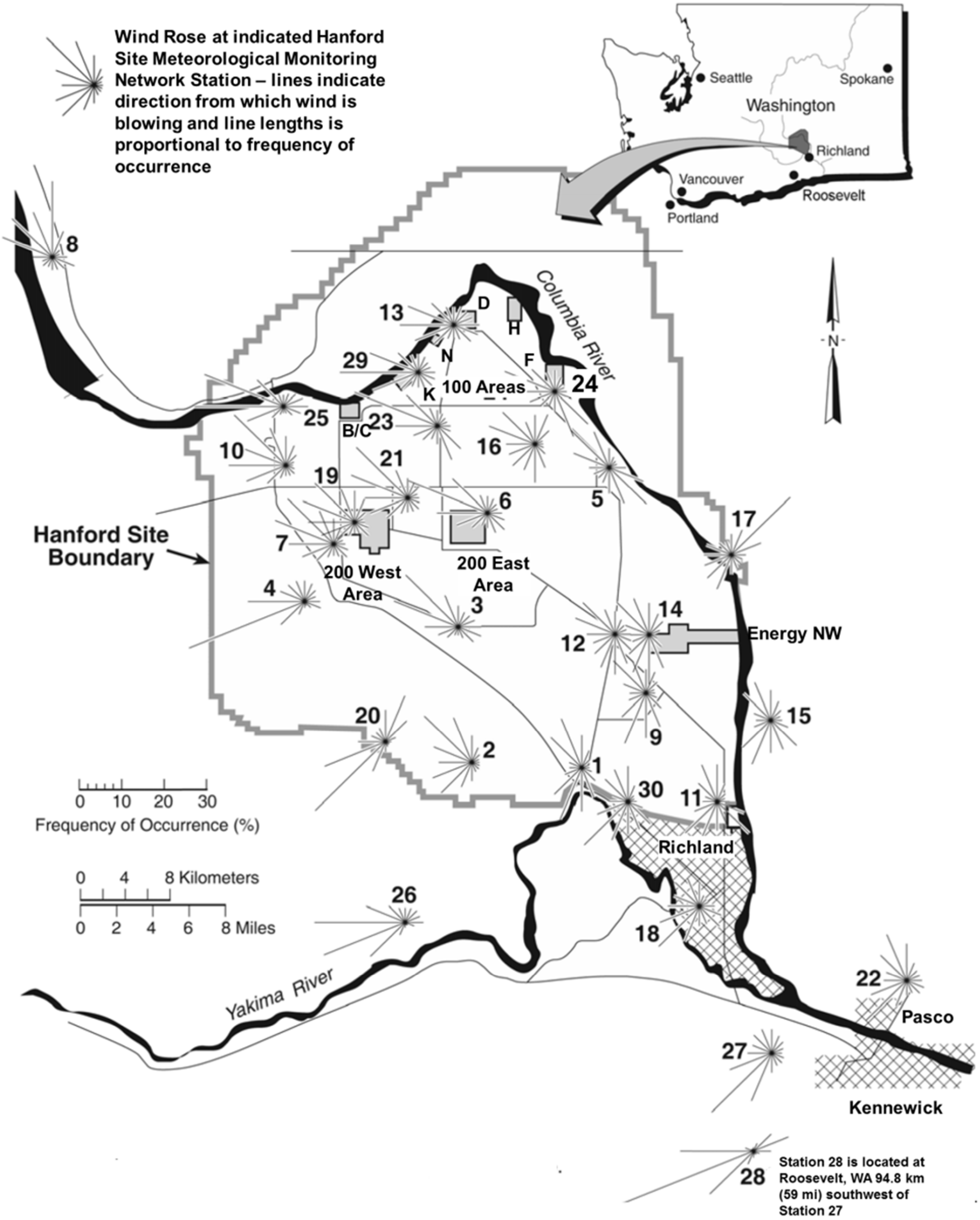
[1] Normal is a 30-year average from 1980 to 2010.

**Table 3-2. Monthly and Average Annual Precipitation at Hanford Meteorological Station since 2000 (cm).**

| YEAR | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | ANNUAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **2000** | 2.77 | 2.84 | 2.39 | 1.45 | 1.96 | 0.64 | 1.17 | Trace | 1.42 | 1.45 | 2.74 | 1.70 | 20.52 |
| **2001** | 0.74 | 1.07 | 1.70 | 2.11 | 0.20 | 3.23 | 0.13 | 0.20 | 0.33 | 0.94 | 4.24 | 2.03 | 16.92 |
| **2002** | 1.07 | 1.70 | 0.48 | 0.74 | 0.41 | 1.65 | 0.41 | 0.03 | Trace | 0.30 | 0.97 | 5.99 | 13.74 |
| **2003** | 4.75 | 2.08 | 0.66 | 5.66 | 0.20 | Trace | 0.00 | 1.17 | 0.61 | 0.18 | 0.38 | 4.98 | 20.68 |
| **2004** | 5.38 | 2.34 | 0.91 | 0.53 | 2.26 | 2.08 | 0.08 | 2.41 | 0.36 | 2.18 | 0.74 | 0.94 | 20.22 |
| **2005** | 2.36 | 0.10 | 0.79 | 0.66 | 2.01 | 0.15 | 0.23 | 0.15 | 1.68 | 0.74 | 2.26 | 5.11 | 16.23 |
| **2006** | 3.00 | 1.04 | 0.61 | 3.30 | 1.45 | 3.38 | Trace | Trace | 0.53 | 1.93 | 1.80 | 4.45 | 21.49 |
| **2007** | 0.36 | 1.93 | 1.88 | 0.66 | 0.76 | 1.14 | 0.18 | 0.81 | 1.45 | 0.53 | 2.87 | 1.35 | 13.92 |
| **2008** | 3.25 | 1.40 | 0.51 | 0.20 | 1.42 | 0.99 | Trace | 1.22 | 0.10 | 0.56 | 1.88 | 2.41 | 13.94 |
| **2009** | 2.92 | 1.63 | 2.03 | 0.99 | 0.46 | 0.41 | Trace | 0.10 | 0.15 | 1.98 | 1.42 | 1.80 | 13.89 |
| **2010** | 3.15 | 1.42 | 0.51 | 1.50 | 3.38 | 2.92 | 1.17 | 0.33 | 2.41 | 1.57 | 2.90 | 4.62 | 25.88 |
| **2011** | 1.35 | 0.08 | 2.21 | 0.64 | 3.10 | 0.99 | 0.30 | Trace | 0.13 | 1.96 | 0.30 | 0.25 | 11.30 |
| **2012** | 2.77 | 1.70 | 1.63 | 1.55 | 0.56 | 3.84 | 0.38 | Trace | 0.08 | 1.05 | 0.80 | 1.41 | 8.18 |
| **2013** | 0.41 | 0.23 | 0.99 | 0.76 | 4.06 | 3.45 | 0.03 | 0.61 | 1.07 | 0.97 | 0.91 | 0.18 | 13.67 |
| **AVERAGE** | 2.36 | 1.57 | 1.27 | 1.19 | 1.37 | 1.42 | 0.51 | 0.58 | 0.76 | 1.37 | 2.18 | 2.62 | 17.22 |
| **NORMAL[1]** | 2.39 | 1.78 | 1.45 | 1.40 | 1.30 | 1.30 | 0.58 | 0.46 | 0.79 | 1.24 | 2.41 | 3.05 | 18.14 |

[1] Normal is a 30 year average from 1980 to 2010.

**Figure 3-7. Hanford Meteorological Monitoring Network Wind Roses from 1982 to 2006 at the 9.1-meter (30-foot) Level.**



Adapted from PNNL-6415, "Hanford Site National Environmental Policy Act (NEPA) Characterization."

**3.1.2.5 Severe Weather.** Concerns about severe weather usually center on hurricanes, tornadoes, and thunderstorms. Fortunately, the occurrence of hurricanes and tornadoes is infrequent and their scale is generally small in the northwestern portion of the United States. According to the records of the HMS and the National Severe Storms Forecast Center database, only 24 separate tornados have occurred between 1916 and 1994 within 160 km (99 mi) of the Hanford Site. Only one of these tornadoes was observed within the boundaries of the Hanford Site itself (at the extreme western edge), and no damage resulted. The estimated probability of a tornado striking a point at the Hanford Site is $9.6 \times 10^{-6}$/yr. Hurricanes do not reach the interior of the Pacific Northwest.

Severe winds are associated with thunderstorms or the passage of strong cold fronts. The average occurrence of thunderstorms in the vicinity of the HMS is 10 per year. They are most frequent during the summer; however, they have occurred in every month. High speed winds at the Site are more commonly associated with strong cold frontal passages. In rare cases, intense low pressure systems can generate winds of near-hurricane force. The greatest peak wind gust was 130 km/hr (81 mi/hr), recorded at 15 m (49 ft) above ground level at the HMS. Extrapolations based on 35 years of observation indicate a return period of ~200 years for a peak gust in excess of 145 km/hr (90 mi/hr) at 15 m (49 ft) above ground level.

**3.1.2.6 Climate Change.** In Global Climate Change Impacts in the United States: A State of Knowledge Report from the U.S. Global Change Research Program, Karl et al. (2009) projects that the in Pacific Northwest, regionally averaged temperatures are expected to increase 1.7 to 5.6 °C (3 to 10 °F) during this century. They also noted that temperatures rose 0.83 °C (1.5 °F) over the past century and some areas saw increases up to 2.2 °C (4.0 °F). Karl et al. (2009) also suggests that winter precipitation will increase and summer precipitation will decrease. Most of the concern is with snowpack because it dominates water storage for irrigation and hydro system functioning. Scenarios of future climate for the Pacific Northwest, Climate Impacts Group (Mote et al. 2008) stated that the best estimate of future temperature change in the Pacific Northwest is 0.28 °C (0.5 °F) per decade until about 2050. Mote et al. (2008) estimated precipitation changes would range from -10% to +20% by the year 2080. They also noted that warming will be greater in summer than in the other seasons.

For an analysis of recharge in the 200 East Area, PNNL-13033, "Recharge Data Package for the Immobilized Low-Activity Waste 2001 Performance Assessment" represented future climate conditions by scaling the current temperature and precipitation data to match paleoclimate observations derived from pollen data. "Vegetation and climate change in northwest America during the past 125 kyr" (Whitlock and Bartlein 1997) described a 125,000-year paleoclimate record constructed from the pollen record in cores taken from Carp Lake, near Goldendale, Washington. Carp Lake is located ~175 km (~109 mi) southwest of the Hanford Site, at an elevation of 714 m (2,343 ft). Similar pollen records at the Hanford Site were eliminated during the glacial flooding 13,000 years ago. Thus, Carp Lake provides a proxy for paleoclimate information relevant to the Hanford Site. BHI-00144, "Long-term Climate Change Effects Task for the Hanford Site Permanent Isolation Barrier Development Program: Final Report" described the Carp Lake pollen interpretation relative to precipitation and temperature. For the entire Holocene (i.e., the last 10,000 years), the data suggest that annual temperatures and precipitation ranged from 0 to 2.8 °C (0 to 5 °F) warmer and 0 to 50% drier compared to modern climate. During the glacial period prior to the Holocene, annual temperatures ranged from 0.2 °C (0.36 °F) warmer to 2.5 °C (4.5 °F) cooler and precipitation ranged from 75 to 128% of modern levels. In summary, for the last 100,000 years, annual precipitation ranged from 50 to 128% of modern levels and annual temperatures ranged from -2.5 to 2.8 °C (-4.5 to 5 °F) of modern levels. These ranges appear to bracket the latest estimates for precipitation and temperature changes in the Pacific Northwest. Figures 3-8 and 3-9 illustrate the pollen-derived precipitation and temperature records, respectively.

### 3.1.3 Ecology

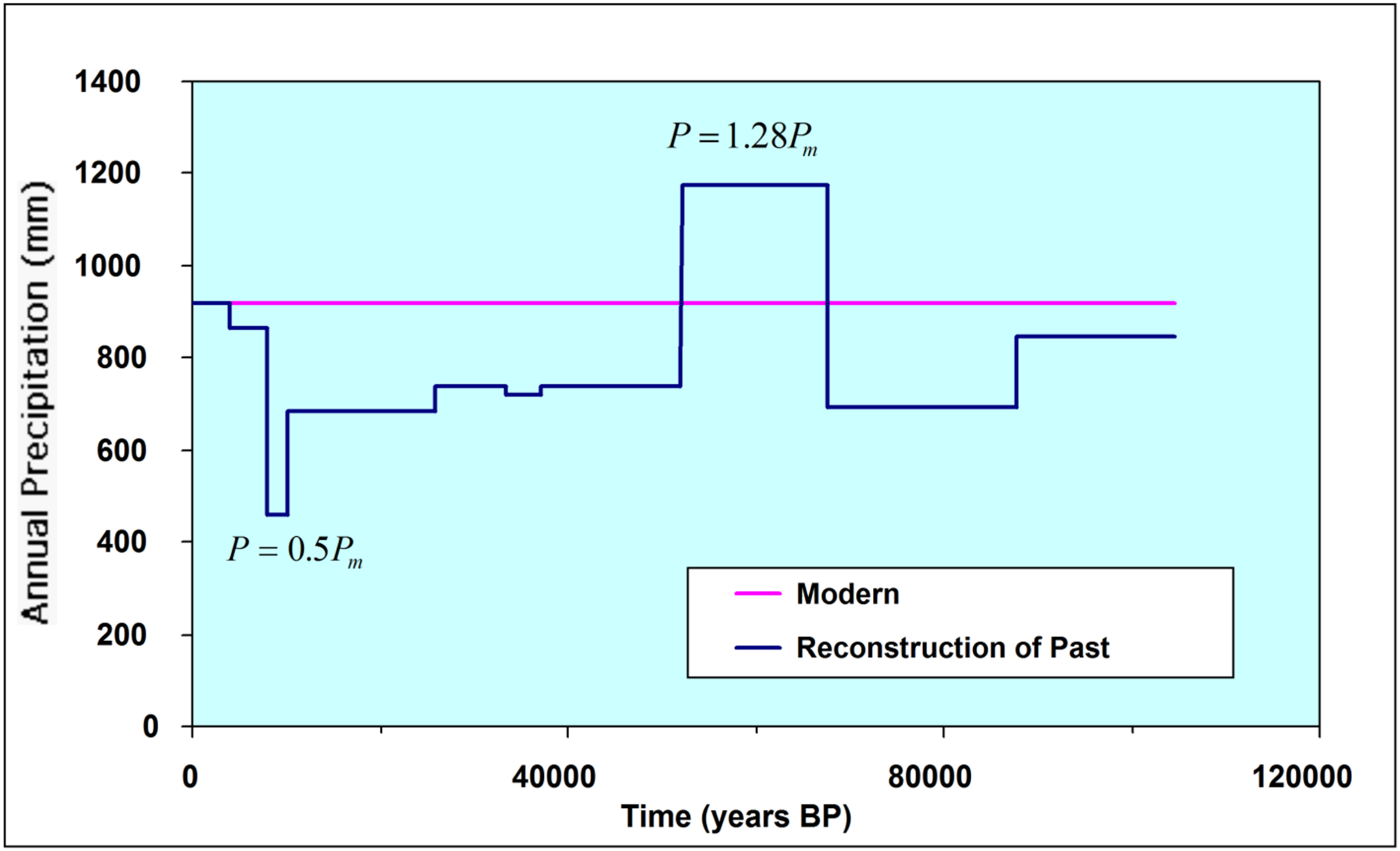
This section summarizes the ecology of the Hanford Site (PNNL-6415, Section 4.5; DOE/EIS-0391, Section 3.7), highlighting the 200 Areas where WMA C is located. The information in this section emphasizes plant and animal activities that may affect exposure pathways. The primary impact would be through roots penetrating and animals burrowing through surface barriers into a disposal facility. Secondarily, the types of plants and animals and their density can affect net recharge to groundwater, which is greatly influenced by surface vegetation and burrowing. PNNL-6415 details both the terrestrial and aquatic ecology of the Hanford Site and presents extensive listings of plant and animal species, but this section considers only terrestrial ecological effects because WMA C is not located near significant aquatic ecological systems.

The Hanford Site consists of primarily undeveloped land. Chemical processing facilities, nuclear reactors that have been shut down, and supporting facilities occupy only ~6% of the 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 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, needle and thread grass, Indian rice grass, and prairie June grass.

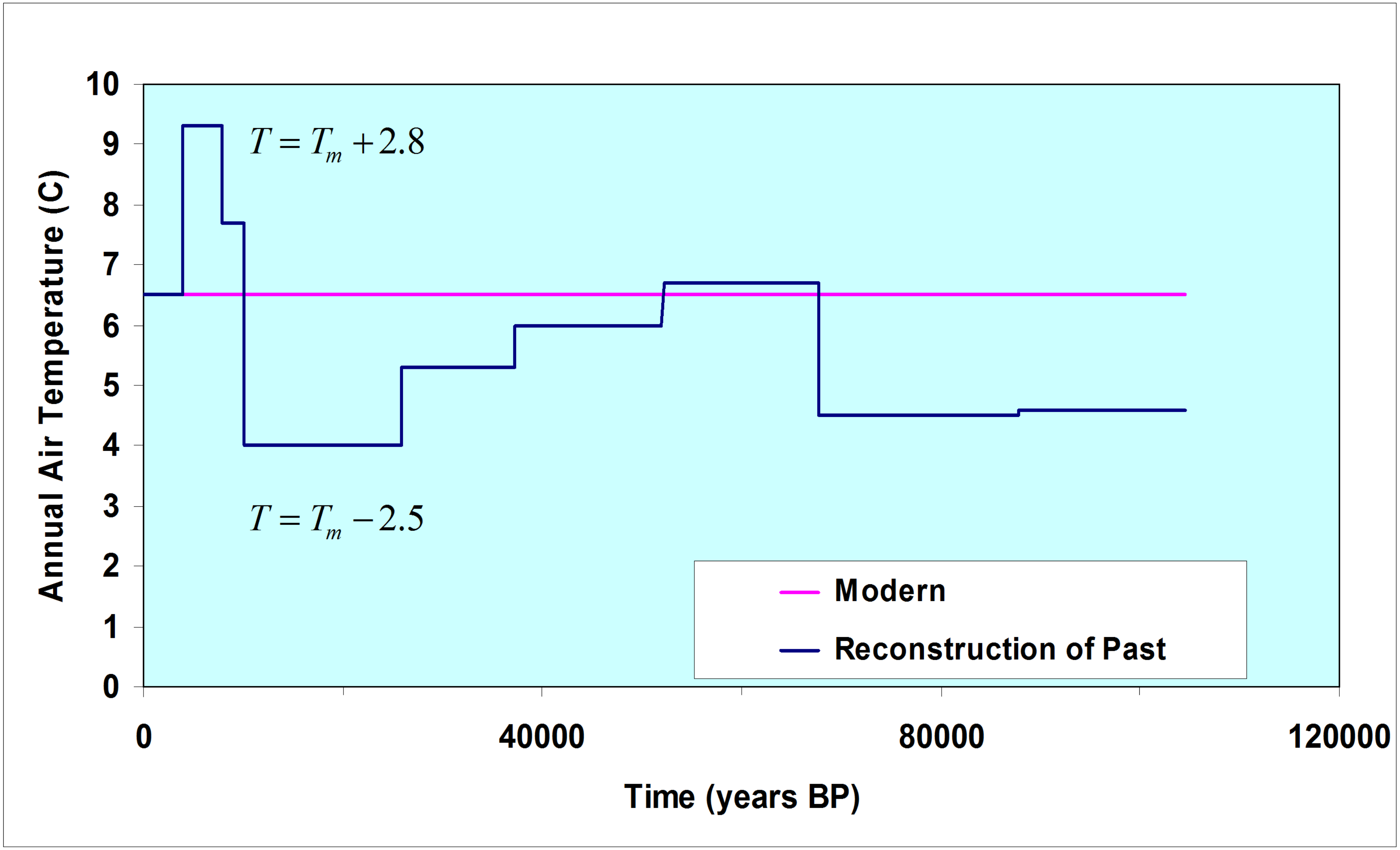
With the advent of settlement, livestock grazing and agricultural production contributed to colonization by non-native vegetation species that currently dominate portions of the landscape. Although agriculture and livestock production were the primary subsistence activities at the turn of the century, 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.

Figure 3-8. Precipitation Reconstruction for Past 100,000 Years Based on Pollen Data.



BP = before present

Figure 3-9. Temperature Reconstruction for Past 100,000 Years Based on Pollen Data.



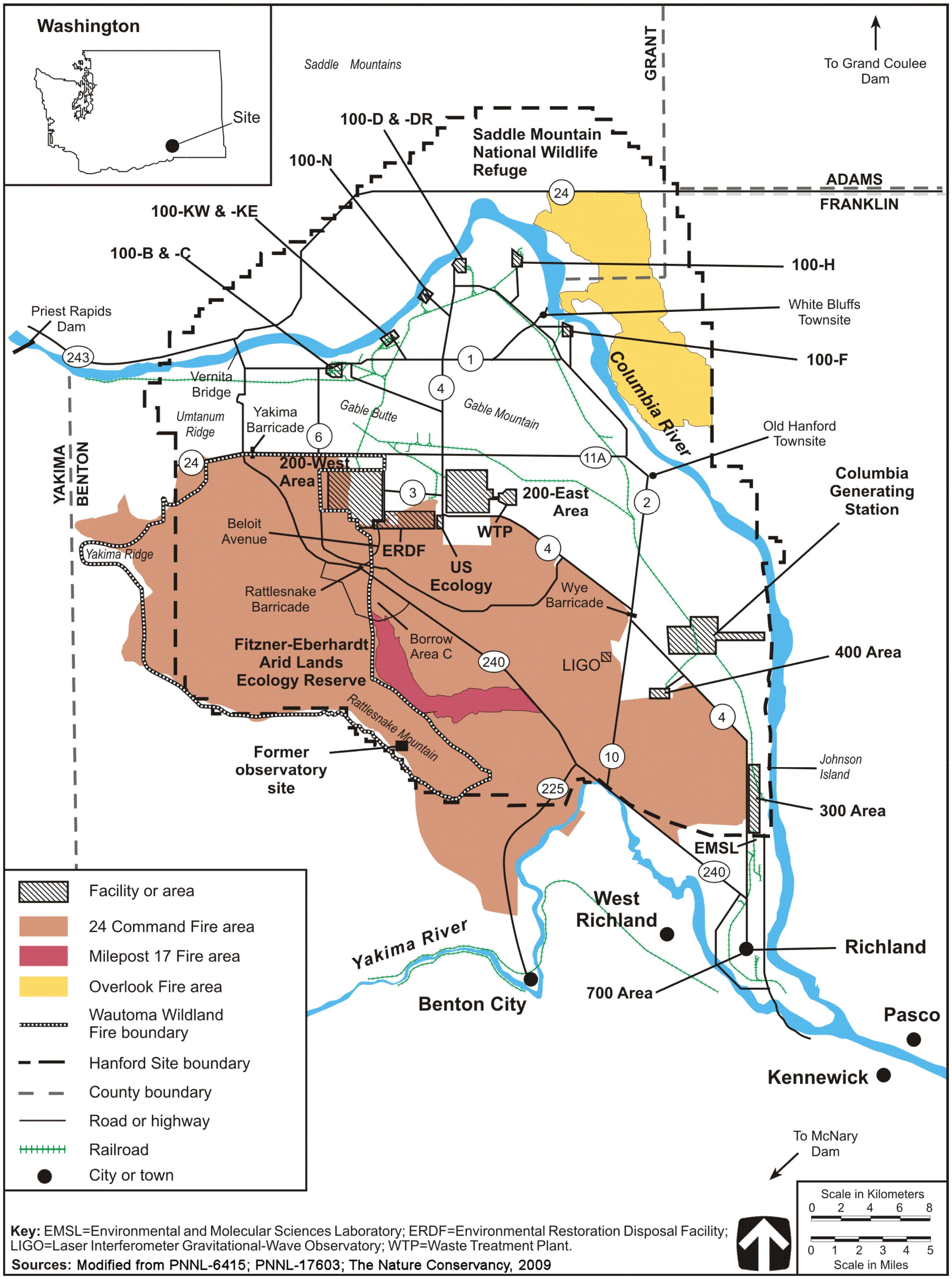
BP = before present

The dominant non-native species, cheat grass, 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, ~20% are non-native. Wildfires are frequent on the Hanford Site. Several of the more recent fires are shown on Figure 3-10 and are described on page 3-7 of DOE/EIS-0391. Vegetation loss due to fires and firefighting activities exposed the soil to erosion by subsequent wind and rain, and can enhance recharge by removing vegetation from evapotranspiration barriers placed over the site.

Figure 3-11 illustrates vegetation and land cover in and around the 200 East Area following the 24 Command (June/July 2000) and Wautoma Fires (August 2007). Most of the 200 Areas were not directly impacted by either fire (see Figure 3-10). Undisturbed portions of the 200 Areas are characterized by the following communities: big sagebrush/bunchgrass-cheat grass, cheat grass-bluegrass, crested wheatgrass-bunchgrass-cheat grass, and gray rabbit brush/cheat grass-bluegrass. The former two communities are prominent in the 200 East Area, while the latter two are more common in the 200 West Area. Most of the waste disposal and storage sites are covered by non-native vegetation or are kept in a vegetation-free condition by the controlled application of approved herbicides because plants could potentially accumulate waste constituents. Where vegetation is present, it aids in stabilizing surface soil, controlling soil moisture, or displacing more-invasive, deep-rooted species like Russian thistle (PNNL-6415, page 4.98). Due to the disturbed nature of most of the 200 Areas, wildlife use is limited; however, surveys have recorded the badger, coyote, Great Basin pocket mouse, mule deer, long-billed curlew, killdeer, horned lark, Say’s phoebe, American robin, American kestrel, western meadowlark, and common raven [PNNL-14133, “Blanket Biological Review for General Maintenance Activities Within Active Burial Grounds, 200 E and 200 W Areas, ECR #2002-200-034,” page 3; PNNL-14233, “Biological Review of the Hanford Solid Waste EIS – Borrow Area C (600 Area), Stockpile and Conveyance Road Area (600 Area), Environmental Restoration Disposal Facility (ERDF) (600 Area), Central Waste Complex (CWC) Expansion (200 West), 218-W-5 Expansion Area (200 West), New Waste Processing Facility (200 West), Undeveloped Portion of 218-W-4C (200 West), Western Half & Northeastern Corner of 218-W-6 (200 West), Disposal Facility Near Plutonium-Uranium Extraction (PUREX) Facility (200 East), ECR #2002-600-012b,” pages 9, 10; PNNL-16620, “Ecological Data in Support of the Tank Closure and Waste Management Environmental Impact Statement Part 2: Results of Spring 2007 Field Surveys”].

All WMAs in the tank farm system are actively managed to prevent vegetation, insects, and wildlife from using the WMA as habitat, including WMA C. Herbicides and pesticides are used on a regular basis 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. Figure 3-12 provides the size of the habitat areas within 152 m (500 ft) of WMA C.

**Figure 3-10. Extent of Area Burned During Recent Fires at the Hanford Site.**

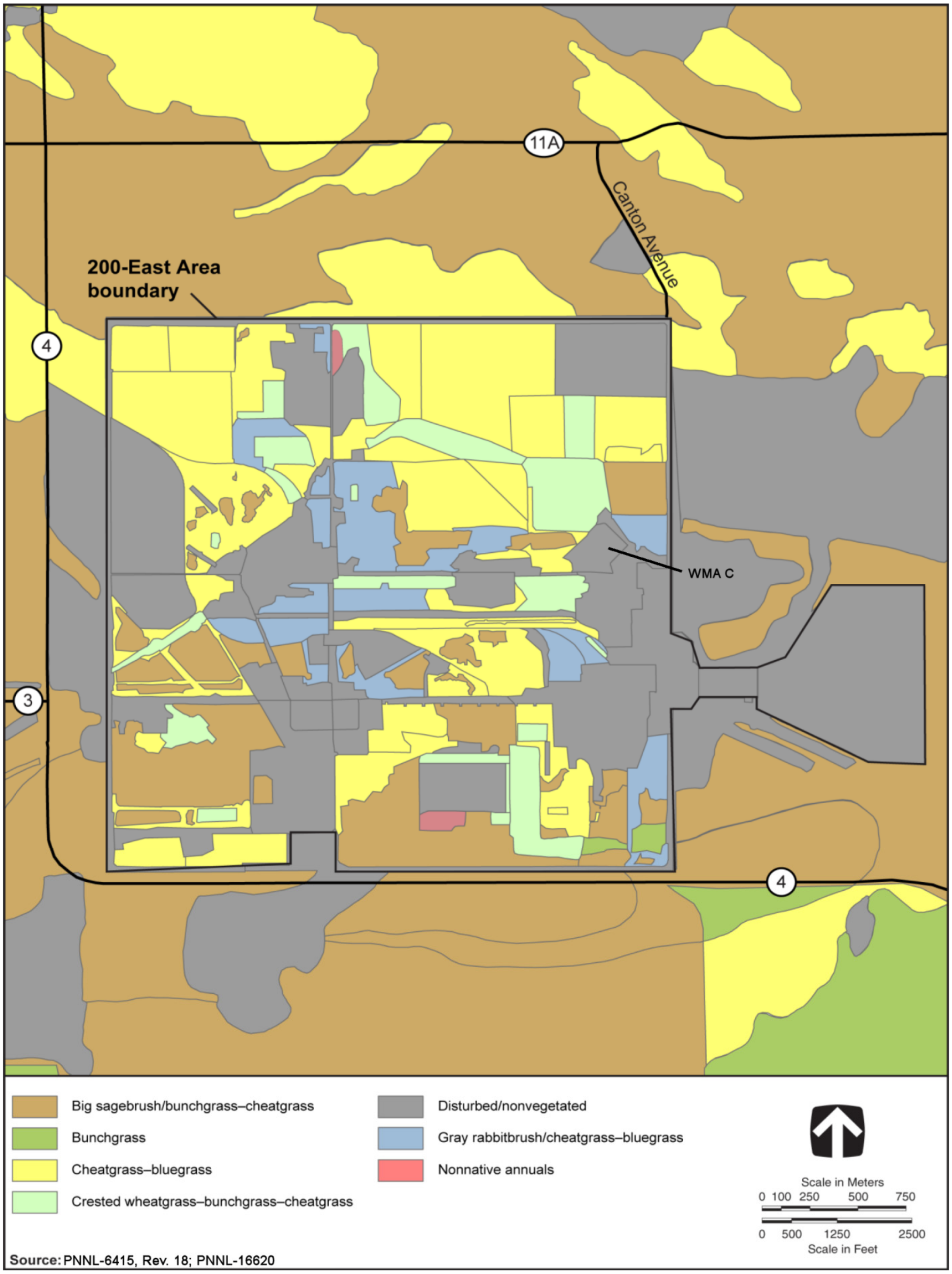


**Key:** EMSL=Environmental and Molecular Sciences Laboratory; ERDF=Environmental Restoration Disposal Facility; LIGO=Laser Interferometer Gravitational-Wave Observatory; WTP=Waste Treatment Plant.

**Sources: Modified from PNNL-6415; PNNL-17603; The Nature Conservancy, 2009**

Source: DOE/EIS-0391, "Final Tank Closure and Waste Management Environmental Impact Statement for the Hanford Site, Richland, Washington."

**Figure 3-11. Vegetation Communities in and near 200 East Area.**



**Source:** PNNL-6415, Rev. 18; PNNL-16620

Modified from DOE/EIS-0391, "Final Tank Closure and Waste Management Environmental Impact Statement for the Hanford Site, Richland, Washington."

References:
PNNL-6415, "Hanford Site National Environmental Policy Act (NEPA) Characterization."
PNNL-16620, "Ecological Data in Support of the Tank Closure and Waste Management Environmental Impact Statement Part 2: Results of Spring 2007 Field Surveys."

### 3.1.4 Geology, Seismology, and Volcanology

Since the Hanford Site started operating in the early 1940s, a large volume of information on the geology, seismology, and volcanology of the Site has been collected and evaluated. Over the last several years, the following two data packages have been prepared to describe the geology, hydrology, and geochemistry of the SST system and WMA C:

1) RPP-RPT-46088, "Flow and Transport in the Natural System at Waste Management Area C"

2) PNNL-15955, "Geology Data Package for the Single-Shell Tank Waste Management Areas at the Hanford Site."

Most of the data included in the geologic data package were collected by (or used by) several projects between about 1980 and the present. Those projects include the Basalt Waste Isolation Project, the Skagit Hanford Nuclear Project, the Washington Public Power Supply System safety analysis, several PAs, and numerous regulatory-driven geologic and hydrologic characterizations, assessments, and monitoring projects.

The technical aspects of all of these projects, and thus the data, interpretations of the data, and conclusions, have been overseen by one or more regulatory agencies and stakeholder groups including the NRC, the National Academy of Science, the Defense Nuclear Facilities Safety Board (DNFSB), the EPA, the U.S. Geological Survey, the Washington State Departments of Ecology and Health, the Oregon Department of Energy, and the Yakama, Nez Perce, and Wanapum Indian Nations and the Confederated Tribes of the Umatilla Reservation. The high level of oversight has helped ensure a rigorous understanding of bounding geologic, seismic, and volcanic risks.

This section provides a summary of the data in the two data packages, highlighting those aspects that are important to developing the conceptual model describing transport of contaminants away from the waste facility to a receptor. This section will focus on the regional and Hanford Site geologic framework. The geology of WMA C is discussed in Section 3.1.9 Waste Management Area C Site Characterization.

**3.1.4.1 Regional Geologic Framework.** The Hanford Site (Figure 3-13) lies within the Columbia Plateau, a broad plain situated between the Cascade Range to the west and the Rocky Mountains to the east, and is underlain by the Miocene Columbia River Basalt Group (CRBG) (Figure 3-14). The northern Oregon and Washington portion of the Columbia Plateau is often called the Columbia Basin because it forms a lowland surrounded on all sides by mountains. The low-relief plains of the Central Plains physiographic region and anticlinal ridges of the Yakima Folds region dominate the physiographic setting of the Hanford Site. In the central and western parts of the Columbia Basin and Pasco Basin where the Hanford Site is located, the basalt is underlain predominantly by Tertiary continental sedimentary rocks and overlain by late Tertiary and Quaternary fluvial and glacio-fluvial deposits. All these were folded and faulted during the Cenozoic Era to form the current landscape of the region.

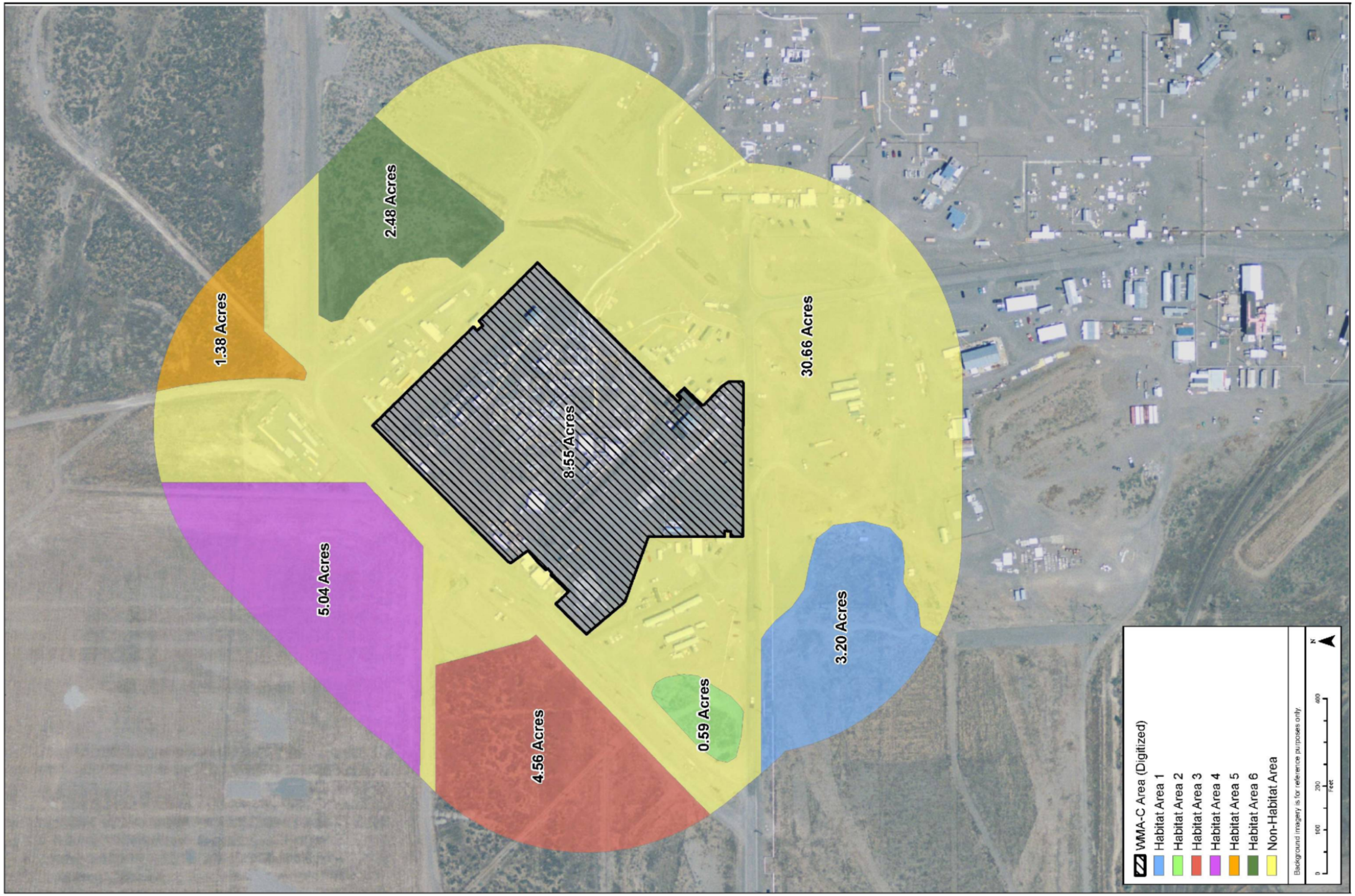


**Figure 3-12. Habitat Areas within a 500 Foot Perimeter of Waste Management Area C.**

WMA = Waste Management Area

Figure 3-13. Geologic Elements of the Pasco Basin Portion of the Columbia Basin, Washington.

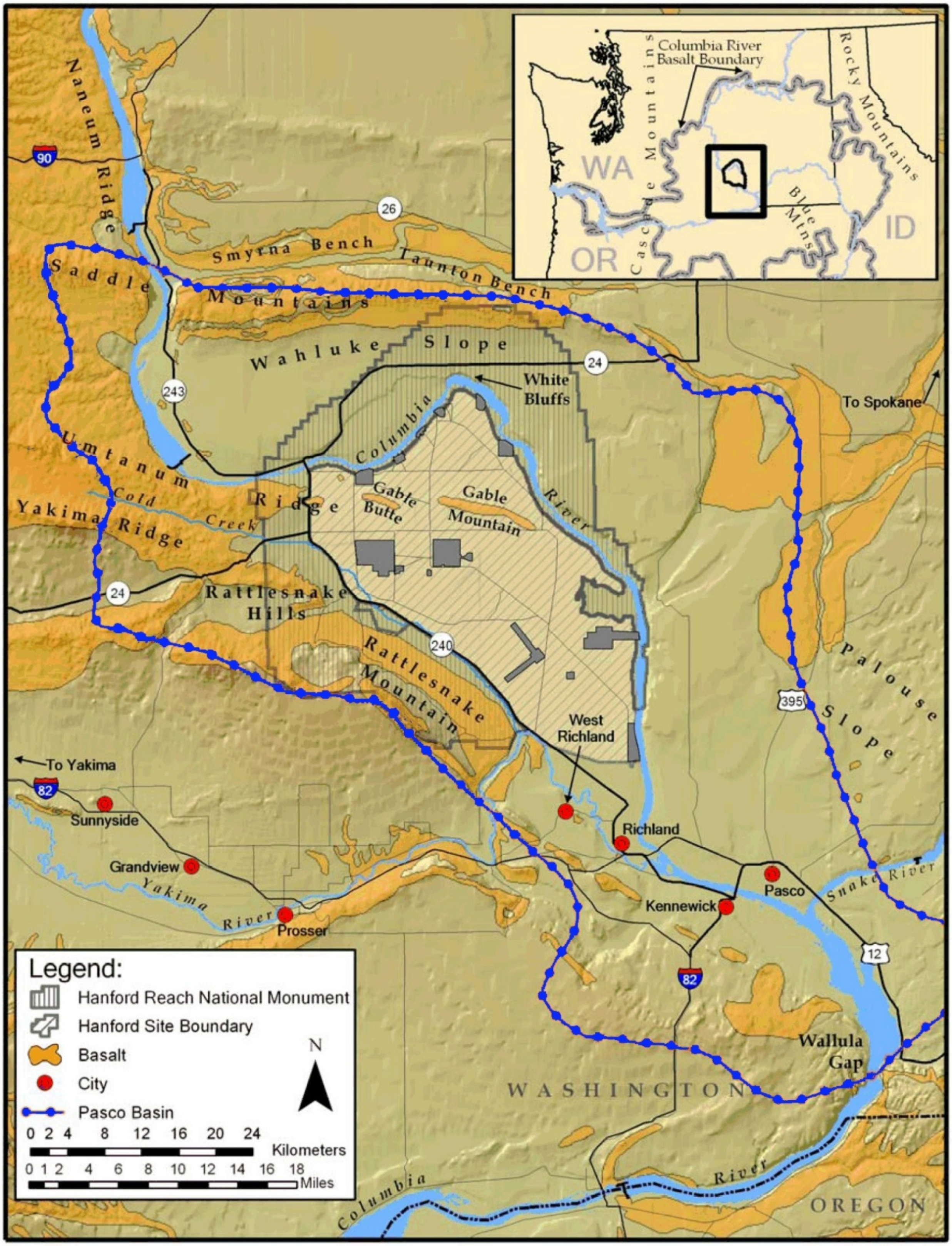
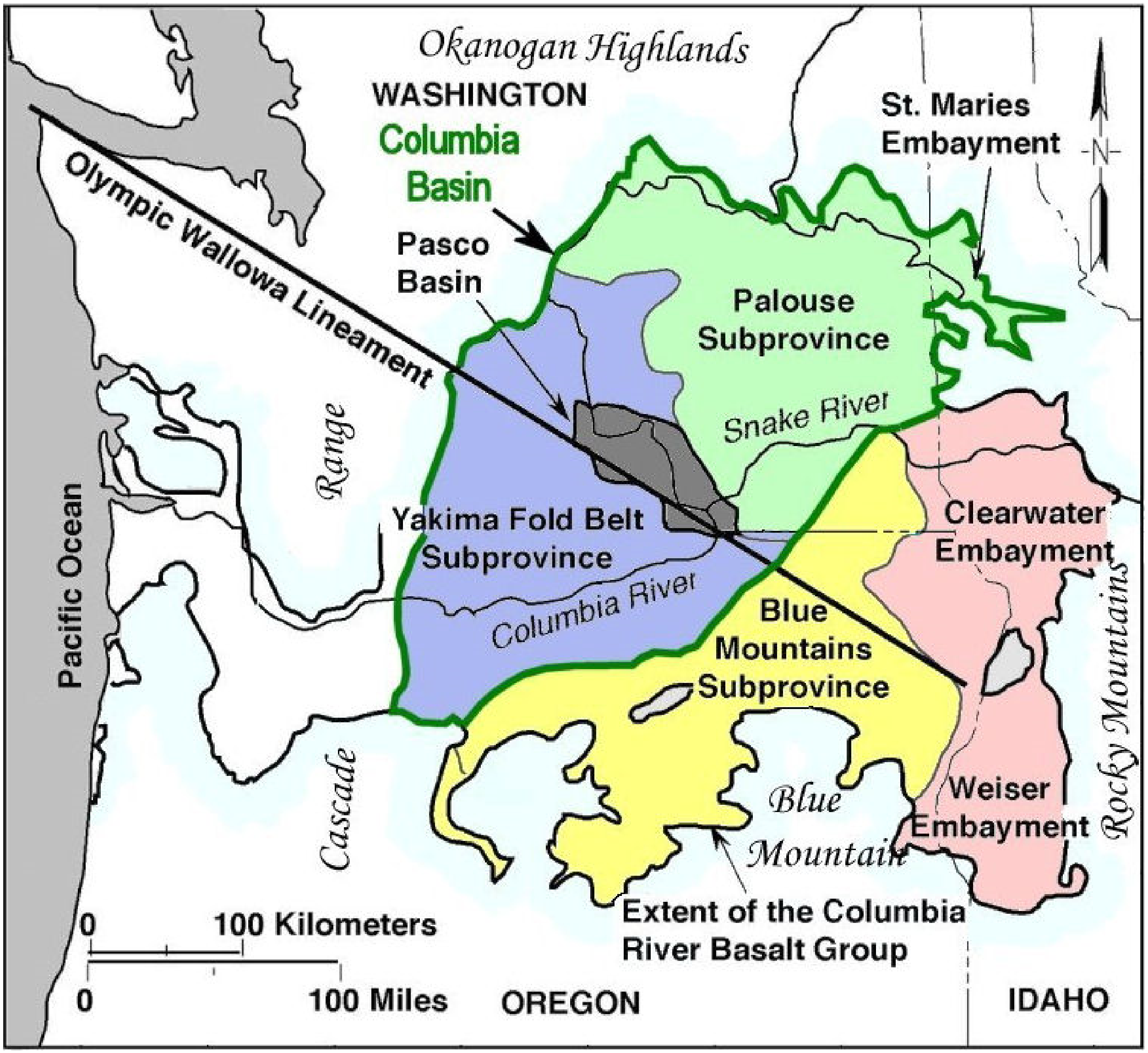


**Figure 3-14. Geologic Setting of the Columbia Basin and Pasco Basin.**



The Columbia Basin is a structurally and topographically low area surrounded by mountains ranging in age from the late Mesozoic to recent (Figure 3-14). The Columbia Basin is composed of two fundamental sub-provinces, the Palouse Slope and the Yakima Fold Belt (Figure 3-14). The Palouse Slope 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 Basin. The edge of the old continental craton lies at the junction of these two structural sub-provinces and is currently marked by the Ice Harbor dike swarm of the CRBG east of the Hanford Site. The Blue Mountains sub-province 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 Basin and the southern part of the Columbia Plateau.

**3.1.4.1.1 Lava Flows.** Lava flows erupted over a period of time from 17 to 6 million years ago. Under the Hanford Site, basaltic lava deposits (CRBG) are over 4 km (13,000 ft) thick ("Volcanism and Tectonism in the Columbia River Flood-Basalt Province," page 386, plate 1 [Reidel and Hooper 1989]), spreading over portions of Idaho, Oregon, and Washington. The Columbia Basin encloses the CRBG. A depression in the lower part of the Columbia Basin is referred to as the Pasco Basin (Figure 3-14). The Pasco Basin is bounded by the Saddle Mountains to the north, Naneum Ridge to the west, Rattlesnake Hills to the south, and the Palouse Slope to the east, generally the area north of where the Snake River flows into the Columbia River. Geographically, the ridges surrounding the Hanford Site and vicinity define the Pasco Basin, which contains Ringold Formation sediment from the ancestral Columbia River and sediment deposited by the Ice Age floods.

**3.1.4.1.2 Crustal Folding.** During and after the eruption of the lava flows, the Earth's tectonic forces buckled and folded the basalt in the western Columbia Basin into generally east-west trending, long, narrow ridges (anticlines), and intervening valleys (synclines). Collectively, this is identified as the Yakima Fold Belt.

**3.1.4.1.3 Ancestral Columbia River Deposits.** The ancestral Columbia River repeatedly changed its course over the past 15 million years, depositing gravel, sand, silt, and clay (RHO-BWI-ST-14, "Subsurface Geology of the Cold Creek Syncline," "Chapter 2 – Suprabasalt Sediments of the Cold Creek Syncline Area"; "Paleodrainage of the Columbia River System on the Columbia Plateau of Washington State – A Summary" [Fecht et al. 1987]; DOE/RW-0164, Consultation Draft Site Characterization Plan Reference Repository Location, Hanford Site, Washington; "Late Cenozoic Structure and Stratigraphy of South-Central Washington" [Reidel et al. 1994]; 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"). Uplifting basalt ridges diverted the course of the Columbia River from a southerly direction (toward Goldendale) to an easterly direction (toward Wallula Gap) and left behind the Ringold Formation (Fecht et al. 1987). Later regional uplift associated with the Cascade Mountains caused the river to cut through its own earlier deposits (the Ringold Formation), exposing the White Bluffs. Within the Hanford Reach, the Columbia River continues to erode the White Bluffs. Groundwater seepage from irrigation along the bluffs makes them unstable. Consequently, the White Bluffs are land sliding and sloughing into the Columbia River along much of the shoreline (Fecht et al. 1987).

**3.1.4.1.4 Ice Age Floods.** During the Pleistocene, cataclysmic floods inundated the Pasco Basin several times when ice dams failed on the Clark Fork River that created Glacial Lake Missoula ("Quaternary Geology of the Columbia Plateau" [Baker et al. 1991]). The Ice Age floods began as early as 2.5 million years ago ("Long History of Pre-Wisconsin, Ice Age Cataclysmic Floods: Evidence from Southeastern Washington State" [Bjornstad et al. 2001]) with the most recent occurring 18,000 to 13,000 years ago. Current interpretations suggest as many as 40 flooding events occurred as ice dams holding back glacial Lake Missoula repeatedly formed and broke. In addition to larger major flood episodes, there were probably numerous smaller individual flood events. Deciphering the history of cataclysmic flooding in the Pasco Basin is complicated, not only because of floods from multiple sources but also because the paths of Missoula floodwaters migrated and changed course with the advance and retreat of the Cordilleran Ice Sheet.

Along with sedimentological evidence for cataclysmic flooding in the Pasco Basin, high-water marks and faint strandlines occur along the basin margins. Temporary lakes were created when flood waters were hydraulically dammed, resulting in the formation of the short-lived Lake Lewis behind Wallula Gap. High water mark elevations for Lake Lewis (Figure 3-15), inferred from ice-rafted erratics on ridges, range from 370 to 385 m (1,214 to 1,263 ft) above sea level.

The sediment deposited by the cataclysmic flood waters has been informally called the Hanford formation because the best exposures and most complete deposits are found there. The coarse-grained flood facies (gravel-dominated facies of DOE/RL-2002-39, Standardized Stratigraphic Nomenclature for Post-Ringold-Formation Sediments Within the Central Pasco Basin) is generally confined to relatively narrow tracts within or near flood channel ways. The plane-laminated sand facies (sand-dominated facies of DOE/RL-2002-39), on the other hand, occurs as a broad sheet over most of the central basin.

**3.1.4.2 Hanford Site Geologic Framework.** The previous section provided the regional geologic framework. This section provides a summary of the geologic structure and stratigraphy unique to the Hanford Site. Please see the geologic data packages for more complete descriptions.

**3.1.4.2.1 Geologic Structure.** The Cold Creek syncline (Figure 3-16) lies between the Umtanum Ridge-Gable Mountain uplift and the Yakima Ridge uplift and is an asymmetric and relatively flat-bottomed structure. The Cold Creek syncline began developing during the eruption of the CRBG and has continued to subside since that time. The 200 Areas lie on the northern flank, and the bedrock dips gently (approximately 5°) to the south. The deepest parts of the Cold Creek syncline, the Wye Barricade depression and the Cold Creek depression, are ~12 km (~7.5 mi) southeast of the 200 Areas and southwest of the 200 West Area, respectively (Figure 3-16).

The Wahluke syncline north of Gable Mountain is the principal structural unit that contains the 100 Areas. The Wahluke syncline is an asymmetric and relatively flat-bottomed structure similar to the Cold Creek syncline. The northern limb dips gently (approximately 5°) to the south. The steepest limb is adjacent to the Umtanum Ridge-Gable Mountain structure.

The 200 East Area is located on the eastern part of the Cold Creek bar, which is along the northern flank of the Cold Creek syncline (Figure 3-16). Another deep structural low, the Wye Barricade depression, developed along the Cold Creek syncline southeast of the 200 East Area. The May Junction fault is a normal fault that marks the western boundary of the depression.

The 200 East Area sits at the southern end of a series of secondary doubly plunging anticlines and synclines that are associated with the Umtanum Ridge-Gable Mountain anticlinal structure. Waste Management Areas A, AX, B-BX-BY, and C in the 200 East Area lie near the southern flank of the closest secondary anticline. A fault was recently detected during drilling of seismic test boreholes at the Waste Treatment Plant. The fault caused some displacement in the Pomona Basalt that lies beneath the Elephant Mountain Member but is not thought to have caused any displacement in younger basalts or overlying sediments (PNNL-16407, “Geology of the Waste Treatment Plant Seismic Boreholes”).

Figure 3-15. Flood in the South of the Hanford Site, Washington, between 18,000 to 13,000 Years Ago.

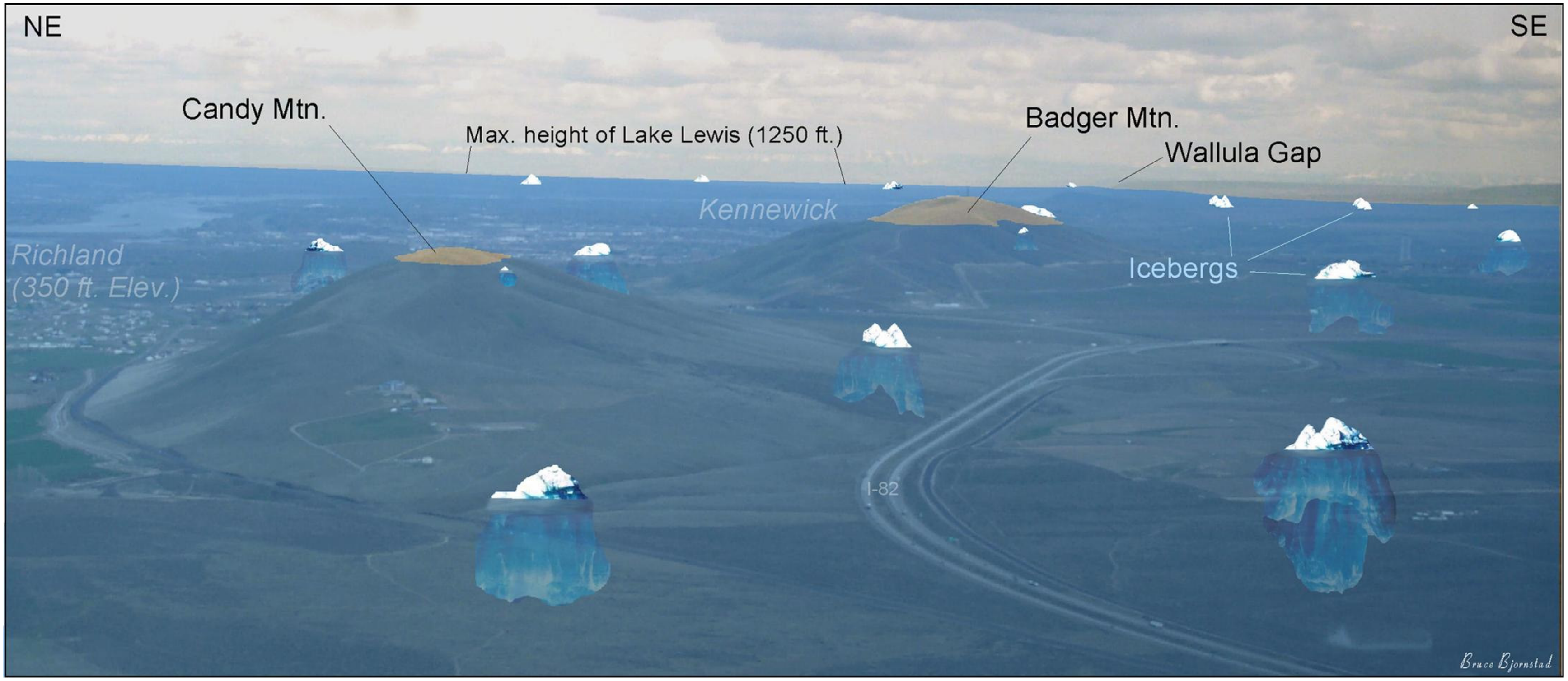
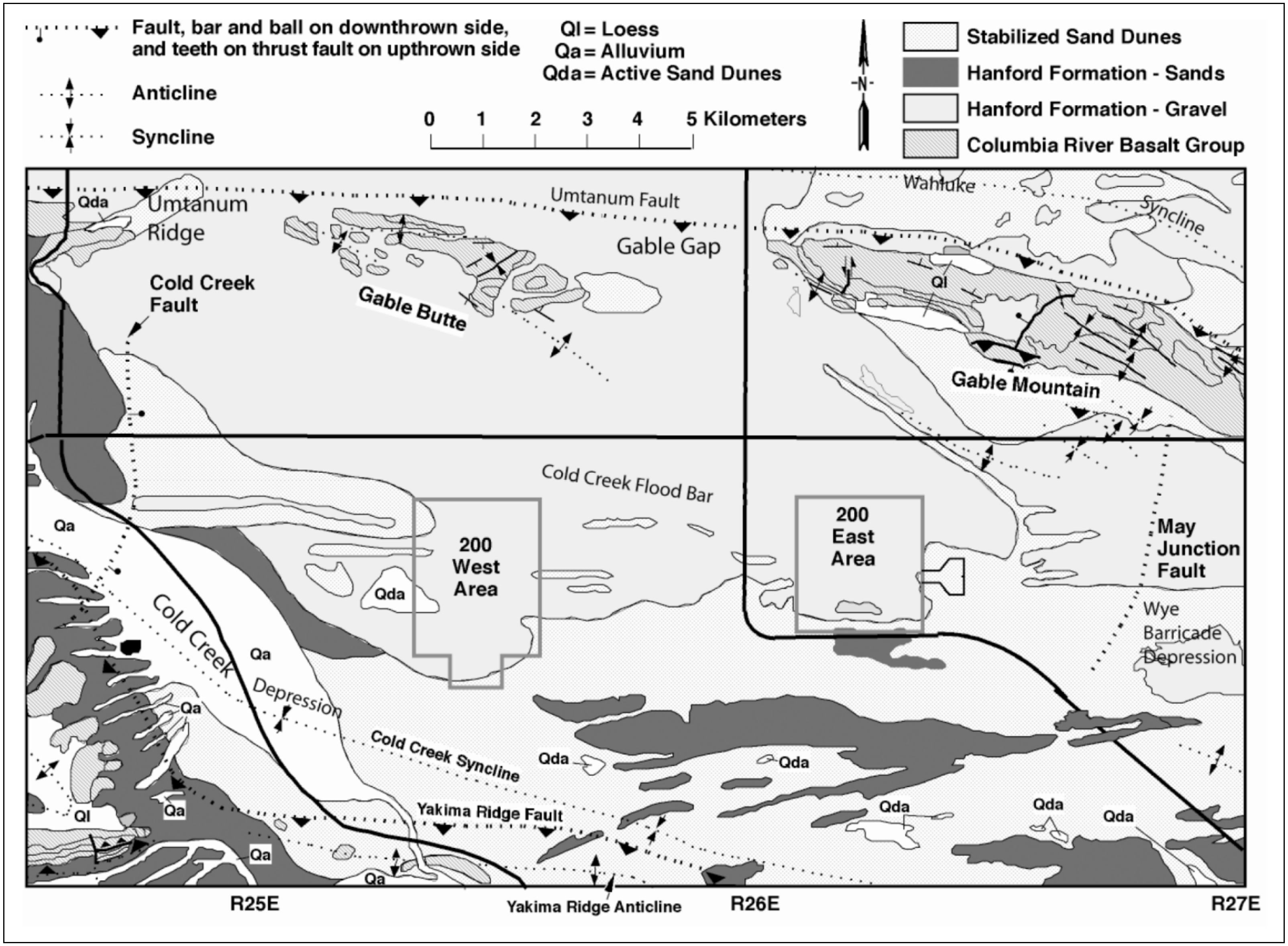


Figure 3-16. Geologic and Geomorphic Map of the 200 Areas and Vicinity.



**3.1.4.2.2 Stratigraphy.** The generalized stratigraphy of the Pasco Basin and Hanford Site is shown in Figure 3-17. The principal rocks exposed at the surface of the surrounding ridges are the CRBG and intercalated sedimentary rocks of the Ellensburg Formation. In the low-lying basins and valleys, these are overlain by younger sedimentary rocks of the Ringold Formation, Cold Creek unit (CCU), and the Pleistocene cataclysmic flood deposits of the Hanford formation. Figure 3-18 provides an approximate west to east cross section through the Hanford Site.

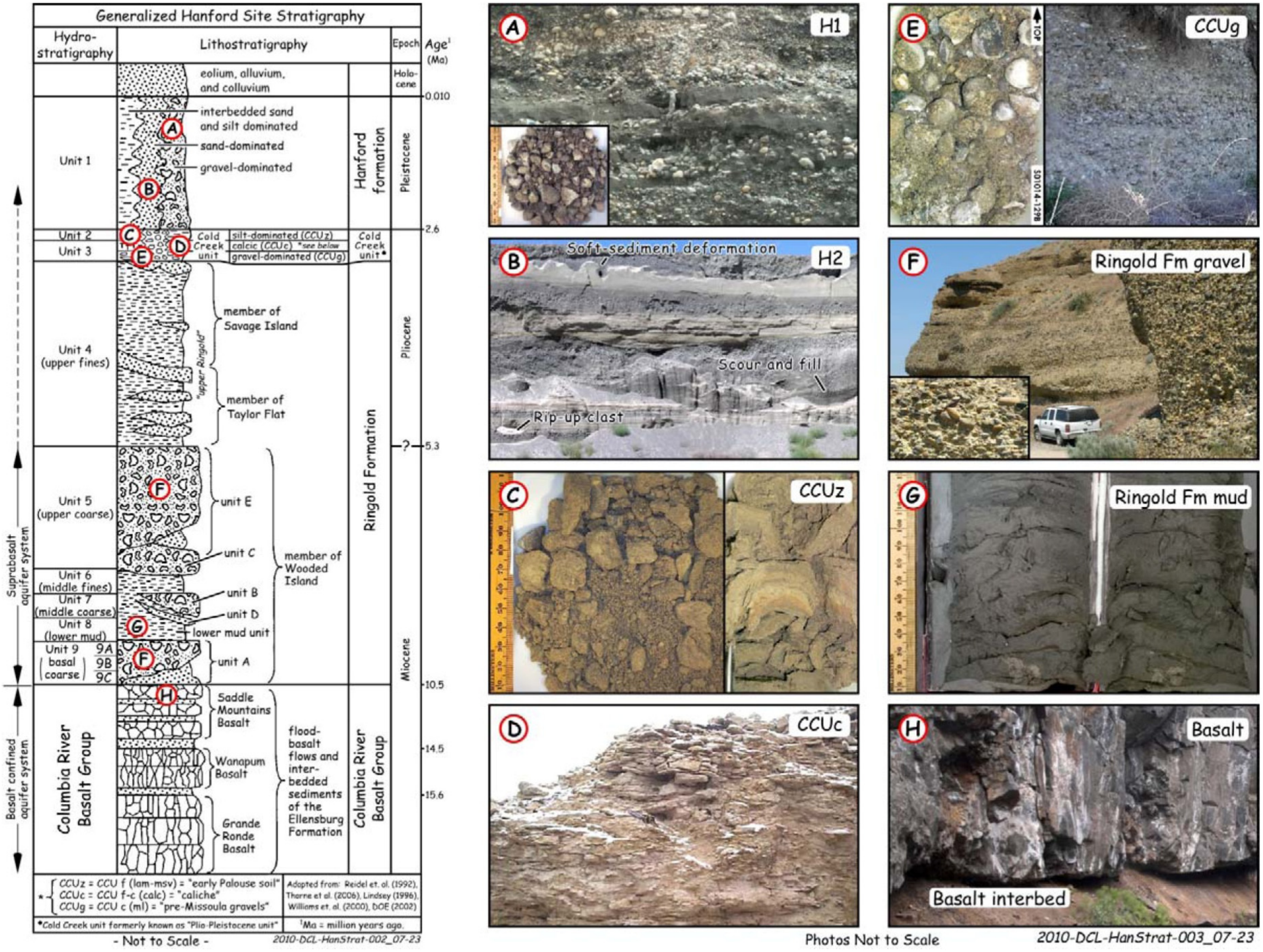
**Columbia River Basalt Group and Ellensburg Formation:** The Elephant Mountain Member is the uppermost basalt flow beneath the 200 Areas and much of the Hanford Site. Where folds and faults have formed basalt ridges, other flows from the Saddle Mountains, Wanapum, and Grande Ronde Formations are exposed.

The Ellensburg Formation is intercalated with and overlies the CRBG in the Pasco Basin and includes epiclastic and volcaniclastic sedimentary rocks ("Stratigraphic and Lithologic Variations in the Columbia River Basalt" [Waters 1961]; USGS Bulletin 1457-G, "Revisions in stratigraphic nomenclature of the Columbia River Basalt Group"). The upper Ellensburg Formation consists of sand and gravel marking mainstream deposits and sand, silt, and clay overbank deposits that are sandwiched between basalt flows. Along with the more permeable basalt flow bottoms and flow tops, these sediments form the uppermost confined basalt aquifer system beneath the Hanford Site. The upper, younger Ellensburg Formation interbedded with the Saddle Mountains Basalt (as noted on Figure 3-17 as part of the CRBG) reflects changes in river courses, with sediments from the Columbia River becoming dominant as developing anticlinal ridges pushed the Columbia River east and basalt flows pushed the Clearwater-Salmon system to the south. Relatively few boreholes in the 200 Areas penetrate the Ellensburg Formation. Those boreholes that do penetrate the Ellensburg Formation generally find tuffaceous siltstones and sandstones, with conglomerates marking ancient main river channels. The Ellensburg stratigraphy of the Hanford Site has been discussed in more detail in Fecht et al. (1987).

The uppermost basalt flow beneath the Central Plateau is the Elephant Mountain Member (RHO-BWI-ST-14, "Chapter 3 – Wanapum and Saddle Mountains Basalts of the Cold Creek Syncline Area"). The top of basalt surface dips to the southwest beneath the 200 West Area and to the south-southwest beneath the 200 East Area. Low-amplitude secondary folds such as the one to the northeast of the 200 East Area may occur throughout the area and have probably not been fully identified. Between the 200 East Area and Gable Gap to the north, the Elephant Mountain has been eroded to expose underlying basalt flows. There is also a suspected window eroded through the Elephant Mountain near the northeast corner of the 200 East Area.

**Post-Columbia River Basalt Sediments:** The Hanford Site and tank farms are situated on a sequence of Ringold Formation, CCU, and Hanford formation sediments overlying the CRBG (Figure 3-19). The upper Miocene to middle Pliocene record of the Columbia River system in the Columbia Basin is represented by the upper Ellensburg and Ringold Formations. Except for local deposits (e.g., the CCU), there is a hiatus (erosion or lack of sedimentation) in the stratigraphic record between the end of the Ringold Formation deposition (3.4 Ma) and the beginning of Pleistocene (1.6 Ma) time (DOE/RW-0164, DOE/RL-2002-39).

**Figure 3-17. Generalized Stratigraphy of the Hanford Site Including the Central Plateau.**



### Figure 3-18. Cross-Section Running through the Central Plateau of the Hanford Site.

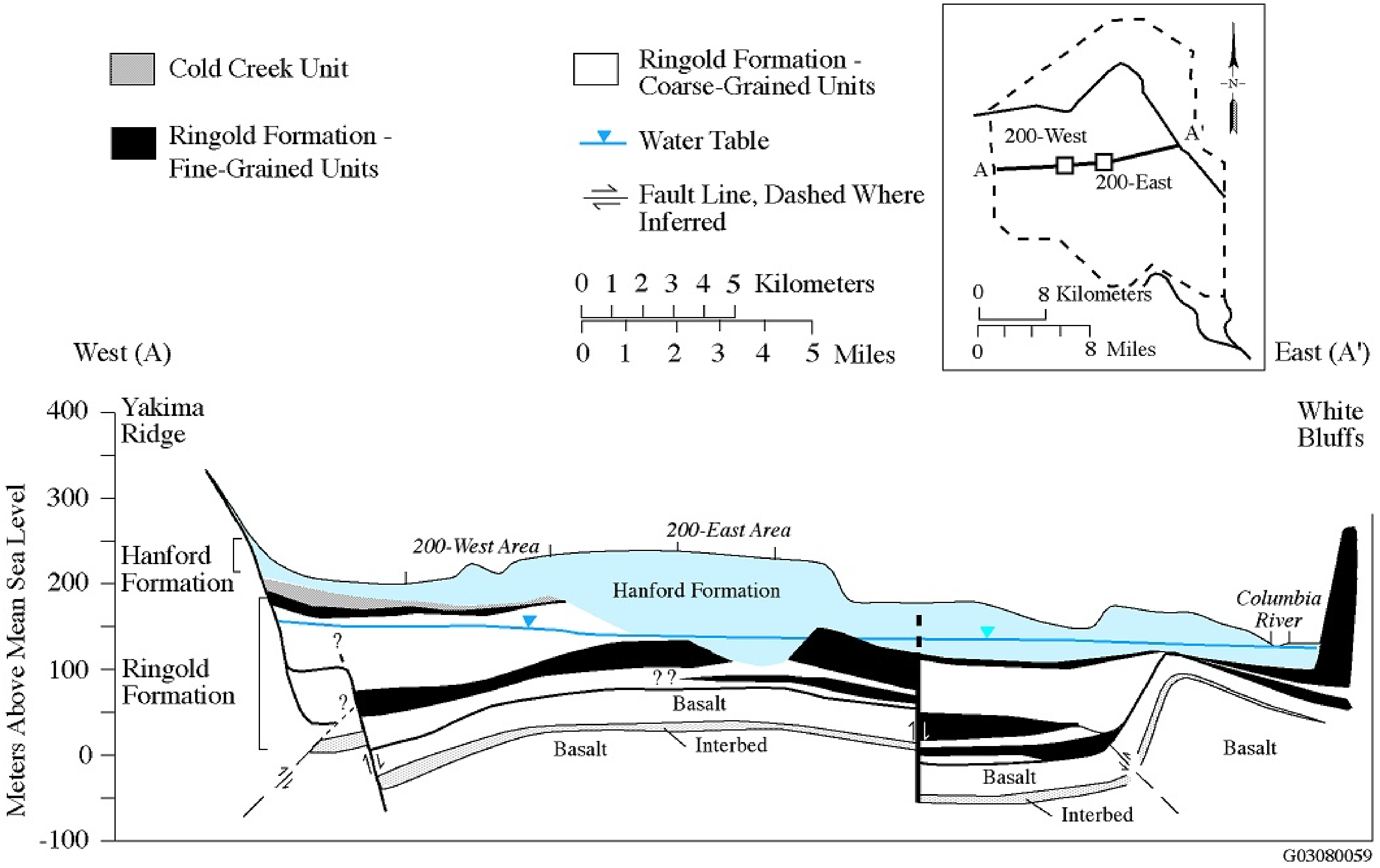
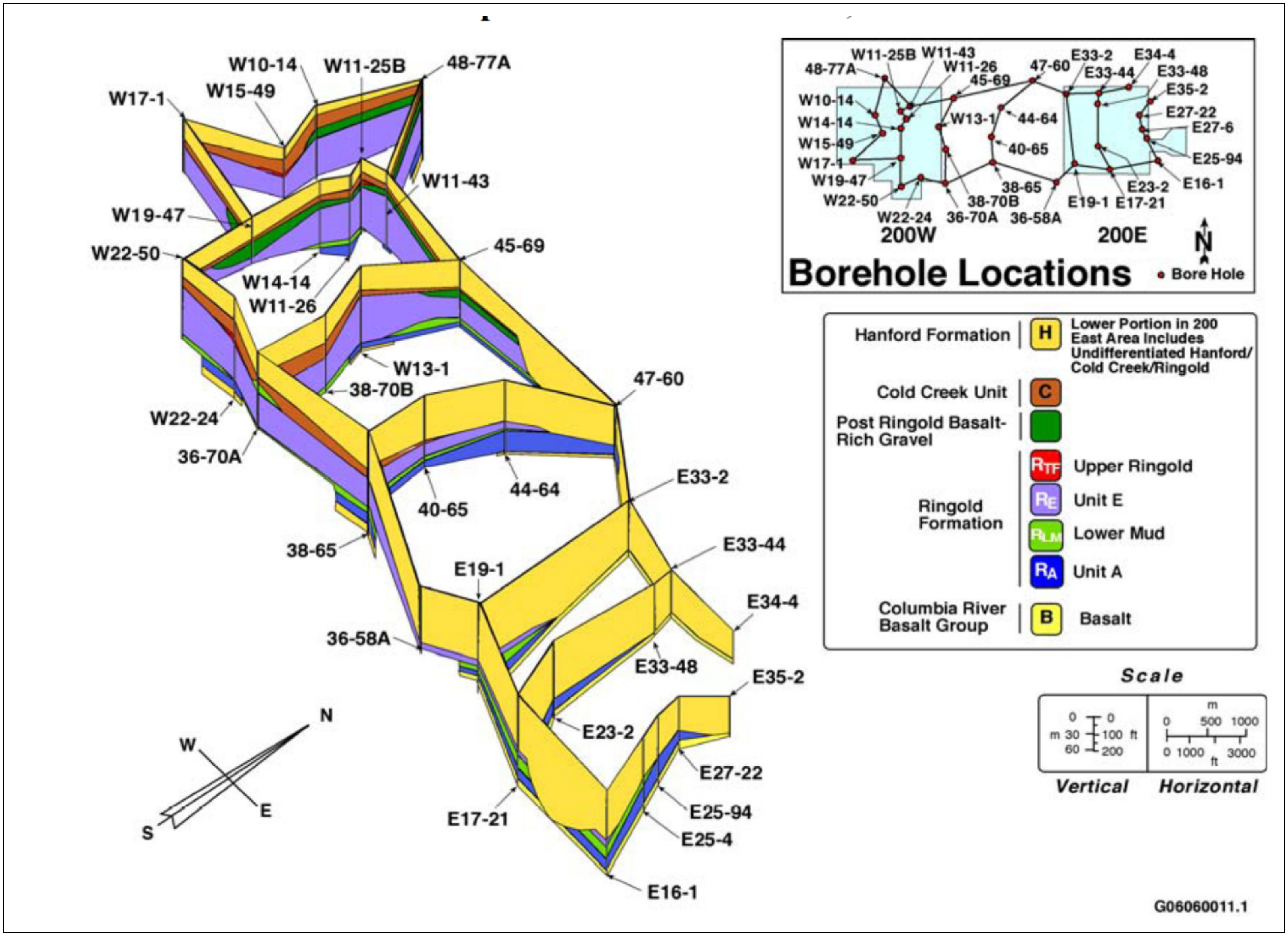


Figure 3-19. Fence Diagram of Sediment Overlying the Columbia River Basalt Group in the Central Plateau, Hanford Site.



**Ringold Formation:** The Ringold Formation at the Hanford Site is up to 185 m (607 ft) thick in the deepest part of the Cold Creek syncline south of the 200 West Area and 170 m (558 ft) thick in the western Wahluke syncline near the 100 B Area. The Ringold Formation pinches out against the Gable Mountain, Yakima Ridge, Saddle Mountains, and Rattlesnake Mountain anticlines. It is largely absent in the northern and northeastern parts of the 200 East Area. It consists of semi-indurated clay, silt, pedo-genically altered sediment, fine- to coarse-grained sand, and granule to cobble gravel. Ringold Formation strata typically are below the water table on the Hanford Site, and the textural variations influence groundwater flow.

In the Pasco Basin, the lower half of the Ringold Formation, the member of Wooded Island, is the main unconfined aquifer under the Hanford Site and contains five separate stratigraphic intervals dominated by the fluvial gravel facies. These gravels, designated units A, B, C, D, and E, are separated by intervals containing deposits typical of the overbank and lacustrine facies (WHC-SD-EN-EE-004, “Revised Stratigraphy for the Ringold Formation, Hanford Site, South-Central Washington”). In the 200 Areas, only fluvial gravel units A and E occur. Between these two gravel units in many places is the lowermost of the fine-grained.

The upper part of the Ringold Formation, informally called the member of Taylor Flat (BHI-00184, “Miocene- to Pliocene-Aged Suprabasalt Sediments of the Hanford Site, South-Central Washington”) consists of the sequence of fluvial sands, overbank deposits, and lacustrine sediments overlying unit E. This corresponds to the upper unit as originally defined by “Ringold Formation of Pleistocene Age in Type Locality, the White Bluffs, Washington” (Newcomb 1958) along the White Bluffs in the eastern Pasco Basin. The fluvial sand facies is the principal facies of the upper part under the tank farms at the Hanford Site.

**Cold Creek Unit:** The CCU (DOE-RL-2002-39) includes all material underlying the Hanford formation, overlying the Ringold Formation in the vicinity of the 200 West Area, and may extend over most of the central Pasco Basin. The CCU distinguishes itself from the Hanford and Ringold formations because it was formed when the Ringold Formation was eroding and relatively little was being deposited at the Hanford Site. This subunit is found locally in the Cold Creek syncline in the subsurface.

The CCU is laterally discontinuous and overlies the tilted and truncated Ringold Formation in an unconformable relationship in the western Cold Creek syncline in the vicinity of the 200 West Area (DOE/RL-2002-39). To the east, the pre-Missoula gravels replace the calcrete and silt-dominated subunits of the CCU. The CCU appears to be correlative to other side stream alluvial, eolian, and pedogenic deposits found near the base of the ridges bounding the Pasco Basin on the north, west, and south. These sedimentary deposits are inferred to have a late Pliocene to early Pleistocene age on the basis of stratigraphic position and magnetic polarity of interfingering loess units (DOE/RW-0164).

Distribution of the CCU depends in part on erosion and weathering of the underlying Ringold Formation and post-depositional erosion by the Ice Age floods (“Buried carbonate paleosols developed in Pliocene-Pleistocene deposits of the Pasco Basin, south-central Washington, U.S.A.” [Slate 1996]). The thickness of the Cold Creek deposit ranges from 0 to 20 m (0 to 66 ft). Locally the CCU contains very hard rock that formed as precipitation evaporated and left behind minerals forming what geologists call caliche or hardpan. This layer can influence contaminant migration by slowing its rate of downward movement and potentially diverting contaminants laterally (Slate 1996). However, CCU as described above is largely absent from the 200 East Area.

**Hanford formation**: The Hanford formation is the informal name given to all glacio-fluvial deposits from cataclysmic Ice Age floods found in the Pasco Basin (RHO-BWI-ST-4, "Geologic Studies of the Columbia Plateau: A Status Report"). Sources for floodwaters included glacial Lake Missoula, and ice-margin lakes that formed around the margins of the Columbia Plateau and Lake Bonneville (Baker et al. 1991). On average, interglacial conditions lasting ~50,000 years have been separated by major glacial advances, also averaging ~50,000 years. To date, Ice Age flood deposits from only four of the major glacial events that occurred between 1 million and 13,000 years ago are identified within the Pasco Basin (Baker et al. 1991; Open File Report 94-8, "Geologic Map of the Richland 1:100,000 Quadrangle, Washington"). Evidence to support the other major glacial cycles in the Pasco Basin either are masked or have been destroyed by subsequent Ice Age floods.

When the Ice Age floodwaters entered the Pasco Basin, they quickly became impounded behind Wallula Gap, which was too restrictive for the volume of water involved. Floodwaters formed temporary lakes with shorelines up to 381 m (1,250 ft) in elevation. The lakes lasted not more than a few days ("Magnitudes and implications of peak discharges from glacial Lake Missoula" [O'Connor and Baker 1992]). The deposits that were left after the floodwater receded, known as the Hanford formation, blanket low-lying areas over most of the Hanford Site. These Ice Age floods created Cold Creek bar (Figure 3-20), a giant, streamlined deposit of gravel, sand, and silt that extends for 19.3 km (12 mi) downstream of Umtanum Ridge. Gravel-dominated deposits, laid down under the strongest flood currents, are generally restricted to the north side of the bar. At the south end of the bar, where flood currents were gentler, interbedded sand and silt deposits were laid down. In between these two areas deposits of predominantly sand accumulated, which includes the area beneath C Farm.

The Hanford formation consists of mostly unconsolidated sediments that cover grain sizes from pebble to boulder gravel, fine- to coarse-grained sand, silty sand, and silt. The formation is further subdivided into gravel-, sand-, and silt-dominated facies, which transition into one another laterally with distance from the main, high-energy, flood channels. Beneath much of the Hanford Site the Hanford formation has been locally subdivided into several informal subunits. WHC-SD-EN-TI-290, "Geologic Setting of the Low-Level Burial Grounds" subdivides the Hanford formation in the 200 East and West Areas into three basic units: H1, H2, and H3. H1 is described as consisting of a gravel facies-dominated interval in the upper part of the formation throughout much of the 200 East and West Areas. Unit H2 is described as a predominantly sand facies-dominated unit, which increases in predominance within the formation from north to south across the same area. The H3 unit is generally described as a mixed sand and gravel facies unit found comprising the lower part of the formation in much of the 200 East Area, and possibly locally in the 200 West Area.

Furthermore, PNNL-19702, "Hydrogeologic Model for the Gable Gap Area, Hanford Site" identified five paleochannels (A through E) running through the Central Plateau that are filled with coarse-grained, highly permeable flood deposits of the Hanford formation. These paleochannels may have initially formed during Ringold time, and if so, were further deepened during cataclysmic flooding which removed all Ringold-age deposits from the channel. Paleochannel D, which has a remnant of Ringold Formation along its east side, might be an example of a Ringold-age channel that was cut deeper during Ice Age flooding. Paleochannel D runs from the northwest corner through to the southeast corner of 200 East Area.

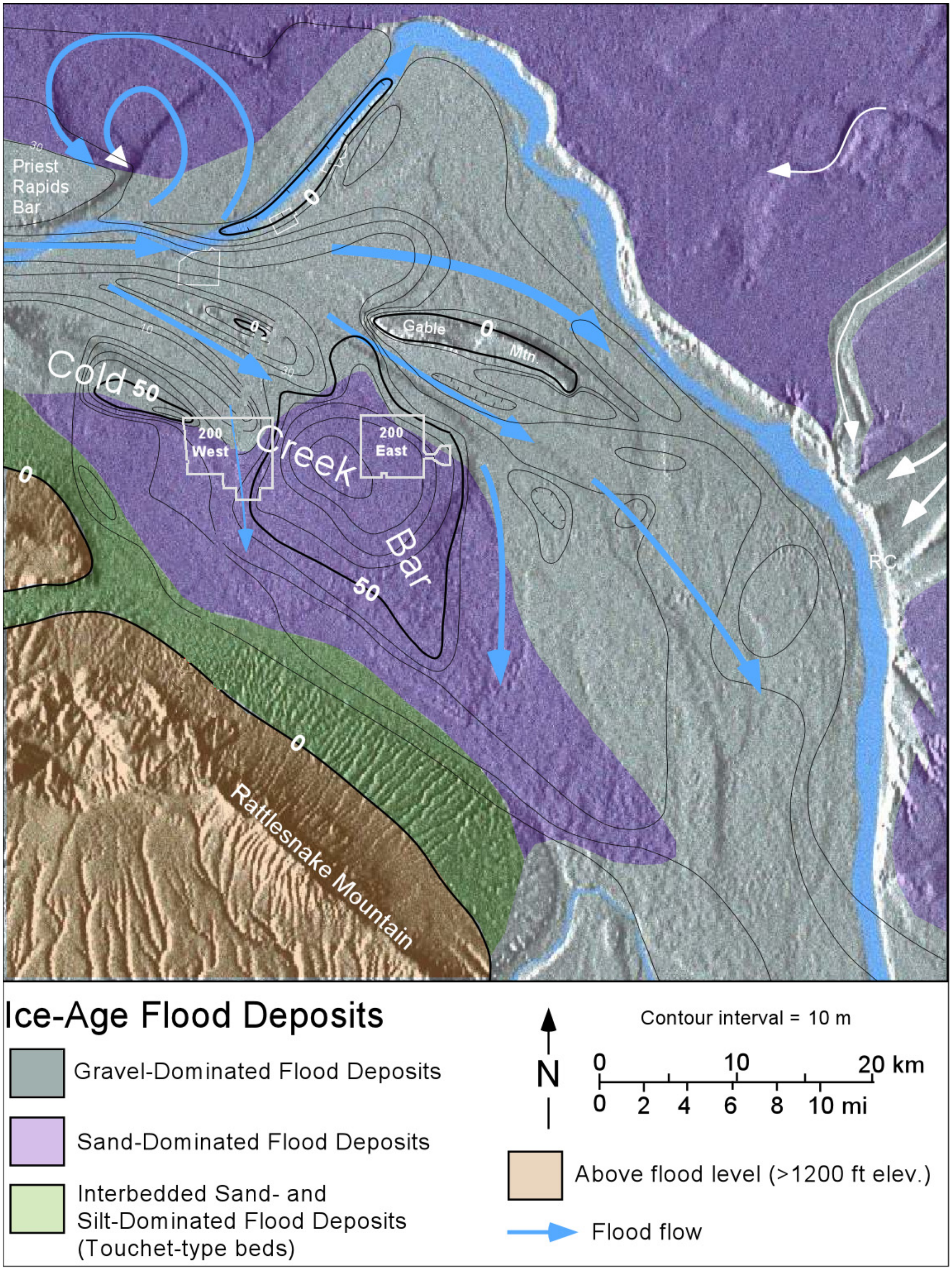
**Holocene Surficial Deposits:** Holocene surficial deposits consist of silt, sand, and gravel that form a thin layer across much of the Hanford Site. These sediments were deposited by a combination of eolian and alluvial processes.

**Tank Farm Backfill:** The shallowest sediments found within the confines of the tank farm are described primarily as basaltic pebble-cobble gravel with a sand and silt matrix. This material is commonly brown in color and contains construction debris, including nails, wood, and cement. These strata are interpreted to be tank farm backfill, which is consistent with previous interpretations of area geology (ARH-LD-132, “Geology of the 241-C Tank Farm”). Moisture logs collected in many of the tank farm leak detection borings show increased moisture ~12 to 13 m (40 to 42 ft) below ground surface (bgs). This is interpreted to be moisture accumulating above the compacted base of the original tank farm excavation. No soil has developed over the backfill and the vegetation within the WMA is controlled through herbicides.

**3.1.4.2.3 Clastic Dikes.** Clastic dikes are found in the Hanford formation and locally in other sedimentary units (RHO-BWI-C-64, “Clastic Dikes Of The Pasco Basin, Southeastern Washington, Final Report”; BHI-00230, “Geologic Field Inspection of the Sedimentary Sequence at the Environmental Restoration Disposal Facility”; BHI-01103, “Clastic Injection Dikes of the Pasco Basin and Vicinity – Geologic Atlas Series”). Clastic dikes (Figure 3-21) are vertical to sub-horizontal fissures filled by multiple layers of unconsolidated sand, silt, clay, and minor gravel aligned parallel to sub-parallel to dike walls. Clastic dikes range in vertical extent from 0.3 m to 55 m (1 ft to 180 ft). In cross-section, clastic dikes range from 1 millimeter to 1.8 m (0.04 in. to 5.91 ft) in thickness, and in plan view clastic dikes extend up to 100 m (328 ft) along strike. Clastic dikes form a branching pattern that in plan view forms polygons many feet across. Where the dikes intersect the ground surface, a feature known as patterned ground is observed. Patterned ground features are most abundant when Hanford formation sand-dominated and silt-dominated facies are at or near ground surface. BHI-01103 summarizes the location at Hanford where clastic dikes have been identified. Clastic dikes are inferred to be present beneath the SST farms, and at least locally, they cross-cut the Plio-Pleistocene boundary (WHC-EP-0698, “Groundwater Impact Assessment Report for the 216-U-14 Ditch”). BHI-01103 did not identify any clastic dikes in the vicinity of WMA C.

**3.1.4.2.4 200 Areas Topography.** Figure 3-22 shows the 200 Areas and the WMAs in a perspective view (note that the vertical to horizontal exaggeration in this figure is 5:1). The 200 Areas Central Plateau contains a topographic high in between the 200 East and 200 West Areas with gently dipping sides, except in the northwest corner of the 200 West Area. The WMAs were always located downhill from the waste-generating facilities to allow gravity flow in the pipelines from the facilities to the tanks. The relative flatness of the WMAs means that the final topography will be determined by the surface cover and grading of the surrounding soil.

1 **Figure 3-20. Isopach Map of the Ice Age Flood Deposits (Hanford Formation).**
2

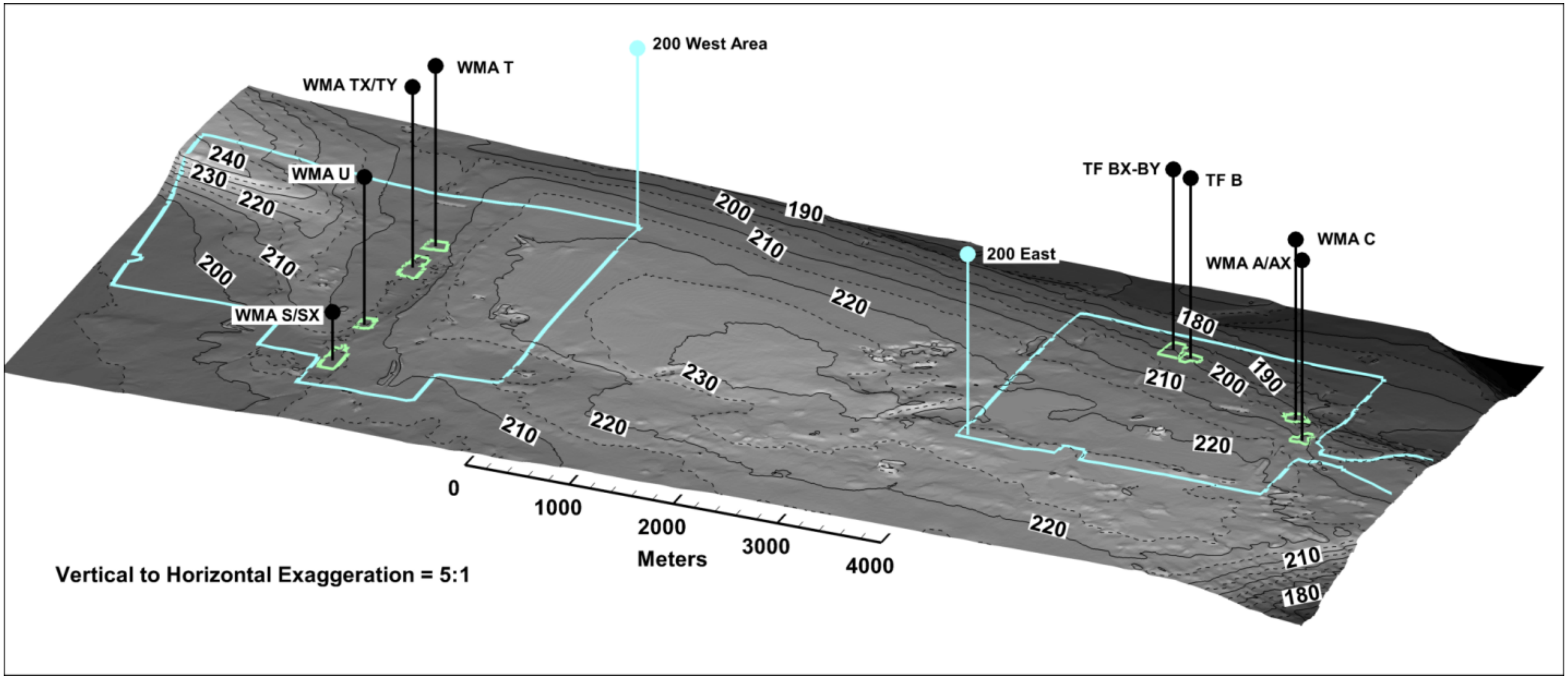


3

**Figure 3-21. Typical Type II Clastic Injection Dike Exposed in a Wall of the Environmental Restoration Disposal Facility Excavation Exposed during Construction. The facility is located on the 200 Area Pleistocene Glacio-fluvial Flood Bar in the central Hanford Site.**

Source: BHI-01103, "Clastic Injection Dikes of the Pasco Basin and Vicinity – Geologic Atlas Series."

**Figure 3-22. Topography of the 200 Areas Central Plateau in Meters above Mean Sea Level.**



WMA = Waste Management Area

**3.1.4.2.5 Surface Soils.** The Holocene deposits and exposed Hanford formation sediments have experienced soil development and evolved into identifiable soil types. BNWL-243, "Soil Survey Hanford Project in Benton County Washington" describes 15 different surface soil types on the Hanford Site, varying from sand to silty and sandy loam. Various classifications, including land use, are also given in BNWL-243. These soil types control the flux of water reaching the water table (i.e., recharge) (PNNL-13033). The soils found in the Central Plateau in and around the 200 Areas are Quincy Sand (formally known as Rupert Sand), Burbank Loamy Sand, and Ephrata Sandy Loam. BNWL-243 described these types of soil as follows.

- **Quincy Sand (formally known as Rupert Sand).** This mapping unit represents one of the most extensive soils on the Hanford Site. The surface is a brown to grayish-brown coarse sand, which grades to a dark grayish-brown sand at ~1 m (~36 in.). Rupert soils developed under grass, sagebrush, and hopsage in coarse sandy alluvial deposits, which were mantled by wind-blown sand. Relief characteristically consists of hummocky terraces and dune-like ridges. This soil may be correlated as Quincy Sand, which was not separated here. Active sand dunes are present. Some dune areas are separated; however, many small dunes, blow-outs, and associated small areas of Ephrata and Burbank soils are included.

- **Burbank Loamy Sand.** This is a dark-colored (surface is very dark grayish-brown; subsoil is dark grayish-brown), coarse-textured soil which is underlain by gravel. The surface soil is usually 0.41 m (~16 in.) thick but can be 0.76 m (30 in.) thick. The gravel content of the subsoil may range from 20 to 80% by volume.

- **Ephrata Sandy Loam.** The surface of this soil is dark colored with subsoil that is dark grayish-brown and medium-textured. It is underlain by gravelly material that may extend for many feet.

- **Esquatzel Silt Loam.** This soil is not found within the 200 Areas Central Plateau, but rather to the south of the 200 West Area. It is mentioned here because it is a possible source for borrow material needed for the Modified RCRA Subtitle C Barrier (D&D-25575, "Silt Borrow Source Field Investigation Report"). It is deep dark-brown soil formed in recent alluvium and is derived from loess and lake sediment. The subsoil grades to dark grayish-brown in many areas, but color and texture of the subsoil are variable because of the stratified nature of the alluvial deposits.

Since the end of the Pleistocene, the main geologic process at the Hanford Site has been wind. After the last Missoula flood drained from the Pasco Basin, winds moved the loose, unconsolidated material until vegetation was able to stabilize it. Stabilized sand dunes cover much of the Pasco Basin, but there are areas, such as along the Hanford Reach National Monument, where active sand dunes remain.

**3.1.4.3 Seismology.** The historic record of earthquakes in the Pacific Northwest dates from about 1840. The early part of this record is based on newspaper reports of human perception of shaking and structural damage as classified using the Modified Mercalli Intensity (MMI) scale; the early record is probably incomplete because the region was sparsely populated. The historical record appears to be complete since 1905 for MMI V and since 1890 for MMI VI ("Earthquake Recurrence Rate Estimates for Eastern Washington and the Hanford Site," CONF-8910192--18 [Rohay 1989]). Seismograph networks did not start providing earthquake locations and magnitudes of earthquakes in the Pacific Northwest until about 1960. A comprehensive network of seismic stations that provides accurate locating information for most earthquakes of magnitude greater than 2.5 on the Richter scale was installed in eastern Washington during 1969. Currently, measured seismic activity for the Hanford Site is reported quarterly and annually (e.g., PNNL-20302, "First Quarter Hanford Seismic Report for Fiscal Year 2011"). Figure 3-23 provides summaries of known events at and around the Hanford Site between 1890 and 2005 (PNNL-6415).

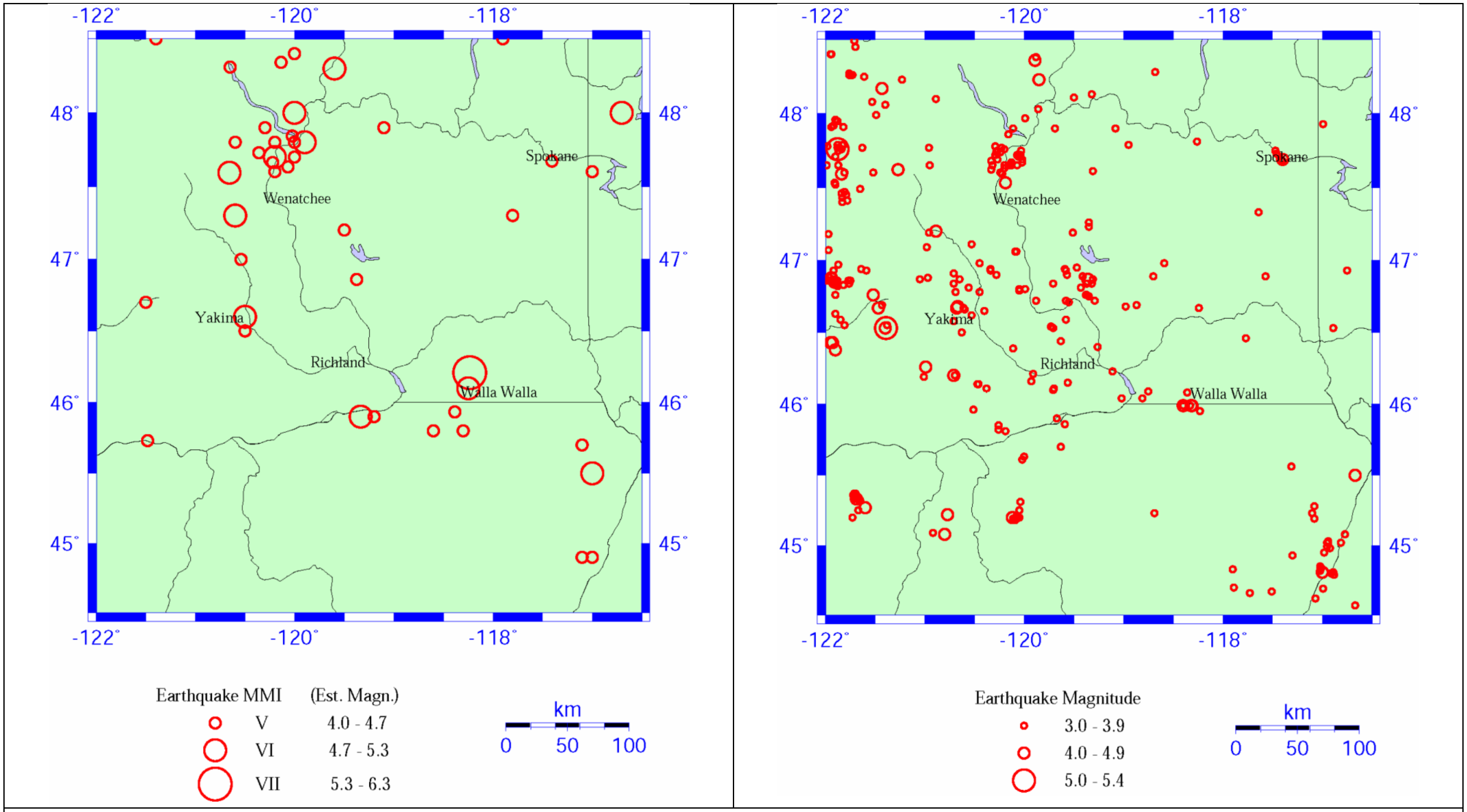
Three horizontal layers of stratigraphy related to seismicity exist at the Hanford Site and vicinity including the CRBG, the pre-basalt sediments, and the crystalline basement. About 75% of Hanford Site earthquake events originate in the CRBG layer. The pre-basalt sedimentary layer has been the origin of 8% of the events, and the crystalline basement has been the origin of 17% of these events (Revision 5-C of RPP-13033, "Tank Farms Documented Safety Analysis").

The most frequent seismic occurrences at the Hanford Site are earthquake swarms (Figure 3-24) that consist of multiple small energy events that fall within a small energy range and are constrained temporally (weeks to months) and spatially (5 to 10 km [3 to 6 mi] in length). Swarms tend to reoccur in particular locations, ~90% of individual earthquakes are at Richter scale magnitudes of 2 or less, and 70% to 80% of them occur at depths less than 4 km (2.5 mi) bgs.

Larger isolated earthquakes also occur nearby (DOE/RW-0164). The largest single event earthquake recorded near the Hanford Site occurred in Milton-Freewater, Oregon, located ~80 km (50 mi) away in 1936 at a Richter magnitude of 5.75 and a maximum MMI of VII. The two next largest nearby earthquakes occurred north of the Hanford Site in 1917 and 1973 near Othello, Washington, ~48 km (30 mi) north of the 200 Areas with magnitudes above 4 on the Richter scale and MMI of V. The 1973 earthquake occurred ~1 km (0.6 mi) bgs. Since 1973, 80 small earthquakes (2.5 to 4.3 magnitudes) have been recorded within a radius of 90 km (56 mi) of the Hanford Site Central Plateau, the closest being a magnitude 3.3 event with the epicenter 8 km (5 mi) north of the 200 Areas. Earthquake depths vary for isolated events and have been estimated as deep as 30 km (~19 mi).

Greater magnitude earthquakes have been recorded at greater distances from the Hanford Site at the edges of the Columbia Plateau, along the coastal subduction zones to the west and in the Rocky Mountains to the east. The Columbia Plateau, which is made up of thick and extensive sequences of flood basalt layers in the Columbia River Group, extends well beyond the Hanford Site covering parts of eastern Washington, eastern Oregon, and Idaho. Notable events in these areas are the 2001 "Nisqually earthquake" in the Puget Sound (6.8 magnitude), an approximate magnitude 6.8 to 7.4 earthquake in north-central Washington in 1872 near Lake Chelan, the 1959 Hebgen Lake earthquake (7.5 magnitude) in western Montana, and the 1983 Borah Peak earthquake in eastern Idaho (7.3 magnitude).

## Figure 3-23. Historical Earthquake Activity of the Columbia Basin, Washington, and Surrounding Areas.

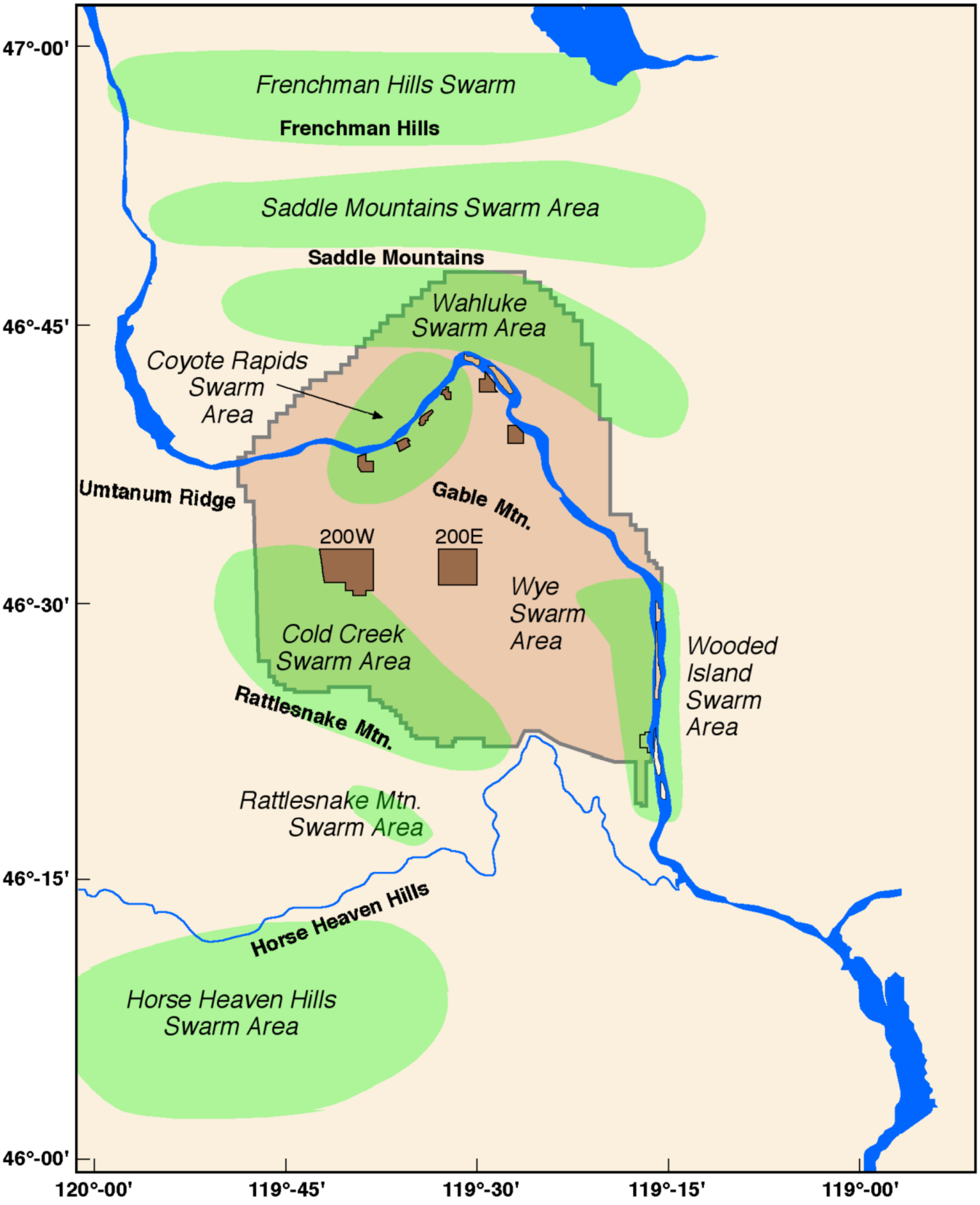


**Left:** *Historical Earthquake Activity of the Columbia Basin, Washington, and Surrounding Areas. All earthquakes between 1890 and 1970 with a Modified Mercalli Intensity (MMI) V or larger and/or a magnitude 4 or larger are shown ("Earthquake Recurrence Rate Estimates for Eastern Washington and the Hanford Site," CONF-8910192--18 [Rohay 1989]).*

**Right:** *Earthquake Activity of the Columbia Basin, Washington, and Surrounding Areas as Measured by Seismographs. All earthquakes between 1970 and 2005 with Richter magnitudes of 3 or larger are shown (Northern California Earthquake Data Center, Queried 09/2005, [Advanced National Seismic System (ANSS) Catalog Search], http://www.quake.geo.berkeley.edu/anss/catalog-search.html).*

Source: PNNL-6415, "Hanford Site National Environmental Policy Act (NEPA) Characterization."

**Figure 3-24. Earthquake Swarm Areas in the Vicinity of the Hanford Site.**



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The gross pattern of seismic activity around the Hanford Site is consistent with our understanding of regional tectonic characteristics of the Northwest. That is, the flood basalts form a large and relatively competent block of rock that is surrounded by numerous complex zones of active faults where large-scale stresses, imposed primarily by the ongoing subduction of the Pacific and Juan de Fuca Plates underneath the North American Plate, are mostly relieved. Consequently, relatively minimal stress relief occurs in the Columbia Plateau and earthquake energy is correspondingly small. This means that potential ground motion that accompanies these earthquakes is also relatively small.

Relative movement is commonly quantified as some fraction of gravitational acceleration (g) and has been usually correlated with earthquake magnitude. For the range of earthquake magnitudes suggested by data summarized above for the Hanford Site (<3 to 6), peak accelerations between <0.0017 and 0.18 g are proposed. The associated range of motion is generally imperceptible compared to clearly felt movement that can result in minimal building damage. A probabilistic seismic hazard analysis (WHC-SD-W236A-TI-002, "Probabilistic Seismic Hazard Analysis, DOE Hanford Site, Washington") estimated that a 0.1 g horizontal acceleration would occur every 500 years and a 0.2 g acceleration would occur every 2,500 years.

**3.1.4.4 Volcanology.** Two types of volcanic hazards have affected the Hanford Site in the past 20 million years. The hazards were (1) continental flood basalt volcanism that produced the CRBG and (2) volcanism associated with the Cascade Range. Several volcanoes in the Cascade Range are currently considered to be active, but activity associated with flood basalt volcanism has ceased.

The flood basalt volcanism that produced the CRBG occurred between 17 and 6 million years ago. Most of the lava was extruded during the first 2 to 2.5 million years of the 11-million-year volcanic episode. Volcanic activity has not recurred during the last 6 million years, suggesting that the tectonic processes that created the episode have ceased. The recurrence of CRBG volcanism is not considered to be a credible volcanic hazard (DOE/RW-0164).

Volcanism in the Cascade Range was active throughout the Pleistocene Epoch and has remained active through the Holocene Epoch. The eruption history of the current Holocene Epoch best characterizes the most likely types of activity in the next 100 years. Many of the volcanoes have been active in the last 10,000 years, including Mount Mazama (Crater Lake) and Mount Hood in Oregon; and Mount Saint Helens, Mount Adams, and Mount Rainier in Washington. The Hanford Site is 150 km (~93 mi) from Mount Adams, 175 km (109 mi) from Mount Rainier, and 200 km (124 mi) from Mount Saint Helens, the three closest active volcanoes. At these distances, the deposition of tephra (ash) is the only potential hazard. Mount Saint Helens has been considerably more active throughout the Holocene Epoch than Mount Rainier or Mount Adams, which is the least active of the three. WHC-SD-GN-ER-30038, "Volcano Ashfall Loads for the Hanford Site," concludes that the Hanford Site is sufficiently distant from the Cascade Range volcanoes that hazards from lava flows, pyroclastic flows and surges, landslides, lahars, and ballistic projectiles are below a probability of concern.

**3.1.4.5 Subsurface Subsidence and Liquefaction.** Field and laboratory studies that have been completed at many of the tank farm sites are summarized in WHC-SD-GN-ER-30009, "Bibliography and Summary of Geotechnical Studies at the Hanford Site." These studies reveal that there are no areas of potential surface or subsurface subsidence, uplift, or collapse at the Hanford Site, with the minor exceptions of the Cold Creek and Wye Barricade depressions, neither of which are close to WMA C. With the exception of the loose superficial wind-deposited silt and sand in some locations, the in-place soils are competent and form good foundations.

Liquefaction is the sudden decrease of shearing resistance of a cohesionless soil, caused by the collapse of the structure by shock or strain, and is associated with a sudden but temporary increase of the pore fluid pressure. Saturated or near-saturated soil (sediments) are required for liquefaction to occur. The average volumetric moisture content at WMA C is less than 10% (see Section 3.1.9.2.2). Therefore, liquefaction of soils beneath the tank farms would not be a credible hazard because the water table is greater than 65 m (213 ft) bgs.

### 3.1.5 Hydrology

This section presents the summary of the hydrology/hydrogeology (water and soil characteristics) of the Hanford Site, focusing on surface water, recharge, characteristics of the unsaturated zone or vadose zone and the saturated zone or groundwater. Due to waste disposal operations at the Hanford Site, the hydrology of the Site has been studied and monitored in detail. Therefore, the information presented in this section will primarily be a summation of previous work highlighting those characteristics that affect the WMA C PA. For additional detail, see the following references.

- PNNL-20548, “Hanford Site Environmental Report for Calendar Year 2010 (Including Some Early 2011 Information)” provides the overview of the characterization and monitoring activities conducted at the Hanford Site during the calendar year.

- DOE/RL-2013-22, Hanford Site Groundwater Monitoring Report for 2012. This document describes the groundwater monitoring activities during the fiscal year.

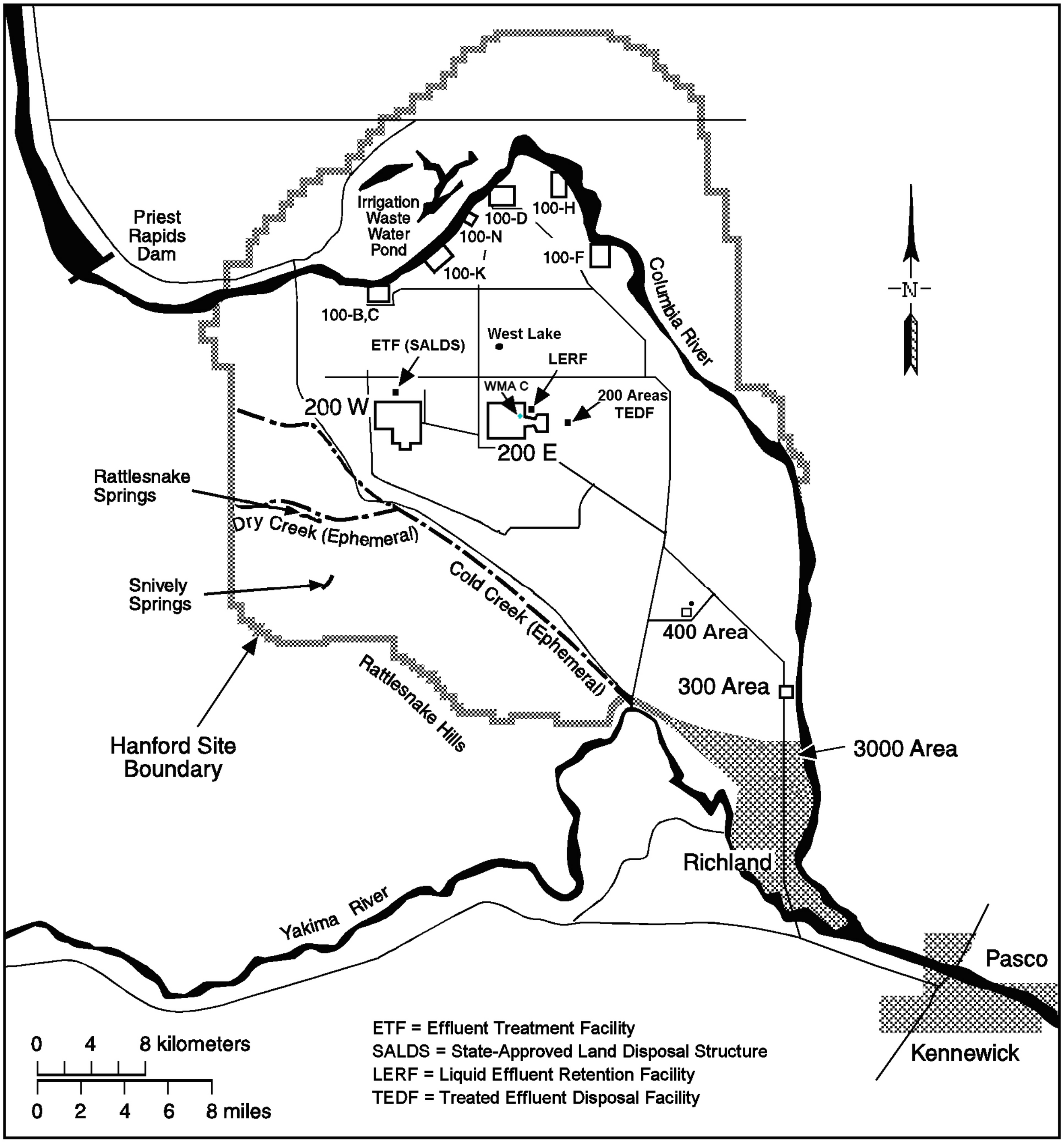
- Revision 18 of PNNL-6415, “Hanford Site National Environmental Policy Act (NEPA) Characterization” provides a standardized description of the Hanford Site environment.

- DOE/ORP-2008-01, RCRA Facility Investigation Report for the Hanford Single-Shell Tank Waste Management Areas. This document describes the Phase 1 vadose zone characterization efforts at the SST farms.

These overview documents will contain references to site-specific documents that describe the hydrology for a particular waste site (e.g., WMA C). A summary of the hydrology for WMA C is given in Section 3.1.9 Waste Management Area C Site Characterization.

**3.1.5.1 Surface Water.** Surface water at the Hanford Site includes the Columbia River, Columbia Riverbank seepage, springs, and ponds. Intermittent surface streams, such as Cold Creek, may also contain water after large precipitation or snowmelt events. In addition, the Yakima River flows along a short section of the southern boundary of the Hanford Site (Figure 3-25), and there is surface water associated with irrigation east and north of the Site.

**Figure 3-25. Surface Water Features including Rivers, Ponds, Major Springs, and Ephemeral Streams on the Hanford Site, Washington.**



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**3.1.5.1.1 Columbia River.** The Columbia River is the second largest river in the contiguous United States in terms of total flow and is the dominant surface-water body on the Hanford Site. The original selection of the Hanford Site for plutonium production and processing was based, in part, on the occurrence of abundant water provided by the Columbia River. The existence of the Hanford Site has precluded development of this section of the river. Waste left at WMA C following closure could impact the Columbia River through the groundwater pathway. Waste Management Area C is located ~11.2 km (7 mi) from the Columbia River.

The Columbia River originates in the mountains of eastern British Columbia, Canada, and drains an area of ~680,000 km$^2$ (262,480 mi$^2$) enroute to the Pacific Ocean. Columbia River flow at the U.S. Geological Survey gauging station, located just west of the Hanford Site boundary (located downstream of Priest Rapids Dam), has been measured during a 90-year period from 1917 to 2007. Daily average flows during this period ranged from 570 to 19,540 m$^3$/s (20,000 to 690,000 ft$^3$/s). The lowest and highest flows occurred before the construction of upstream dams. During the 10-year period from 1997 through 2006, the average flow rate was also ~3,300 m$^3$/s (116,500 ft$^3$/s). The river elevation is ~121 m (396 ft) near the 100 B and C areas and ~105 m (343 ft) at the 300 Area.

The Columbia River flows through the northern part and along the eastern border of the Hanford Site with these areas of the Hanford Site draining into the Columbia River. Except for the Columbia River estuary, the only unimpounded stretch of the river in the United States is the Hanford Reach, which extends from Priest Rapids Dam (located upstream of the Site) downstream ~82 km (51 mi) to the northern upstream extent of Lake Wallula (formed by McNary Dam), which begins above Richland. The Hanford Reach of the Columbia River was recently incorporated into the land area established as the Hanford Reach National Monument.

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 to generate power and promote salmon egg and embryo survival. Several drains and intakes are also present along the Hanford Reach, including irrigation outfalls from the Columbia Basin Irrigation Project, intakes at the Columbia Generating Station operated by Energy Northwest, and Hanford Site intakes for onsite water use.

The State of Washington has promulgated water quality standards for the Columbia River, WAC 173-201A, “Water Quality Standards for Surface Waters of the State of Washington.” The Hanford Reach of the Columbia River has been designated as Class A (Excellent). This designation requires that the water be usable for substantially all needs, including drinking water, recreation, and wildlife. The DOE has conducted routine water-quality monitoring of the Columbia River since 1958.

**3.1.5.1.2 Yakima River.** The Yakima River, which follows a small length of the southwest boundary of the Hanford Site, has much lower flows than the Columbia River. The average flow, based on nearly 72 years of daily flow records (U.S. Geological Survey, Queried 09/2015, [USGS Water Data for the Nation], http://waterdata.usgs.gov/nwis/nwis), is ~100 m$^3$/s (3,530 ft$^3$/s), with an average monthly maximum of ~500 m$^3$/s (17,550 ft$^3$/s), and minimum of 4.7 m$^3$/s (165 ft$^3$/s). The Yakima River System drains surface runoff from approximately one-third of the Hanford Site. Contaminant plumes in groundwater that originate from the Hanford Site do not reach the Yakima River and, because the elevation of the river surface is higher than the adjacent water table (based on well water-level measurements), groundwater is expected to flow from the Yakima River into the aquifer underlying the Site rather than from the aquifer into the river (PNL-10195, "Three-Dimensional Conceptual Model for the Hanford Site Unconfined Aquifer System: FY 1994 Status Report").

**3.1.5.1.3 Springs and Streams.** Springs are found on the slopes of Rattlesnake Hills (Figure 3-25) along the western edge of the Site (DOE/RW-0164). An alkaline spring is located at the east end of Umtanum Ridge ("Biodiversity Inventory and Analysis of the Hanford Site, 1997 Annual Report" [The Nature Conservancy 1998]). Rattlesnake and Snively Springs form small surface streams (Figure 3-25). Water is discharged from Rattlesnake Springs and flows in Dry Creek for ~2.6 km (1.6 mi) before disappearing into the ground. Cold Creek and its tributary, Dry Creek, are ephemeral streams within the Yakima River drainage system in the southwestern portion of the Site. These streams drain areas to the west of the Site and cross the southwestern part of the Site toward the Yakima River. When surface flow occurs, it infiltrates rapidly and disappears into the surface sediments in the western part of the Site. The quality of water in these springs and streams varies depending on the source; they are upgradient of Hanford waste and plumes of contaminated groundwater found on the Hanford Site.

**3.1.5.1.4 Flooding.** Columbia River flow is regulated by three upstream dams in Canada and by seven upstream dams in the United States. The Hanford Reach, ~80 km (50 mi) long, extends from Priest Rapids Dam to just north of the 300 Area. Flow through the Hanford Reach fluctuates significantly and is controlled at Priest Rapids Dam. The three dams with the largest reservoirs upstream from the Hanford Site are the Mica and Hugh Keenleyside Dams in Canada and the Grand Coulee Dam in the United States. The controlled flow of the Columbia River caused by these dams results in a lower flood hazard for high-probability floods (e.g., 100-year floods); however, dam-failure scenarios are significant potential contributors that result in high flood flows.

The probable maximum flood for the Columbia River downstream of Priest Rapids Dam has been calculated to be 40,000 $m^3/s$ (1.4 million $ft^3/s$) (Figure 3-26) and is greater than the 500 year flood. This flood would inundate parts of the 100 Area adjacent to the Columbia River, but the central portion of the Hanford Site would remain unaffected [DOE/RW-0070, Nuclear Waste Policy Act (Section 112), Environmental Assessment, Reference Repository Location, Hanford Site, Washington]. The USACE has derived the Standard Project Flood with both regulated and unregulated peak discharges given for the Columbia River downstream of Priest Rapids Dam ("Water Control Manual for McNary Lock and Dam, Columbia River, Oregon and Washington" [USACE 1989]). The regulated Standard Project Flood for this part of the river is given as 15,200 $m^3/s$ (536,800 $ft^3/s$) and the 100 year regulated flood as 12,400 $m^3/s$ (438,000 $ft^3/s$). Impacts to the Hanford Site are negligible and would be less than the probable maximum flood.

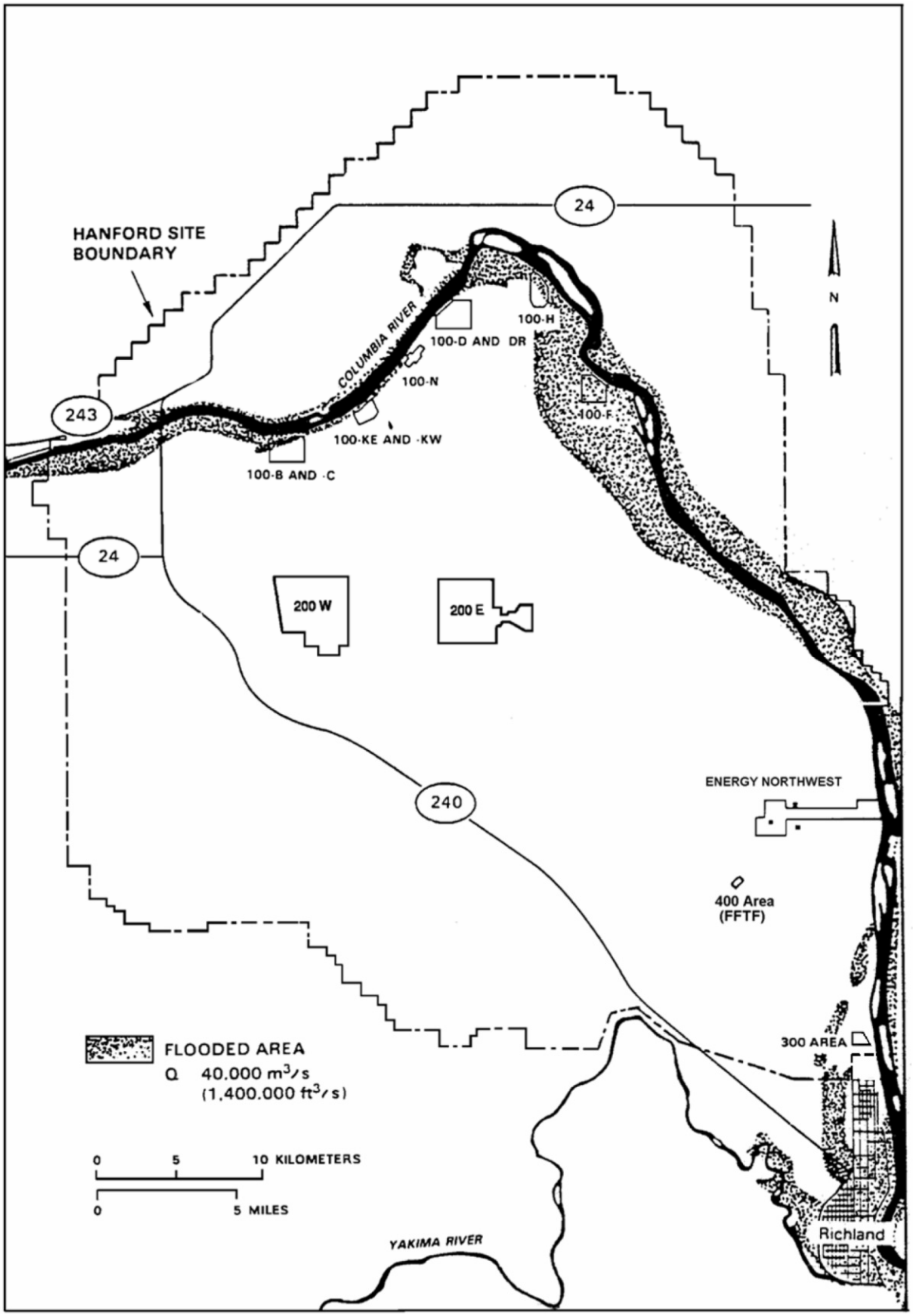
The USACE evaluated a number of scenarios on the effects of failures of Grand Coulee Dam, assuming flow conditions on the order of 11,325 $m^3/s$ (400,000 $ft^3/s$). The discharge resulting from a 50% breach at the outfall of Grand Coulee Dam was determined to be 595,000 $m^3/s$ (21 million $ft^3/s$). In addition to the areas inundated by the probable maximum flood, the remainder of the 100 Area, the 300 Area, and nearly all of Richland would be flooded (DOE/RW-0070) as shown in Figure 3-26. No determinations were made for breaches greater than 50% of Grand Coulee Dam, for failures of dams upstream, or for associated failures downstream of Grand Coulee. Based on a 1951 USACE study (USACE 1951, "Artificial Flood Possibilities on the Columbia River"), the 50% breach scenario was believed to represent the largest realistically conceivable flow resulting from either a natural or human-induced breach (DOE/RW-0070). It was also assumed that a scenario such as the 50% breach would occur only as the result of direct explosive detonation, and not because of a natural event such as an earthquake, and that even a 50% breach under these conditions would indicate an emergency situation in which there might be other overriding major concerns.

A flood scenario of a 50% breach of Grand Coulee Dam results in a flood level of ~143.3 m (470 ft) above mean sea level at Columbia River mile 365; this low point is the closest flood route to the 200 Areas Plateau. River mile 365 is ~45.7 m (150 ft) below the ground surface of the lowest elevation tank farm. The 50% breach of the Grand Coulee Dam would not impact the 200 East and 200 West areas or the land within the 600 Area (i.e., between the 200 East and 200 West areas) occupied by tank farm facilities. Therefore, this scenario bounds all other Columbia River flood scenarios. UCRL-21069, "Probabilistic Flood Hazard Assessment for the N Reactor, Hanford, Washington" provides a detailed hazard assessment of other flood scenarios.

The Yakima River is ~19.3 km (12 mi) south of and greater than 61 m (200 ft) in elevation below the 200 East and 200 West areas. The Yakima River is not a flood hazard for the tank farm facilities. During 1980, a flood risk analysis of Cold Creek was conducted as part of the characterization of a basaltic geologic repository for high-level radioactive waste. In lieu of 100- and 500-year floodplain studies, a probable maximum flood evaluation was performed based on a large rainfall or combined rainfall/snowmelt event in the Cold Creek and Dry Creek watershed (RHO-BWI-C-120/PNL-4219, "Flood Risk Analysis of Cold Creek near the Hanford Site") (Figure 3-27). The probable maximum flood discharge rate for the lower Cold Creek Valley was 2,265 $m^3$/s (80,000 $ft^3$/s) compared to 564 $m^3$/s (19,900 $ft^3$/s) for the 100 year flood. Modeling indicated that State Route 240, along the Hanford Site's southwestern and western areas, would not be usable. Based on this information, flooding of WMA C would not be a credible scenario.

**3.1.5.1.5 Columbia Riverbank Springs**. During the early 1980s, researchers identified 115 springs along the Benton County shoreline of the Hanford Reach (PNL-5289, "Investigation of Ground-Water Seepage from the Hanford Shoreline of the Columbia River"). Seepage occurs both below the river surface and on the exposed riverbank, particularly at low river stage. Riverbank springs flow intermittently, apparently influenced primarily by changes in river level. In many areas, water flows from the river into the aquifer at high river stage and then returns to the river at low river stage. This "bank storage" phenomenon has been modeled numerically for the 100 H Area (PNNL-13674, "Zone of Interaction Between Hanford Site Groundwater and Adjacent Columbia River: Progress Report for the Groundwater/River Interface Task Science and Technology Groundwater/Vadose Zone Integration Project"). In areas of contaminated groundwater, riverbank springs are also generally contaminated. The concentrations in seeping water along the riverbank may be lower than groundwater; however, the mixing between river water and the contaminated aquifer contributed to the fluctuating bank storage phenomenon.

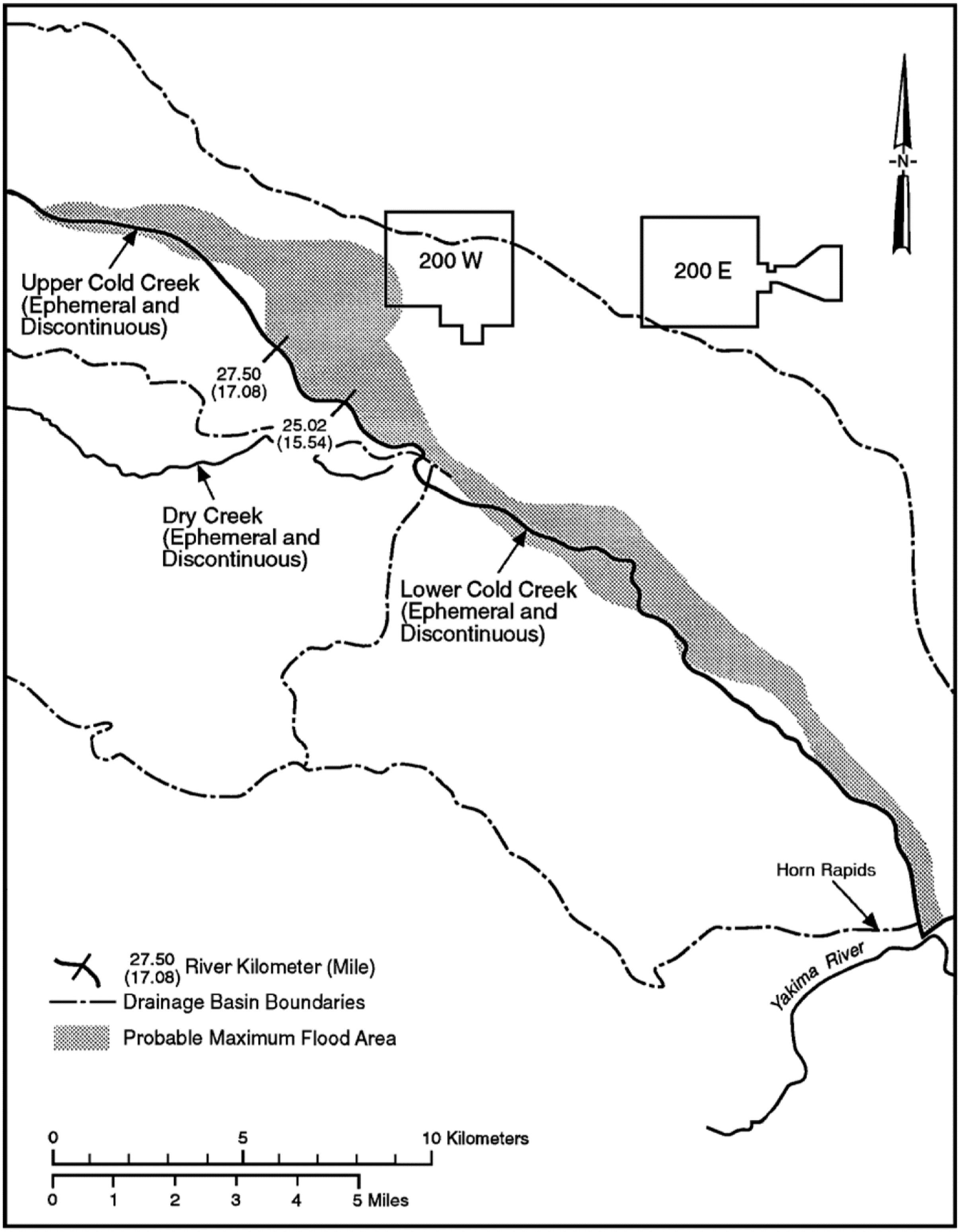
**Figure 3-26. Flood Area for the Probable Maximum Flood on the Hanford Site, Washington, as Determined by the Upper Limit of Precipitation and Maximum Runoff.**



Reference: DOE/RW-0070, Nuclear Waste Policy Act (Section 112), Environmental Assessment, Reference Repository Location, Hanford Site, Washington.

FFTF = Fast Flux Test Facility

**Figure 3-27. Extent of Probable Maximum Flood in Cold Creek Area, Hanford Site, Washington, delineated using the U.S. Army Corps of Engineers' HEC-2 Water Surface Profiles Model.**



Reference: RHO-BWI-C-120/PNL-4219, "Flood Risk Analysis of Cold Creek near the Hanford Site."

Contamination historically has been detected in near-shore samples downstream from riverbank springs (PNNL-20548). Riverbank springs are monitored for radionuclides at each of the 100 Areas, the Hanford town site, and the 300 Area. Detected radionuclides include $^{90}$Sr, $^{99}$Tc, $^{129}$I, $^{234}$U, $^{235}$U, and $^{238}$U, and tritium, as well as arsenic, chromium, chloride, fluoride, nitrate, and sulfate. Metals and anions (chloride, fluoride, nitrate, and sulfate) were detected in spring water from samples collected in 2005. Concentrations of volatile organic compounds were near or below their detection limits in all samples. Trichloroethylene was detected (1.4 µg/L [0.19 oz/gal]) in one sample from the 300 Area and was the only analyte detected at all shoreline spring sampling locations. Trichloroethylene has been consistently detected at low concentrations in the 300 Area shoreline spring water (PNNL-20548).

**3.1.5.1.6 Non-Riverine Surface Water.** The occurrence of non-riverine surface water on the Hanford Site is shown in Figure 3-25. These surface water bodies include West Lake and the 200 Areas Treated Effluent Disposal Facility (TEDF) disposal ponds (see next section). West Lake is located north of the 200 East Area and 5 km (3 mi) north-northwest of WMA C, and is a natural feature recharged from groundwater (ARH-CD-775, "Geohydrologic Study of the West Lake Basin"; PNL-7662, "An Evaluation of the Chemical, Radiological, and Ecological Conditions of West Lake on the Hanford Site"). West Lake is the only natural pond at the Hanford Site. West Lake has not received direct effluent discharges from Site facilities; rather, its existence is caused by the intersection of the elevated water table with the land surface in the topographically low area. Water levels of West Lake fluctuate with water table elevation, which is influenced by wastewater discharges in the 200 Areas. The water level and size of the lake has been decreasing over the past several years because of reduced wastewater discharge.

Several naturally-occurring vernal ponds, which are not depicted on Figure 3-25, are located near Gable Mountain and Gable Butte (The Nature Conservancy 1998). The formation of these ponds in any particular year depends on the amount and temporal distribution of precipitation and snowmelt events. The vernal ponds range in size from ~6.1 m by 6.1 m to 45.73 m by 30.5 m (20 ft by 20 ft to 150 ft by 100 ft), and were found in three clusters. Approximately ten were documented at the eastern end of Umtanum Ridge, seven were observed in the central part of Gable Butte, and three were found at the eastern end of Gable Mountain.

**3.1.5.1.7 Disposal Ponds.** The TEDF in the 200 Areas consists of two disposal ponds. These ponds are each 0.02 km$^2$ (0.008 mi$^2$) in size and receive industrial wastewater permitted in accordance with WAC 173-216, "State Waste Discharge Permit Program." The wastewater percolates into the ground from the disposal ponds. Current disposal ponds (i.e., 200 Area TEDF) have an artificial influence on net contributions to the water table. Since these ponds are located between the WMAs and the Columbia River, they could impact the groundwater flow path. However, the disposal activities within the 200 Areas are not expected to exist after current operations end, so their long-term influence is not considered in this WMA C PA.

Historical Site activities discharged contaminated effluent to liquid waste sites, which caused the groundwater table to rise on the Central Plateau (DOE/RL-2001-54, Central Plateau Ecological Evaluation) creating artificial ponds and wetlands. In 1995, these management practices ceased, eliminating all man-made wetlands, with the exception of a small wetland identified in the 200 East Area during the 2001 Ecological Compliance Assessment Program survey.

**3.1.5.2 Recharge.** Two types of recharge, natural and anthropogenic, occur at the Hanford Site. Natural recharge occurs as the result of the process of water from rain, snow, and other sources moving downward through the soil and reaching the top of the groundwater aquifer. Anthropogenic recharge occurs as a result of water and/or liquids applied to the surface and/or subsurface by human activities. Examples of anthropogenic recharge would include intentional releases of waters and/or wastes into ponds, ditches, and/or cribs; the uncontrolled release of water from testing of fire hydrants; the use of water to wash down, excavate, and/or decontaminate equipment or facilities; the collection of water in low-lying areas with improper drainage control (i.e., ponding of snow melt or precipitation in tank farm areas); water recharge down man-made preferential pathways (i.e., unsealed wells or boreholes); or the unintentional or unplanned loss of waters and/or waste fluids or liquids from tanks and/or water and waste transfer pipelines.

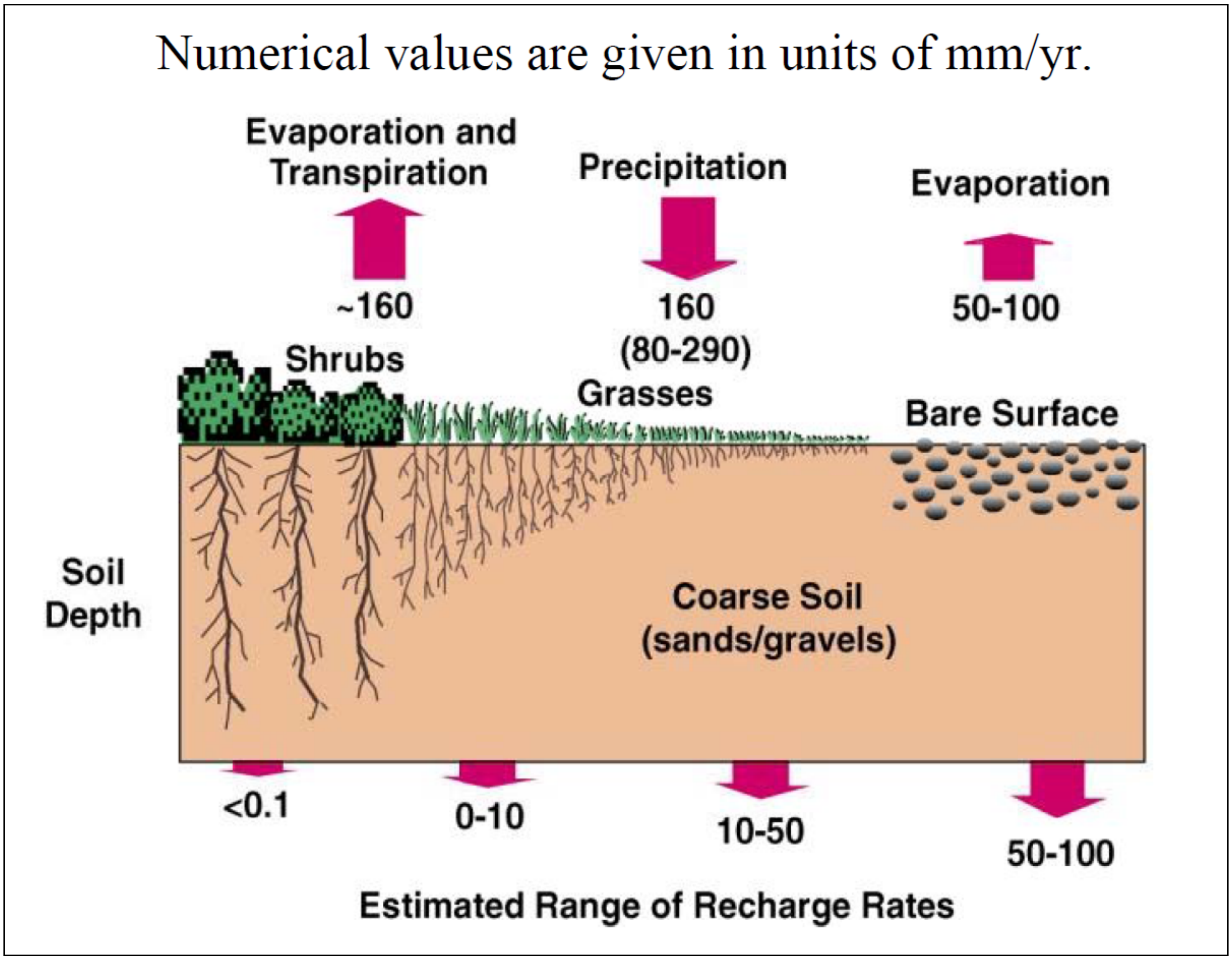
**3.1.5.2.1 Runoff.** Total estimated precipitation over the Pasco Basin is ~$9 \times 10^8$ $m^3$ (~$3.2 \times 10^{10}$ $ft^3$) annually (DOE/RW-0164). This was calculated by multiplying the average annual precipitation averaged over the Pasco Basin by the 4,900 $km^2$ (1,900 $mi^2$) basin area. Precipitation varies both spatially and temporally with higher amounts generally falling at higher elevations. As noted in Section 3.1.2.3, annual precipitation measured at the HMS has varied from 6.8 to 31.3 cm (2.7 to 12.3 in.) since 1947. Most precipitation occurs during the late autumn and winter, with more than half of the annual amount occurring from November through February. Mean annual runoff from the Pasco Basin is estimated at $<3.1 \times 10^7$ $m^3$/yr ($<1.1 \times 10^9$ $ft^3$/yr), or ~3% of the total precipitation (DOE/RW-0164). Most of the remaining precipitation is lost through evapotranspiration. However, some precipitation that infiltrates the soil is not lost to evaporation or transpiration and eventually recharges the groundwater flow system.

**3.1.5.2.2 Natural Recharge.** The recharge rate at a specific location is determined by the soil, plant, and weather conditions that control the water balance at that location. The water balance describes the storage and movement of water in and out of the soil, which is the upper part of the unsaturated zone that experiences soil-forming processes and encompasses the evaporation and plant root zone. Water arrives at the soil surface in the form of precipitation, either as rain or snow. Plant water uptake and evaporation, both of which are influenced by weather conditions, remove water stored in the soil and return it to the atmosphere. Deep drainage is the movement of stored water downward below the root zone. Once water is below the root zone, gravity continues to draw the water downward until it eventually recharges the water table.

“Variations in Recharge at the Hanford Site” (Gee et al. 1992) and “Estimating Recharge Rates for a Groundwater Model Using a GIS” (Fayer et al. 1996) estimate that recharge rates from precipitation across the Hanford Site range from near zero to over 100 mm/year (3.94 in./yr). Recharge is variable both spatially and temporally. It is greatest in areas where coarse-textured soils bare of deep-rooted vegetation exist and in years with rapid snowmelt events and precipitation during cool months. The magnitude of recharge at a particular location is influenced by five main factors: climate, soils, vegetation, topography, and springs and streams. Events such as the fire that burned vegetation from a large portion of the Hanford Site during the summer of 2000 also affect recharge rates. Fayer et al. (1996) used several types of field data and computer modeling to estimate the areal distribution of mean recharge rates for the soil and vegetation conditions at the Hanford Site, including any disturbance by Hanford Site operations.

Figure 3-28 shows how the recharge rate is affected by both the presence and type of plants. Shrubs with deep root systems tend to produce lower recharge rates because the deep roots can access a greater volume of soil and thus more stored water. In contrast, grasses with shallow root systems tend to produce higher recharge rates because the roots can access only a smaller volume of soil (and, thus, less stored water). In addition to rooting depth differences, shrubs tend to be active for a much greater portion of the year than grasses. Having a longer period of activity gives the shrubs a greater likelihood of finding and extracting soil water. Without any plants, water is removed only via evaporation from the soil surface. Annual changes in weather and plant activity ensure that recharge is never absolutely constant. However, the impacts from annual plant and weather changes on recharge are muted when recharge is measured below the root zone and averaged over decades. The result is a recharge rate that appears to be fairly constant.

**Figure 3-28. Recharge Dependence on Surface Conditions.**



Measurements of recharge on the Hanford Site for over 20 years for a variety of precipitation rates, soil, and vegetation conditions, including conditions representative of evapotranspiration barrier, have been made at the Field Lysimeter Test Facility (FLTF) (PNNL-16688, “Recharge Data Package for Hanford Single-Shell Tank Waste Management Areas”). The site is located close to the 200 West Area eastern fence and within a few hundred of the HMS. Figure 3-29 is a cut-away drawing of a key lysimeter facility in operation at the Hanford Site. The FLTF contains 18 large lysimeters (surface areas of 2.3 and 3.1 $m^2$ [24.8 and 33.4 $ft^2$]; depth from 1.5 to 3.0 m [4.9 to 9.8 ft]) and 6 smaller lysimeters (surface area is 0.07 $m^2$ [0.75 $ft^2$]; depth 3.0 m [9.8 ft]).

Treatments include variations of material types and thicknesses, the presence of vegetation, and the use of irrigation to mimic the increased precipitation of a possible future climate. Data from this facility include drainage, water content, matric potential, temperature, and vegetation observations. Challenges for the measurement technique include impacts on recharge (the act of measuring can affect the measurement), difficulty of replicating natural soil conditions in a container, cost of establishing measurement facilities, and length of time needed to gather enough data to get a reasonable estimate of the recharge rate.

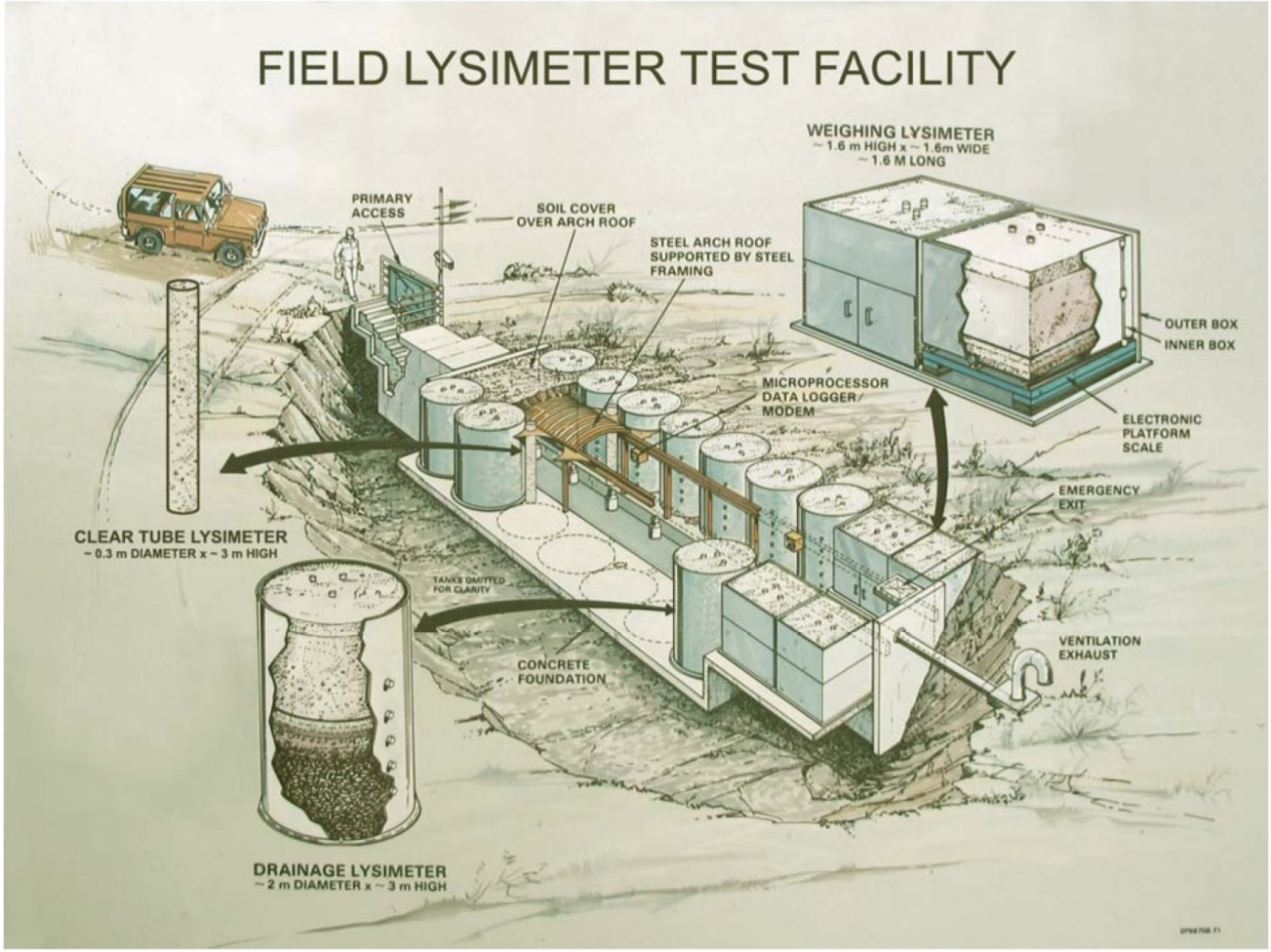
**3.1.5.2.3 Anthropogenic Recharge.** Over and above natural recharge, human activities within the tank farms can provide additional recharge. This occurs because of manmade sources (e.g., leaking waterlines, waste lines, or tanks, testing of fire hydrants, excavation with water), preferential pathways (unsealed abandoned wells or poorly capped boreholes), and improper drainage control (ponding of precipitation at tank farms). Figure 3-30 provides examples of a number of these conditions.

The amount of anthropogenic recharge due to pipeline leaks and improper drainage is extremely difficult to quantify. For example, if a waterline developed a small leak on the order of a quart per minute, this would lead to an additional volume of ~49,000 L (~130,000 gal) released per year. That is equivalent to increasing the natural recharge over the ~3.24-hectare (8-acre) WMA C by 15%. Additionally, the records do not indicate when and how much water was applied during operations [Figure 3-30(d)] or how often ponding occurred on WMA C [Figure 3-30(e)]. Scoping calculations examining the potential effects of anthropogenic recharge on the release and transport of contaminants in past tank waste leaks and losses from WMA C facilities are evaluated and described in RPP-RPT-59197, "Analysis of Past Tank Waste Leaks and Losses in the Vicinity of Waste Management Area C at the Hanford Site, Southeast Washington."

However, for future conditions, anthropogenic recharge is not expected to be a factor in release from the WMAs because in the late 1990s and early 2000s two major efforts took place to eliminate anthropogenic recharge within Hanford's SST System. The first effort was interim stabilization of the SSTs by removing pumpable liquids from the SSTs to mitigate potential future leaks from them. Furthermore, these tanks will be filled with grout prior to the placement of a recharge barrier. The second effort was to apply interim measures to reduce/stop additional recharge in the tank farms. Surface water controls have been constructed to reduce surface water run-on from major meteorological events and from breaks in waterlines. Also, waterlines that were determined unnecessary have been isolated, cut, and capped. Waterlines that were found to be necessary for continued operations have been leak tested and any lines found to be leaking were replaced (DOE/ORP-2008-01). Once retrieval operations cease, the remaining waterlines are expected to be taken out of service.

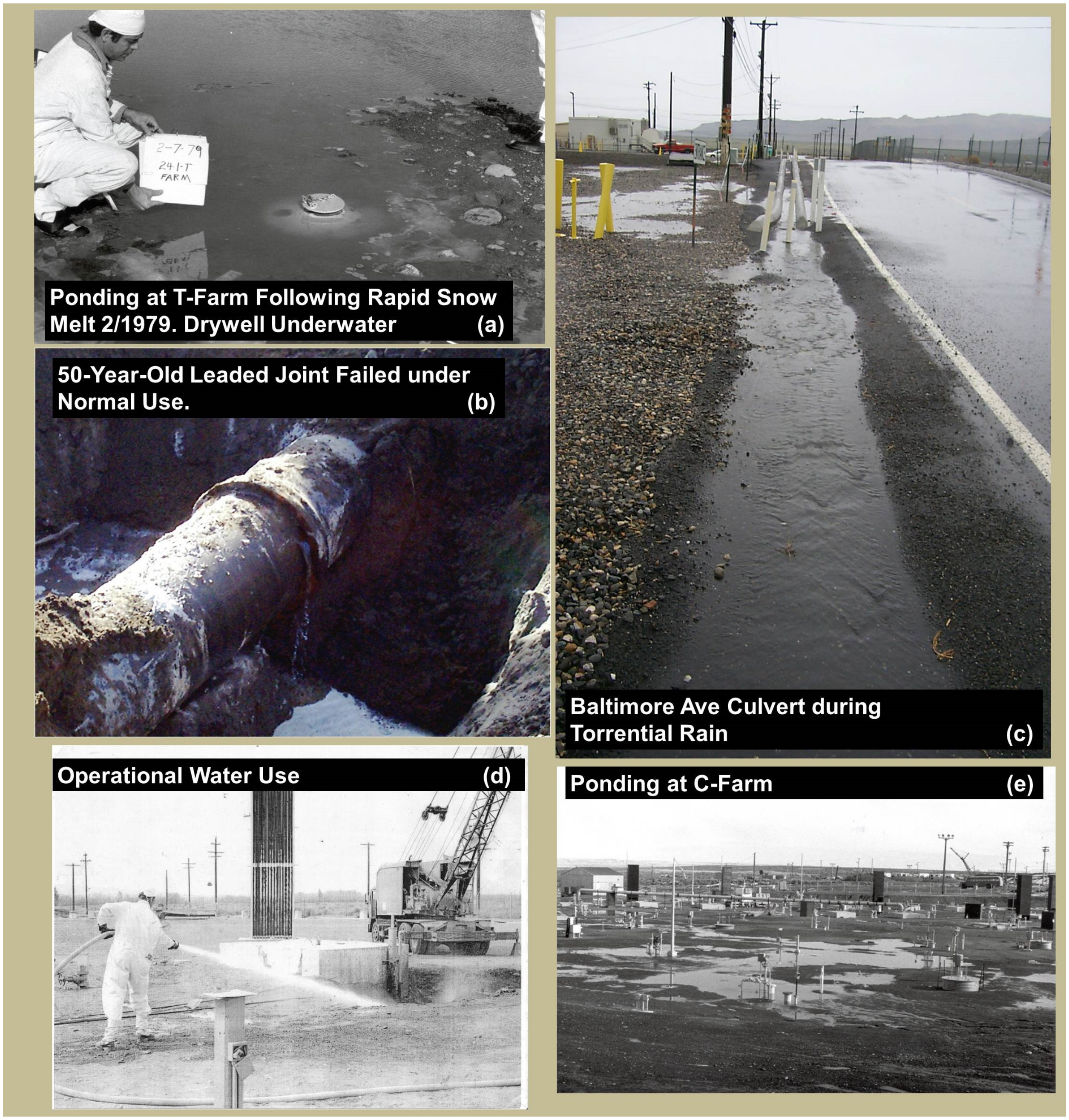
**Figure 3-29. Recharge Dependence on Surface Conditions.**

Data collection at the FLTF began in November 1987. Three separate lysimeter designs are included in the facility.



FLTF = Field Lysimeter Test Facility

**Figure 3-30. Examples of Anthropogenic Recharge in the 200 Area. (Photographs a – c are from DOE/ORP-2008-01 Appendix K, Photographs d and e are Archive Photos).**



Reference: DOE/ORP-2008-01, RCRA Facility Investigation Report for Hanford Single-Shell Tank Waste Management Areas.

**3.1.5.3 Vadose Zone.** The vadose zone is that part of the geologic media which extends from the earth's surface to the water table. At the Hanford Site, the thickness of the vadose zone ranges from 0 m (0 ft) near the Columbia River to greater than 100 m (328 ft) under parts of the Central Plateau (PNNL-13080, "Hanford Site Groundwater Monitoring: Setting, Sources, and Methods"). Unconsolidated glacio-fluvial sands and gravels of the Hanford formation make up most of the vadose zone (Figure 3-17). In some areas, such as most of the 200 West Area and in some of the 100 Areas, the fluvial-lacustrine sediments of the Ringold Formation make up the lower part of the vadose zone. The CCU also makes up part of the vadose zone. The integrated knowledge obtained from previous and ongoing studies provides a good conceptual understanding of the geologic, hydraulic, and geochemical environment and its controls on the distribution and movement of contaminants within the vadose zone (PNNL-14702, "Vadose Zone Hydrogeology Data Package for Hanford Assessments"). Figure 3-19 provides a fence diagram of sediment overlying the Columbia River Basalt Group in the Central Plateau. In the 200 East Area around WMA C, the undifferentiated low Hanford gravels (H3), CCU, Ringold formation would replace the CCU and upper Ringold and Ringold E shown in this figure.

The primary features relevant to the vadose zone flow and transport include the hydrogeologic materials (and their physical, hydraulic, and geochemical properties), subsurface conditions (e.g., fluid statics and thermal conditions), and fluid properties. Other features relevant to the vadose zone conceptual model, such as climate and weather statistics, terrestrial ecology, and projected land use were given in the previous sections.

**3.1.5.3.1 Hydrostratigraphy.** The vadose zone stratigraphy influences the movement of liquid through the soil column. The vadose zone beneath the 200 East Area can be subdivided into six principal hydrostratigraphic units (HSUs), including three units within the Hanford formation, a fluvial gravel facies of the CCU (equivalent to the Pre-Missoula Gravels of "Appendix 2R - Stratigraphic Investigation of the Skagit/Hanford Nuclear Project," in Skagit/Hanford Nuclear Project, Preliminary Safety Analysis Report [Webster and Crosby 1982] and WHC-SD-ER-TI-003, "Geology and Hydrology of the Hanford Site: A Standardized Text for Use in Westinghouse Hanford Company Documents and Reports"), and two units belonging to the Ringold Formation (WHC-SD-EN-TI-012, "Geologic Setting of the 200 East Area: An Update"; WHC-SD-EN-TI-019, "Hydrogeologic Model for the 200 East Groundwater Aggregate Area"; PNNL-12261, "Revised Hydrogeology for the Suprabasalt Aquifer System, 200-East Area and Vicinity, Hanford Site, Washington"; DOE/RL-2002-39).

The Hanford formation units include (1) an upper gravel-dominated facies, (2) a sand-dominated facies, and (3) a lower gravel-dominated facies. Over most of the 200 East Area, the Hanford sand-dominated facies lies between the upper and lower gravel-dominated facies (WHC-SD-EN-TI-012, WHC-SD-EN-TI-019, DOE/RL-2002-39). Based on borehole samples, the upper and lower gravel-dominated facies appear to have similar physical and chemical properties. The Ringold Formation in the 200 East Area is, for the most part, eroded away in the northern half of the 200 East Area. Here, the Hanford formation lies directly on top of basalt bedrock. With the dropping water table, basalt crops out above the water table and, thus, is unsaturated beneath the northeastern portion of the 200 East Area. Underneath WMA C, the top of the unconfined aquifer lies within a unit composed of undifferentiated gravels from the lower Hanford formation gravels (H3), the CCU, and the Ringold formation.

The vadose zone stratigraphy influences the potential for spreading of liquid within the soil column. Where conditions are favorable, lateral spreading of liquid effluent and/or local perched water zones may develop. Lateral spreading can occur along any strata with contrasting hydraulic conductivity. Where low-permeability layers within the Hanford formation have been documented, they are thin (0.5 m [1.6 ft] or less) and laterally discontinuous. Low-permeability layers within the sand-dominated facies of the Hanford formation are generally thicker and more continuous than those in the gravel-dominated facies. Some paleosols and facies changes (i.e., the contact between fine-grained and coarser-grained facies) may be fairly continuous over the range of 100 m (328 ft) or so, with some lateral spreading of crib effluent noted on that same scale. Lateral spreading can delay the arrival of contaminants at the water table but may cause mixing of the subsurface plume at one site with that of an adjacent site. Spreading may also require increasing the area of surface barriers to cover wider plumes.

Clastic dikes have also been observed in the Hanford formation beneath the 200 East Area. Their most important feature is their potential to either enhance or inhibit vertical and lateral movement of contaminants in the subsurface, depending on textural relationships (BHI-01103). For example, the vertically-oriented clay skins within clastic dikes may locally form an impediment to lateral flow. This could then cause ponding (perching) of the water and eventual breakthrough to underlying strata.

Sublinear channel-cut scour and fill features occur within the Hanford formation and may act as preferential pathways in the horizontal direction. Other types of heterogeneity are associated with stratigraphic pinch-out or offlapping/onlapping of facies.

**3.1.5.3.2 Hydraulic and Transport Properties.** Accurate predictions of flow and transport in the vadose zone require a detailed characterization of the hydrologic properties and their variability, as well as estimates of transport parameters such as dispersivity. In particular, data that are essential for quantifying the water storage and flow properties of unsaturated soil include the soil moisture characteristics (i.e., soil moisture content versus pressure head, and unsaturated hydraulic conductivity versus pressure head relations) for sediment in various geologic units.

Data on particle-size distribution, moisture retention, and saturated hydraulic conductivity ($K_s$) have been cataloged for over 284 samples from throughout the Hanford Site, including 12 locations in the 200 East and West Areas (WHC-EP-0883, “Variability and Scaling of Hydraulic Properties for 200 Area Soils, Hanford Site”; “Evaluation of van Genuchten-Mualem Relationships to Estimate Unsaturated Hydraulic Conductivity at Low Water Contents” [Khaleel et al. 1995]; “Correcting Laboratory-Measured Moisture Retention Data for Gravels” [Khaleel and Relyea 1997]; PNNL-13672, “A Catalog of Vadose Zone Hydraulic Properties for the Hanford Site”; WMP-17524, “Vadose Zone Hydraulic Property Letter Reports”; and “On the Hydraulic Properties of Coarse-Textured Sediments at Intermediate Water Contents” [Khaleel and Heller 2003]). Laboratory analyses of the hydraulic properties of samples collected at Hanford have been performed at a number of different laboratories using techniques similar to those described by Methods of Soil Analysis, Part 1—Physical and Mineralogical Methods (Klute 1986).

Macrodispersivity estimates for non-reactive species have been estimated using the “Three-dimensional stochastic analysis of macrodispersion in aquifers” (Gelhar and Axness 1983) equation where the longitudinal macrodispersivity depends on the mean pressure head. HNF-4769, “Far-Field Hydrology Data Package for Immobilized Low-Activity Tank Waste Performance Assessment” estimated a longitudinal macrodispersivity of ~1 m (~3 ft) for the sand-dominated facies of the Hanford formation in the 200 East Area. The transverse dispersivities have been estimated as one tenth of the longitudinal values ("A Critical Review of Data on Field-Scale Dispersion in Aquifers" [Gelhar et al. 1992]). Based on a survey of literature, Stochastic Subsurface Hydrology (Gelhar 1993) examined the longitudinal vadose zone dispersivities as a function of the scale of the experiment, and found an increase of dispersivity with an increase in scale.

**3.1.5.3.3 Vadose Zone Contamination.** The Hanford Site has more than 800 past-practice liquid-disposal facilities. Mixed radioactive liquid waste was discharged to the vadose zone through reverse (injection) wells, French drains, cribs, ponds, trenches, and ditches. From 1944 through the late 1980s, 1.5 to 1.7 billion $m^3$ (396 to 449 billion gal) of effluent were disposed to the soils (PNNL-SA-32152, "A Short History of Plutonium Production and Nuclear Waste Generation, Storage, and Release at the Hanford Site"). Most effluent was released in the 200 Areas. The largest groundwater contaminant plumes emanating from the 200 Areas are those of tritium and nitrate. The major source for both was discharges from chemical processing of irradiated nuclear fuel rods.

Also present are $^{99}$Tc and $^{129}$I that, like tritium and nitrate, are mobile in both the vadose zone and groundwater. The major sources of $^{99}$Tc and $^{129}$I were discharges to liquid disposal facilities. Vadose zone sources for these contaminants remain beneath many past-practice disposal facilities. However, other than physical sampling and laboratory analysis, few direct ways exist to monitor tritium, nitrate, $^{99}$Tc, and $^{129}$I in the vadose zone.

Approximately 280 UPRs in the 200 Areas also contributed contaminants to the vadose zone (DOE/RL-96-81, Waste Site Grouping for 200 Areas Soil Investigations). Many of these were associated with tank farm operations, and have contributed significant contamination to the vadose zone. Over the past 15 years, a significant effort has been implemented to better understand and quantify vadose zone contamination in and around the WMAs. These investigations have focused on developing a better understanding of major releases and of the potential impacts on groundwater quality. These efforts have integrated information from a number of different DOE and Hanford Site projects and have focused on evaluating the past release events that contribute the bulk of subsurface contamination.

The information sources used for the SST WMA-level vadose zone investigations included baseline spectral gamma logging of the ~750 shallow monitoring boreholes (referred to as drywells) within each of the seven WMAs, as well as assessments of the historical gross gamma logging data from each WMA. "Gross gamma logging" refers to logs in which gamma activity is measured without regard to energy level. The gross gamma log simply reports the total gamma activity as a function of depth. Drywell gross gamma logging data were used as part of the tank farm leak detection program until 1994. "Spectral gamma logging" refers to logs in which energy spectra are collected in the borehole. In a spectral gamma log, individual gamma photons are counted as a function of energy level. This allows radionuclides to be identified and quantified on the basis of gamma activity at specific energy levels. From 1995 to 2000, spectral gamma logging was performed in the existing drywell network to develop a baseline understanding of subsurface contamination conditions in each of the SST WMAs. Results of the baseline spectral gamma logging project are summarized in a series of 12 reports (one for each SST farm). In 2000, DOE/RL-99-36, Phase 1 RCRA Facility Investigation/Corrective Measures

Study Work Plan for Single-Shell Tank Waste Management Areas was issued to collect vadose zone characterization data in the single-shell WMAs, and characterization data related to this work plan was collected from 2000 to 2008.

Vadose zone characterization efforts have included drilling, sampling, and soil analysis in multiple SST WMAs, coupled with review of historical process records and gamma logging data. The information collected during this time is provided in DOE/ORP-2008-01. Since the issuance of this report, a Phase 2 vadose characterization program was initiated at WMA C to collect additional vadose zone data (RPP-PLAN-39114). The results of the vadose zone sampling at WMA C are documented in RPP-RPT-58339.

In 2007, a process was started (RPP-32681, "Process to Assess Tank Farm Leaks in Support of Retrieval and Closure Planning") to re-assess SST leak volumes based on a synthesis of available information, including vadose zone borehole drilling and sampling data from DOE/ORP-2008-01, gamma-ray logging data, and historical information. In Table 3-3 of HNF-EP-0182, "Waste Tank Summary Report for Month Ending August 31, 2005," Rev. 209, 67 tanks were classified as "confirmed or suspected" of having leaked contaminated liquid to the vadose zone. These classifications were assigned based largely on data and priorities from the period of tank farm operations. As a result of the re-assessment process, the most recent "Waste Tank Summary Report for Month Ending May 31, 2014" (HNF-EP-0182, Rev. 317, Table 3-2) has 64 tanks classified "confirmed or suspected" of having leaked. The re-assessment has added one new tank to the list (C-105) and removed five tanks (241-A-103, C-110, C-111, 241-SX-104, 241-SX-110) from the list. Vadose zone inventory estimates based on the revised leak volumes are being developed. Presently, inventory estimates are available for WMA C (RPP-RPT-42294, "Hanford Waste Management Area C Soil Contamination Inventory Estimates," Rev. 2), 241-B Tank Farm (RPP-RPT-49089, "Hanford B-Farm Leak Inventory Assessments Report"), WMA U (RPP-RPT-50097, "Hanford 241-U Farm Leak Inventory Assessment Report"), 241-TX Tank Farm (RPP-RPT-50870, "Hanford 241-TX Farm Leak Inventory Assessment Report"), and WMA T (RPP-RPT-55084, "Hanford 241-T Farm Leak Inventory Assessment Report"). Uncertainties in leak volume estimates are addressed as part of the inventory estimates.

**3.1.5.4 Groundwater.** This section describes the relevant characteristics of the groundwater hydrology, which has been studied and monitored in detail because of the waste disposal operations at the site. The hydrology characteristics of the Hanford Site are important to the definition of potential pathways for the WMA C contaminants to the public and the estimation of the magnitudes of the environmental impacts. Evaluating this pathway requires information about the types of aquifers, depth to the water table, and regional flow paths toward surface water discharge points. Surface water flow represents an exposure pathway for both human health and the environment.

The discussion focuses on the geohydrology of the 200 Areas but also includes information on the Hanford Site in general, highlighting those aspects that were important to the modeling of the post-closure system performance. This information was summarized largely from material presented in PNNL-6415, DOE/RL-2014-32, Hanford Site Groundwater Monitoring Report for 2013 and PNNL-20548, as follows.

- "Hanford Site Environmental Report for Calendar Year 2010 (Including Some Early 2011 Information)" (PNNL-20548) provides the overview of the characterization and monitoring activities conducted at the Hanford Site during the calendar year.

- Hanford Site Groundwater Monitoring Report for 2014 (DOE/RL-2014-32) describes the groundwater monitoring activities during the fiscal year.

- "Hanford Site National Environmental Policy Act (NEPA) Characterization" (PNNL-6415) provides a standardized description of the Hanford Site environment.

Groundwater beneath the Hanford Site 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 site-wide scale, it is referred to in this report as the Hanford unconfined aquifer system.

**3.1.5.4.1 Basalt-Confined Aquifer System.** The upper basalt-confined aquifer groundwater system occurs within basalt fractures and joints, interflow contacts, and sedimentary interbeds within the upper Saddle Mountains Basalt. The thickest and most widespread sedimentary unit in this system is the Rattlesnake Ridge interbed, which is present beneath much of the Hanford Site. Groundwater also occurs within the Levey interbed, which is present only in the southern portion of the Site. A small interflow zone occurs within the Elephant Mountain Member of the upper Saddle Mountains Basalt and may be significant to the lateral transmission of water. The upper basalt-confined aquifer system is confined by the dense, low-permeability interior portions of the overlying basalt flows and in some places by silt and clay units of the lower Ringold Formation that overlie the basalt. Approximately 50 wells screened in the upper basalt-confined aquifer have been sampled or had water levels measured in recent years.

The horizontal hydraulic conductivities of most of these basalt-confined aquifers fall in the range of $10^{-10}$ to $10^{-4}$ m/s ($3 \times 10^{-10}$ to $3 \times 10^{-4}$ ft/s). Saturated but relatively impermeable dense interior sections of the basalt flows have horizontal hydraulic conductivities ranging from $10^{-15}$ to $10^{-9}$ m/s ($3 \times 10^{-15}$ to $3 \times 10^{-9}$ ft/s), about five orders of magnitude lower than some of the confined aquifers that lie between these basalt flows (DOE/RW-0164). Hydraulic-head information indicates that groundwater in the basalt-confined aquifers generally flows toward the Columbia River and, in some places, toward areas of enhanced vertical inter-aquifer flow within the unconfined aquifer system (PNNL-16346, "Hanford Site Groundwater Monitoring for Fiscal Year 2006"; DOE/RW-0164; SD-BWI-TI-335, "Fresh-Water Potentiometric Map and Inferred Flow Direction of Ground Water Within the Mabton Interbed, Hanford Site, Washington State -- January 1987").

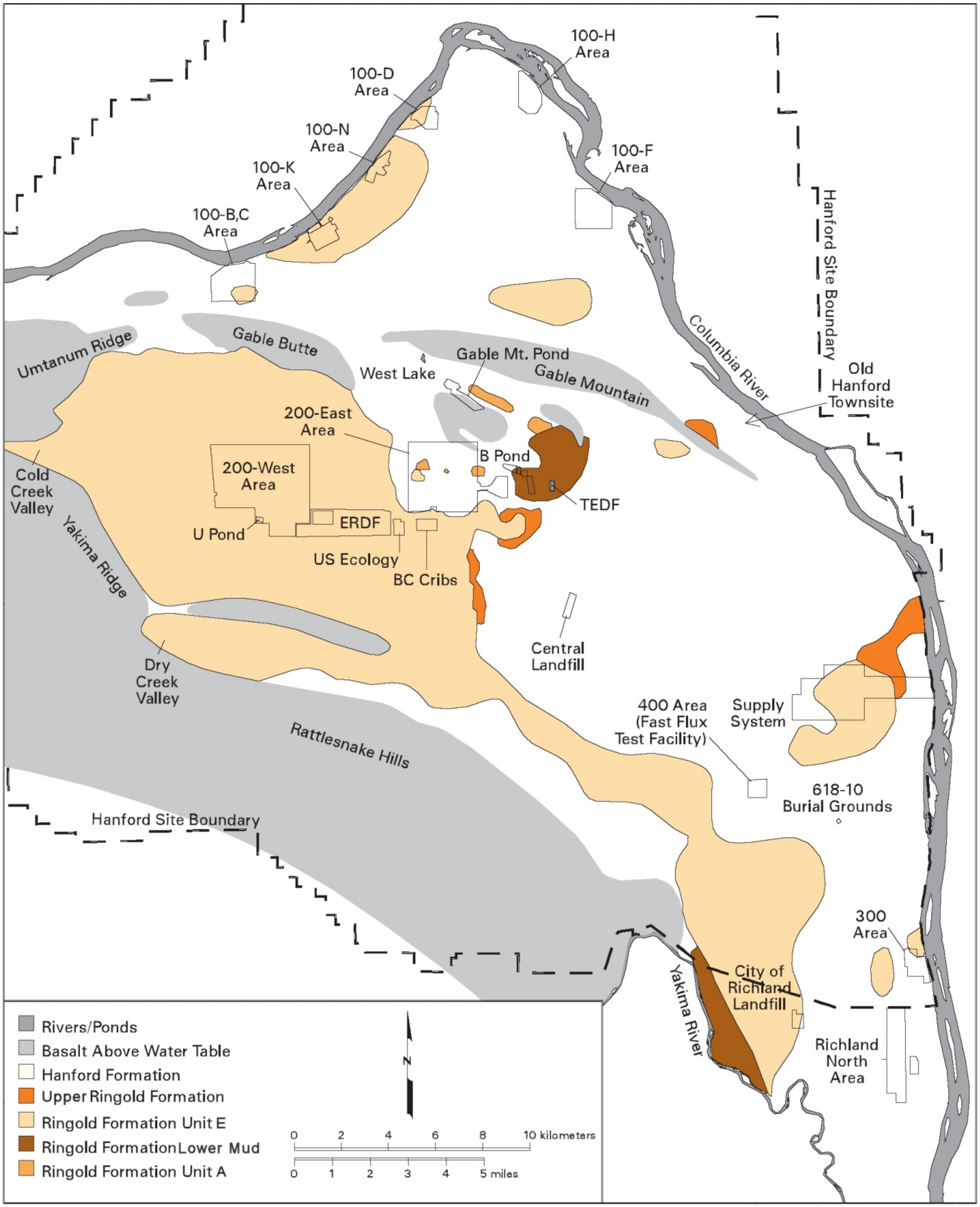
The DOE monitors groundwater quality in the upper basalt-confined aquifer system because of the potential for downward migration of contaminants from the overlying unconfined aquifer in areas where confining units are absent or fractured. The upper basalt-confined aquifer system is not affected by contamination as much as the unconfined aquifer. Contamination found in the upper basalt-confined aquifer system is most likely to occur in areas where the confining units have been eroded away or were never deposited, and where past disposal of large amounts of wastewater resulted in downward hydraulic gradients.

Researchers have identified areas of intercommunication between the contaminated unconfined aquifer and the upper basalt-confined aquifer by geochemical signatures and the presence of nitrate and tritium in groundwater in some basalt-confined wells near the 200 East Area (PNL-10817, "Hydrochemistry and Hydrogeologic Conditions within the Hanford Site Upper Basalt Confined Aquifer System"). However, groundwater monitoring data do not indicate that contamination has migrated into the upper basalt-confined aquifer. Because of poor seals in wells constructed prior to implementation of WAC 173-160, "Minimum Standards for Construction and Maintenance of Wells," intercommunication between aquifers has permitted groundwater flow from the unconfined aquifer to the underlying confined aquifer in the past, increasing the potential to spread contamination. Section 2.14.2 of DOE/RL-2008-01 further discusses communication between the upper basalt-confined aquifer system and the overlying aquifers. The small amount of contamination detected in the upper basalt-confined aquifer is attributed to areas where confining units of basalt have been partially removed by erosion or are absent, or where wells provided a pathway for migration. The basalt-confined aquifer system would not provide a pathway for contaminants from WMA C to the accessible environment.

**3.1.5.4.2 Unconfined Aquifer System.** The base of the uppermost aquifer system is defined as the top of the uppermost basalt flow, with the top of the system being the water table. This aquifer system is bounded laterally by anticlinal basalt ridges and is ~152 m (500 ft) thick near the center of the Pasco Basin. Within the Hanford Site, this uppermost aquifer system lies at depths ranging from less than 0.3 m (1 ft) below the ground surface near West Lake and the Columbia and Yakima Rivers, to more than 107 m (350 ft) in the central portion of the Cold Creek syncline. Groundwater in the unconfined aquifer at the Hanford Site generally flows from recharge areas in the elevated region near the western boundary of the Hanford Site toward the Columbia River on the eastern and northern boundaries. The Columbia River is the primary discharge area for the unconfined aquifer. The Yakima River borders the Hanford Site on the southwest and is generally regarded as a source of recharge.

The unconfined aquifer system underlying the Hanford Site exists within sediments deposited on top of the Columbia River Basalts. It is composed primarily of the Ringold Formation and overlying Hanford formation. Figure 3-31 is a hydrogeologic map of the units present at the water table surface in June 1998, which represents the top of the unconfined aquifer just prior to the start of active remediation. In the 200 West Area, the water table occurs almost entirely in the Ringold Unit E gravels, while in the 200 East Area, it occurs primarily in the Hanford formation and in the Ringold Unit A gravels (Figure 3-18). Along the southern edge of the 200 East Area, the water table is in the Ringold Unit E gravels. The upper Ringold facies were eroded in most of the 200 East Area by the ancestral Columbia River and, in some places, by the Missoula floods that subsequently deposited Hanford gravels and sands on what was left of the Ringold Formation (DOE/RL-2002-39). Because the Hanford formation and possibly the CCU sand and gravel deposits are much more permeable than the Ringold gravels, the water table is relatively flat in the 200 East Area, but groundwater flow velocities are higher.

**Figure 3-31. Hydrogeologic Units Present at the Water Table in June 1998.**



jpm99034 February 10, 1999 12:34 PM

Source: WCH-520, "Performance Assessment for the Environmental Restoration Disposal Facility, Hanford Site, Washington."

ERDF = Environmental Restoration Disposal Facility

TEDF = Treated Effluent Disposal Facility

The hydrology of the 200 Areas has been strongly influenced by the discharge of large quantities of wastewater to the ground. Between 1944 and the mid-1990s, an estimated $1.68 \times 10^{12}$ L ($4.44 \times 10^{11}$ gal) of liquid was discharged to disposal ponds, trenches, and cribs. Wastewater discharge has decreased since 1984 and currently only contributes a volume of recharge in the same range as the estimated natural recharge from precipitation. The largest volumes of discharge around the 200 East Area were to the 216-B Pond system, the 216-A-25 (Gable Mountain) pond system, and several of the PUREX cribs in the southeast corner of 200 East Area. Figure 3-32 shows the liquid discharge history for the two ponds. The Gable Mountain Pond is estimated to have received ~293 billion L (77 billion gal) of effluent, while the 216-B Pond to have received ~256 billion L (68 billion gal) of effluent. In the 200 West Area, the largest volumes of discharge were to the 216-T Pond system and the 216-U-10 Pond (Figure 3-33). The 216-T Pond system is estimated to have received ~424 billion L (112 billion gal) of effluent (WHC-EP-0815, "Groundwater Impact Assessment Report for the 216-T-4-2 Ditch"), while the 216-U Pond to have received ~158 billion L (41.7 billion gal) of effluent (WHC-EP-0707, "216-U-10 Pond and 216-Z-19 Ditch Characterization Studies").

**Figure 3-32. Discharge History for the 216-B Pond System and Gable Mountain Pond.**

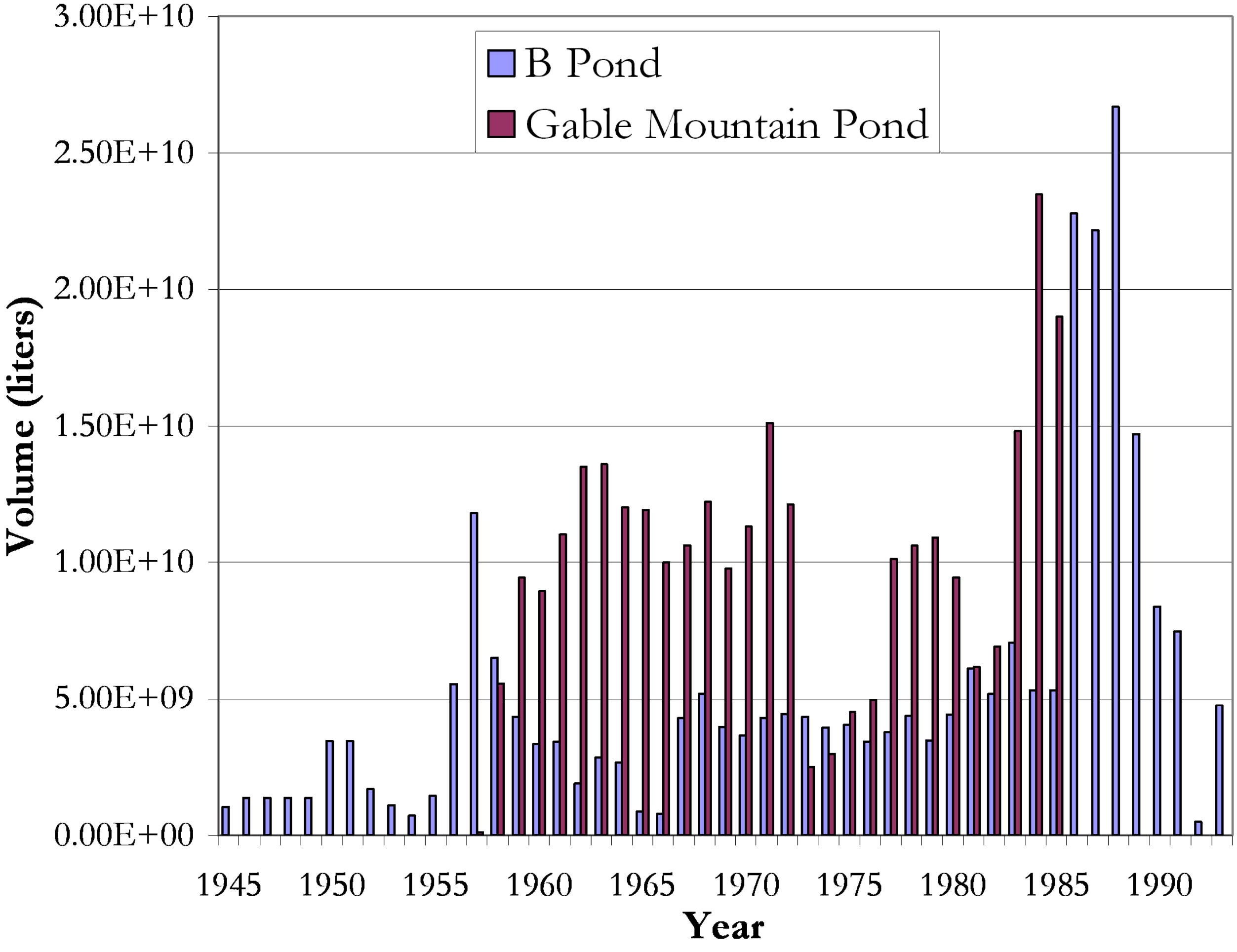


Figure 3-34 shows a series of water table elevation maps for the time periods representing pre-operational conditions, operational conditions, and present day conditions for the Hanford

Site. The first water table map (Figure 3-34a) is a hind cast map of water table elevations (ERDA-1538, "Final Environmental Impact Statement, Waste Management Operations, Hanford Reservation, Richland, Washington") prior to the start of significant Hanford Site wastewater discharges. This water map includes the effects of limited irrigation near the former towns of White Bluff and Hanford, but not the effects of extensive irrigation now common in Cold and Dry Creeks. The 1944 water table contours indicate that groundwater flow is easterly toward the Columbia River with a relatively uniform hydraulic gradient (~1.5 m/km [5 ft/mi]). Regional groundwater flow was generally toward the east-northeast, while flow north of Gable Mountain was more to the north.

The pre-Manhattan Project water table in the 200 West Area and 200 East Area was ~123 m (404 ft) and 120 m (394 ft) above sea level, respectively (BNWL-B-360, "Selected Water Table Contour Maps and Well Hydrographs for the Hanford Reservation, 1944-1973"). In the 200 West Area, the water table elevation increased rapidly from 1949 to 1956, but appeared to stabilize between the late 1960s and the late 1980s. Water levels began to decline in the late 1980s when wastewater discharges in the 200 West Area were reduced. In the 200 East Area, the water table elevation increased rapidly from 1954 to 1963. The water table declined somewhat in the late 1960s and early 1970s, but then increased again in the early 1980s before beginning a final decline throughout the 1990s when wastewater discharges in the 200 East Area were reduced.

During operations, water levels in the uppermost and unconfined aquifer rose as much as 26 m (85 ft) and 9 m (30 ft) beneath the 200 West Area and 200 East Area, respectively, because of artificial recharge caused by liquid waste disposed from the mid-1940s to 1995. Figure 3-34b shows water table mounding present in the 200 Areas for June 1987. 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 near the 200 West Area inhibited groundwater movement in this area, resulting in a higher groundwater mound.

Presently, groundwater in the unconfined aquifer generally flows from upland areas in the west toward the regional discharge area north and east along the Columbia River (Figure 3-34c). Steep hydraulic gradients occur in the western, eastern, and northern regions of the Site. Shallow gradients occur southeast of 100-FR and in a broad arc extending from west of 100-BC toward the southeast between Gable Butte and Gable Mountain (Gable Gap), through the 200 East Area and into the central portion of the Site. The reduction of wastewater discharges has caused water levels to drop significantly; however, a residual groundwater mound beneath the 200 West Area is still present today as shown by the curved water table contours near this area. Additionally, small groundwater mounds exist near the 200 Area TEDF and State-Approved Land Disposal Site wastewater disposal sites.

Comparing the approximate rate of water table decline in the 200 East Area with that in the 200 West Area shows that the rate of decline is three to four times faster in the 200 West Area. This is probably due, in part, to the greater increase in water level at U Pond than at B Pond. Also, the water table gradient is extremely flat in the 200 East Area, whereas the gradient is steeper beneath the 200 West Area. This indicates that a small increment of water table decline must be spread out over a much larger area in the 200 East Area than in the 200 West Area.

**Figure 3-33. Discharge History for the 216-T Pond and 216-U Pond.**

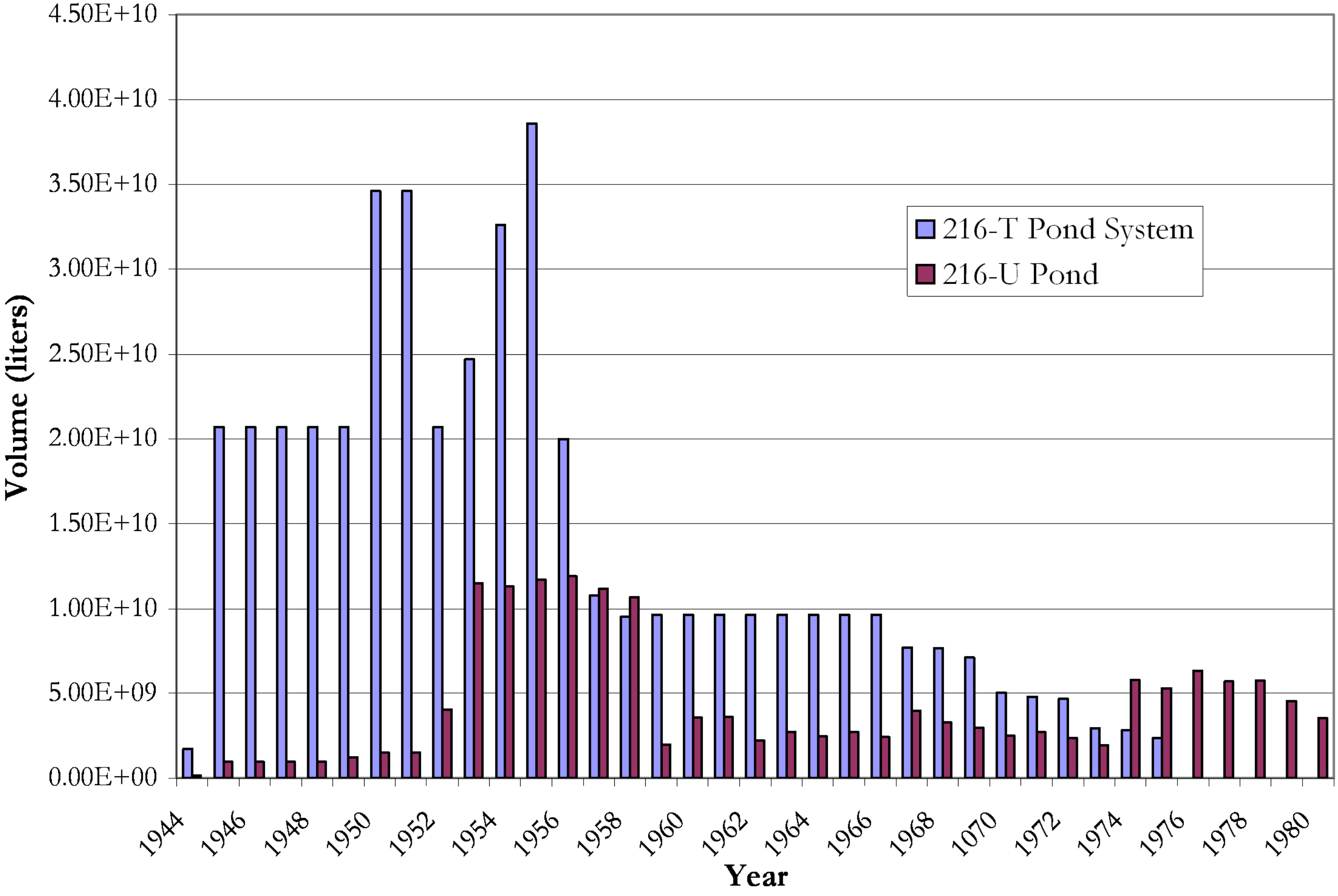
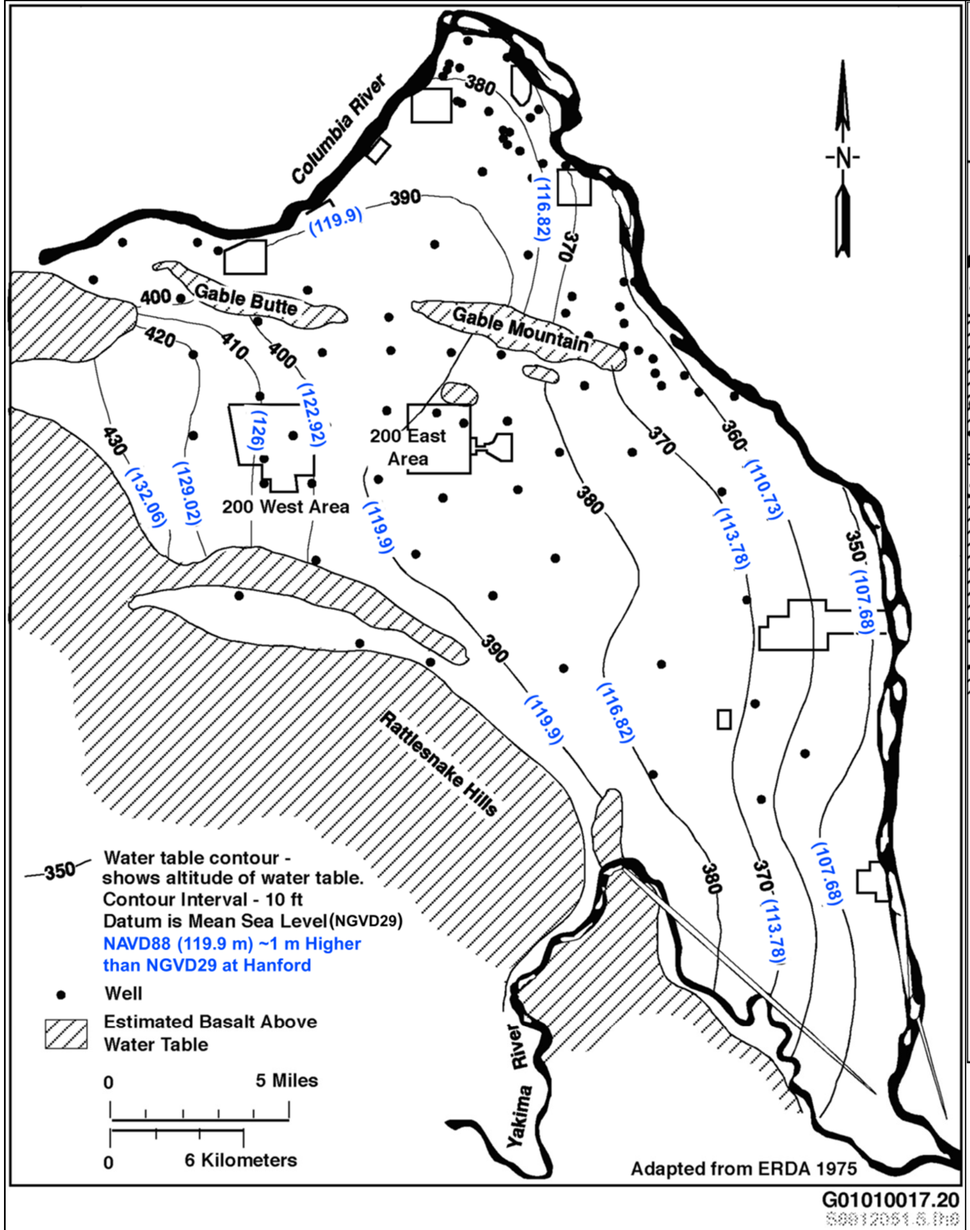
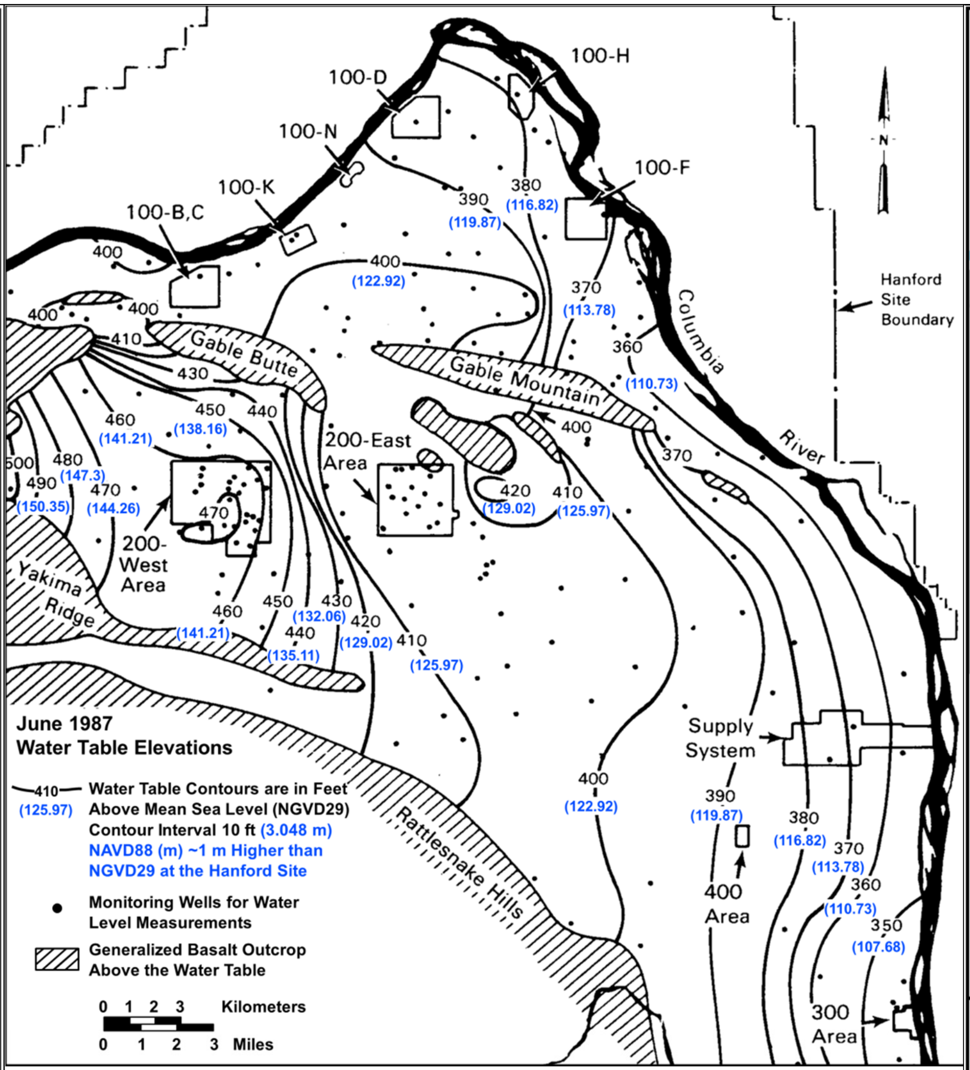


Figure 3-34a. Hind Cast Water Table Map of the Hanford Site, January 1944.



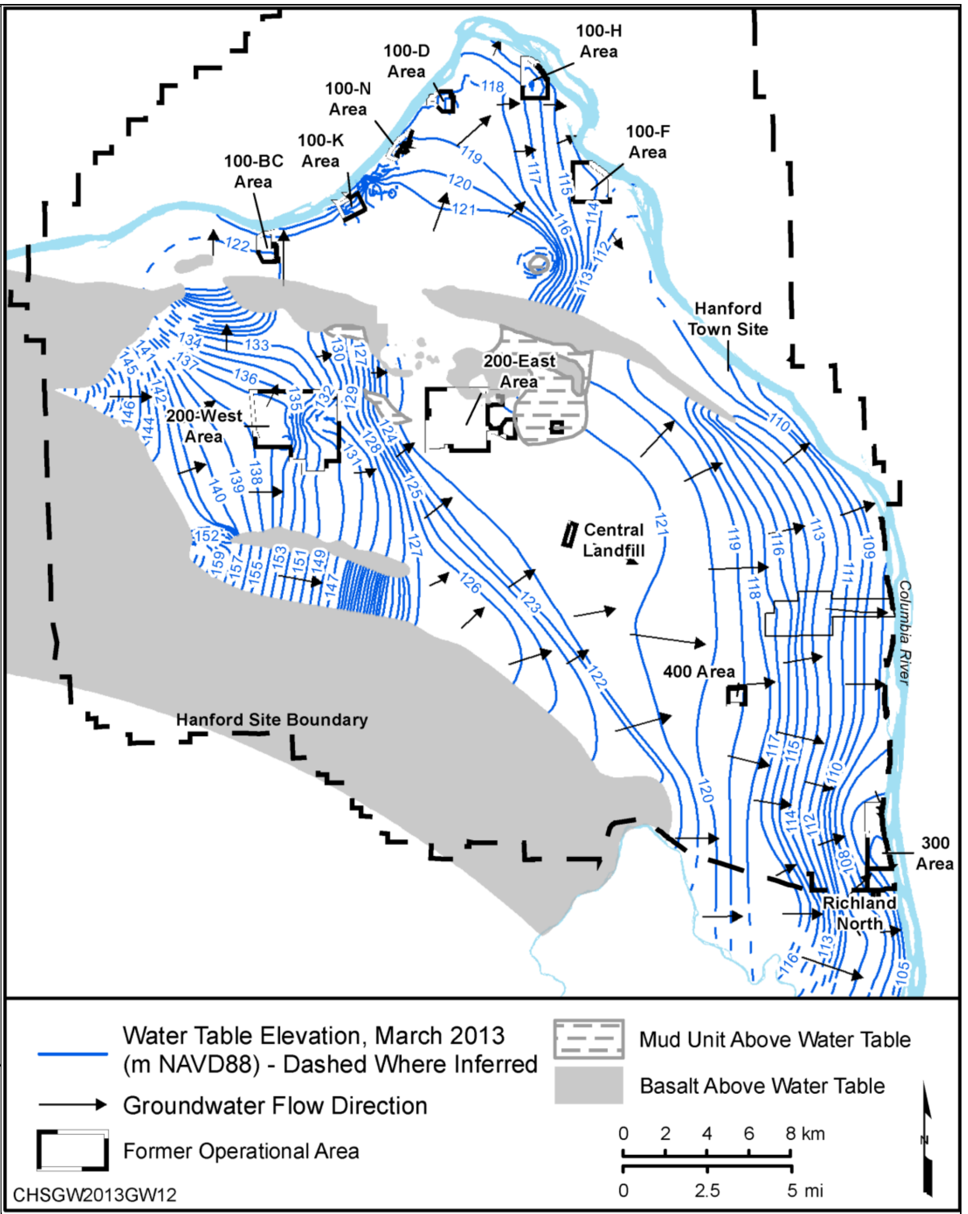
ERDA 1975 refers to ERDA-1538, "Final Environmental Impact Statement, Waste Management Operations, Hanford Reservation, Richland, Washington."

Figure 3-34b. Water Table Elevations for June 1987.



Reference: PNL-6464, "Environmental Monitoring at Hanford for 1987."

Figure 3-34c. Water Table Elevations for 2013.



Source: DOE/RL-2014-32, Hanford Site Groundwater Monitoring Report for 2013.

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The groundwater mounds drastically changed the flow direction causing radial flow from the discharge areas, and, in some areas, resulted in a complete reversal of flow direction. Until about 1980, the edge of the mounds migrated outward from the sources. Groundwater levels have declined over most of the Hanford Site since 1984 because of decreased wastewater discharges (DOE/RL-2014-32), and since 1996, when all non-permitted discharges to the ground ceased, groundwater flow has begun to return to pre-Hanford Site conditions.

The dominant source of water in the unconfined aquifer beneath the 200 East Area and vicinity is inflow of groundwater from upgradient areas to the west. Formerly, the direction of groundwater flow diverged beneath the 200 East Area in the general vicinity of WMA C and the B Complex (WMA B-BX-BY and nearby Cribs), with some water flowing toward the north through Gable Gap and some flowing southeast. The flow direction changed during 2011; since then, flow has been toward the south and southeast across much of the 200 East Area. This change in flow directions is important because contaminant plumes located in the northwest corner of the 200 East Area located near and under the B Complex could flow under WMA C.

A limited amount of hydraulic property data is available from testing of wells. Hydraulic test results from wells on the Hanford Site have been compiled for the Hanford Groundwater Monitoring Project and for environmental restoration efforts (BNWL-1709, “Collection and Analysis of Pump Test Data for Transmissivity Values”; PNL-8337, “Summary and Evaluation of Available Hydraulic Property Data for the Hanford Site Unconfined Aquifer System”; PNL-10835, “Comparison of Constant-Rate Pumping Test and Slug Interference Test Results at the Hanford Site B Pond Multilevel Test Facility”; PNNL-13342, “Analysis of the Hydrologic Response Associated with Shutdown and Restart of the 200-ZP-1 Pump-and-Treat System”; PNNL-13378, “Results of Detailed Hydrologic Characterization Tests – Fiscal Year 1999”; PNNL-13514, “Results of Detailed Hydrologic Characterization Tests – Fiscal Year 2000”; PNNL-14058, “Prototype Database and User’s Guide of Saturated Zone Hydraulic Properties for the Hanford Site”; PNNL-14113, “Results of Detailed Hydrologic Characterization Tests – Fiscal Year 2001”; WHC-SD-EN-TI-014, “Hydrogeologic Model for the 200 West Groundwater Aggregate Area”; and WHC-SD-EN-TI-019). Most hydraulic tests were conducted within the upper 15 m (49 ft) of the aquifer, and many were open to more than one geologic unit. In some cases, changes in water table elevation may have significantly changed the unconfined aquifer transmissivity at a well since the time of the hydraulic test. Few hydraulic tests within the Hanford Site unconfined aquifer system have yielded accurate estimates of aquifer-specific yield.

Horizontal hydraulic conductivities of sand and gravel facies within the Ringold Formation generally range from ~1 to 100 m/day (3 to 328 ft/day), compared to 10 to 7,000 m/day (33 to 23,000 ft/day) for the Hanford formation and the coarse-grained multi-lithic facies of the CCU (pre-Missoula gravels) (DOE/RW-0164; PNNL-13641, “Uncertainty Analysis Framework – Hanford Site-Wide Groundwater Flow and Transport Model”; PNNL-14058; 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”; PNNL-14804, “Results of Detailed Hydrologic Characterization Tests – Fiscal Year 2003”; WHC-SD-EN-TI-019). Because the Ringold Formation sediments are more consolidated and partially cemented, they are ~10 to 100 times less permeable than the sediments of the overlying Hanford formation. Before wastewater disposal operations at the Hanford Site, the uppermost aquifer was mainly within the Ringold Formation, and the water table extended into the Hanford formation at only a few locations ("Geology and Ground-Water Characteristics of the Hanford Reservation of the U.S. Atomic Energy Commission, Washington" [Newcomb et al. 1972]). However, wastewater discharges raised the water table elevation across the site. The general increase in groundwater elevation caused the unconfined aquifer to extend upward into the Hanford formation over a larger area, particularly near the 200 East Area. This 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.

**3.1.5.4.3 Existing Groundwater Contamination.** When the Hanford Site was operating, 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 Site. Waste disposal within the 200 Areas began with startup of plutonium-separation operations in late 1944 (WHC-MR-0521, "The Plutonium Production Story at the Hanford Site: Processes and Facilities History"). Three separations processes were used. The earliest was the bismuth-phosphate process, which was used between 1944 and 1956 at T Plant in the 200 West Area (200-ZP groundwater interest area), and between 1945 and 1952 at B Plant in the 200 East Area (200-BP). The REDOX process was used between 1952 and 1967 at the REDOX Plant in the 200 West Area (200-UP). Finally, the PUREX process was used from 1956 to 1972, and again from 1983 to 1989 at the PUREX Plant in the 200 East Area (200-PO).

Beginning in 1949, the product from the separations plants was further processed at the Plutonium Finishing Plant (PFP) (200-ZP), which operated until 1989. Other chemical processes performed in the 200 Areas included uranium recovery, using the tributyl phosphate process at U Plant (200-UP) between 1952 and 1957, and radionuclide recovery by various methods at B Plant (200-BP) between 1963 and 1983 [PNL-SA-23121 S, "Hanford Technical Exchange Program: Process Chemistry at Hanford (Genesis of Hanford Wastes)"]. Each chemical processing facility generated multiple waste streams and used multiple waste sites for waste management and disposal.

Additionally, the 200 Areas contain seven SST WMAs: A-AX, B-BX-BY, and C within the 200 East Area and S-SX, T, TX-TY, and U within the 200 West Area. Unplanned releases (e.g., tank liner leaks or releases from cascade lines or spare ports) have contaminated the vadose zone and some of this contamination has migrated downward to the groundwater (e.g., PNNL-11810, "Results of Phase I Groundwater Quality Assessment for Single-Shell Tank Waste Management Areas S-SX at the Hanford Site"). Migration through the vadose zone may have been facilitated in the past by additions of water from various sources, most notably nearby wastewater ditches and cribs, water supply pipeline leaks, and rainfall/snowmelt runoff events. Nitrate, chromium and $^{99}$Tc from many of the tank farms, as well as uranium specifically from WMA B-BX-BY, form substantial groundwater plumes. These plumes generally are expanding in areal extent and exhibit increasing constituent concentrations indicating that contaminants continue to enter the groundwater from the vadose zone.

The intentional disposal of waste streams to ponds, ditches, and cribs, combined with the UPRs from the WMAs has resulted in a complex mixture of soil and groundwater contamination that complicates the process of interpreting specific contaminant sources for specific plumes.

Groundwater monitoring is/has been performed on a regular basis to evaluate levels of contamination, movement of groundwater plumes, and changes to the unconfined/confined aquifers. Each year an annual groundwater monitoring report is issued with the most recent being DOE/RL-2014-32. This annual report provides monitoring results for the AEA, as required by DOE Orders; for RCRA treatment, storage, and disposal (TSD) units; and for CERCLA groundwater OUs.

The annual report divides the Central Plateau into four geographical groundwater interest areas (200-BP-5, 200-PO-1, 200-UP-1, and 200-ZP-1). These groundwater interest areas encompass groundwater contamination from the 200 East and 200 West Areas and regions into which this contamination has migrated beyond the Central Plateau (Figure 3-35). WMA C falls within the 200-BP-5 OU, which also contains WMA B-BX-BY.

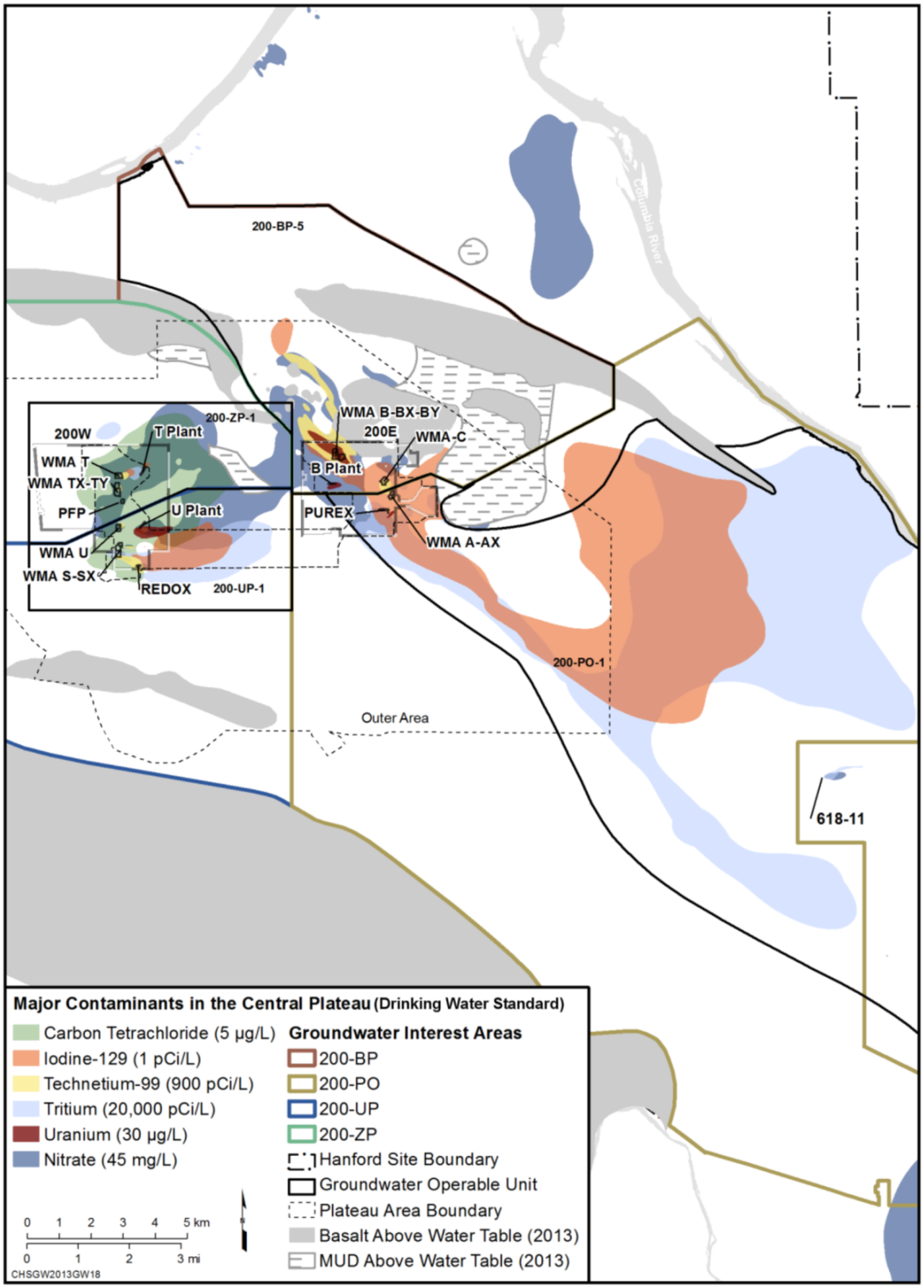
Groundwater contaminant plumes of tritium, nitrate, and $^{129}$I formed when the waste discharged to ponds and cribs reached the aquifer. These contaminants form regional plumes originating on the Central Plateau (Figure 3-35). The tritium and nitrate plumes have decreased in area over the years as a result of radioactive decay (tritium only) and dispersion; the area of $^{129}$I has remained stable. A large carbon tetrachloride plume originated in the 200 West Area. Other groundwater contaminants in the Central Plateau include $^{99}$Tc, uranium, $^{90}$Sr, trichloroethene, cyanide, and other dangerous waste constituents.

The unconfined aquifer within the 200 East Area boundary is the primary aquifer impacted by past waste disposal operations and is associated with the suprabasalt sediment of the Ringold Formation, CCU, and Hanford formation (Figure 3-17). The greatest concentration/activity of nitrate, $^{99}$Tc, and uranium is in the 200-BP-5 OU area within the northwest portion of the 200 East Area, also referred to as the B Complex (e.g., 241-B-BX-BY single-shell underground storage tank [UST] area “Waste Management Area B-BX-BY” and adjacent liquid waste sites). These plumes extend both to the northwest and southeast within an ancestral Columbia River paleochannel that incised semi-consolidated gravels and cohesive fluvial-lacustrine Ringold deposits. With the groundwater flow in the vicinity of the B Complex changing flow direction from northwest through Gable Gap to the southeast toward the Columbia River and through the paleochannel, contaminant plumes in the vicinity of the B Complex could intersect contaminant plumes originating at WMA C in the near future.

Below is a summary description for existing groundwater contamination in the 200-BP-5 groundwater interest area taken from DOE/RL-2014-32 (the reader is referred to that document for more information) for the following contaminants:

- Tritium
- $^{129}$I
- Nitrate
- $^{99}$Tc
- Uranium
- Cyanide.

**Figure 3-35. Groundwater Contamination for 2013 which Originated within the Central Plateau along with Central Plateau Groundwater Interest Areas.**



Source: DOE/RL-2014-32, Hanford Site Groundwater Monitoring Report for 2013.

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

**Tritium**

The major sources of tritium within the 200-BP-5 groundwater interest area were the 216-B-50 and 216-B-57 cribs located north and northwest of 241-BY Tank Farm (BY Farm), 216-BX-102 UPR from SST 241-BX-102 (BX-102), 216-B-3 pond just east of the 200 East Area and the 216-B-12 Crib ~750 m (2,460 ft) south-southwest of WMA B-BX-BY. However, at 216-B-12 crib, the source could also be from the 200-PO sources (DOE/RL-2014-32). The size of the tritium plume in the upper part of the unconfined aquifer within 200-BP has decreased since 2003. The decline is attributed with radioactive decay, dispersion, and possibly diminishing levels of drainage from the vadose zone at certain locations. The maximum tritium levels near the 216-B-50 and 216-B-57 cribs are ~22,000 pCi/L; at the BX-102 site, the maximum tritium levels are on the order of 25,000; at the 216-B-12 crib, the levels range from 94,000 pCi/L to 150,000 pCi/L and finally at the 216-B-3 pond the maximum levels observed are ~42,000 pCi/L. While tritium is found in the unconfined aquifer underneath WMA C at levels below the drinking water standard (DWS), no known sources for the tritium are suspected to have originated from WMA C.

**Iodine-129**

There are three sources of iodine in southeast 200 East Area (216-A-10 Crib vicinity, 216-A-29 Ditch, and B Pond) that were contributors to the widespread distribution of $^{129}$I within the 200 East Area and Gable Gap. Other potential sources of $^{129}$I to groundwater include the BY Cribs, 241-BX-102 UPR, and the 216-B-8 Crib. Overall $^{129}$I activity in 2013 within the 200-BP-5 groundwater interest area ranged from ~7 pCi/L near WMA C (299-E27-22 [Figure 3-4]) to less than 1 pCi/L at wells in the northern part of Gable Gap. The northwest plume extent reflects the primary flow path in the late 1980s when discharges to Gable Mountain Pond were terminated. Although WMA C is not considered a source for $^{129}$I, all 12 groundwater monitoring wells at WMA C had $^{129}$I levels exceeding DWS. 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.

**Nitrate**

The most extensive plume in 2013 within the 200-BP-5 groundwater interest area is the nitrate (Figure 3-35). Nitrate sources have been identified as: BY Cribs (located just to the north of BY Farm), 216-B-7A&B Cribs, 216-B-8 Crib, SST 241-BX-102 UPR, releases with 241-B Tank Farm (B Farm) (part of WMA B-BX-BY), 216-B-12 Crib, 216-B-5 Injection Well, 216-B-2-2 Ditch, WMA C, Gable Mountain Pond, and Gable Gap. The highest nitrate levels observed in 2013 were at B Farm with a level of close to 1,700 mg/L (0.23 oz/gal), followed by the BY Cribs at ~1,400 mg/L (0.19 oz/gal). Contaminant levels drop off to ~300 to 800 mg/L (0.04 oz/gal to 0.11 oz/gal) at 241-BX-102 UPR and 216-B-7A&B Cribs. Waste Management Area C is the source of nitrate found at monitoring wells around WMA C. A total of three wells had nitrate levels above the DWS (45 mg/L [0.006 oz/gal]). The highest level observed was 110 mg/L (0.015 oz/gal) at well 299-E27-14 (Figure 3-4) on the east side of the tank farm. The contaminant level has been fairly constant at well 299-E27-14 for the past several years. The other two wells at WMA C with levels above the DWS are 299-E27-21 (~46 mg/L [0.006 oz/gal]) and 299-E-27-24 (70 mg/L [0.009 oz/gal]).

**Technetium-99**

Technetium-99 sources have been identified at BY Cribs, 216-B-7A&B Cribs, 216-B-8 Crib, 241-BX-102 UPR, releases with B Farm (WMA B-BX-BY), WMA C and Gable Gap. Three general plume areas are present within the 200-BP-5 groundwater interest area (Figure 3-35); one area north of 200 East, one near WMA B-BX-BY, and one near WMA C. The largest of the three plumes is near WMA B-BX-BY and sources include the BY Cribs, 216-B-7A&B Cribs, 216-B-8 Crib, 241-BX-102 UPR, and releases associated with the B Farm. The greatest $^{99}$Tc activity in the 200-BP-5 groundwater interest area in 2013 occurred at well 299-E33-18, with a maximum activity of 36,000 pCi/L. The ratio of $^{99}$Tc to nitrate in groundwater is potentially useful for evaluating source contributions. The $^{99}$Tc-to-nitrate ratio associated with this area indicates a potentially different source than the other high activity wells in this area, due to the greater $^{99}$Tc activity and lower nitrate concentration. This is consistent with the type of waste released; metal waste from tank BX-102.

Technetium-99 in the 200-BP-5 groundwater interest area is primarily from liquid waste associated with the BY Cribs, which received a mean inventory of 128.6 Ci of $^{99}$Tc (Appendix C of RPP-26744, “Hanford Soil Inventory Model, Rev. 1”). Prior to the 2011 groundwater flow reversal, $^{99}$Tc activity beneath the BY Cribs exceeded 30,000 pCi/L in all three wells located within the BY Cribs footprint. The increased activity was the result of minimal groundwater flow between 2006 and 2011 and continuous $^{99}$Tc infiltration into the aquifer at an average activity of ~3.8 µCi/L based on RPP-26744. Since 2011 this concentrated $^{99}$Tc plume has migrated and expanded to the southeast as a result of the groundwater flow reversal in this area.

**Uranium**

Uranium found in the 200-BP-5 groundwater interest area primarily originated from large disposal inventories to the 216-B-12 Crib and the 241-BX-102 UPR. The uranium inventory disposed to these sites exceeded 10,000 kg, which is at least an order of magnitude greater than other waste sites within the 200-BP-5 groundwater interest area. Rough order of magnitude calculations indicated that 1,050 kg (2,310 lbs) of water-extractable uranium may reside in the Cold Creek silt-dominated unit ~3 m (10 ft) above the aquifer. The estimate was based on sample results from three boreholes in an east-west orientation within the perched water zone. The highest concentration of uranium observed in the unconfined aquifer in 2013 was 3,330 µg/L ($4.4 \times 10^{-4}$ oz/gal) (DWS is 30 µg/L [$4.4 \times 10^{-6}$ oz/gal]) at well 299-E33-18 (~80 m [262 ft] due east of 241-BX Tank Farm). At WMA C, uranium has leaked from the SSTs and/or pipelines. RPP-35484, “Field Investigation Report for Waste Management Areas C and A-AX” reported $^{236}$U in vadose zone samples taken from well 299-E27-7 as an indication of irradiated fuel fission product being released to the soil. However, it is not clear as to the source of uranium in the groundwater. It may be from WMA C or may be the result of slightly contaminated groundwater flowing into the area around WMA C. There are no clear trends over the last 6 years in the groundwater data for uranium and the concentrations found in groundwater wells bounding WMA C are 3 to 10 times less than the DWS (i.e., ~2 to 11 µg/L [$2.7 \times 10^{-7}$ to $1.5 \times 10^{-6}$ oz/gal]).

**Cyanide**

Cyanide found in the 200-BP-5 interest area originated from disposal of tributyl phosphate wastes scavenged for $^{137}$Cs. After scavenging was completed, the tank supernate, including the remaining dissolved ferrocyanide compounds, was discharged to the BY Cribs at the B Complex. In the late 1990s, cyanide concentrations began to increase in the groundwater beneath the BY Cribs along with nitrate and $^{99}$Tc. In addition, low concentrations of cyanide detected in the vicinity of WMA C are attributed to historical releases of ferrocyanide-containing waste at that facility.

As of 2013, cyanide is the only dangerous waste constituent determined as impacting groundwater from C Farm. More specifically, cyanide only exceeded the detection limit in three wells in 2013 (299-E27-14, 299-E27-23, and 299-E27-24 [Figure 3-4]). The concentrations were significantly less than the 200 µg/L ($2.7 \times 10^{-5}$ oz/gal) DWS. 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 ($1.9 \times 10^{-6}$ oz/gal), in 2013 was in well 299-E27-24, which is screened across the bottom of the aquifer. During 2013 the cyanide concentration in this well ranged between 8.64 and 13.9 µg/L ($1.2 \times 10^{-6}$ oz/gal and $1.9 \times 10^{-6}$ oz/gal).

**3.1.5.4.4 Groundwater Travel Times.** Travel time of water through the unconfined aquifer from the 200 East Area to the Columbia River has been estimated to be in the range of 10 to 30 years (Open File Report 87-222, "Subsurface Transport of Radionuclides in Shallow Deposits of the Hanford Nuclear Reservation, Washington – Review of Selected Previous Work and Suggestions for Further Study"; PNL-6328, "Estimation of Ground-Water Travel Time at the Hanford Site: Description, Past Work, and Future Needs"). This is because of large volumes of recharge from wastewater that were disposed in the 200 Areas between 1944 and the mid-1990s, and the relatively high permeability of Hanford formation sediments, which are below the water table between the 200 East Area and the Columbia River. Analysis of the tritium plume in DOE/RL-2009-85, Remedial Investigation Report for the 200-PO-1 Groundwater Operable Unit estimated a travel time of 33 years. It further states that this estimate is likely to be conservative (i.e., overstates the groundwater contamination migration rates compared to current conditions) because of the past groundwater mounding in the Central Plateau.

### 3.1.6 Geochemical Properties

The Hanford formation sediment in the 200 Areas consists of glacio-fluvial materials deposited by cataclysmic Ice Age floods. The mineralogy of this sediment is highly variable, depending on grain size. Gravel-dominated sediment tends to have a high abundance of lithic fragments (mostly basaltic, with some plutonic, metamorphic, and detrital caliche fragments) (DOE/RL-2002-39). Finer-grained facies have proportionally less lithic fragments and more quartz, feldspar, and mica grains. Microprobe analysis of the sand and finer-grained fraction indicates dominance by quartz (18 to 67.1% by weight), plagioclase (5.1 to 41.5%) and microcline (1.8 to 30.1%) (RHO-ST-23, "Geology Of The Separation Areas, Hanford Site, South-Central Washington"; PNL-8889, "Solid-Waste Leach Characteristics and Contaminant-Sediment Interactions, Volume 1: Batch Leach and Adsorption Tests and Sediment Characterization"; PNNL-14202, "Mineralogical and Bulk-Rock Geochemical Signatures of

Ringold and Hanford Formation Sediments"). Other common minerals include amphiboles up to 36.6%, pyroxenes up to 27.5%, mica (biotite/illite) up to 13.1%, and calcite up to 6.5% by weight. Smectite clays represent a few weight percent of the bulk sand fraction (3.3 to 5% [PNL-8889]) and generally dominate the clay fraction (RHO-ST-23). PNNL-14586, "Geologic Data Package for 2005 Integrated Disposal Facility Waste Performance Assessment" reported chlorite concentrations generally <3% by weight except for one sample that had 8% by weight of chlorite.

Hanford formation sediment is typified as having low organic carbon content, generally <0.1% by weight (PNL-8889), and low-to-moderate cation exchange capacity (2.6 to 7.8 milli-equivalents per 100 g [3.53 oz] [PNL-8889]). The sediment has a slightly basic pH when wetted (PNL-8889 found the pH of saturation extract ranging from 7.66 to 8.17). Small amounts of detrital calcium carbonate (calcite) are common and can act as a weak buffer.

Empirical bulk distribution coefficient ($K_d$) data for Hanford formation and Ringold Formation sediments are fairly abundant for dilute waste solutions and groundwater (PNNL-13895, "Hanford Contaminant Distribution Coefficient Database and Users Guide"). Fewer $K_d$ data are available for the CCU sediments, or for high ionic strength waste solutions with slightly acidic to slightly basic pH values. A relatively small amount of $K_d$ data exists for the combined high ionic-strength/highly-basic tank liquors for many common radionuclides. These distribution coefficient ($K_d$) data have been well tabulated [PNNL-13895; PNNL-11800; PNL-7297, "Hanford Waste-Form Release and Sediment Interaction – A Status Report with Rationale and Recommendations for Additional Studies"; PNNL-13037, "Geochemical Data Package for the Hanford Immobilized Low-Activity Tank Waste Performance Assessment (ILAW PA)," Rev. 1; PNNL-11485, "Radionuclide Adsorption Distribution Coefficients Measured in Hanford Sediments for the Low Level Waste Performance Assessment Project"; PNNL-11965, "Effects of Aging Quartz Sand and Hanford Site Sediment with Sodium Hydroxide on Radionuclide Sorption Coefficients and Sediment Physical and Hydrological Properties: Final Report for Subtask 2a"; and PNNL-13037, "Geochemical Data Package for the 2005 Hanford Integrated Disposal Facility Performance Assessment," Rev. 2]. In most instances, adsorption appears to be the controlling geochemical process, but neutralization of acid waste by the alkaline sediment and neutralization of basic tank waste can cause precipitation of some contaminant species within the sediment pores. Outside the zone of pH neutralization, adsorption is considered to be the dominant contaminant retardation process in the vadose zone.

### 3.1.7 Natural Resources

The following section discusses the natural geologic and water resources on the Hanford Site. The Central Plateau of the Hanford Site has no important natural resources.

**3.1.7.1 Geologic Resources.** Geologic resources at the Hanford Site are very limited. Hanford Site mineral resources include sand, gravel, silt, clay, and aggregate. Historically, these resources were extracted at several quarries or pits at the Hanford Site and used for road construction and maintenance, and waste burial activities. No major mining operations exist in the Hanford Site area. Oil and gas exploration have occurred; however, no economically viable accumulations were found.

**3.1.7.2 Water Resources.** The Columbia River is used as a source of both drinking water and industrial water for several Site facilities (PNNL-20548). The water systems of Richland, Pasco, and Kennewick withdrew a large portion of the 48.8 billion L (12.9 billion gal) used during 2006 from the Columbia River. Each city operates its own supply and treatment system, located downgradient and downriver of the Site. The Richland water supply system derives ~82% of its water directly from the Columbia River, while the remainder is split between a well field in north Richland (that is recharged from the river) and groundwater wells.

The City of Richland's total water usage during 2006 was 20.1 billion L (5.3 billion gal). The Kennewick system uses two wells and the Columbia River for its water supplies. These wells serve as the sole source of water between November and March and can provide ~40% of the total maximum supply of 94.6 billion L/day (25 million gal/day). Total 2006 usage in Kennewick was 13.4 billion L (3.5 billion gal). A significant number of Kennewick's residents (~22,000 residential customers) draw irrigation water from the Kennewick Irrigation District, which has the Yakima River as its source. The City of Pasco system also draws from the Columbia River for its water needs. During 2006, Pasco consumed 15.5 billion L (4.1 billion gal). Energy Northwest operates the Columbia Generating Station northeast of the 400 Area. Energy Northwest uses Columbia River water for both potable and process/cooling water applications.

### 3.1.8 Natural Background Radiation

The Hanford Site has an extensive monitoring program. Studies have been directed at determining background levels of possible contaminants in the soil (DOE/RL-92-94, Hanford Site Background: Part 1, Soil Background for Nonradioactive Analytes; DOE/RL-95-55, Hanford Site Background: Evaluation of Existing Soil Radionuclide Data; DOE/RL-96-12, Hanford Site Background: Part 2, Soil Background for Radionuclides) and in the groundwater (WHC-EP-0595, "Westinghouse Hanford Company Operational Groundwater Status Report, 1990-1992"). Also, reports are issued annually covering general environmental conditions (PNNL-6415) and groundwater monitoring (DOE/RL-2014-32).

Low concentrations of some longer-lived radionuclides such as isotopes of cesium, plutonium, potassium, strontium, and uranium are detectable that are associated with particulate matter that accumulated in riverbed sediments (PNNL-20548). The levels were similar to those measured in previous years. No discernible increase in concentration could be attributed to current Hanford Site operations. DOE/RL-91-45, Hanford Site Risk Assessment Methodology, summarizes all the measurements taken to determine radionuclide background levels at the Hanford Site (see Appendix B, Section B.2.8).

Recent annual Hanford Site environmental reports (e.g., PNNL-20548) estimate that the total annual dose from Hanford Site operations in 2010 to a hypothetical maximally-exposed individual at an offsite location was ~0.18 mrem. The air-pathway annual dose was 0.053 mrem (excluding radon) and 0.067 mrem (including radon). These radiation exposures are small compared to other natural and human-produced sources that are estimated to contribute ~365 mrem annual dose to individuals living near the Hanford Site (NCRP Report No. 93, "Ionizing Radiation Exposure of the Population of the United States").

### 3.1.9 Waste Management Area C Site Characterization

The previous sections provided summary information on the Hanford Site characteristics. This section provides a brief summary of the characterization of the vadose zone and unconfined aquifer in and around WMA C, including contamination in both the vadose zone and unconfined aquifer. Since the late 1990s there has been an extensive effort to characterize the vadose zone and unconfined aquifer around WMA C. These efforts are described in numerous documents including, but not limited to, DOE/ORP-2008-01 Appendix L; DOE/RL-2014-32; GJO-98-39-TAR/GJO-HAN-18, “Hanford Tank Farms Vadose Zone: C Tank Farm Report”; GJO-98-39-TARA/GJO-HAN-18, “Hanford Tank Farms Vadose Zone: Addendum to the C Tank Farm Report”; RPP-PLAN-39114; RPP-RPT-56356, “Development of Alternative Digital Geologic Models of Waste Management Area C”; and RPP-RPT-58339. For more detailed information, please refer to the characterization documents.

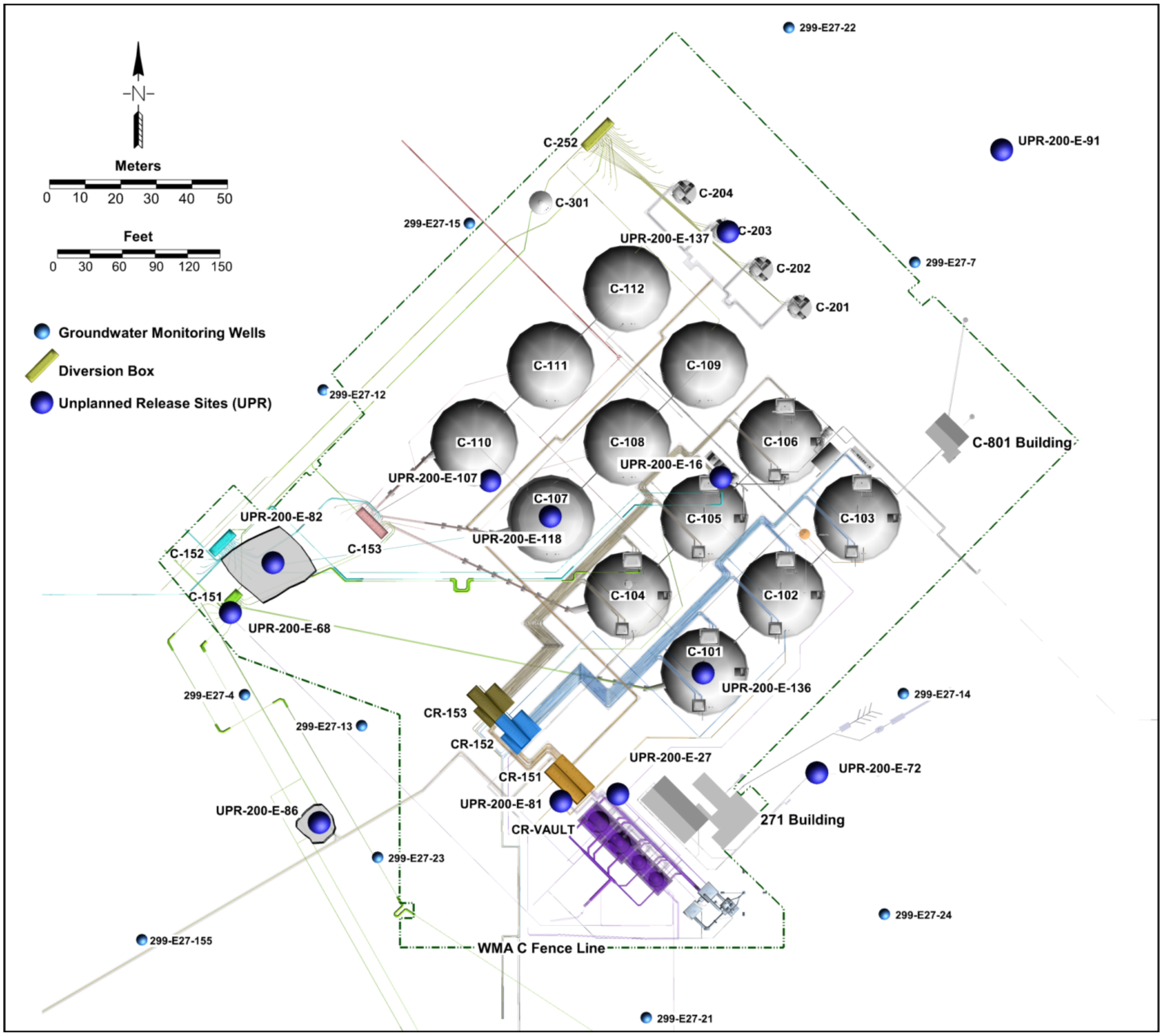
The principal driver for site characterization at WMA C is a number of confirmed or suspected waste loss events which occurred in WMA C (labeled as UPRs in Figure 3-36) during its operational history. These included suspected tank leaks and known waste losses from waste transfer piping systems. The current understanding of contaminant occurrences and environmental conditions at WMA C is described in RPP-ENV-33418, “Hanford C-Farm Leak Inventory Assessments Report” and DOE/ORP-2008-01. The primary contamination zones currently identified in WMA C include a localized high $^{137}$Cs activity zone near the bottom of the southwest part of tank C-105 and three UPRs near waste transfer pipelines and diversion boxes in the southwest part of WMA C. Sampling at groundwater wells 299-E27-21 and 299-E27-23 along the southern boundary (Figure 3-36) of WMA C had results for $^{99}$Tc at concentrations greater than 25 times the DWS of 900 pCi/L.

**3.1.9.1 Geology.** The geology of WMA C is summarized from the information provided in DOE/ORP-2008-01, RPP-RPT-46088, and RPP-RPT-56356. A generalized fence diagram through WMAs A-AX and C is shown in Figure 3-37.

Six stratigraphic units lie within WMAs A-AX and C. From oldest to youngest, the primary geologic units are:

- Columbia River Basalt Group
- Undifferentiated Hanford lower gravelly sequence (H3 unit)/Cold Creek/Ringold formations
- Hanford formation – sand sequence (H2 unit)
- Hanford formation – upper gravelly sequence (H1 unit)
- Backfill
- Recent deposits.

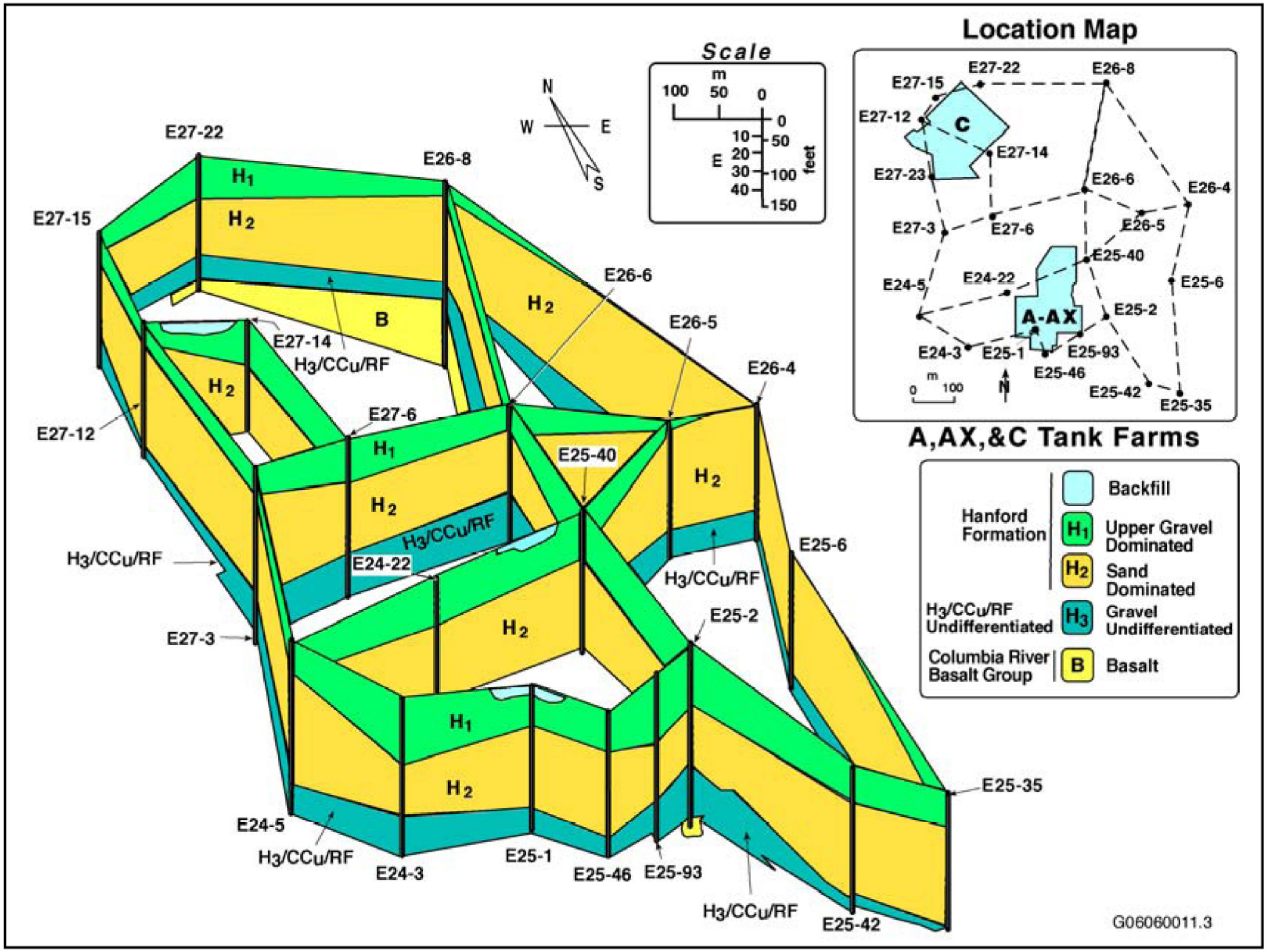
**Figure 3-36. Waste Management Area C Tanks, Infrastructure, and Associated Unplanned Releases.**



WMA = Waste Management Area

The general characteristics of these units are described in more detail in Section 3.1.4, RPP-RPT-46088 and RPP-RPT-56356. At WMA C, it is not possible to separate out the Ringold Formation, CCU and the lower gravely sequence of the Hanford formation (H3). In the vicinity of WMA C, this unit is referred to as undifferentiated H3, CCU and Ringold Formation ($H_3/CC_u/RF$). The SSTs at WMA C were emplaced in an excavation of the Hanford formation sediments of the upper, gravel-dominated (H1) unit. This excavation may also locally intercept the upper portions of the sand-dominated Hanford (H2) unit. Once the tanks were built, the excavation was backfilled with reworked sediments of the upper, gravel-dominated (H1) unit. The water table or the unconfined aquifer's surface lies ~60 m (~200 ft) below the bottom of the tank farms excavations within the undifferentiated $H_3/CC_u/RF$.

Figure 3-37. Fence Diagram Showing Cross-Sections through Waste Management Areas A-AX and C.



Source: RPP-RPT-46088, “Flow and Transport in the Natural System at Waste Management Area C.”

The geologic strata underlying WMA C was characterized in conjunction with soil sampling and borehole logging for radionuclides and hazardous waste constituents as part of the Phase 1 and 2 RCRA Facility Investigations at WMA C. The borehole and geologic logging was used to identify the elevations of tops of the geologic units in the vicinity of WMA C. Specifically potassium, uranium, thorium (K-U-T) data from geophysical logs were used to map the tops of the different geologic units at WMA C (RPP-RPT-56356). Two alternative geologic models were developed based on this data.

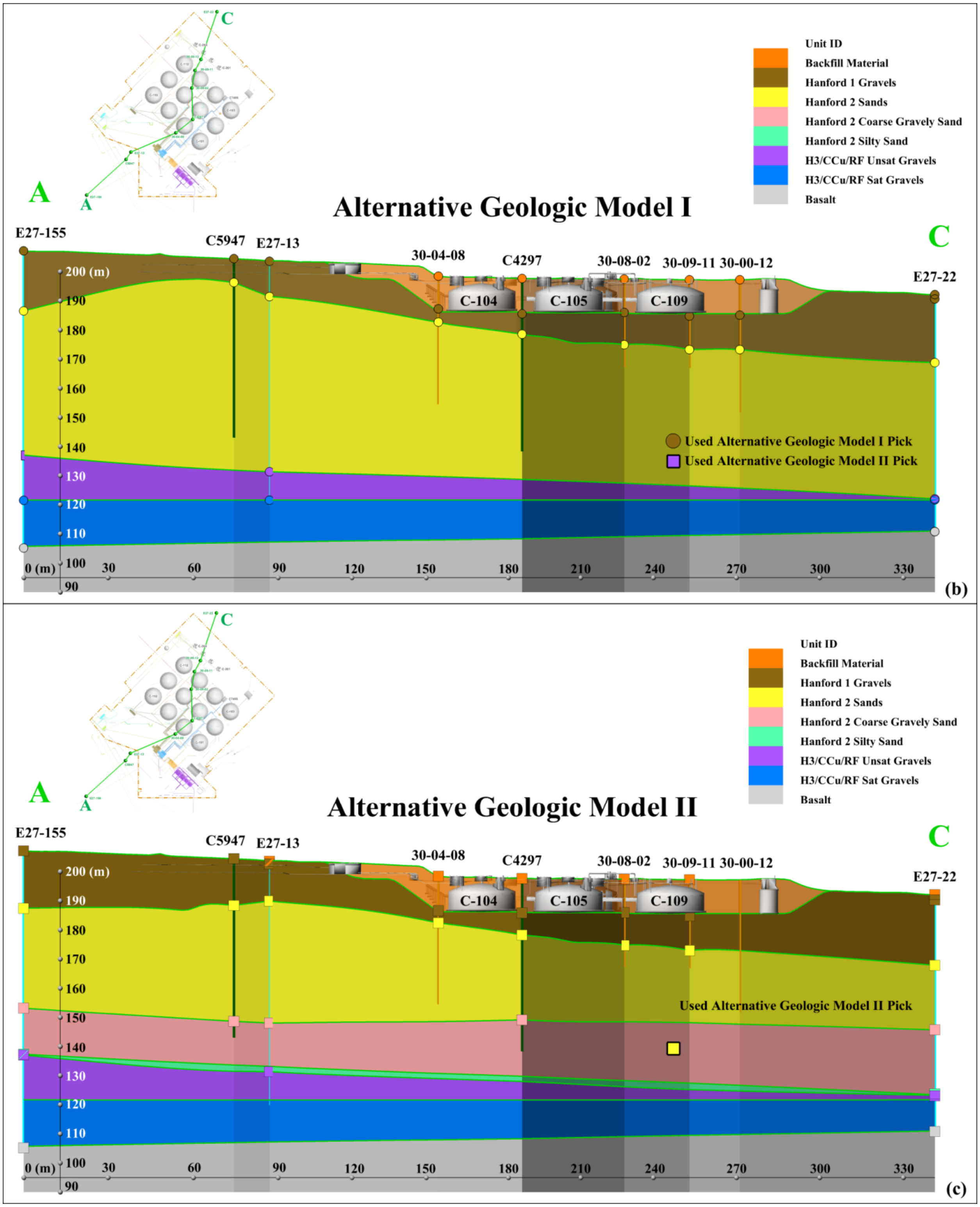
Additional conceptual models are being developed with detailed heterogeneous representations of the geologic framework at WMA C. One is a facies-based model based primarily on a geostatistical analysis of the K-U-T data collected in selected direct push boreholes within WMA C; the other is based on geostatistical evaluations of volumetric moisture content measured in multiple direct push boreholes and drywells within WMA C.

The major difference between the two existing developed alternative models is whether or not a sandy gravel facies is to include a silt layer identified at the bottom of the H2 subunit in the vicinity of WMA C. The K-U-T data (i.e., a lower gross gamma and potassium count) indicates that there is a coarsening of the sand at the bottom of the H2 turning more into a sandy gravel. Underlying this sandy gravel facies is a silt unit with a strong potassium peak and occasional strong natural uranium peak. The difficulty in making this determination is that there are few direct pushes or drywells that are at a sufficient depth to obtain both good geophysical logs and geologic logs (with drill cuttings). The drill cuttings from some of the nearby groundwater wells indicated that there was definite fining of the sands along with some silt found at the vertical location as indicated by the K-U-T data in the geophysical logs, but a competent silt layer was not observed. Alternative Geologic Model I does not include the sandy gravel and underlying silt unit with the H2 unit, while Alternative Geologic Model II does include them. The existence 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 3-38.

**3.1.9.2 Hydrology.** Following is an overview of the hydrology of the vadose zone and uppermost, unconfined aquifer beneath WMA C. More detailed information supporting this section can be found in DOE/ORP-2008-01, RPP-RPT-46088, and RPP-RPT-58339.

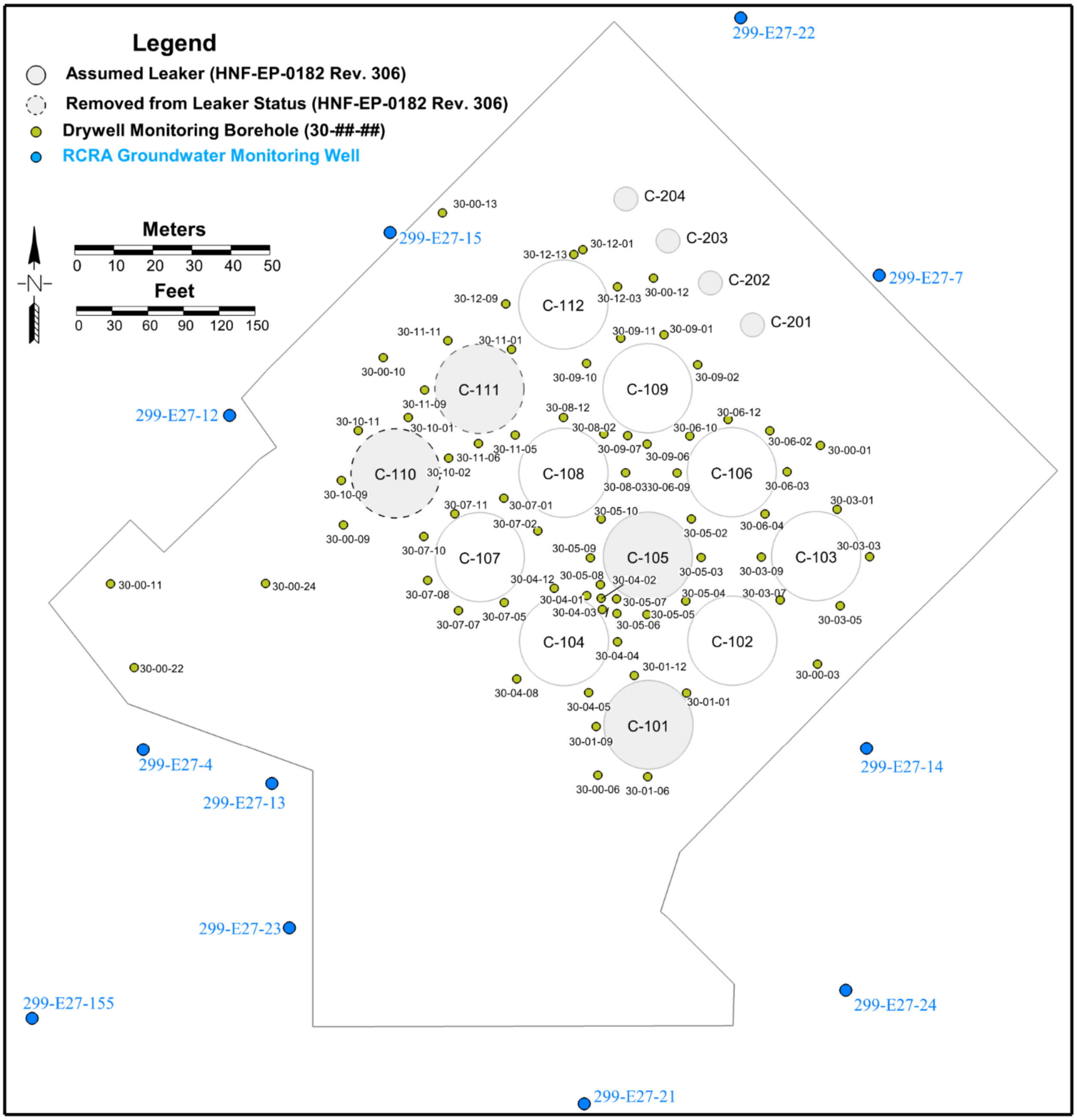
**3.1.9.2.1 Vadose Zone – Monitoring and Characterization Activities.** Waste Management Area C has 70 drywell monitoring boreholes (see Figure 3-39) available for leak detection monitoring and to provide access for limited vadose zone characterization (e.g., geophysical logging). These drywells were drilled from 1944 to 1982. In 1997, C Farm drywells were logged using a high-resolution spectral gamma logging system. This effort was part of the baseline characterization for WMA C. Results are documented in GJO-98-39-TAR/GJO-HAN-18 and its associated addendum GJO-98-39-TARA/GJO-HAN-18. The depth ranges for most of these drywells is between 30.5 and 45.7 m bgs (100 and 150 ft bgs). The deepest drywell in WMA C is 47.2 m bgs (155 ft bgs) (30-00-03), and the maximum logged depth is 43.6 m bgs (143 ft bgs) (30-04-08).

# Figure 3-38. Fence Diagram of Alternative Geologic Models to be Used in Waste Management Area C.



H3/CCu/RF = undifferentiated H3, Cold Creek Unit and Ringold Formation

**Figure 3-39. Vadose Zone and Groundwater Monitoring Network for Waste Management Area C.**



Reference: HNF-EP-0182, "Waste Tank Summary Report for Month Ending September 30, 2013," Rev. 306.

RCRA = Resource Conservation and Recovery Act of 1976

The major gamma-emitting contaminants associated with WMA C are $^{137}$Cs and $^{60}$Co with lesser amounts of $^{154}$Eu. These contaminants are located mostly in and around areas of confirmed or suspected tank and pipeline leaks. Although most of the drywells are deeper than the surrounding contamination, some zones of contamination extend deeper than nearby drywells.

Consequently, the maximum depth of vadose zone contamination is not known in some areas of WMA C.

Since 2004, extensive vadose characterization activities have been conducted at WMA C in support of the RCRA corrective action. The characterization was divided into two phases. The first phase concentrated on characterizing an area of high $^{137}$Cs concentrations observed in drywells at the depth of the base of tank C-105 below the cascade line running between tanks C-104 and C-105 and the pipeline leak known as UPR-200-E-82 close to the 241-C-152 diversion box. The characterization borehole drilled next to tank C-105 was the deepest characterization within WMA C at 59.9 m (196.5 ft) bgs at the time. Results from soil sampling show the greatest concentration of $^{99}$Tc (8.4 pCi/g) and nitrate (20 µg/g [$2.7 \times 10^{-6}$ oz/gal]) at 41.1 to 47.2 m bgs (~135 to 155 ft bgs). Slant direct pushes underneath UPR-200-E-82 found $^{99}$Tc (28.6 pCi/g) and nitrate (19.7 µg/g [$2.6 \times 10^{-6}$ oz/gal]) centered below the pipeline leak at 23.5 m bgs (77 ft bgs). Complete results of the first phase of characterization are documented in DOE/ORP-2008-01 Appendix L.

The second phase started in 2008 and characterization data was collected per the work plan (RPP-PLAN-39114). For Phase 2, site characterization data was collected at the 23 sites identified in Figure 3-40a. Each characterization site was given a letter map designation. The site characterization activities for Phase 2 included the following:

a. Soil collection and analysis through direct push boreholes technology

b. Geophysical logging at drywell boreholes and groundwater monitoring wells

c. Surface Geophysical Exploration

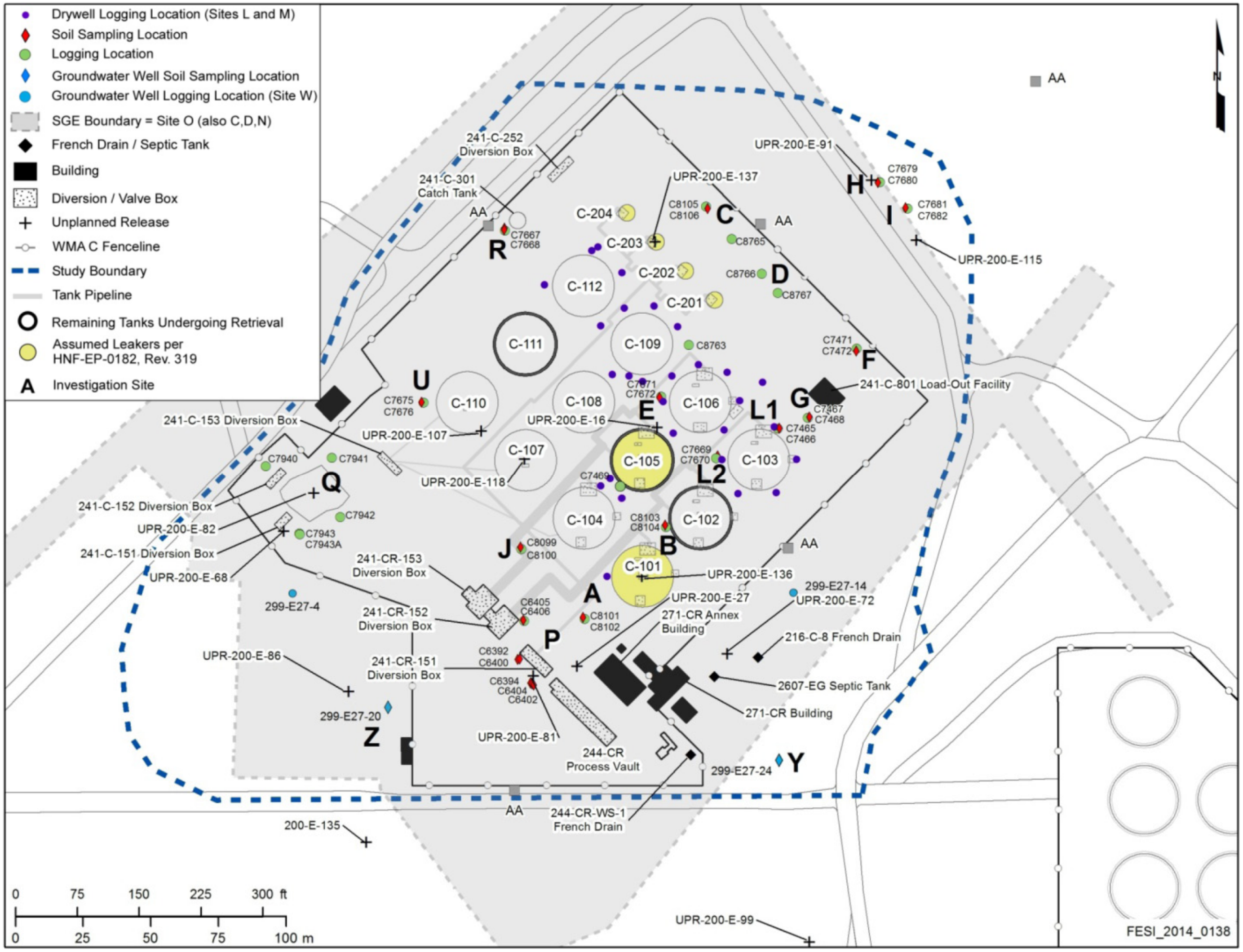
d. Tissue sampling for ecological risk assessment

e. Possible sampling of vadose zone during the installation of any new groundwater wells within ~30 m (~100 ft) of WMA C.

RPP-PLAN-39114 provides a complete description of what was to be collected at each of these sites. During the preparation of the work plan for the Phase 2 characterization, a transitional characterization (Phase 1.5) effort was undertaken and vadose zone characterization took place at two past UPR sites (UPR-200-E-81 and UPR-200-E-86) (Figure 3-40b). 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 collection of soil samples. The results of both the transitional characterization and the Phase 2 characterization efforts are given in RPP-RPT-58339.

**3.1.9.2.2 Vadose Zone – Moisture Content.** Moisture content data from both neutron logging and laboratory analyses were collected during both Phase 1 and 2 characterization efforts of the RCRA Facility Investigation. A statistical summary of this moisture content data is provided here. The reader is referred to Appendix B for additional detailed information about this moisture content data and its use in the PA model development process.

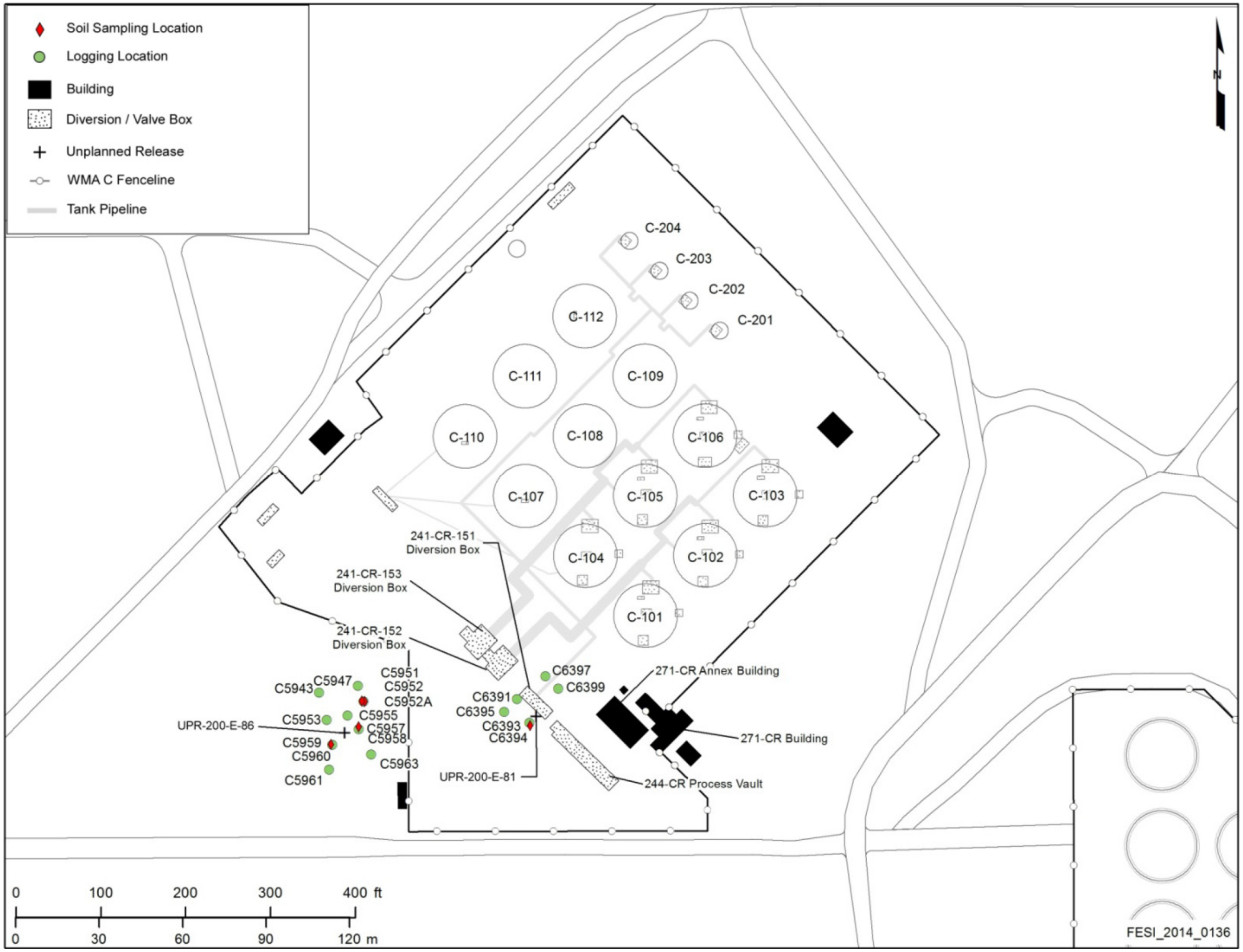
## Figure 3-40a. Completed Phase 2 RCRA Facility Investigation Characterization Locations.



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

RCRA = Resource Conservation and Recovery Act of 1976, 42 USC 6901, et seq.
SGE = Surface Geophysical Exploration
WMA = Waste Management Area

Figure 3-40b. Completed Transitional (Phase 1.5) Characterization Locations.



WMA = Waste Management Area

The neutron logging data came from two drywells and 63 direct push boreholes. Laboratory measured moisture content (weight % converted to volumetric moisture content) came from one groundwater well (299-E27-22) and one characterization borehole (C4297).

The spacing for the neutron logging of moisture content varied from 0.05 m to 0.15 m (~0.15 ft to 0.5 ft). The spacing on the laboratory samples was greater. A total 32,912 measurements were made and moisture content ranged from 0.11 to 30.64 volumetric percent, with a mean of 5.69, and a median of 5.09. Furthermore, the formations were identified in each well/borehole/direct push and a statistical analysis of volumetric moisture content data was run for each formation (Table 3-3). The locations for the moisture content measurements are shown in Figure 3-41.

**3.1.9.2.3 Vadose Zone – Contamination.** Figure 3-42 provides a visualization of the vadose zone contamination beneath WMA C as represented by $^{137}$Cs data and the $^{99}$Tc at borehole C4297. This figure is a three-dimensional (3-D) perspective of WMA C providing locations of tanks and associated drywells. Tanks considered to be leakers are based on information in HNF-EP-0182, "Waste Tank Summary Report for Month Ending February 28, 2015," Rev. 326. For $^{137}$Cs each drywell is represented with a single vertical line. Shaded rings around the drywells indicate the level of vadose zone contamination based on spectral gamma logging results. Only the more significant soil contamination zones (i.e., $^{137}$Cs contamination levels greater than 10 pCi/g) are shown.

Spectral gamma logging data provided in Figure 3-42 indicate the presence of contamination in the region between tanks C-104 and C-105. The most concentrated contamination occurs at drywell 30-05-07 on the southwest side of tank C-105 (Figure 3-42), where two high $^{137}$Cs concentration zones occur at and below the tank bottom (DOE/ORP-2008-01). Also shown on Figure 3-42 are sample locations showing where the more mobile $^{99}$Tc was found in characterization borehole C4297. In addition to the high $^{137}$Cs at tank C-105, evidence from the historical record indicates that three unplanned near-surface release events (UPR-200-E-81, UPR-200-E-82, UPR-200-E-86) occurred on the southwest side of C Farm (Figure 3-36). These events are known to have made relatively significant contributions to vadose zone contamination (RPP-14430, "Subsurface Conditions Description of the C and A-AX Waste Management Area").

The UPR-200-E-81 event occurred near the 241-CR-151 diversion box and involved the loss of ~140,000 L (~36,000 gal) of waste. The UPR-200-E-82 event occurred near the 241-C-152 diversion box and involved the loss of ~10,000 L (~2,600 gal) of waste. The UPR-200-E-86 event occurred in a pipeline break near the southwest corner of C Farm and involved the loss of ~66,000 L (~17,400 gal) of waste. Other UPRs occurred within or near to WMA C (RPP-ENV-33418) and are the subject of further characterization efforts at WMA C (RPP-PLAN-39114). These other UPRs are also shown on Figure 3-36. The Phase 2 RCRA Facility Investigation (RPP-RPT-58339) found low levels of contaminants related to tank waste. However, the contaminant concentrations levels found in the soil are so low that the areas in which they are found are not considered to be the sources for the groundwater contamination at WMA C.

## Table 3-3. Summary Statistics for Volumetric Moisture Content in the Lithologic Units Underlying Waste Management Area C.

| Unit | Count of Wells | Count of Measurements | Minimum (Vol %) | Maximum (Vol %) | Average (Vol %) | Median (Vol %) | Mode (Vol %) | Standard Deviation | Variance |
|---|---|---|---|---|---|---|---|---|---|
| Backfill | 52 | 4,052 | 0.11 | 30.61 | 8.09 | 7.48 | 6.20 | 3.71 | 13.75 |
| H1 | 66 | 7,977 | 0.13 | 30.64 | 5.88 | 4.72 | 3.26 | 3.67 | 13.47 |
| H2 | 64 | 20,876 | 1.06 | 26.32 | 5.15 | 4.96 | 4.89 | 1.82 | 3.30 |
| H3 | 1 | 7 | 5.54 | 7.09 | 6.18 | 6.01 | Too Few | 0.65 | 0.43 |
| Waste Management Area C | 67 | 32,912 | 0.11 | 30.64 | 5.69 | 5.09 | 4.89 | 2.82 | 7.95 |

**Figure 3-41. Moisture Content (% Vol) Measurements in Vadose Zone at Waste Management Area C.**

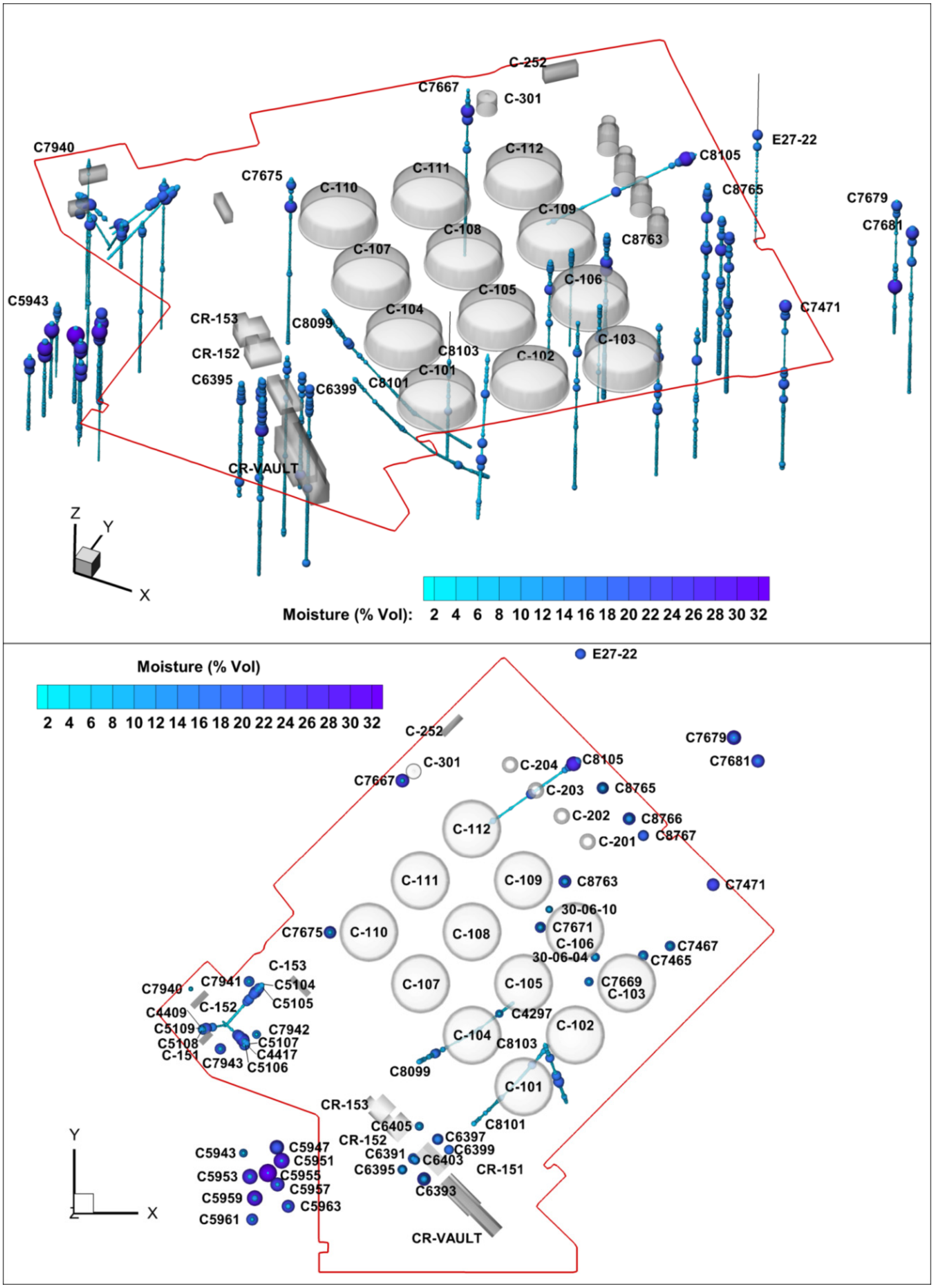
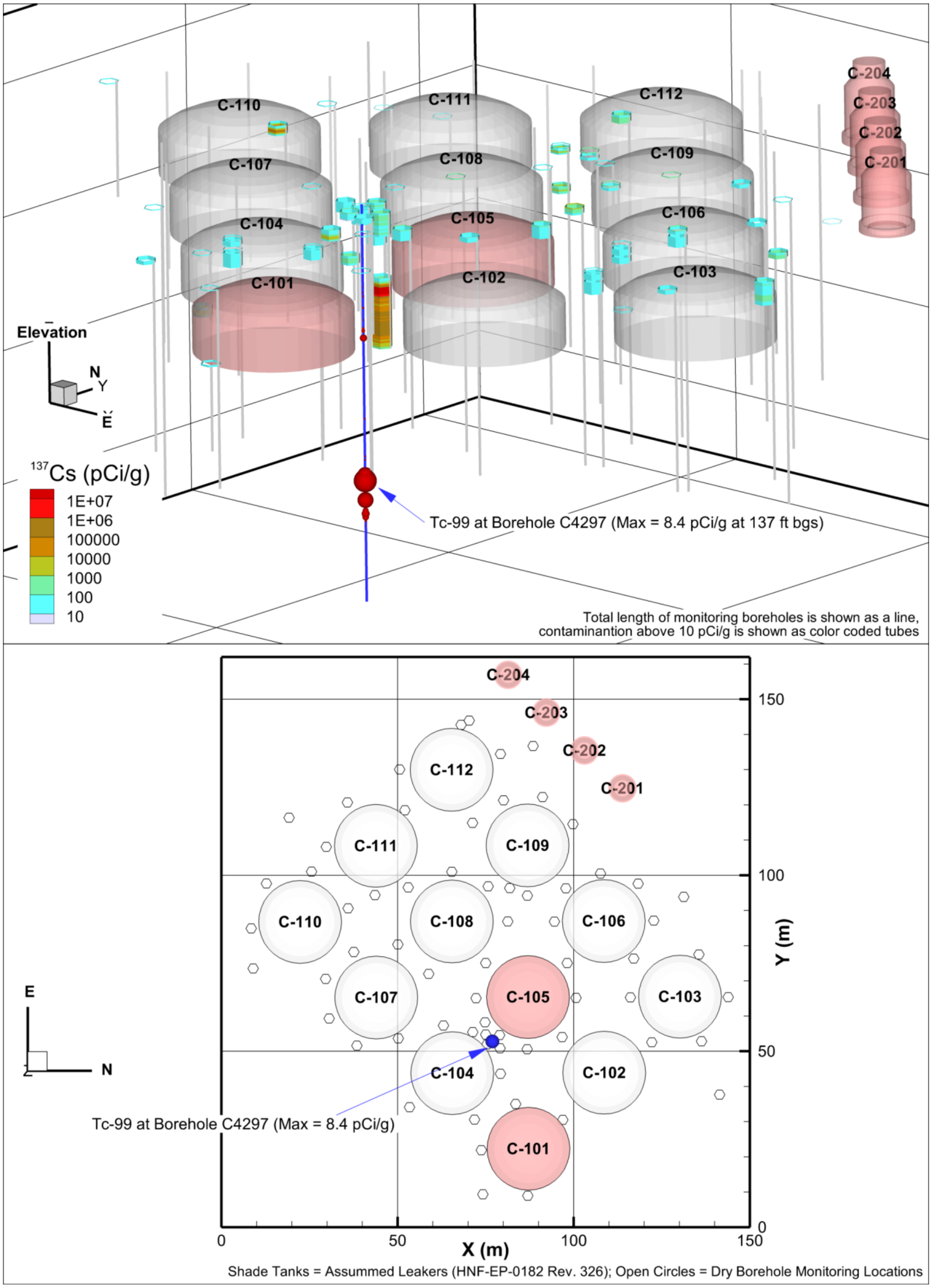


**Figure 3-42. Three-Dimensional Perspective of Waste Management Area C Tanks and Drywells Showing Occurrence of Significant (>10 pCi/g) Cesium-137 Contamination in the Vadose Zone along with Technetium-99 at Borehole C4297.**



Reference: HNF-EP-0182, "Waste Tank Summary Report for Month Ending February 28, 2015," Rev. 326.

**3.1.9.2.4 Unconfined Aquifer – Monitoring.** Quarterly groundwater monitoring was initiated at WMA C in 1992 in accordance with WHC-SD-EN-AP-012, "Interim-Status Groundwater Monitoring Plan for the Single-Shell Tanks." The initial well network consisted of five wells: 299-E27-7, 299-E27-12, 299-E27-13, 299-E27-14, and 299-E27-15 (Figure 3-39). These wells were used for quarterly groundwater monitoring beginning in March 1992 and continued until the Fall of 1993. In the Spring of 1994, semi-annual sampling began for indicator parameter evaluation. Monthly sampling began in June 1998 to prepare for sluicing at tank C-106. The monthly sampling was scaled back to bi-monthly in 2000 and then returned to quarterly sampling in 2001. In 2001, a new monitoring plan, PNNL-13024, "RCRA Groundwater Monitoring Plan for Single-Shell Tank Waste Management Area C at the Hanford Site," was initiated and required additional wells to ensure adequate monitoring network coverage for WMA C. Wells 299-E27-4, 299-E27-21, 299-E27-22, and 299-E27-23 (Figure 3-39) were subsequently added to the network.

In 2009, WMA C was placed in assessment monitoring because of the exceedance of the critical mean for the indicator parameter specific conductance. In addition, the dangerous constituent cyanide has been found in groundwater beneath WMA C, albeit at levels much lower than the DWS. To meet quarterly RCRA assessment requirements, a new monitoring plan (DOE/RL-2009-77, Groundwater Quality Assessment Plan for the Single-Shell Tank Waste Management Area C) was developed which superseded PNNL-13024. Currently, assessment monitoring is being completed in accordance with DOE/RL-2009-77. Three wells (299-E27-24, 299-E27-25, and 299-E27-155; see Figure 3-39) were added to the network per DOE/RL-2009-77. Well 299-E27-25 is not shown on Figure 3-39; it is located ~170 m (~550 ft) northeast of the northeast fenceline of WMA C. The network now is composed of 12 WMA C monitoring network wells.

In addition to meeting the quarterly assessment requirements, quarterly monitoring is also done to meet the requirements of External letter 04-TPD-083, "Agreement on Content of Tank Waste Retrieval Work Plans," in which quarterly groundwater monitoring sample results are to be provided to Ecology during tank retrievals. To meet the sampling requirements, the groundwater monitoring analyses include RCRA and AEA constituents from the following: anions, cyanide, metals, $^{99}$Tc, gross beta, total uranium, and low-level gamma scan. The most recent quarterly monitoring report is SGW-58561, "WMA C Quarterly October Through December 2014 Quarterly Groundwater Monitoring Report."

**3.1.9.2.5 Unconfined Aquifer – Groundwater Flow Conditions.** The water table or potentiometric surface lies ~60 m (~200 ft) below the bottom of the tank farm excavations within the undifferentiated $H_3/CC_u/RF$. The aquifer materials consist dominantly of sandy gravel or silty sandy gravel. The water table elevation beneath WMA C is ~122 m (400 ft) NGVD88 with ~77 m (255 ft) of vadose zone. The aquifer thickness, based on the top of basalt at 108 m (355 ft), is ~13.4 m (44 ft). Hydraulic conductivity values reported for the aquifer in this area vary considerably, ranging from 0.04 (silt lenses within the sandy gravel) to 6,900 m/day (1.6 in. to 22,600 ft). Additional hydraulic property data from aquifer testing at wells near WMA C is provided in RPP-RPT-46088.

Currently, the general groundwater flow direction in the unconfined aquifer beneath WMA C is to the south/southeast. The water table is very flat overall, with an estimated hydraulic gradient between $1 \times 10^{-5}$ to $2 \times 10^{-5}$ m/m; the estimated groundwater flow velocity ranges from 0.2 to 0.4 m/day (0.7 to 1.3 ft/day) (RPP-RPT-46088). Those hydraulic gradient estimates are also consistent with those recently reported in SGW-54165, "Evaluation of the Unconfined Aquifer Hydraulic Gradient Beneath the 200 East Area, Hanford Site" for the unconfined aquifer near the Integrated Disposal Facility (IDF) and PUREX cribs. Also coincident with the flow change are decreasing concentrations of other contaminants in monitoring wells west of C Farm, indicating a change in flow direction. These observations and other interpretations discussed in SGW-58561 provide sufficient evidence for the determination of a south to southeast flow direction at WMA C.

The discharge of large volumes of wastewater in the early 1950s to B Pond raised the water table in the vicinity of WMAs C and A-AX as much as 4.9 m (16 ft) above the pre-Hanford Site operations level (PNNL-14548, "Hanford Site Groundwater Monitoring for Fiscal Year 2003"). The corresponding flow direction underneath WMA C at this time was toward the southwest (DOE/ORP-2008-01 Appendix H). Water levels began to decline in the late 1980s when wastewater discharges were reduced. The decline has become even more pronounced since other effluent discharges throughout the 200 Areas ceased in 1995. Water levels are expected to continue declining within the region surrounding WMAs A-AX and C, with the flow direction changing to the southeast. With the change in flow direction, contamination originating in the B Complex in the northwest corner of 200 East may flow underneath WMA C in the not too distant future.

**3.1.9.2.6 Unconfined Aquifer – Contamination.** Observations of elevated concentrations of nitrate, sulfate, and $^{99}$Tc appear to be associated with past releases from WMA C because these constituents are much higher in the downgradient wells compared to upgradient wells, and they exceed their respective groundwater DWSs. Additionally, cyanide, which is a dangerous waste constituent, is also found in the aquifer at levels above the detection limit, but well below the DWS of 200 µg/L ($2.7 \times 10^{-5}$ oz/gal). The measured cyanide concentration was 13.9 µg/L ($1.9 \times 10^{-6}$ oz/gal) in December 2013 at well 299-E27-14. Only $^{99}$Tc and cyanide are discussed further in this section. Technetium-99 exceeded the DWS by a factor of almost 30 and cyanide is a dangerous waste constituent. For discussions and interpretations of the overall trends of other constituents in monitoring wells in the vicinity of WMA C, the reader is referred to SGW-58561.

In December 2014, $^{99}$Tc had concentrations exceeding the 900 pCi/L DWS in 7 of the 11 monitoring wells surrounding WMA C (Figure 3-43). However in 2006, only 4 of the 11 wells exceeded the DWS. Three of these wells (299-E27-4, 299-E27-13, and 299-E27-23) are located just outside the south-central region of WMA C (Figure 3-39). The other well that exceeded the DWS is 299-E27-14, located east of WMA C. Two new wells (299-E27-155 and 299-E27-4) placed to the south and east of WMA C after 2006 also showed $^{99}$Tc concentrations above the DWS when they were installed. The $^{99}$Tc in the groundwater in that region appears to be centered on well 299-E27-23 with the trend in that well increasing from ~5,000 pCi/L in late 2006 to ~26,000 pCi/L by April 2012. Since then, the trend at the well has been decreasing, falling to ~3,400 pCi/L by December 2014. This decline is associated with changes in the flow direction to the east and southeast. The resulting change in flow direction and sampling in downgradient wells (299-E27-21 and 299-E27-24) from 299-E27-23 show $^{99}$Tc increasing in these wells, indicating plume movement to the east-southeast. Finally, at well 299-E27-14, $^{99}$Tc values ranged between 1,500 and 2,600 pCi/L from 2006 to late 2012. However, in early 2013 they started increasing, peaking in June of 2013 at 10,700 pCi/L and decreasing since then; they had decreased to 6,200 pCi/L by December 2014. It is believed the $^{99}$Tc found at well 299-E27-14 is from a different source than $^{99}$Tc found in the south-central region of WMA C.

The specific source of $^{99}$Tc in the groundwater at WMA C has not been identified.

The dangerous waste constituent cyanide was detected at four WMA C wells in December 2014 at concentrations far below the 200 µg/L DWS. A possible reason for the increased number of wells with detectable cyanide between June and December is that the detection limit for cyanide decreased from 4 to 1.67 µg/L ($5.3 \times 10^{-7}$ oz/gal to $2.2 \times 10^{-7}$ oz/gal). Three of the four wells (299-E27-7, 299-E27-14, and 299-E27-23) with detected cyanide were reported with concentrations between 3 and 4 µg/L ($4.0 \times 10^{-7}$ oz/gal to $5.3 \times 10^{-7}$ oz/gal). The other well (299-E27-4) was detected with 7.9 µg/L ($1.1 \times 10^{-6}$ oz/gal). Concentrations at well 299-E27-4 are generally near the detection level but were higher in December of 2009, 2011, and 2014 (10.4, 7.98, and 7.9 µg/L [$1.39 \times 10^{-6}$ oz/gal, $1.06 \times 10^{-6}$ oz/gal and $1.07 \times 10^{-6}$ oz/gal], respectively). Remnant levels of low cyanide concentrations appear to be present sporadically beneath the eastern and western portions of the C Farm facility, while more persistent concentrations exist to the southeast (wells 299-E27-14 and 299-E27-24) as can be seen in Figure 3-44. However, cyanide concentrations have appeared to diminish beneath C Farm. The highest cyanide concentration in December 2014 was 7.9 µg/L ($1.1 \times 10^{-6}$ oz/gal) at well 299-E27-4. As discussed in DOE/RL-2009-77, the source is likely be related to past releases from WMA C, but a specific source within WMA C has not been identified.

## 3.2 WASTE MANAGEMENT AREA C PRINCIPAL FACILITY DESIGN FEATURES

Waste Management Area C is part of the Hanford Site SST system consisting of 149 underground SSTs and processing equipment designed and constructed between 1940 and 1964 to transport and store radioactive and hazardous chemical wastes generated from irradiated nuclear fuel processing. The tanks, designed to store waste, vary in size from 190,000 to 3,800,000 L (50,000 gal to 1,000,000 gal) and contain a variety of solid and liquid waste. In addition to the tanks, a large amount of ancillary equipment associated with the system exists and, although not designed to store wastes, the ancillary equipment is contaminated through contact with the waste. Waste was routed to the tanks through a network of underground waste transfer piping, with interconnections provided in concrete pits that allowed changes to the routing through instrumentation. Processing vaults used during waste handling operations, evaporators used to reduce the waste stored in the system, and other miscellaneous structures used for a variety of waste handling operations are also included in the system. The SST system was taken out of service in 1980 and no additional waste has been added to the tanks.

**Figure 3-43. Technetium-99 Concentrations in Waste Management Area C Wells from January 2006 through December 2014.**

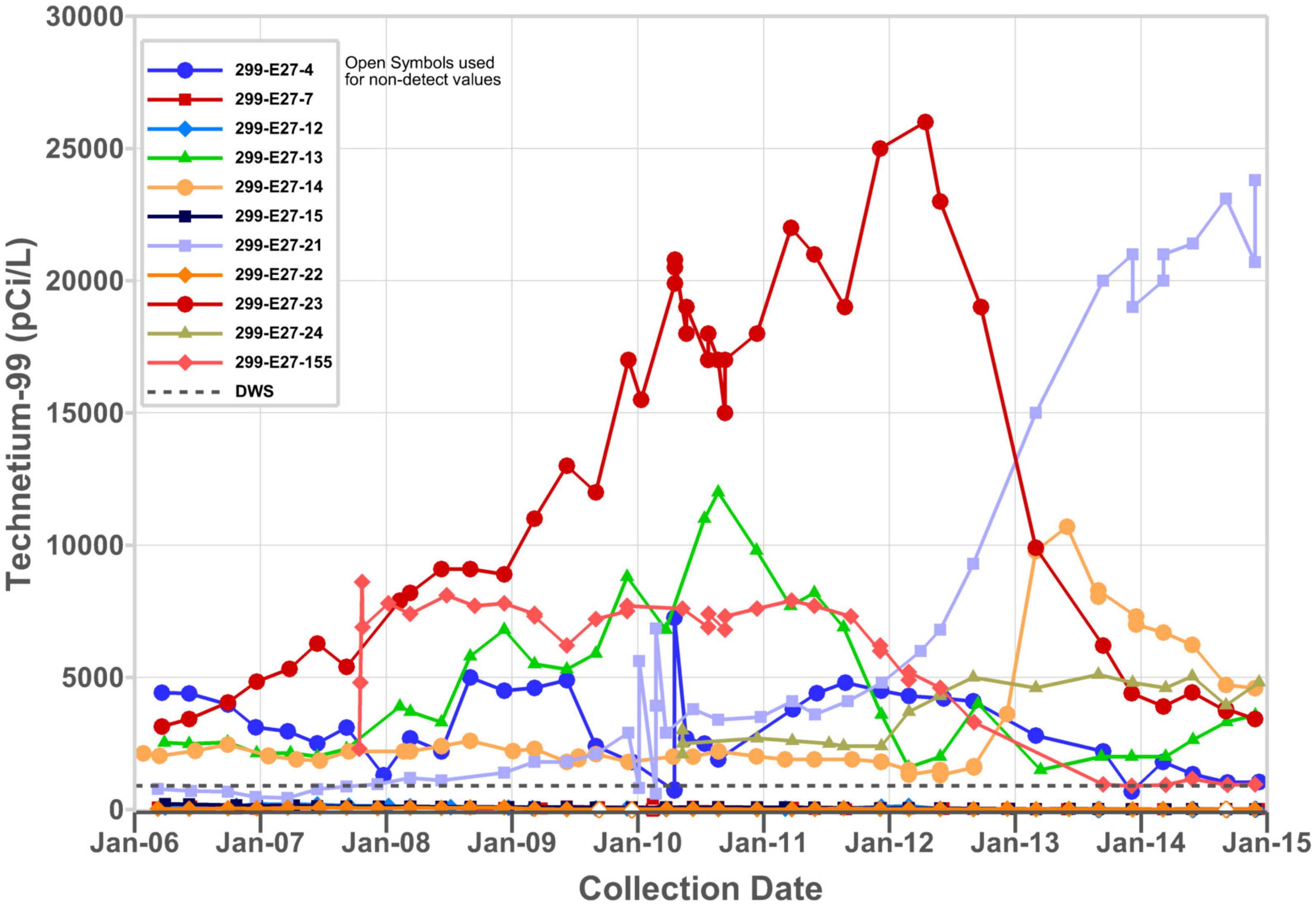
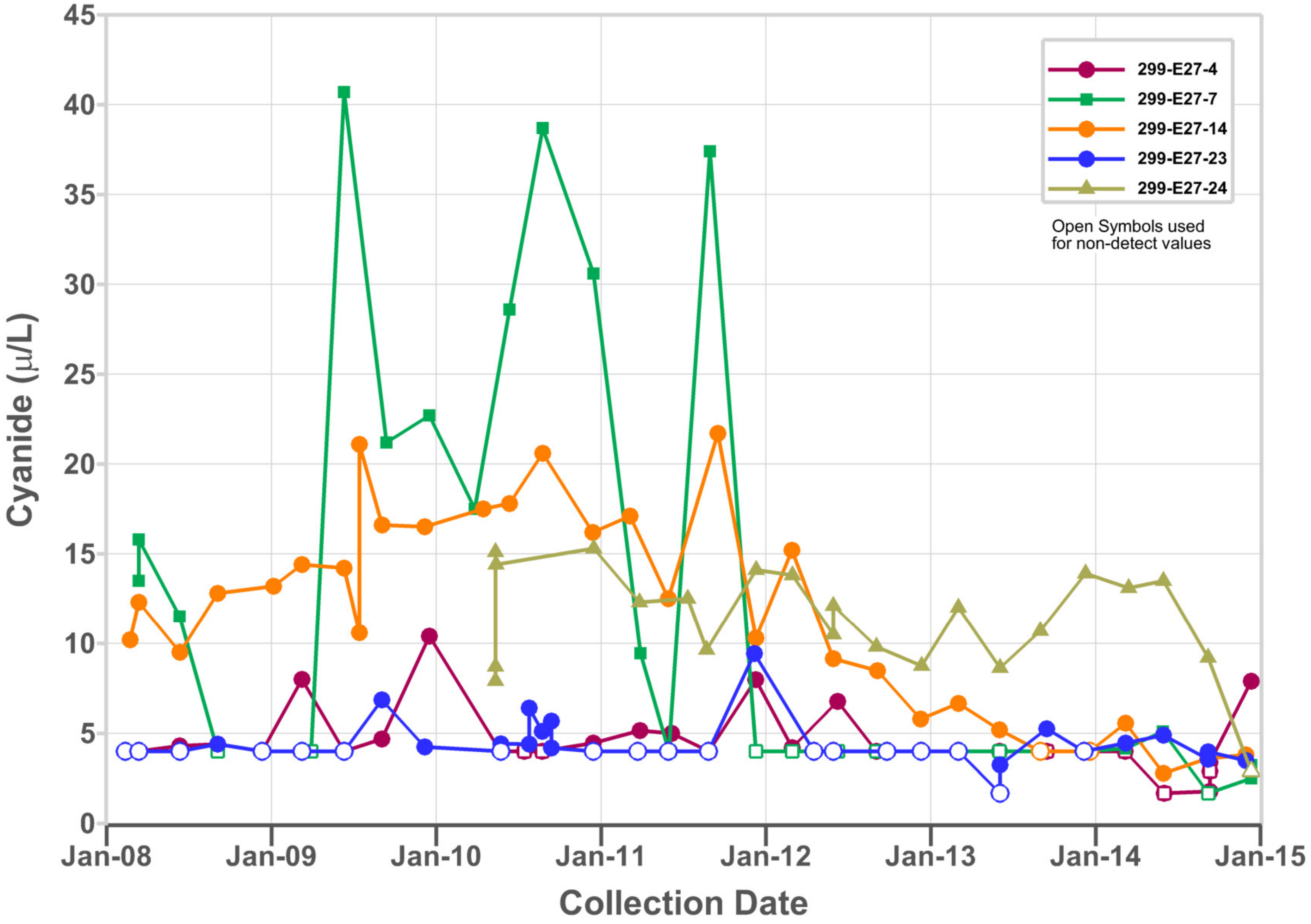


Figure 3-44. Cyanide Concentrations in Waste Management Area C Wells from January 2006 through December 2014.



For the landfill closure[1] of WMA C, site closure 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. This section provides site-specific information for WMA C. It is a summary from the most recent documents that describe present conditions, geology and hydrology, subsurface contamination, and source terms. The list of these documents and what they contain is given in Appendix A. The majority of these documents were produced to support the working sessions for the WMA C PA that took place from February 2009 to May 2011. In addition to the data packages, several other documents have been produced after the working sessions that provide updated information on WMA C facility characteristics.

### 3.2.1 Facility Description

Waste Management Area C is located in the east central portion of the 200 East Area (Figure 3-4) in land that is designated to be Industrial-Exclusive. Waste Management Area C is one of seven WMAs (A-AX, B-BX-BY, C, S-SX, T, TX-TY, and U) containing 149 SSTs built from 1943 to 1964 (Figure 3-2). In general, the WMA C boundary is represented by the fenceline surrounding the C Farm (Figure 3-3). Waste Management Area C contains twelve 100-Series SSTs and four 200-Series SSTs that were constructed in 1943 to 1944 along with associated ancillary equipment (i.e., diversion boxes, pipes). It was placed in service in 1946, and used to store and transfer waste until the mid-1980s. Additional ancillary equipment (244-CR vault and CR diversion boxes) were added in the early 1950s. Because of its long operational history, C Farm received waste generated by essentially all of the Hanford Site major chemical processing operations including bismuth phosphate fuel processing, uranium recovery, PUREX fuel processing, Hot Semiworks Facility pilot plant operations, fission product recovery, and tank farm interim stabilization and isolation activities.

Fifteen of the 16 WMA C SSTs were interim stabilized between 1981 and 2003 (HNF-SD-RE-TI-178, "Single-Shell Tank Interim Stabilization Record"). The interim stabilization process removed as much pumpable liquid as practicable. "Practicable" means pumping was continued until the pump rate was less than 0.19 L/min (0.05 gpm). Only tank C-106 was not interim stabilized. This tank went directly to retrieval. The waste in the WMA C tanks is currently in the process of being retrieved and transferred to Hanford's double-shell tanks. However, not all waste can be retrieved and estimates of the inventory of radionuclides and hazardous chemicals remaining in the tank residuals after closure are given in Section 3.2.2.

**3.2.1.1 Infrastructure.** This section summarizes the information given in the following data packages produced for the working sessions: RPP-RPT-44042, "Recharge and Waste Release within Engineered System in Waste Management Area C" and RPP-RPT-46879, "Corrosion and Structural Degradation within Engineered System in Waste Management Area C." Table 3-4 lists the WMA C infrastructure components that were included in the WMA C PA. Inventories of radionuclides and hazardous chemicals remaining in these components are provided in Section 3.2.2.

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[1] 78 FR 75913, "Record of Decision: Final Tank Closure and Waste Management Environmental Impact Statement for the Hanford Site, Richland, Washington" (December 13, 2013).

## Table 3-4. Operating Period and Capacities for Waste Management Area C Facilities Included in the Performance Assessment.*

| Facility | Interim Stabilized | Constructed | Operating Capacity (gal) |
|---|---|---|---|
| *Single-Shell Tanks* | | | |
| 241-C-101 | 1983 | 1943 to 1944 | 530,000 |
| 241-C-102 | 1995 | 1943 to 1944 | |
| 241-C-103 | 2003 | 1943 to 1944 | |
| 241-C-104 | 1989 | 1943 to 1944 | |
| 241-C-105 | 1995 | 1943 to 1944 | |
| 241-C-106 | N/A | 1943 to 1944 | |
| 241-C-107 | 1995 | 1943 to 1944 | |
| 241-C-108 | 1984 | 1943 to 1944 | |
| 241-C-109 | 1983 | 1943 to 1944 | |
| 241-C-110 | 1995 | 1943 to 1944 | |
| 241-C-111 | 1984 | 1943 to 1944 | |
| 241-C-112 | 1990 | 1943 to 1944 | |
| 241-C-201 | 1982 | 1943 to 1944 | 55,000 |
| 241-C-202 | 1981 | 1943 to 1944 | |
| 241-C-203 | 1982 | 1943 to 1944 | |
| 241-C-204 | 1982 | 1943 to 1944 | |
| *Miscellaneous Underground Storage Tanks* | | | |
| **Facility** | **Removed From Service** | **Constructed** | **Operating Capacity (gal)** |
| 241-C-301 catch tank | 1988 | 1946 | 36,000 |
| 244-CR-001 vault tank** | 1988<br>(244-CR Process Tank Vault) | 1946 | 40,000 |
| 244-CR-002 vault tank** | | 1946 | 15,000 |
| 244-CR-003 vault tank** | | 1946 | 15,000 |
| 244-CR-011 vault tank** | | 1946 | 40,000 |
| *Underground Waste Transfer Lines* | | | |
| 241-C tank farm pipelines | N/A | 1943 to 1944 | ~26,700 |
| 241-C-151 | 1985 | 1946 | N/A |
| 241-C-152 | 1985 | 1946 | N/A |
| 241-C-153 | 1985 | 1946 | N/A |
| 241-C-252 | 1985 | 1946 | N/A |
| 241-CR-151 | 1985 | 1952 | N/A |
| 241-CR-152 | 1985 | 1952 | N/A |
| 241-CR-153 | 1985 | 1952 | N/A |

* Data on the facilities are from DOE-RL-88-30, Hanford Site Waste Management Units Report; RPP-15043, "Single-Shell Tank System Description"; RPP-PLAN-47559, Single-Shell Tank Waste Management Area C Pipeline Feasibility Evaluation."

** Capacity estimates for tanks associated with the 244-CR Process Tank Vault are from HNF-EP-0182, "Waste Tank Summary Report for Month Ending February 29, 2016," Rev. 338.

N/A = not applicable

**3.2.1.1.1 Single-Shell Tanks.** The 241-C Tank Farm (C Farm, i.e., WMA C) contains 12 first-generation, reinforced-concrete tanks with carbon steel liners covering the sides and bottoms. The 100-series tanks are 23 m (75 ft) in diameter, with a maximum 5-m (16-ft) depth and 2,006,000-L (530,000-gal) design capacity. The 200-series tanks are 6 m (20 ft) in diameter with a maximum 7-m (24-ft) depth and 208,000-L (55,000-gal) design capacity. Typical tank configuration and dimensions are shown in Figure 3-45. The 100-series tanks sit below grade with at least 2 m (7 ft) of soil cover to provide shielding from radiation exposure to operating personnel. Tank pits are located on top of the 100-series tanks and provide access to the tank, pumps, and monitoring equipment.

The SSTs were constructed in place with carbon steel (ASTM A283/A283M-03, "Standard Specification for Low and Intermediate Tensile Strength Carbon Steel Plates") lining the bottom and sides of a reinforced concrete shell. The tanks have concave bottoms (i.e., center of tanks lower than the perimeter) and a curving intersection of the sides and bottom (Figure 3-46). The inlet and outlet lines are located near the top of the liners (Figure 3-45). The tanks are arranged in four rows of three tanks. The tanks in each row are piped together so that when the first tank fills, it overflows (cascades) into the second tank, and the second into the third. The four smaller 200-series tanks are piped to diversion box 241-C-252 (Figure 3-45). For additional history of types of waste that went into WMA C, please see RPP-RPT-44042.

The HFFACO Appendix H requires that tanks C-103 and C-106 be retrieved to less than 10.2 $m^3$ (360 $ft^3$) for 100-series SSTs and 0.85 $m^3$ (30 $ft^3$) for 200-series SSTs or the limit of technology, whichever is lower. The thresholds of 10.2 $m^3$ (360 $ft^3$) and 0.85 $m^3$ (30 $ft^3$) were the average calculated residual volume left in each of the 100-series and 200-series SSTs, respectively, after 99% of the waste is retrieved. The C Farm will be the first tank farm at Hanford to be completely retrieved. The limits of technology that govern the retrieval process for tanks C-101, C-102, C-104, C-105, C-107, C-108, C-109, C-110, C-111, C-112 are provided in the Consent Decree in Washington v. DOE, Case No. CV-08-5085-RMP (E.D. Wa. October 25, 2010). Table 3-5 provides the current status of retrieval operations at WMA C as of February 28, 2015.

**3.2.1.1.2 Ancillary Equipment.** To support the transfer and storage of waste within the WMA C SSTs, a complex waste transfer system of pipelines (waste transfer lines), diversion boxes, vaults, valve pits, and other miscellaneous structures exists. Collectively, these are referred to as ancillary equipment, as shown in Figure 3-36. Multiple levels of piping were installed over time in WMA C. A time line of piping installations is described in (RPP-7494). It is estimated that there are ~11 km (~7 mi) of waste transfer piping in C Farm (RPP-PLAN-47559). Estimated total volume of piping is given in Table 3-4; estimated volume of residuals remaining in pipes after closure is 5,962 L (1,575 gal) (RPP-PLAN-47559).

The 244-CR vault is located south of the tanks. The vault is a two-level, multi-cell, reinforced-concrete structure constructed below grade (DOE/RL-92-04, PUREX Source Aggregate Area Management Study Report), which contains four underground tanks along with overhead piping and equipment. This reference estimated a capacity of 170,343 L (45,000 gal) each for two tanks (TK-CR-001 and TK-CR-011) and a capacity of 55,494 L (14,700 gal) each for the other two tanks (TK-CR-002 and TK-CR-003). HNF-EP-0182 currently lists the capacities of TK-CR-001 and TK-CR-011 as 151,400 L (40,000 gal) each and the capacities of

TK-CR-002 and TK-CR-003 as 56,775 L (15,000 gal) each. This vault and associated diversion boxes 241-CR-151, 241-CR-152, and 241-CR-153 were constructed in 1951 and ceased operating in 1988. Figure 3-47 shows the waste pH, temperature, and volume estimates in 2005. Approximately 98% of the liquid volume in the cells was removed in early 2010 (RPP-RPT-45845, "Completion of Pumpable Liquid Removal from 244-CR Vault"). In addition to the tanks in the 244-CR vault, a catch tank C-301 exists that was used to catch waste from the diversion boxes.

The routing of liquid waste from the operations buildings to the tank farms was accomplished using underground transfer lines, diversion boxes, and valve pits. The diversion boxes housed jumpers (remote pipeline connectors) where waste could be routed from one transfer line to another. The diversion boxes are below-ground, reinforced-concrete boxes that were designed to contain any waste that leaked from the high-level waste (HLW) transfer line connections. Per 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), the interior surfaces of diversion boxes were coated with a chemically resistant paint. If waste leaked into a diversion box, it generally drained by gravity to nearby catch tanks where any spilled waste was stored and then pumped to SSTs (DOE/RL-92-04). The seven diversion boxes located within WMA C are labeled (241-) C-151, C-152, C-153, C-252, CR-151, CR-152, and CR-153 on Figure 3-36.

**3.2.1.2 Closure.** The TC&WM EIS ROD (78 FR 75913) was published on December 13, 2013. It states the following:

> "SST closure operations include filling the tanks and ancillary equipment with grout to immobilize the residual waste. Disposal of contaminated equipment and soil will occur on site. The tanks will be grouted 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 post-closure care."

Waste Management Area C closure is anticipated to occur during the next decade (i.e., ~2020), at which time the tanks will be filled with grout and covered with a final closure cover. Although tank leaks and soil releases have been identified in C Farm, for a nominal modeling case it is assumed that at the time of closure the C Farm tank liners will be intact. This is because tank C-105 is the only C Farm tank currently assumed to have a breach in the liner, with ~40% probability (RPP-ASMT-46452, "Tank 241-C-105 Leak Assessment Completion Report"). There are several other sources of releases near this tank and a liner breach for this tank is not confirmed. Other releases were assessed to have occurred high on the tank wall or to be cascade line or spare inlet releases (tanks C-101, C-104, C-108 and C-110). Liquid level decreases in tank C-111 and in the C-200-series tanks were assessed to be caused by evaporation with no apparent releases to the soil (RPP-ENV-33418). Drywell and leak detection monitoring to date in the vicinity of tanks retrieved showed no evidence of leakage during retrieval (RPP-RPT-58386, "Retrieval Data Report for Single-Shell Tank 241-C-101"; RPP-RPT-33060, "Retrieval Data Report for Single-Shell Tank 241-C-103"; RPP-RPT-54072, "Retrieval Data Report for Single-Shell Tank 241-C-104"; RPP-20577, "Stage II Retrieval Data Report for

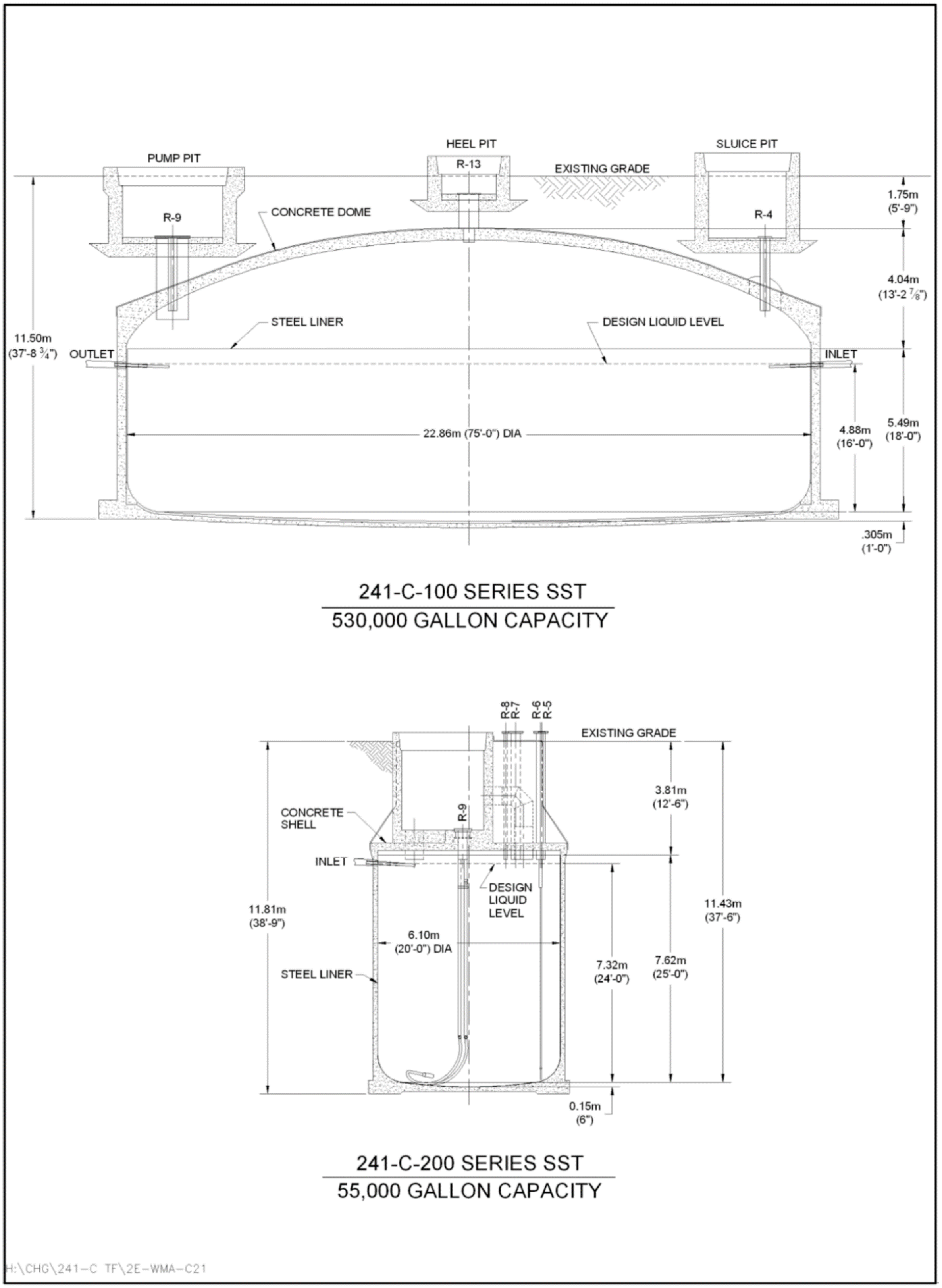
Single-Shell Tank 241-C-106"; RPP-RPT-58295, "Retrieval Data Report for Single-Shell Tank 241-C-107"; RPP-RPT-55896, "Retrieval Data Report for Single-Shell Tank 241-C-108"; RPP-RPT-55284, "Retrieval Data Report for Single-Shell Tank 241-C-109"; RPP-RPT-56796, "Retrieval Data Report for Single-Shell Tank 241-C-110"; RPP-RPT-58490, "Retrieval Data Report for Single-Shell Tank 241-C-112"; RPP-RPT-26475, "Retrieval Data Report for Single-Shell Tank 241-C-203"; RPP-RPT-29095, "Retrieval Data Report for Single-Shell Tank 241-C-202"; RPP-RPT-30181, "Retrieval Data Report for Single-Shell Tank 241-C-201"; RPP-RPT-34062, "Retrieval Data Report for Single-Shell Tank 241-C-204"), indicating that the waste containment appears to be intact for these tanks. In addition, operational high resolution resistivity monitoring data to date, in the vicinity of the remaining tanks undergoing retrieval (C-102, C-105, and C-111), shows no evidence of waste losses during the retrieval process (e-mail from A. R. Olander to J. G. Field, "RE: WMA C PA - Editing" (Olander, A. R., 2016-05-03); e-mail from A. R. Olander to M. P. Bergeron, "RE: WMA C PA - Editing" (Olander, A. R., 2016-08-18)). Recent summary information on depth gamma and moisture measurements made in dry wells near tank C-102 (HGLP-MBL-018, "241-C-102 Tank Waste Retrieval Project Final Report of Drywell Monitoring Data") before and after retrieval supports this general conclusion. The monitoring data results collected during retrieval of tank C-105 call into question the hypothesis of a possible breach in the liner of tank C-105.

While the tanks most likely will be filled with grout following retrieval of the waste in the tanks, the final closure cover may be delayed because of the proximity to nearby single-shell and double-shell tanks just to the east and southeast of WMA C. With the presence of grout in tanks and the possible use of a suitable interim cover over the tank farm, the delay in placement of final closure cover is not expected to have a significant adverse impact on the potential contaminant releases to the groundwater pathway from the tank farm after closure. This section summarizes information provided in RPP-RPT-44042 and RPP-RPT-46879.

**3.2.1.2.1 Stabilization of Tank and Selected Components with Grout Fill.** After the retrieval of the residual waste, the SSTs and some of the ancillary equipment and components (i.e., C-301 catch tank, 244-CR vault, and diversion boxes but not pipelines) within WMA C will be filled with grout. Grout is a material formed from cement, fly ash, fine aggregate, sodium bentonite clay, and water to create a free-flowing material that can be used to fill the tanks after waste retrieval is completed. The grout hardens in the tanks to stabilize the residual waste and provide structural stability for landfill closure of the tank farms.

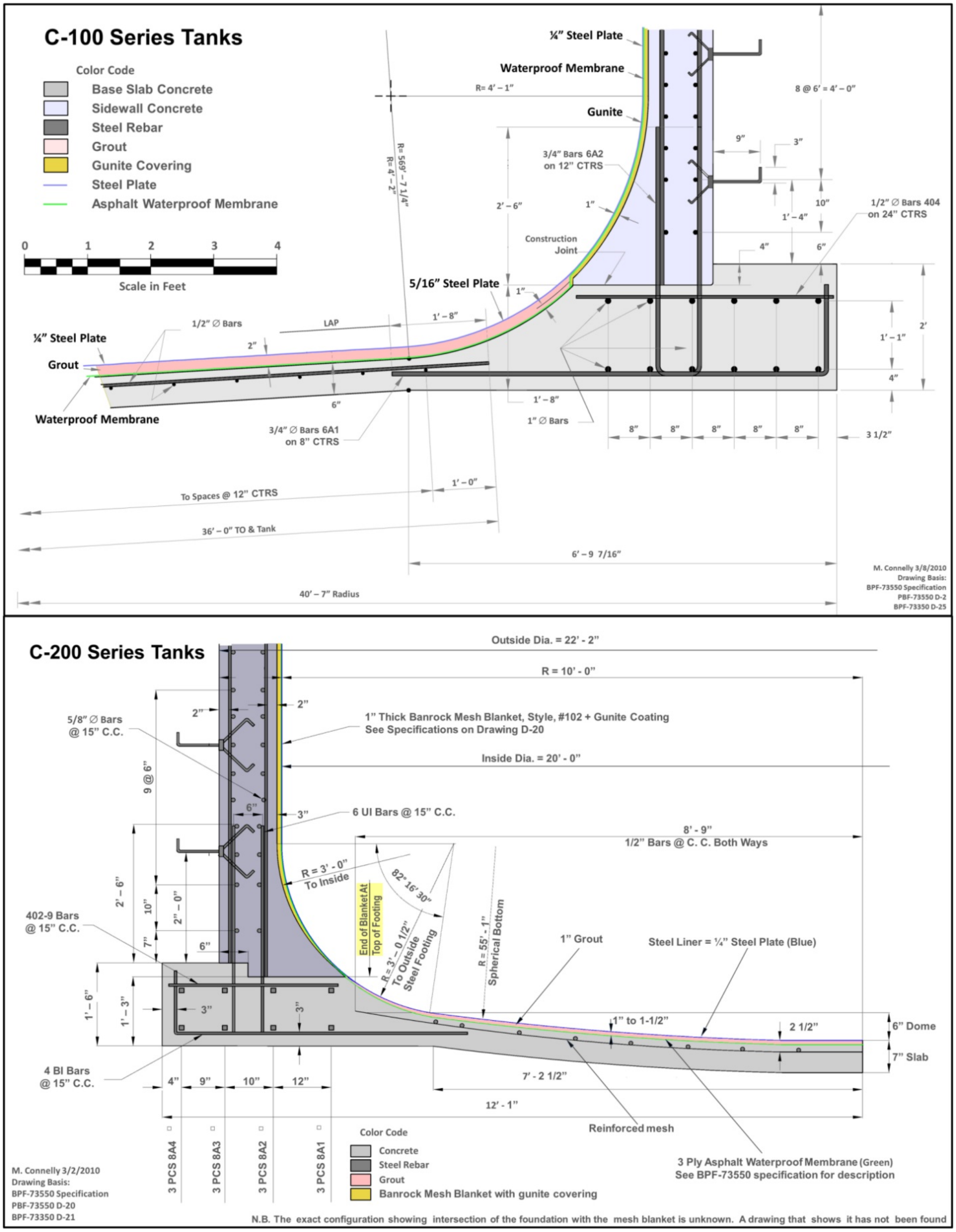
The closure plan approach to fill the tanks will provide a high quality grout throughout the tank (DOE/EIS-0391, 2012). Although the final formulation of the grout has not been developed, it is assumed the grout would be similar to the cold-cap grout formulation developed by USACE for the Hanford Grout Vault Program. This formulation exhibits a low-hydration heat and is free-flowing, self-leveling, and designed to generate little or no free water during curing (DOE/EIS-0391 Appendix E). Figure 3-48 shows the conceptual model of an SST shortly after the emplacement of the grout, while Figure 3-49 shows the conceptual model of an aged tank system. The modified RCRA C barrier is not shown in either of these figures.

**Figure 3-45. Waste Management Area C Tanks and Associated Tank Infrastructure.**



SST = single-shell tank

**Figure 3-46. Corner of Tank Floor with Tank Sides for the C-100 and C-200 Series Tanks.**



Reference: BPF-73550, "Specifications For Construction of Composite Storage Tanks Bldg. No. 241 Hanford Engineer Works Project 9536."

### Table 3-5. Single-Shell Tank Retrieval Status at Waste Management Area C as of May 31, 2014.[a] (2 sheets)

| Tank Number | Status | Comments | Nominal Volume of Remaining Waste[b] | Reference |
|---|---|---|---|---|
| 241-C-101 | Complete | Declared “Retrieved to Limit of First and Second Retrieval Technologies,” September 25, 2013 | 5.0 kgal | RPP-CALC-56434, “Post-Retrieval Camera/CAD Modeling System Waste Volume Estimate for Tank 241-C-101” |
| 241-C-102 | Ongoing | Retrieval in progress – retrieval initiated April 27, 2014 | 51.7 kgal | HNF-EP-0182, “Waste Tank Summary Report for Month Ending February 28, 2015,” Rev. 326 Note 10 |
| 241-C-103 | Complete | Declared “Retrieval Completed,” August 23, 2006 | 2.5 kgal | RPP-RPT-33060, “Retrieval Data Report for Single-Shell Tank 241-C-103” |
| 241-C-104 | Complete | Declared “Retrieval Completed,” August 17, 2012 | 1.9 kgal | RPP-CALC-54284, “Post-Hard Heel Retrieval Camera/CAD Modeling System Waste Volume Estimate for Tank 241-C-104” |
| 241-C-105 | Ongoing | Retrieval in progress – retrieval initiated June 11, 2014 | 131.3 kgal | HNF-EP-0182<br>Rev. 326 Note 13 |
| 241-C-106 | Complete | Declared “Retrieval Completed,” December 31, 2003 | 2.8 kgal | RPP-20577, “Stage II Retrieval Data Report for Single-Shell Tank 241-C-106” |
| 241-C-107 | Complete | Declared “Retrieved to Limit of Third Retrieval Technology,” September 30, 2014 | 10.7 kgal | RPP-CALC-59985, “Post-Retrieval Camera/CAD Modeling System Waste Volume Estimate for Tank 241-C-107” |
| 241-C-108 | Complete | Declared “Retrieved to Limit of Modified Sluicing Technology,” March 22, 2012 | 3.4 kgal | RPP-CALC-54266, “Post-Hard Heel Retrieval Camera/CAD Modeling System Waste Volume Estimate for Tank 241-C-108” |
| 241-C-109 | Complete | Declared “Retrieved to Limit of Modified Sluicing Technology,” September 12, 2012 | 2.0 kgal | RPP-CALC-54759, “Post-Hard Heel Retrieval Camera/CAD Modeling System Waste Volume Estimate for Tank 241-C-109” |
| 241-C-110 | Complete | Declared “Retrieval Completed,” October 30, 2013 | 1.8 kgal | RPP-CALC-56399, “Post-Hard Heel Retrieval Camera/CAD Modeling System Waste Volume Estimate for Tank 241-C-110” |
| 241-C-111 | Ongoing | Retrieval in progress – retrieval initiated September 14, 2010 | 32.8 kgal | HNF-EP-0182<br>Rev. 326 Note 19 |
| 241-C-112 | Ongoing | Declared “Retrieval Completed,” May 29, 2014 | 12.7 kgal | RPP-CALC-56856, “Estimated Waste Volume Remaining in Single Shell Tank 241-C-112 after Hard Heel Retrieval” |

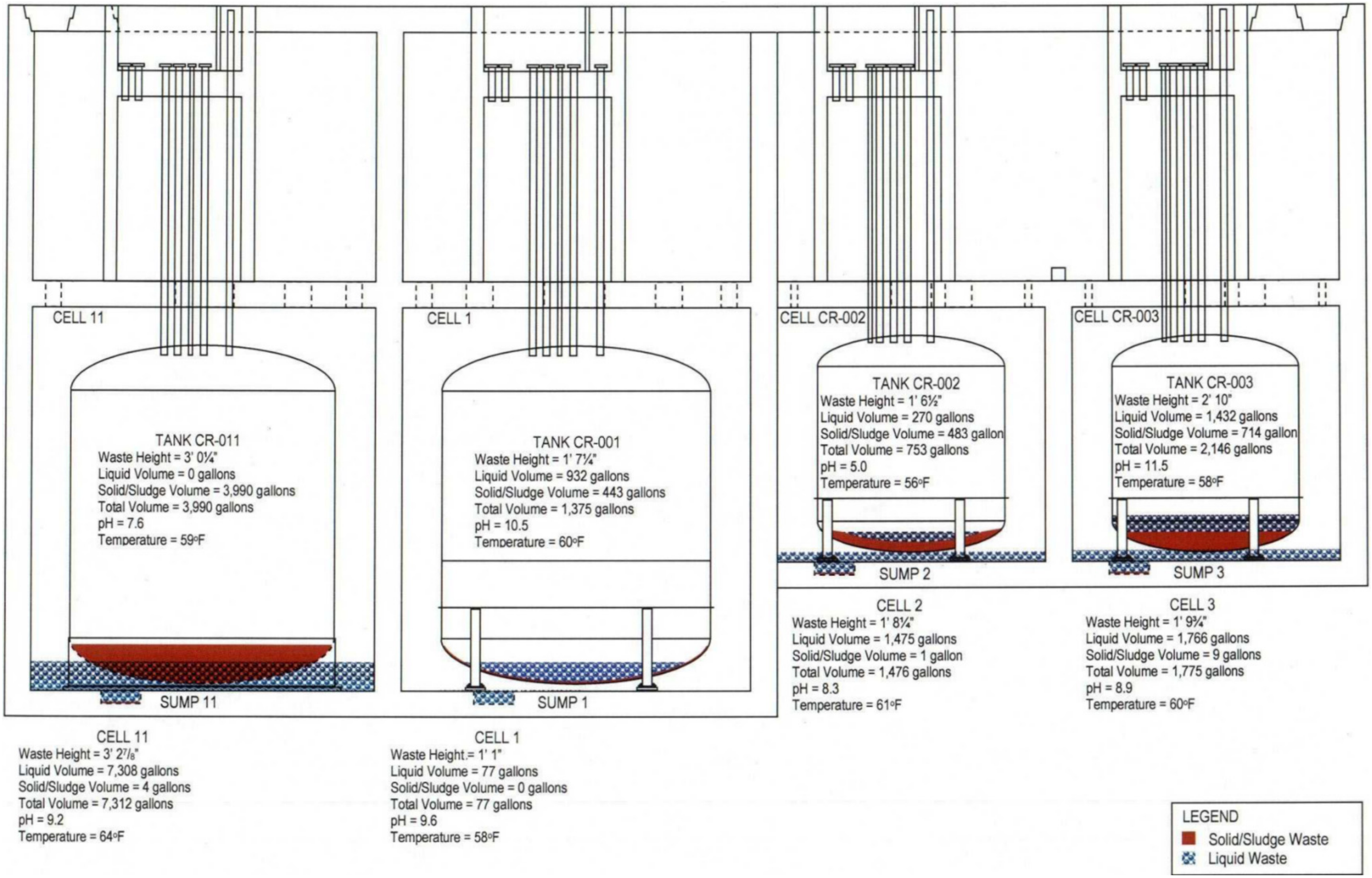
**Table 3-5. Single-Shell Tank Retrieval Status at Waste Management Area C as of May 31, 2014.[a] (2 sheets)**

| Tank Number | Status | Comments | Nominal Volume of Remaining Waste[b] | Reference |
|---|---|---|---|---|
| 241-C-201 | Complete | Declared "Retrieval Completed," March 23, 2006 | 0.14 kgal | RPP-29441, "Post-Retrieval Waste Volume Determination for Single-Shell Tank 241-C-201" |
| 241-C-202 | Complete | Declared "Retrieval Completed," August 11, 2005 | 0.15 kgal | RPP-RPT-29095, "Retrieval Data Report for Single-Shell Tank 241-C-202" |
| 241-C-203 | Complete | Declared "Retrieval Completed," March 24, 2005 | 0.14 kgal | RPP-RPT-26475, "Retrieval Data Report for Single Shell Tank 241-C-203" |
| 241-C-204 | Complete | Declared "Retrieval Completed," December 11, 2006 | 0.14 kgal | RPP-RPT-34062, "Retrieval Data Report for Single-Shell Tank 241-C-204" |

[a] Status taken from HNF-EP-0182, Rev 326.

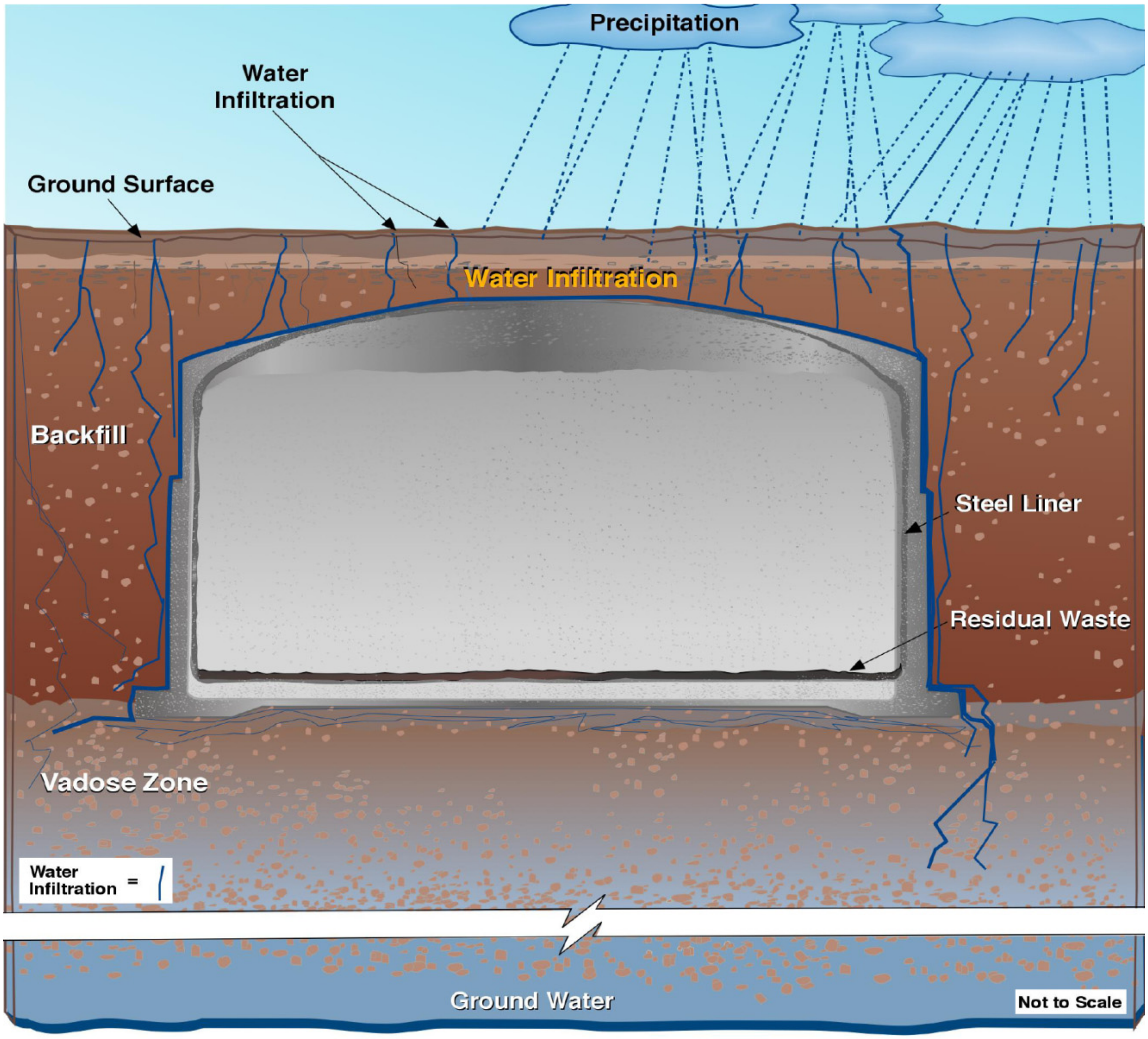
[b] Nominal volume of waste inventory is the best estimate of residual volume. Retrieval Data Reports also provide 95% upper confidence level volume as the bounding estimate of remaining waste.

**Figure 3-47. 244-CR Process Tank Vault Waste pH, Temperature, and Volume Estimates in 2005.**



Source: RPP-RPT-24257, "244-CR Vault Liquid Level Assessment and Video Inspection Completion Report."

**Figure 3-48. Conceptual Model of Tank Filled with Cementitious Grout.**



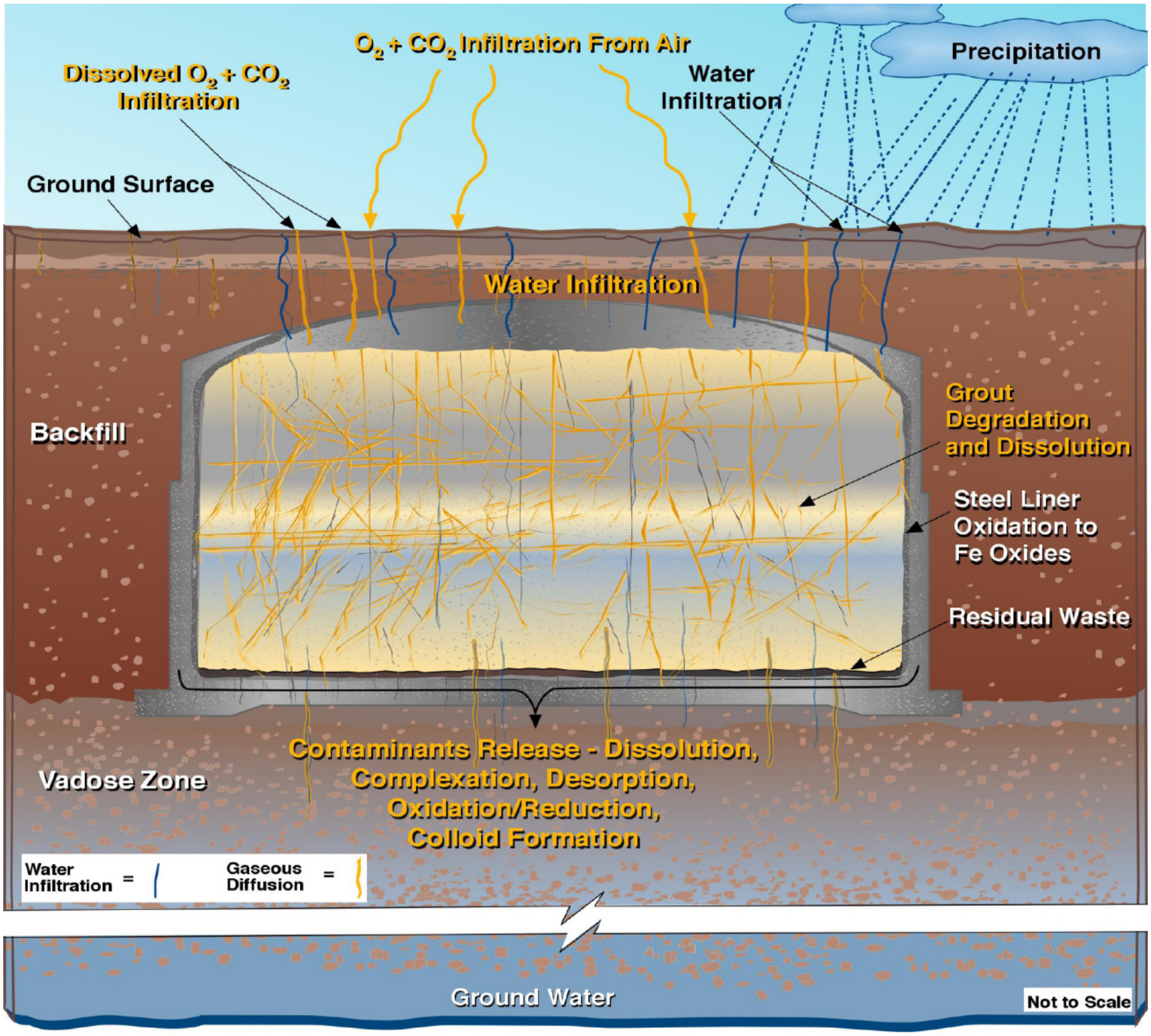
This is a schematic to illustrate infiltration of precipitation which is typically through slow gravitational drainage.

Pacific Northwest National Laboratory (PNNL) has conducted numerous studies to understand release of $^{99}$Tc, chromium, and uranium from residual waste left in the WMA C SSTs (C-103, C-104, C-106, C-108, C-202, C-203, and C-204) after closure using distilled water, as well as water in equilibrium with a young grout and an aged grout. The results of these studies are given in Section 5.0 of this document.

**3.2.1.2.2 Use of Modified RCRA Subtitle C Barrier.** After the tank and ancillary equipment have been grouted, the closure plan approach would be to place an engineered modified RCRA Subtitle C barrier over the site. DOE/RL-93-33 provides the conceptual design criteria, regulatory requirements, technical guidance, and the conceptual baseline design of the modified RCRA Subtitle C barrier. The surface cover does not currently exist, but the expected performance of the barrier comes from lysimeter studies, tracer tests, and computer simulations

(PNNL-14744) as well as monitoring of the 200-BP-1 Prototype Hanford Barrier (PNNL-18845, "200-BP-1 Prototype Hanford Barrier – 15 Years of Performance Monitoring").

**Figure 3-49. Conceptual Model of Cementitious Grouted Tank Aging.**



This is a schematic to illustrate the physical and chemical processes acting on grouted tank over time

The modified RCRA Subtitle C barrier generally consists of a layer of clay, geo-membrane material, and sand and gravel. This RCRA-compliant barrier will be modified by the addition of ~4.6 m (15 ft) of soil to provide shielding from radioactive material and to deter intrusion. The cover includes a vegetated surface layer of fine-grained soils to retain moisture and encourage evapotranspiration, thereby minimizing infiltration and vadose zone transport of contaminants to groundwater. It is expected that thickness of the top layer of the barrier will be increased to provide additional defense-in-depth against direct contact exposure from a basement excavation over the site. Prior to cover construction, specific closure cover designs will be evaluated and the most appropriate closure cover design will be selected for construction.

Figure 3-50 provides the generic modified RCRA Subtitle C barrier baseline design from DOE/RL-93-33. The expected performance of this design configuration is used in building the fate and transport model. The performance of the barrier with regard to recharge comes from the upper one meter of the barrier which contains the silt loam layer. This layer collects and holds the precipitation that falls over the site during the winter months; then during the summer months, evapotranspiration takes place that removes the stored precipitation from an assumed silt loam layer.

For a degraded surface barrier, a range of potential recharge rates may result. PNNL-14744 investigated the possibility of the most likely natural failure mechanisms (i.e., bioturbation of the silt loam layer, wind erosion, and accretion of windblown sand). With appropriate design considerations, PNNL-14744 argues that the failure possibility of these natural systems is quite low, and the emplaced silt-loam soils will continue to perform for as long as they remain in place. Based on these arguments, PNNL-14744 concluded that the long-term effectiveness of the surface barrier would continue to limit recharge rates to less than 0.1 mm/yr for thousands of years.

These arguments are further supported by the monitoring of the Hanford Barrier documented in PNNL-18845, which reports 15 years of data collection on the following:

- water-balance monitoring, consisting of precipitation, runoff, soil moisture storage, and drainage measurements with evapotranspiration calculated by difference

- stability monitoring, consisting of asphalt-layer-settlement, basalt-side-slope-stability, and surface-elevation measurements

- vegetation dynamics

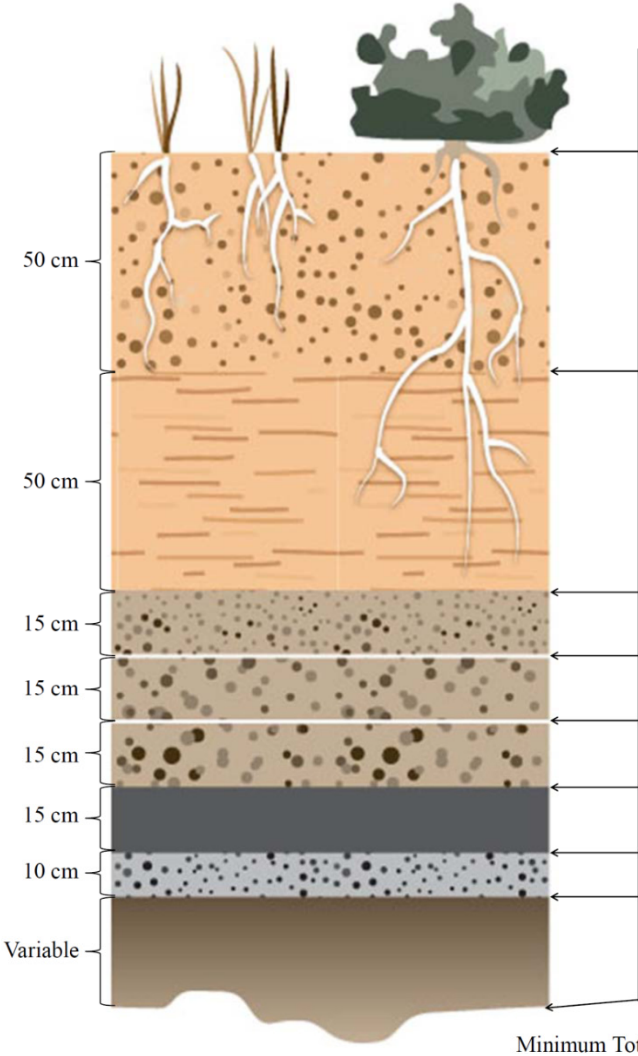
- animal use.

The 200-BP-1 Prototype Hanford Barrier was installed in 1994 over the 216-B-57 Crib. Based on monitoring of the Prototype Hanford Barrier, it is expected that the barrier will continue to perform even after fires have burned off the vegetation (PNNL-18934, “The Effects of Fire on the Function of the 200-BP-1 Engineered Surface Barrier”) and extreme precipitation events (PNNL-14143, “The Hanford Site 1000-Year Cap Design Test”). The lessons learned from the Prototype Hanford Barrier indicate that the cover design for the WMA C barrier will be very robust and will be able to continue to perform as designed for very long time frames, but to address potential uncertainties, cases are considered that address increased infiltration/recharge that could occur as a result of a variety of changes that may happen in the far future.

The modified RCRA-compliant closure cover being considered for WMA C will be designed to meet or exceed the regulatory requirements for applications at Category 1 LLW and Category 3 LLW (NRC Class C waste) facilities (see DOE/RL-93-93 for complete listing of regulatory requirements. The basis for cover design criteria is summarized in Table 3-6 (DOE/RL-93-33, Table 2-5).

**Figure 3-50. Generic Modified RCRA C Baseline Design from DOE/RL-93-33.**

## Modified RCRA C Barrier



| Layer Number | Thickness cm (in) | Layer Description | Function |
|---|---|---|---|
| 0 | N/A | Cover Vegetation | Mixed perennial grasses to enhance transpiration |
| 1 | 50 (20) | Silt loam with pea gravel admix | The topsoil material was identified for optimal water retention properties and should provide a good rooting medium for cover vegetation. The pea gravel is designed to minimize wind erosion of the silt loam without significantly affecting its moisture retention capabilities. (thickness may be increased to provided for protection against inadvertent intruder [DOE/RL-93-93 *Focused Feasibility Study of Engineered Barriers for Waste Management Units in the 200 Area*]) |
| 2 | 50 (20) | Compacted topsoil | Same as Layer 1. Layer 2 provides a supplemental soil moisture storage capacity. Compaction of this layer is intended to retard the rate of infiltration of soil moisture. The extended residence time of moisture in Layer 2 will increase the amount of moisture removed by evapotranspiration. (thickness may be increased to provided for protection against inadvertent intruder [DOE/RL-93-93]) |
| 3 | 15 (6) | Sand Filter | This layer is part of a two-layer graded filter designed to prevent the migration of topsoil particles into Layer 5. |
| 4 | 15 (6) | Gravel Filter | Same as Layer 3. |
| 5 | 15 (6) | Lateral drainage aggregate | The lateral drainage layer will intercept and divert moisture along a 2% slope to the margin of the cover for collection and/or discharge. |
| 6 | 15 (6) | Asphaltic concrete with spray applied asphalt coating | This layer will function as a hydrologic barrier and as a biointrusion barrier. |
| 7 | 10 (4) | Asphalt base course | The function of the material in this layer is to provide a stable base for placing and supporting the asphalt layer. |
| 8 | Variable | Grading Fill | This layer will provide a smooth, level subgrade for construction of the overlying layers. (thickness may be increased to provided for protection against inadvertent intruder [DOE/RL-93-93]) |

Minimum Total Thickness = 1.7 m

Reference: DOE/RL-93-33, Focused Feasibility Study of Engineered Barriers for Waste Management Units in the 200 Areas.

RCRA = Resource Conservation and Recovery Act of 1976, 42 USC 6901, et seq.

**Table 3-6. Summary of Design Criteria for the Modified RCRA C Barrier*.**

| | |
|---|---|
| 1 | Minimize moisture infiltration through the cover. |
| 2 | Design a multilayer cover of materials that are resistant to natural degradation processes. |
| 3 | Design a durable cover that needs minimal maintenance during its design life. |
| 4 | Design a cover with a functional life of 500 years. |
| 5 | Prevent plants from accessing and mobilizing contamination (i.e., prevent root penetration into the waste zone). |
| 6 | Prevent burrowing animals from accessing and mobilizing contamination. |
| 7 | Ensure that the top of the waste is at least 5 m (16 ft) below final grade or include appropriate design provisions to limit inadvertent human intrusion. |
| 8 | Facilitate drainage and minimize surface erosion by wind and water. |
| 9 | Design the low-permeability layer of the cover to have a permeability less than or equal to any natural subsoil present. |
| 10 | Design the cover to prevent the migration and accumulation of topsoil material within the lateral drainage layer (i.e., clogging of the lateral drainage layer). |
| 11 | For frost protection, the lateral drainage layer and the low-permeability asphalt layer must be located at least 0.76 m (2.5 ft) below final grade. |

RCRA = Resource Conservation and Recovery Act of 1976, 42 USC 6901, et seq.

* Reference: Table 2-5 DOE/RL-93-33, Focused Feasibility Study of Engineered Barriers for Waste Management Units in the 200 Areas.

**Erosion Protection.** Water and wind erosion surface cover material can impact the integrity of a surface cover. The low precipitation, the low intensity of precipitation events, the absence of surface run-on features at the Hanford Site, and stability monitoring (PNNL-18845) all support the assumption that water erosion will not be a significant factor at WMA C barrier. Wind erosion, however, has been observed at the Hanford Site, primarily in exposed sandy areas and in the sand dunes to the southeast of WMA C.

DOE/RL-99-11, 200-BP-1 Prototype Barrier Treatability Test Report evaluated the potential for wind erosion for surface barriers. DOE/RL-99-11 calculated that the worst-case potential erosion rate would be to lose 15 cm (6 in.) of silt loam in 500 years. The analysis method was derived for agricultural soils and did not consider the benefits of the pea gravel admix. Extensive wind tunnel studies performed at the Hanford Site show that a mixture of fine-grained soil and pea gravel significantly reduced erosion due to wind forces. Soil/pea gravel armoring can reduce erosion rates from 96.5% to more than 99% at wind speeds of 72, 90 and 108 km/hr (45, 56, and 67 mi/hr) (PNL-8478, “Soil Erosion Rates Caused by Wind and Saltating Sand Stresses in Wind Tunnel”; WHC-EP-0673, “Permanent Isolation Surface Barrier Development Plan”). With the lower reduction value (96%), the wind erosion potential would be 15 cm (6 in.) in 12,500 years. The experience at the Prototype Hanford Barrier (“Quest for the Perfect Cap” [Wing and Gee 1994]) suggests that wind erosion will be negligible within months after the barrier surface is vegetated. Therefore, for all intents and purposes, wind erosion of the silt loam should be minor and is assumed to be so for the WMA C vegetated, closure surface barrier.

The engineered cover system surface will be seeded and fertilized to promote plant growth. Vegetation will minimize erosion and accelerate removal of water from the water storage layer through transpiration. Long-term considerations include periods of drought or fire so erosion and hydrologic modeling studies have assumed a poor stand of vegetation. The vegetation will consist of local plant species based on vegetation studies performed for Hanford disturbed areas.

**Post-Closure Inadvertent Intrusion Protection.** DOE/RL-93-33 included design criteria 4 and 7 listed in Table 3-6 as part of the design of the Modified RCRA Subtitle C Barrier to meet the requirements of 10 CFR 61.42 and 10 CFR 61.52 for the protection of the inadvertent intruder. Additionally, to further deter the inadvertent intrusion of humans into the waste, a marker system will be used to warn future generations of the dangers of the buried waste. Permanent markers that identify the potential exposure hazards will be installed at all corner boundaries of the closed facility. The DOE is expected to maintain active control of the Hanford Site (using fences, patrols, alarms, and monitoring instruments). Site information will be provided on an Internet website, U.S. Geological Survey maps, libraries, and other information repositories that would be readily available to the public. Land-use restrictions and institutional controls will be placed on the closed WMA C facility and its adjacent buffer zone to permanently preclude development until unacceptable risk no longer remains at the site.

The closed WMA C facility will clearly delineate the boundaries of the surface barrier by providing a distinct contrast with the surrounding terrain. The side slopes are engineered structures that will point to an obvious anthropogenic origin. These distinct side slopes in combination with warning signs are intended to minimize the risk of human intrusion.

As discussed above, the WMA C engineered surface cover system also contains a bio-intrusion layer consisting of gravel. The function of this layer is to prevent small burrowing animals and rodents from penetrating the underlying cover components and the waste material. Barrier studies at Hanford have shown that a thin layer of gravel is effective in preventing animals and rodents from penetrating underlying waste materials (WHC-EP-0673). The bio-intrusion material will consist of gravel screened from the local available alluvium at the Hanford Site. The alluvium gravels at the Hanford Site are composed of granite, quartz, and other durable minerals that make it ideally suited for long-term applications.

### 3.2.2 Tank Residual Waste Inventory

This section summarizes residual waste inventory information and describes the methods and assumptions used to estimate the inventories and concentrations of radionuclides and chemicals in residual waste in the WMA C SSTs and ancillary equipment at closure. The ancillary equipment includes the C-301 catch tank, the 244-CR vault, diversion boxes and pits, and waste transfer pipelines associated with WMA C.

The following topics are discussed in this section:

- Major waste types

- Updated waste inventory estimates for tanks and ancillary equipment
    - Retrieved tanks with post-retrieval sampling
    - Retrieved tanks without post-retrieval sampling
    - Tanks undergoing retrieval
    - Ancillary Equipment including C-301 catch tank, the 244-CR vault, waste transfer pipelines, pits and diversion boxes
- Inventory uncertainties.

Tank waste inventories for the 25 chemicals and 46 radionuclides are tracked using a Best-Basis Inventory (BBI) process. A listing of these constituents is provided in Table 3-7. Available analytical data are evaluated to identify which data best represent the waste concentrations in a tank. When analytical data are not available for a chemical or radionuclide, waste concentrations are estimated based on waste process information. Waste volume estimates in the BBI are based on waste-level measurements and/or waste transfer information. In addition to standard chemical and radionuclide BBI inventory estimates, after sampling tank residuals, inventories were developed for primary and secondary constituents in RPP-23403, "Single-Shell Tank Component Closure Data Quality Objectives."

As of September, 2014, waste was retrieved from 13 of 16 SSTs in C Farm (C-101, C-103, C-104, C-106, C-107, C-108, C-109, C-110, C-112, C-201, C-202, C-203, and C-204) and was in progress for the remaining 3 tanks (C-102, C-105 and C-111). Only BBI inventory estimates based on pre-retrieval samples and model estimates are currently available for the three unretrieved tanks (i.e., C-102, C-105, and C-111). After waste is retrieved, residual waste is sampled for constituents specified in RPP-23403. Tables 3-8 and 3-9 show primary chemical and radionuclide constituents in RPP-23403.

**3.2.2.1 Waste Inventory Assumptions.** Key enabling assumptions for current residual inventory estimates for C Farm SSTs and ancillary equipment include the following.

a. For tanks retrieved, the retrieval volumes and inventories documented in applicable retrieval data reports or residual inventory reports are the assumed inventories in WMA C SSTs at closure (see RPP-RPT-42323, "Hanford C-Farm Tank and Ancillary Equipment Residual Waste Inventory Estimates").

b. Radionuclides were decayed to January 1, 2020. Therefore, the radionuclide values presented differ from the 2014 BBI values, which are decayed to January 1, 2008 (see RPP-RPT-42323).

c. For tanks not yet retrieved (i.e., C-102, C-105, and C-111), it was assumed that, for a lower bound estimate, the minimum volume remaining would be 10 kL (360 $\text{ft}^3$). This is the threshold goal for 100-series SSTs specified in the HFFACO.

d. The Hanford Tank Waste Operations Simulator (HTWOS) model is assumed to provide a minimum estimate for threshold residual waste inventory estimates for tanks not yet retrieved (i.e., C-102, C-105, and C-111). This is because HTWOS assumes soluble constituents are mobilized during the retrieval process and largely removed when waste is retrieved to the threshold goal. The HTWOS assumptions are located in HNF-SD-WM-SP-012, "Tank Farm Contractor Operation and Utilization Plan."

e. The current BBI inventory is assumed to provide an upper bound estimate for tanks not yet retrieved (i.e., C-102, C-105, and C-111). These upper bound estimates presented for the tanks not yet retrieved reflect conditions in WMA C as of September 1, 2014.

f. Waste concentrations in ancillary equipment are assumed to be represented by the average concentration of waste in WMA C tanks that have been retrieved.

This simplifying assumption is made because:

- Little analytical data is available for waste in ancillary equipment,

- Ancillary equipment was flushed, mobilizing soluble constituents similar to retrieval,

- Ancillary equipment received waste to or from many of the tanks in a farm, and

- Process history of waste types and volumes received by different ancillary equipment has not been developed and estimates would be highly uncertain.

g. It is assumed that waste in the C-301 catch tank and 244-CR vault will be retrieved prior to closure (no specific goals or limits have been established for these facilities). Retrieval of 90% of the waste was assumed for these facilities. The average residual concentrations for WMA C tanks retrieved to date was assumed for these facilities.

h. It was assumed that the waste was or will be flushed from pits and diversion boxes and the primary residual waste remaining at closure will be limited to waste adsorbed to concrete surfaces with waste penetration to a depth of 0.04 cm (0.0157 in.) (RPP-15043, "Single-Shell Tank System Description").

i. It was assumed that the majority of waste transfer pipelines are 5% full of waste except for a plugged line and cascade lines which are assumed to be full. The technical basis for these assumptions and the associated pipeline lengths and estimated waste volumes are given in RPP-PLAN-47559.

**Table 3-7. Standard Best-Basis Inventory Constituents.**

| Chemicals | | Radionuclides | | |
|---|---|---|---|---|
| Al | Na | $^{3}$H | $^{134}$Cs | $^{234}$U |
| Bi | Ni | $^{14}$C | $^{137}$Cs | $^{235}$U |
| Ca | $NO_2$ | $^{59}$Ni | $^{137m}$Ba | $^{236}$U |
| Cl | $NO_3$ | $^{60}$Co | $^{151}$Sm | $^{237}$Np |
| $CO_3$ | Oxalate | $^{63}$Ni | $^{152}$Eu | $^{238}$Pu |
| Cr | Pb | $^{79}$Se | $^{154}$Eu | $^{238}$U |
| F | $PO_4$ | $^{90}$Sr | $^{155}$Eu | $^{239}$Pu |
| Fe | Si | $^{90}$Y | $^{226}$Ra | $^{240}$Pu |
| Hg | $SO_4$ | $^{93}$Zr | $^{227}$Ac | $^{241}$Am |
| K | Sr | $^{93m}$Nb | $^{228}$Ra | $^{241}$Pu |
| La | Total organic carbon | $^{99}$Tc | $^{229}$Th | $^{242}$Cm |
| Mn | U-TOTAL | $^{106}$Ru | $^{231}$Pa | $^{242}$Pu |
| | Zr | $^{113m}$Cd | $^{232}$Th | $^{243}$Am |
| | | $^{125}$Sb | $^{232}$U | $^{243}$Cm |
| | | $^{126}$Sn | $^{233}$U | $^{244}$Cm |
| | | $^{129}$I | | |

**3.2.2.2 Major Waste Types.** The residual waste in WMA C at closure will be contained in tanks, vaults, pits/boxes, and waste transfer pipelines. The waste originally stored in these tanks and ancillary equipment consisted of supernate and sludge from the processing of irradiated uranium fuel. Supernate is free-standing liquid from the waste processing operations and sludge is precipitate from the supernate.

Tables 3-10 and 3-11 show waste types and processes that generated wastes transferred to C Farm. These processes and the waste types generated are discussed in HNF-SD-WM-TI-740, "Standard Inventories of Chemicals and Radionuclides in Hanford Tank Wastes." Table 3-12 shows the principal types of sludge remaining in the C Farm tanks and ancillary equipment. The waste consists of a large array of chemicals and radionuclides. Process knowledge-based waste type composition estimates based on reactor fuel irradiation records and process plant records are provided in RPP-19822, "Hanford Defined Waste Model – Revision 5.0."

**3.2.2.3 Residual Waste Inventory Estimates.** Residual inventory estimates used in this PA were determined based on information and conditions as of September 2014. Inventory estimates were developed for 1) residuals in retrieved tanks with post-retrieval sampling, 2) residuals in retrieved tanks without post-retrieval sampling, 3) residuals in tanks undergoing retrieval and 4) post-retrieval residual inventory estimates for ancillary equipment, including:

C-301 catch tank, 244-CR vault tanks, and sumps, pits, diversion boxes, and waste transfer pipelines. These inventory estimates are reported in Tables 3-13, 3-14, 3-15, 3-16, and 3-17.

### Table 3-8. Primary Chemical Constituents.

| | | | |
|---|---|---|---|
| **Inorganic Constituents** | | | |
| Acetate – $C_2H_3O_2^-$ | Chromium – Cr | Iron – Fe | pH |
| Aluminum – Al | Cobalt – Co | Lead – Pb | Selenium – Se |
| Ammonium – $NH_4^+$ | Copper – Cu | Manganese – Mn | Silver – Ag |
| Antimony – Sb | Cyanide – $CN^-$ | Mercury – Hg | Strontium – Sr |
| Arsenic – As | Ferrocyanide – $Fe(CN)_6^{4-}$ | Nickel – Ni | Thallium – Tl |
| Barium – Ba | Fluoride – $F^-$ | Nitrate – $NO_3^-$ | Uranium – U |
| Beryllium – Be | Formate – $CHO_2^-$ | Nitrite – $NO_2^-$ | Vanadium – V |
| Cadmium – Cd | Glycolate – $C_2H_3O_3^-$ | Oxalate – $C_2O_4^{2-}$ | Zinc – Zn |
| **Organic Constituents** | | | |
| 1,1,2-Trichloroethylene | 4-Methyl-2-pentanone (MIBK) | m-Xylene | Polychlorinated biphenyls |
| 2-Butanone (MEK) | Xylenes (Mixed isomers of o-, m-, and p-) | p-Xylene | |
| 2-Propanone (Acetone) | o-Xylene | Tributyl phosphate | |

Reference: RPP-23403, “Single-Shell Tank Component Closure Data Quality Objectives.”

### Table 3-9. Primary Radiological Constituents.

| | | |
|---|---|---|
| Cesium 137 – $^{137}$Cs | Technetium 99 – $^{99}$Tc | Plutonium 238 – $^{238}$Pu |
| Cobalt 60 – $^{60}$Co | Antimony 125 – $^{125}$Sb | Plutonium 239/240 – $^{239/240}$Pu |
| Europium 152 – $^{152}$Eu | Seleniium 79 – $^{79}$Se | Plutonium 241 – $^{241}$Pu |
| Europium 154 – $^{154}$Eu | Tin 126 – $^{126}$Sn | Americium241 – $^{241}$Am |
| Europium 155 – $^{155}$Eu | Uranium 233 – $^{233}$U | Curium 242 – $^{242}$Cm |
| Carbon 14 – $^{14}$C | Uranium 234 – $^{234}$U | Curium 243 – $^{243}$Cm |
| Tritium – $^{3}$H | Uranium 235 – $^{235}$U | Curium 244 – $^{244}$Cm |
| Iodine 129 – $^{129}$I | Uranium 236 – $^{236}$U | Thorium 228 – $^{228}$Th |
| Nickel 63 – $^{63}$Ni | Uranium 238 – $^{238}$U | Thorium 230 – $^{230}$Th |
| Strontium 90 – $^{90}$Sr | Neptunium 237 – $^{237}$Np | Thorium 232 – $^{232}$Th |

Reference: RPP-23403, “Single-Shell Tank Component Closure Data Quality Objectives,” Rev. 5.

## Table 3-10. Waste Types Received into 241-C 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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:

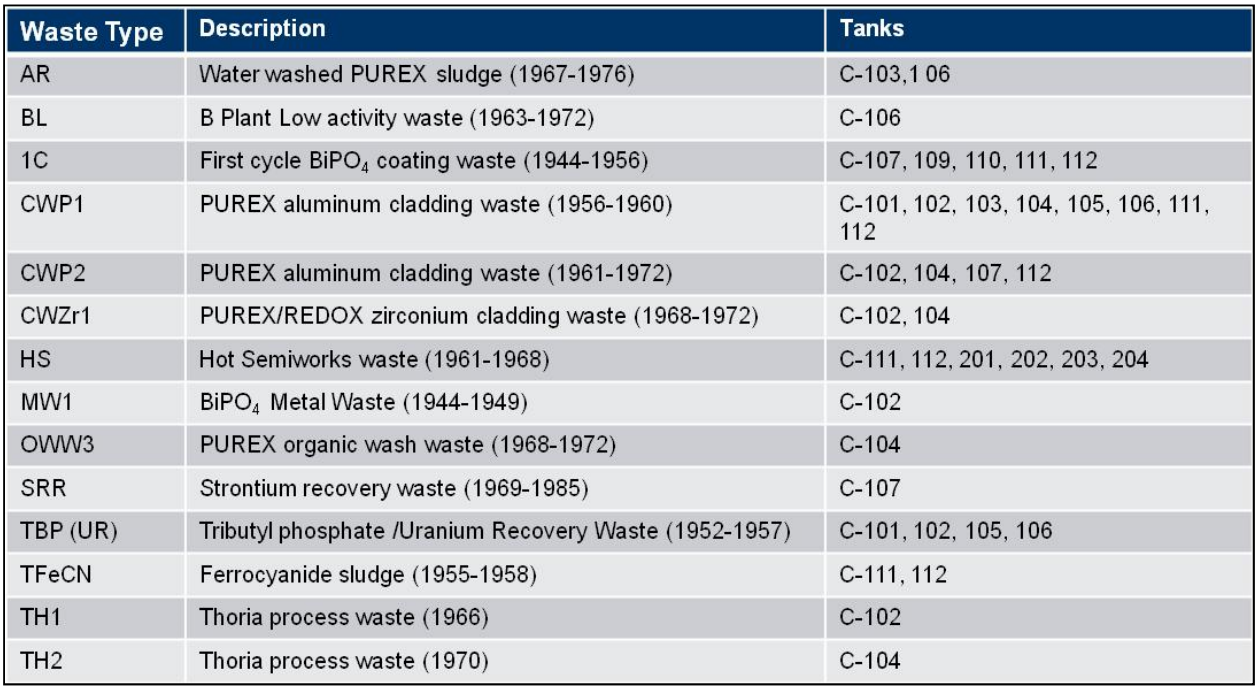
Colors in table are used to highlight each waste type

| | |
|---|---|
| BL | 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 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 tributyl phosphate waste |
| TH | Thorium process waste from PUREX Plant |

### Table 3-11. Waste Types in C-200 Series Tanks.

| Waste Type | 241-C-201 | 241-C-202 | 241-C-203 | 241-C-204 |
|---|---|---|---|---|
| Metal Waste – Addition from B Plant | November 1947 – December 1948 | | | |
| Metal Waste Supernate – Removal to 241-C-106 | December 1953 | | | |
| Metal Waste Supernate – Removal to 241-C-104 | None | None | None | 7,000 gallons 11/1954 |
| Metal Waste Sluicing to 244-CR Process Tank Vault | 2/15/1954 – 3/17/1954 | 1/9/1954 – 1/14/1954 | 1/15/1954 – 1/28/1954 | 1/1955 – 2/1955 |
| Hot Semiworks – PUREX process waste (5/1955 – 3/1956)<br>Process equipment and facility flushes for modifications | 5/1955 – 11/1955 | 11/1955 – 5/1956 | 12/1955 – 11/1956<br>4/1956 – 11/1956 | 12/1955 – 11/1956<br>4/1956 – 11/1956 |
| Supernate Removal | | | 1/1970 – 3/1970 | |
| Supernate Removal | 4/1970 – 6/1970 | | | |
| Supernate Removal | | | | 7/1977 |
| Supernate Removal | 10/1980 | | | |

### Table 3-12. Current Waste Types in 241-C Farm Tanks.



| Waste Type | Description | Tanks |
|---|---|---|
| AR | Water washed PUREX sludge (1967-1976) | C-103,1 06 |
| BL | B Plant Low activity waste (1963-1972) | C-106 |
| 1C | First cycle $BiPO_4$ coating waste (1944-1956) | C-107, 109, 110, 111, 112 |
| CWP1 | PUREX aluminum cladding waste (1956-1960) | C-101, 102, 103, 104, 105, 106, 111, 112 |
| CWP2 | PUREX aluminum cladding waste (1961-1972) | C-102, 104, 107, 112 |
| CWZr1 | PUREX/REDOX zirconium cladding waste (1968-1972) | C-102, 104 |
| HS | Hot Semiworks waste (1961-1968) | C-111, 112, 201, 202, 203, 204 |
| MW1 | $BiPO_4$ Metal Waste (1944-1949) | C-102 |
| OWW3 | PUREX organic wash waste (1968-1972) | C-104 |
| SRR | Strontium recovery waste (1969-1985) | C-107 |
| TBP (UR) | Tributyl phosphate /Uranium Recovery Waste (1952-1957) | C-101, 102, 105, 106 |
| TFeCN | Ferrocyanide sludge (1955-1958) | C-111, 112 |
| TH1 | Thoria process waste (1966) | C-102 |
| TH2 | Thoria process waste (1970) | C-104 |

$BiPO_4$ = bismuth phosphate
PUREX = Plutonium-Uranium Extraction (facility)
REDOX = Reduction-Oxidation (S Plant)

Inventory estimates for other constituents for which analytical results are available are reported in Appendix D of RPP-RPT-42323. These include primary analytes in RPP-23403 shown in Tables 3-8 and 3-9 and secondary constituents in the data quality objectives (DQO) document (RPP-23403). Additional discussion and details for current residual inventory estimates are provided in RPP-RPT-42323.

Concentrations for BBI constituents for the SSTs were calculated by dividing the inventories by associated volumes shown in the respective residual inventory tables (Tables 3-13 and 3-14). This calculation provides average concentrations for sludge, interstitial liquids and supernate and for multiple waste types in a tank. Where available, concentrations are based on analytical results. As of September 2014, analytical results were obtained for 10 of the 13 SSTs retrieved for constituents shown in Tables 3-8 and 3-9.

**3.2.2.3.1 Retrieved Tanks with Post-Retrieval Sampling.** Inventory estimates for the 10 SSTs (C-103, C-104, C-106, C-108, C-109, C-110, C-201, C-202, C-203, and C-204) for which retrieval operations have been completed and post-retrieval samples have been obtained are based on the BBI. As of September 2014, waste volume estimates were completed using a camera/computer-aided design (CAD) modeling system (CCMS) and post-retrieval residual sampling and analysis was completed for these 10 SSTs. In addition to standard chemical and radionuclide BBI inventory estimates, inventories were developed for many other constituents after sampling tank residuals.

The base case inventory for these tanks is the average BBI estimate and the upper bound inventory is the upper 95% confidence interval for the mean inventory. These inventories are provided in Tables 3-13 and 3-16.

Average and upper limit concentrations for these tanks for constituents specified in RPP-23403 are shown in Appendix D of RPP-RPT-42323.

**3.2.2.3.2 Retrieved Tanks without Post-Retrieval Sampling.** Inventory estimates for the three SSTs (C-101, C-107 and C-112) for which retrieval operations have been completed, but post-retrieval samples have not been obtained, are also based on the BBI and CCMS estimates. However, the basis for waste composition estimates for these tanks varies. For tanks C-101 and C-107 the BBI inventory estimates are based on pre-retrieval sample results, sample-based templates and process knowledge. For tank C-112, the BBI inventory estimates are based on in-process transfer samples representative of the C1 waste type and sample and process knowledge templates. Statistical uncertainties were not estimated for inventories based on process knowledge.

The base case inventory for retrieved tanks without post-retrieval sampling is the average BBI estimate. Because many of the constituents are not sample based, an upper bound inventory could not be estimated for many constituents for these tanks. It is believed that the concentration and inventories of soluble constituents will be lower than those currently estimated by the BBI. Inventory estimates for these tanks will be adjusted as needed, after post-retrieval sampling and analyses are completed. The inventories for tanks in this category are provided in Table 3-13; average waste concentrations are shown in Appendix B of RPP-RPT-42323.

## Table 3-13a. 241-C Tank Farm Residual Inventory Estimates for Retrieved Tanks with Post-Retrieval Sampling. (sheet 1 of 2)

| **Tanks Retrieved (BBI average)**[a] | **241-C-101**[b] | **241-C-103** | **241-C-104** | **241-C-106** | **241-C-107**[b] | **241-C-108** | **241-C-109** | **241-C-110** | **241-C-112**[b] | **241-C-201** | **241-C-202** | **241-C-203** | **241-C-204** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Residual Volume (kL [kgal]) | 18.9(4.99) | 9.57(2.53) | 7.2(1.9) | 10.49(2.77) | 53(14) | 12.9(3.4) | 7.6(2.0) | 8(2.1) | 48(12.7) | 0.6(0.16) | 0.6(0.16) | 0.5(0.13) | 0.5(0.13) |
| Total Radionuclides (Ci)[c] | 7.30E+03 | 1.47E+04 | 1.43E+04 | 1.00E+05 | 6.37E+04 | 2.67E+03 | 4.75E+03 | 5.28E+03 | 1.92E+03 | 4.10E+02 | 7.25E+02 | 3.50E+02 | 2.33E+02 |
| $^{106}$Ru | 9.11E-20 | 1.72E-16 | 2.14E-10 | 8.59E-10 | 8.85E-17 | 7.01E-17 | 4.86E-17 | 1.38E-17 | 6.52E-17 | 2.82E-11 | 2.87E-11 | 2.35E-11 | 2.20E-11 |
| $^{113m}$Cd | 1.47E-03 | 1.49E-02 | 5.11E-02 | 2.13E+00 | 2.50E-03 | 1.97E-03 | 1.37E-03 | 3.89E-04 | 1.84E-03 | 5.77E-04 | 5.88E-04 | 4.80E-04 | 4.50E-04 |
| $^{125}$Sb | 9.36E-07 | 6.96E-07 | 9.60E-01 | 3.62E-03 | 1.31E-06 | 1.04E-06 | 7.20E-07 | 2.04E-07 | 9.70E-07 | 5.39E-05 | 5.49E-05 | 4.50E-05 | 4.21E-05 |
| $^{126}$Sn | 5.13E-04 | 5.27E-05 | 8.81E-03 | 1.76E+00 | 4.94E-04 | 3.91E-04 | 2.71E-04 | 2.38E-02 | 3.65E-04 | 1.10E-04 | 1.13E-04 | 9.21E-05 | 8.61E-05 |
| $^{129}$I | 5.55E-05 | 3.00E-03 | 4.84E-04 | 6.31E-04 | 4.07E-02 | 3.81E-05 | 2.65E-05 | 2.65E-04 | 3.57E-05 | 4.57E-07 | 7.35E-06 | 1.47E-05 | 3.57E-07 |
| $^{134}$Cs | 2.01E-09 | 3.78E-09 | 7.18E-06 | 1.54E-05 | 2.59E-10 | 2.05E-10 | 1.42E-10 | 4.04E-11 | 1.92E-10 | 4.13E-08 | 4.22E-08 | 3.46E-08 | 3.22E-08 |
| $^{137}$Cs | 3.61E+02 | 6.07E+02 | 6.22E+02 | 1.00E+03 | 2.32E+03 | 8.57E+01 | 4.31E+01 | 2.02E+01 | 7.66E+02 | 7.01E+00 | 6.18E+00 | 9.10E+00 | 4.13E+00 |
| $^{137m}$Ba | 3.22E+02 | 5.41E+02 | 5.54E+02 | 8.95E+02 | 2.06E+03 | 7.59E+01 | 3.84E+01 | 1.80E+01 | 6.80E+02 | 6.25E+00 | 5.51E+00 | 8.09E+00 | 3.67E+00 |
| $^{14}$C | 2.76E-03 | 6.99E-03 | 3.08E-03 | 8.21E-03 | 2.16E-02 | 8.18E-03 | 7.65E-04 | 1.51E-03 | 1.60E-02 | 7.64E-04 | 2.03E-04 | 1.66E-04 | 1.88E-04 |
| $^{151}$Sm | 4.00E+00 | 4.30E-01 | 3.17E+03 | 7.82E+03 | 1.04E+04 | 6.66E+00 | 4.65E+00 | 1.32E+00 | 6.25E+00 | 2.39E+01 | 2.43E+01 | 1.99E+01 | 1.86E+01 |
| $^{152}$Eu | 6.38E-05 | 2.58E-05 | 3.54E-02 | 2.02E+00 | 1.35E-04 | 1.07E-04 | 7.41E-05 | 2.11E-05 | 1.00E-04 | 2.10E-03 | 2.14E-03 | 1.75E-03 | 1.64E-03 |
| $^{154}$Eu | 2.77E-03 | 1.41E+00 | 1.57E+00 | 2.25E+01 | 5.70E-03 | 4.52E-03 | 3.13E-03 | 8.89E-04 | 4.22E-03 | 9.42E-02 | 9.61E-02 | 1.50E-02 | 5.62E-02 |
| $^{155}$Eu | 4.69E-04 | 4.37E-01 | 2.29E-01 | 7.65E+00 | 8.66E-04 | 6.84E-04 | 4.74E-04 | 1.35E-04 | 6.39E-04 | 1.45E-02 | 1.48E-02 | 1.81E-02 | 1.13E-02 |
| $^{226}$Ra | 5.90E-07 | 1.54E-08 | 3.24E-07 | 5.13E-04 | 5.95E-07 | 4.73E-07 | 3.26E-07 | 9.27E-08 | 4.40E-07 | 1.00E-09 | 1.02E-09 | 8.40E-10 | 7.86E-10 |
| $^{227}$Ac | 1.58E-06 | 6.39E-08 | 1.11E-05 | 1.74E-03 | 6.20E-06 | 7.78E-07 | 3.40E-06 | 9.62E-07 | 4.57E-06 | 3.45E-09 | 3.51E-09 | 2.87E-09 | 2.69E-09 |
| $^{228}$Ra | 2.64E-13 | 4.70E-05 | 8.73E-04 | 1.32E-04 | 9.70E-04 | 3.70E-06 | 2.06E-12 | 5.85E-13 | 2.78E-12 | 9.51E-07 | 9.70E-07 | 4.48E-07 | 3.35E-06 |
| $^{229}$Th | 1.33E-10 | 2.60E-11 | 8.56E-08 | 1.91E-05 | 1.89E-09 | 1.50E-09 | 1.04E-09 | 2.95E-10 | 1.40E-09 | 1.18E-11 | 1.20E-11 | 9.81E-12 | 9.17E-12 |
| $^{230}$Th[d] | — | — | — | 9.38E-04 | — | — | — | — | — | — | — | — | — |
| $^{231}$Pa | 2.48E-08 | 1.66E-07 | 7.47E-05 | 2.53E-03 | 3.83E-05 | 3.02E-05 | 2.10E-05 | 5.96E-06 | 2.82E-05 | 6.79E-09 | 6.93E-09 | 5.67E-09 | 5.30E-09 |
| $^{232}$Th | 1.12E-12 | 1.99E-04 | 3.70E-03 | 5.60E-04 | 4.11E-03 | 1.57E-05 | 8.72E-12 | 2.48E-12 | 1.18E-11 | 4.03E-06 | 4.11E-06 | 1.90E-06 | 1.42E-05 |
| $^{232}$U | 1.75E-06 | 4.29E-06 | 3.53E-02 | 4.87E-04 | 2.20E-06 | 4.50E-07 | 9.94E-08 | 1.91E-08 | 4.50E-07 | 2.25E-06 | 2.00E-06 | 6.60E-06 | 4.93E-06 |
| $^{233}$U | 1.71E-07 | 5.85E-03 | 2.18E+00 | 1.82E-03 | 2.15E-07 | 4.10E-08 | 9.69E-09 | 1.86E-09 | 4.39E-08 | 1.14E-05 | 1.02E-05 | 3.37E-05 | 2.51E-05 |
| $^{234}$U | 1.69E-01 | 1.36E-02 | 4.17E-01 | 9.40E-04 | 2.07E-01 | 3.25E-02 | 9.35E-03 | 2.64E-03 | 4.23E-02 | 3.65E-02 | 3.52E-02 | 1.13E-01 | 8.27E-02 |
| $^{235}$U | 7.54E-03 | 7.10E-04 | 1.98E-02 | 3.86E-05 | 9.24E-03 | 1.82E-03 | 4.01E-04 | 1.14E-04 | 1.89E-03 | 1.48E-03 | 1.42E-03 | 4.79E-03 | 3.42E-03 |
| $^{236}$U | 1.93E-03 | 3.74E-04 | 4.85E-03 | 1.73E-05 | 2.31E-03 | 2.85E-04 | 9.61E-05 | 2.93E-05 | 4.73E-04 | 5.23E-04 | 3.52E-04 | 8.33E-04 | 5.13E-04 |
| $^{237}$Np | 3.45E-04 | 1.35E-02 | 7.97E-02 | 5.41E-02 | 2.08E-04 | 2.17E-05 | 6.46E-04 | 1.09E-03 | 1.54E-04 | 3.42E-03 | 2.90E-03 | 2.70E-05 | 2.16E-02 |
| $^{238}$Pu | 1.13E-01 | 1.30E+00 | 5.89E-01 | 2.38E+00 | 8.05E-01 | 4.37E-03 | 1.56E-02 | 1.56E-02 | 3.59E-02 | 4.42E-01 | 3.99E-01 | 1.36E-02 | 2.76E-04 |

### Table 3-13a. 241-C Tank Farm Residual Inventory Estimates for Retrieved Tanks with Post-Retrieval Sampling. (sheet 2 of 2)

| **Tanks Retrieved (BBI average)[a]** | **241-C-101** | **241-C-103** | **241-C-104** | **241-C-106** | **241-C-107** | **241-C-108** | **241-C-109** | **241-C-110** | **241-C-112** | **241-C-201** | **241-C-202** | **241-C-203** | **241-C-204** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $^{238}$U | 1.72E-01 | 1.64E-02 | 4.39E-01 | 9.02E-04 | 2.11E-01 | 4.03E-02 | 9.53E-03 | 2.59E-03 | 4.32E-02 | 3.69E-02 | 3.28E-02 | 1.09E-01 | 8.13E-02 |
| $^{239}$Pu | 1.83E+01 | 4.99E+00 | 5.15E+00 | 1.67E+01 | 1.30E+02 | 6.68E-01 | 4.01E-01 | 1.17E+00 | 5.79E+00 | 1.58E+01 | 1.43E+01 | 4.86E-01 | 9.84E-03 |
| $^{240}$Pu | 1.96E+00 | 1.04E+00 | 1.55E+00 | 3.57E+00 | 1.42E+01 | 7.27E-02 | 4.36E-02 | 1.27E-01 | 6.29E-01 | 3.40E+00 | 3.08E+00 | 1.05E-01 | 2.12E-03 |
| $^{241}$Am | 9.91E+00 | 4.83E+00 | 8.46E+00 | 6.38E+01 | 3.70E+02 | 9.46E-01 | 3.71E-01 | 4.94E-02 | 9.42E-01 | 2.46E+00 | 1.21E+00 | 3.16E-02 | 3.16E-03 |
| $^{241}$Pu | 1.54E+00 | 1.80E+00 | 1.14E+01 | 1.84E+01 | 1.10E+01 | 7.91E-02 | 5.09E-01 | 3.58E-01 | 4.91E-01 | 8.36E+00 | 7.52E+00 | 2.58E-01 | 5.21E-03 |
| $^{242}$Cm | 2.23E-03 | 5.73E-05 | 3.13E-02 | 1.45E-01 | 6.09E-02 | 1.59E-04 | 6.17E-05 | 8.75E-06 | 1.54E-04 | 8.30E-02 | 4.01E-02 | 1.04E-03 | 1.04E-04 |
| $^{242}$Pu | 2.70E-05 | 3.24E-05 | 1.97E-02 | 4.16E-04 | 1.97E-04 | 1.01E-06 | 6.07E-07 | 1.77E-06 | 8.76E-06 | 1.60E-04 | 1.45E-04 | 4.94E-06 | 9.98E-08 |
| $^{243}$Am | 1.43E-03 | 3.70E-05 | 5.25E-03 | 3.05E-03 | 3.86E-02 | 9.78E-05 | 3.91E-05 | 5.54E-06 | 9.72E-05 | 9.76E-04 | 4.71E-04 | 1.22E-05 | 1.22E-06 |
| $^{243}$Cm | 1.86E-05 | 7.66E-07 | 3.64E-03 | 5.55E-02 | 5.02E-04 | 1.50E-06 | 5.09E-07 | 7.22E-08 | 1.26E-06 | 3.10E-03 | 1.50E-03 | 3.88E-05 | 3.87E-06 |
| $^{244}$Cm | 3.32E-04 | 1.52E-05 | 6.69E-02 | 7.39E-01 | 8.95E-03 | 2.96E-05 | 9.09E-06 | 1.29E-06 | 2.25E-05 | 5.55E-02 | 2.68E-02 | 6.95E-04 | 6.95E-05 |
| $^{3}$H | 2.45E-02 | 3.98E-03 | 9.32E-03 | 4.17E-03 | 1.44E-02 | 1.94E-02 | 3.51E-03 | 1.80E-03 | 1.06E-02 | 1.57E-04 | 1.60E-04 | 1.31E-04 | 1.13E-04 |
| $^{59}$Ni | 7.23E-04 | 1.12E-01 | 8.64E-02 | 1.05E+01 | 1.18E-03 | 9.30E-04 | 6.46E-04 | 1.83E-04 | 8.69E-04 | 4.07E-03 | 4.16E-03 | 3.40E-03 | 3.18E-03 |
| $^{60}$Co | 1.76E-04 | 1.83E-02 | 4.66E-01 | 2.23E+00 | 9.14E-04 | 7.22E-04 | 5.02E-04 | 1.42E-04 | 6.75E-04 | 2.37E-03 | 2.44E-03 | 2.15E-03 | 1.86E-03 |
| $^{63}$Ni | 5.53E-02 | 1.86E+01 | 9.95E+01 | 6.53E+01 | 1.46E-01 | 2.80E+00 | 8.78E-01 | 4.08E-01 | 1.08E-01 | 8.33E-01 | 2.00E-01 | 5.54E-02 | 1.46E-02 |
| $^{79}$Se | 2.80E-04 | 2.64E-05 | 8.56E-03 | 9.57E-03 | 2.70E-04 | 1.62E-03 | 1.48E-04 | 4.21E-05 | 1.99E-04 | 5.49E-05 | 5.61E-05 | 4.58E-05 | 4.29E-05 |
| $^{90}$Sr | 3.29E+03 | 6.78E+03 | 4.89E+03 | 4.50E+04 | 2.42E+04 | 1.25E+03 | 2.33E+03 | 2.62E+03 | 2.28E+02 | 1.71E+02 | 3.31E+02 | 1.56E+02 | 1.03E+02 |
| $^{90}$Y | 3.29E+03 | 6.78E+03 | 4.89E+03 | 4.50E+04 | 2.42E+04 | 1.25E+03 | 2.33E+03 | 2.62E+03 | 2.28E+02 | 1.71E+02 | 3.31E+02 | 1.56E+02 | 1.03E+02 |
| $^{93m}$Nb | 1.83E-05 | 3.69E-04 | 3.16E-02 | 5.92E+00 | 8.45E-02 | 4.80E-02 | 4.64E-02 | 1.32E-02 | 6.26E-02 | 7.46E-04 | 7.64E-04 | 6.26E-04 | 5.84E-04 |
| $^{93}$Zr | 3.35E-05 | 7.03E-04 | 6.24E-02 | 1.04E+01 | 1.55E-01 | 1.22E-01 | 8.45E-02 | 2.41E-02 | 1.14E-01 | 1.46E-03 | 1.49E-03 | 1.22E-03 | 1.14E-03 |
| $^{99}$Tc | 4.34E-02 | 4.48E-02 | 3.04E-01 | 1.64E-01 | 2.14E+00 | 4.87E-02 | 8.77E-03 | 4.46E-02 | 1.69E+00 | 2.63E-03 | 2.50E-03 | 2.32E-03 | 3.18E-03 |

Source: RPP-RPT-42323, "Hanford C-Farm Tank and Ancillary Equipment Residual Waste Inventory Estimates."

[a] September 1, 2014 Best-Basis Inventory (BBI), includes tank 241-C-106 for which retrieval completion is under review. Note: for less than detect values; BBI mean uses less than detect values or process knowledge estimate, whichever is lower.

[b] Inventories estimated without post-retrieval sampling.

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

[d] Thorium-230 is not a standard BBI constituent but is included for Performance Assessment modeling estimates. Only the tank 241-C-106 nominal inventory based on analytical results is presented. Concentrations for other tanks sampled were below detection limits.

### Table 3-13b. 241-C Tank Farm Residual Inventory Estimates for Retrieved Tanks with Post-Retrieval Sampling.

| Tanks Retrieved (BBI average)[a] | 241-C-101[b] | 241-C-103 | 241-C-104 | 241-C-106 | 241-C-107[b] | 241-C-108 | 241-C-109 | 241-C-110 | 241-C-112[b] | 241-C-201 | 241-C-202 | 241-C-203 | 241-C-204 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Residual Volume (kL [kgal]) | 18.9 [4.99] | 9.57 [2.53] | 7.2 [1.9] | 10.49 [2.77] | 53 [14] | 12.9 [3.4] | 7.6 [2.0] | 8 [2.1] | 48 [12.7] | 0.6 [0.16] | 0.6 [0.16] | 0.5 [0.13] | 0.5 [0.13] |
| Total Chemicals (kg) | 2.00E+04 | 4.15E+03 | 4.79E+03 | 1.90E+03 | 2.74E+04 | 9.05E+03 | 4.97E+03 | 4.87E+03 | 2.64E+04 | 4.55E+02 | 3.96E+02 | 5.08E+02 | 4.57E+02 |
| Al | 7.93E+01 | 3.63E+03 | 1.14E+03 | 3.82E+02 | 1.98E+03 | 3.47E+03 | 2.15E+03 | 1.29E+03 | 3.32E+02 | 4.11E+00 | 8.48E+00 | 0.00E+00 | 5.88E+00 |
| Bi | 2.23E+01 | 9.49E-05 | 2.91E+00 | 2.94E+00 | 1.02E+03 | 7.56E+01 | 1.98E+00 | 3.63E+01 | 1.32E+03 | 6.10E-01 | 6.34E-01 | 1.29E+00 | 0.00E+00 |
| Ca | 1.15E+02 | 2.17E+01 | 1.35E+01 | 1.18E+02 | 5.04E+01 | 2.40E+01 | 1.56E+01 | 5.84E+00 | 6.44E+01 | 6.76E+00 | 7.12E+00 | 2.02E+00 | 5.90E-01 |
| Cl | 6.17E+01 | 1.94E-01 | 5.95E-01 | 6.14E+00 | 5.99E+01 | 9.01E-02 | 6.46E-02 | 6.26E-01 | 7.86E+01 | 2.93E-01 | 2.87E-01 | 5.86E-02 | 5.58E-03 |
| Cr | 7.23E+00 | 2.38E+00 | 3.06E+00 | 3.78E+00 | 5.54E+01 | 6.31E-01 | 1.76E-01 | 1.12E+00 | 5.78E+01 | 1.22E+01 | 9.09E+00 | 2.60E+00 | 1.36E+00 |
| F | 3.46E+01 | 1.62E-01 | 1.54E+01 | 5.43E-01 | 6.05E+02 | 1.21E+02 | 9.68E+01 | 1.38E+02 | 7.09E+02 | 2.69E+00 | 2.26E+00 | 1.64E+00 | 8.05E-03 |
| Fe | 8.77E+02 | 1.19E+02 | 3.24E+02 | 2.07E+02 | 4.37E+03 | 2.82E+02 | 9.28E+01 | 1.90E+02 | 7.02E+02 | 1.10E+02 | 8.70E+01 | 1.28E+01 | 3.21E+01 |
| Hg | 2.98E+00 | 1.06E+00 | 1.35E+00 | 1.93E+00 | 3.78E+00 | 2.03E-02 | 1.84E-02 | 1.07E-01 | 2.63E-02 | 1.07E-01 | 2.87E-01 | 2.23E-03 | 1.47E-01 |
| K | 8.68E+00 | 3.60E+00 | 1.31E+00 | 1.77E+01 | 2.58E+01 | 2.74E+00 | 2.61E-01 | 4.46E-01 | 2.21E+01 | 8.91E-01 | 9.09E-01 | 1.83E+00 | 2.02E+00 |
| La | 1.56E+00 | 1.82E-01 | 2.34E-02 | 2.44E+00 | 1.03E+01 | 1.32E-02 | 1.20E-01 | 9.98E-03 | 1.18E-01 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| Mn | 7.14E+00 | 4.42E+00 | 4.29E+01 | 5.49E+02 | 1.93E+02 | 4.08E+00 | 5.63E-01 | 7.61E-01 | 6.52E+00 | 1.90E+01 | 1.69E+01 | 5.13E-01 | 2.39E-01 |
| Na | 4.80E+03 | 9.60E+01 | 1.15E+03 | 1.88E+02 | 6.13E+03 | 3.27E+03 | 1.30E+03 | 1.20E+03 | 6.90E+03 | 4.91E+01 | 4.58E+01 | 5.59E+01 | 3.33E+01 |
| Ni | 3.27E+00 | 4.58E+00 | 6.00E+00 | 3.02E+01 | 9.86E+01 | 7.45E+01 | 1.33E+01 | 4.13E-01 | 1.46E+00 | 6.15E+00 | 7.28E+00 | 2.04E-01 | 8.01E-01 |
| $NO_2$ | 5.64E+02 | 4.82E-01 | 5.06E+00 | 4.14E+01 | 2.15E+03 | 5.78E+00 | 3.83E+00 | 2.74E+00 | 6.75E+02 | 5.27E-01 | 4.52E-01 | 9.94E-01 | 3.13E-02 |
| $NO_3$ | 8.20E+03 | 8.71E-01 | 9.38E+00 | 3.48E+01 | 3.59E+03 | 9.16E+00 | 4.52E+00 | 6.73E+00 | 8.76E+03 | 1.35E+00 | 1.25E+00 | 3.76E+00 | 2.22E-02 |
| Pb | 2.07E+01 | 8.50E+00 | 6.48E+00 | 2.56E+01 | 3.62E+02 | 1.71E+01 | 5.39E+00 | 5.62E+00 | 1.36E+01 | 6.25E+00 | 5.84E+00 | 3.07E+00 | 1.02E+00 |
| $PO_4$ | 3.79E+03 | 2.99E+01 | 4.28E+01 | 9.00E+01 | 4.74E+03 | 1.18E+03 | 9.82E+02 | 1.40E+03 | 4.83E+03 | 5.46E+01 | 3.46E+01 | 7.24E+01 | 7.96E+01 |
| Si | 2.40E+01 | 1.27E+02 | 1.31E+02 | 1.60E+01 | 1.02E+02 | 8.78E+01 | 2.79E+01 | 2.05E+01 | 4.28E+02 | 6.99E+00 | 8.60E+00 | 2.01E+00 | 7.33E+00 |
| $SO_4$ | 7.71E+02 | 2.16E+00 | 1.15E+00 | 3.90E+00 | 5.17E+02 | 2.93E+00 | 2.86E+00 | 7.46E+00 | 9.32E+02 | 3.66E+00 | 4.01E-01 | 6.58E-01 | 1.28E-02 |
| Sr | 2.34E+01 | 2.41E+00 | 9.35E-01 | 1.83E+00 | 1.71E+01 | 1.97E+01 | 4.91E-01 | 5.63E+01 | 1.00E+01 | 9.09E-01 | 1.22E+00 | 2.30E-01 | 3.67E-01 |
| Total Inorganic Carbon as $CO_3$ | 6.57E+01 | 1.68E+01 | 4.77E+02 | 7.58E+01 | 6.45E+02 | 2.77E+02 | 2.03E+02 | 4.89E+02 | 4.12E+02 | 3.36E+01 | 3.43E+01 | 1.50E+01 | 1.41E+01 |
| Total Organic Carbon | 3.00E+01 | 1.25E+01 | 6.53E+01 | 9.07E+01 | 4.16E+01 | 3.96E+00 | 3.38E+01 | 1.20E+01 | 3.66E+01 | 2.43E+01 | 2.48E+01 | 4.47E+00 | 3.54E+01 |
| UTOTAL | 5.16E+02 | 4.91E+01 | 1.32E+03 | 2.70E+00 | 6.32E+02 | 1.21E+02 | 2.86E+01 | 5.49E+00 | 1.29E+02 | 1.11E+02 | 9.88E+01 | 3.26E+02 | 2.43E+02 |
| Zr | 3.79E-01 | 1.33E+01 | 2.49E+01 | 2.79E+00 | 2.80E+00 | 5.98E-01 | 7.05E+00 | 3.62E-01 | 9.53E+00 | 1.02E-02 | 9.45E-02 | 1.05E-01 | 0.00E+00 |

Source: RPP-RPT-42323, "Hanford C-Farm Tank and Ancillary Equipment Residual Waste Inventory Estimates."

[a] September 1, 2014 Best-Basis Inventory (BBI), includes tank 241-C-106 for which retrieval completion is under review. 95% Confidence Interval = Mean + 2 × Standard Deviation (Closure mean for tanks with closure reports, BBI mean for tanks 241-C-101, 241-C-107 and 241-C-112: no closure report). Difference between closure mean and BBI mean: Closure mean uses less than detect values in inventory estimates; BBI mean uses less than detect values or process knowledge estimate, whichever is lower. As a result, closure means may be higher than BBI means for some constituents.

[b] Inventories estimated without post-retrieval sampling.

## Table 3-14a. 241-C Tank Farm Residual Inventory Estimates for Tanks Undergoing Retrieval. (2 sheets)

| **Base Case for Tanks not Retrieved** [a] | **241-C-102** | **241-C-105** | **241-C-111** |
|---|---|---|---|
| Residual Volume (kL [kgal]) | 10.2 [2.69] | 48.0 [12.7] | 132 [34.9] |
| Total Radionuclides (Ci) [b] | 9.19E+02 | 6.74E+04 | 6.24E+05 |
| $^{106}$Ru | 1.71E-13 | 6.76E-16 | 7.13E-10 |
| $^{113m}$Cd | 1.78E-02 | 5.85E-02 | 5.99E-02 |
| $^{125}$Sb | 1.27E-05 | 2.89E-06 | 1.37E-03 |
| $^{126}$Sn | 1.83E-04 | 2.93E-04 | 6.72E-03 |
| $^{129}$I | 2.56E-03 | 8.93E-03 | 1.41E-02 |
| $^{134}$Cs | 1.54E-07 | 1.52E-08 | 1.42E-06 |
| $^{137}$Cs | 8.07E+01 | 5.07E+03 | 7.14E+03 |
| $^{137m}$Ba | 8.07E+01 | 4.52E+03 | 6.36E+03 |
| $^{14}$C | 9.88E-04 | 4.85E-02 | 1.04E-01 |
| $^{151}$Sm | 9.72E-01 | 2.36E+00 | 6.39E+02 |
| $^{152}$Eu | 1.26E-04 | 1.12E-04 | 5.38E-02 |
| $^{154}$Eu | 1.36E-01 | 4.67E-03 | 2.41E+00 |
| $^{155}$Eu | 2.62E-02 | 6.07E-04 | 3.70E-01 |
| $^{226}$Ra | 2.88E-07 | 1.59E-07 | 4.51E-06 |
| $^{227}$Ac | 1.93E-02 | 5.16E-07 | 1.82E-05 |
| $^{228}$Ra | 3.64E-01 | 2.36E-13 | 6.54E-12 |
| $^{229}$Th | 1.06E-02 | 1.25E-10 | 3.56E-09 |
| $^{231}$Pa | 2.12E-03 | 6.56E-07 | 4.99E-05 |
| $^{232}$Th | 2.29E-02 | 9.98E-13 | 2.77E-11 |
| $^{232}$U | 2.83E-02 | 8.61E-06 | 2.22E-05 |
| $^{233}$U | 2.17E+00 | 5.01E-07 | 4.80E-05 |
| $^{234}$U | 1.13E-01 | 2.38E-01 | 7.74E-01 |
| $^{235}$U | 4.27E-03 | 1.02E-02 | 3.37E-02 |
| $^{236}$U | 1.43E-03 | 5.16E-03 | 1.32E-02 |
| $^{237}$Np | 5.16E-05 | 1.93E-04 | 3.32E-03 |
| $^{238}$Pu | 1.48E+00 | 7.48E-01 | 1.70E+00 |
| $^{238}$U | 9.78E-02 | 2.44E-01 | 7.88E-01 |
| $^{239}$Pu | 6.49E+01 | 5.27E+01 | 9.45E+01 |

### Table 3-14a. 241-C Tank Farm Residual Inventory Estimates for Tanks Undergoing Retrieval. (2 sheets)

| Base Case for Tanks not Retrieved [a] | 241-C-102 | 241-C-105 | 241-C-111 |
|---|---|---|---|
| $^{240}$Pu | 1.55E+01 | 1.04E+01 | 1.85E+01 |
| $^{241}$Am | 2.12E+01 | 2.83E+01 | 8.32E+01 |
| $^{241}$Pu | 4.87E+01 | 1.75E+01 | 3.54E+01 |
| $^{242}$Cm | 1.15E-03 | 1.01E-03 | 6.21E-02 |
| $^{242}$Pu | 9.00E-04 | 3.13E-04 | 6.54E-04 |
| $^{243}$Am | 7.93E-04 | 6.71E-04 | 1.15E-02 |
| $^{243}$Cm | 6.22E-05 | 9.09E-06 | 1.82E-03 |
| $^{244}$Cm | 1.28E-03 | 1.56E-04 | 3.26E-02 |
| $^{3}$H | 2.15E-05 | 4.08E+00 | 2.58E+00 |
| $^{59}$Ni | 1.62E-01 | 4.40E-01 | 1.40E+00 |
| $^{60}$Co | 2.14E-01 | 6.82E-01 | 1.03E-01 |
| $^{63}$Ni | 1.36E+01 | 3.61E+01 | 1.13E+02 |
| $^{79}$Se | 1.60E-06 | 1.51E-04 | 3.53E-03 |
| $^{90}$Sr | 2.94E+02 | 2.88E+04 | 3.05E+05 |
| $^{90}$Y | 2.94E+02 | 2.88E+04 | 3.05E+05 |
| $^{93m}$Nb | 1.10E-02 | 1.45E-03 | 9.78E-02 |
| $^{93}$Zr | 4.22E-03 | 2.76E-03 | 1.81E-01 |
| $^{99}$Tc | 3.56E-03 | 7.81E+00 | 2.19E+00 |

Source: RPP-RPT-42323, "Hanford C-Farm Tank and Ancillary Equipment Residual Waste Inventory Estimates."

[a] Includes tanks 241-C-102, 241-C-105 and 241-C-111 for which retrieval is in progress as of September 1, 2014. Note: Based on retrieval results for other tanks and in-process results for these tanks, it appears that the retrieval goal of 360 ft$^3$ or less will not be met for these tanks. The base case reflects the assumed retrieval end state based on retrieval performance to date.

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

**3.2.2.3.3 Tanks Undergoing Retrieval.** Future residual waste volumes are unknown for the three SSTs for which retrieval is in progress (C-102, C-105 and C-111); therefore, lower and upper bound residual inventories were estimated for these tanks (C-102, C-105, and C-111). These inventories are provided in Table 3-17.

The lower bound residual waste volume was assumed to be 10.2 m$^3$ (360 ft$^3$) (the retrieval threshold goal) because it appears likely that more than 10.2 m$^3$ (360 ft$^3$) of residual waste will be left in these tanks after retrieval.

## Table 3-14b. 241-C Tank Farm Residual Inventory Estimates for Tanks Undergoing Retrieval.

| **Base Case for Tanks not Retrieved*** | **241-C-102** | **241-C-105** | **241-C-111** |
|---|---|---|---|
| Residual Volume (kL [kgal]) | 10.2 [2.69] | 48.0 [12.7] | 132 [34.9] |
| Total Chemicals (kg) | 7.51E+03 | 2.76E+04 | 8.34E+04 |
| Al | 5.29E+03 | 1.49E+04 | 1.60E+04 |
| Bi | 4.53E+01 | 3.57E+01 | 1.55E+03 |
| Ca | 1.22E+02 | 1.90E+02 | 2.20E+03 |
| Cl | 2.62E-03 | 2.98E+01 | 2.21E+02 |
| Cr | 1.13E+01 | 3.70E+01 | 7.33E+01 |
| F | 6.06E-03 | 7.90E+01 | 8.07E+02 |
| Fe | 3.37E+02 | 3.92E+02 | 7.53E+03 |
| Hg | 7.55E-02 | 5.02E-01 | 4.69E+01 |
| K | 7.85E+00 | 8.26E+01 | 1.87E+02 |
| La | 2.26E+00 | 2.62E-01 | 5.68E+01 |
| Mn | 2.86E+01 | 1.82E+02 | 4.68E+01 |
| Na | 4.30E+02 | 3.66E+03 | 1.03E+04 |
| Ni | 1.20E+02 | 1.59E+02 | 2.65E+03 |
| $NO_2$ | 2.78E-02 | 6.46E+02 | 5.50E+03 |
| $NO_3$ | 9.54E-02 | 7.81E+02 | 1.47E+04 |
| Pb | 2.84E+01 | 3.45E+01 | 7.65E+02 |
| $PO_4$ | 6.12E+01 | 5.77E+02 | 1.20E+04 |
| Si | 5.49E+02 | 2.97E+03 | 1.42E+03 |
| $SO_4$ | 7.21E+00 | 2.80E+02 | 1.26E+03 |
| Sr | 2.38E+00 | 1.37E+01 | 3.58E+01 |
| Total Inorganic Carbon as $CO_3$ | 5.80E+01 | 1.26E+03 | 3.47E+03 |
| Total Organic Carbon | 2.18E+01 | 4.14E+02 | 1.46E+02 |
| UTOTAL | 2.93E+02 | 7.32E+02 | 2.36E+03 |
| Zr | 9.46E+01 | 1.56E+01 | 3.02E+01 |

Source: RPP-RPT-42323, "Hanford C-Farm Tank and Ancillary Equipment Residual Waste Inventory Estimates."

* Includes tanks 241-C-102, 241-C-105 and 241-C-111 for which retrieval is in progress as of September 1, 2014. Note: Based on retrieval results for other tanks and in-process results for these tanks, it appears that the retrieval goal of 360 $ft^3$ or less will not be met for these tanks. The base case reflects the assumed retrieval end state based on retrieval performance to date.

### Table 3-15a. 241-C Tank Farm Residual Inventory Estimates for Ancillary Equipment. (2 sheets)

| Ancillary Equipment | Catch Tank 241-C-301 [a] | 244-CR Process Tank Vault [a] | Pits [b] | Diversion Boxes [b] | Pipelines [b] |
|---|---|---|---|---|---|
| Residual Volume (kL [kgal]) | 4.0 [1.06] | 4.1 [1.08] | 0.1 [0.03] | 0.2 [0.06] | 6.1 [1.6] |
| Total Radionuclides (Ci) [b] | 7.04E+03 | 7.22E+03 | 2.13E+02 | 4.13E+02 | 1.07E+04 |
| $^{106}$Ru | 1.19E-10 | 1.22E-10 | 3.60E-12 | 6.98E-12 | 1.80E-10 |
| $^{113m}$Cd | 8.63E-02 | 8.85E-02 | 2.61E-03 | 5.06E-03 | 1.31E-01 |
| $^{125}$Sb | 5.36E-02 | 5.50E-02 | 1.62E-03 | 3.15E-03 | 8.12E-02 |
| $^{126}$Sn | 6.91E-02 | 7.08E-02 | 2.09E-03 | 4.05E-03 | 1.05E-01 |
| $^{129}$I | 2.09E-04 | 2.15E-04 | 6.34E-06 | 1.23E-05 | 3.17E-04 |
| $^{134}$Cs | 1.10E-06 | 1.12E-06 | 3.32E-08 | 6.43E-08 | 1.66E-06 |
| $^{137}$Cs | 1.23E+02 | 1.26E+02 | 3.74E+00 | 7.24E+00 | 1.87E+02 |
| $^{137m}$Ba | 1.10E+02 | 1.13E+02 | 3.33E+00 | 6.46E+00 | 1.67E+02 |
| $^{14}$C | 2.07E-03 | 2.12E-03 | 6.28E-05 | 1.22E-04 | 3.14E-03 |
| $^{151}$Sm | 5.38E+02 | 5.51E+02 | 1.63E+01 | 3.16E+01 | 8.15E+02 |
| $^{152}$Eu | 8.45E-02 | 8.66E-02 | 2.56E-03 | 4.96E-03 | 1.28E-01 |
| $^{154}$Eu | 1.19E+00 | 1.22E+00 | 3.60E-02 | 6.98E-02 | 1.80E+00 |
| $^{155}$Eu | 3.66E-01 | 3.75E-01 | 1.11E-02 | 2.15E-02 | 5.54E-01 |
| $^{226}$Ra | 1.96E-05 | 2.01E-05 | 5.94E-07 | 1.15E-06 | 2.97E-05 |
| $^{227}$Ac | 6.72E-05 | 6.89E-05 | 2.04E-06 | 3.94E-06 | 1.02E-04 |
| $^{228}$Ra | 5.99E-05 | 6.14E-05 | 1.82E-06 | 3.52E-06 | 9.08E-05 |
| $^{229}$Th | 7.32E-07 | 7.51E-07 | 2.22E-08 | 4.30E-08 | 1.11E-06 |
| $^{231}$Pa | 1.03E-04 | 1.06E-04 | 3.12E-06 | 6.04E-06 | 1.56E-04 |
| $^{232}$Th | 2.54E-04 | 2.60E-04 | 7.69E-06 | 1.49E-05 | 3.85E-04 |
| $^{232}$U | 1.99E-03 | 2.04E-03 | 6.04E-05 | 1.17E-04 | 3.02E-03 |
| $^{233}$U | 1.21E-01 | 1.25E-01 | 3.68E-03 | 7.13E-03 | 1.84E-01 |
| $^{234}$U | 2.30E-01 | 2.35E-01 | 6.96E-03 | 1.35E-02 | 3.48E-01 |
| $^{235}$U | 9.72E-03 | 9.96E-03 | 2.94E-04 | 5.70E-04 | 1.47E-02 |
| $^{236}$U | 1.96E-03 | 2.01E-03 | 5.94E-05 | 1.15E-04 | 2.97E-03 |
| $^{237}$Np | 2.87E-02 | 2.94E-02 | 8.68E-04 | 1.68E-03 | 4.34E-02 |
| $^{238}$Pu | 7.52E-01 | 7.71E-01 | 2.28E-02 | 4.41E-02 | 1.14E+00 |
| $^{238}$U | 2.26E-01 | 2.31E-01 | 6.83E-03 | 1.32E-02 | 3.42E-01 |

### Table 3-15a. 241-C Tank Farm Residual Inventory Estimates for Ancillary Equipment. (2 sheets)

| Ancillary Equipment | Catch Tank 241-C-301 [a] | 244-CR Process Tank Vault [a] | Pits [b] | Diversion Boxes [b] | Pipelines [b] |
|---|---|---|---|---|---|
| $^{239}$Pu | 2.17E+01 | 2.22E+01 | 6.57E-01 | 1.27E+00 | 3.28E+01 |
| $^{240}$Pu | 4.68E+00 | 4.79E+00 | 1.42E-01 | 2.74E-01 | 7.08E+00 |
| $^{241}$Am | 5.63E+00 | 5.77E+00 | 1.70E-01 | 3.30E-01 | 8.52E+00 |
| $^{241}$Pu | 1.23E+01 | 1.26E+01 | 3.71E-01 | 7.19E-01 | 1.86E+01 |
| $^{242}$Cm | 9.02E-02 | 9.25E-02 | 2.73E-03 | 5.29E-03 | 1.37E-01 |
| $^{242}$Pu | 1.32E-03 | 1.35E-03 | 3.99E-05 | 7.74E-05 | 2.00E-03 |
| $^{243}$Am | 1.39E-03 | 1.43E-03 | 4.21E-05 | 8.16E-05 | 2.11E-03 |
| $^{243}$Cm | 5.41E-03 | 5.55E-03 | 1.64E-04 | 3.17E-04 | 8.19E-03 |
| $^{244}$Cm | 8.74E-02 | 8.96E-02 | 2.65E-03 | 5.13E-03 | 1.32E-01 |
| $^{3}$H | 2.13E-03 | 2.18E-03 | 6.44E-05 | 1.25E-04 | 3.22E-03 |
| $^{59}$Ni | 4.21E-01 | 4.31E-01 | 1.27E-02 | 2.47E-02 | 6.37E-01 |
| $^{60}$Co | 1.18E-01 | 1.21E-01 | 3.58E-03 | 6.93E-03 | 1.79E-01 |
| $^{63}$Ni | 9.69E+00 | 9.93E+00 | 2.93E-01 | 5.69E-01 | 1.47E+01 |
| $^{79}$Se | 1.05E-03 | 1.07E-03 | 3.17E-05 | 6.14E-05 | 1.58E-03 |
| $^{90}$Sr | 3.11E+03 | 3.18E+03 | 9.40E+01 | 1.82E+02 | 4.70E+03 |
| $^{90}$Y | 3.11E+03 | 3.18E+03 | 9.40E+01 | 1.82E+02 | 4.70E+03 |
| $^{93m}$Nb | 2.34E-01 | 2.40E-01 | 7.08E-03 | 1.37E-02 | 3.54E-01 |
| $^{93}$Zr | 4.13E-01 | 4.24E-01 | 1.25E-02 | 2.43E-02 | 6.26E-01 |
| $^{99}$Tc | 3.70E-02 | 3.80E-02 | 1.12E-03 | 2.17E-03 | 5.61E-02 |

Source: RPP-RPT-42323, "Hanford C-Farm Tank and Ancillary Equipment Residual Waste Inventory Estimates."

[a] Assumes 90% retrieval for C-301 catch tank and 244-CR vault. Note: Current volumes and inventories for these tanks are 10 times the values shown in this table.

[b] Estimated waste volumes and inventories at closure for pits, diversion boxes and waste transfer pipelines.

Note: Radionuclides are decayed to January 1, 2020 for 241-C Tank Farm closure assessments.

The HTWOS model was used to estimate residual inventories for the lower bound if tanks are retrieved to the threshold goal of 10.2 $m^3$ (360 $ft^3$). The HTWOS model simulates retrieval operations considering the mobility and composition of waste and retrieval fluids to estimate the waste residual inventories after retrieval. As such, it provides a more rigorous approach to estimate residual inventories compared to estimates based on simple percentage of waste currently in the tanks and differentiates between soluble and insoluble constituents. However, if only a portion of the waste is retrieved and if soluble constituents are not washed from the waste, the inventories of soluble and insoluble constituents may be much different than that predicted by the HTWOS model.

**Table 3-15b. 241-C Tank Farm Residual Inventory Estimates for Ancillary Equipment.**

| Ancillary Equipment | Catch Tank 241-C-301 [a] | 244-CR Process Tank Vault [a] | Pits [b] | Diversion Boxes [b] | Pipelines [b] |
|---|---|---|---|---|---|
| Residual Volume (kL [kgal]) | 4.0 [1.06] | 4.1 [1.08] | 0.1 [0.03] | 0.2 [0.06] | 6.1 [1.6] |
| Total Chemicals (kg) | 2.64E+03 | 2.70E+03 | 7.98E+01 | 1.55E+02 | 3.99E+03 |
| Al | 5.28E+02 | 5.41E+02 | 1.60E+01 | 3.10E+01 | 7.99E+02 |
| Bi | 6.40E+00 | 6.56E+00 | 1.94E-01 | 3.75E-01 | 9.69E+00 |
| Ca | 1.94E+01 | 1.98E+01 | 5.86E-01 | 1.14E+00 | 2.93E+01 |
| Cl | 7.51E-01 | 7.70E-01 | 2.27E-02 | 4.40E-02 | 1.14E+00 |
| Cr | 1.79E+01 | 1.83E+01 | 5.41E-01 | 1.05E+00 | 2.70E+01 |
| F | 2.12E+01 | 2.18E+01 | 6.43E-01 | 1.25E+00 | 3.22E+01 |
| Fe | 2.21E+02 | 2.27E+02 | 6.70E+00 | 1.30E+01 | 3.35E+02 |
| Hg | 5.82E-01 | 5.96E-01 | 1.76E-02 | 3.41E-02 | 8.81E-01 |
| K | 5.30E+00 | 5.43E+00 | 1.60E-01 | 3.11E-01 | 8.02E+00 |
| La | 1.09E-01 | 1.12E-01 | 3.31E-03 | 6.40E-03 | 1.65E-01 |
| Mn | 4.82E+01 | 4.94E+01 | 1.46E+00 | 2.83E+00 | 7.30E+01 |
| Na | 4.40E+02 | 4.51E+02 | 1.33E+01 | 2.58E+01 | 6.65E+02 |
| Ni | 1.45E+01 | 1.48E+01 | 4.38E-01 | 8.49E-01 | 2.19E+01 |
| $NO_2$ | 3.87E+00 | 3.97E+00 | 1.17E-01 | 2.27E-01 | 5.86E+00 |
| $NO_3$ | 7.50E+00 | 7.69E+00 | 2.27E-01 | 4.40E-01 | 1.14E+01 |
| Pb | 1.41E+01 | 1.45E+01 | 4.28E-01 | 8.28E-01 | 2.14E+01 |
| $PO_4$ | 3.46E+02 | 3.55E+02 | 1.05E+01 | 2.03E+01 | 5.24E+02 |
| Si | 3.63E+01 | 3.72E+01 | 1.10E+00 | 2.13E+00 | 5.49E+01 |
| $SO_4$ | 4.16E+00 | 4.27E+00 | 1.26E-01 | 2.44E-01 | 6.30E+00 |
| Sr | 5.57E+00 | 5.71E+00 | 1.69E-01 | 3.27E-01 | 8.43E+00 |
| Total Inorganic Carbon as $CO_3$ | 1.42E+02 | 1.46E+02 | 4.31E+00 | 8.35E+00 | 2.16E+02 |
| Total Organic Carbon | 7.47E+01 | 7.66E+01 | 2.26E+00 | 4.38E+00 | 1.13E+02 |
| UTOTAL | 6.76E+02 | 6.93E+02 | 2.05E+01 | 3.97E+01 | 1.02E+03 |
| Zr | 2.61E+00 | 2.67E+00 | 7.89E-02 | 1.53E-01 | 3.95E+00 |

Source: RPP-RPT-42323, "Hanford C-Farm Tank and Ancillary Equipment Residual Waste Inventory Estimates."

[a] Assumes 90% retrieval for C-301 catch tank and 244-CR vault. Note: Current volumes and inventories for these tanks are 10 times the values shown in this table.

[b] Estimated waste volumes and inventories at closure for pits, diversion boxes and waste transfer pipelines.

## Table 3-16a. 241-C Tank Farm Residual Inventory 95% Confidence Interval Estimates for Retrieved Tanks with Post-Retrieval Sampling. (3 sheets)

| Tanks Retrieved (95% Confidence Interval with post-retrieval residual data)[a] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 241-C-103 | 241-C-104 | 241-C-106 | 241-C-108 | 241-C-109 | 241-C-110 | 241-C-201 | 241-C-202 | 241-C-203 | 241-C-204 |
| $^{106}$Ru | —[b] | —[b] | —[b] | —[b] | —[b] | —[b] | —[b] | —[b] | —[b] | —[b] |
| $^{113m}$Cd | — | — | — | — | — | — | — | — | — | — |
| $^{125}$Sb | —[b] | —[b] | —[b] | —[b] | —[b] | —[b] | —[b] | —[b] | —[b] | —[b] |
| $^{126}$Sn | — | 1.68E-02 | — | —[b] | —[b] | 3.53E-02 | — | — | — | — |
| $^{129}$I | 3.81E-03 | —[b] | —[b] | —[b] | —[b] | —[b] | —[b] | 9.64E-06 | 3.84E-05 | —[b] |
| $^{134}$Cs | 2.08E-06 | — | —[b] | — | — | — | — | — | — | — |
| $^{137}$Cs | 7.40E+02 | 1.14E+03 | 1.35E+03 | 1.07E+02 | 5.55E+01 | 3.18E+01 | 9.13E+00 | 7.18E+00 | 1.09E+01 | 5.16E+00 |
| $^{137m}$Ba | 6.60E+02 | 9.99E+02 | 1.20E+03 | 9.52E+01 | 4.91E+01 | 2.83E+01 | 8.14E+00 | 6.40E+00 | 9.70E+00 | 4.60E+00 |
| $^{14}$C | —[b] | 4.64E-03 | —[b] | —[b] | —[b] | —[b] | 1.38E-03 | —[b] | —[b] | —[b] |
| $^{151}$Sm | — | — | — | — | — | — | — | — | — | — |
| $^{152}$Eu | —[b] | —[b] | —[b] | —[b] | —[b] | —[b] | —[b] | —[b] | —[b] | —[b] |
| $^{154}$Eu | 1.89E+00 | —[b] | —[b] | —[b] | —[b] | —[b] | —[b] | —[b] | —[b] | —[b] |
| $^{155}$Eu | —[b] | —[b] | —[b] | —[b] | —[b] | —[b] | —[b] | —[b] | —[b] | —[b] |
| $^{226}$Ra | — | —[b] | — | — | — | — | — | — | — | — |
| $^{227}$Ac | — | — | — | — | — | — | — | — | — | — |
| $^{228}$Ra | — | — | — | — | — | — | — | — | — | — |
| $^{229}$Th | — | — | — | — | — | — | — | — | — | — |
| $^{231}$Pa | — | —[b] | —[b] | —[b] | —[b] | —[b] | — | — | — | — |

**Table 3-16a. 241-C Tank Farm Residual Inventory 95% Confidence Interval Estimates for Retrieved Tanks with Post-Retrieval Sampling. (3 sheets)**

| | Tanks Retrieved (95% Confidence Interval with post-retrieval residual data)[a] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 241-C-103 | 241-C-104 | 241-C-106 | 241-C-108 | 241-C-109 | 241-C-110 | 241-C-201 | 241-C-202 | 241-C-203 | 241-C-204 |
| $^{230}$Th[c] | —[b] | —[b] | 1.45E-03 | —[b] | —[b] | —[b] | —[b] | —[b] | —[b] | —[b] |
| $^{232}$Th | 2.36E-04 | 7.21E-03 | 7.68E-04 | 1.99E-05 | 1.32E-05 | — | 7.76E-06 | 7.75E-06 | 4.27E-06 | 2.52E-05 |
| $^{232}$U | — | — | — | — | — | — | — | — | — | — |
| $^{233}$U | 6.95E-03 | —[b] | 2.36E-03 | —[b] | —[b] | —[b] | 2.03E-07 | —[b] | —[b] | —[b] |
| $^{234}$U | 1.84E-02 | 6.08E-01 | 1.21E-03 | 4.72E-02 | —[b] | 3.80E-03 | 4.27E-04 | 4.44E-02 | 1.41E-01 | 1.07E-01 |
| $^{235}$U | 8.69E-04 | 2.99E-02 | 5.16E-05 | 2.20E-03 | 5.93E-04 | 1.53E-04 | 6.22E-09 | 1.75E-03 | 5.67E-03 | 4.26E-03 |
| $^{236}$U | 4.58E-04 | 7.30E-03 | 2.40E-05 | 5.12E-04 | 1.75E-04 | 3.72E-05 | 1.12E-07 | 4.90E-04 | 1.06E-03 | 6.57E-04 |
| $^{237}$Np | 2.52E+01 | —[b] | 1.03E-01 | —[b] | —[b] | 1.43E-03 | 7.33E+00 | 5.02E+00 | —[b] | 5.61E+01 |
| $^{238}$Pu | 2.19E+00 | 1.06E+00 | —[b] | 4.85E-03 | 2.12E-02 | 2.20E-02 | —[b] | —[b] | —[b] | —[b] |
| $^{238}$U | 2.01E-02 | 8.57E-01 | 1.30E-03 | 4.97E-02 | 1.41E-02 | — | 2.30E-08 | 4.00E-02 | 1.29E-01 | 1.01E-01 |
| $^{239}$Pu | 7.26E+00 | 9.01E+00 | 2.24E+01 | 7.83E-01 | 6.03E-01 | 1.69E+00 | 2.76E+01 | 1.63E+01 | 7.34E-01 | 1.23E-02 |
| $^{240}$Pu | 1.57E+00 | 2.71E+00 | 4.83E+00 | 8.52E-02 | 6.56E-02 | 1.85E-01 | 5.95E+00 | 3.52E+00 | 1.58E-01 | 2.64E-03 |
| $^{241}$Am | 6.90E+00 | 1.67E+01 | 8.13E+01 | 1.18E+00 | 4.41E-01 | 6.67E-02 | 4.06E+00 | 1.39E+00 | 4.16E-02 | 3.93E-03 |
| $^{241}$Pu | 3.08E+00 | 1.90E+01 | 2.04E+01 | 6.63E-02 | 6.05E-01 | 4.62E-01 | 1.10E+01 | 7.10E+00 | 3.71E-01 | 6.17E-03 |
| $^{242}$Cm | —[b] | 5.86E-02 | — | —[b] | —[b] | —[b] | — | —[b] | —[b] | —[b] |
| $^{242}$Pu | — | 3.54E-02 | — | 1.18E-06 | —[b] | 2.57E-06 | — | — | — | — |
| $^{243}$Am | — | — | — | — | — | — | — | — | — | — |
| $^{243}$Cm | 5.32E-02 | 8.10E-03 | 6.30E-01 | —[b] | —[b] | —[b] | 2.92E-02 | —[b] | —[b] | 2.41E-05 |
| $^{244}$Cm | 1.06E+00 | 1.48E-01 | 1.20E+01 | —[b] | —[b] | —[b] | 5.57E-01 | —[b] | —[b] | 4.78E-04 |

## Table 3-16a. 241-C Tank Farm Residual Inventory 95% Confidence Interval Estimates for Retrieved Tanks with Post-Retrieval Sampling. (3 sheets)

| | Tanks Retrieved (95% Confidence Interval with post-retrieval residual data)[a] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **241-C-103** | **241-C-104** | **241-C-106** | **241-C-108** | **241-C-109** | **241-C-110** | **241-C-201** | **241-C-202** | **241-C-203** | **241-C-204** |
| $^{3}$H | —[b] | —[b] | —[b] | —[b] | —[b] | 2.46E-03 | —[b] | —[b] | —[b] | —[b] |
| $^{59}$Ni | —[b] | —[b] | —[b] | —[b] | —[b] | —[b] | —[b] | —[b] | —[b] | —[b] |
| $^{60}$Co | —[b] | —[b] | —[b] | —[b] | —[b] | —[b] | —[b] | —[b] | —[b] | —[b] |
| $^{63}$Ni | 2.26E+01 | 2.60E+02 | 8.78E+01 | 3.69E+00 | 1.08E+00 | 5.38E-01 | 1.27E+00 | 2.40E-01 | 6.90E-02 | 1.86E-02 |
| $^{79}$Se | —[b] | —[b] | —[b] | 2.15E-03 | —[b] | —[b] | —[b] | —[b] | —[b] | —[b] |
| $^{90}$Sr | 9.73E+03 | 9.74E+03 | 5.75E+04 | 1.77E+03 | 2.99E+03 | 3.69E+03 | 2.30E+02 | 3.60E+02 | 2.11E+00 | 1.29E+02 |
| $^{90}$Y | 9.73E+03 | 9.74E+03 | 5.75E+04 | 1.77E+03 | 2.99E+03 | 3.69E+03 | 2.30E+02 | 3.60E+02 | 2.11E+00 | 1.29E+02 |
| $^{93m}$Nb | — | — | — | — | — | — | — | — | — | — |
| $^{93}$Zr | — | — | — | — | — | — | — | — | — | — |
| $^{99}$Tc | 5.37E-02 | 4.65E-01 | 2.22E-01 | 6.12E-02 | 1.10E-02 | 7.08E-02 | 4.78E-03 | 3.88E-03 | 3.97E-03 | 4.03E-03 |

Source: RPP-RPT-42323, "Hanford C-Farm Tank and Ancillary Equipment Residual Waste Inventory Estimates."

[a] Analytical data as of September 1, 2014, Best-Basis Inventory (BBI) constituents only, includes tank 241-C-106 for which retrieval completion is under review. 95% confidence interval = Mean + 2 × Standard Deviation (Closure mean for tanks with closure reports, BBI mean for C-101, C-107 and C-112: no closure report). 95% confidence intervals are not included for constituents with concentrations below analytical detection limits.

[b] Concentration less than analytical detection limit.

[c] Thorium-230 is not a standard BBI constituent, but is included for Performance Assessment model estimates. Radionuclides are decayed to January 1, 2020 for 241-C Tank Farm closure assessments.

## Table 3-16b. 241-C Tank Farm Residual Inventory 95% Confidence Interval Estimates for Retrieved Tanks with Post-Retrieval Sampling. (2 sheets)

| Tanks Retrieved (Best-Basis Inventory, 95% Confidence Intervals for Single-Shell Tanks with post-retrieval residual data)[a] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **241-C-103** | **241-C-104** | **241-C-106** | **241-C-108** | **241-C-109** | **241-C-110** | **241-C-201** | **241-C-202** | **241-C-203** | **241-C-204** |
| Al | 4.34E+03 | 1.80E+03 | 4.89E+02 | 4.17E+03 | 2.94E+03 | 1.74E+03 | 5.50E+00 | 9.28E+00 | —[b] | 5.88E+00 |
| Bi | —[b] | 4.35E+00 | —[b] | —[b] | 2.49E+00 | 4.72E+01 | 1.08E+00 | 1.03E+00 | 1.52E+00 | —[b] |
| Ca | 2.65E+01 | 2.39E+01 | 1.53E+02 | 2.86E+01 | 2.26E+01 | 7.49E+00 | 1.02E+01 | 7.86E+00 | 2.45E+00 | 5.90E-01 |
| Cl | 4.97E-01 | 9.06E-01 | —[b] | —[b] | —[b] | —[b] | 6.15E-01 | 5.86E-01 | 7.36E-02 | 6.98E-03 |
| Cr | 3.02E+00 | 4.45E+00 | 4.85E+00 | 7.98E-01 | 2.45E-01 | 1.61E+00 | 2.52E+01 | 9.94E+00 | 3.70E+00 | 1.36E+00 |
| F | 2.02E-01 | 3.01E+01 | —[b] | 1.60E+02 | 1.20E+02 | 1.84E+02 | 4.97E+00 | 2.84E+00 | 2.20E+00 | 8.05E-03 |
| Fe | 1.62E+02 | 4.83E+02 | 2.65E+02 | 3.71E+02 | 1.41E+02 | 2.68E+02 | 2.01E+02 | 9.99E+01 | 1.90E+01 | 3.21E+01 |
| Hg | 1.71E+00 | 1.95E+00 | 2.86E+00 | 2.49E-02 | 3.03E-02 | 1.64E-01 | 1.53E-01 | 3.34E-01 | 2.98E-03 | 1.47E-01 |
| K | 4.46E+00 | 1.82E+00 | —[b] | — | —[b] | 6.73E-01 | —[b] | —[b] | —[b] | —[b] |
| La | 2.51E-01 | —[b] | 3.12E+00 | —[b] | 1.78E-01 | —[b] | —[b] | —[b] | —[b] | —[b] |
| Mn | 5.44E+00 | 8.90E+01 | 7.11E+02 | 6.73E+00 | 9.34E-01 | 1.04E+00 | 3.91E+01 | 1.86E+01 | 7.02E-01 | 2.39E-01 |
| Na | 1.14E+02 | 1.60E+03 | 2.43E+02 | 3.97E+03 | 1.91E+03 | 1.56E+03 | 7.03E+01 | 5.75E+01 | 6.64E+01 | 3.33E+01 |
| Ni | 5.60E+00 | 1.10E+01 | 3.99E+01 | 8.99E+01 | 1.97E+01 | 5.38E-01 | 1.28E+01 | 8.05E+00 | 3.01E-01 | 8.01E-01 |
| $NO_2$ | 6.13E-01 | 7.81E+00 | —[b] | 6.85E+00 | 4.49E+00 | —[b] | 8.86E-01 | 6.63E-01 | 2.98E+00 | 3.12E-02 |
| $NO_3$ | 1.10E+00 | 1.30E+01 | —[b] | 1.15E+01 | 5.79E+00 | 1.33E+01 | 2.11E+00 | 1.73E+00 | —[b] | 2.23E-02 |
| Pb | 1.08E+01 | 9.91E+00 | 3.31E+01 | 2.26E+01 | 6.39E+00 | 7.32E+00 | 8.93E+00 | 6.45E+00 | 4.00E+00 | 1.02E+00 |
| $PO_4$ | 4.81E-01 | 7.52E+01 | —[b] | 1.68E+03 | 1.49E+03 | 1.82E+03 | — | — | — | 7.96E+01 |
| Si | 1.53E+02 | 1.82E+02 | 2.07E+01 | 1.49E+02 | 5.12E+01 | 2.76E+01 | 1.14E+01 | 1.00E+01 | 2.90E+00 | 7.33E+00 |

## Table 3-16b. 241-C Tank Farm Residual Inventory 95% Confidence Interval Estimates for Retrieved Tanks with Post-Retrieval Sampling. (2 sheets)

**Tanks Retrieved (Best-Basis Inventory, 95% Confidence Intervals for Single-Shell Tanks with post-retrieval residual data)[a]**

| | **241-C-103** | **241-C-104** | **241-C-106** | **241-C-108** | **241-C-109** | **241-C-110** | **241-C-201** | **241-C-202** | **241-C-203** | **241-C-204** |
|---|---|---|---|---|---|---|---|---|---|---|
| $SO_4$ | 2.27E-01 | 1.60E+00 | —[b] | 3.54E+00 | 3.62E+00 | 9.33E+00 | 5.41E+00 | 4.41E-01 | 1.98E+00 | 1.28E-02 |
| Sr | 3.16E+00 | 1.46E+00 | 2.34E+00 | 2.61E+01 | 7.52E-01 | 8.94E+01 | 1.68E+00 | 1.33E+00 | 2.78E-01 | 3.67E-01 |
| TIC as $CO_3$ | — | — | — | — | — | — | — | — | — | — |
| TOC | — | — | — | — | — | — | — | — | — | — |
| UTOTAL | 6.03E+01 | 1.99E+03 | —[b] | 1.48E+02 | 4.24E+01 | 7.51E+00 | 2.12E+02 | 1.54E+02 | 3.70E+02 | 3.04E+02 |
| Zr | 1.65E+01 | 5.55E+01 | 3.60E+00 | 7.57E-01 | — | 4.63E-01 | 2.19E-02 | 1.08E-01 | 1.25E-01 | —[b] |

Source: RPP-RPT-42323, "Hanford C-Farm Tank and Ancillary Equipment Residual Waste Inventory Estimates."

[a] September 1, 2014 Best-Basis Inventory (BBI), includes tank 241-C-106 for which retrieval completion is under review.
95% Confidence Interval = Mean + 2 × Standard Deviation (Closure mean for tanks with closure reports, BBI mean for C-101, C-107 and C-112: no closure report).
95% confidence intervals were not calculated for constituents with concentrations below analytical detection limits.

[b] Concentration less than analytical detection limit.

TIC = Total inorganic carbon

TOC = Total organic carbon

## Table 3-17a. 241-C Tank Farm Residual Inventory Lower Bound and Upper Bound Estimates for Tanks Undergoing Retrieval. (2 sheets)

| | BBI – Upper Bound Estimate for Tanks not Retrieved as of September 1, 2014 [a] | | | HTWOS – Lower Bound Estimate for Tanks not Retrieved (assumes 360 $ft^3$ in tanks after retrieval) [a] | | |
|---|---|---|---|---|---|---|
| | **241-C-102** | **241-C-105** | **241-C-111** | **241-C-102** | **241-C-105** | **241-C-111** |
| Residual Volume (kL [kgal]) | 405 [107] | 500 [132] | 132 [34.9] | 10.2 [2.69] | 10.2 [2.69] | 10.2 [2.69] |
| Total Radionuclides (Ci)[b] | 2.75E+04 | 7.02E+05 | 6.24E+05 | 9.19E+02 | 2.28E+04 | 1.39E+05 |
| $^{106}$Ru | 1.13E-12 | 7.04E-15 | 7.13E-10 | 1.71E-13 | 2.33E-16 | 1.63E-10 |
| $^{113m}$Cd | 3.24E-01 | 6.10E-01 | 5.99E-02 | 1.78E-02 | 1.30E-02 | 1.22E-02 |
| $^{125}$Sb | 2.27E-04 | 3.01E-05 | 1.37E-03 | 1.27E-05 | 8.84E-07 | 3.12E-04 |
| $^{126}$Sn | 3.54E-03 | 3.05E-03 | 6.72E-03 | 1.83E-04 | 7.72E-05 | 1.53E-03 |
| $^{129}$I | 7.89E-02 | 9.30E-02 | 1.41E-02 | 2.56E-03 | 2.72E-07 | 1.75E-08 |
| $^{134}$Cs | 1.09E-05 | 1.58E-07 | 1.42E-06 | 1.54E-07 | 4.81E-09 | 2.02E-12 |
| $^{137}$Cs | 6.08E+03 | 5.29E+04 | 7.14E+03 | 8.07E+01 | 1.52E+03 | 8.40E-03 |
| $^{137m}$Ba | 5.43E+03 | 4.71E+04 | 6.36E+03 | 8.07E+01 | 1.52E+03 | 8.40E-03 |
| $^{14}$C | 4.89E-01 | 5.05E-01 | 1.04E-01 | 9.88E-04 | 5.54E-04 | 1.31E-07 |
| $^{151}$Sm | 1.73E+01 | 2.46E+01 | 6.39E+02 | 9.72E-01 | 8.14E-01 | 1.46E+02 |
| $^{152}$Eu | 2.24E-03 | 1.16E-03 | 5.38E-02 | 1.26E-04 | 3.85E-05 | 1.23E-02 |
| $^{154}$Eu | 2.42E+00 | 4.86E-02 | 2.41E+00 | 1.36E-01 | 1.60E-03 | 5.50E-01 |
| $^{155}$Eu | 4.66E-01 | 6.32E-03 | 3.70E-01 | 2.62E-02 | 2.09E-04 | 8.45E-02 |
| $^{226}$Ra | 5.21E-06 | 1.66E-06 | 4.51E-06 | 2.88E-07 | 5.46E-08 | 1.03E-06 |
| $^{227}$Ac | 2.90E-01 | 5.38E-06 | 1.82E-05 | 1.93E-02 | 4.89E-07 | 1.91E-05 |
| $^{228}$Ra | 9.63E-02 | 2.45E-12 | 6.54E-12 | 3.64E-01 | 5.17E-12 | 1.14E-10 |
| $^{229}$Th | 1.90E-01 | 1.30E-09 | 3.56E-09 | 1.06E-02 | 4.06E-11 | 8.12E-10 |
| $^{231}$Pa | 3.77E-02 | 6.83E-06 | 4.99E-05 | 2.12E-03 | 2.23E-07 | 1.07E-05 |
| $^{232}$Th | 4.08E-01 | 1.04E-11 | 2.77E-11 | 2.29E-02 | 3.25E-13 | 7.14E-12 |
| $^{232}$U | 5.10E-01 | 8.97E-05 | 2.22E-05 | 2.83E-02 | 2.80E-06 | 5.06E-06 |
| $^{233}$U | 3.91E+01 | 5.22E-06 | 4.80E-05 | 2.17E+00 | 1.63E-07 | 1.10E-05 |
| $^{234}$U | 2.04E+00 | 2.48E+00 | 7.74E-01 | 1.13E-01 | 7.77E-02 | 1.77E-01 |
| $^{235}$U | 7.68E-02 | 1.06E-01 | 3.37E-02 | 4.27E-03 | 3.33E-03 | 7.70E-03 |
| $^{236}$U | 2.58E-02 | 5.37E-02 | 1.32E-02 | 1.43E-03 | 1.68E-03 | 3.02E-03 |
| $^{237}$Np | 9.45E-04 | 2.01E-03 | 3.32E-03 | 5.16E-05 | 6.30E-05 | 7.58E-04 |

## Table 3-17a. 241-C Tank Farm Residual Inventory Lower Bound and Upper Bound Estimates for Tanks Undergoing Retrieval. (2 sheets)

| | BBI – Upper Bound Estimate for Tanks not Retrieved as of September 1, 2014 [a] | | | HTWOS – Lower Bound Estimate for Tanks not Retrieved (assumes 360 $ft^3$ in tanks after retrieval) [a] | | |
|---|---|---|---|---|---|---|
| | **241-C-102** | **241-C-105** | **241-C-111** | **241-C-102** | **241-C-105** | **241-C-111** |
| $^{238}$Pu | 2.64E+01 | 7.79E+00 | 1.70E+00 | 1.48E+00 | 2.58E-01 | 3.89E-01 |
| $^{238}$U | 1.76E+00 | 2.54E+00 | 7.88E-01 | 9.78E-02 | 7.97E-02 | 1.80E-01 |
| $^{239}$Pu | 1.16E+03 | 5.49E+02 | 9.45E+01 | 6.49E+01 | 1.81E+01 | 2.16E+01 |
| $^{240}$Pu | 2.77E+02 | 1.08E+02 | 1.85E+01 | 1.55E+01 | 3.57E+00 | 4.21E+00 |
| $^{241}$Am | 3.50E+02 | 2.95E+02 | 8.32E+01 | 2.12E+01 | 1.00E+01 | 1.94E+01 |
| $^{241}$Pu | 8.68E+02 | 1.82E+02 | 3.54E+01 | 4.87E+01 | 6.01E+00 | 8.06E+00 |
| $^{242}$Cm | 2.09E-02 | 1.06E-02 | 6.21E-02 | 1.15E-03 | 3.50E-04 | 1.41E-02 |
| $^{242}$Pu | 1.60E-02 | 3.26E-03 | 6.54E-04 | 9.00E-04 | 1.08E-04 | 1.49E-04 |
| $^{243}$Am | 1.47E-02 | 6.99E-03 | 1.15E-02 | 7.93E-04 | 5.83E-05 | 2.62E-03 |
| $^{243}$Cm | 1.13E-03 | 9.47E-05 | 1.82E-03 | 6.22E-05 | 3.14E-06 | 4.13E-04 |
| $^{244}$Cm | 2.34E-02 | 1.62E-03 | 3.26E-02 | 1.28E-03 | 5.36E-05 | 7.39E-03 |
| $^{3}$H | 5.00E+00 | 4.25E+01 | 2.58E+00 | 2.15E-05 | 1.24E-04 | 3.22E-06 |
| $^{59}$Ni | 2.93E+00 | 4.58E+00 | 1.40E+00 | 1.62E-01 | 1.51E-01 | 3.20E-01 |
| $^{60}$Co | 3.90E+00 | 7.10E+00 | 1.03E-01 | 2.14E-01 | 2.27E-01 | 2.35E-02 |
| $^{63}$Ni | 2.46E+02 | 3.76E+02 | 1.13E+02 | 1.36E+01 | 1.24E+01 | 2.57E+01 |
| $^{79}$Se | 2.03E-03 | 1.57E-03 | 3.53E-03 | 1.60E-06 | 4.59E-09 | 4.80E-09 |
| $^{90}$Sr | 6.47E+03 | 3.00E+05 | 3.05E+05 | 2.94E+02 | 9.86E+03 | 6.95E+04 |
| $^{90}$Y | 6.47E+03 | 3.00E+05 | 3.05E+05 | 2.94E+02 | 9.86E+03 | 6.95E+04 |
| $^{93m}$Nb | 3.89E-02 | 1.51E-02 | 9.78E-02 | 1.10E-02 | 2.41E-03 | 1.04E-01 |
| $^{93}$Zr | 7.82E-02 | 2.88E-02 | 1.81E-01 | 4.22E-03 | 9.39E-04 | 3.90E-02 |
| $^{99}$Tc | 3.02E-01 | 8.14E+01 | 2.19E+00 | 3.56E-03 | 9.43E-01 | 5.49E-02 |

Source: RPP-RPT-42323, "Hanford C-Farm Tank and Ancillary Equipment Residual Waste Inventory Estimates."

[a] Inventory estimates based on retrievals through September 1, 2014 for tanks 241-C-102, 241-C-105, and 241-C-111. These would be the residual inventories if no additional waste was retrieved from these tanks after September 1, 2014. Note: Based on retrieval results for other tanks and in-process results for these tanks, it appears that the retrieval goal of 360 $ft^3$ or less will not be met for these tanks. The base case reflects the assumed retrieval end state based on retrieval performance to date.

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

BBI = Best-Basis Inventory

HTWOS = Hanford Tank Waste Operations Simulator

### Table 3-17b. 241-C Tank Farm Residual Inventory Lower Bound and Upper Bound Estimates for Tanks Undergoing Retrieval.

| | BBI – Upper Bound Estimate for Tanks not Retrieved as of September 1, 2014 [a] | | | HTWOS – Lower Bound Estimate for Tanks not Retrieved (assumes 360 $ft^3$ in tanks after retrieval) [a] | | |
|---|---|---|---|---|---|---|
| | **241-C-102** | **241-C-105** | **241-C-111** | **241-C-102** | **241-C-105** | **241-C-111** |
| Residual Volume (kL [kgal]) | 405 [107] | 500 [132] | 132 [34.9] | 10.2 [2.69] | 10.2 [2.69] | 10.2 [2.69] |
| Total Chemicals (kg) | 2.28E+05 | 2.86E+05 | 8.34E+04 | 7.51E+03 | 7.55E+03 | 1.017E+04 |
| Al | 9.45E+04 | 1.55E+05 | 1.60E+04 | 5.29E+03 | 5.14E+03 | 3.51E+03 |
| Bi | 8.23E+02 | 3.72E+02 | 1.55E+03 | 4.53E+01 | 1.09E+01 | 3.52E+02 |
| Ca | 2.25E+03 | 1.98E+03 | 2.20E+03 | 1.22E+02 | 6.49E+01 | 5.02E+02 |
| Cl | 6.09E+02 | 3.10E+02 | 2.21E+02 | 2.62E-03 | 9.07E-04 | 2.76E-04 |
| Cr | 2.19E+02 | 3.85E+02 | 7.33E+01 | 1.13E+01 | 2.42E+00 | 1.25E+01 |
| F | 1.41E+03 | 8.23E+02 | 8.07E+02 | 6.06E-03 | 2.41E-03 | 1.01E-03 |
| Fe | 5.98E+03 | 4.08E+03 | 7.53E+03 | 3.37E+02 | 1.35E+02 | 1.72E+03 |
| Hg | 2.06E+00 | 5.23E+00 | 4.69E+01 | 7.55E-02 | 1.53E-05 | 5.83E-05 |
| K | 4.08E+02 | 8.60E+02 | 1.87E+02 | 7.85E+00 | 1.86E+01 | 9.32E+00 |
| La | 4.01E+01 | 2.73E+00 | 5.68E+01 | 2.26E+00 | 9.05E-02 | 1.30E+01 |
| Mn | 5.10E+02 | 1.90E+03 | 4.68E+01 | 2.86E+01 | 6.22E+01 | 1.06E+01 |
| Na | 3.60E+04 | 3.81E+04 | 1.03E+04 | 4.30E+02 | 5.80E+02 | 2.42E+02 |
| Ni | 2.18E+03 | 1.66E+03 | 2.65E+03 | 1.20E+02 | 5.47E+01 | 6.05E+02 |
| $NO_2$ | 6.46E+03 | 6.73E+03 | 5.50E+03 | 2.78E-02 | 1.97E-02 | 6.86E-03 |
| $NO_3$ | 2.22E+04 | 8.14E+03 | 1.47E+04 | 9.54E-02 | 2.38E-02 | 1.83E-02 |
| Pb | 5.47E+02 | 3.59E+02 | 7.65E+02 | 2.84E+01 | 9.07E+00 | 1.75E+02 |
| $PO_4$ | 5.58E+03 | 6.01E+03 | 1.20E+04 | 6.12E+01 | 1.76E-02 | 1.37E+03 |
| Si | 1.20E+04 | 3.09E+04 | 1.42E+03 | 5.49E+02 | 1.02E+03 | 1.83E+02 |
| $SO_4$ | 2.45E+03 | 2.92E+03 | 1.26E+03 | 7.21E+00 | 8.55E-03 | 1.57E-03 |
| Sr | 5.24E+01 | 1.43E+02 | 3.58E+01 | 2.38E+00 | 4.59E+00 | 7.49E+00 |
| TIC as $CO_3$ | 2.57E+04 | 1.31E+04 | 3.47E+03 | 5.80E+01 | 1.18E+02 | 7.91E+02 |
| TOC | 6.32E+02 | 4.31E+03 | 1.46E+02 | 2.18E+01 | 8.78E+01 | 2.05E+01 |
| UTOTAL | 5.27E+03 | 7.63E+03 | 2.36E+03 | 2.93E+02 | 2.39E+02 | 5.38E+02 |
| Zr | 1.75E+03 | 1.62E+02 | 3.02E+01 | 9.46E+01 | 5.29E+00 | 6.49E+00 |

Source: RPP-RPT-42323, “Hanford C-Farm Tank and Ancillary Equipment Residual Waste Inventory Estimates.”

[a] Inventory estimates based on retrievals through September 1, 2014 for tanks 241-C-102, 241-C-105, and 241-C-111. These would be the residual inventories if no additional waste was retrieved from these tanks after September 1, 2014. Note: Based on retrieval results for other tanks and in-process results for these tanks, it appears that the retrieval goal of 360 $ft^3$ or less will not be met for these tanks. The base case reflects the assumed retrieval end state based on retrieval performance to date.

BBI = Best-Basis Inventory
HTWOS = Hanford Tank Waste Operations Simulator
TIC = Total inorganic carbon
TOC = Total organic carbon

The upper bound inventory was the BBI inventory on September 1, 2014 for each tank; this would be the residual inventory if no additional waste can be retrieved from these tanks. The BBI waste volumes and concentrations were used to calculate upper bound inventories for these tanks.

A base case estimate for the volume and concentration of residual waste that will remain after retrieval was also made based on characteristics of the waste and retrieval performance to date for these tanks. Base case estimates are presented in Table 3-14 and discussed in Section 3.2.2.4.3.

**3.2.2.3.4 Residual Inventory Estimates for Ancillary Equipment.** Because little information is available for waste in catch tanks and waste transfer pipelines, it was assumed that the composition of waste in pipelines and catch tanks is the same as the average composition of waste in the BBI for retrieved and sampled C Farm SSTs. Waste volumes for C-301 catch tank and the 244-CR vault were based on measurements. However, the amount of waste remaining in pits, diversion boxes and pipelines is unknown. Based on operations information, most of the waste has been flushed from the pits, diversion boxes, and pipelines. Hence, the residual waste volume is expected to be small compared to catch tank and SST post-retrieval residuals. A volume estimate for pits and diversion boxes was developed based on the surface area of pits and diversion boxes in C Farm. A volume estimate for pipelines was developed based on the length and size of pipelines in C Farm.

The inventory estimates for the ancillary equipment are provided in Table 3-15. RPP-RPT-42323 Appendix C-3 shows average waste concentrations for retrieved and sampled tanks.

**3.2.2.4 Inventory Uncertainty.** Table 3-18 shows different sources of uncertainties that must be considered for inventory estimates for retrieved and non-retrieved tanks and different types of ancillary equipment. The following sections address inventory uncertainties.

**3.2.2.4.1 Inventory Estimates for Retrieved Tanks with Post-Retrieval Sample Analyses.** The primary sources of uncertainty for retrieved tanks with post-retrieval samples and analysis are analytical uncertainty and residual waste volume uncertainty. Post-retrieval samples were collected in accordance with the SST Component Closure DQO (RPP-23403). Samples were collected at multiple locations in the residual waste in an attempt to provide a representative sample. Analytical uncertainty estimates are determined for each constituent and sample analyzed considering precision and accuracy of samples based on variability between primary and duplicate samples, and other quality controls specified in the DQO and sampling and analysis plan. Differences between sample results from two or more locations provide a measure of spatial variability and representativeness of the tank samples.

The median sample-based relative standard deviation (RSD) for the 10 tanks sampled was ~0.17. Radionuclides and chemical constituents with low concentrations tend to have higher RSDs than those with high concentrations. The RSDs by constituent for C Farm tanks are included in applicable Retrieval Data Reports and in Appendix D.1 and D.2 of RPP-RPT-42323. Based on tank sample data and sample analytical reports, mean concentrations, RSDs of the mean and

95% upper confidence limit (UCL) values were calculated for the constituents in each waste phase. As shown in Appendix D.1, for some constituents analytical results were below detection levels for the method used. Nominal concentration estimates for these constituents are based on the detection limit or other estimates, whichever is lower. Upper bound inventories (Table 3-16) were not calculated for constituents with concentrations lower than analytical detection limits.

**Table 3-18. Inventory Uncertainties.**

| Facility | Uncertainties |
|---|---|
| Retrieved tanks with post-retrieval sample analyses | • Analytical uncertainties.<br>• Waste volume measurement uncertainties. |
| Retrieved tanks without post-retrieval analyses | • Pre-retrieval analytical sample uncertainties.<br>• Process knowledge uncertainty for constituents without sample analysis.<br>• Uncertainty in waste composition changes after retrieval.<br>• Waste volume measurement uncertainties. |
| Tanks undergoing retrieval | • Uncertainty in waste volume that will be retrieved.<br>• Pre-retrieval analytical sample uncertainties.<br>• Process knowledge uncertainty for constituents without sample analysis.<br>• Uncertainty in waste composition changes after retrieval. |
| Catch Tank 241-C-301 and 244-CR Process Tank Vault | • Waste volume measurement uncertainties.<br>• Uncertainty in waste volume that will be retrieved.<br>• Limited sample data, inventories based on average composition of residual tank waste samples. |
| Pits, Diversion Boxes, and Waste Transfer Pipelines | • Uncertainty in waste volume remaining in waste transfer pipelines.<br>• Uncertainty in the number and length of waste transfer pipelines.<br>• No sample data and limited process knowledge data. Inventories based on the average composition of residual tank waste samples. |

Waste volume measurements for retrieved tanks were performed using a CCMS. In-tank videos of SSTs were recorded following retrieval. The videos document the location of residual solids and liquid waste remaining in the tank. Using CAD 3-D software, a 3-D model of the SST was built, and video of the tank waste was reviewed. Knowledge of tank construction, plate lengths and heights, the size of debris in the tanks, and other measurable features were used as a guide to estimate the area and height of waste remaining in a tank. Based on CCMS estimates of sand piles with known volumes, a regression line was calculated to determine uncertainty for CCMS measurements. The regression equation was changed over time as additional data was obtained. Uncertainty equations and requirements for CCMS are specified in RPP-23403. Tables 3-19 and 3-20 and Appendix D of RPP-RPT-42323 show volume uncertainty estimates for tanks retrieved to date.

**3.2.2.4.2 Inventory Estimates for Retrieved Tanks without Post-Retrieval Sample Analyses.** For tanks without post-retrieval analysis or for which analysis is in progress (C-101, C-107), current inventory estimates are based on pre-retrieval sample results, sample-based templates, or process knowledge. Sample results after bulk retrieval are included in the BBI for tank C-112; however, the closure inventory report and retrieval data report with the complete set of inventories and analytical results for constituents specified in the DQO was not available as of September 1, 2014.

**Table 3-19. 241-C Tank Farm Post-Retrieval Waste Volume Estimates (cubic feet).**

| Component | 241-C-103[a] | 241-C-106[b] | 241-C-201[c] | 241-C-202[d] | 241-C-203[e] | 241-C-204[f] |
|---|---|---|---|---|---|---|
| In dish bottom | 266 | 348 | 10.7 | 8.5 | 13.4 | 9.6 |
| In tank equipment | 3.6 | 4.8 | 3.4 | 6.1 | 0 | 3.4 |
| On stiffener rings and walls | 68.4 | 17 | 5.1 | 5.1 | 5.1 | 5.3 |
| Total | 338 | 370 | 19.2 | 19.7 | 18.5 | 18.3 |
| 95% upper confidence limit | 351[g] | 466[h] | 20.5 | 20.9 | 19.9 | 19.6 |

[a] RPP-RPT-33060, "Retrieval Data Report for Single-Shell Tank 241-C-103."

[b] RPP-20577, "Stage II Retrieval Data Report for Single-Shell Tank 241-C-106," and RPP-19866, "Calculation for the Post-Retrieval Waste Volume Determination for Tank 241-C-106."

[c] RPP-RPT-30181, "Retrieval Data Report for Single-Shell Tank 241-C-201."

[d] RPP-RPT-29095, "Retrieval Data Report for Single-Shell Tank 241-C-202."

[e] RPP-RPT-26475, "Retrieval Data Report for Single-Shell Tank 241-C-203."

[f] RPP-RPT-34062, "Retrieval Data Report for Single-Shell Tank 241-C-204."

[g] In accordance with RPP-23403, "Single-Shell Tank Component Closure Data Quality Objectives," Rev. 3, 1.04 × dish bottom volume + 0.85 + Equip + Rings + Wall.

[h] In accordance with RPP-13889, "Tank 241-C-106 Component Closure Action Data Quality Objectives."

For tanks C-101 and C-107, current BBI concentration estimates take no credit for soluble analytes that may have been washed out of the waste during retrieval processes. However, because the volume of waste remaining in these tanks was well above the retrieval goal of 10.2 $m^3$ (360 $ft^3$), it is unknown what portion of the soluble analytes were removed. Pre-retrieval sample results were not available for many of the constituents specified in the BBI and sample-based templates or process knowledge estimates were developed to fill these gaps.

Sample-based template values were developed from a review of sample data for tanks with similar process histories and at least one waste layer from the same waste process (i.e., same waste type). Table 3-21 lists waste type groupings for waste transferred to C Farm tanks. The decision to include tank data in a template was based on tank transfer records indicating the expected waste type and depth in a tank and a comparison with expected analytical concentrations for a given waste type, and is documented in each update of the BBI for that tank. Although sample-based template RSDs fall between 0 and 1.0, template RSDs can be much larger (as large as 17.0 for uranium; most values are 5.0 or lower). These results have large uncertainties because some are based on tank averages which have large variability with few data points. Waste type templates and uncertainties are described in RPP-8847, "Best-Basis Inventory Template Compositions of Common Tank Waste Layers."

**Table 3-20. 241-C Tank Farm Post-Retrieval Waste Volume Estimates (cubic feet).**

| Component | 241-C-101[a] | 241-C-104[b] | 241-C-108[c] | 241-C-109[d] | 241-C-110[e] | 241-C-112[f] |
|---|---|---|---|---|---|---|
| In dish bottom | 511 | 190 | 305 | 192 | 224 | 1,657 |
| In tank equipment | 0 | 0 | 0 | 1.9 | 0 | 0 |
| On stiffener rings and walls | 156 | 26.6 | 91.9 | 35.7 | 13.4 | 42.9 |
| Total | 667 | 217 | 397 | 230 | 237 | 1,700 |
| Total Residual Volume[g] | 767 | 254 | 456 | 267 | 281 | 1,700 |

[a] RPP-CALC-56434, "Post-Retrieval Camera/CAD Modeling System Waste Volume Estimate for Tank 241-C-101."

[b] RPP-CALC-54284, "Post-Hard Heel Retrieval Camera/CAD Modeling System Waste Volume Estimate for Tank 241-C-104."

[c] RPP-CALC-54266, "Post-Hard Heel Retrieval Camera/CAD Modeling System Waste Volume Estimate for Tank 241-C-108."

[d] RPP-CALC-54759, "Post-Hard Heel Retrieval Camera/CAD Modeling System Waste Volume Estimate for Tank 241-C-109."

[e] RPP-CALC-56399, "Post-Hard Heel Retrieval Camera/CAD Modeling System Waste Volume Estimate for Tank 241-C-110."

[f] RPP-CALC-56856, "Estimated Waste Volume Remaining in Single Shell Tank 241-C-112 after Hard Heel Retrieval."

[g] In accordance with RPP-23403, "Single-Shell Tank Component Closure Data Quality Objectives," Rev. 5, 1.195 × dish bottom volume + 0.27 + Equip + Rings + Wall.

Due to the uncertainty associated with modeling, process knowledge model results are generally only used in the BBI in the absence of analytical data or waste sample-based templates for a given waste type. The process knowledge results are model results from the Hanford Defined Waste Model (HDW) Rev. 5. In the 1990s, Steve Agnew of the Los Alamos National Laboratory developed the HDW model (WHC-SD-WM-TI-632, "Hanford Defined Wastes: Chemical and Radionuclide Compositions"). The HDW Rev. 4 uses radionuclide fuel production output from the Oak Ridge Isotope Generation and Depletion Code 2 (ORIGEN2) model (RPP-13489, "Activity of Fuel Batches Processed Through Hanford Separations Plants, 1944 Through 1989"), then models fuel transfers through various processing steps to estimate waste types and composition for each Hanford tank through 1994. In 2004, the ORIGEN2 and HDW models were updated and with new data and methods (RPP-19822, Rev. 0-A). The scope of HDW Rev. 5 was limited to estimating waste type compositions, because sample data and volume measurements appeared to provide better estimates for distribution of the waste types between the tanks and the volume of waste in the tanks. The uncertainty in HDW waste type composition estimates has not been quantified. RPP-26744 shows the range of variability for different waste types and constituents based on reactor production variability as a function of time. Although this is only one of several potential sources of uncertainty, variability ranges by over an order of magnitude for some constituents.

**3.2.2.4.3 Inventory Estimates for Tanks Undergoing Retrieval.** The basis for a base case estimate for post-retrieval residual inventories varies for each of the three tanks remaining to be retrieved (C-102, C-105 and C-111). The largest uncertainty is how much waste can be retrieved and the extent to which soluble analytes (such as $^{99}$Tc) will be removed.

**Table 3-21. Sample-Based Template Waste Type Groups for 241-C Tank Farm.**

| Waste Type Group | Common Factors to Group |
|---|---|
| **1C**, 2C, 1CFeCN | Bismuth phosphate-bearing waste generated by decontamination of the bismuth phosphate process plutonium product. |
| **CWP1, CWP2**, CWR1 | Wastes generated by the decladding of aluminum clad reactor fuel. |
| **TBP**, PFeCN, **TFeCN** | Wastes resulting from the retrieval of metal waste for uranium recovery (typically high fission product waste). |

Note: Bold text for waste types in 241-C Tank Farm.

1C = First cycle bismuth phosphate decontamination waste
1CFeCN = Ferrocyanide sludge from in-plant scavenging of T-Plant 1C waste (without coating waste)
2C = Second cycle bismuth phosphate decontamination waste
CWR1 = Reduction-Oxidation (S Plant) aluminum cladding waste
PFeCN = Ferrocyanide sludge from tributyl phosphate (TBP) in-plant scavenged supernate and co-disposed TBP sludge

**Base Case Estimate of Inventory.** For purposes of modeling, the following subjective base case estimates were made for each of the three tanks based on retrieval results to-date and based on remaining waste properties. Details for these estimates are provided in RPP-RPT-42323.

Tank C-102: The initial waste retrieval performance information shows that for tank C-102, through August 2014 waste removal has been tracking as for other similar waste type tanks for which retrievals were completed to below 10.2 m$^3$ (360 ft$^3$). Therefore, achieving a final waste volume of 10.2 m$^3$ (360 ft$^3$) and using HTWOS model estimates for the residual inventory seems to be a reasonable assumption for this tank.

Tank C-105: Initial waste retrieval performance information for tank C-105 indicates that equipment and waste characteristics limit the performance of the designated retrieval technology (Mobile Arm Retrieval System [MARS]-Vacuum [V]) and that other waste retrieval technologies (e.g., sluicing), or equipment modifications would be required to remove additional waste from the tank. Application of sluicing (particularly hot water sluicing) is expected to result in additional retrieval from tank C-105. The waste types and waste transfer history for tank C-105 are unique but there are some similarities to other C Farm tanks. In an effort to establish a residual waste volume that would be plausible, it is assumed that the quantity of waste remaining in tank C-105 will be similar to the quantity remaining in tank C-112, ~1,700 ft$^3$, 48 kL (~12,700 gal) (the maximum quantity remaining in any of the C Farm tanks retrieved as of September 2014).

Tank C-111: Waste retrieval performance data indicates that it will be difficult to remove any additional waste from tank C-111. The waste physical characteristics are such that negligible waste was removed during modified sluicing. Additional waste retrieval technologies, caustic and water dissolution, are planned. However, because of the hard, low-permeability waste layer remaining in tank C-111, little or none of the remaining waste may be removed by waste retrieval operations. Therefore, the BBI provides a reasonable volume estimate for tank C-111.

**Lower-bound Estimates of Inventory.** As a lower bound, the HTWOS inventory estimates were used for tanks remaining to be retrieved. The HTWOS estimate assumes the retrieval goal of 10.2 $m^3$ (360 $ft^3$) will be met. It also factors in wash/leach processes to estimate the composition of residuals after retrieval.

A general idea of how well HTWOS predicts tank waste residual inventories can be shown by comparing the 2002 HTWOS residual concentration estimates for tank C-103 with post-retrieval measurements for the tank (Table 3-22). On average, the HTWOS overestimated the measured chemical values for concentrations greater than $10^{-3}$ g/L ($1.34 \times 10^{-4}$ oz/gal) by a factor of ~3 and underestimated measured radionuclide concentrations > $10^{-7}$ Ci/L by a factor of ~0.7. In general, the HTWOS estimates were closer to measured values for constituents with higher concentrations.

**Table 3-22. Comparison of Hanford Tank Waste Operations Simulator Pre-Retrieval Concentration Estimates for Tank 241-C-103 Residuals with Post-Retrieval Sample Results. (2 sheets)**

| Constituent | Units | HTWOS 2002 Residual Waste Estimate | 2014 Residual Data | Ratio of HTWOS 2002/ 2014 Residuals |
|---|---|---|---|---|
| **Al** | g/L | 2.45E+01 | 3.79E+02 | 6.47E-02 |
| **Ca** | g/L | 4.68E-01 | 2.27E+00 | 2.06E-01 |
| **Cl** | g/L | 8.22E-02 | 2.03E-02 | 4.05E+00 |
| **Cr** | g/L | 1.23E-01 | 2.49E-01 | 4.93E-01 |
| **F** | g/L | 1.29E-01 | 1.69E-02 | 7.64E+00 |
| **Fe** | g/L | 2.00E+00 | 1.24E+01 | 1.61E-01 |
| **Hg** | g/L | 2.52E-02 | 1.11E-01 | 2.27E-01 |
| **K** | g/L | 8.22E-02 | 3.76E-01 | 2.19E-01 |
| **La** | g/L | 2.59E-02 | 1.90E-02 | 1.36E+00 |
| **Mn** | g/L | 5.98E-02 | 4.62E-01 | 1.30E-01 |
| **Na** | g/L | 3.26E+00 | 1.00E+01 | 3.25E-01 |
| **Ni** | g/L | 5.48E-01 | 4.79E-01 | 1.15E+00 |
| **$NO_2$** | g/L | 1.99E+00 | 5.04E-02 | 3.96E+01 |
| **$NO_3$** | g/L | 1.94E-01 | 9.10E-02 | 2.13E+00 |
| **Pb** | g/L | 8.01E-02 | 8.88E-01 | 9.02E-02 |
| **$PO_4$** | g/L | 3.95E-01 | 3.12E+00 | 1.27E-01 |
| **Si** | g/L | 4.46E+00 | 1.33E+01 | 3.36E-01 |

### Table 3-22. Comparison of Hanford Tank Waste Operations Simulator Pre-Retrieval Concentration Estimates for Tank 241-C-103 Residuals with Post-Retrieval Sample Results. (2 sheets)

| Constituent | Units | HTWOS 2002 Residual Waste Estimate | 2014 Residual Data | Ratio of HTWOS 2002/ 2014 Residuals |
|---|---|---|---|---|
| **$SO_4$** | g/L | 3.27E-01 | 2.26E-01 | 1.45E+00 |
| **Sr** | g/L | 3.99E-03 | 2.52E-01 | 1.58E-02 |
| **TIC as $CO_3$** | g/L | 3.27E+00 | 1.76E+00 | 1.86E+00 |
| **TOC** | g/L | 1.03E+00 | 1.31E+00 | 7.91E-01 |
| **Zr** | g/L | 1.45E+00 | 1.39E+00 | 1.04E+00 |
| **$^{137}Cs$** | Ci/L | 9.55E-03 | 6.35E-02 | 1.50E-01 |
| **$^{14}C$** | Ci/L | 5.94E-07 | 7.30E-07 | 8.14E-01 |
| **$^{154}Eu$** | Ci/L | 2.13E-04 | 1.47E-04 | 1.45E+00 |
| **$^{155}Eu$** | Ci/L | 3.69E-05 | 4.57E-05 | 8.07E-01 |
| **$^{234}U$** | Ci/L | 2.71E-07 | 1.42E-06 | 1.91E-01 |
| **$^{238}Pu$** | Ci/L | 1.02E-05 | 1.36E-04 | 7.50E-02 |
| **$^{238}U$** | Ci/L | 2.78E-07 | 1.71E-06 | 1.62E-01 |
| **$^{241}Am$** | Ci/L | 5.46E-04 | 5.04E-04 | 1.08E+00 |
| **$^{241}Pu$** | Ci/L | 2.60E-04 | 1.88E-04 | 1.38E+00 |
| **$^{60}Co$** | Ci/L | 1.06E-05 | 1.91E-06 | 5.56E+00 |
| **$^{63}Ni$** | Ci/L | 4.93E-04 | 1.94E-03 | 2.54E-01 |
| **$^{90}Sr$** | Ci/L | 3.43E-01 | 7.08E-01 | 4.84E-01 |
| **$^{99}Tc$** | Ci/L | 4.20E-06 | 4.68E-06 | 8.97E-01 |

HTWOS = Hanford Tank Waste Operations Simulator
TOC = Total organic carbon
TIC = Total inorganic carbon

For all tanks retrieved, the HTWOS concentration estimates for total chemicals (kg/L) were a factor of 1.8 times higher than post-retrieval measurements for tank C-106 and 0 to 10 times lower for other tanks. The HTWOS concentration estimates for total radionuclides (Ci/L) were 2 to 35 times lower than post-retrieval measurements.

**Upper-bound Estimates of Inventory.** The BBI, showing the current inventories for these tanks, provides the best available information for an upper-bound estimate. This would be the residual waste volume if no additional waste can be retrieved from the tanks. The BBI waste concentrations for these tanks are based on pre-retrieval measurements and pre-retrieval process knowledge. Current BBI concentration estimates take no credit for soluble analytes that may have been washed out of the waste during retrieval processes to-date.

#### 3.2.2.4.4 Residual Inventory in Ancillary Equipment.

**Residual Inventory Volume in Catch Tank 241-C-301 and 244-CR Process Tank Vault.** For the base case an assumption was made that 90% of the waste will be retrieved from these tanks. Whether more or less waste is retrieved is unknown. Therefore, as an upper bound it should be assumed that no retrieval occurs and the current waste volume will remain at closure.

Although the C-301 tank was sampled, few sample data were obtained. An estimate of waste types and contents could be made based on waste transfer sources, but the correlation of sources to residual waste remaining in C-301 would be highly speculative. Furthermore, some or all of the waste may have been diluted for transfer. Therefore, a simplifying assumption was made that the composition of waste in tank C-301 and in the 244-CR vault tanks and sumps is similar to the average composition of residual waste samples from the C Farm SSTs. Although there is high uncertainty in this assumption, if the waste was more dilute than tank waste, the actual composition should be lower. Nevertheless, it is recommended that improved characterization of the C-301 catch tank and the 244-CR vault should be included in the PA maintenance plan.

**Residual Inventory Volume in Pits, Diversion Boxes and Waste Transfer Pipelines.** Sources of volume uncertainty include the number and length of pits, diversion boxes and waste transfer pipelines. For pits and pipelines, another uncertainty is the thickness of waste adsorbed and whether any other residual waste remains in the tank. The volume of waste expected to be in the pits and diversion boxes is very small compared to the pipelines, and as a result, uncertainty in the waste inventory is of negligible importance for the PA. As a result, no uncertainty evaluations are recommended. For the waste pipelines base case, the volume is from RPP-PLAN-47559 and assumes all pipelines are only 5% full except for a plugged line and cascade lines, which are assumed to be completely full. Studies suggest that the pipelines may be less than 5% full; however, it is possible that some pipelines contain more waste.

**Waste Composition (Same as Catch Tank 241-C-301 and 244-CR Process Tank Vault).** The waste composition was assumed to be similar to post-retrieval tank residuals because, like a retrieved tank, the pits, diversion boxes and pipelines are flushed. It could be argued that the waste, especially in plugged pipelines, is more similar to waste in tanks before retrieval than after. However, post-retrieval residual waste compositions were assumed given the relatively small length of plugged lines compared to unplugged lines, uncertainty in assumptions about the applicability of pre- or post-retrieval average waste composition for pipelines, and the fact that analytical data for many of the closure DQO constituents is only available for post-retrieved tanks.

# 4.0 SCREENING APPROACHES

Radiological COPCs were identified for the PA effort using two types of screening evaluations: 1) one evaluation that considered inventory-related information including radionuclide half-lives, the in-growth of constituents from chain decay, and activity level, and 2) another evaluation that considered information on the groundwater pathway including travel times to the accessible environment and constituent-specific mobility. These evaluations and their results are described in the following sections.

## 4.1 SCREENING BASED ON INVENTORY-RELATED INFORMATION

The approach for identifying specific radionuclides subject to additional analysis in the PA is based on an evaluation of inventory-related information as outlined below.

- The first step in the evaluation was to identify all radionuclides in the BBI for WMA C tank inventory information within the official Tank Waste Information Network System (TWINS). The BBI contained inventory estimates for 46 radionuclides.

- The second step in the evaluation examined radioactive decay. 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 ($^{106}$Ru, $^{125}$Sb, $^{134}$Cs, $^{242}$Cm) or their parents were already included in the PA calculations ($^{90}$Y, $^{137m}$Ba). When the parent was included in the PA calculations, the contribution of the progeny was also included in the dose calculation for the parent.

- An additional evaluation was conducted to identify any supplemental radionuclides that were not included in the BBI estimates for retrieved tanks, but may be of interest for the PA evaluations. For this, the residual inventory estimates for retrieved tanks were obtained from RPP-RPT-42323, Table D-1. Radionuclides identified in RPP-RPT-42323, Table D-1 were eliminated because they had half-lives less than three years and are not directly related to Hanford Site operations or are non-detects. This led to assumption of zero initial mass of $^{228}$Th (naturally occurring with half-life of 1.91 years) and $^{230}$Th (naturally occurring/non-detect). Only the tank C-106 nominal inventory for $^{230}$Th was above the detection limit and was included.

- The next step was to include radionuclides needed to complete the uranium decay chain to calculate radon flux. This step identified $^{222}$Rn along with intermediate parent $^{230}$Th that forms during the decay from $^{234}$U. In addition, $^{210}$Pb was identified 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 (except for $^{230}$Th for tank C-106).

- The next step in the screening evaluation was to ensure that the daughter radionuclides that are part of the decay chain are included and tracked in PA calculations. Necessary radionuclide data (atomic weights, decay rates, and daughter products stoichiometry) needed for this evaluation were obtained from "ICRP Publication 107: Nuclear Decay Data for Dosimetric Calculations" (International Commission on Radiological Protection [ICRP] 2008). This source of information was consistent with the information in DOE's Derived Concentration Technical Standard (DOE-STD-1196-2011). Progeny radionuclides with a half-life of less than two years are assumed to be in secular equilibrium with their parent, which yielded a reduced number of species but still accounted for the radiological effects of the progeny.

Additional screening was performed using the 3-D flow and transport STOMP© model to determine the maximum $K_d$ value of radionuclides in the WMA C tank residuals that are capable of reaching the water table in 1,000 and 10,000 years. Methodology used in that screening analysis is presented in Section 6.3.2.3, and results are provided in Section 7.2.1.

The results of this overall screening process identified a total of 43 radionuclides to be included in the more detailed PA analysis.

## 4.2 SUMMARY OF RADIONUCLIDE SCREENING

The final set of 43 radionuclides are presented in Table 4-1. The list of radionuclides screened out of the PA analysis with a rational for their elimination is provided in Table 4-2.

The initial inventory estimates are decay corrected to the assumed closure date of January 1, 2020. Furthermore, the residual inventory of pits is not considered due to very small estimated residual volume, which is a factor of 50 smaller than the pipeline estimate. The final base case estimate of inventory for radionuclides considered in the PA is presented in Table 4-3.

### Table 4-1. List of Radionuclides Considered for the Performance Assessment. (2 sheets)

| Number | Species ID | Description | Atomic Weight | Half-life | Daughter1 | Stoichiometry 1 | Daughter2 | Stoichiometry 2 |
|---|---|---|---|---|---|---|---|---|
| 1 | Ac227 | Actinium-227 | 227.028 | 21.772 yr | | | | |
| 2 | Am241 | Americium-241 | 241.057 | 432.2 yr | Np237 | 1 | | |
| 3 | Am243 | Americium-243 | 243.061 | 7,370 yr | Pu239 | 1 | | |
| 4 | C14 | Carbon-14 | 14.0032 | 5,700 yr | | | | |
| 5 | Cd113m | Cadmium-113 | 112.904 | 14.1 yr | | | | |
| 6 | Cm243 | Curium-243 | 243.061 | 29.1 yr | Pu239 | 0.9976 | Am243 | 0.0024 |
| 7 | Cm244 | Curium-244 | 244.063 | 18.1 yr | Pu240 | 1 | | |
| 8 | Co60 | Cobalt-60 | 59.9338 | 5.2713 yr | | | | |
| 9 | Cs137 | Cesium-137 | 136.907 | 30.167 yr | | | | |
| 10 | Eu152 | Europium-152 | 151.922 | 13.537 yr | | | | |
| 11 | Eu154 | Europium-154 | 153.923 | 8.593 yr | | | | |
| 12 | Eu155 | Europium-155 | 154.923 | 4.7611 yr | | | | |
| 13 | H3 | Hydrogen-3 | 3.01605 | 12.32 yr | | | | |
| 14 | I129 | Iodine-129 | 128.905 | 1.57E+7 yr | | | | |
| 15 | Nb93m | Niobium-93 | 92.9064 | 16.13 yr | | | | |
| 16 | Ni59 | Nickel-59 | 58.9343 | 1.01E+5 yr | | | | |
| 17 | Ni63 | Nickel-63 | 62.9297 | 100.1 yr | | | | |
| 18 | Np237 | Neptunium-237 | 237.048 | 2.144E+6 yr | U233 | 1 | | |
| 19 | Pa231 | Protactinium-231 | 231.036 | 32,760 yr | Ac227 | 1 | | |
| 20 | Pb210 | Lead-210 | 209.984 | 22.2 yr | | | | |
| 21 | Pu238 | Plutonium-238 | 238.05 | 87.7 yr | U234 | 1 | | |
| 22 | Pu239 | Plutonium-239 | 239.052 | 24,110 yr | U235 | 1 | | |
| 23 | Pu240 | Plutonium-240 | 240.054 | 6,564 yr | U236 | 1 | | |

## Table 4-1. List of Radionuclides Considered for the Performance Assessment. (2 sheets)

| Number | Species ID | Description | Atomic Weight | Half-life | Daughter1 | Stoichiometry 1 | Daughter2 | Stoichiometry 2 |
|---|---|---|---|---|---|---|---|---|
| 24 | Pu241 | Plutonium-241 | 241.057 | 14.35 yr | Am241 | 0.99998 | Np237 | 2.45E-05 |
| 25 | Pu242 | Plutonium-242 | 242.059 | 3.75E+5 yr | U238 | 1 | | |
| 26 | Ra226 | Radium-226 | 226.025 | 1,600 yr | Rn222 | 1 | | |
| 27 | Ra228 | Radium-228 | 228.031 | 5.75 yr | | | | |
| 28 | Rn222 | Radon-222 | 222.018 | 3.8235 day | Pb210 | 0.9998 | | |
| 29 | Se79 | Selenium-79 | 78.9185 | 2.95E+5 yr | | | | |
| 30 | Sm151 | Samarium-151 | 150.92 | 90 yr | | | | |
| 31 | Sn126 | Tin-126 | 125.908 | 2.3E+5 yr | | | | |
| 32 | Sr90 | Strontium-90 | 89.9077 | 28.79 yr | | | | |
| 33 | Tc99 | Technetium-99 | 98.9063 | 2.111E+5 yr | | | | |
| 34 | Th229 | Thorium-229 | 229.032 | 7340 yr | | | | |
| 35 | Th230 | Thorium-230 | 230.033 | 75,380 yr | Ra226 | 1 | | |
| 36 | Th232 | Thorium-232 | 232.038 | 1.405E+10 yr | Ra228 | 1 | | |
| 37 | U232 | Uranium-232 | 232.037 | 68.9 yr | | | | |
| 38 | U233 | Uranium-233 | 233.04 | 1.592E+5 yr | Th229 | 1 | | |
| 39 | U234 | Uranium-234 | 234.041 | 2.455E+5 yr | Th230 | 1 | | |
| 40 | U235 | Uranium-235 | 235.044 | 7.04E+8 yr | Pa231 | 1 | | |
| 41 | U236 | Uranium-236 | 236.046 | 2.342E+7 yr | Th232 | 1 | | |
| 42 | U238 | Uranium-238 | 238.051 | 4.468E+9 yr | U234 | 1 | | |
| 43 | Zr93 | Zirconium-93 | 92.9065 | 1.53E+6 yr | Nb93m | 0.975 | | |

**Table 4-2. List of Radionuclides Screened from the Performance Assessment with the Rationale for their Elimination.**

| Species ID | Description | Half-life | Exclusion |
|---|---|---|---|
| $^{125}$Sb | Antimony-125 | 2.759 yr | Half-life less than 3 years |
| $^{137m}$Ba | Barium-137m* | 2.552 m | |
| $^{134}$Cs | Cesium-134 | 2.065 yr | |
| $^{242}$Cm | Curium-242 | 162.8 d | |
| $^{106}$Ru | Ruthenium-106 | 373.59 d | |
| $^{228}$Th | Thorium-228 | 1.91 yr | |
| $^{90}$Y | Yttrium-90* | 64.1 hr | |

* $^{90}$Y and $^{137m}$Ba are included through the evaluation of their parents $^{90}$Sr and $^{137}$Cs, respectively.

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**Table 4-3. Estimated Inventory of Radionuclides (in Curies) at Closure of Waste Management Area C (Decay Corrected to January 1, 2020) Used in the Performance Assessment Calculation.**

| Tank/ Equipment | Ac-227 | Am-241 | Am-243 | C-14 | Cd-113m | Cm-243 | Cm-244 | Co-60 | Cs-137 | Eu-152 | Eu-154 | Eu-155 | H-3 | I-129 | Nb-93m | Ni-59 | Ni-63 | Np-237 | Pa-231 | Pb-210 | Pu-238 | Pu-239 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **241-C-101** | 1.58E-06 | 9.91E+00 | 1.43E-03 | 2.76E-03 | 1.47E-03 | 1.86E-05 | 3.32E-04 | 1.76E-04 | 3.61E+02 | 6.38E-05 | 2.77E-03 | 4.69E-04 | 2.45E-02 | 5.55E-05 | 1.83E-05 | 7.23E-04 | 5.53E-02 | 3.45E-04 | 2.48E-08 | 0.00E+00 | 1.13E-01 | 1.83E+01 |
| **241-C-102** | 1.93E-02 | 2.12E+01 | 7.93E-04 | 9.88E-04 | 1.78E-02 | 6.22E-05 | 1.28E-03 | 2.14E-01 | 8.07E+01 | 1.26E-04 | 1.36E-01 | 2.62E-02 | 2.15E-05 | 2.56E-03 | 1.10E-02 | 1.62E-01 | 1.36E+01 | 5.16E-05 | 2.12E-03 | 0.00E+00 | 1.48E+00 | 6.49E+01 |
| **241-C-103** | 6.39E-08 | 4.83E+00 | 3.70E-05 | 6.99E-03 | 1.49E-02 | 7.66E-07 | 1.52E-05 | 1.83E-02 | 6.07E+02 | 2.58E-05 | 1.41E+00 | 4.37E-01 | 3.98E-03 | 3.00E-03 | 3.69E-04 | 1.12E-01 | 1.86E+01 | 1.35E-02 | 1.66E-07 | 0.00E+00 | 1.30E+00 | 4.99E+00 |
| **241-C-104** | 1.11E-05 | 8.46E+00 | 5.25E-03 | 3.08E-03 | 5.11E-02 | 3.64E-03 | 6.69E-02 | 4.66E-01 | 6.22E+02 | 3.54E-02 | 1.57E+00 | 2.29E-01 | 9.32E-03 | 4.84E-04 | 3.16E-02 | 8.64E-02 | 9.95E+01 | 7.97E-02 | 7.47E-05 | 0.00E+00 | 5.89E-01 | 5.15E+00 |
| **241-C-105** | 5.17E-07 | 2.84E+01 | 6.73E-04 | 4.86E-02 | 5.87E-02 | 9.11E-06 | 1.56E-04 | 6.83E-01 | 5.08E+03 | 1.12E-04 | 4.68E-03 | 6.08E-04 | 4.08E+00 | 8.95E-03 | 1.45E-03 | 4.41E-01 | 3.61E+01 | 1.93E-04 | 6.57E-07 | 0.00E+00 | 7.50E-01 | 5.28E+01 |
| **241-C-106** | 1.74E-03 | 6.38E+01 | 3.05E-03 | 8.21E-03 | 2.13E+00 | 5.55E-02 | 7.39E-01 | 2.23E+00 | 1.00E+03 | 2.02E+00 | 2.25E+01 | 7.65E+00 | 4.17E-03 | 6.31E-04 | 5.92E+00 | 1.05E+01 | 6.53E+01 | 5.41E-02 | 2.53E-03 | 0.00E+00 | 2.38E+00 | 1.67E+01 |
| **241-C-107** | 6.20E-06 | 3.70E+02 | 3.86E-02 | 2.16E-02 | 2.50E-03 | 5.02E-04 | 8.95E-03 | 9.14E-04 | 2.32E+03 | 1.35E-04 | 5.70E-03 | 8.66E-04 | 1.44E-02 | 4.07E-02 | 8.45E-02 | 1.18E-03 | 1.46E-01 | 2.08E-04 | 3.83E-05 | 0.00E+00 | 8.05E-01 | 1.30E+02 |
| **241-C-108** | 7.78E-07 | 9.46E-01 | 9.78E-05 | 8.18E-03 | 1.97E-03 | 1.50E-06 | 2.96E-05 | 7.22E-04 | 8.57E+01 | 1.07E-04 | 4.52E-03 | 6.84E-04 | 1.94E-02 | 3.81E-05 | 4.80E-02 | 9.30E-04 | 2.80E+00 | 2.17E-05 | 3.02E-05 | 0.00E+00 | 4.37E-03 | 6.68E-01 |
| **241-C-109** | 3.40E-06 | 3.71E-01 | 3.91E-05 | 7.65E-04 | 1.37E-03 | 5.09E-07 | 9.09E-06 | 5.02E-04 | 4.31E+01 | 7.41E-05 | 3.13E-03 | 4.74E-04 | 3.51E-03 | 2.65E-05 | 4.64E-02 | 6.46E-04 | 8.78E-01 | 6.46E-04 | 2.10E-05 | 0.00E+00 | 1.56E-02 | 4.01E-01 |
| **241-C-110** | 9.62E-07 | 4.94E-02 | 5.54E-06 | 1.51E-03 | 3.89E-04 | 7.22E-08 | 1.29E-06 | 1.42E-04 | 2.02E+01 | 2.11E-05 | 8.89E-04 | 1.35E-04 | 1.80E-03 | 2.65E-04 | 1.32E-02 | 1.83E-04 | 4.08E-01 | 1.09E-03 | 5.96E-06 | 0.00E+00 | 1.56E-02 | 1.17E+00 |
| **241-C-111** | 1.82E-05 | 8.32E+01 | 1.15E-02 | 1.04E-01 | 5.99E-02 | 1.82E-03 | 3.26E-02 | 1.03E-01 | 7.14E+03 | 5.38E-02 | 2.41E+00 | 3.70E-01 | 2.58E+00 | 1.41E-02 | 9.78E-02 | 1.40E+00 | 1.13E+02 | 3.32E-03 | 4.99E-05 | 0.00E+00 | 1.70E+00 | 9.45E+01 |
| **241-C-112** | 4.57E-06 | 9.42E-01 | 9.72E-05 | 1.60E-02 | 1.84E-03 | 1.26E-06 | 2.25E-05 | 6.75E-04 | 7.66E+02 | 1.00E-04 | 4.22E-03 | 6.39E-04 | 1.06E-02 | 3.57E-05 | 6.26E-02 | 8.69E-04 | 1.08E-01 | 1.54E-04 | 2.82E-05 | 0.00E+00 | 3.59E-02 | 5.79E+00 |
| **241-C-201** | 3.45E-09 | 2.46E+00 | 9.76E-04 | 7.64E-04 | 5.77E-04 | 3.10E-03 | 5.55E-02 | 2.37E-03 | 7.01E+00 | 2.10E-03 | 9.42E-02 | 1.45E-02 | 1.57E-04 | 4.57E-07 | 7.46E-04 | 4.07E-03 | 8.33E-01 | 3.42E-03 | 6.79E-09 | 0.00E+00 | 4.42E-01 | 1.58E+01 |
| **241-C-202** | 3.51E-09 | 1.21E+00 | 4.71E-04 | 2.03E-04 | 5.88E-04 | 1.50E-03 | 2.68E-02 | 2.44E-03 | 6.18E+00 | 2.14E-03 | 9.61E-02 | 1.48E-02 | 1.60E-04 | 7.35E-06 | 7.64E-04 | 4.16E-03 | 2.00E-01 | 2.90E-03 | 6.93E-09 | 0.00E+00 | 3.99E-01 | 1.43E+01 |
| **241-C-203** | 2.87E-09 | 3.16E-02 | 1.22E-05 | 1.66E-04 | 4.80E-04 | 3.88E-05 | 6.95E-04 | 2.15E-03 | 9.10E+00 | 1.75E-03 | 1.50E-02 | 1.81E-02 | 1.31E-04 | 1.47E-05 | 6.26E-04 | 3.40E-03 | 5.54E-02 | 2.70E-05 | 5.67E-09 | 0.00E+00 | 1.36E-02 | 4.86E-01 |
| **241-C-204** | 2.69E-09 | 3.16E-03 | 1.22E-06 | 1.88E-04 | 4.50E-04 | 3.87E-06 | 6.95E-05 | 1.86E-03 | 4.13E+00 | 1.64E-03 | 5.62E-02 | 1.13E-02 | 1.13E-04 | 3.57E-07 | 5.84E-04 | 3.18E-03 | 1.46E-02 | 2.16E-02 | 5.30E-09 | 0.00E+00 | 2.76E-04 | 9.84E-03 |
| **C-301** | 6.62E-05 | 5.54E+00 | 1.37E-03 | 2.04E-03 | 8.49E-02 | 5.33E-03 | 8.60E-02 | 1.16E-01 | 1.21E+02 | 8.31E-02 | 1.17E+00 | 3.60E-01 | 2.09E-03 | 2.06E-04 | 2.30E-01 | 4.14E-01 | 9.54E+00 | 2.82E-02 | 1.01E-04 | 0.00E+00 | 7.40E-01 | 2.13E+01 |
| **CR-Vault** | 1.20E-04 | 1.01E+01 | 2.49E-03 | 3.71E-03 | 1.54E-01 | 9.68E-03 | 1.56E-01 | 2.11E-01 | 2.21E+02 | 1.51E-01 | 2.13E+00 | 6.54E-01 | 3.80E-03 | 3.75E-04 | 4.18E-01 | 7.52E-01 | 1.73E+01 | 5.13E-02 | 1.84E-04 | 0.00E+00 | 1.34E+00 | 3.88E+01 |
| **Pipelines** | 1.02E-04 | 8.52E+00 | 2.11E-03 | 3.14E-03 | 1.31E-01 | 8.19E-03 | 1.32E-01 | 1.79E-01 | 1.87E+02 | 1.28E-01 | 1.80E+00 | 5.54E-01 | 3.22E-03 | 3.17E-04 | 3.54E-01 | 6.37E-01 | 1.47E+01 | 4.34E-02 | 1.56E-04 | 0.00E+00 | 1.14E+00 | 3.28E+01 |

| Tank/ Equipment | Pu-240 | Pu-241 | Pu-242 | Ra-226 | Ra-228 | Rn-222 | Se-79 | Sm-151 | Sn-126 | Sr-90 | Tc-99 | Th-229 | Th-230 | Th-232 | U-232 | U-233 | U-234 | U-235 | U-236 | U-238 | Zr-93 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **241-C-101** | 1.96E+00 | 1.54E+00 | 2.70E-05 | 5.90E-07 | 2.64E-13 | 0.00E+00 | 2.80E-04 | 4.00E+00 | 5.13E-04 | 3.29E+03 | 4.34E-02 | 1.33E-10 | 0.00E+00 | 1.12E-12 | 1.75E-06 | 1.71E-07 | 1.69E-01 | 7.54E-03 | 1.93E-03 | 1.72E-01 | 3.35E-05 |
| **241-C-102** | 1.55E+01 | 4.87E+01 | 9.00E-04 | 2.88E-07 | 3.64E-01 | 0.00E+00 | 1.60E-06 | 9.72E-01 | 1.83E-04 | 2.94E+02 | 3.56E-03 | 1.06E-02 | 0.00E+00 | 2.29E-02 | 2.83E-02 | 2.17E+00 | 1.13E-01 | 4.27E-03 | 1.43E-03 | 9.78E-02 | 4.22E-03 |
| **241-C-103** | 1.04E+00 | 1.80E+00 | 3.24E-05 | 1.54E-08 | 4.70E-05 | 0.00E+00 | 2.64E-05 | 4.30E-01 | 5.27E-05 | 6.78E+03 | 4.48E-02 | 2.60E-11 | 0.00E+00 | 1.99E-04 | 4.29E-06 | 5.85E-03 | 1.36E-02 | 7.10E-04 | 3.74E-04 | 1.64E-02 | 7.03E-04 |
| **241-C-104** | 1.55E+00 | 1.14E+01 | 1.97E-02 | 3.24E-07 | 8.73E-04 | 0.00E+00 | 8.56E-03 | 3.17E+03 | 8.81E-03 | 4.89E+03 | 3.04E-01 | 8.56E-08 | 0.00E+00 | 3.70E-03 | 3.53E-02 | 2.18E+00 | 4.17E-01 | 1.98E-02 | 4.85E-03 | 4.39E-01 | 6.24E-02 |
| **241-C-105** | 1.04E+01 | 1.75E+01 | 3.14E-04 | 1.60E-07 | 2.36E-13 | 0.00E+00 | 1.51E-04 | 2.37E+00 | 2.93E-04 | 2.89E+04 | 7.83E+00 | 1.25E-10 | 0.00E+00 | 1.00E-12 | 8.62E-06 | 5.02E-07 | 2.39E-01 | 1.02E-02 | 5.17E-03 | 2.44E-01 | 2.77E-03 |
| **241-C-106** | 3.57E+00 | 1.84E+01 | 4.16E-04 | 5.13E-04 | 1.32E-04 | 0.00E+00 | 9.57E-03 | 7.82E+03 | 1.76E+00 | 4.50E+04 | 1.64E-01 | 1.91E-05 | 9.38E-04 | 5.60E-04 | 4.87E-04 | 1.82E-03 | 9.40E-04 | 3.86E-05 | 1.73E-05 | 9.02E-04 | 1.04E+01 |
| **241-C-107** | 1.42E+01 | 1.10E+01 | 1.97E-04 | 5.95E-07 | 9.70E-04 | 0.00E+00 | 2.70E-04 | 1.04E+04 | 4.94E-04 | 2.42E+04 | 2.14E+00 | 1.89E-09 | 0.00E+00 | 4.11E-03 | 2.20E-06 | 2.15E-07 | 2.07E-01 | 9.24E-03 | 2.31E-03 | 2.11E-01 | 1.55E-01 |
| **241-C-108** | 7.27E-02 | 7.91E-02 | 1.01E-06 | 4.73E-07 | 3.70E-06 | 0.00E+00 | 1.62E-03 | 6.66E+00 | 3.91E-04 | 1.25E+03 | 4.87E-02 | 1.50E-09 | 0.00E+00 | 1.57E-05 | 4.50E-07 | 4.10E-08 | 3.25E-02 | 1.82E-03 | 2.85E-04 | 4.03E-02 | 1.22E-01 |
| **241-C-109** | 4.36E-02 | 5.09E-01 | 6.07E-07 | 3.26E-07 | 2.06E-12 | 0.00E+00 | 1.48E-04 | 4.65E+00 | 2.71E-04 | 2.33E+03 | 8.77E-03 | 1.04E-09 | 0.00E+00 | 8.72E-12 | 9.94E-08 | 9.69E-09 | 9.35E-03 | 4.01E-04 | 9.61E-05 | 9.53E-03 | 8.45E-02 |
| **241-C-110** | 1.27E-01 | 3.58E-01 | 1.77E-06 | 9.27E-08 | 5.85E-13 | 0.00E+00 | 4.21E-05 | 1.32E+00 | 2.38E-02 | 2.62E+03 | 4.46E-02 | 2.95E-10 | 0.00E+00 | 2.48E-12 | 1.91E-08 | 1.86E-09 | 2.64E-03 | 1.14E-04 | 2.93E-05 | 2.59E-03 | 2.41E-02 |
| **241-C-111** | 1.85E+01 | 3.54E+01 | 6.54E-04 | 4.51E-06 | 6.54E-12 | 0.00E+00 | 3.53E-03 | 6.39E+02 | 6.72E-03 | 3.05E+05 | 2.19E+00 | 3.56E-09 | 0.00E+00 | 2.77E-11 | 2.22E-05 | 4.80E-05 | 7.74E-01 | 3.37E-02 | 1.32E-02 | 7.88E-01 | 1.81E-01 |
| **241-C-112** | 6.29E-01 | 4.91E-01 | 8.76E-06 | 4.40E-07 | 2.78E-12 | 0.00E+00 | 1.99E-04 | 6.25E+00 | 3.65E-04 | 2.28E+02 | 1.69E+00 | 1.40E-09 | 0.00E+00 | 1.18E-11 | 4.50E-07 | 4.39E-08 | 4.23E-02 | 1.89E-03 | 4.73E-04 | 4.32E-02 | 1.14E-01 |
| **241-C-201** | 3.40E+00 | 8.36E+00 | 1.60E-04 | 1.00E-09 | 9.51E-07 | 0.00E+00 | 5.49E-05 | 2.39E+01 | 1.10E-04 | 1.71E+02 | 2.63E-03 | 1.18E-11 | 0.00E+00 | 4.03E-06 | 2.25E-06 | 1.14E-05 | 3.65E-02 | 1.48E-03 | 5.23E-04 | 3.69E-02 | 1.46E-03 |
| **241-C-202** | 3.08E+00 | 7.52E+00 | 1.45E-04 | 1.02E-09 | 9.70E-07 | 0.00E+00 | 5.61E-05 | 2.43E+01 | 1.13E-04 | 3.31E+02 | 2.50E-03 | 1.20E-11 | 0.00E+00 | 4.11E-06 | 2.00E-06 | 1.02E-05 | 3.52E-02 | 1.42E-03 | 3.52E-04 | 3.28E-02 | 1.49E-03 |
| **241-C-203** | 1.05E-01 | 2.58E-01 | 4.94E-06 | 8.40E-10 | 4.48E-07 | 0.00E+00 | 4.58E-05 | 1.99E+01 | 9.21E-05 | 1.56E+02 | 2.32E-03 | 9.81E-12 | 0.00E+00 | 1.90E-06 | 6.60E-06 | 3.37E-05 | 1.13E-01 | 4.79E-03 | 8.33E-04 | 1.09E-01 | 1.22E-03 |
| **241-C-204** | 2.12E-03 | 5.21E-03 | 9.98E-08 | 7.86E-10 | 3.35E-06 | 0.00E+00 | 4.29E-05 | 1.86E+01 | 8.61E-05 | 1.03E+02 | 3.18E-03 | 9.17E-12 | 0.00E+00 | 1.42E-05 | 4.93E-06 | 2.51E-05 | 8.27E-02 | 3.42E-03 | 5.13E-04 | 8.13E-02 | 1.14E-03 |
| **C-301** | 4.60E+00 | 1.21E+01 | 1.30E-03 | 1.93E-05 | 5.90E-05 | 0.00E+00 | 1.03E-03 | 5.29E+02 | 6.80E-02 | 3.06E+03 | 3.64E-02 | 7.21E-07 | 0.00E+00 | 2.50E-04 | 1.96E-03 | 1.20E-01 | 2.26E-01 | 9.56E-03 | 1.93E-03 | 2.22E-01 | 4.07E-01 |
| **CR-Vault** | 8.36E+00 | 2.19E+01 | 2.36E-03 | 3.51E-05 | 1.07E-04 | 0.00E+00 | 1.87E-03 | 9.62E+02 | 1.24E-01 | 5.55E+03 | 6.62E-02 | 1.31E-06 | 0.00E+00 | 4.54E-04 | 3.57E-03 | 2.17E-01 | 4.11E-01 | 1.74E-02 | 3.51E-03 | 4.04E-01 | 7.39E-01 |
| **Pipelines** | 7.08E+00 | 1.86E+01 | 2.00E-03 | 2.97E-05 | 9.08E-05 | 0.00E+00 | 1.58E-03 | 8.15E+02 | 1.05E-01 | 4.70E+03 | 5.61E-02 | 1.11E-06 | 0.00E+00 | 3.85E-04 | 3.02E-03 | 1.84E-01 | 3.48E-01 | 1.47E-02 | 2.97E-03 | 3.42E-01 | 6.26E-01 |

# 5.0 WASTE CHARACTERISTICS

The WMA C tanks and ancillary equipment received a wide range of waste streams produced from processing of spent nuclear fuel and selective extraction of isotopes of concern to support the Hanford operations. The wastes consist of a large array of chemicals and radionuclides and their inventory is estimated on a tank-by-tank basis. As of September 2014, waste has been retrieved from 13 of 16 SSTs in WMA C and is in progress for the remaining 3 tanks (C-102, C-105, and C-111). This section provides information related to the chemical and physical characteristics of the residual waste that are relevant to developing conceptual and mathematical models for source term release.

Following retrieval of tanks, post-retrieval sampling of the residual waste has been conducted for various constituents as indicated in Section 3.2.2 to estimate the residual inventory and volume. Table 3-12 summarizes the current waste types (primarily sludge) present in various WMA C tanks and Tables 3-13 through 3-15 provide residual inventory and residual volume estimates for the tanks and ancillary equipment. For the retrieved tanks that have undergone post-retrieval sampling, the density of sludge typically varies from ~1,550 to 2,000 $kg/m^3$ (96.8 to 124.9 $lbs/ft^3$) and the gravimetric moisture content varies from 20 to 40 wt.%.

As part of the waste characterization efforts, analytical methods are used to measure the chemical and radiological constituents in the waste sludge and to understand their composition, solid-phase characteristics, and the leachability of primary contaminants of interest. (e.g., PNNL-16738, “Hanford Tank 241-C-103 Residual Waste Contaminant Release Models and Supporting Data”; PNNL-15187, “Hanford Tank 241-C-106: Residual Waste Contaminant Release Model and Supporting Data,” Rev. 1; PNNL-19425, “Hanford Site Tank 241-C-108 Residual Waste Contaminant Release Models and Supporting Data”; PNNL-14903, “Hanford Tanks 241-C-203 and 241-C-204: Residual Waste Contaminant Release Model and Supporting Data,” Rev. 1; PNNL-16229, “Hanford Tanks 241-C-202 and 241-C-203: Residual Waste Contaminant Release Model and Supporting Data”).

“Hanford tank residual waste – Contaminant source terms and release models” (Deutsch et al. 2011) summarized the characterization information of solid phases from four WMA C tank residuals (C-103, C-106, C-202, and C-203). Multiple samples of residual waste from each tank were received. The samples represent composite samples of solids collected from several locations in each storage tank. The photographs of the samples are shown in Figure 5-1. The yellowish color of the tank C-203 residual sample is due to presence of uranium at a concentration of ~50 wt.% while the color of the tank C-106 sample is likely due to presence of high manganese concentration resulting from oxalate reaction with the metals in the waste solids. Tank C-106 is the only tank from which waste was removed using oxalic acid.

The average reported composition (µg/g dry weight) for selected elements, primary contaminants of interest, and anions in bulk residual waste developed from laboratory analysis of selected tank waste residual samples used for waste release studies by Deutsch et al. (2011), are presented in Table 5-1. Concentrations of certain contaminants and elements differ by orders of magnitude, indicating large variability. For example, the uranium concentrations for adjacent tanks C-202 and C-203 are relatively high (207,000 and 505,000 µg/g [7,302 and 17,813 oz/ton], respectively) while they are relatively low for tanks C-103 and C-106 (3,730 and 310 µg/g [132 and 11 oz/ton], respectively). On the other hand, the trend in aluminum concentrations is reversed, being relatively high for tanks C-103 and C-106 compared to tanks C-202 and C-203. The iron (Fe) concentration for tank C-202 is 122,000 µg/g (4,300 oz/ton) and for tank C-203 is 16,300 µg/g (575 oz/ton). These compositional differences between tanks are due to 1) the mixing of various types of waste disposed over the decades when they were in use, 2) the chemical reactions within the tanks from heating and evaporation, and 3) the effects of various waste retrieval methods (sluicing of wastes using tank supernates, groundwater, and/or oxalic acid). Additional information on average composition of selective constituents in waste residuals developed from inventory estimates in RPP-RPT-42323 is summarized in Tables 3-13 through 3-17.

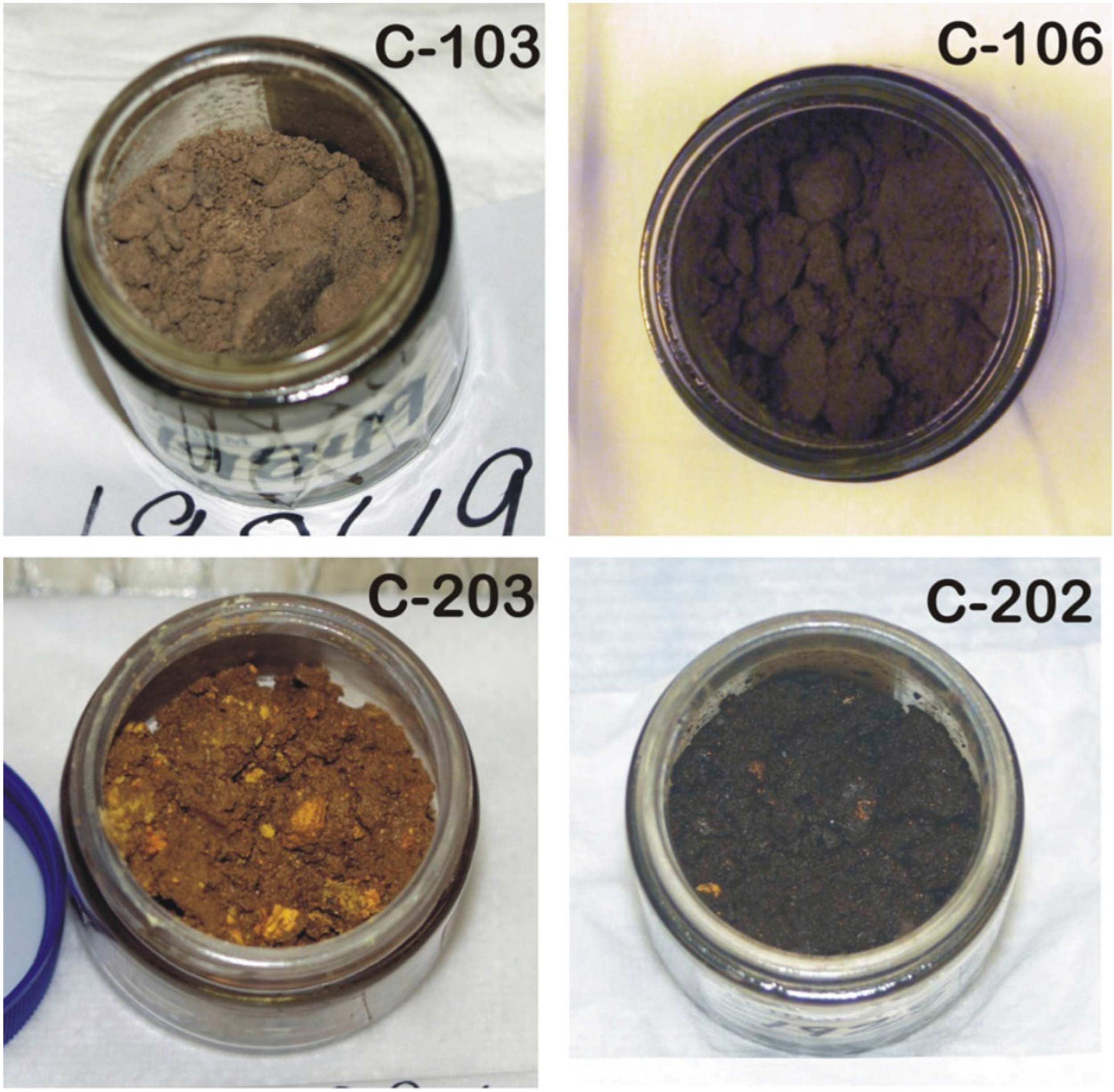
The mineralogy of solid phases from the retrieved tanks has been summarized by Deutsch et al. (2011) and provided in Table 5-2. Gibbsite [$Al(OH)_3$] is a common mineral in tanks with high aluminum concentrations, while non-crystalline U–Na–C–O–P ± H phases are common in the uranium-rich residual wastes from tanks C-202 and C-203. Iron oxides/hydroxides have been identified in all residual waste samples studied to date. Figure 5-2 shows the electron micrograph of typical solids present in unleached tank C-103 residual waste.

Technetium was identified by scanning electron microscopy/energy dispersive spectroscopy (SEM/EDS) associated with iron oxide/hydroxide particles in tank C-103 residual waste at concentration from ~0.6 to 1.0 wt.%, providing direct evidence of technetium in solid phases. No iodine-containing phases could be identified, perhaps due to low mass concentrations. In tank C-106, due to leaching with oxalate, the manganese-bearing mineral phases are dominant; however, the presence of aluminum and iron-bearing mineral phases exists. The majority of the manganese occurs as Mn(II). Spectral analysis of tank C-106 samples indicate that uranium occurs primarily in the hexavalent oxidation state [U(VI)]; however, a small fraction may be present as U(IV). The majority of the chromium appears to be in the reduced trivalent [Cr(III)] oxidation state, while the iron is present in the oxidized trivalent [Fe(III)] state.

The residual waste in tanks C-202 and C-203 contains mostly amorphous solids of U-Na-C-O-P ± H and iron oxide/hydroxide as shown in Figure 5-3. No phases containing iodine or technetium were detected, most likely due to low concentration of these contaminants.

"Single-pass flow-through test elucidation of weathering behavior and evaluation of contaminant release models for Hanford tank residual radioactive waste" (Cantrell et al. 2013) evaluated contaminant release models for Hanford tank residuals using single-pass flow-through tests. This work provided an analysis of solid phases in the radioactive residual waste following leaching with three different leachates, namely the deionized (DI) water, $CaCO_3$ saturated solution, and 0.005 M $Ca(OH)_2$ solution which represented a range of possible water types contacting the residual waste. In general, the nature of the leachate did not have a large impact on the phases that were identified. For the tank C-103 samples, the only phase identified was gibbsite, regardless of the leachate used. In the tank C-202 samples, calcite was positively identified, while for tank C-203 samples, calcite and schoepite were positively identified. Besides these, some possible (tentative) phases identified for tanks C-202 and C-203 included hydroxylapatite, $CaUO_4$, soddyite, studtite, $Na_2U_2O_7.6H_2O$, and boltwoodite.

**Figure 5-1. Photographs of As-Received, Post-Final Retrieval Residual Waste Samples from Tanks 241-C-103, 241-C-106, 241-C-202, and 241-C-203.**



Source: "Hanford tank residual waste – Contaminant source terms and release models" (Deutsch et al. 2011).

### Table 5-1. Average Composition (μg/g[a] dry weight) for Selected Elements, Primary Contaminants of Interest, and Anions in Bulk Residual Waste from Some Waste Management Area C Tanks.

| Analyte | 241-C-103 (μg/g dry wt.) | 241-C-106 (μg/g dry wt.) | 241-C-202 (μg/g dry wt.) | 241-C-203 (μg/g dry wt.) |
|---|---|---|---|---|
| Al | 136,000 | 81,699 | 13,600 | <710 |
| Ba | 181 | 914 | 208 | <142 |
| Ca | 616 | 46,490 | 14,500 | 3,140 |
| Cr | 193 | (727)[a] | 13,200 | 5,910 |
| Fe | 12,000 | 36,663 | 122,000 | 16,300 |
| K | Below detection limit | 8,526 | <15,800 | <355,000 |
| Mg | -42 | 3,162 | 2,560 | -729 |
| Mn | 470 | 108,069 | 25,700 | 956 |
| Na | 7,840 | 46,720 | 58,800 | 95,800 |
| Ni | 420 | 5,373 | 9,070 | 510 |
| Pb | 892 | 4,814 | 7,980 | 5,630 |
| Si | 9,070 | (4,895)[a] | 25,000 | 3,490 |
| Sr | 90.7 | (493)[a] | 1,510 | 409 |
| $^{238}U$ | 3,730 | 310 | 207,000 | 505,000 |
| $^{239}Pu$ | 8.02 | 27.7 | 435 | 18.2 |
| $^{237}Np$ | 1.3 | 9.04 | 2.16 | (0.0519)[a] |
| $^{241}Am$ | 0.053 | 2.05 | 0.449 | 0.014 |
| $^{99}Tc$ | 0.231 | 1.14 | 0.149 | (0.0947)[a] |
| $^{129}I$ | (1.11E-5)[a] | Not available | Not available | Not available |
| $F^-$ | (31)[a] | 33 | 6,030 | 2,760 |
| $Cl^-$ | (5.4)[a] | 87 | 161 | 201 |
| $NO_2^-$ | (59)[a] | <73 | 485 | 610 |
| $NO_3^-$ | (250)[a] | <70 | 3,540 | 4,840 |
| $CO_3^{2-}$ | Below detection limit | 39,500 | 12,200 | 49,900 |
| $SO_4^{2-}$ | Below detection limit | <66 | 334 | 288 |
| $PO_4^{3-}$ | (66)[b] | <91 | 17,700 | 43,300 |
| Oxalate | — | 63,900 | 32,400 | 1,500 |

[a] 1 ug/g is equal to 0.0352 oz/ton.

[b] Value in parenthesis is the estimated quantification limit.

Modified from "Hanford tank residual waste – Contaminant source terms and release models" (Deutsch et al. 2011).

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**Table 5-2. Solid Phases Identified in Tank Residual Waste Samples.**

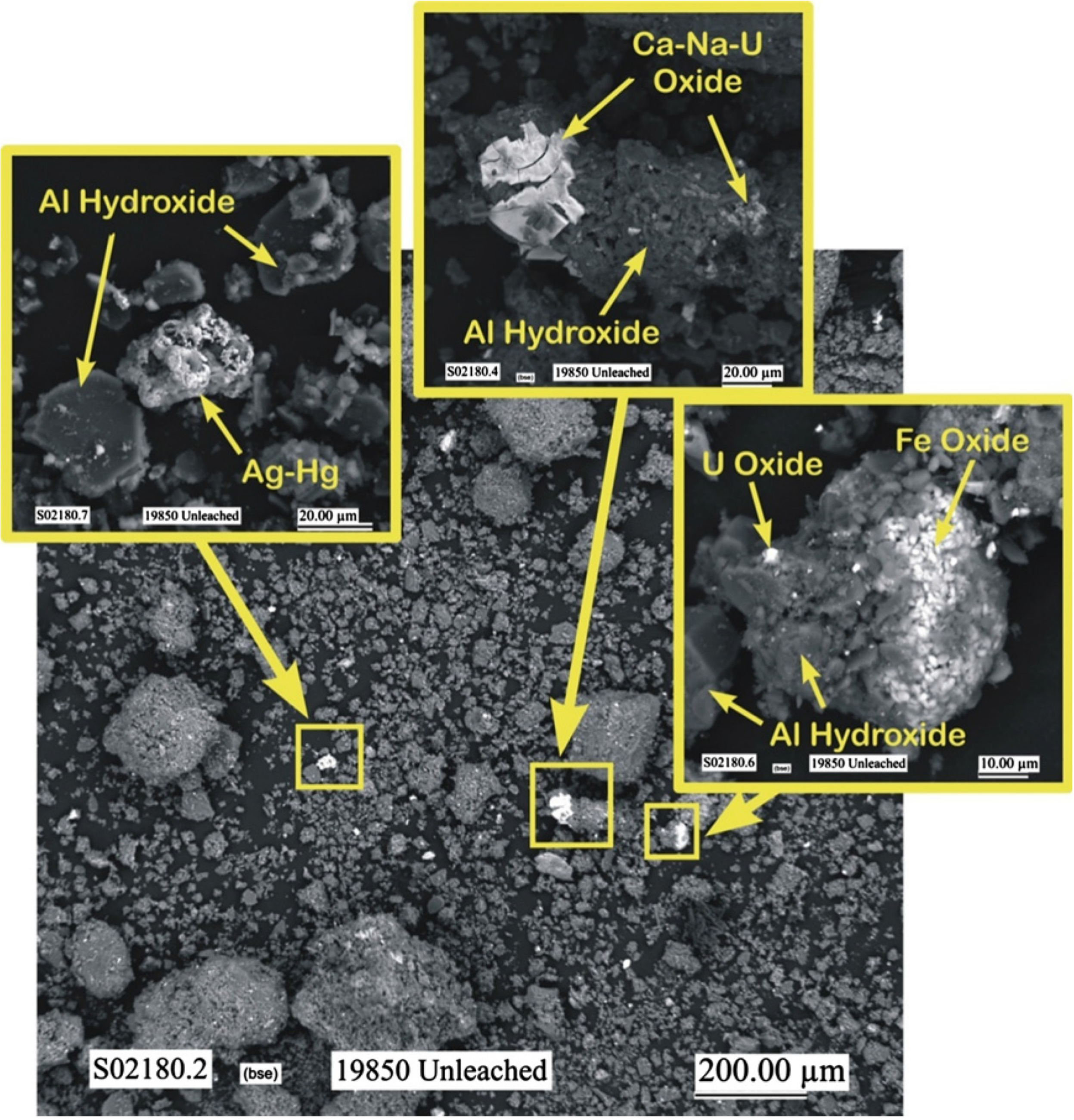
| Tank Number | Solid Phases | | Comments |
|---|---|---|---|
| | Major | Minor/Trace | |
| 241-C-103 | Gibbsite [$Al(OH)_3$];<br>hematite (a-$Fe_2O_3$) | Two Fe oxide/hydroxides; cancrinite [$Na_6CaAl_6Si_6(CO_3)O_{24}\_2H_2O$]; oxides of Ag ± Hg, U, Ca–P, Na–Ca–U, Si–Al–Mg–Na–Fe, Zr, and Th | Tc in three Fe oxide/hydroxide particles |
| 241-C-106 | Lindbergite ($MnC_2O_4.2H_2O$);<br>whewellite ($CaC_2O_4.2H_2O$);<br>gibbsite; böhmite [$AlO(OH)$];<br>dawsonite [$NaAlCO_3(OH)_2$];<br>hematite; rhodochrosite [$MnCO_3$]; possible Ag–Hg phase | Mn–Al–Fe–Na–P–Si–Ca–O ± C ± H;<br>Mn–O–P ± Al ± C± H;<br>Si–Al–Na–O ± C ±H; REE-rich oxide;<br>Ca–Si–Al–O ± C ± H; $Ag^0$;<br>Pb-containing phase | Tank leached with 0.9 M oxalic acid ($H_2C_2O_4$) during waste retrieval |
| 241-C-202 | Amorphous (non-crystalline) solids of either U Na–C–O–P ± H or Fe oxide/hydroxide | Trace amounts of Mn and Cr and sometimes Pb | No crystalline phases identified |
| 241-C-203 | Amorphous solids of primarily U Na–C–O–P ± H | Amorphous solids of Fe oxide/ hydroxide with trace amounts of Mn, Cr, Pb, and/or Cu | No crystalline phases identified; Similar to C-202 |

Modified from "Hanford tank residual waste – Contaminant source terms and release models" (Deutsch et al. 2011).

The general trends in uranium leachate concentrations for the C-103, C-202, and C-203 tank residual wastes used in Cantrell et al. (2013) were very similar. The results are presented for tank C-202 in Figure 5-4. The leached uranium concentration using DI water and $CaCO_3$ saturated solution are significantly higher than those in the 0.005 M $Ca(OH)_2$ leachates. This is attributed to the formation of Ca-rich precipitates (Ca phosphate and calcite) on the surfaces of the waste particles when using $Ca(OH)_2$ leachate, inhibiting dissolution of the underlying uranium phases in the waste. Since the tanks are planned to be grouted prior to the closure, the primary leachate is expected to be $Ca(OH)_2$ solution, which is likely to reduce the leaching of uranium.

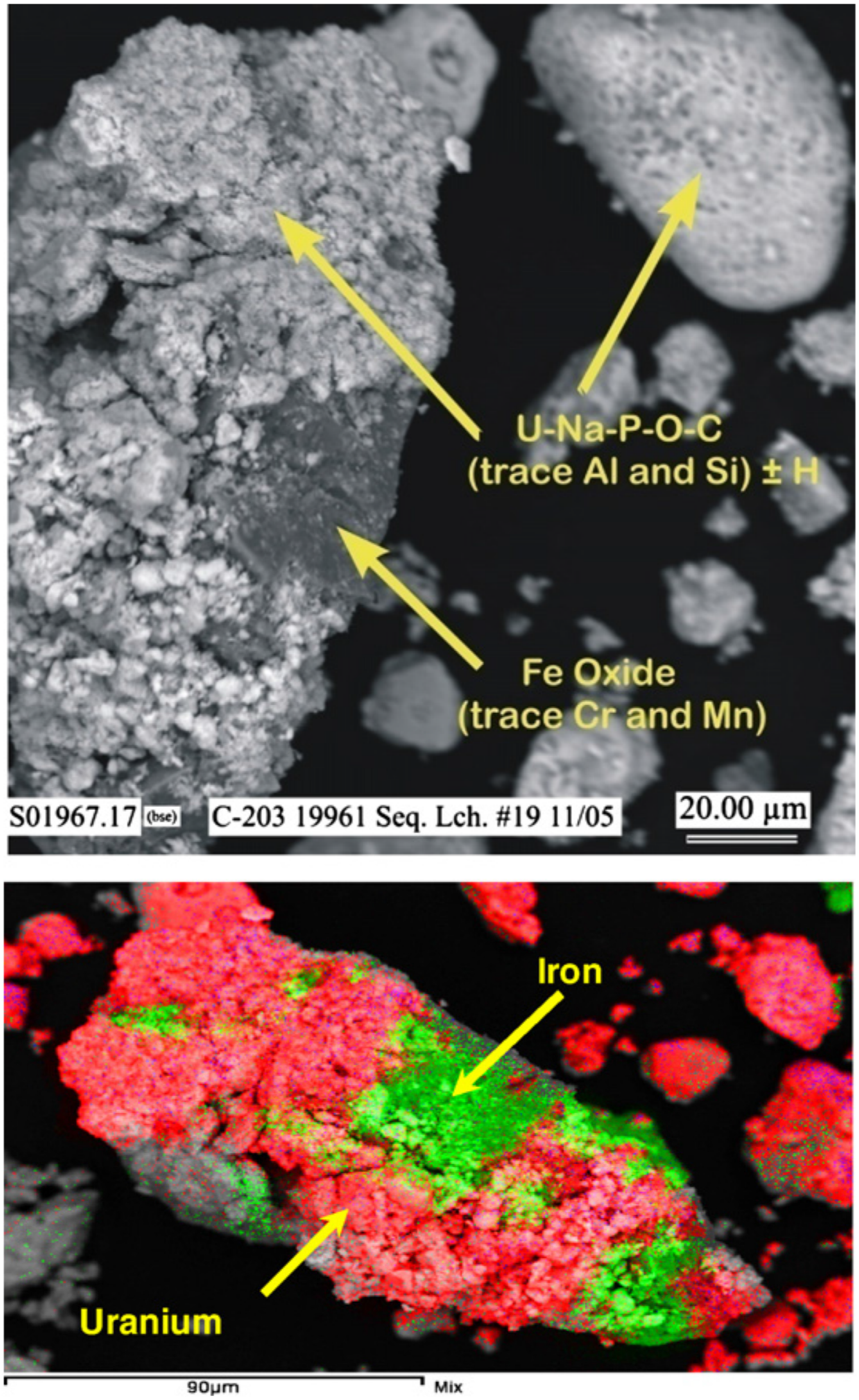
To investigate this leaching behavior, thermodynamic equilibrium modeling was conducted to calculate the mineral saturation indices and to identify solid phases potentially in equilibrium with the leachate composition. The saturation index is defined as SI = log ($Q/K_{sp}$), where Q is the activity product and $K_{sp}$ is the mineral solubility product at equilibrium at the temperature of interest. Minerals with SI values near zero (within ± 0.5) are generally considered to be at or near equilibrium, more positive values are considered supersaturated, and more negative values are considered undersaturated with respect to the solution composition. The SI calculated for the tank C-202 single-pass flow-through (SPFT) test effluents for the three leachates indicated that DI water and $CaCO_3$ saturated leachate give similar SI results while the $Ca(OH)_2$ leachate-based SI results are quite different. Results from DI water and $CaCO_3$ saturated leachates indicate that $NaUO_2PO_4.xH_2O$ is near equilibrium while Ca-containing phases (such as calcite and hydroxylapatite) were all undersaturated. The SI results for the $Ca(OH)_2$ leachates indicate all uranium-bearing phases to be highly undersaturated, but near saturation with respect to Ca-containing phases. Calcite was near saturation while hydroxylapatite and flourapatite were consistently highly supersaturated. These results are consistent with the observed leaching behavior of uranium. It is hypothesized that precipitation of Ca-rich phases resulted in coatings on the waste particles that could have temporarily inhibited dissolution and attainment of equilibrium for any uranium phase in contact with $Ca(OH)_2$ leachate solutions.

**Figure 5-2. Low- and High-Magnification Electron Micrographs of Typical Solids Present in Unleached Tank 241-C-103 Residual Waste.**



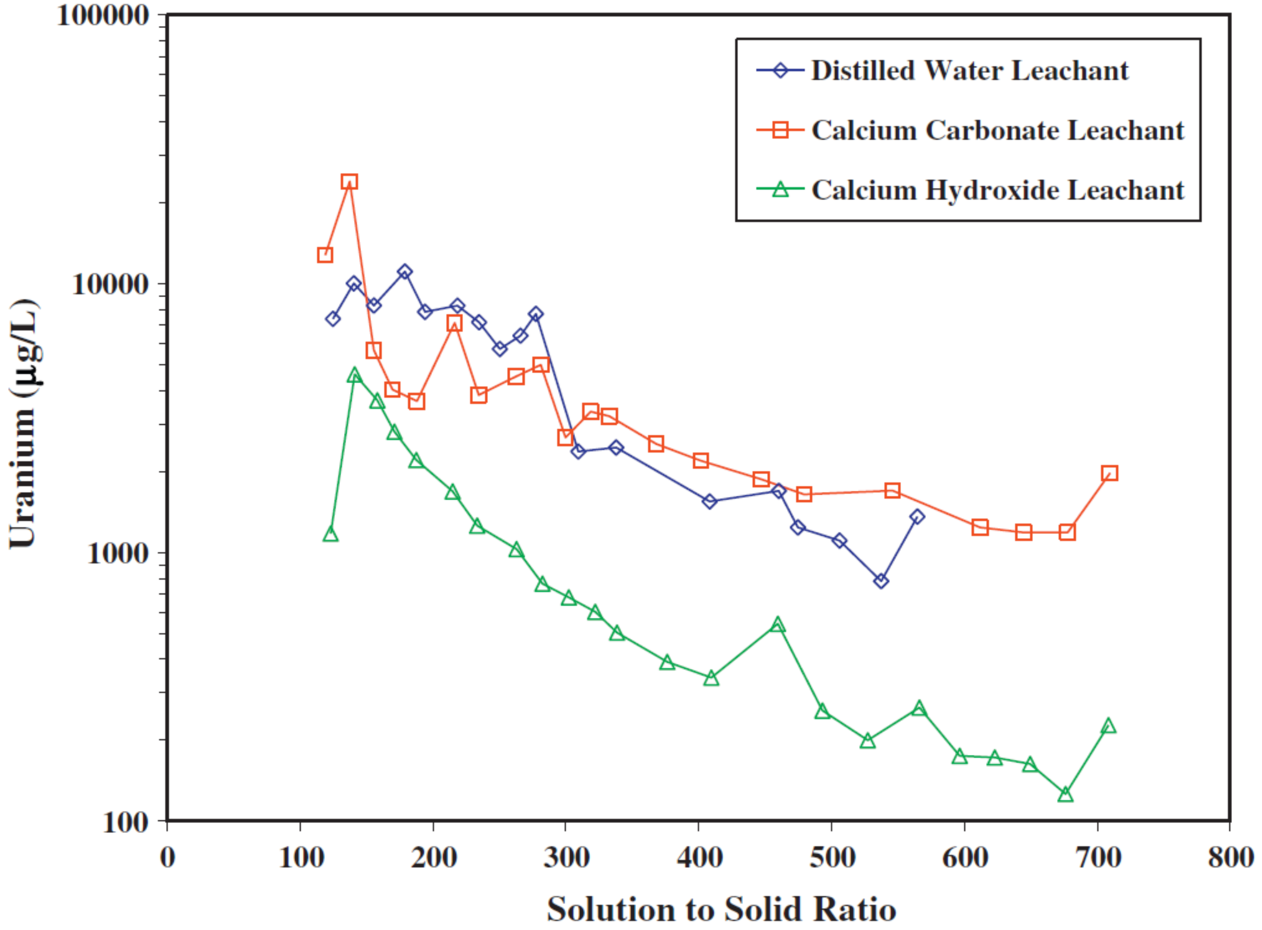
Reference: PNNL-16738, “Hanford Tank 241-C-103 Residual Waste Contaminant Release Models and Supporting Data.”

**Figure 5-3. Electron Micrograph (top) and Multi-Element Energy Dispersive Spectroscopy Map (bottom) for an Aggregate of U-Na-C-O-P ± H and Fe Oxide/Hydroxide Particles Present in Sequential-Leached Water Extraction Sample of Tank 241-C-203 Residual Waste.**
**(The large aggregate at the center of the colored element distribution map is the same large aggregate, but rotated 45 degree counterclockwise, shown in the electron micrograph).**



Reference: PNNL-16229, “Hanford Tanks 241-C-202 and 241-C-203: Residual Waste Contaminant Release Models and Supporting Data.”

**Figure 5-4. Uranium Concentrations in Tank 241-C-202 Single-Pass Flow-Through Leachates as a Function of the Total Volume of Leachate that has Contacted the Waste in Terms of Leachate/Solid (Initial) Weight Ratio.**

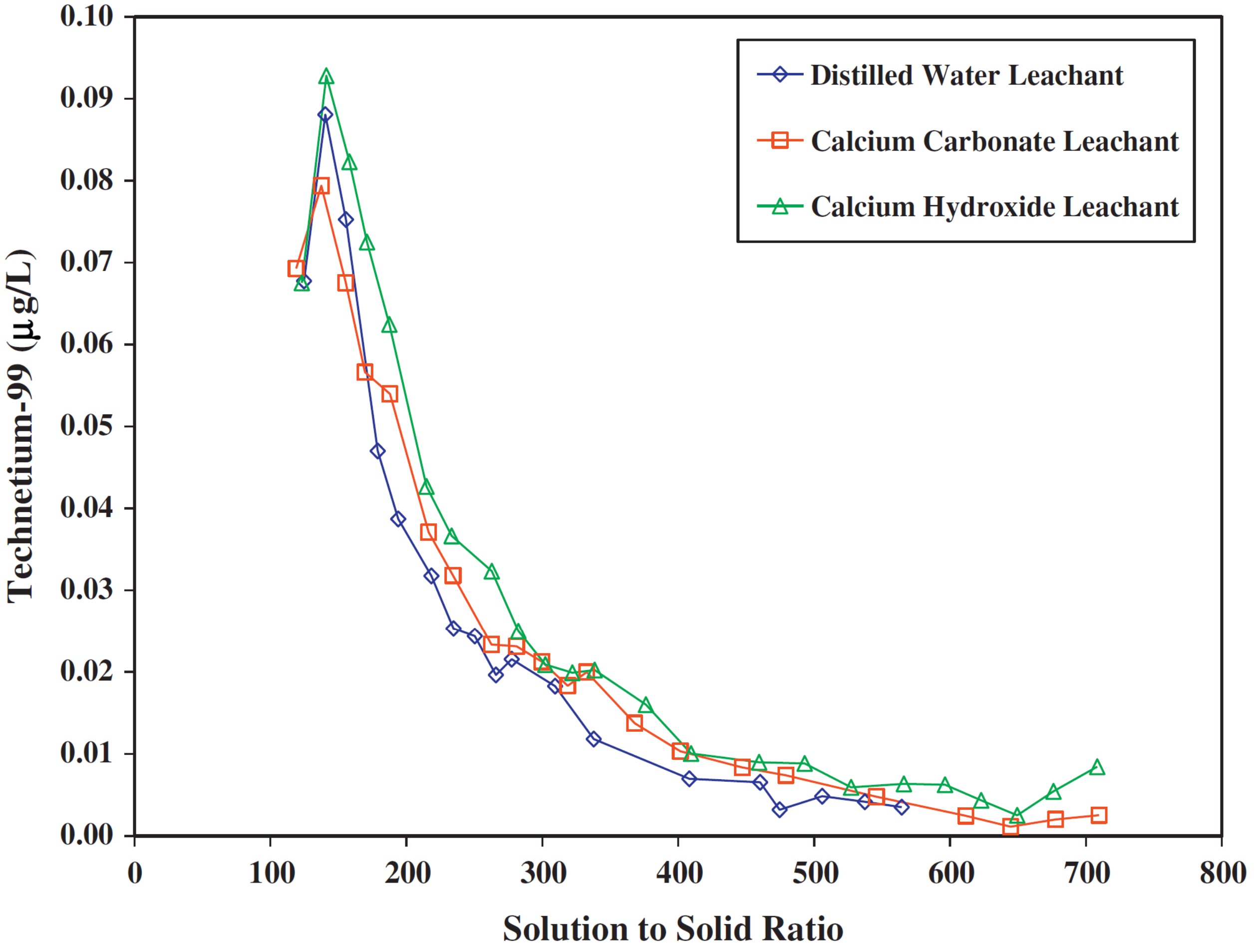


Reference: "Single-pass flow-through test elucidation of weathering behavior and evaluation of contaminant release models for Hanford tank residual radioactive waste" (Cantrell et al. 2013).

These results indicate that as long as the infiltrating water through the tank passes through the infill grout material, it will be conditioned to be similar to a dilute $Ca(OH)_2$ leachate solution and the uranium dissolution will remain inhibited. At some distant time in the future when the tank is assumed to be sufficiently degraded such that large open fractures develop that do not allow appreciable residence time for infiltrating waters to contact the grout material, the leachate would be similar to the $CaCO_3$ saturated water, and at that time, the uranium concentrations may increase when the residual waste is contacted.

Similar SPFT experiments, as indicated above to evaluate the uranium leaching, were conducted by Cantrell et al. (2013) to evaluate the leaching characteristics of $^{99}$Tc and chromium from tank C-202. Figures 5-5 and 5-6 indicate the $^{99}$Tc and chromium concentrations in tank C-202 SPFT leachates for the three leachate solutions as a function of solution to solid ratio. Figure 5-5 indicates that the $^{99}$Tc concentrations in all three leachates are very similar, with concentrations dropping near exponentially with increasing solution to solid ratio. Results for tanks C-203 and C-103 are very similar to tank C-202, although the magnitudes of the concentrations vary as a function of the residual inventory. The actual release mechanism for $^{99}$Tc remains indeterminate; however, it is likely that $^{99}$Tc is adsorbed onto and/or co-precipitated with iron oxides/hydroxides (Cantrell et al. 2013), and may slowly leach from dissolution of iron oxides/hydroxides mineral phases. This is consistent with the observation where technetium was identified by SEM/EDS associated with iron oxide/hydroxide particles in tank C-103 residual waste at concentration from ~0.6 to 1.0 wt.%.

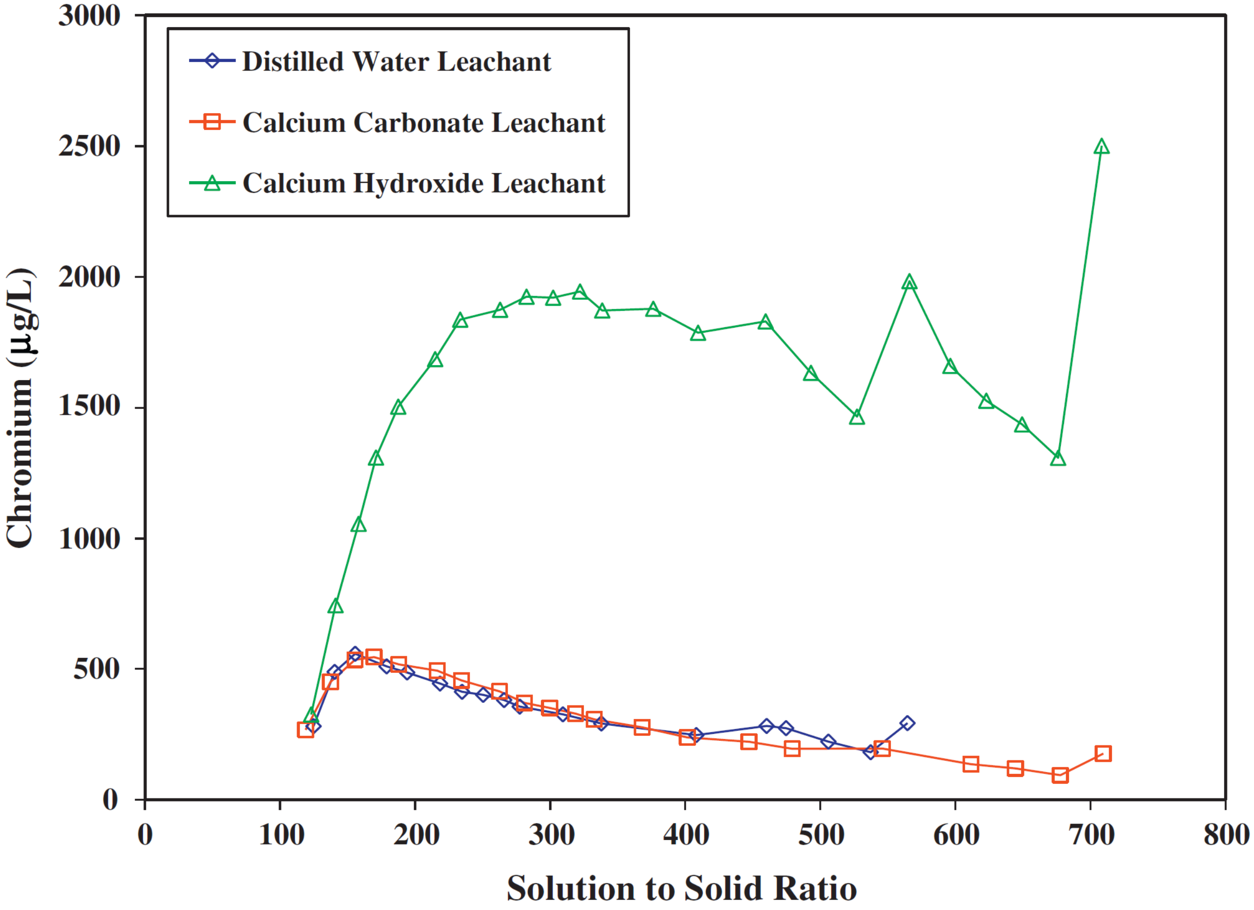
**Figure 5-5. Technetium-99 Concentration in Tank 241-C-202 Single-Pass Flow-Through Leachates as a Function of the Total Volume of Leachate that has Contacted the Waste in Terms of Leachate/Solid (Initial) Weight Ratio.**



Reference: "Single-pass flow-through test elucidation of weathering behavior and evaluation of contaminant release models for Hanford tank residual radioactive waste" (Cantrell et al. 2013).

Chromium in the SPFT leachates for tank C-202 residual waste (Figure 5-6) shows relatively high release concentrations initially, with concentrations in the $Ca(OH)_2$ leachates being much higher than those of the DI water and $CaCO_3$ leachates. The relatively high concentrations of chromium in $Ca(OH)_2$ leachate were not found for tank C-203, and the reason for this difference is not readily apparent. The leachate concentrations from C-103 tank residual waste were below the detection limit of 5 ppb. These results indicate large variations in the chromium release characteristics, and perhaps reflect the variability in the chromium present in trivalent and hexavalent oxidation states along with association with iron oxides/hydroxides. It is also possible that some chromate may also have been co-precipitated with phosphate in $NaUO_2PO_4.xH_2O$. As residual waste is leached with $Ca(OH)_2$ and portions of $NaUO_2PO_4.xH_2O$ are converted to $CaUO_4$, both $PO_4$ and $CrO_4$ are slowly released.

**Figure 5-6. Chromium Concentration in Tank 241-C-202 Single-Pass Flow-Through Leachates as a Function of the Total Volume of Leachate that has Contacted the Waste in Terms of Leachate/Solid (Initial) Weight Ratio.**



Reference: "Single-pass flow-through test elucidation of weathering behavior and evaluation of contaminant release models for Hanford tank residual radioactive waste" (Cantrell et al. 2013).

The total percentages of uranium and $^{99}$Tc leached from the residual waste samples during the course of the SPFT experiments were calculated and are presented in Table 5-3. The percent uranium leached varies from 0.3% to 9.4%, while the percent $^{99}$Tc leached ranges from 4.5% to 15%. The percentage of uranium leached varies by the leachate type, with greater amount leached using DI water and $CaCO_3$ saturated water and significantly less with the $Ca(OH)_2$ leachate. In contrast, the percentage of $^{99}$Tc leached does not vary by the leachate type, but is influenced more by the particular sample.

### Table 5-3. Percentages of Total Uranium and Technetium-99 Leached from Tanks 241-C-202, 241-C-203, and 241-C-103 Residual Wastes during the Single-Pass Flow-Through Experiments.

| Tank | Leachate | Percent Uranium Leached | Percent Technetium-99 Leached |
|---|---|---|---|
| 241-C-202 | Deionized water | 1.3 | 7.8 |
| 241-C-202 | $CaCO_3$ | 1.7 | 8.3 |
| 241-C-202 | $Ca(OH)_2$ | 0.3 | 9.0 |
| 241-C-203 | Deionized water | 2.5 | 6.2 |
| 241-C-203 | $CaCO_3$ | 2.1 | 7.4 |
| 241-C-203 | $Ca(OH)_2$ | 0.22 | 4.5 |
| 241-C-103 | Deionized water | 5.4 | 15 |
| 241-C-103 | $CaCO_3$ | 9.4 | 15 |
| 241-C-103 | $Ca(OH)_2$ | 3.5 | 12 |

Reference: “Single-pass flow-through test elucidation of weathering behavior and evaluation of contaminant release models for Hanford tank residual radioactive waste” (Cantrell et al. 2013).

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