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Section 2 of 6

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2.0 SITE AND WASTE CHARACTERISTICS

CONTENTS

2.1 INTRODUCTION 2-1

2.2 OVERVIEW 2-3
- 2.2.1 Hydrogeology 2-3
- 2.2.2 Meteorology and Climatology 2-4
- 2.2.3 Source Terms 2-5
- 2.2.4 Land Use 2-7

2.3 HANFORD SITE CHARACTERISTICS 2-7
- 2.3.1 Geography and Demography 2-7
- 2.3.2 Meteorology and Climatology 2-15
- 2.3.3 Ecology 2-18
- 2.3.4 Geology, Seismology, and Volcanology 2-19
- 2.3.5 Hydrology 2-36

2.4 FACILITY DESCRIPTIONS COMMON TO ALL TANK FARMS 2-54
- 2.4.1 100-Series Tanks 2-58
- 2.4.2 200-Series Tanks 2-61
- 2.4.3 Ancillary Equipment 2-62

2.5 SOURCE TERM INVENTORY 2-66
- 2.5.1 Inventory Models 2-69
- 2.5.2 Past Releases 2-71
- 2.5.3 Residual Tank Waste 2-72
- 2.5.4 Residual Ancillary Equipment Waste 2-73
- 2.5.5 Hypothetical Retrieval Leaks 2-74
- 2.5.6 Inventory Summary 2-74

2.6 DESCRIPTION OF WASTE MANAGEMENT AREA S-SX 2-74
- 2.6.1 Background 2-74
- 2.6.2 Infrastructure 2-78
- 2.6.3 Geology 2-81
- 2.6.4 Hydrology 2-81
- 2.6.5 Vadose Zone Conditions 2-83
- 2.6.6 Unconfined Aquifer Conditions 2-89
- 2.6.7 Reference Case Source Terms 2-94

2.7 DESCRIPTION OF WASTE MANAGEMENT AREA T 2-98
- 2.7.1 Background 2-98
- 2.7.2 Infrastructure 2-100
- 2.7.3 Geology 2-103
- 2.7.4 Hydrology 2-105
- 2.7.5 Vadose Zone Conditions 2-105
- 2.7.6 Unconfined Aquifer Conditions 2-110
- 2.7.7 Reference Case Source Terms 2-112

2.8 DESCRIPTION OF WASTE MANAGEMENT AREA TX-TY 2-116
2.8.1 Background 2-116
2.8.2 Infrastructure 2-119
2.8.3 Geology 2-121
2.8.4 Hydrology 2-123
2.8.5 Vadose Zone Conditions 2-123
2.8.6 Unconfined Aquifer Conditions 2-130
2.8.7 Reference Case Source Terms 2-131

2.9 DESCRIPTION OF WASTE MANAGEMENT AREA U 2-136
2.9.1 Background 2-136
2.9.2 Infrastructure 2-138
2.9.3 Geology 2-141
2.9.4 Hydrology 2-142
2.9.5 Vadose Zone Conditions 2-143
2.9.6 Unconfined Aquifer Conditions 2-145
2.9.7 Reference Case Source Terms 2-149

2.10 DESCRIPTION OF WASTE MANAGEMENT AREA C 2-153
2.10.1 Background 2-153
2.10.2 Infrastructure 2-155
2.10.3 Geology 2-157
2.10.4 Hydrology 2-160
2.10.5 Vadose Zone Conditions 2-160
2.10.6 Unconfined Aquifer Conditions 2-164
2.10.7 Reference Case Source Terms 2-165

2.11 DESCRIPTION OF WASTE MANAGEMENT AREA B-BX-BY 2-170
2.11.1 Background 2-170
2.11.2 Infrastructure 2-173
2.11.3 Geology 2-177
2.11.4 Hydrology 2-178
2.11.5 Vadose Zone Conditions 2-179
2.11.6 Unconfined Aquifer Conditions 2-187
2.11.7 Reference Case Source Terms 2-189

2.12 DESCRIPTION OF WASTE MANAGEMENT AREA A-AX 2-195
2.12.1 Background 2-195
2.12.2 Infrastructure 2-197
2.12.3 Geology 2-200
2.12.4 Hydrology 2-201
2.12.5 Vadose Zone Conditions 2-202
2.12.6 Unconfined Aquifer Conditions 2-205
2.12.7 Reference Case Source Terms 2-209

2.13 REFERENCES 2-212

FIGURES

Figure 2-1. Hanford Site and Surrounding Area 2-2
Figure 2-2. Location of the Single-Shell and Double-Shell Tank Farms within the 200 Areas 2-6
Figure 2-3. Population Centers within an 80-km Radius of the Hanford Site 2-9
Figure 2-4. Risk Framework for the Hanford Central Plateau 2-14
Figure 2-5. Geologic Elements of the Pasco Basin Portion of the Columbia Basin, Washington 2-20
Figure 2-6. Geologic Setting of the Columbia Basin and Pasco Basin 2-21
Figure 2-7. Flood in the South of the Hanford Site, Washington, between 18,000 to 13,000 Years Ago 2-23
Figure 2-8. Geologic Structures of the Pasco Basin and Vicinity 2-24
Figure 2-9. Generalized Stratigraphy of the Pasco Basin and Vicinity 2-25
Figure 2-10. Isopach Map of the Ice Age Flood Deposits (Hanford formation) 2-28
Figure 2-11. Cross-Section Running from the Rattlesnake Mountains through the 200 Areas and out to the Columbia River 2-30
Figure 2-12. Hydrogeologic Units Present at the Water Table in June 1998 2-31
Figure 2-13. Topography of the 200 Areas Central Plateau 2-33
Figure 2-14. Historical Earthquake Activity of the Columbia Basin, Washington, and Surrounding Areas 2-35
Figure 2-15. Surface Water Features including Rivers, Ponds, Major Springs, and Ephemeral Streams on the Hanford Site, Washington 2-37
Figure 2-16. Water Table Elevations in Meters and Inferred Groundwater Flow Directions for the Unconfined Aquifer at Hanford, Washington, March 2003 2-44
Figure 2-17. Hindcast Water Table Map of the Hanford Site, January 1944 2-45
Figure 2-18. Discharge History for the 216-T Pond and the 216-U Pond 2-46
Figure 2-19. Discharge History for the 216-B Pond and the Gable Mountain Pond 2-47
Figure 2-20. Distribution of Radionuclides in Groundwater on the Hanford Site, Washington, at Concentrations above the Maximum Contaminant Level or Interim Drinking Water Standard during Fiscal Year 2003 2-52
Figure 2-21. Distribution of Hazardous Chemicals in Groundwater on the Hanford Site, Washington, at Concentrations above the Maximum Contaminant Level or Interim Drinking Water Standard during Fiscal Year 2003 2-53
Figure 2-22. Hanford Site Map and Location in Washington State 2-55
Figure 2-23. Facilities in the 200 East and 200 West Areas 2-56
Figure 2-24. Tank Infrastructure at Waste Management Area C 2-57

Figure 2-25. Typical Single-Shell Tank 2-58
Figure 2-26. Bare Concrete Single-Shell Tank Dome 2-59
Figure 2-27. Transition from Tank Base to Vertical Wall (BX Tank Farm) 2-59
Figure 2-28. Flat Bottom and Butt Weld Joint, AX Tank Farm Construction 2-60
Figure 2-29. 200-Series Single-Shell Tank 2-61
Figure 2-30. 244-CR Waste Vault 2-62
Figure 2-31. Diversion Box with Fixed Jumpers 2-64
Figure 2-32. Waste Transfer Pipelines, BX Tank Farm, circa 1948 2-65
Figure 2-33. Location Map of Waste Management Area S-SX and Surrounding Facilities 2-76
Figure 2-34. Typical Configuration and Dimensions of Single-Shell Tanks in Waste Management Area S-SX 2-80
Figure 2-35. Fence Diagram Showing Cross-Sections through Waste Management Area S-SX 2-82
Figure 2-36. Vadose Zone Monitoring Network for S Tank Farm in Waste Management Area S-SX 2-84
Figure 2-37. Vadose Zone Monitoring Network for SX Tank Farm in Waste Management Area S-SX 2-85
Figure 2-38. Three-Dimensional Perspective of S Tank Farm Tanks and Drywells Showing Occurrence of Significant (>5 pCi/g) Cesium-137 Contamination in the Vadose Zone 2-87
Figure 2-39. Three-Dimensional Perspective of SX Tank Farm Tanks and Drywells Showing Occurrence of Significant (>10 pCi/g) Cesium-137 Contamination in the Vadose Zone 2-88
Figure 2-40. Average Nitrate Concentrations at Waste Management Area S-SX, Top of Unconfined Aquifer 2-91
Figure 2-41. Average Technetium-99 Concentrations at Waste Management Area S-SX, Top of Unconfined Aquifer 2-92
Figure 2-42. Technetium-99, Chromium, and Nitrate Concentrations East of the S Tank Farm 2-93
Figure 2-43. Technetium-99 Concentrations at Waste Management Area S-SX 2-93
Figure 2-44. Location Map of Waste Management Area T and Surrounding Facilities 2-99
Figure 2-45. Typical Configuration and Dimensions of Single-Shell Tanks in Waste Management Area T 2-102
Figure 2-46. Fence Diagram Showing Cross-Sections through Waste Management Areas T and TX-TY 2-104
Figure 2-47. Vadose Zone Monitoring Network for Waste Management Area T 2-106

Figure 2-48. Three-Dimensional Perspective of Waste Management Area T Tanks and Drywells Showing Occurrence of Significant (>10 pCi/g) Cesium-137 Contamination in the Vadose Zone 2-108

Figure 2-49. Technetium-99 Distribution in Groundwater at Waste Management Area T 2-111

Figure 2-50. Location Map of TX and TY Tank Farms and Surrounding Facilities 2-117

Figure 2-51. Typical Configuration and Dimensions of Single-Shell Tanks in Waste Management Areas T and TX-TY 2-121

Figure 2-52. Fence Diagram Showing Cross-Sections through Waste Management Areas T and TX-TY 2-122

Figure 2-53. Vadose Zone Monitoring Network for TX Tank Farm in Waste Management Area TX-TY 2-125

Figure 2-54. Vadose Zone Monitoring Network for TY Tank Farm in Waste Management Area TX-TY 2-126

Figure 2-55. Three-Dimensional Perspective of TX Tank Farm Tanks and Drywells Showing Occurrence of Significant (>5 pCi/g) Cesium-137 Contamination in the Vadose Zone 2-128

Figure 2-56. Three-Dimensional Perspective of TX Tank Farm Tanks and Drywells Showing Occurrence of Significant (>5 pCi/g) Cesium-137 Contamination in the Vadose Zone 2-129

Figure 2-57. Location Map of U Tank Farm and Surrounding Facilities 2-137

Figure 2-58. Typical Configuration and Dimensions of Single-Shell Tanks in Waste Management Area U 2-140

Figure 2-59. Fence Diagram Showing Cross-Sections through Waste Management Area U 2-142

Figure 2-60. Vadose Zone Monitoring Network for Waste Management Area U 2-144

Figure 2-61. Three-Dimensional Perspective of Waste Management Area U Tanks and Drywells Showing Occurrence of Significant (>10 pCi/g) Cesium-137 Contamination in the Vadose Zone 2-146

Figure 2-62. Tank U-104 Uranium Plume in Waste Management Area U 2-147

Figure 2-63. Location Map of C Tank Farm and Surrounding Facilities 2-154

Figure 2-64. Typical Configuration and Dimensions of Single-Shell Tanks in Waste Management Area C 2-158

Figure 2-65. Fence Diagram Showing Cross-Sections through Waste Management Areas A-AX and C 2-159

Figure 2-66. Vadose Zone Monitoring Network for Waste Management Area C 2-161

Figure 2-67. 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 2-163

Figure 2-68. Technetium-99 Concentrations Compared to Nitrate Concentrations for Upgradient Well 299-E27-7 at Waste Management Area C 2-165

Figure 2-69. General Configuration of Waste Management Area B-BX-BY 2-171

Figure 2-70. Typical Configuration and Dimensions of Single-Shell Tanks in Waste Management Area B-BX-BY 2-176

Figure 2-71. Fence Diagram Showing Cross-Sections through Waste Management Area B-BX-BY 2-178

Figure 2-72. Vadose Zone Monitoring System for the B Tank Farm within Waste Management Area B-BX-BY 2-180

Figure 2-73. Vadose Zone Monitoring System for the BX Tank Farm within Waste Management Area B-BX-BY 2-181

Figure 2-74. Vadose Zone Monitoring System for the BY Tank Farm within Waste Management Area B-BX-BY 2-182

Figure 2-75. Three-Dimensional Perspective of B Tank Farm Tanks and Drywells Showing Occurrence of Significant (>5 pCi/g) Cesium-137 Contamination in the Vadose Zone 2-184

Figure 2-76. Three-Dimensional Perspective of BX Tank Farm Tanks and Drywells Showing Occurrence of Significant (>5 pCi/g) Cesium-137 Contamination in the Vadose Zone 2-185

Figure 2-77. Three-Dimensional Perspective of BY Tank Farm Tanks and Drywells Showing Occurrence of Significant (>10 pCi/g) Cesium-137 Contamination in the Vadose Zone 2-186

Figure 2-78. Ground Water Monitoring Network for Waste Management Area B-BX-BY [a] 2-188

Figure 2-79. Location Map of Waste Management Area A-AX and Surrounding Facilities 2-196

Figure 2-80. Typical Configuration and Dimensions of Single-Shell Tanks in Waste Management Area A-AX 2-199

Figure 2-81. Fence Diagram Showing Cross-Sections through Waste Management Areas A-AX and C 2-201

Figure 2-82. Vadose Zone Monitoring Network for the A Tank Farm 2-203

Figure 2-83. Vadose Zone Monitoring Network for the AX Tank Farm 2-204

Figure 2-84. Three-Dimensional Perspective of A Tank Farm Tanks and Drywells Showing Occurrence of Significant (>10 pCi/g) Cesium-137 Contamination in the Vadose Zone 2-206

Figure 2-85. Three-Dimensional Perspective of AX Tank Farm Tanks and Drywells Showing Occurrence of Significant (>10 pCi/g) Cesium-137 Contamination in the Vadose Zone 2-207

Figure 2-86. Chromium and Technetium-99 Trends at Well 299-E24-19 2-208

TABLES

Table 2-1. Number of Source Terms Presently within Each Single-Shell Tank Waste Management Area 2-6

Table 2-2. Water Level Changes beneath the 200 West Single-Shell Tank Farms 2-48

Table 2-3. Historic Water Level Changes beneath the 200 East Single-Shell Tank Farms 2-49

Table 2-4. Single-Shell Tank System Post-Closure Inventory Estimates by Source Type 2-68

Table 2-5. Waste Volume Estimates as of November 30, 2004, in Waste Management Area S-SX Single-Shell Tanks 2-77

Table 2-6. Operating Period and Capacities for Waste Management Area S-SX Facilities Included in the Performance Assessment 2-79

Table 2-7. Reference Case Analysis of Waste Management Area S-SX 2-95

Table 2-8. Reference Case Inventory Estimates for Waste Management Area S-SX 2-97

Table 2-9. Waste Volume Estimates as of November 30, 2004, in Waste Management Area T Single-Shell Tanks 2-100

Table 2-10. Operating Period and Capacities for Waste Management Area T Facilities Included in the Performance Assessment 2-101

Table 2-11. Reference Case Analysis of Waste Management Area T 2-113

Table 2-12. Reference Case Inventory Estimates for Waste Management Area T 2-115

Table 2-13. Waste Volume Estimates as of November 30, 2004, in Waste Management Area TX-TY Single-Shell Tanks 2-118

Table 2-14. Operating Period and Capacities for Waste Management Area TX-TY Facilities Included in the Performance Assessment 2-119

Table 2-15. Reference Case Analysis of Waste Management Area TX-TY 2-133

Table 2-16. Reference Case Inventory Estimates for Waste Management Area TX-TY 2-135

Table 2-17. Waste Volume Estimates as of November 30, 2004, in Waste Management Area U Single-Shell Tanks 2-138

Table 2-18. Operating Period and Capacities for Waste Management Area U Facilities Included in the Performance Assessment 2-139

Table 2-19. Reference Case Analysis of Waste Management Area U 2-150

Table 2-20. Reference Case Inventory Estimates for Waste Management Area U 2-152

Table 2-21. Waste Volume Estimates as of November 30, 2004, in Waste Management Area C Single-Shell Tanks 2-155

Table 2-22. Operating Period and Capacities for Waste Management Area C Facilities Included in the Performance Assessment 2-156

Table 2-23. Reference Case Analysis of Waste Management Area C 2-167

Table 2-24. Reference Case Inventory Estimates for Waste Management Area C 2-169
Table 2-25. Waste Volume Estimates as of November 30, 2004, in Waste Management Area B-BX-BY Single-Shell Tanks 2-172
Table 2-26. Operating Period and Capacities for Waste Management Area B-BX-BY Facilities Included in the Performance Assessment 2-174
Table 2-27. Reference Case Analysis of Waste Management Area B-BX-BY 2-191
Table 2-28. Reference Case Inventory Estimates for Waste Management Area B-BX-BY 2-194
Table 2-29. Waste Volume Estimates as of November 30, 2004, in Waste Management Area A-AX Single-Shell Tanks 2-197
Table 2-30. Operating Period and Capacities for Waste Management Area A-AX Facilities Included in Performance Assessment 2-198
Table 2-31. Reference Case Analysis of Waste Management Area A-AX 2-210
Table 2-32. Reference Case Inventory Estimates for Waste Management Area A-AX 2-211

2.0 SITE AND WASTE CHARACTERISTICS

2.1 INTRODUCTION

This chapter provides information and data relevant to the DOE Hanford Site (Figure 2-1) environment, disposal facilities, and waste characteristics important to the closure of the SST system. The information provides the basis for the conceptual model of the disposal facility and site, and supports a thorough understanding of the method of analysis. Section 1.7 of this SST PA describes the expected closure condition of the SST system. The focus of this chapter is the description of information relevant to the groundwater pathway.

The contents of each section of this chapter are summarized below:

2.2 **Overview** summarizes the directly modeled aspects of site and waste characteristics to be simulated in the contaminant migration pathway analyses. More extensive descriptions of these characteristics are provided in subsequent sections. Those aspects of site and waste characteristics that are not simulated are also identified, and a rationale for not including them directly in the analysis is provided.

2.3 **Hanford Site Characteristics** discusses the regional and local geography; land use including demography, meteorology and climate, ecology, geology, seismology and volcanology, hydrology, and geochemistry; natural background radiation and contamination values; and past Hanford Site impacts to groundwater.

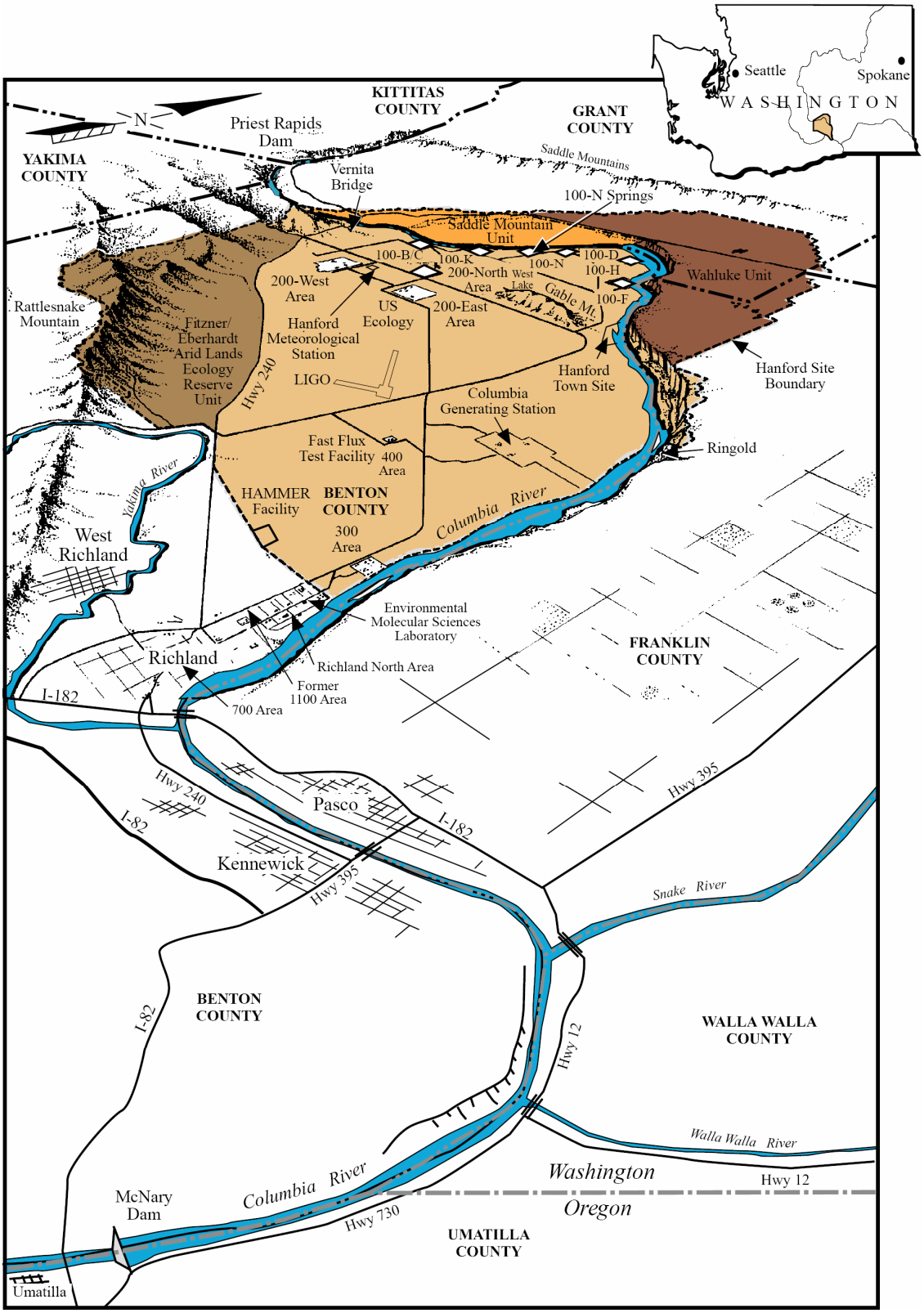
2.4 **Common Facility Description** discusses facilities common to all tank farms (i.e., size and volume of different tanks, ancillary equipment, and operation of the tank farm).

2.5 **Source Term Characteristics** discusses the expected inventory left in the environment after closure, source term characteristics, and source term types.

2.6 through 2.12 **WMA-Specific Information** sections provide site-specific information for each WMA. This information is provided at a summary level. For detailed information, the reader is referred to other documents.

The organization of this chapter was modified from the format given in *Format and Content Guide for U.S. Department of Energy Low-Level Waste Disposal Facility Performance Assessments and Composite Analyses* (DOE 1999d). These modifications were necessary because of the complexity of the residual waste forms, the long operating history of the Hanford Site, and the size of the area over which the tank farms are located. Appendix A provides a crosswalk between this SST PA and the guidance document to ensure the necessary subject matter has been addressed.

Figure 2-1. Hanford Site and Surrounding Area



2.2 OVERVIEW

The closure system for SST farms is a composite of multiple waste sources distributed within a heterogeneous hydrogeology at the Hanford Site (Figure 2-1). This complex system is the medium through which contaminants migrate, and site-specific conditions control contaminant migration. Depending on the migration pathway, features and processes associated with the hydrogeology, meteorology, climatology, and disposed waste affect the contaminant migration process. When contaminants reach the accessible environment, historical and proposed local land use practices indicate the likely activities of a receptor who contacts contamination.

Of the three pathways considered in this SST PA analysis (groundwater, air, and human intrusion) (Figure 1-6), the groundwater pathway is the most complicated because it involves all parts of the closure setting. Migration through the air and intruder pathways is essentially independent of the hydrogeologic, meteorologic, and climatologic part of the system although both pathways are sensitive to the disposed waste configuration, waste inventory, and land use assumptions. Consequently, the focus of this chapter is the description of information relevant to the groundwater pathway.

The significant features and processes affecting contaminant migration are discussed in some detail in the following sections. However, not all aspects of these characteristics can be incorporated into a numerical model that simulates contaminant migration (Chapter 3.0). The detailed discussion below shows that the natural system is inherently heterogeneous on a small scale. Quantification of natural system characteristics below some level and over time is not reasonable. Similarly, at closure, waste will reside within a multicomponent tank waste infrastructure including areas of the vadose zone. Finally, when considering future exposure of humans to contamination, specific exposure scenarios that could occur are dependent on human actions.

Given these realities and the need to establish a workable numerical modeling approach, attention is focused on site-specific, large-scale features and well-accepted treatments of migration processes. A key decision has been made to consider future contaminant migration beginning with conditions that exist at closure rather than from the beginning of waste losses into the subsurface. This decision removes the need to estimate the effects of previous tank waste losses (e.g., chemical and thermal effects) on ambient system conditions that cannot be well quantified. This decision is justified because available historical records and field characterization studies (e.g., Knepp 2002a, 2002b; Myers 2005) indicate that these perturbations were temporary. This information, coupled with planned additional data gathering prior to closure, provides an adequate basis for defining initial post-closure conditions and subsequent contaminant migration conditions. This approach provides useful contaminant migration projections within the constraints of computing capability, and adequacy of the supporting database. Critical information addressed directly in the numerical modeling approach includes the following: hydrogeology, meteorology and climatology, source terms, and land use.

2.2.1 Hydrogeology

The local hydrogeologic features provide the pathway for contaminated groundwater. Three primary geologic units are present in the vadose zone and unconfined aquifer underlying the SST WMAs including the Hanford formation, the Cold Creek unit, and the

Ringold Formation. These units tend to be flat-lying with little dip and relatively uniform in thickness under the WMA areas. The finer scale heterogeneities in each major unit that cannot be accurately mapped and anomalous features (e.g., clastic dikes) are not directly modeled in the reference case analysis (Chapter 3.0). Unit thicknesses are based on field characterization data which show distinct differences between the 200 West and 200 East Area stratigraphy. The stratigraphy underlying WMAs S-SX and C are used to represent 200 West and 200 East Area WMAs, respectively. Additional discussion of the extrapolation approach is provided in Section 3.2.2.4.8. The surface layer created by tank farm construction that currently envelops the tank farm structures is also represented in the modeling analysis.

In the modeling analysis (Chapter 3.0), unique hydrogeologic properties are assigned to each major unit or subunit (no more than three subunits) that represent average values based on numerous laboratory-scale measurements of retrieved soil samples. Different vertical and horizontal properties are assigned (e.g., anisotropic effects) to simulate both lateral and vertical migration of contaminants dissolved in groundwater in the vadose zone.

An extensive series of sequential basalt flows that underlie the sedimentary units of the vadose zone and unconfined aquifer are not modeled beyond defining the top of the basalt as an impermeable lower boundary to the unconfined aquifer. However, the size and extent of the basalt structure is of considerable importance to the modeling approach because it provides regional tectonic stability that eliminates catastrophic local seismic and volcanic activity over the time period of concern (approximately 10,000 years).

Hydrologic properties that are assigned to the unconfined aquifer essentially represent pre-Hanford Site operations conditions. Extensive groundwater monitoring over the last 50 years has shown many transient changes in groundwater characteristics (e.g., water table elevations, hydraulic gradients, general flow paths) caused by intentional discharges of Hanford Site operations wastewater. Currently, groundwater paths under the SST WMAs are gradually returning to pre-Hanford Site conditions because essentially all intentional discharges on site, particularly those affecting local SST WMA areas, have been eliminated. Analysis of the current trends shows that pre-Hanford Site conditions will be present by the time of closure.

2.2.2 Meteorology and Climatology

The geologic structures of the Pacific Northwest region have created a semiarid environment that permits only limited annual rainfall (about 6 in.) that occurs primarily in the winter months. Potential infiltration through the vadose zone and into the unconfined aquifer is further reduced by evapotranspiration processes and the projected installation of surface barriers that promote evapotranspiration. Episodic infiltration is represented by average annual recharge rates that reflect the effectiveness of the local surface cover (e.g., gravel-covered tank operations layers versus engineered surface barriers).

Catastrophic infiltration events such as surface water flooding were not modeled. The geologic record shows that the Columbia River has already migrated over the 200 Areas site and is well away from the WMAs. Also, the WMAs are elevated over 200 ft above the river and even the rupture of the Grand Coulee Dam will not provide flood waters at the elevation of the 200 Areas (Neitzel et al. 2004). The geologic record also indicates the periodicity of ice ages such as those

that created the Hanford formation is greater than the time period of concern. No attempt has been made to model very uncertain major climate change events during the period of analysis.

2.2.3 Source Terms

When the SST WMAs are closed, some tank waste is expected to be present in the subsurface. For the purposes of projecting further contaminant migration and long-term impacts in this analysis, the following source terms were evaluated:

- **Tank residuals following retrieval** (reference case). Inventory remaining with facilities after future retrieval activities is estimated assuming residual waste volumes meet the goal currently defined in the HFFACO (Ecology et al. 1989).
- **Past unplanned releases (UPR) from tanks and ancillary equipment** (reference case). Past release inventory estimates have been studied extensively in recent years (e.g., Knepp 2002a, 2002b). Characterization studies indicate that almost all past leak inventories are currently in the vadose zone (Knepp 2002a, 2002b; Myers 2005).
- **Residues in pipelines and other ancillary equipment** (reference case). Waste remaining in ancillary equipment has not been characterized; however, the inventory associated with this waste is estimated to be comparatively small.
- **Potential retrieval leaks** (sensitivity case). A leak during retrieval leak could potentially occur. This possibility is evaluated as part of the sensitivity analysis.

For the purposes of projecting further contaminant migration and long-term impacts in this analysis, the following source terms were evaluated:

- Tank residuals following retrieval (reference case)
- Past UPRs from tanks and ancillary equipment (reference case)
- Residues in pipelines and other ancillary equipment (reference case)
- Potential retrieval leaks (sensitivity case).

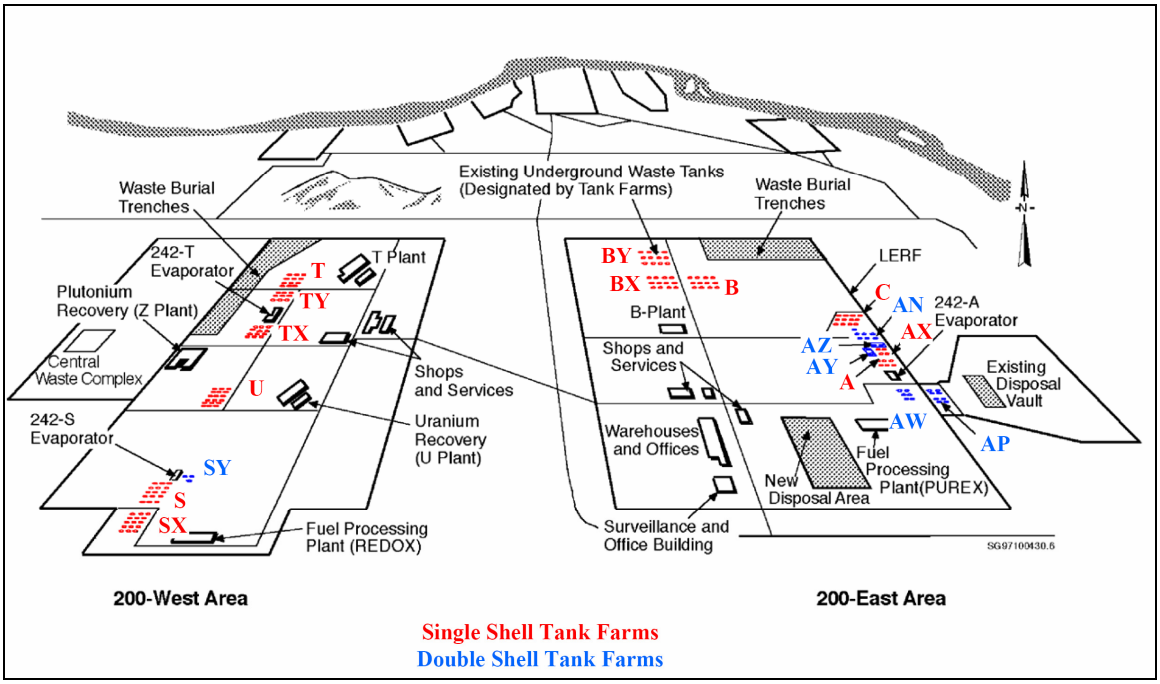
Table 2-1 provides the total number of source terms evaluated at each WMA (Figure 2-2) as part of this SST PA. An inventory of radionuclides and hazardous chemicals must be allocated for each of the source terms listed in Table 2-1. The development of inventory for each of the source terms listed above is provided in Section 2.5.

Table 2-1. Number of Source Terms Presently within Each Single-Shell Tank Waste Management Area [a]

WMA	Tank Residual	Past Tank and Unplanned Releases	Ancillary Equipment and Pipelines
A-AX	100-Series tanks = 10	Past tank leak = 4 UPRs = 0	MUSTs = 2 + pipelines
B-BX-BY	100-Series tanks = 36 200-Series tanks = 4	Past tank leaks = 12 UPRs = 9	MUSTs = 7 + pipelines + BX vault
C	100-Series tanks =12 200-Series tanks = 4	Past tank leaks = 8 UPRs = 4	MUSTs = 1 + pipelines + CR vault
S-SX	100-Series tanks = 27	Past tank leaks = 10 UPRs = 0	MUSTs = 6 + pipelines
T	100-Series tanks =12 200-Series tanks = 4	Past tank leaks = 6 UPRs = 0	MUSTs = 2 + pipelines
TX-TY	100-Series tanks = 24	Past tank leaks = 6 UPRs = 2	MUSTs = 6 + pipelines + TX vault
U	100-Series tanks =12 200-Series tanks = 4	Past tank leaks = 4 UPRs = 2	MUSTs = 2 + pipelines + UR vault
Total	100-Series tanks = 133 200-Series tanks = 16	Past tank leaks = 50 UPRs = 17	MUSTs = 26 + pipelines + vaults
Total Number of Sources		133 + 16 + 50+ 17 + 26 = 242 + pipelines and vaults	

[a] Potential future loses due to hypothetical retrieval leaks are evaluated as part of the sensitivity analysis presented in Chapter 3.0.

Figure 2-2. Location of the Single-Shell and Double-Shell Tank Farms within the 200 Areas



2.2.4 Land Use

Selection of human activity scenarios that lead to exposure to waste contaminants are based on traditional land use. On the Hanford Plateau where the SST WMAs are located, archeological and historical records indicate essentially no extended land use, primarily because water has been neither easily accessible (approximately 200 ft to the water table) nor plentiful (the unconfined aquifer is not productive). Contaminated waste zones (soils and groundwater) are currently well isolated from the public and will not be accessible during periods of active institutional control. Thus, when considering future land use, either some industrial use or subsistence farming that require minimal groundwater use are the only plausible uses considered as exposure scenarios. Either of these options is not expected to occur for at least 300 years after closure.

The remainder of this chapter provides a detailed summary of the site characteristics that describe the system with an emphasis on highlighting those features that are important to this analysis. However, this chapter can only provide a summary level of the available data because of the long operating history of the site. Each subsection of this chapter provides references to documents containing additional detail.

2.3 HANFORD SITE CHARACTERISTICS

The purpose of this section is to present the Hanford Site characteristics that are sufficient to support the analysis presented in Chapters 3.0 through 6.0. This section provides the following information: site geography, demography, land use plans, meteorology, ecology, geology, seismology, volcanology, surface water and groundwater hydrology, geochemistry, geologic resources, water resources, and natural background radiation.

2.3.1 Geography and Demography

This section describes the geography and demography of the Hanford Site, including use of adjacent lands, the current population database, area socioeconomics, 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* (DOE 1999b). This information is used to help set the exposure scenarios for risk assessments and to select the appropriate dosimetry parameters. The site-specific information for each individual WMA is provided in Sections 2.6 through 2.12. Additional information on the geography and demography of the site can be found in Neitzel et al. (2004).

2.3.1.1 Geography of the Hanford Site

The Hanford Site lies within the semiarid Pasco Basin of the Columbia Plateau in southeastern Washington State (Figure 2-1) and occupies an area of approximately 586 mi^2 located north of the city of Richland. It 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.

The Columbia River flows eastward through the northern part of the Hanford Site and then turns south, forming part of the eastern site boundary. 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 about 160 km (100 mi) to the west, have an important effect on the climate of the area (Section 2.3.2).

As a plutonium-production complex with nine nuclear reactors and associated processing facilities, the Hanford Site played a pivotal role in the production of materials for the defense of the nation for more than 40 years, beginning in the 1940s with the Manhattan Project. The site has restricted public access, and its large land area provides a buffer for the smaller areas on the site that historically were used for production of nuclear materials, waste storage, and waste disposal.

In June 2000, the 195,000-acre Hanford Reach National Monument was established by a Presidential proclamation (65 FR 37253) to protect the nation's only unimpounded stretch of the Columbia River above Bonneville Dam and the largest remnant of the shrub-steppe ecosystem once blanketing 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 approximately 258 mi^2. These included: 1) the Fitzner/Eberhardt Arid Lands Ecology Reserve Unit, a 120-mi^2 tract of land in the southwestern portion of the Hanford Site; 2) the Saddle Mountain Unit, a 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 87-mi^2 tract of land located north and east of both the Columbia River and the Saddle Mountain Unit.

Approximately 400 acres along the north side of the Columbia River, west of the Vernita Bridge, and south of State Highway 243, are managed by the Washington State Department of Fish and Wildlife. These lands have served as a safety and security buffer zone for Hanford Site operations since 1943.

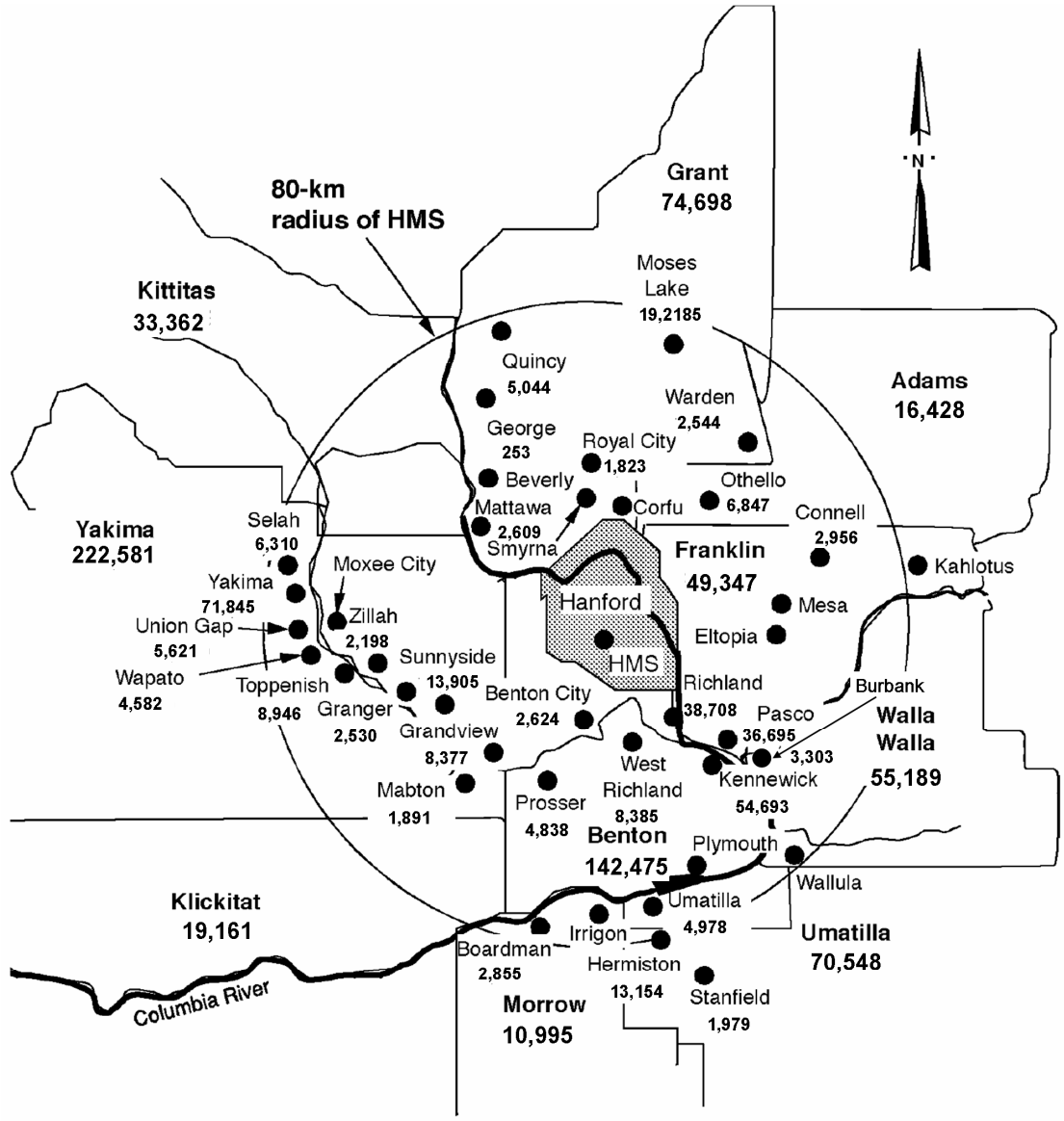
The portion of the monument administered only by DOE included the McGee Ranch/Riverlands Unit (north and west of State Highway 24 and south of the Columbia River), the Columbia River islands in Benton County, the Columbia River corridor (one-quarter mile inland from the shoreline) on the Benton County side of the Columbia River, and the sand dunes area located along the Hanford Site side of the Columbia River north of the Energy Northwest facilities.

2.3.1.2 Population Distribution

The major population centers within 80 km (50 mi) of the Hanford Site are identified in Figure 2-3, along with populations based on the 2000 Census (OFM 2002) estimates. This radius is centered on the Hanford Meteorological Station (HMS), located between the 200 East and 200 West Areas. The Tri-Cities (i.e., Richland, Kennewick, and Pasco), southeast of the site, is the largest population center close to the Hanford Site. Other major population centers are Yakima (including other Yakima Valley towns) and Moses Lake in Washington to the west and north, respectively, and Umatilla and Hermiston in Oregon to the south. The cities of Ellensburg and Walla Walla, Washington, lie just beyond the 80-km (50-mi) radius. 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.

An estimated total of 147,600 people lived in Benton County and 51,300 lived in Franklin County during 2002, for a total of 198,900, which is an almost 4% increase from 2000 (OFM 2002). According to the 2000 Census, population totals for Benton and Franklin counties were 142,475 and 49,347, respectively (OFM 2002). Both Benton and Franklin counties grew at a faster pace than Washington State as a whole in the 1990s. The population of Benton County grew 26.6%, up from 112,560 in 1990. The population of Franklin County grew by 31.7%, up from 37,473 in 1990 (OFM 2002).

Figure 2-3. Population Centers within an 80-km Radius of the Hanford Site



Note: If population not listed, less than 1,000

HMS = Hanford Meteorological Station

Populations shown are based on 2000 census (OFM 2002).

The distribution of the Tri-Cities population by city is as follows: Richland, 40,150; Pasco, 34,630; and Kennewick, 56,280. The combined populations of Benton City, Prosser, and West Richland totaled 16,560 during 2001. The unincorporated population of Benton County was 34,610. In Franklin County, incorporated areas other than Pasco had a total population of 3,755. The unincorporated population of Franklin County was 12,915 (OFM 2002). Neitzel et al. (2004) provides further information concerning the demographics surrounding the Hanford Site.

2.3.1.3 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. Also included is guidance given by the Hanford Advisory Board (HAB) Advice 132 Response, "Exposure Scenarios Task Force on the 200 Area" (Martin 2002), which recommends the exposure scenarios and risk framework to be used in the 200 Areas for the HFFACO (Ecology et al. 1989)

2.3.1.3.1 Socioeconomics. The major employers in the Tri-Cities area since 1970 have been DOE and the Hanford Site contractors; Energy Northwest (formerly the Washington Public Power Supply System), which operates a nuclear power plant north of Richland; agriculture; and a large food-processing industry; plus several smaller industrial operations. Other than DOE activities, agriculture and food processing are the dominant industries. The socioeconomics of the area surrounding the Hanford Site are more fully described in Section 4.6 of Neitzel et al. (2004).

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 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 also used for recreation and hydroelectric power production for the western United States, and is a primary salmon spawning ground.

2.3.1.3.2 Past and Present DOE Activities at the Hanford Site. In 1943, the U.S. Army Corps of Engineers created the Hanford Site from small farming areas along the Columbia River to locate facilities used to produce nuclear weapon materials for World War II (Gerber 1992). Since then, the major activities on the Hanford Site have been controlled by DOE and its predecessors, the U.S. Atomic Energy Commission (1945 through 1975) and the Energy and Research Development Administration (1975 through 1976). Current major programs at the Hanford Site are dedicated to waste management, environmental restoration, long-term stewardship, and research and development.

DOE nuclear facilities occupy about 6% of the total available area of the site. The major operating areas, as shown in Figure 2-1, are identified by numbers: 100 Areas, 200 Areas, 300 Area, and 400 Area. The activities conducted in these areas are described in the following paragraphs.

100 Areas. The 100 Areas, directly bordering the Columbia River (Figure 2-1), contain nine graphite-moderated plutonium production reactors, eight of which were shut down by the early 1970s. The ninth is the N Reactor, the first dual-purpose reactor built in the United States. N Reactor began operating in 1963 and was shut down in 1986.

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 the Fast Flux Test Facility (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 (Figure 2-1). The following major facilities, many of which are inactive, are located in the 200 Areas (Figure 2-2):

- Burial trenches, burial grounds, low-level waste burial grounds
- 18 underground storage tank farms (A, AN, AP, AW, AX, AY, AZ, B, BX, BY, C, S, SX, SY, T, TX, TY, and U tank farms)
- Very large fuel processing and recovery facilities (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 ERDF (Figure 2-1). 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.

400 Area. FFTF is located in the 400 Area. This facility contains a liquid-metal cooled fast reactor previously used for testing breeder reactor fuels, materials, and components. FFTF operated from 1982 until 1992. Energy Northwest leases a 4.4-km^2 (1.7-mi^2) parcel northeast of the 400 Area for a commercial nuclear power reactor. The Columbia Generating Station, a boiling-water reactor, currently is the only operating nuclear reactor on the Hanford Site.

300 Area. Originally, the 300 Area was dedicated to fabricating fuel for Hanford Site reactors. Now, the 300 Area laboratories constructed over the last 30 years are used for research programs. Accelerated deactivation in the 300 Area focuses on several 300 Area buildings and structures that date back to 1943. It includes fuel supply facilities that were used to support the manufacturing of nuclear fuel for the Hanford Site reactors.

2.3.1.4 Future Hanford Land Use

In 1992, DOE, EPA, and Ecology gathered a group of stakeholders to study potential future uses for the Hanford Site land. This HFSUWG issued a summary (HFSUWG 1992a) and a detailed report (HFSUWG 1992b) of its findings. The *Final Hanford Comprehensive Land-Use Plan Environmental Impact Statement* (DOE 1999b) 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 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 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 record of decision (64 FR 61615) for the *Final Hanford Comprehensive Land-Use Plan Environmental Impact Statement* (DOE 1999b) identifies near-term land uses for the Hanford Site. The record of decision 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 in lands at the northern and western

edges of the site (65 FR 37253). However, no formal land use planning is expected to be accurate over the thousands of years covered in this SST PA.

2.3.1.4.1 Central Plateau Risk Framework. DOE, EPA, and Ecology initiated the development of a Central Plateau risk framework in October 2001. The product of this effort provides a basis for making cleanup decisions in the Central Plateau and will be considered as future HFFACO (Ecology et al. 1989) milestones are developed. Through a series of technical workshops attended by representatives from all the Central Plateau programs and regulators, initial agreements were made on the basic assumptions for the risk framework. Salient points of the risk framework description include the following items:

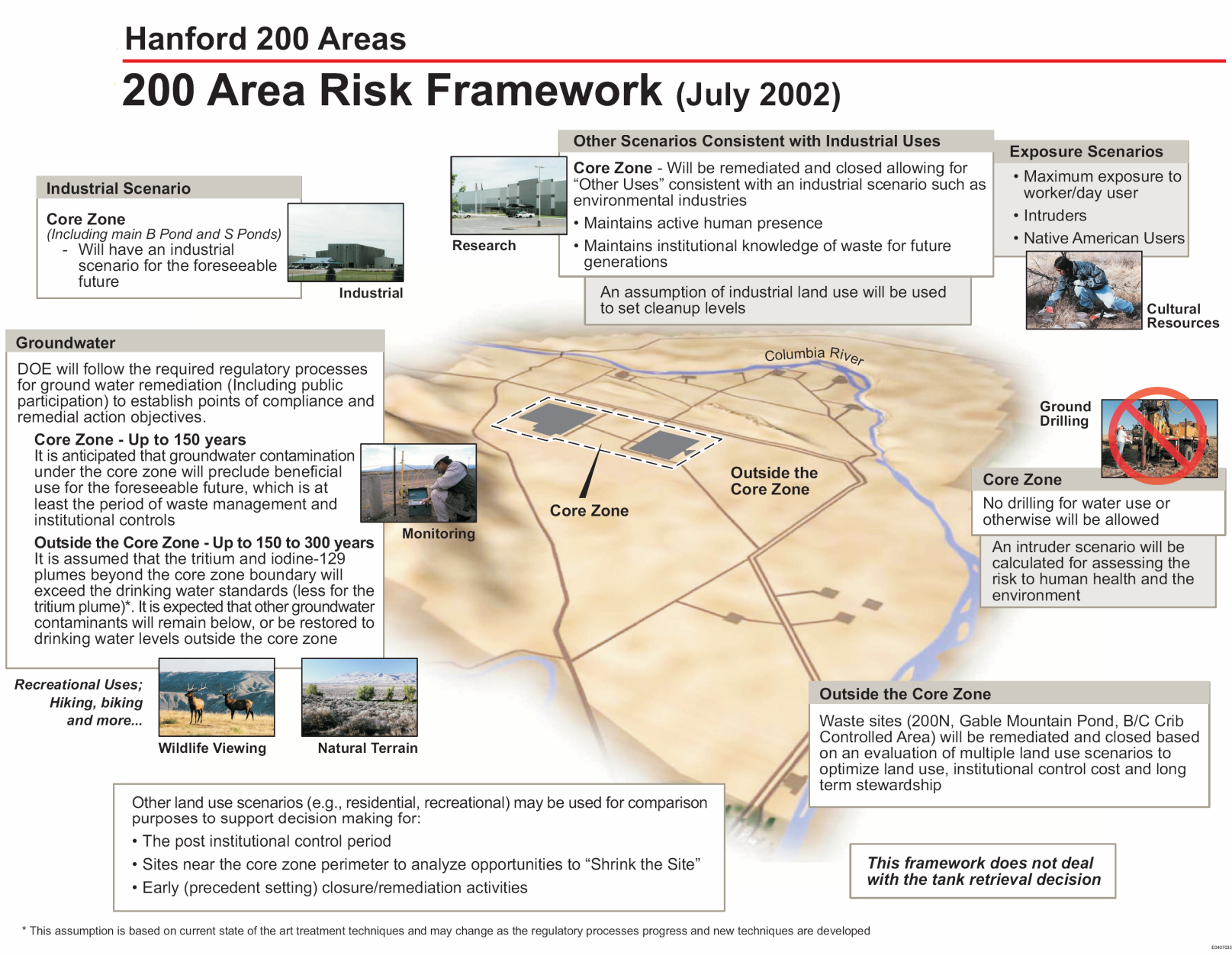
- The 200 Areas, including B Pond (main pond) and S Ponds, will have an industrial scenario for the foreseeable future (Figure 2-4)
- Waste sites outside the 200 Areas but within the Central Plateau (200-N, Gable Mountain Pond, B/C Crib Controlled Area) will be remediated and closed based on an evaluation of multiple land use scenarios to optimize land use, institutional control cost, and long-term stewardship
- Other land use scenarios (e.g., residential, recreational) may be used for comparison purposes to support decision-making for the following:
  - Post-active institutional controls period
  - Sites near the 200 Areas perimeter to analyze opportunities to “shrink the site”
  - Early (precedent-setting) closure/remediation decisions.

This framework does not address tank waste retrieval decisions.

This risk framework was developed subsequent to the Comprehensive Land-Use Plan (CLUP) DOE (1999b) and is not completely consistent with the land uses envisioned in the CLUP and the likely allowable land uses included in the comprehensive conservation plan being developed for the Hanford Reach National Monument.

In the future, activities at the Hanford Site will be concentrated at the Central Plateau. The associated buffer zone, required for safety purposes, that presently extends to the Columbia River, should shrink back to the Central Plateau boundary over time. Three hundred years has been identified as the reasonable time period to change from active control to passive control outside the Central Plateau (Martin 2002).

Figure 2-4. Risk Framework for the Hanford Central Plateau



2.3.2 Meteorology and Climatology

Local and regional climate patterns and expected future conditions must be considered when estimating the effect of water on the closure system. Both total precipitation and seasonal frequency are important. Potential long-term climatic conditions must be projected to evaluate future climate changes that might cause higher precipitation rates or glaciation. Climate also affects the potential for flooding. The information in this section is a summary; additional detail can be found in the annual climatological data summary reports, which have been issued each year since 1993. The most recent is *Hanford Site Climatological Data Summary 2003 with Historical Data* (Hoitink et al. 2004). Additional information can be found in Neitzel et al. (2004).

2.3.2.1 Overview

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 nighttime cooling. Summers are warm and dry with abundant sunshine. Daytime high temperatures in June, July, and August can exceed 40°C. Winters are cool with occasional precipitation that makes up about 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. Overcast skies and fog occur during the fall and winter months.

The Cascade Mountain Range greatly affects the temperature, wind, and precipitation in the region. Air masses that reach the Pasco Basin are changed as they pass over the region's relatively complex topography of the region. The mountains limit the maritime influence of the Pacific Ocean, making the climate of Eastern Washington drier and with greater temperature extremes than the coastal region. In addition to this rain shadow effect, the Cascade Mountains are a source of cold air drainage, which has a considerable effect on the wind regime of the site.

2.3.2.2 Current Data

Climatological data are available from the HMS, located between the 200 East and 200 West Areas at about 215 m elevation (Figure 2-2). Data have been collected at this location since 1945. Temperature and precipitation data also are available from nearby locations for the period from 1912 through 1943. Data from the HMS are representative of the general climatic conditions for the region and describe the specific climate of the 200 Areas.

Daily maximum temperatures vary from a normal maximum of 2°C in late December and early January to 35°C in late July. On the average, 52 days during the summer months have maximum temperatures of 32°C or higher and 12 days with maxima of 38°C or higher. From mid November through early March, minimum temperatures average ≤0°C, with the minima in late December and early January averaging –6°C. During the winter, on average, 3 days have minimum temperatures of –18°C or lower; however, only about one winter in two experiences such temperatures. The record maximum temperature is 45°C, and the record minimum temperature is –31°C. The highest winter monthly average temperature at the HMS was 6.9°C in February 1958, while the record lowest average temperature was –11.1°C during

January 1950. The record maximum summer monthly average temperature was 27.9°C in July 1985, while the record lowest average temperature was 17.2°C in June 1953.

Between 1946 and 1998, annual precipitation at the HMS averaged 16 cm and varied between 7.6 cm and 31.3 cm. The wettest season on record was the winter of 1996–1997 with 141 mm of precipitation; the driest season was the summer of 1973 when only 1 mm of precipitation was measured. Most precipitation occurs during the winter, with more than half of the annual amount occurring from November through February. Days with more than 13 mm precipitation occur on average less than once each year. Rainfall intensities of 13 mm/hr persisting for 1 hour are expected once every 10 years. Rainfall intensities of 25 mm/hr for 1 hour are expected only once every 500 years.

About 38% of the precipitation during December through February falls as snow. Winter monthly average snowfall ranges from 0.8 cm in March to 13.5 cm in January. Only one winter in four is expected to accumulate as much as 15 cm of snow on the ground. During these winters, 4 days, on average, have 15.2 cm or more of snow on the ground. However, the 1964–1965 winter had 35 days with snow on the ground, 32 of which were consecutive. That winter also provided one of the deepest accumulations, with 31 cm of snow occurring in December 1964. The record accumulation of snow is 62.2 cm in February 1916.

Prevailing wind direction on the 200 Area plateau is from the northwest in all months of the year. Secondary maxima occur for southwesterly winds. Summaries of wind direction indicate that winds from the northwest quadrant occur most often during the winter and summer. During the spring and fall, the frequency of southwesterly winds increases with a corresponding decrease in northwest flow. Winds blowing from other directions (e.g., northeast) display minimal variation from month to month. Monthly average wind speeds are lowest during the winter months, averaging 10 to 11 km/hr, and highest during the summer, averaging 13 to 15 km/hr. Wind speeds that are well above average are usually associated with southwesterly winds. However, the summertime drainage winds are generally northwesterly and frequently reach 50 km/hr. These winds are most prevalent over the northern portion of the Hanford Site.

This climate profile suggests opportunities for moisture infiltration or recharge. This infiltration is centered around the frequency of precipitation during the winter months when evaporation is low and plant uptake and transpiration are minimal.

2.3.2.3 Historical Data

Historical climate data can provide insights into how future and current climate patterns may differ. Information exists on climate for the past few centuries and, in less detail, for the last 10,000 years.

Cropper et al. (1986) derived a 360-year regional reconstruction of seasonal and annual variations in temperature and precipitation from statistical relationships between meteorological records from Columbia Basin stations and tree ring data from western North America. They calibrated the relationship between Columbia Basin weather records and a network of 65 tree ring chronologies. The results suggest that the average temperature of the Columbia Basin for the past three centuries was slightly higher by 0.09°C and more variable (4% higher standard deviation) than in the twentieth century. The increase was primarily attributed to

warmer winters. This reconstruction also suggests that the past three centuries were wetter on the average by 0.8 cm, primarily in the autumn. Furthermore, droughts were apparently more frequent starting in the second half of the seventeenth century and lasted longer than twentieth century droughts. Gramulich (1987) also used multiple regression models to reconstruct precipitation in the Pacific Northwest. The results indicate that the average precipitation in the eighteenth and nineteenth centuries was the same as the average precipitation in the twentieth century.

Chatters (1991) and Chatters and Hoover (1992) summarized proxy evidence for climatic change in the Columbia Basin for the past 10,000 to 13,000 years. They identify an environment for about 13,000 years ago that was kept cool and dry by masses of ice and glacial meltwater, supporting a mosaic of isolated plant and animal communities. This was followed between 10,000 and 8,500 years ago by a period of warmer than modern summers, colder than modern winters, and low, but spring-dominant, precipitation. This climate supported extensive grasslands and their associated fauna. By 8,000 years ago, summers and winters were both relatively warm, and precipitation was at least 33% below current levels. This climate pattern resulted in reduced stream flows, with late spring flow maxima, and extensive development of shrub-steppe vegetation throughout most of the region. Between 4,500 and 3,900 years ago, the climate evolved to wetter and cooler conditions. Rivers flooded frequently and forests expanded into steppe zones. From 3,900 to 2,400 years ago, the climate was cool in the summer and cold in the winter, with winter-dominant precipitation at least 30% above current levels. Warmer, drier conditions returned between 2,400 and 2,000 years ago, reducing vegetation density and renewing flooding.

2.3.2.4 Long-Range Forecasts

Climatologists universally accept that global climates have undergone significant variation in the past and that such natural variations are expected to continue into the future. Berger et al. (1991) reviewed seven models of different complexity developed to predict the global climate for the next 10,000 to 100,000 years. All the models are in relatively good agreement. Without human disturbances, the long-term cooling trend that began some 6,000 years ago is expected to continue for the next 5,000 years. This trend should be followed by a stabilization at about 15,000 years, a cold interval centered at approximately 25,000 years, and finally a major glaciation at about 55,000 years. Although human disturbances (such as the green-house effect) could occur, their main effect will be to delay the onset of these trends.

2.3.2.5 Severe Weather

Severe weather events are not significant to the Hanford Site. According to the records of the HMS and the National Severe Storms Forecast Center database, only 24 separate tornados have occurred between 1916 to 1994 within 160 km (100 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 9.6×10^{-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 greatest peak wind gust was 130 km/hr, recorded at 15 m above ground level at the HMS.

Extrapolations based on 35 years of observation indicate a return period of about 200 years for a peak gust in excess of 145 km/hr at 15 m above ground level.

2.3.2.6 Climate Summary

The analyses of present and future climatic conditions at the Hanford Site and in the surrounding region suggest that conditions similar to the current climate will prevail for at least 10,000 years and probably considerably longer. However, because of the uncertainty inherent in any analysis of climate, wetter conditions and associated higher recharge or infiltration rates also will be considered.

2.3.3 Ecology

The information in this section is taken from Section 4.4 of Neitzel et al. (2004). This section summarizes the ecology of the Hanford Site, emphasizing 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 groundwater recharge, which is greatly influenced by surface vegetation and burrowing.

Neitzel et al. (2004) details both the terrestrial and aquatic ecology of the Hanford Site and presents extensive listings of plant and animal species. This section considers only terrestrial ecological effects because all SSTs are not located near significant aquatic ecological systems.

The Hanford Site consists of mostly undeveloped land. Chemical processing facilities, shutdown nuclear reactors, and supporting facilities occupy only about 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. Such ecosystems are typically dominated by a shrub overstory with a grass understory. In the early 1800s, dominant plants in the area were big sagebrush (*Artemisia tridentata*) and an understory consisting of perennial Sandberg's bluegrass (*Poa sandbergii*) and bluebunch wheatgrass (*Pseudoregneria spicata*). Other species included threetip sagebrush, bitterbrush, gray rabbitbrush, spiny hopsage, bluebunch wheatgrass, needle-and-thread grass, Indian rice grass, and prairie June grass.

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. The dominant non-native species, cheatgrass, is an aggressive colonizer and has become well-established across the site. Over the past decade, several knapweed species also have become persistent invasive species in areas not dominated by shrubs.

Range fires that historically burned through the area during the dry summers eliminate fire-intolerant species (e.g., big sagebrush) and allow more opportunistic and fire-resistant species to establish. Of the 590 species of vascular plants recorded for the Hanford Site,

approximately 20% are non-native. Wildfires are frequent on the Hanford Site. Three large wildfires in the past two decades have burned over 15% of the site.

All WMAs in the tank farm system are actively managed to prevent vegetation, insects, and wildlife from using the WMA as habitat. 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. Neitzel et al. (2004) provides a more complete description of the plant, insect, and animal life outside the WMAs.

2.3.4 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. As part of this SST PA, a geologic data package (Reidel et al. 2006) was prepared that describes the geology, hydrology, and geochemistry of the region, site, and WMAs. 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 under the watchful eye of one or more regulatory agencies and stakeholder groups including the NRC, the National Academy of Science, the 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.

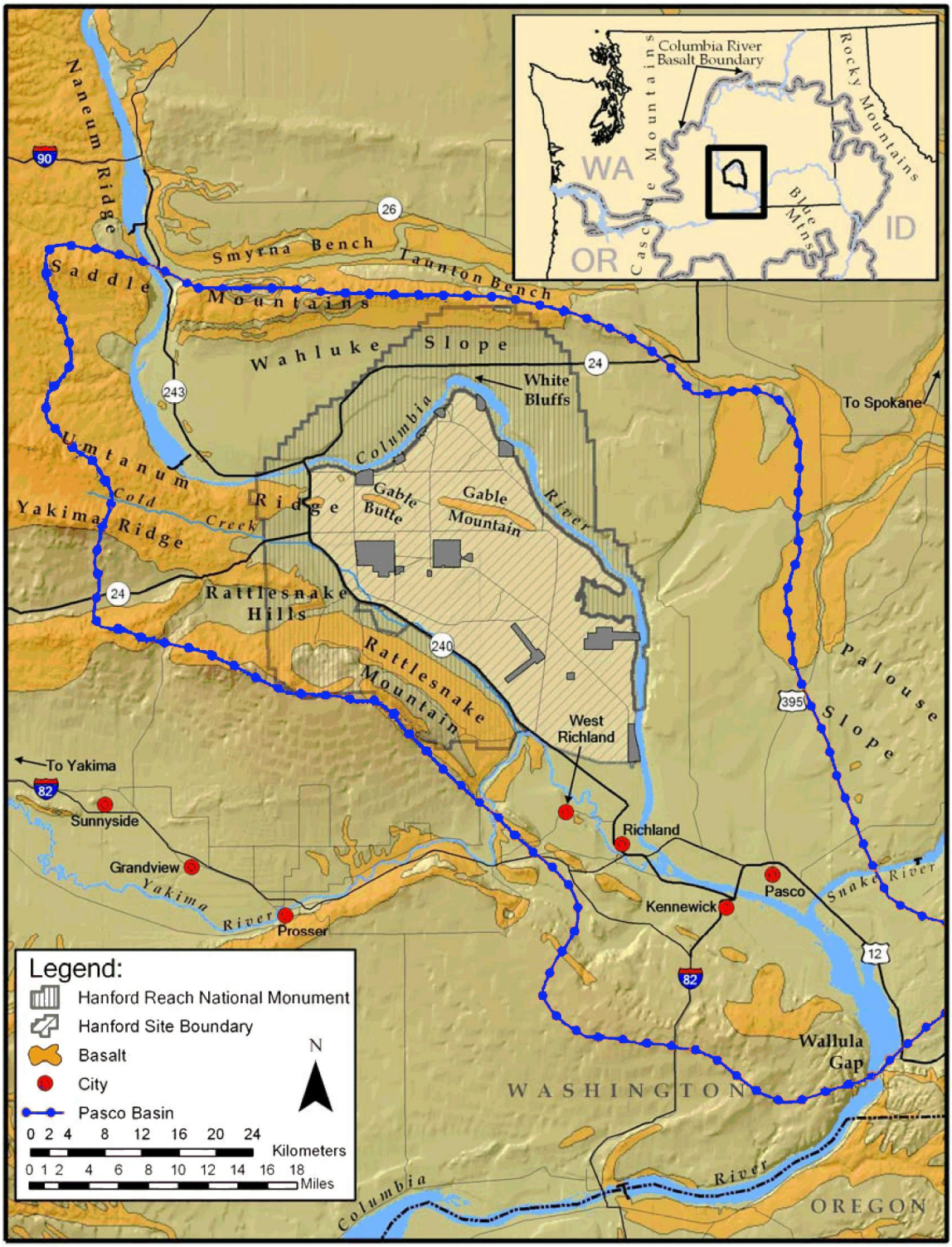
Section 2.3.4 provides a summary of the data in Reidel et al. (2006) highlighting those aspects that are important to developing the conceptual model describing transport of contaminants away from the waste facility to a receptor. For additional information relating to geology, hydrology, and geochemistry of the Hanford Site, see Reidel et al. (2006). Additionally, because there are seven different SST waste management units, the general geology of the Hanford Site is described in this section. Descriptions of the geology underlying each of the WMAs are given in Sections 2.6 through 2.12.

2.3.4.1 Regional Geology

The Hanford Site contains all the main geologic elements of the Columbia Basin (DOE 1988). The Columbia Basin is the area bounded by the Cascade Range to the west, the Rocky Mountains to the northeast, and the Blue Mountains to the southeast (Figure 2-5). Four major geologic processes, occurring over millions of years, formed the soil, rocks, and geologic features (ridges and valleys) of the Columbia Basin and, therefore, the Hanford Site. The area was flooded with numerous basaltic lava flows between 17 and 6 million years ago, followed by tectonic forces that folded the basalt. In this landscape, the ancestral Columbia River meandered across the area leaving behind layers of sediment called the Ringold Formation. About 13,000 years ago, the area was inundated by a series of Ice Age floods (including the

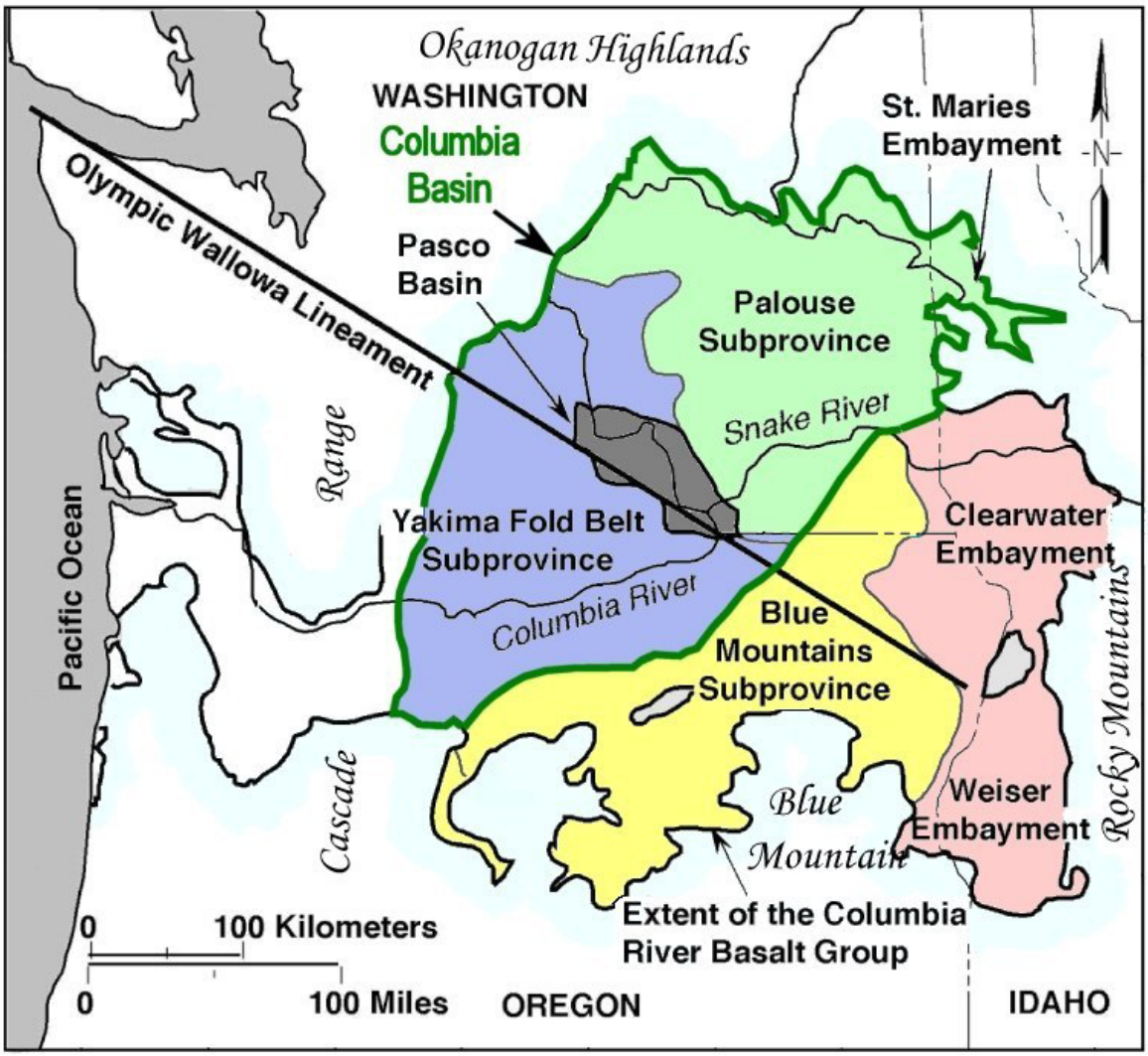
Missoula floods), which deposited more sediment in what is referred to informally as the Hanford formation.

Figure 2-5. Geologic Elements of the Pasco Basin Portion of the Columbia Basin, Washington



2.3.4.1.1 Lava Flows. Lava flows erupted over a period of time from 17 to 6 million years ago. Under the Hanford Site, basaltic lava deposits (Columbia River Basalt Group) are over 4 km (13,000 ft) thick (Reidel and Hooper 1989), spreading over portions of Idaho, Oregon, and Washington. The Columbia Basin encloses the Columbia River Basalt Group. A depression in the lower part of the Columbia Basin is referred to as the Pasco Basin (Figure 2-6). 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.

Figure 2-6. Geologic Setting of the Columbia Basin and Pasco Basin



2.3.4.1.2 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.

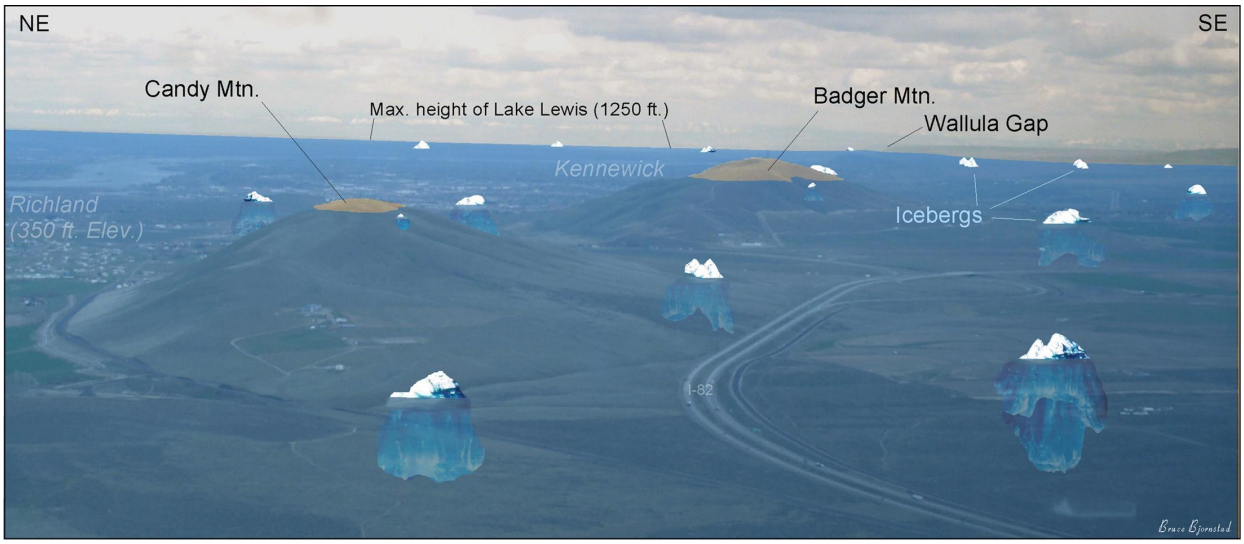
2.3.4.1.3 Ancestral Columbia River Deposits. The ancestral Columbia River repeatedly changed its course over the past 15 million years, depositing gravel, sand, silt, and clay (Tallman et al. 1981; Fecht et al. 1987; DOE 1988; Reidel et al. 1994; Lindsey 1996). Uplifting basalt ridges diverted the course 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 landsliding and sloughing into the Columbia River along much of the shoreline (Fecht et al. 1987).

2.3.4.1.4 Ice Age Floods. The last major geological event was the Ice Age floods. The Ice Age floods began as early as 2.5 million years ago (Bjornstad et al. 2001) with the most recent occurring 18,000 to 13,000 years ago. During the freezes and thaws that occurred in the Ice Age, an ice dam across the Clark Fork River in Montana formed and failed many times, each time releasing a wall of water that surged southwest through the Columbia Basin, inundating the area that is now the Hanford Site. As the water moved across eastern Washington, it eroded the basalt, forming channels of barren rocky land referred to as the Channeled Scabland. At other localities, such as away from the main flood channels, the water deposited bars of gravel and sand. The waste management facilities in the 200 Areas of the Hanford Site are located on one prominent flood bar of sand and gravel, the Cold Creek bar (Bretz et al. 1956; DOE 1988). Where the waters pooled behind obstacles such as Wallula Gap, they left behind deposits of sand and silt known as the Touchet Beds. Examples of Touchet Bed silt deposits are found in the Central Plateau of the Hanford Site at the U.S. Ecology, Inc. site near the 200 Areas.

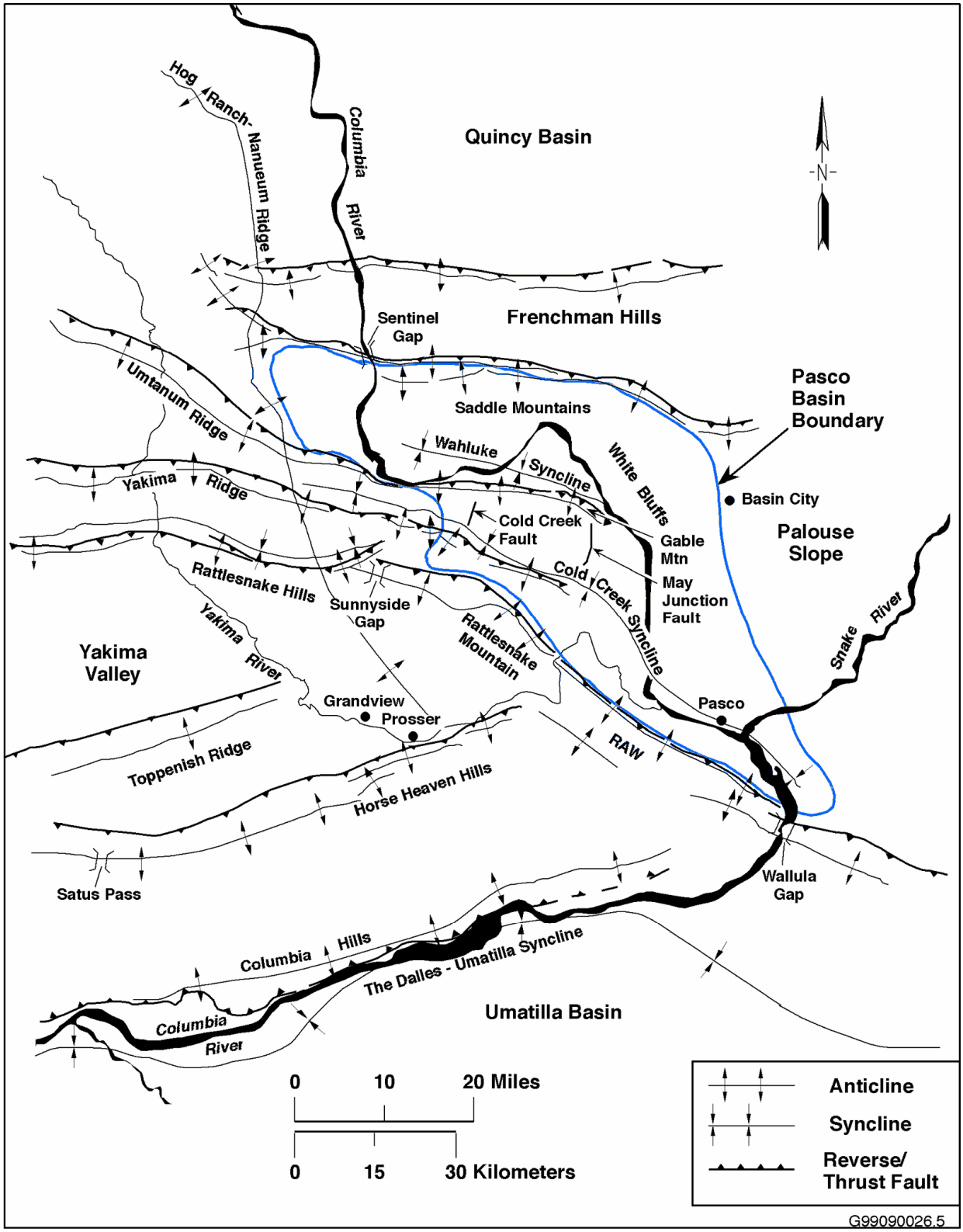
Figure 2-7 shows the southern Pasco Basin under water during the largest Ice Age flood. Ice Age floods became hydraulically dammed behind Wallula Gap, forming Lake Lewis. The largest and most frequent floods came from glacial Lake Missoula in northwestern Montana. Other floods may have escaped down-valley from the glacial lakes Clark and Columbia along the northern margin of the Columbia Basin (Waitt 1980; Baker and Bunker 1985) or down the Snake River from glacial Lake Bonneville (Malde 1968; O'Connor 1993) or from subglacial outbursts (Shaw et al. 1999).

Figure 2-7. Flood in the South of the Hanford Site, Washington, between 18,000 to 13,000 Years Ago



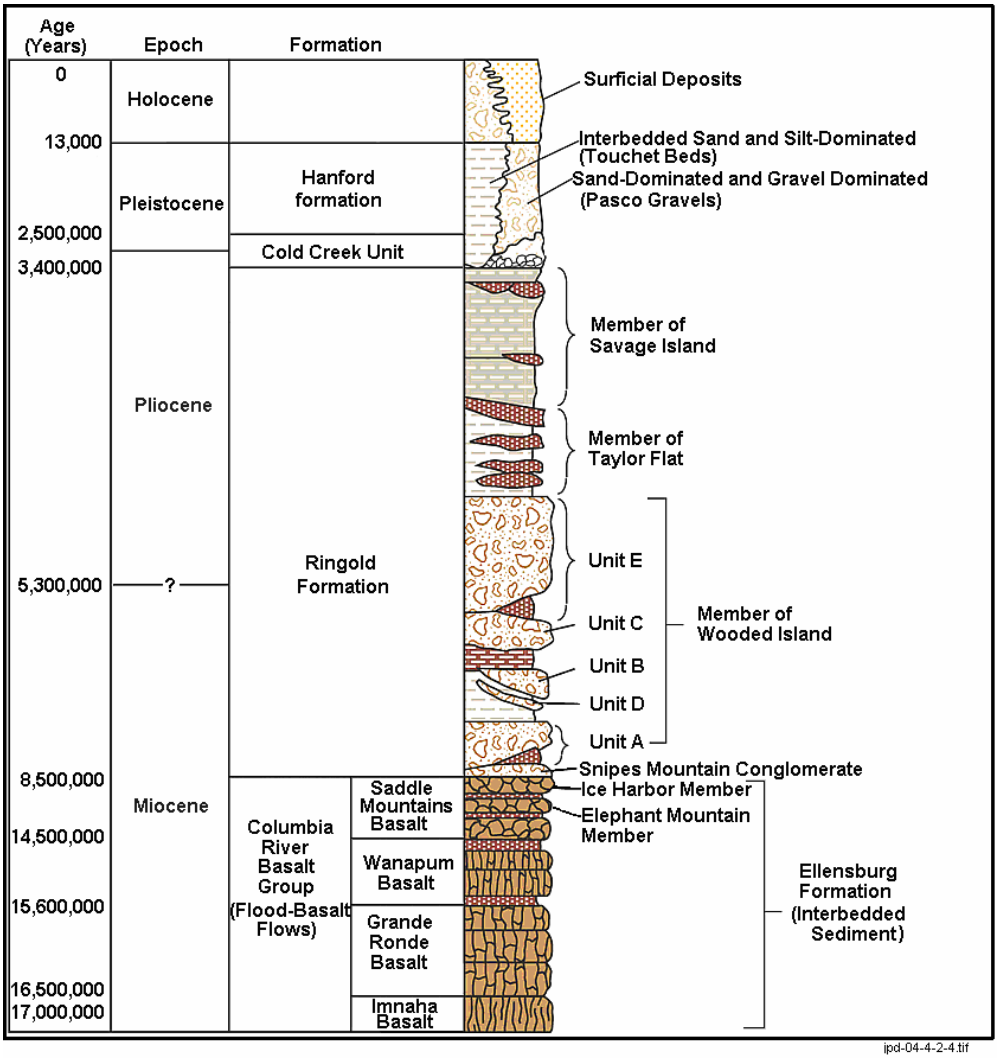
2.3.4.1.5 Geologic Structure. This section briefly describes the geologic structure of the Columbia Basin; for additional information on the geologic structure see Chapter 4.0 of Reidel et al. 2006. The Columbia Basin has two structural subdivisions or subprovinces: the Yakima Fold Belt and the Palouse Subprovince (Figure 2-6). The Yakima Fold Belt is a series of anticlinal ridges and synclinal valleys in the western part of the basin that has predominantly an east-west structural trend. The Palouse Subprovince is the eastern part of the basin and shows little deformation with only a few faults and low amplitude, long wavelength folds on an otherwise gently westward dipping paleoslope (DOE 1988). The Hanford Site lies within the Pasco Basin, which is a smaller basin in the Yakima Fold Belt along the western margin of the Palouse Subprovince. The Saddle Mountains form the northern boundary of the Pasco Basin, Rattlesnake Mountain is the southern boundary, and the Hog Ranch-Naneum Ridge anticline forms the western boundary (Figure 2-8). The main Hanford Site WMAs, 200 East and 200 West Areas, lie in the Cold Creek syncline between Yakima Ridge and Umtanum Ridge in the southern portion of the Pasco Basin (Figure 2-8).

Figure 2-8. Geologic Structures of the Pasco Basin and Vicinity



2.3.4.1.6 Stratigraphy. This section summarizes the strata and structure of the sediment and rocks that affect the Hanford Site/Pasco Basin. Figure 2-9 shows the various strata, their age, and epoch names for those geological periods of time. Additional information on the geology of the Pasco Basin, as well as more detailed descriptions of the stratigraphic units is given in Chapter 3.0 of Reidel et al. (2006).

Figure 2-9. Generalized Stratigraphy of the Pasco Basin and Vicinity



Columbia River Basalt Group: The bedrock of the Hanford Site is volcanic rock (basalt). Beneath the Hanford Site lay a minimum of 100 basalt flows with a maximum combined thickness of more than 4 km (almost 13,000 ft) (DOE 1988), all part of the Columbia River Basalt Group.

To organize the many basalt deposits into a consistent nomenclature, geologists have named and grouped them based on their physical and chemical properties. The basalt deposit closest to the surface at the Hanford Site, and therefore most often referred to, is Saddle Mountains Basalt (Figure 2-9). Saddle Mountains Basalt consists of 10 distinct basaltic lava deposits (members).

The most recent basalt flow underlying most of the Hanford Site is the Elephant Mountain Member of the Saddle Mountains Basalt. A younger basalt flow, the Ice Harbor Member, is found in the southern portion of the site near the 300 Area (DOE 1988). This unit forms the base of the unconfined aquifer.

In addition to basalt, the Hanford Site has sedimentary formations. These are sediment (material that settles to the bottom of a liquid) that often has hardened into rock. Some of the sediment at the Hanford Site is found between the basaltic lavas and is called the Ellensburg Formation. The majority of the sediment is above the basalt with the Ringold Formation on the bottom, overlain by the Cold Creek unit, and topped with the Hanford formation (Figure 2-9). Understanding the formations, along with clastic dikes and the soil of the Hanford Site, contributes to understanding of how, for example, contaminants might travel through the vadose zone and unconfined aquifer in the 200 Areas.

Ellensburg Formation. This is the sediment found interbedded with the Columbia River Basalt Group. The Ellensburg Formation formed as early as 15.6 million years ago, although the youngest portion on the Hanford Site may have formed as recently as 8 million years ago (DOE 1988). The Ellensburg Formation was created when volcanic rock and sediment from uplands surrounding the Columbia Plateau interfingered with the basalt of the Columbia River Basalt Group (Swanson et al. 1979a, 1979b). The thickest accumulations of the Ellensburg Formation lie along the western margin of the Columbia Basin. While deposition along the western margin was primarily from volcanic debris flows and related stream and sheet floods, no volcanic debris flows have been identified at the Hanford Site (Reidel et al. 1994). Volcanic rock (formed from falling ash known as tuff) is the dominant material in the Hanford Site portion of the Ellensburg Formation. The Ellensburg Formation is commonly exposed along the ridges of the Yakima Fold Belt. The confined aquifer system underlying the Hanford Site is found in the basalt breccia or flow tops of this formation.

2.3.4.1.7 Ringold Formation, Cold Creek Unit, and Hanford formation. Sediments overlying basalt in the Pasco Basin and Hanford Site, known as the suprabasalt, include the Ringold Formation, Cold Creek unit, and the Hanford formation. These formations are primarily exposed in the lower elevation areas around the Hanford Site, including White Bluffs.

Ringold Formation. The lower half of the Ringold Formation is the main unconfined aquifer under the Hanford Site and contains five separate stratigraphic intervals dominated by the fluvial gravels facies. These gravels, designated units A, B, C, D, and E (Figure 2-9), are separated by intervals containing deposits typical of the overbank and lacustrine facies (Lindsey 1991). The lowermost of the fine-grained sequences overlying, unit A, is designated the lower mud sequence. The uppermost gravel unit, unit E, grades upwards into interbedded fluvial sand and overbank deposits that are in turn overlain by lacustrine-dominated strata.

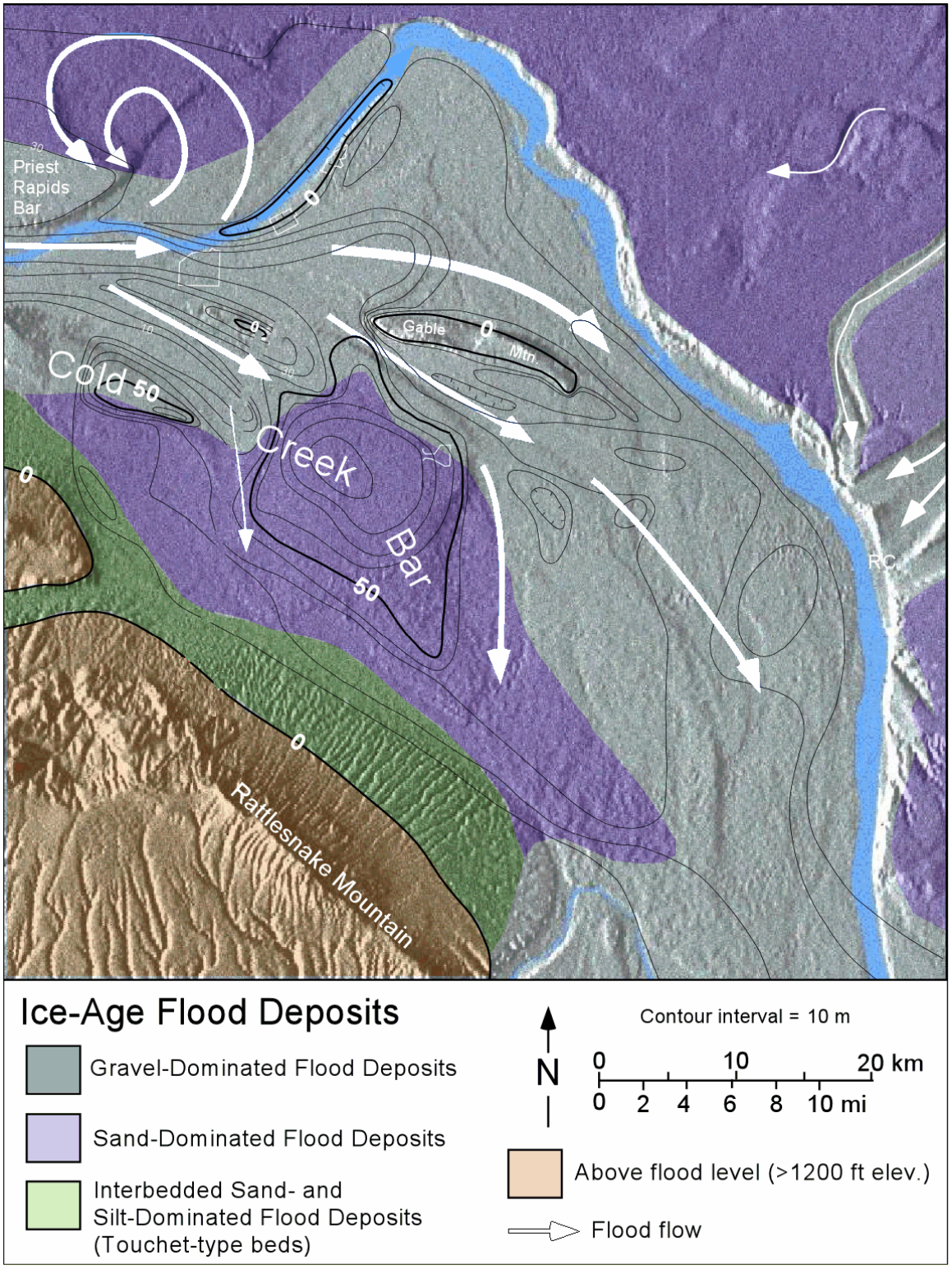
The upper part of the Ringold Formation, informally called the member of Taylor Flat (Lindsey 1995) consists of the sequence of fluvial sands, overbank deposits, and lacustrine sediments overlying unit E. This corresponds to the upper unit as originally defined by Newcomb (1958) along the White Bluffs 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 Cold Creek unit (DOE-RL 2002) 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 Cold Creek unit 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. Distribution of the Cold Creek unit depends in part on erosion and weathering of the underlying Ringold Formation and post-depositional erosion by the Ice Age floods (Slate 1996). The thickness of the Cold Creek deposit ranges from 0 to 20 m. Locally the Cold Creek unit 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, this layer has no more influence than other layers. Thin, fine-grained layers in the Hanford formation also cause lateral migration (Serne et al. 2002).

Hanford formation. The Hanford formation is the informal name for the strata that lie on top of Cold Creek unit above the Ringold Formation. The Ice Age floods inundated the Hanford Site a number of times beginning as early as 1 to 2 million years ago (Bjornstad et al. 2001). The last major flood sequence occurred about 13,000 years ago. 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 (O'Connor and Baker 1992). The deposits, known as the Hanford formation, that were left after the floodwater receded (Figure 2-10), blanket low-lying areas over most of the Hanford Site.

The Hanford formation is thickest in the vicinity of the 200 Areas where it is up to 100 m (300 ft) thick (DOE-RL 2002). Gravel, sand, and silt (Touchet Beds) dominate the Hanford formation (Reidel et al. 1992). The different sediment types of the Hanford formation commonly interfinger laterally. The relative proportion of each sediment type at any given location is related to its distance from main high-energy flows at the time of deposition (DOE 1988). Generally, gravel was deposited in the center of the Pasco Basin, while finer-grained sand and silt were deposited along the margins of the basin.

Figure 2-10. Isopach Map of the Ice Age Flood Deposits (Hanford formation)



2.3.4.1.8 Clastic Dikes. Clastic dikes are fissures filled with sand, silt, clay, and minor coarser debris. They are commonly associated with, but not restricted to, Ice Age flood deposits in the Columbia Basin. Many dikes occur as sharp-walled, near-vertical tabular bodies filled with multiple layers of unconsolidated sediment. Thin clay/silt linings separate the margins of dikes and internal layers (Fecht et al. 1999). Dikes vary in width from less than 1 mm (0.039 in.) to greater than 2 m (6.5 ft). Vertical extents range from less than 1 m (3 ft) to greater than 50 m (164 ft) with a large number greater than 20 m (65 ft) (Fecht et al. 1999).

Clastic dikes are characteristic of unstable environments and tend to form when three conditions exist: 1) a state of horizontal tension, leading to cracking, 2) the presence of suitable source materials, and 3) excess pore-water pressure (Allen 1982). In glacial and subglacial environments, movement of a glacier or ice sheet over saturated, unconsolidated, fine-grained sediment could lead to such conditions. In warmer climates, such conditions could have resulted from the rapid dewatering of saturated, unconsolidated, fine-grained sediment in response to a triggering event. Both seismic events and hydraulic fracturing during flooding have been proposed as possible mechanisms for the injections (Lupher 1944; Alwin 1970; Obermeier 1996; Pogue 1998; Fecht et al. 1999). Newcomb (1962) suggested that clastic dikes in the Touchet Beds resulted from upward injections of groundwater, caused by bank-storage effluent when a large lowering of Lake Lewis created a pressure differential. Newcomb (1962) suggested the lowering could produce a hydraulic lift causing the injection of water into an equi-dimensional (polygonal) system of fractures. Later injections followed the established dike planes producing the many narrow beds of rock.

2.3.4.1.9 200 Areas Strata and Structure. At the end of Ringold time, western North America underwent regional uplift resulting in a change in the base level of the Columbia River system. Uplift caused a change from sediment deposition to regional incision and sediment removal. Regional incision is especially apparent in the Pasco Basin where nearly 100 m (328 ft) of Ringold sediment has been removed from the Hanford area. The regional incision marks the beginning of Cold Creek time and the end of major deposition by the Columbia River.

Regional incision and erosion during the Cold Creek time is most apparent in the surface elevation change of the Ringold Formation across the Hanford Site, shown in Figure 2-11, which is an east-west cross-section through the Hanford Site. The elevation of the surface of the Ringold Formation decreases toward the present day Columbia River channel. In the southwest part of the Pasco Basin near the 200 West Area, less incision of the Ringold Formation occurred than at the 200 East Area. The greatest amount of incision is near the present channel. This increasing incision into the Ringold Formation toward the present Columbia River channel occurred with time as the channel of the Columbia River moved eastward across the Hanford Site.

These events have caused the geology in the 200 West Area to be notably different from that in the 200 East Area even though they are separated by a distance of only 6 km (4 mi) (DOE 1988) as shown in Figures 2-11 and 2-12. Figure 2-12 is a geologic map of the units present at the water table surface. The 200 West Area has sections containing all three formations including most of the Ringold Formation as well as the Cold Creek unit and the Hanford formation (DOE 1988).

In the 200 East Area, some of the Ringold Formation is present in the southern part but has been completely eroded in the northern part. On the north side of the 200 East Area, the Hanford formation rests directly on the basalt, and no Ringold sediment is present. Erosion by the ancestral Columbia River and Ice Age flooding are believed to have removed the Ringold Formation from this area. Material of questionable origin overlies basalt within WMA B-BX-BY (Wood et al. 2000). This material may be equivalent or partially equivalent to the Cold Creek unit or it may represent the earliest ice-age flood deposits overlain by a locally thick sequence of fine-grained non-flood deposits. This unit is referred to informally as Hanford-Cold Creek deposits.

Figure 2-11. Cross-Section Running from the Rattlesnake Mountains through the 200 Areas and out to the Columbia River

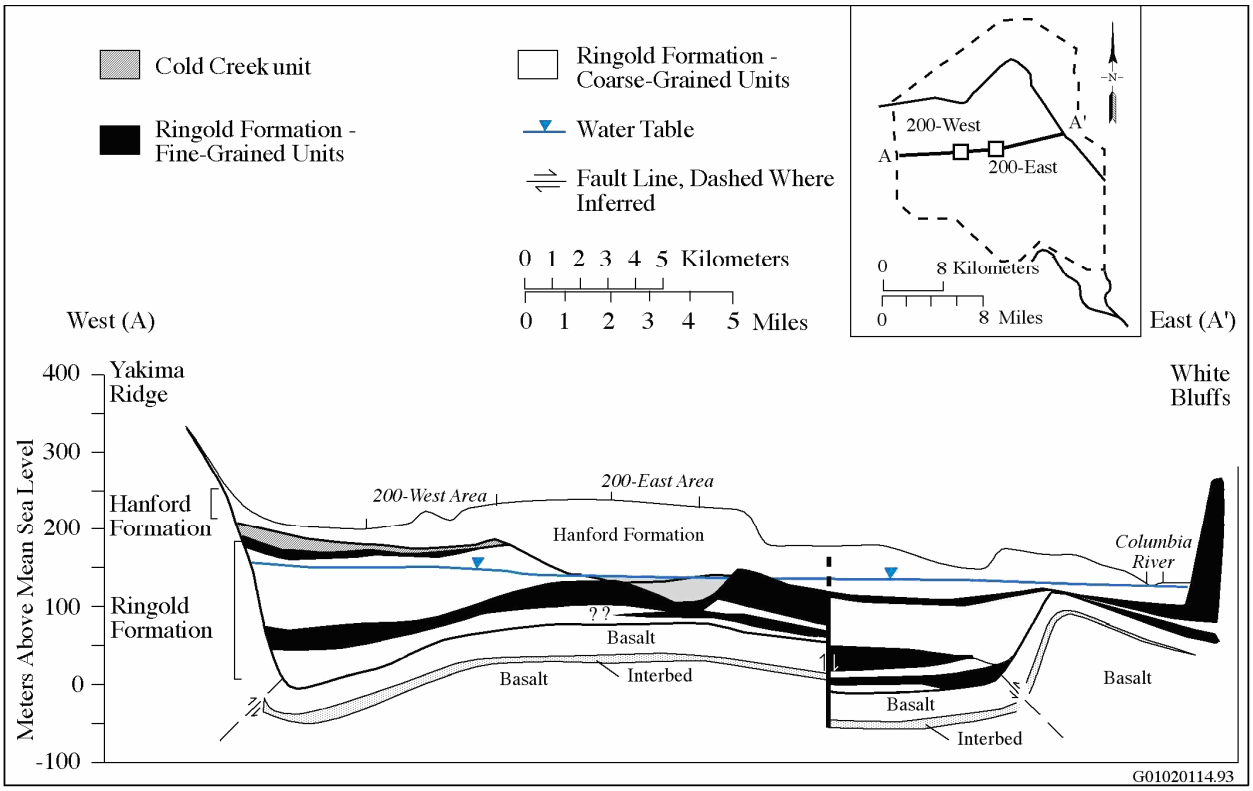
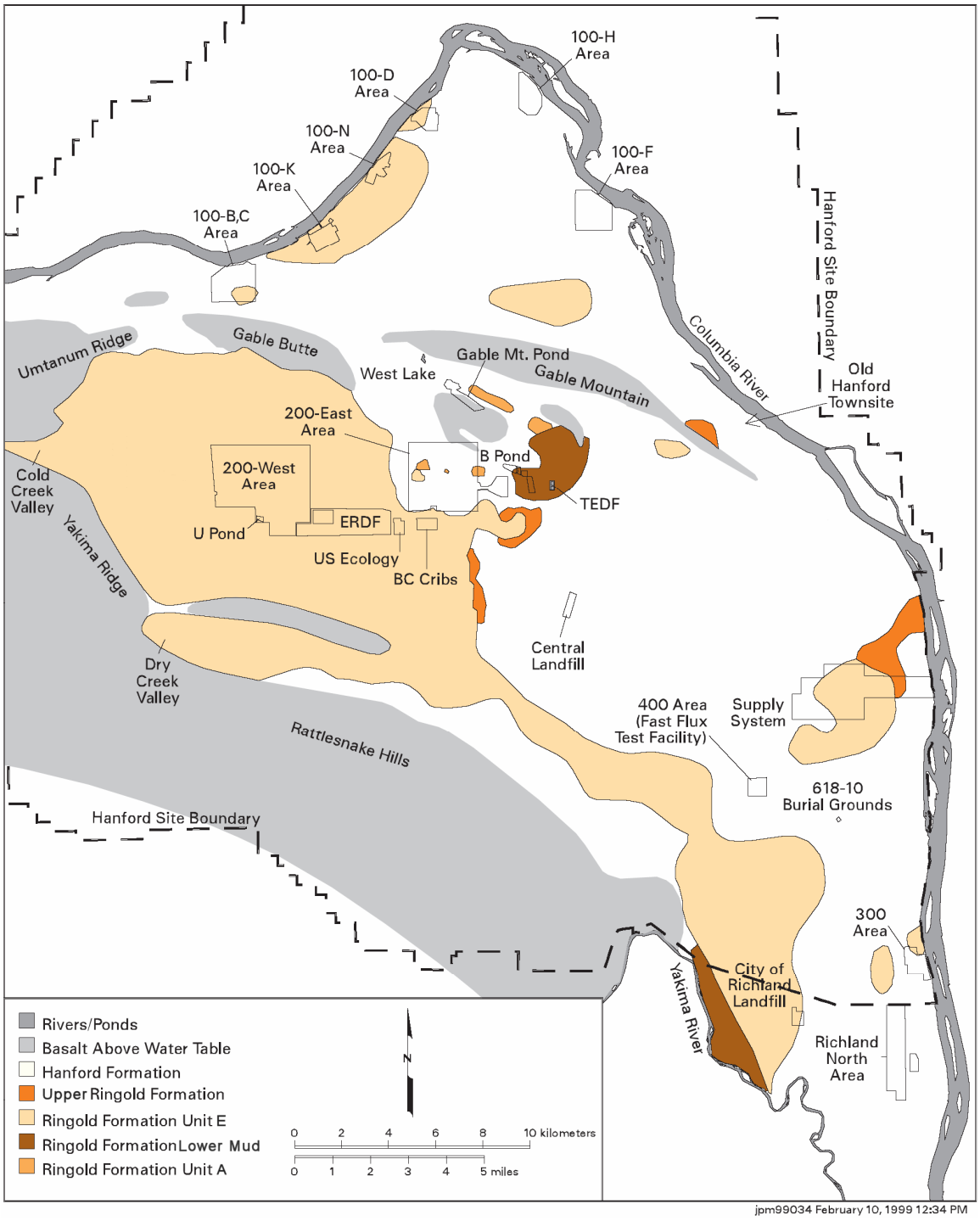


Figure 2-12. Hydrogeologic Units Present at the Water Table in June 1998



2.3.4.1.10 Surface Soils. The Holocene deposits and exposed Hanford formation sediments have experienced soil development and evolved into identifiable soil types. Hajek (1966) 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 Hajek (1966). These soil types control the flux of water reaching the water table (i.e., recharge) (Fayer et al. 1999). 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. Hajek (1966) 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 about 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 about 16 in. thick but can be 30 in. thick. The gravel content of the subsoil may range from 20 to 80 vol%.

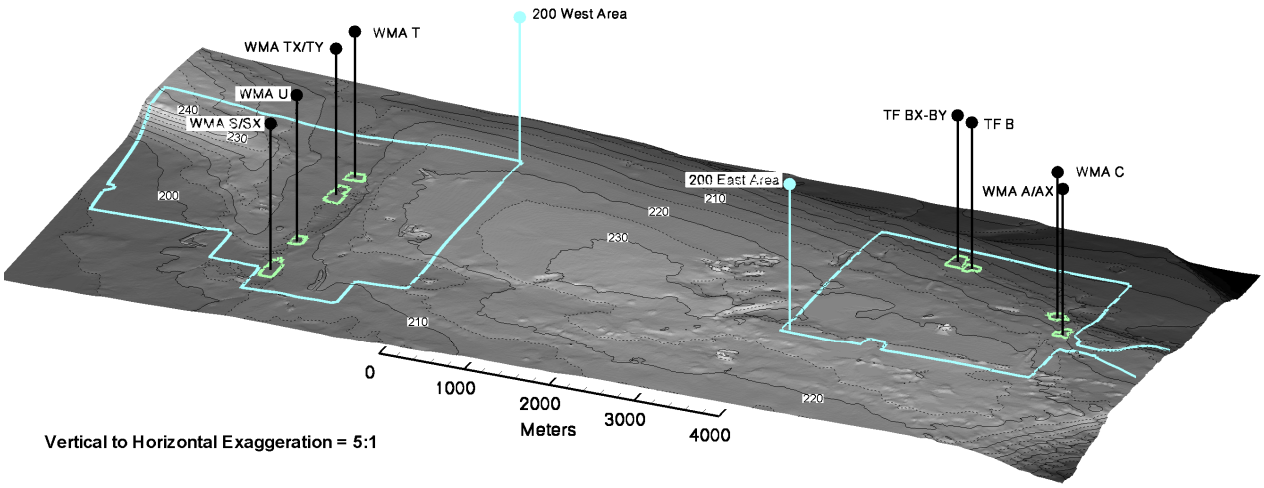
Ephrata Sandy Loam. The surface of this soil is dark colored with subsoil that is dark grayish-brown and medium-textured. It is underlain by gravelly material that may continue for many feet.

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 (Petersen 2005). 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.

In addition to these soil types, a backfill was placed around and over the tanks following construction. This backfill consists predominantly of poorly sorted cobbles, pebbles, and coarse to medium sands to silt derived from the Hanford formation. Lindsey et al. (2000) describes the backfill as relatively non-cohesive, friable, massive sand with variable amounts of silt and pebbles. No soil has developed over the backfill and vegetation is controlled through herbicides.

2.3.4.1.11 200 Areas Topography. Figure 2-13 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.

Figure 2-13. Topography of the 200 Areas Central Plateau



2.3.4.2 Seismology

This section summarizes the seismology of the Hanford Site. Chapter 6.0 of Reidel et al. 2006 provides additional details on the tectonic setting, seismology, and volcanology of the Hanford Site. 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 the shaking and structural damage as classified by 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 (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 >2.5 was installed in eastern Washington in 1969. DOE (1988) provides a summary of the seismicity of the Pacific Northwest, a detailed review of the seismicity in the Columbia Plateau region and the Hanford Site, and a description of the seismic networks used to collect the data.

Seismicity of the Columbia Plateau, as determined by the rate of earthquakes per area and the historical magnitude of these events, is relatively low when compared with other regions of the Pacific Northwest, the Puget Sound area, and western Montana/eastern Idaho. Figure 2-14 (left side) shows the locations of all earthquakes that occurred in the Columbia Plateau before 1969 with an MMI of >V and at Richter magnitude >4. Figure 2-14 (right side) shows the locations of all earthquakes that occurred from 1969 to 2000 at Richter magnitudes >3. The largest known earthquake in the Columbia Plateau occurred in 1936 near Milton-Freewater, Oregon. This earthquake had a Richter magnitude of 5.75 and a maximum MMI of VII, and was followed by a number of aftershocks indicating a northeast-trending fault plane.

Other earthquakes with Richter magnitudes >5 and/or MMIs of VI occurred along the boundaries of the Columbia Plateau in a cluster near Lake Chelan in 1872, extending into the northern Cascade Range in northern Idaho and Washington, and along the boundary between the western Columbia Plateau and the Cascade Range. Three MMI VI earthquakes have occurred within the

Columbia Plateau, including one event in the Milton-Freewater, Oregon, region in 1921; one near Yakima, Washington, in 1892; and one near Umatilla, Oregon, in 1893. In the central portion of the Columbia Plateau, the largest earthquakes near the Hanford Site are two earthquakes that occurred in 1918 and 1973. These two events were Richter magnitude 4.4 and intensity MMI V, and were located north of the Hanford Site near Othello, Washington.

Earthquakes often occur in spatial and temporal clusters in the central Columbia Plateau and are termed "earthquake swarms." The region north and east of the Hanford Site is a region of concentrated earthquake swarm activity, but earthquake swarms have also occurred in several locations within the Hanford Site. The frequency of earthquakes in a swarm tends to gradually increase and decay with no one outstanding large event within the sequence. Roughly 90% of the earthquakes in swarms have Richter magnitudes of 2 or less. These earthquake swarms generally occur at shallow depths, with 75% of the events located at depths <4 km (2.5 mi). Each earthquake swarm typically lasts several weeks to months, consists of several to 100 or more earthquakes, and the locations are clustered in an area 5 to 10 km (3 to 6 mi) in lateral dimension. Often, the longest dimension of the swarm area is elongated in an east-west direction. However, detailed locations of swarm earthquakes indicate that the events occur on fault planes of variable orientation and not on a single, through-going fault plane.

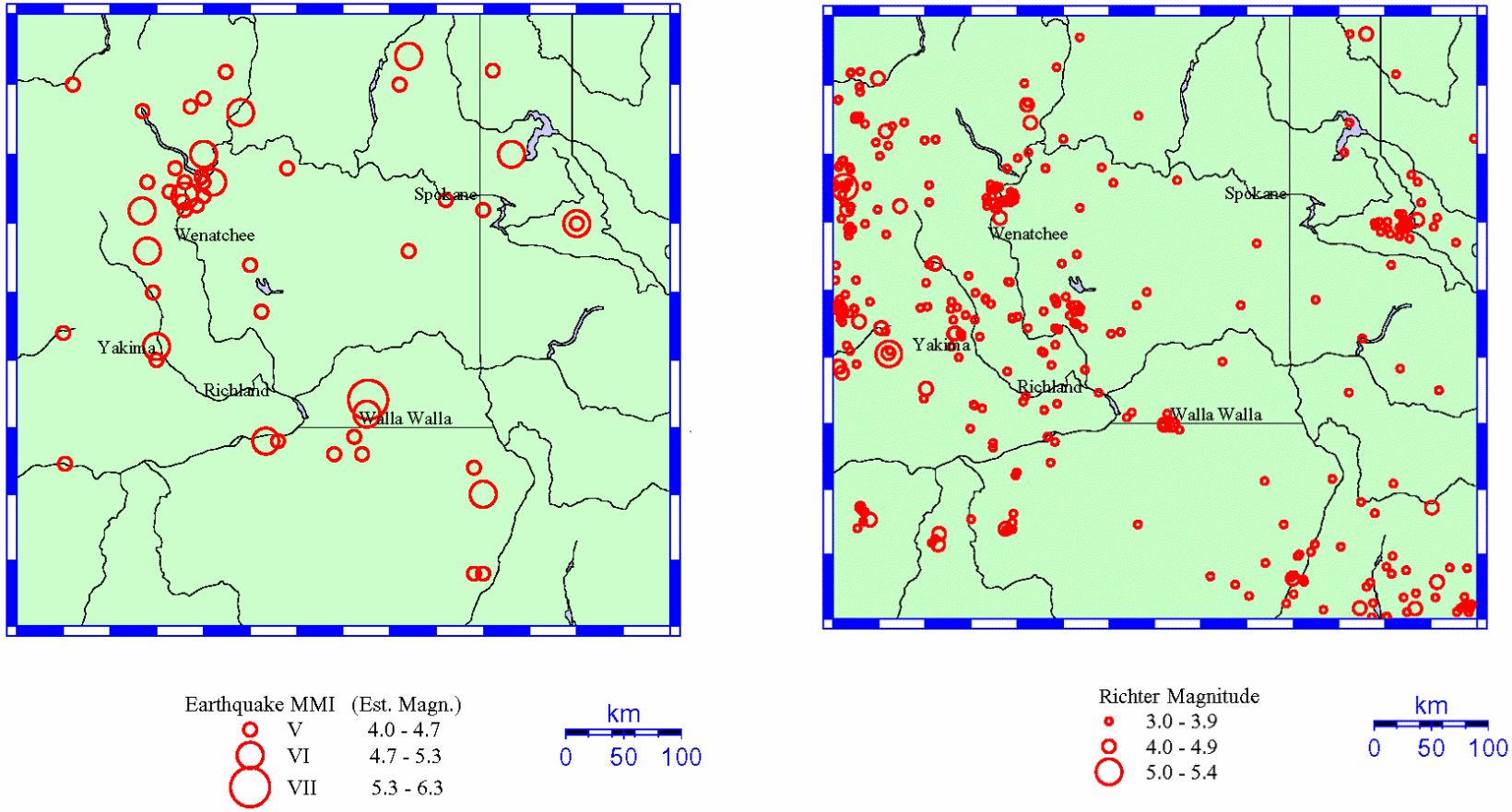
2.3.4.2.1 Seismic Hazard Assessment. Estimates for the earthquake potential and resulting hazard of structures and zones in the central Columbia Basin have been developed during the licensing of nuclear power plants at the Hanford Site. In reviewing the operating license application for the Washington Public Power Supply System (now Energy Northwest) Columbia Generating Station (formerly WNP-2), the NRC concluded that four earthquake sources should be considered for seismic design: the Rattlesnake Mountain-Wallula Gap structures, Gable Mountain, a floating earthquake in the tectonic province, and a swarm area (Geomatrix 1996).

Probabilistic seismic hazard analyses have been used to determine the seismic ground motions expected from multiple earthquake sources, and these are used to design or evaluate facilities on the Hanford Site. The most recent Hanford Site-specific hazard analysis (Geomatrix 1996) estimated that 0.10 g (1 g is the acceleration of gravity) horizontal acceleration would be experienced on average every 500 years (or with a 10% chance every 50 years). This study also estimated that 0.2 g would be experienced on average every 2,500 years (or with a 2% chance in 50 years). These estimates are in approximate agreement with the results of national seismic hazard maps produced by the U.S. Geological Survey (USGS 1996).

2.3.4.3 Volcanology

Several major volcanoes are located in the Cascade Range, west of the Hanford Site. The nearest volcano, Mount Adams, is about 160 km (100 mi) from the Hanford Site. The most recently active volcano, Mount St. Helens, is located approximately 220 km (136 mi) west-southwest of the Hanford Site. Because of the distance from the range, volcanic flows are not expected; the only effect of an eruption would be ash fall. The impacts of any such ash fall are not expected to have any long-term significance to contaminant movement.

Figure 2-14. Historical Earthquake Activity of the Columbia Basin, Washington, and Surrounding Areas



Left: All Earthquakes between 1850 and March 20, 1969, with a Modified Mercalli Intensity of V or larger and/or a Richter Magnitude of 4 or Larger (Rohay 1989).

Right: Earthquakes measured by seismographs from March 20, 1969, to December 31, 2000, with Richter magnitude 3 or larger (UWGP 2001; CNSS 2001).

2.3.5 Hydrology

This section describes the relevant characteristics of the surface and groundwater hydrology. Due to waste disposal operations at the 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 SST PA. For additional detail, see the following references:

- *Hanford Site Environmental Report for Calendar Year 2003* (Poston et al. 2004) provides the overview of the characterization and monitoring activities conducted at the Hanford Site during the calendar year. This document has been published annually since 1958.
- *Hanford Site Groundwater Monitoring for Fiscal Year 2004* (Hartman et al 2005). This document describes the groundwater monitoring activities during the fiscal year. Pacific Northwest National Laboratory (PNNL) has published this document annually since 1996. Prior to 1996, annual RCRA groundwater monitoring reports date to 1988.
- *Hanford Site National Environmental Policy Act (NEPA) Characterization,* (Neitzel et al. 2004) provides a standardized description of the Hanford Site environment. This document has been published annually since 1988.

In addition to these overview documents, there have been numerous site-specific documents that describe the groundwater hydrology at a particular WMA; examples of these documents are Reidel et al. (2006), Knepp (2002a, 2002b), Myer (2005), and Wood et al. (2000).

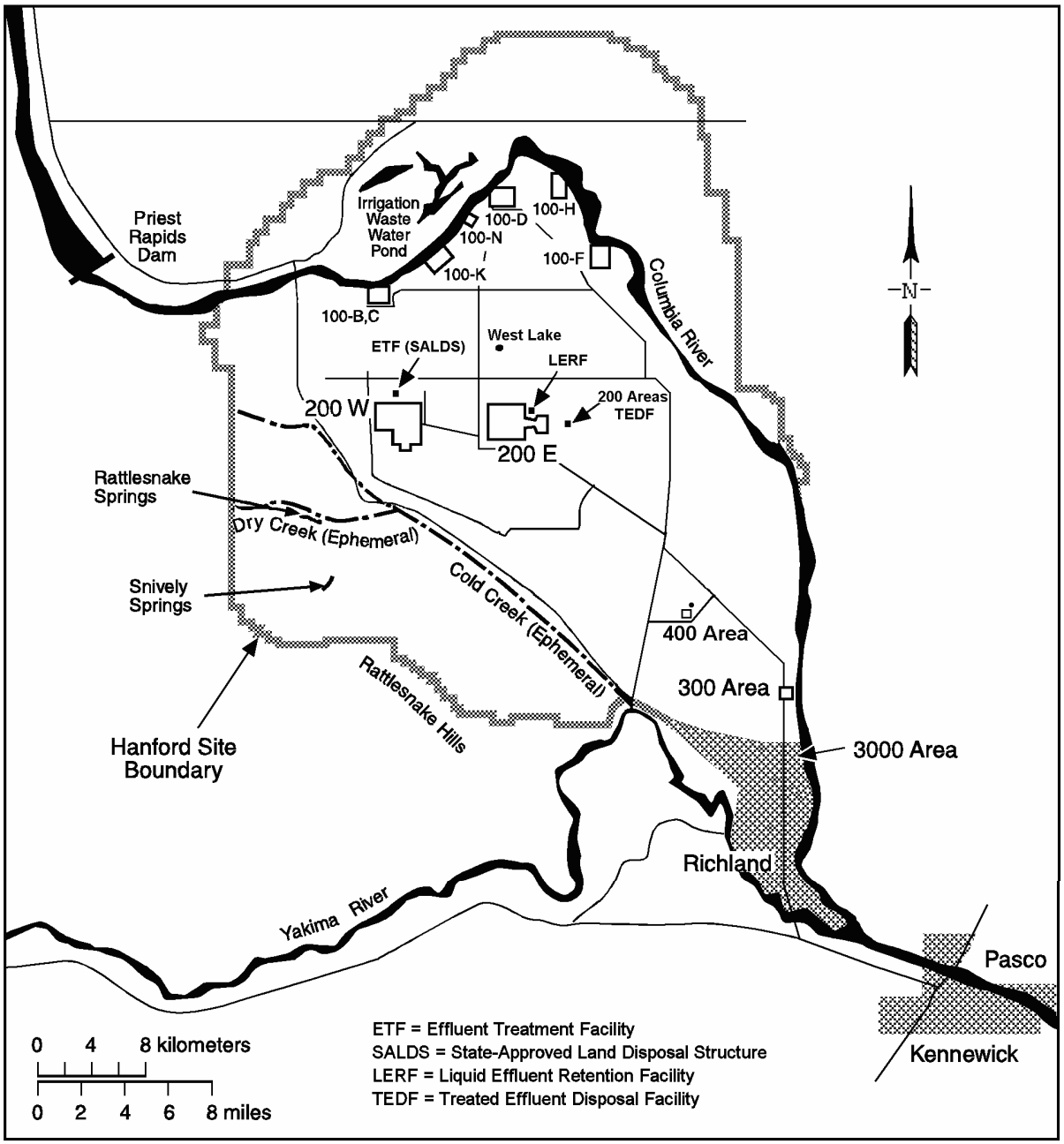
2.3.5.1 Surface Water

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 2-15), and there is surface water associated with irrigation east and north of the site.

2.3.5.1.1 Columbia River and Yakima Rivers. 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. Waste left at the WMAs following closure could impact the Columbia River through the groundwater pathway. The WMAs are located approximately 15 to 30 km from the Columbia River.

Originating in the Canadian Rockies of southeastern British Columbia, Canada, the Columbia River drains a total area of approximately 680,000 km^2 (262,480 mi^2) en route to the Pacific Ocean. Most of the Columbia River is impounded by 11 dams within the United States: 7 upstream and 4 downstream of the Hanford Site. Priest Rapids is the nearest upstream dam, and McNary is the nearest downstream dam. Lake Wallula, the impoundment created by McNary Dam, extends upstream past Richland, Washington, to the southern part of the Hanford Site. The portion of the Columbia River between these two dams is known as the Hanford Reach and is the longest free-flowing, non-tidal stretch of the Columbia River in the United States.

Figure 2-15. Surface Water Features including Rivers, Ponds, Major Springs, and Ephemeral Streams on the Hanford Site, Washington



Columbia River flow rates near Priest Rapids during the 83-year period from 1917 to 2000 averaged nearly 3360 m^3/s (Neitzel et al. 2004). Daily average flows during this period ranged from 570 to 19,500 m^3/s (Neitzel et al. 2004). The original selection of the Hanford Site for plutonium production and processing was based, in part, on the abundant water provided by the Columbia River. The existence of the Hanford Site has precluded development of this section of the river.

The state of Washington has promulgated water quality standards for the Columbia River, *Washington Administrative Code* (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. DOE has conducted routine water-quality monitoring of the Columbia River since 1958, with PNNL reporting on the water quality data since 1973. A low suspended load, low nutrient content, and an absence of microbial contaminants (Mann et al. 2001) characterize the Columbia River water.

The Yakima River, which follows a small length of the southwestern boundary of the Hanford Site, has much lower flows than the Columbia River. The average flow, based on nearly 60 years of daily flow records, is about 104 m^3/s, with an average monthly maximum of 490 m^3/s, and minimum of 4.6 m^3/s (Neitzel et al. 2004). The Yakima River System drains surface runoff from approximately one-third of the Hanford Site. Cold Creek and its tributary, Dry Creek, are ephemeral streams within the Yakima River drainage system in the southwestern portion of the Hanford Site. These streams drain areas to the west of the Hanford 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.

Contaminant plumes 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 (Thorne et al. 1994).

2.3.5.1.2 Non-Riverine Surface Water. Currently active ponds on the Hanford Site are shown in Figure 2-15. There are no currently active ditches on the Hanford Site. Ponds include West Lake and the 200 Areas Treated Effluent Disposal Facility (TEDF) disposal ponds. West Lake is north of the 200 East Area and is a natural feature recharged from groundwater (Gephart et al. 1976; Poston et al. 1991). 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 discharge 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.

2.3.5.1.3 Disposal Ponds. 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 "Waste Discharge Permit Program" (WAC 173-216). 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 SST PA.

2.3.5.1.4 Runoff and Net Infiltration. Total estimated precipitation over the Pasco Basin is about 9×10^8 m^3 annually (DOE 1988). This was calculated by multiplying the average annual precipitation averaged over the Pasco Basin by the 4,900 km^2 basin area. Precipitation varies both spatially and temporally with higher amounts generally falling at higher elevations. As noted in Section 2.3.2, annual precipitation measured at the HMS has varied from 7.6 to 31.3 cm since 1945. 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, or approximately 3% of the total precipitation (DOE 1988). 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.

2.3.5.1.5 Flooding. Large Columbia River floods have occurred in the past (DOE 1987), but the likelihood of recurrence of large-scale flooding has been reduced by the construction of several flood control/water-storage dams upstream of the Hanford Site. Major floods on the Columbia River are typically the result of rapid melting of the winter snow pack over a wide area augmented by above-normal precipitation. The maximum historical flood on record occurred June 7, 1894, with a peak discharge at the Hanford Site of 21,000 m^3/s (Neitzel et al. 2004).

The probable maximum flood for the Columbia River downstream of Priest Rapids Dam has been calculated to be 40,000 m^3/s (Neitzel et al. 2004) and is greater than the 500-year flood. The probable maximum flood would inundate parts of the 100 Areas located adjacent to the Columbia River, but the central portion of the Hanford Site would remain unaffected (DOE 1986).

2.3.5.2 Groundwater

This section provides information characterizing the geohydrology of the Hanford Site. Information is presented on the characteristics of both the unsaturated (vadose) and saturated (aquifer) zones. This information supported the development of the tank farm conceptual model and provided essential data for modeling the flow of water and transport of contaminants in the subsurface environment (Chapter 3.0).

This section was summarized largely from information presented in Neitzel et al. (2004) and Reidel et al. (2006), highlighting those aspects that were important to the modeling of system performance. Additional information was taken from Hartman et al. (2005) and Poston et al. (2004). The discussion focuses on the geohydrology of the 200 Areas but also includes information on the Hanford Site in general. Information characterizing the geohydrology of the individual WMAs is provided in Sections 2.6 through 2.12.

2.3.5.2.1 Vadose Zone Properties. 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) beneath parts of the Central Plateau (Hartman 2000). Unconsolidated glacio-fluvial sands and gravels of the Hanford formation make up most of the vadose zone (Figure 2-9). 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 Cold Creek unit 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 (Last et al. 2004a).

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

Except for the State Approved Land Disposal Site (SALDS), the 200 Area TEDF ponds (Figure 2-15), and septic drain fields, liquid discharges to the vadose zone ended during the mid 1990s. Currently, the major source of moisture to the vadose zone is precipitation. Infiltration and deep drainage of meteoric water in the vadose zone causes older pre-existing water to be displaced downward by newly infiltrated water. The amount of deep drainage (below the root zone) at any particular site is dependent on the total amount of water available at the time of the event, soil type, and the presence of vegetation. Usually, vegetation reduces the amount of deep drainage through the biological process of transpiration.

The WMAs were constructed with a gravel surface layer that has been maintained free of vegetation with the use of herbicides. These conditions promote higher rates of infiltration of meteoric water that are expected to continue until the time of WMA closure. Interim measures to control infiltration have been implemented at the WMAs and an evaluation of accelerated corrective measures is being conducted under a RCRA Corrective Action program. At closure, the WMAs are expected to be covered with a surface barrier designed to significantly reduce the infiltration rate. Contaminant transport modeling conducted for the SST PA accounted for these differences in infiltration rate.

The vadose zone stratigraphy influences the movement of liquid through 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. Perched water zones form where downward moving moisture accumulates on top of less permeable soil lenses or highly cemented horizons. Even in relatively uniform sediments, the influence of grain orientation is important and can give rise to anisotropic hydraulic properties, causing significant lateral movement of contaminant plumes (Ward et al. 2002a, 2002b; Zhang et al. 2003). 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.

Preferential flow may also occur along discontinuities, such as clastic dikes and fractures. Clastic dikes are a common geologic feature in the suprabasalt sediments at the Hanford Site (Section 2.3.4.1.4). 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 (Fecht et al. 1999).

2.3.5.2.2 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 (Gephart 1999). Most effluent was released in the 200 Areas. The major 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 technetium-99 and iodine-129 that, like tritium and nitrate, are mobile in both the vadose zone and groundwater. The major sources of technetium-99 and iodine-129 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, there are few direct ways to monitor tritium, nitrate, technetium-99, and iodine-129 in the vadose zone.

Approximately 280 UPRs in the 200 Areas also contributed contaminants to the vadose zone (DOE-RL 1997a). Many of these were associated with tank farm operations have contributed significant contamination to the vadose zone. Sixty-seven of the SSTs are classified in *Waste Tank Summary Report for Month Ending November 31, 2004* (Hanlon 2005) 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. A recent reassessment of tank farm vadose zone contamination data has been provided in the tank farm SCDRs and FIRs prepared in support of the RCRA Corrective Action process (Section 1.10.2.1.2). This effort has provided revised SST leak volume estimates based on a synthesis of available information, including vadose zone borehole drilling and sampling data, gamma-ray logging data, and historical information (Field and Jones 2005). This reassessment has added one new estimate and provided revised leak volumes for 68 SSTs. Vadose zone inventory estimates based on the revised leak volumes have been developed (Corbin et al. 2005) and were used in the SST PA modeling. Uncertainties in leak volume estimates were addressed as part of the sensitivity analysis (Section 3.5).

In addition to removing pumpable liquids from the SSTs, interim measures have been taken to reduce the movement of tank farm contaminants in the vadose zone. Infiltration of water has been identified as the primary means by which contaminants are displaced beneath the 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.

Over the past decade, there has been a significant effort to better understand and quantify vadose zone contamination in and around the WMAs. The investigations have focused on developing a better understanding of major releases and developing an understanding of the potential impacts on groundwater quality. Vadose zone characterization efforts have included drilling, sampling, and soil analysis in multiple WMAs, coupled with review of historical process records and gamma logging data (Knepp 2002a, 2002b). 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 WMA vadose zone investigations included baseline spectral gamma logging of the approximately 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 WMA. Results of the baseline spectral gamma logging project are summarized in a series of 12 reports (one for each SST farm). Extensive work is ongoing to better characterize vadose zone contamination in the WMAs. Further information on vadose zone characterization and monitoring activities is available in Hartman et al. (2005) and Poston et al. (2004).

2.3.5.2.3 Unconfined Aquifer Properties. Groundwater at the Hanford Site originated as either recharge from rain and snowmelt, or from excess irrigation, canal seepage, and wastewater disposal. Most of this groundwater will eventually discharge to the Columbia River. Some will be brought to the surface through wells, or excavations, or through evaporation or transpiration in shallow water table areas. Groundwater beneath the 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 (Figure 2-9). 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 SST PA as the Hanford unconfined aquifer system.

2.3.5.2.4 Unconfined Aquifer System. The unconfined aquifer system is composed primarily of the Ringold Formation and overlying Hanford formation (Figure 2-11). In some areas, the coarse-grained multilithic facies of the Cold Creek unit (pre-Missoula gravels) lie between these formations and below the water table. The other subunits of the Cold Creek unit are generally above the water table.

Water table elevations (Figure 2-16) show that 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. Along the Columbia River shoreline, daily river level fluctuations may result in water table elevation changes of up to 3 m (10 ft). During the high river stage periods of 1996 and 1997, some wells near the Columbia River showed water level changes of more than 3 m (10 ft).

Gee et al. (1992) and 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 for coarse-textured soils bare of deep-rooted vegetation 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.

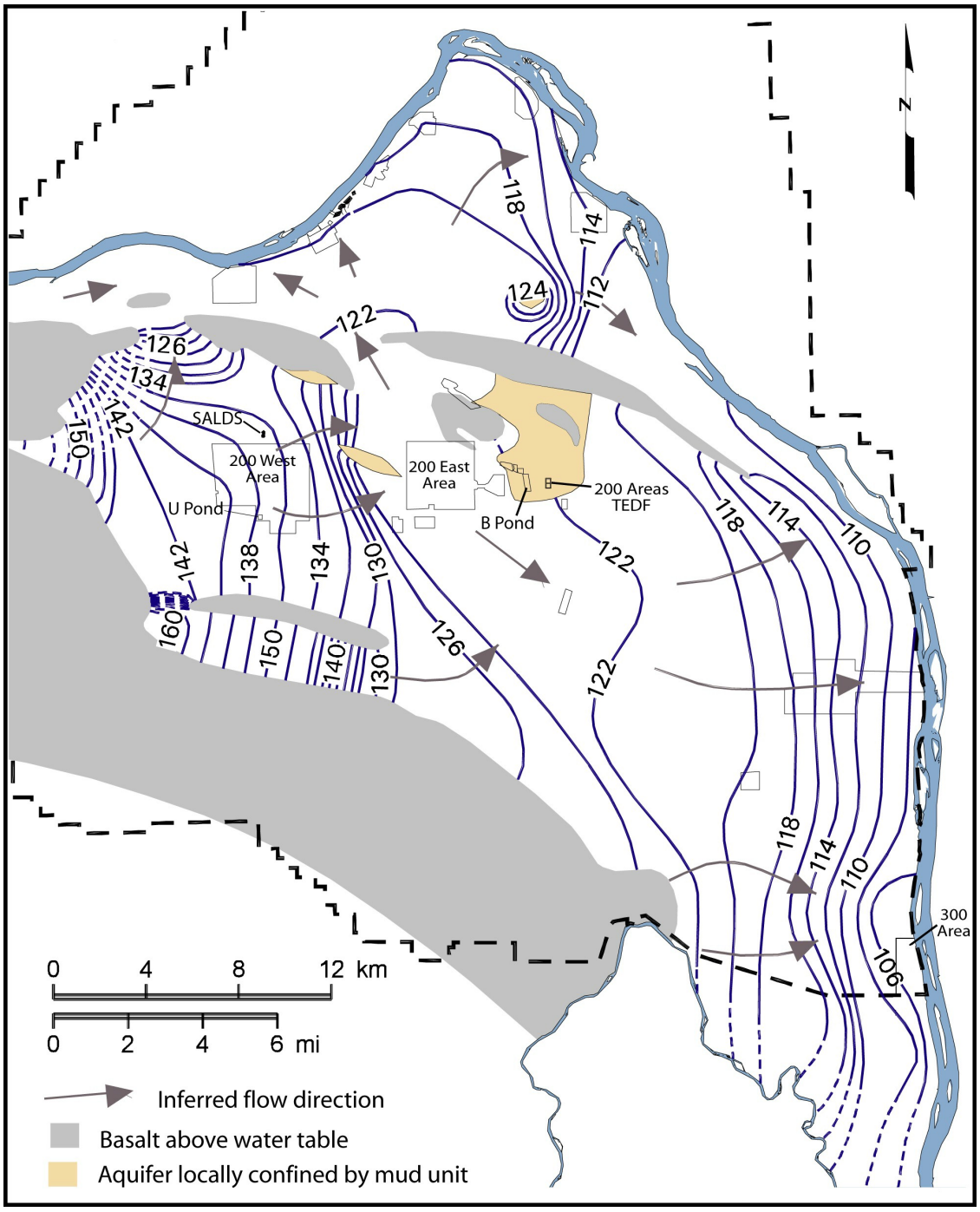
Between 1944 and the mid 1990s, the volume of artificial recharge from Hanford Site operations wastewater disposal was significantly greater than recharge from precipitation. An estimated 1.68×10^{12} L (4.44×10^{11} gal) of liquid was discharged to disposal ponds, trenches, and cribs during this period. Wastewater discharge has decreased since 1984 and currently contributes a volume of recharge in the same range as the estimated natural recharge from precipitation. Because of the reduction in discharges, groundwater levels are falling, particularly around the operational areas (Hartman et al. 2004).

A hindcast map showing water table elevations prior to the start of significant Hanford Site wastewater discharges is provided in Figure 2-17 (ERDA 1975). After the beginning of Hanford Site operations during 1943, the water table rose about 27 m (89 ft) under the U Pond disposal area (Figure 2-16) in the 200 West Area and about 9.1 m (30 ft) under disposal ponds near the 200 East Area. 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.

The presence of the groundwater mounds locally affected the direction of groundwater movement, causing radial flow from the discharge areas. Zimmerman et al. (1986) documented changes in water table elevations between 1950 and 1980. Until about 1980, the edge of the mounds migrated outward from the sources over time. Groundwater levels have declined over most of the Hanford Site since 1984 because of decreased wastewater discharges (Hartman et al. 2004). Although the reduction of wastewater discharges has caused water levels to drop significantly, a residual groundwater mound beneath the 200 West Area is still shown by the curved water table contours near this area, and small groundwater mounds exist near the 200 Area TEDF and SALDS wastewater disposal sites (Figure 2-16).

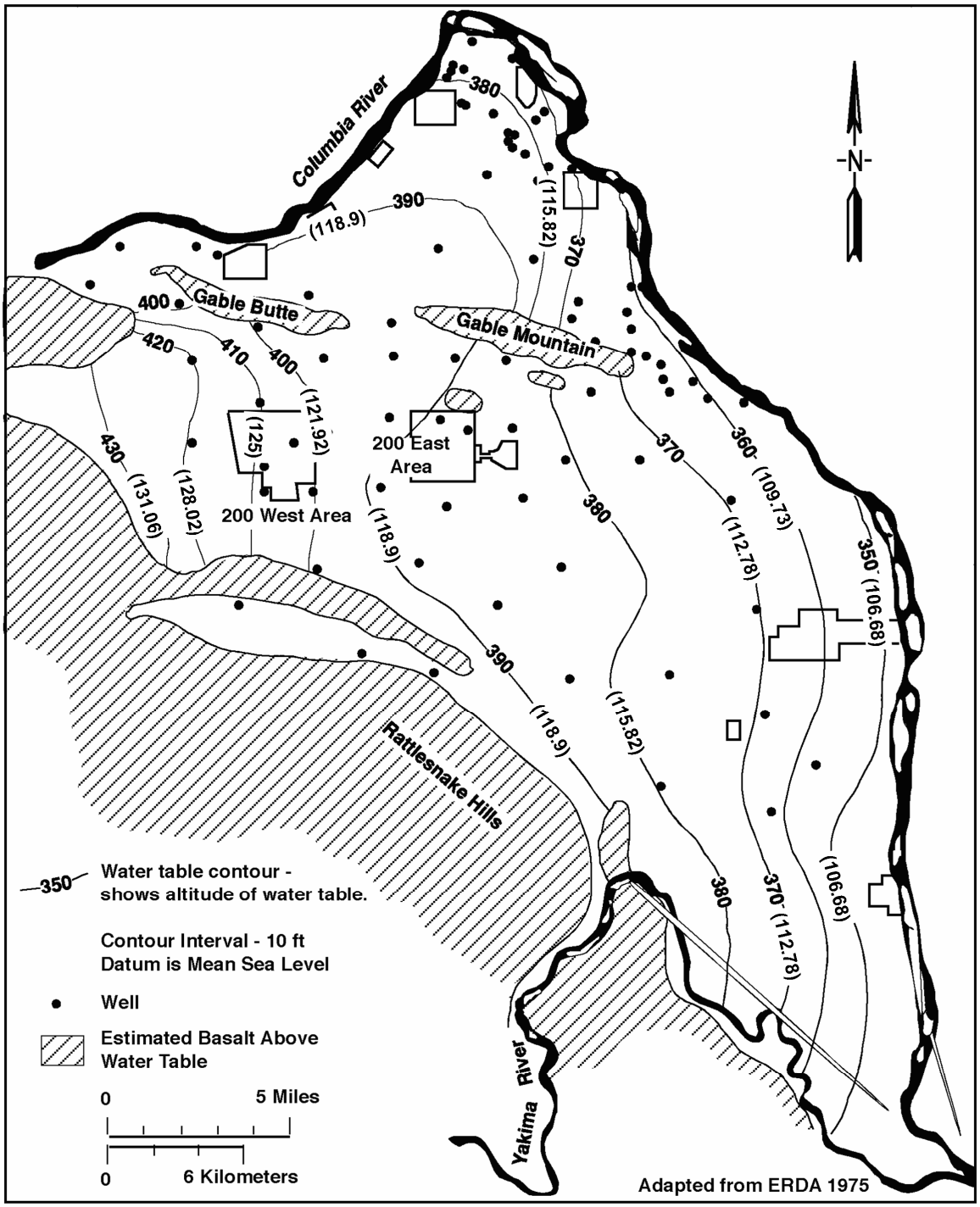
Horizontal hydraulic conductivities of sand and gravel facies within the Ringold Formation generally range from about 1 to 100 m/day, compared to 10 to 3,000 m/day for the Hanford formation and the coarse-grained multilithic facies of the Cold Creek unit (pre-Missoula gravels) (DOE 1988; Cole et al. 2001a; Thorne and Newcomer 2002). Because the Ringold Formation sediments are more consolidated and partially cemented, they are about 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 (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.

Figure 2-16. Water Table Elevations in Meters and Inferred Groundwater Flow Directions for the Unconfined Aquifer at Hanford, Washington, March 2003 [a]



[a] *Hartman et al. (2004)*
1 m = 3.28 ft

Figure 2-17. Hindcast Water Table Map of the Hanford Site, January 1944

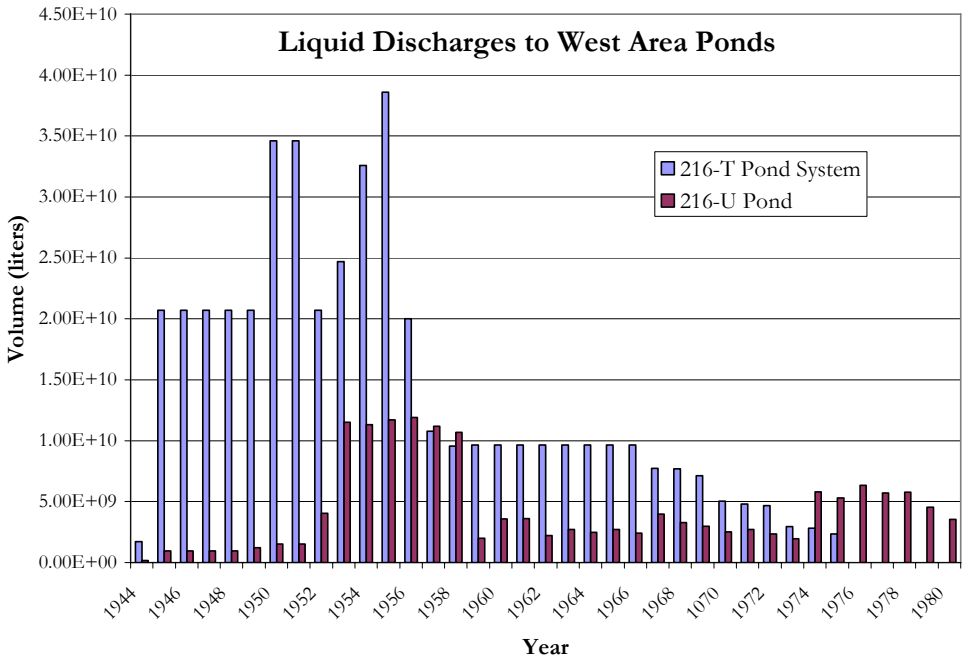


Water table elevations shown in the figure are in feet; meters are shown in parentheses.

2.3.5.2.5 200 Areas Hydrology. 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 2-9). 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). Because the Hanford formation and possibly the Cold Creek unit 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. On the north side of the 200 East Area, there is evidence of erosional channels that may allow interaquifer flow between the unconfined and uppermost basalt-confined aquifer (Graham et al. 1984; Jensen 1987).

The hydrology of the 200 Areas has been strongly influenced by the discharge of large quantities of wastewater to the ground during a 50-year period. Water levels in the uppermost and unconfined aquifer have risen as much as 26 m beneath the 200 West Area (Hodges and Chou 2000a) because of artificial recharge from liquid waste disposal operations active from the mid 1940s to 1995. The largest volumes of discharge were to the 216-T Pond system and the 216-U-10 pond. Figure 2-18 shows the liquid discharge history for the two ponds. The 216-T Pond system is estimated to have received approximately 424 billion L of effluent (Alexander et al. 1995) and the 216-U Pond to have received about 158 billion L of effluent (Last et al. 1994). The increase in water-table elevation was most rapid from 1949 to 1956 and was somewhat stabilized 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.

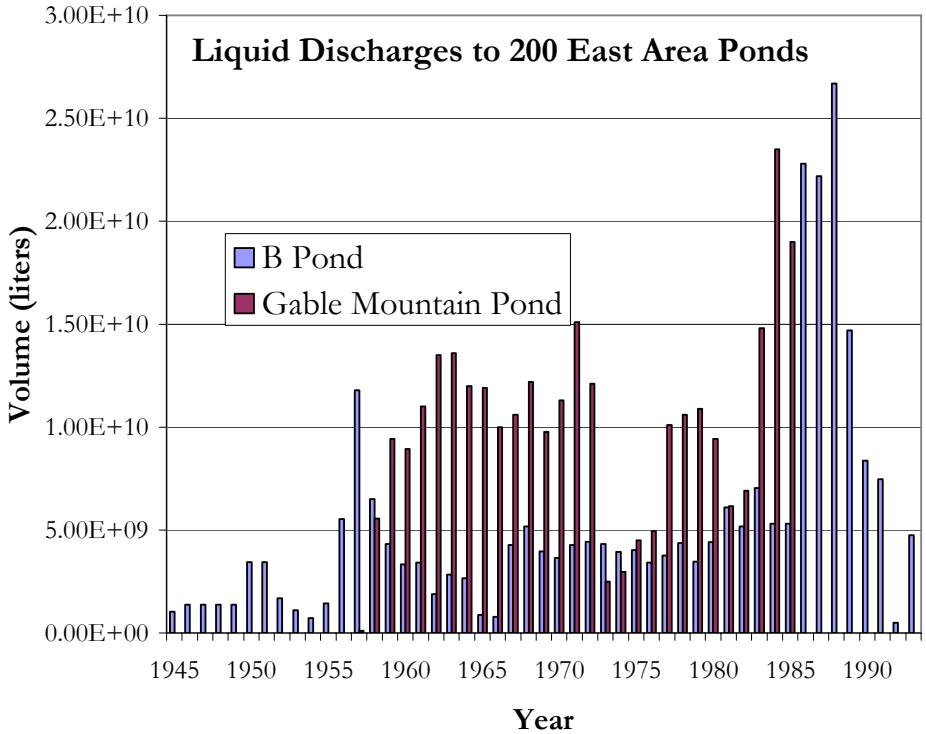
Figure 2-18. Discharge History for the 216-T Pond and the 216-U Pond [a]



[a] *Data for the 216-T Pond are from Alexander et al. 1995; data for the 216-U Pond are from Last et al. 1994.*

Water levels in the uppermost unconfined aquifer have risen as much as 9 m beneath the 200 East Area (well 699-45-42, located near B pond) because of artificial recharge from liquid waste disposal operations since the mid 1940s. The largest volumes of discharge were to the 216-B Pond system east of 200 East Area, the 216-A-25 (Gable Mountain) pond system north of the 200 East Area, and several of the PUREX cribs east and south of WMAs A-AX and C. Figure 2-19 shows the liquid discharge history for the two ponds. The 216-B Pond system is estimated to have received approximately 293 billion L of effluent and the 216-B Pond to have received about 256 billion L of effluent. The increase in water-table elevation was most rapid from 1954 to 1963. The water table declined somewhat in the late 1960s and early 1970s then increased again in the early 1980s before a final decline throughout the 1990s when wastewater discharges in the 200 East Area were reduced.

Figure 2-19. Discharge History for the 216-B Pond and the Gable Mountain Pond [a]



[a] *Data are from the Virtual Library (Vaughan 2002), figure from Reidel et al. (2006).*

The pre-Manhattan Project water table in the 200 West Area was at approximately 123 m above sea level (Kipp and Mudd 1974). However, Bergeron and Wurstner (2000) more recently modeled the elevation of the water table beneath the Hanford Site for the immobilized low-activity waste PA (Mann et al. 2001). Their model resulted in a water table elevation of about 128 m above sea level in the 200 West Area after all influences from the Hanford Site have dissipated. Since all non-permitted discharges of liquid effluent to the ground were stopped, rapid changes have occurred in the water table elevation. Table 2-2 gives the average rate of decline in wells at each WMA during the past 5 years. The average rate of decline was obtained by averaging the rate of decline in each monitoring well in the RCRA monitoring network at each WMA between March 1999 and March 2004. All data used are in the electronic database

known as the Virtual Library (Vaughan 2002). For wells newer than 1999, the water table decline during the entire life of the well was used.

Table 2-2. Water Level Changes beneath the 200 West Single-Shell Tank Farms [a]

WMA	Approximate Pre-Hanford Water Table Elevation m amsl [b]	Estimated Post-Hanford Water Table Elevation m amsl [c]	Approximate Maximum Water Table Elevation (m amsl) and Date of Measurement	Approximate Current Water Table Elevation m amsl [d]	Approximate Rate of Decline in the Past 5 Years m/yr
T	123 – 125	130 – 132	148.6 – Aug 1955 (299-W10-1)	136.7 – 137.2	0.37
TX-TY	123 – 125	130 – 132	145.9 – June 1985 (299-W14-1)	136.5 – 137.2	0.25
U	123 – 125	130 – 132	147.9 – June 1984 (299-W19-1)	136.7 – 137.3	0.45
S-SX	123 – 125	130 – 132	148.2 - July 1984 (299-W23-4)	136.7 – 137.2	0.30

[a] Reidel et al. (2006).
[b] Kipp and Mudd (1974).
[c] Bergeron and Wurstner (2000).
[d] Hartman et al. (2003).
amsl = above mean sea level

Table 2-3 summarizes the changes in water level elevations that have occurred beneath the 200 East Area tank farms since the beginning of the Hanford Site operations. The pre-Manhattan Project water table was at approximately 120 m above sea level (Kipp and Mudd 1974). However, the recent modeling by Bergeron and Wurstner (2000) resulted in a water table elevation of about 116 to 118 m above sea level in the 200 East Area after all influences from the Hanford Site have dissipated. All non-permitted discharges of liquid effluent to the ground were stopped in 1996. Since that time, rapid changes have occurred in the water table elevation. Table 2-3 also gives the average rate of water table decline in wells at each WMA during the past 5 years. The average rate of decline was obtained by averaging the rate of decline in each monitoring well in the RCRA monitoring network at each WMA between March 1999 and March 2004. All data used are in the Virtual Library (Vaughan 2002). For wells newer than 1999, the water table decline during the entire life of the well was used.

Comparing the approximate rate of water table decline in 200 East Area (Table 2-3) with that in 200 West Area (Table 2-2) 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 due to U Pond than to B Pond and that the 200 West Area tank farms are closer to the U Pond mound than are the 200 East Area tank farms to the B Pond mound. Also, the water table gradient is extremely flat in the 200 East Area, whereas the gradient is steeper beneath the 200 West Area. This means 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.

Table 2-3. Historic Water Level Changes beneath the 200 East Single-Shell Tank Farms [a]

WMA	Approximate Pre-Hanford Water Table Elevation m amsl [b]	Estimated Post-Hanford Water Table Elevation m amsl [c]	Approximate Maximum Water Table Elevation (m amsl) and Date of Measurement	Approximate Current Water Table Elevation m amsl [d]	Approximate Rate of Decline in the Past 5 Years m/yr
A-AX	120	116 – 118	124.7 Dec. 1985 (299-E24-4)	122.3 – 122.4	0.10
B-BX-BY	120	116 – 118	124.8 Dec. 1985 (299-E33-14)	122.3 – 122.4	0.12
C	120	116 - 118	124.8 Mar. 1988 (299-E27-7)	122.3 – 122.4	0.12

[a] Reidel et al. (2006).
[b] Kipp and Mudd (1974).
[c] Bergeron and Wurstner (2000).
[d] Hartman et al. (2003).
amsl = above mean sea level

Accompanying the changes in water level were changes in groundwater flow direction. Pre-Hanford Site groundwater flow direction was generally toward the east (Kipp and Mudd 1974) (Figure 2-17). The groundwater mounds drastically changed the flow direction and, in some areas, resulted in a complete reversal of flow direction. Since 1996, when all non-permitted discharges to the ground ceased, groundwater flow began to return to pre-Hanford Site conditions. For the SST PA, a steady-state post-Hanford Site water table was estimated for the 200 Areas. The water table gradients and flow velocities used for the post-closure contaminant transport simulations were defined based on the estimated pre-Hanford water table elevations. This assumes the water table will eventually return to those conditions when water discharges due to operations have ceased.

2.3.5.2.6 Limitations of Hydrogeologic Information. The sedimentary architecture of the unconfined aquifer is very complex because of repeated deposition and erosion. Although hundreds of wells have been drilled on the Hanford Site, many penetrate only a small percentage of the total unconfined aquifer thickness; therefore, there are a limited number of wells that can be used for defining the deeper sediment facies. A number of relatively deep wells were drilled in the early 1980s as part of a study for a proposed nuclear power plant (PSPL 1982), and these data are helpful in defining facies architecture. For most of the thinner and less extensive sedimentary units, correlation between wells is either not possible or uncertain. Major sand and gravel units of the Ringold Formation (e.g., units A, B, C, D, and E) are separated by mud-dominated units (Figure 2-9). In some places, the mud units act as aquitards that locally confine groundwater in deeper permeable sediments.

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 (Kipp and Mudd 1973; Connelly et al. 1992a, 1992b; Thorne and Newcomer 1992, 2002; Spane and Thorne 1995, 2000; Spane et al. 2001a, 2001b, 2002). 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.

2.3.5.2.7 Groundwater Travel Times. Tritium and carbon-14 measurements indicate that groundwater residence time (time that groundwater has been in the subsurface) is up to thousands of years for the unconfined aquifer and more than 10,000 years for groundwater in the shallow confined aquifer (Johnson et al. 1992). Chlorine-36 and noble gas isotope data suggest groundwater ages greater than 100,000 years in the deeper confined systems (Johnson et al. 1992). These relatively long residence times are consistent with semiarid-site recharge conditions. However, groundwater travel time from the 200 East Area to the Columbia River has been shown to be much faster, in the range of 10 to 30 years (USGS 1987; Freshley and Graham 1988). 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. Travel time from the 200 West Area is greater because of the lower permeability of Ringold Formation sediments. Plume monitoring indicates that groundwater from the 200 West Area has moved about 6 km (3.7 mi) during the past 50 years. Since the mid 1990s, large volumes of wastewater are no longer discharged to the 200 Areas (Figures 2-18 and 2-19). This has resulted in lower groundwater gradients. Groundwater travel times from the 200 Areas to the Columbia River are expected to increase because of diminishing wastewater recharge in the 200 Areas and the resulting reduction of the hydraulic gradient.

2.3.5.2.8 Groundwater Quality. The quality of groundwater at the Hanford Site, uncontaminated by Hanford Site activities, varies depending on the aquifer system and depth, which generally is related to residence time in the aquifer (DOE-RL 1992, 1997b; Hartman et al. 2004). The DOE-RL (1997b) study involved examination of historical data and new data from wells in areas not affected by Hanford Site contaminants.

Groundwater chemistry in the basalt-confined aquifers displays a range depending on depth and residence time (DOE 1988). The chemical type varies from calcium- and magnesium-carbonate water to sodium- and chloride-carbonate water. Some of the shallower basalt-confined aquifers in the region (e.g., the Wanapum basalt aquifer) have exceptionally good water quality characteristics: less than 300 mg/L dissolved solids; less than 0.1 mg/L iron and magnesium; less than 20 mg/L sodium, sulfate, and chloride; and less than 10 ppb heavy metals (Johnson et al. 1992). However, deeper basalt-confined aquifers typically have high dissolved solids content and some have fluoride concentrations greater than the drinking water standard of 4 mg/L (DOE 1988).

Groundwater beneath large areas of the Hanford Site has been contaminated by radiological and chemical constituents resulting from past Hanford Site operations. These contaminants were primarily introduced through wastewater discharged to cribs, ditches, injection wells, trenches, and ponds (Kincaid et al. 1998). Additional contaminants from spills, leaking waste tanks, and burial grounds (landfills) have also entered groundwater in some areas. Contaminant concentrations in the existing groundwater plumes are expected to decline through radioactive decay, mineral adsorption, chemical degradation, and dispersion. However, contaminants also exist within the vadose zone beneath waste sites (Section 2.3.5.2.2) as well as in waste storage

and disposal facilities. These contaminants have a potential to continue to move downward into the aquifer. The SST PA modeling addresses future impacts to groundwater from existing vadose zone contamination related to past tank waste releases and contamination left as residual waste inside the SSTs and other tank farm infrastructure components. Existing groundwater plumes are not addressed in the SST PA but are being addressed in revisions to the Hanford Site composite analysis (Kincaid et al. 1998).

Some contaminants, including tritium and chloride, move at the same velocity as groundwater. The movement of other contaminants is slower because they react with, or are sorbed on, the surface of minerals within the aquifer or the vadose zone. The factor by which the velocity of a constituent is reduced compared to average groundwater flow velocity is called the "retardation factor." Therefore, tritium in groundwater will move 10 times faster than a contaminant with a retardation factor of 10. For Hanford sediments, it has been estimated that technetium and chromium have small retardation factors and move at nearly the same velocity as groundwater (Thorne 2004). Iodine, nitrate, uranium, and carbon tetrachloride were estimated to have median retardation factors between 3 and 12. Cesium and plutonium were estimated to have median retardation factors between 290 and 27,000. Cantrell et al. (2003) and Kaplan and Serne (2000) offer additional information on retardation of chemicals transported in groundwater.

Groundwater contamination is being actively remediated through pump-and-treat operations at the 200 West Area, as well as the 100 D, 100 F, 100 K and 100 N Areas (Hartman et al. 2004).

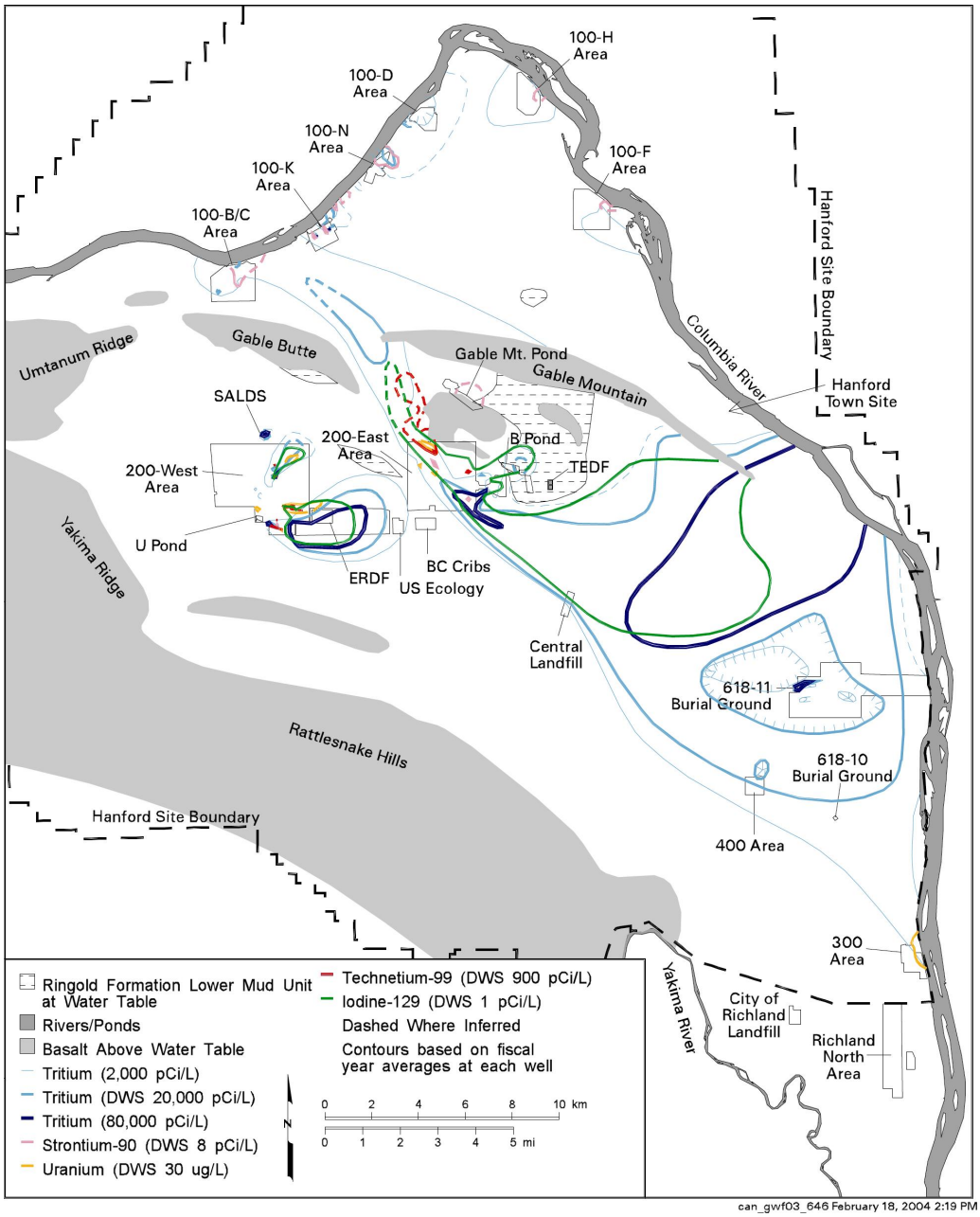
Monitoring of radiological and chemical constituents in groundwater at the Hanford Site is performed to characterize physical and chemical trends in the flow system, establish groundwater quality baselines, assess groundwater remediation, and identify new or existing groundwater problems. Groundwater monitoring is also performed to verify compliance with applicable environmental laws and regulations. Samples were collected from 710 wells and 79 shoreline aquifer sampling tubes during fiscal year 2003 to determine the distributions of radiological and chemical constituents in Hanford Site groundwater (Hartman et al. 2004).

To assess the quality of groundwater, concentrations measured in samples were compared with maximum contaminant levels (MCL) or interim drinking water standards (DWS) and the DOE Derived Concentration Guides (DCG). The MCL or DWS standards are legal limits for contaminant concentrations in public drinking water supplies enforceable by the Washington State Department of Health or EPA. Although these standards are only applicable at the point of consumption of the water, they provide a useful indicator of negative impacts to the groundwater resource. The DCG applies only to radionuclides and is based on the concentration that would result in a dose exposure of 1 mSv/year (100 mrem/year) effective dose equivalent (EDE), a calculation of dose that assumes ingestion under specified intake scenarios.

Radiological constituents including carbon-14, iodine-129, strontium-90, technetium-99, gross alpha, gross beta, tritium, and uranium were detected at levels greater than the DWS in one or more onsite wells. Concentrations of strontium-90, tritium, and uranium were detected at levels greater than the DOE DCG. Certain nonradioactive chemicals regulated by EPA and the state of Washington (i.e., nitrate, fluoride, chromium, cyanide, carbon tetrachloride, chloroform, trichloroethylene, and tetrachloroethylene) were also present in Hanford Site groundwater during fiscal year 2003 (Hartman et al. 2004). The extent of radiological and nonradiological

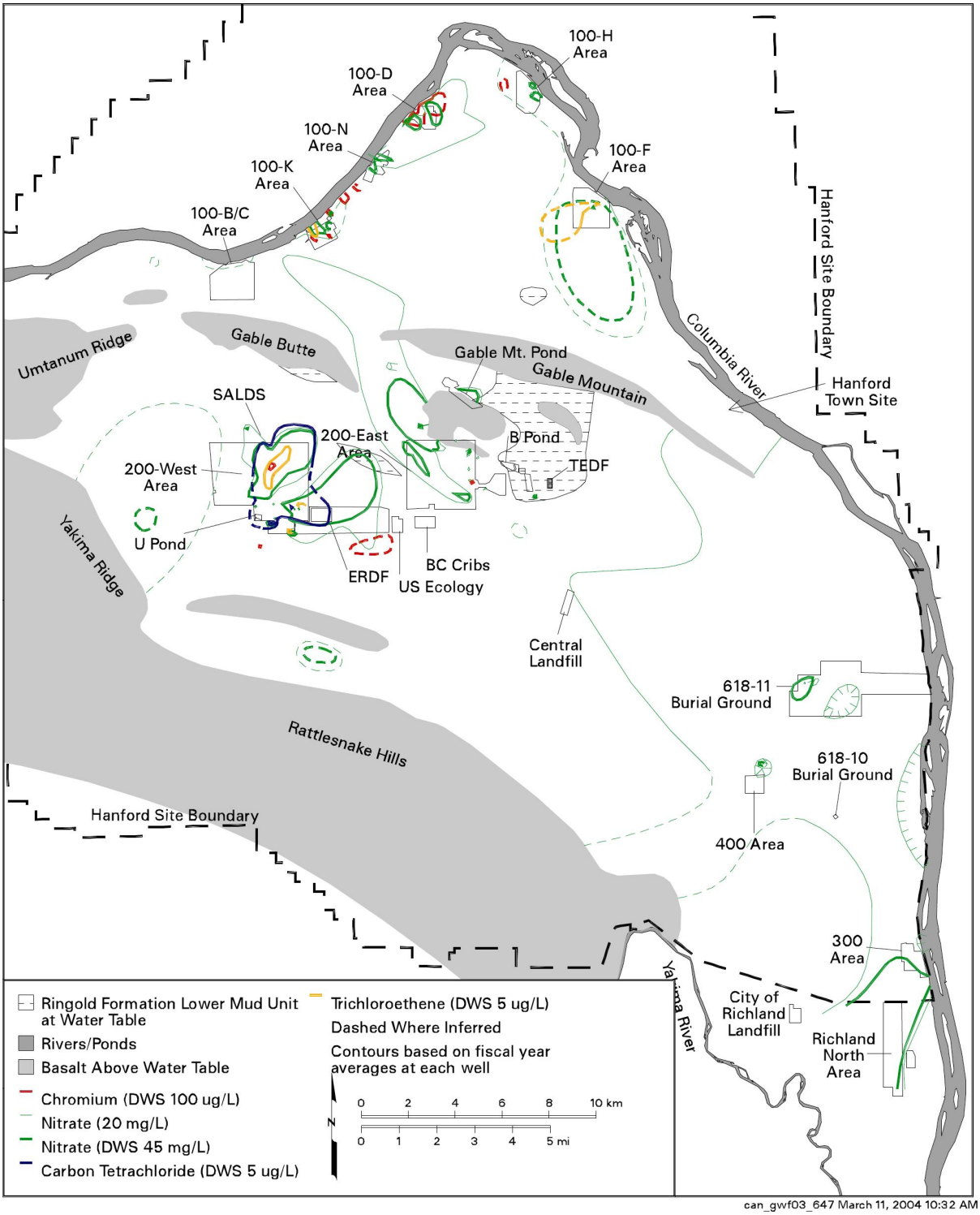
contamination in Hanford Site groundwater above the applicable DWS is determined annually (Figures 2-20 and 2-21). The area of contaminant plumes on the Hanford Site with concentrations exceeding DWS levels was estimated to be 190 km^2 during fiscal year 2004 (Hartman et al. 2004).

Figure 2-20. Distribution of Radionuclides in Groundwater on the Hanford Site, Washington, at Concentrations above the Maximum Contaminant Level or Interim Drinking Water Standard during Fiscal Year 2003 [a]



[a] *Hartman et al. (2004)*
27 pCi/L = 1 Bq/L

Figure 2-21. Distribution of Hazardous Chemicals in Groundwater on the Hanford Site, Washington, at Concentrations above the Maximum Contaminant Level or Interim Drinking Water Standard during Fiscal Year 2003 [a]



[a] *Hartman et al. (2004)*

2.4 FACILITY DESCRIPTIONS COMMON TO ALL TANK FARMS

This section describes the facilities that all tank farms have in common. Descriptions of the 100- and 200-Series tanks are provided, as well as the ancillary equipment. This section also includes a level of detail that illustrates equipment that could be included in a specific tank farm, but does not provide exact descriptions of equipment or engineering data that would be found in design media.

The SSTs were the first large-volume tanks constructed to store radioactive waste and are located in the upper Central Plateau of the 200 Area. The construction of the initial SSTs and associated support infrastructure began in 1943 and all 149 SSTs were completed by 1964. The SSTs were located in the 200 West and 200 East Areas as shown in Figure 2-22 and were grouped into 12 SST farms located near the facilities that generated the waste. The tank farms include 100-Series tanks (530,000 gal, 758,000 gal, and 1,000,000 gal), 200-Series tanks (55,000 gal), and the infrastructure to transfer waste from waste management and irradiated fuel-reprocessing facilities. The 12 SST farms are further divided into 7 WMAs that are discussed in detail in Sections 2.6 through 2.12.

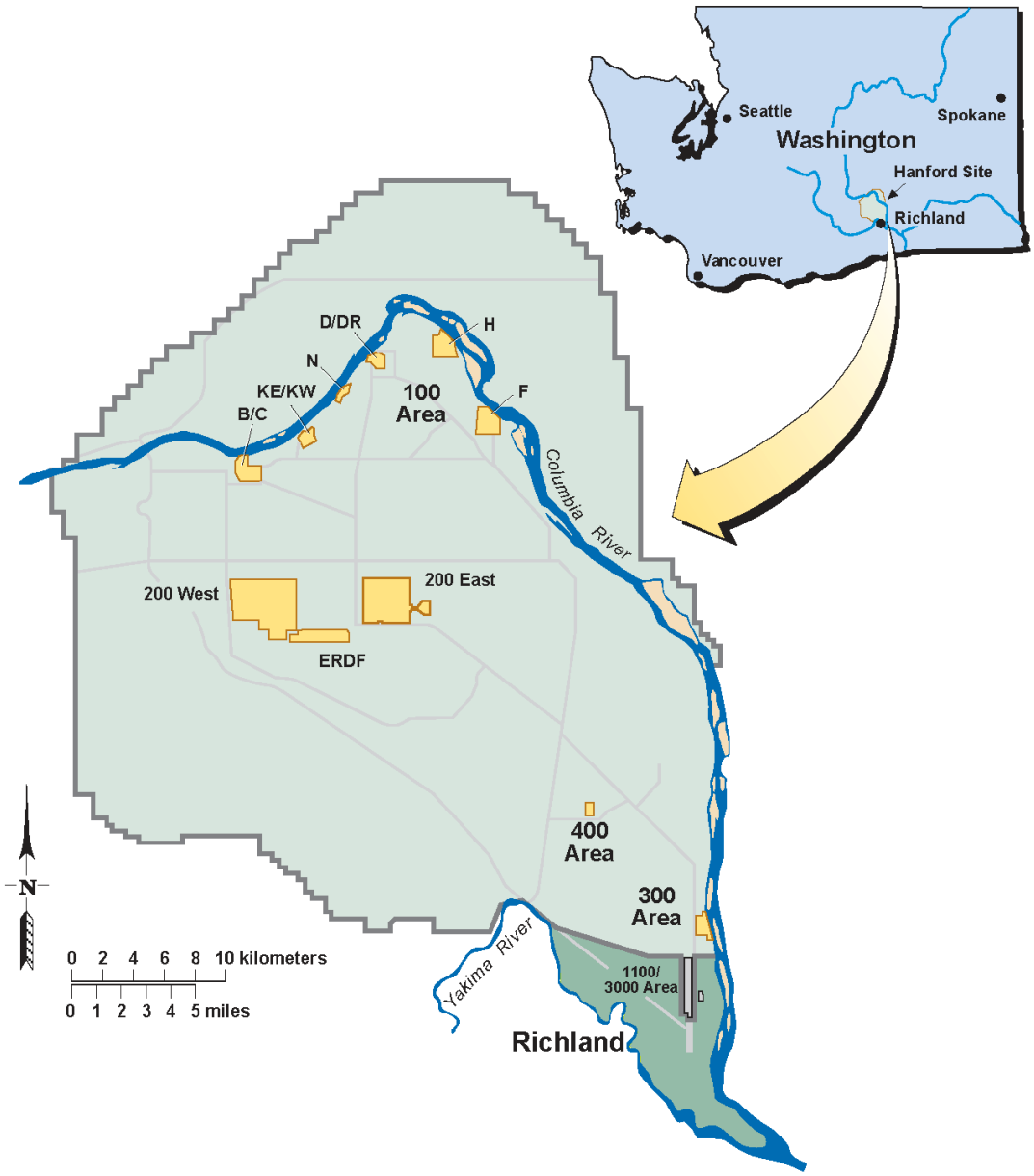
To assist in the transfer of waste to the tank farms, the SSTs were located at a lower elevation from the fuel processing facilities and grouped into farms of 4 to 18 tanks as shown in Figure 2-23. The decision to locate tanks in groups provided adequate tank waste storage close to each fuel and waste reprocessing facility, and reduced the number of pipelines and associated ancillary equipment required to transfer waste between the processing plants and the tank farms. Additionally, the tank farm concept of grouping tanks together allowed for the use of cascades, in which the first tank overflowed into the second tank, the second into the third, and so on, within the tank farms; this allowed the waste solids to settle to the bottom of each tank as waste was transferred. The radioactive waste that was generated and transferred to the SSTs was stored in the form of an alkaline that eventually separated into a mixture of liquid, sludge, and hard saltcake.

The 200 West Area contains six SST farms (S, SX, U, TX, TY, and T) that provided storage for waste generated at the T Plant, U Plant, and REDOX Plant. The 200 East Area contains six SST farms (C, B, BX, BY, A, and AX) that provided storage for waste generated at the PUREX Plant and B Plant. The 200 West and 200 East Areas also include six DST farms (SY, AN, AZ, AY, AW, and AP) that have received waste from the SSTs in past operations and also receive waste from ongoing SST waste retrieval operations.

In addition to the SSTs in the 200 West and 200 East Areas, the waste transfer infrastructure for each tank farm includes a complex system of pipelines (transfer lines), MUSTs, diversion boxes, vaults, valve pits, and other miscellaneous structures that are referred to as ancillary equipment.

Figure 2-24 is a three-dimensional graphic illustration of the tank infrastructure at WMA C as an example of the tanks and associated infrastructure described in this section. This graphic presents the complexity and variety of subsurface structures and equipment that support waste transfers.

Figure 2-22. Hanford Site Map and Location in Washington State



Tanks are grouped into farms within the 200 Areas.

Figure 2-23. Facilities in the 200 East and 200 West Areas

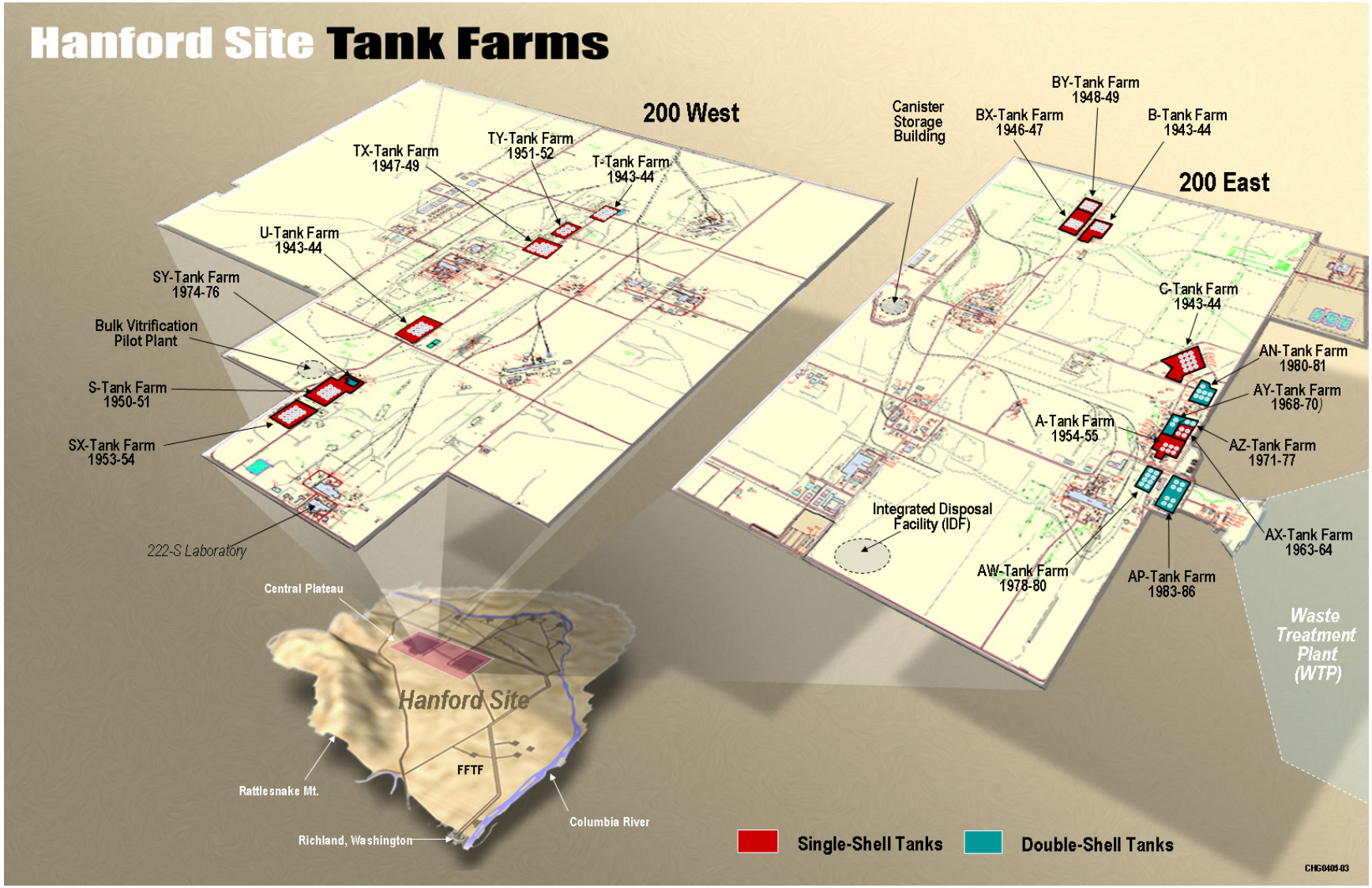
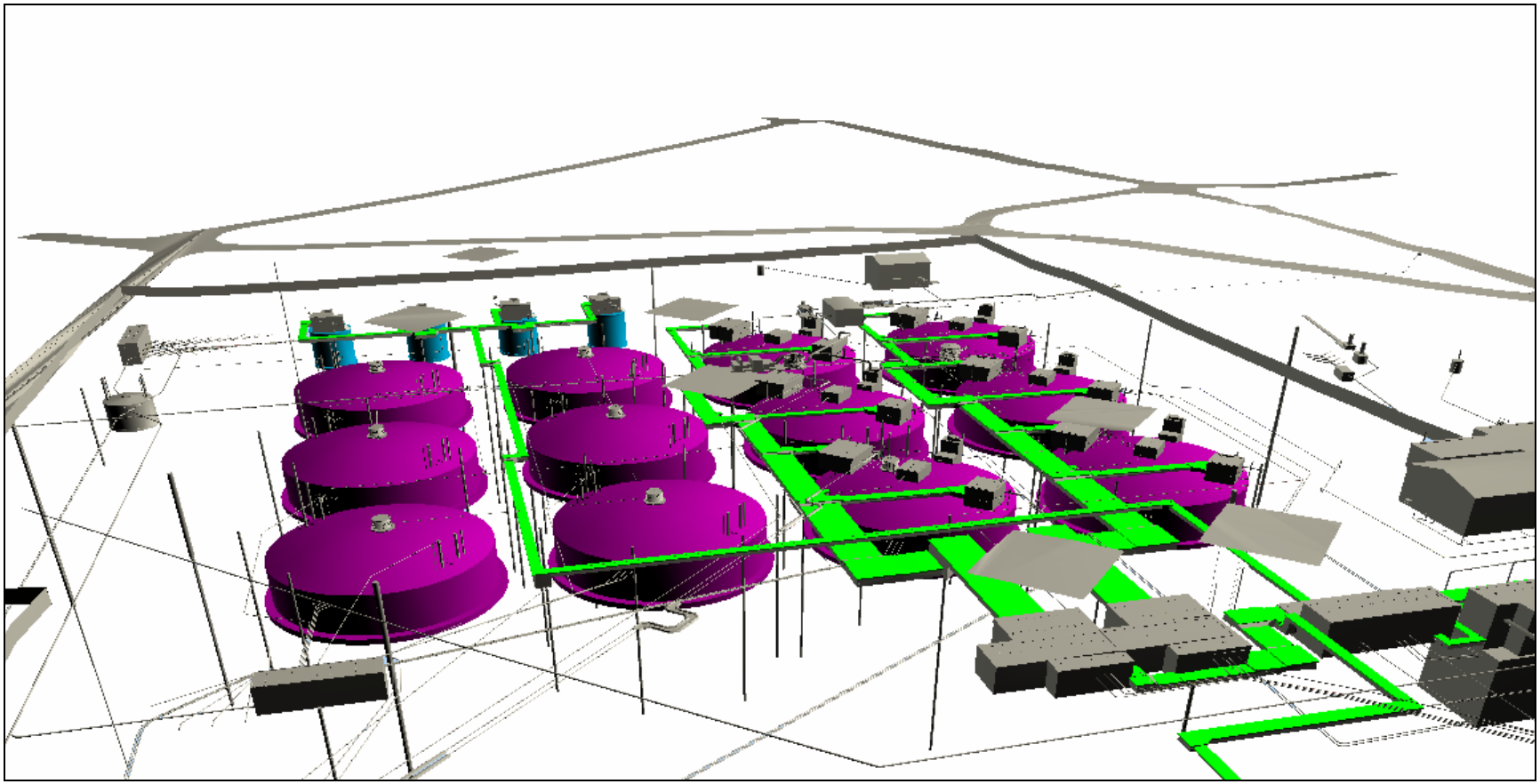


Figure 2-24. Tank Infrastructure at Waste Management Area C



2.4.1 100-Series Tanks

Three generations of 100-Series SSTs of varying sizes were constructed from 1943 to 1964, and all incorporated common design elements such as carbon-steel liners and cylindrical reinforced concrete structures as shown in Figure 2-25. For all designs of SSTs, the carbon steel liners covered the interior bottom and sides of the reinforced concrete cylindrical shell, but did not cover the domed top of each of the 100-Series tanks. All the 100-Series SST domes were designed and constructed with an internal exposed bare concrete surface as shown in Figure 2-26. Also, depending on the volume of the tank, the steel liners varied in height from 18 to 32 ft with specific tank diameters varying from 20 to 75 ft. The capacities of the SSTs range from 55,000 gal to 1,000,000 gal, and for the purpose of shielding personnel from radiation, all SST domes remain covered with a minimum of 7 ft of soil (Anderson 1990).

The first generation of SSTs were built from 1943 through 1948 and are located in B (1943–1944), BX (1946–1947), C (1943–1944), T (1943–1944), and U (1943–1944) tank farms. These tanks have a nominal inside diameter of 75 ft with a maximum design depth of approximately 16 ft, and a capacity of 530 kgal. In the B, C, T, and U farms, a smaller, 20-ft diameter, 24-ft deep tank was also built with a capacity of approximately 55 kgal. There are 60 first generation 530 kgal tanks and 16 first generation 55 kgal tanks (Anderson 1990). These tanks have dished bottoms and curved plates joining the bases to the vertical sides as shown in Figure 2-27.

Figure 2-25. Typical Single-Shell Tank

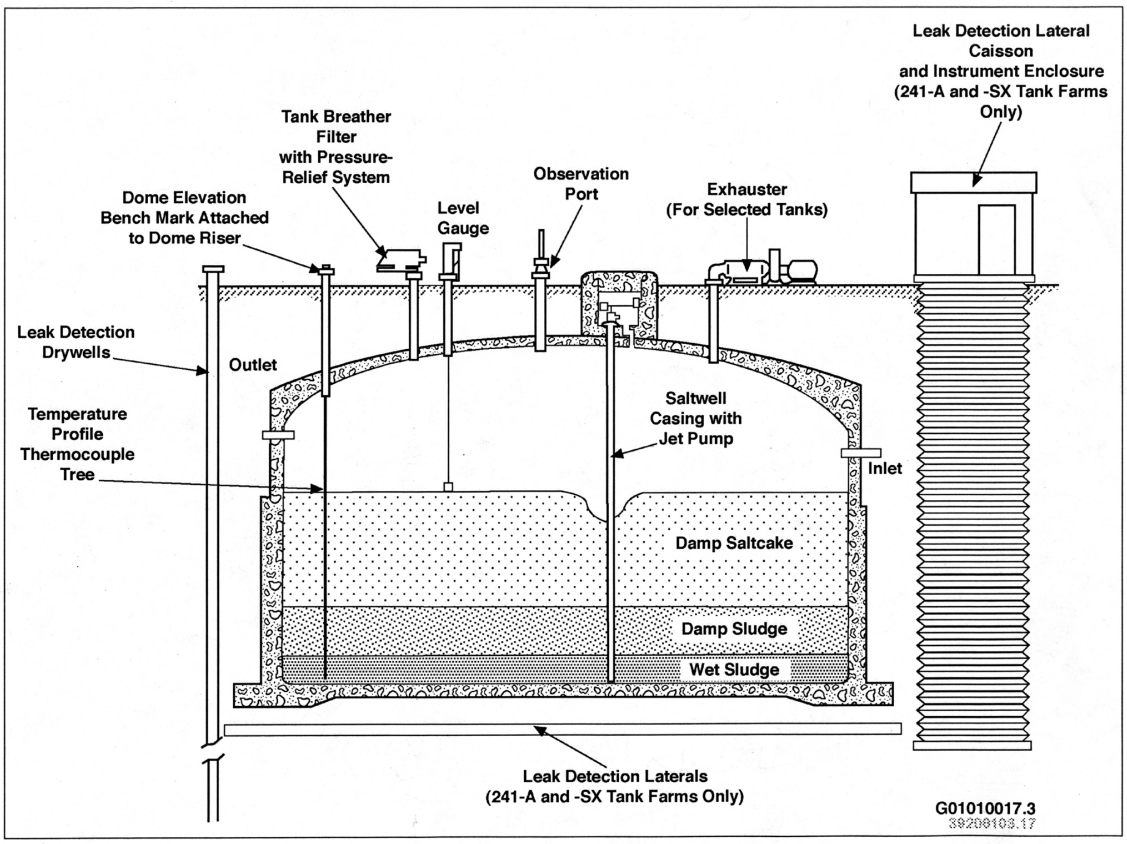


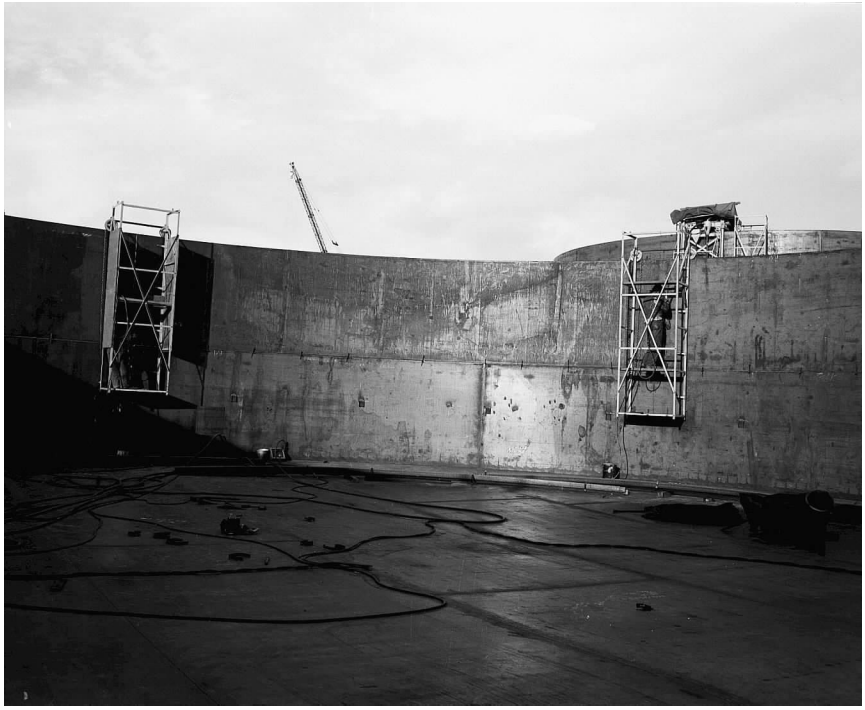
Figure 2-26. Bare Concrete Single-Shell Tank Dome

Figure 2-27. Transition from Tank Base to Vertical Wall (BX Tank Farm)

The second generation of SSTs were built from 1947 through 1953 and are found in the BY (1948–1949), S (1950–1951), TX (1947–1948), and TY (1951–1952) tank farms. These tanks have the same diameter and general construction as first generation tanks, but have an increased working depth of about 23 ft and a capacity of 758 kgal (Anderson 1990). There are 48 second generation 758 kgal tanks.

The third generation of SSTs were built from 1953 through 1963 and are found in the A (1954–1955), AX (1964), and SX (1953–1954) tank farms. The design and construction of the A and AX tanks differ from earlier generations in that the bases are not curved and the vertical sides were butt-welded to the bottoms as shown in Figure 2-28. These tanks have a capacity of approximately 1,000 kgal and a design depth of approximately 30 ft. There are 25 third generation 1,000 kgal tanks (Anderson 1990).

Figure 2-28. Flat Bottom and Butt Weld Joint, AX Tank Farm Construction



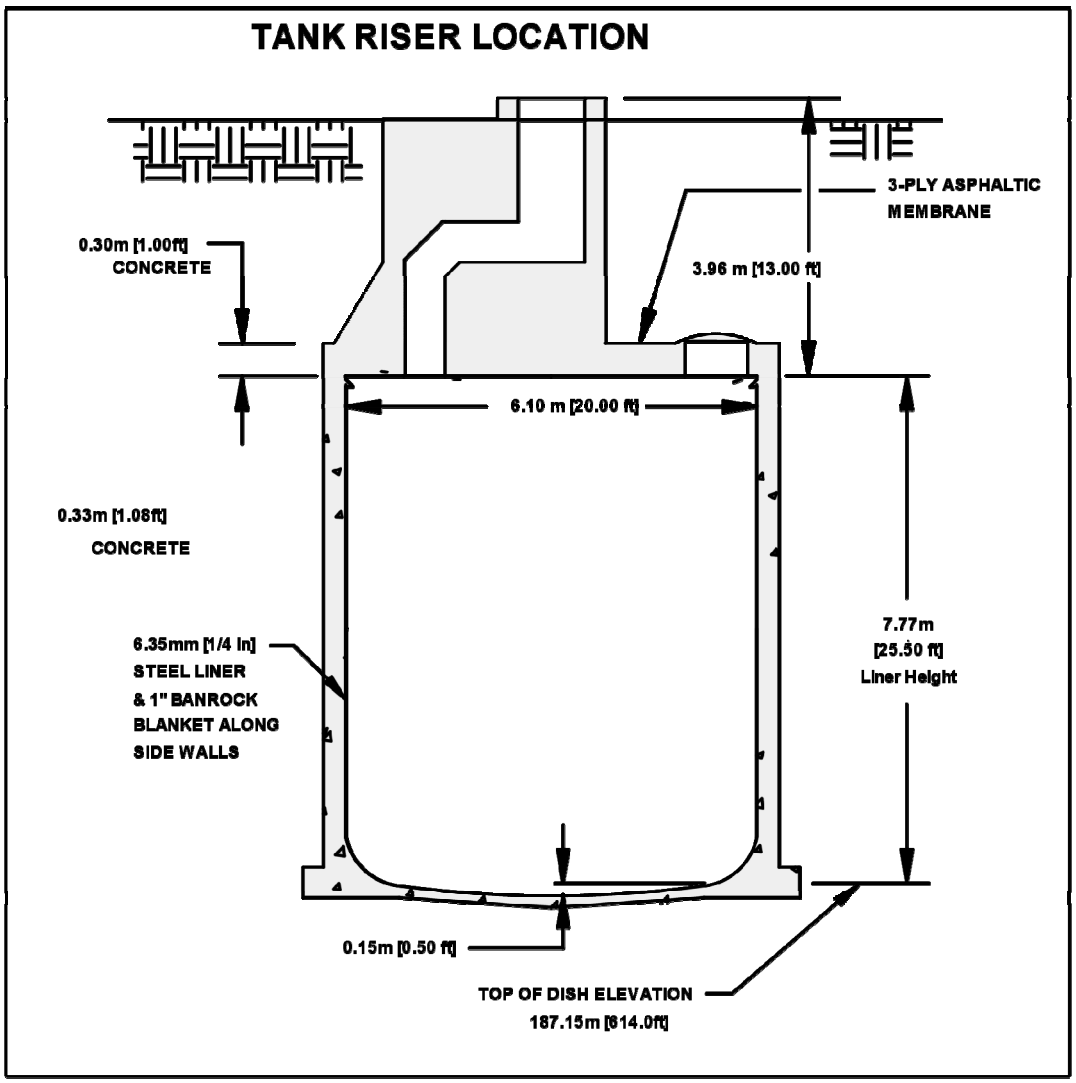
Each of the 100-Series SST design configurations (Figure 2-25) includes multiple risers that provide access to each tank from the surface. The risers are configured as either a section of a pipe or a square concrete pit that connects to the top of the tank from the surface. The risers and pits are placed directly above each tank and connect to the top of the tank at 6 to 8 ft belowgrade. The riser diameters range in size from 4 to 42 in. wide and are utilized to support placement of monitoring instruments, video camera observation equipment, tank ventilation, waste sampling equipment, and retrieval equipment to transfer waste to the DSTs (Anderson 1990).

The waste transfer between tanks occurred in part through inlet and outlet lines located near the top of the liners as shown in Figure 2-25. This allowed transfer of waste between tanks utilizing gravity flow and currently remains an option for waste transfer between some tanks located in the same farm. The risers also support waste retrieval to DSTs (Anderson 1990).

2.4.2 200-Series Tanks

The construction and operating history of the 200-Series tanks began in the late 1940s and ended in the late 1970s when SSTs were decommissioned from operational service. The 200-Series tanks have a diameter of 20 ft and a waste volume capacity of 55,000 gal. The wastes in the 200-Series tanks are typical of tanks designed for a specific process that required less tank volume, such as the pilot process studies of the Hot Semi-Works Facility. These were pre-operational studies that supported the PUREX Plant. The riser locations in the 200-Series tanks are shown in the profile view in Figure 2-29. The number of risers and riser diameters are less than that required to operate the 100-Series tanks. This limits the options for waste retrieval operations in the 200-Series tanks to smaller available retrieval machinery configurations (Anderson 1990).

Figure 2-29. 200-Series Single-Shell Tank



2.4.3 Ancillary Equipment

The following sections describe generic ancillary equipment associated with the SST farms and WMAs.

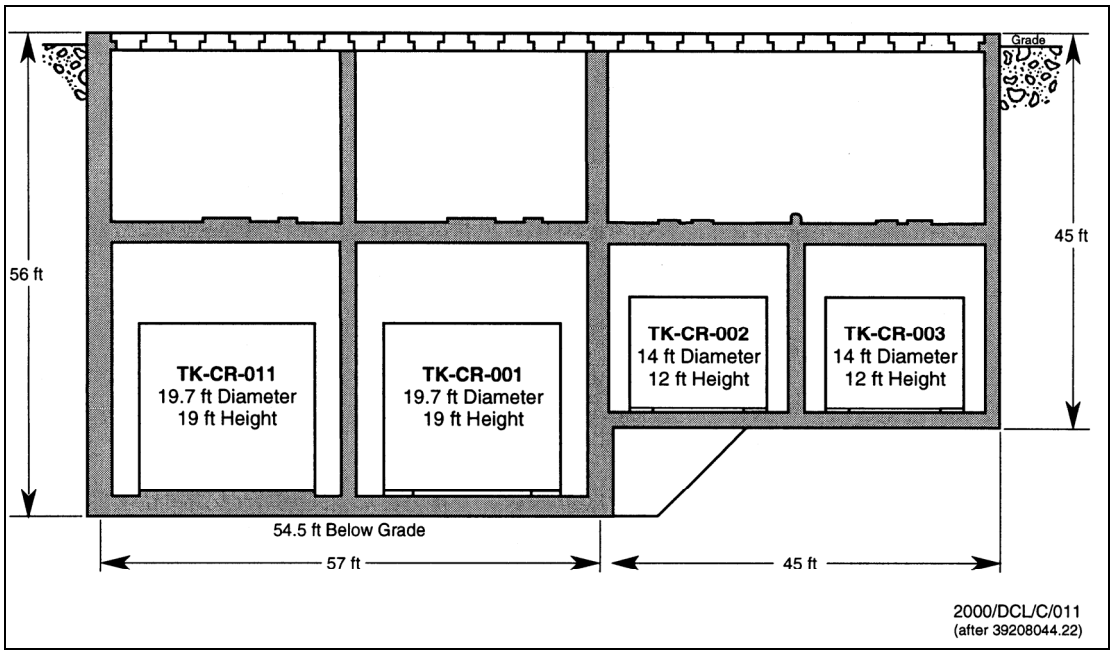
2.4.3.1 Miscellaneous Underground Storage Tanks

In addition to the 149 underground storage tanks (SSTs), there are active and inactive MUSTs in the 200 Areas. These tanks were constructed to three basic designs that included direct-buried concrete, concrete tanks with a steel liner, and direct-buried steel tanks. The MUSTs now designated inactive were used during processing and waste transfer operations and were not intended for use as long-term storage tanks. During past fuel processing operations, MUSTs were used primarily for waste solids settling, adding caustic to the waste stream, and as catch tanks. The MUSTs that are presently active are used as receiver tanks during waste transfer activities or as catch tanks to collect potential spills and leaks. Most of the inactive MUSTs were interim stabilized and isolated before September 1985 and range in size from 900 to 50,000 gal (Field 2003a).

2.4.3.2 Vaults

The 244-CR vault schematic shown in Figure 2-30 describes a typical two-level, multi-cell, reinforced concrete structure that was constructed belowgrade and contains four underground tanks along with overhead piping and equipment. Two of the tanks in this example have a capacity of 50,000 gal and two have capacities of 15,000 gal (Field 2003a).

Figure 2-30. 244-CR Waste Vault



2.4.3.3 Pits

Pits are belowgrade concrete enclosures with removable reinforced concrete cover blocks that contain pumps, monitoring equipment, and transfer systems. The type and number of pits associated with SSTs depend on the type of waste stored and the function of the SST. The pits located above the 100-Series and 200-Series tanks are collectively referred to as "at-tank pits" and include pump pits, sluice pits, heel pits, distribution pits, and saltwell caissons. These pits typically have a floor drain that drains directly back to the SST it services. The at-tank pits serve to collect spills or leaks from the equipment within the pit, but do not provide a storage function (Field 2003a).

The pits between tanks and between tank farms provide for flexible connection to the pipeline network, which allows waste to be transferred between tanks in the SST system. The between-tank pits include diversion boxes, valve pits, and flush pits. The valve pits and diversion boxes were designed to collect spills or leaks from the piping components within the boundaries of the pits (e.g., jumpers, valves). Also, piping encasements were designed to drain back into the valve pits and diversion boxes. As the pits were not designed to store waste, the collected liquids drained from the pit into a connected catch tank. Spray nozzles in the pits provide a means to flush these components after transfer operations (Field 2003a).

The diversion box shown in Figure 2-31 is similar to a valve pit and includes the switching facilities that allowed waste to be routed from one transfer line to another. Diversion of waste is accomplished by connecting two pipe ends by means of a "jumper," which is a rigid or flexible section of pipe used to connect waste transfer lines during transfers using non-dedicated routes.

2.4.3.4 Transfer Lines

Liquid waste was transferred from the processing plants (e.g., T Plant, Plutonium Finishing Plant, B Plant, PUREX) to the tank farms by underground transfer pipelines and also within tank farms to transfer waste between tanks. To shield workers from radiation, all of the transfer lines from each of the processing plants and those located within each farm are buried belowgrade. Most of the transfer lines installed during early operations are single-wall carbon-steel pipelines as shown in Figure 2-32, while lines installed at a later time are double-wall pipe with a stainless-steel inner pipe encased in an outer carbon-steel pipe. Some of the older transfer lines are either blocked or plugged, or failed pressure testing and cannot be used for waste transfers (Lambert 2005).

Figure 2-31. Diversion Box with Fixed Jumpers

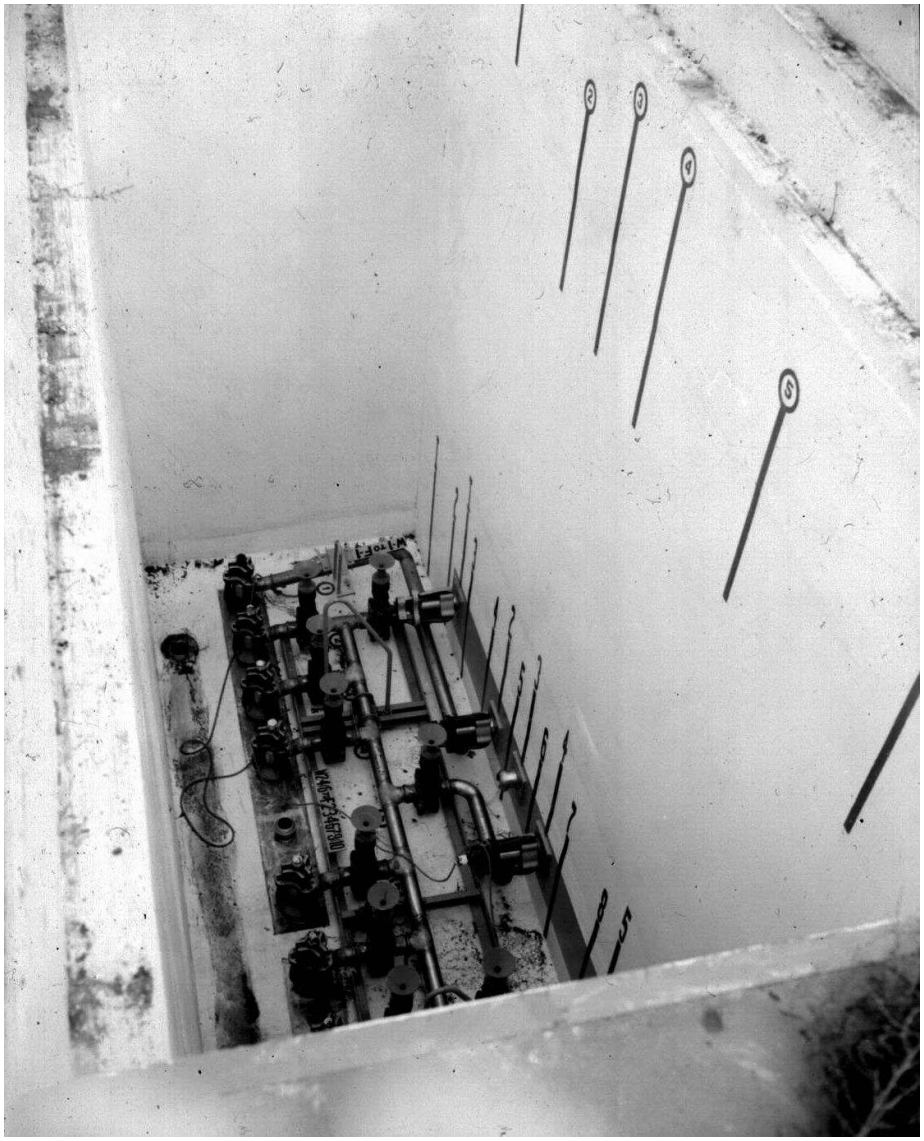


Figure 2-32. Waste Transfer Pipelines, BX Tank Farm, circa 1948

2.4.3.5 Catch Tanks

Catch tanks are underground storage tanks used to collect waste drained from waste transfer systems and tank farm equipment. Catch tank pits are located directly above the catch tank and typically contain pumps and leak detection equipment that support the transfer of drainage waste.

2.4.3.6 Caissons

Caissons are 12-ft diameter vertical structures buried approximately 70 ft belowgrade and are installed to detect radiation and obtain temperature profiles to evaluate tank integrity and monitor changing conditions in the tank. From each caisson, three laterals are bored horizontally under each tank to approximately 10 ft below the base pad elevation.

2.4.3.7 Wells

Each SST is ringed with a series of drywells that are approximately 6 in. in diameter, bottom open-ended, and sunk approximately 75 ft belowgrade. The opening of the encasement is below the elevation base slab of the tanks and located approximately 10 ft from the tank wall. The drywells can accommodate portable gamma and neutron detection devices (Field 2003a).

2.4.3.8 Utilities

Utilities are provided to support the operational capabilities required to stabilize waste, retrieve tank waste, and to ultimately close the tank. The following list describes the existing support facilities required to manage the tank waste in the 200 Areas:

- Water, both sanitary and process, is delivered to the 200 Areas by the Hanford Site water system.
- Electrical power is delivered to the Hanford Site by the Bonneville Power Administration. The 200 Areas have one substation with two independent transformers.
- Road and rail access is established to the 200 Areas.
- Tank waste and any new waste generated by retrieval operations are sent to the 242-A Evaporator to reduce waste volume and thus reduce required storage space.

Present and planned waste retrieval operations often require tank-specific modifications to utilities to support the retrieval equipment and specific technology deployed to retrieve waste from a tank.

2.5 SOURCE TERM INVENTORY

Contamination sources included in the SST PA are described in overview in Section 2.2.3. This section further describes the individual source terms and summarizes the method used to develop inventory estimates for each source term. The SST system conceptual model developed for the SST PA (Section 1.7) included four post-closure contamination sources consisting of tank residuals, ancillary equipment residuals, past UPRs, and hypothetical retrieval leaks. Hypothetical retrieval leaks are not included in the reference case analysis, but are considered in the "what if" scenarios. These sources will remain in the subsurface following waste retrieval and tank farm closure. For each of these source terms, an inventory of radionuclides and chemicals was developed for input into the performance assessment.

The Best-Basis Inventory (BBI) served as the basis for the inventory estimates developed for the SST PA. The BBI is the official database for tank waste inventories at the Hanford Site; its primary purpose is to provide inventories for the 177 SSTs and DSTs using an established methodology and consistent creation rules. The BBI process is described in *Best Basis Inventory Process Requirements* (Bowen 2004). BBI reports are available to approved users on the Tank Waste Information Network System (TWINS) (TWINS 2005). Information provided in the TWINS reports includes volume, inventory, and concentration values by waste phase (i.e., supernate, saltcake, sludge, retained gas) for each tank. The BBI integrates sample-based information (when available), process knowledge calculations, and waste type templates (sample-based or model-based) to estimate inventories for a standard set of analytes comprising 25 chemicals and 46 radionuclides in 177 tanks. Sample-based inventories for supplemental analytes are also included when available. The source term inventories represent the amount of post-closure contamination potentially available to impact human health through the use of groundwater (following contaminant release and migration) and through inadvertent intrusion into the closed waste sites.

Best-Basis Inventory

Official database for Hanford Site tank waste inventories. Provides current tank waste inventory estimates based on the "best" available information. In order of priority, reported inventory values may be sample-based, calculated, engineering-based, or template-based.

- When available, sample analyses are the preferred basis for information. Sample-based data are based directly on analytical results.
- Direct calculations are calculated values based on correlations with another analyte (e.g., yittrium-90 derived from strontium 90).
- Engineering-based values include values based on pre-1989 analytical results, results for one tank applied to another, and engineered process knowledge calculations (e.g., mass balance estimates to account for tank transfers).
- Waste type templates, either sample-based or model-based, are used to estimate tank inventories if tank-specific analyses or process knowledge calculations are not available.

The reference case inventory estimates developed for each source are shown in Table 2-4. The estimates shown are global SST system inventories. Similar tables showing estimates by WMA are given in Sections 2.6 through 2.12. Table 2-4 has been simplified to show only the contaminants that dominate post-closure impacts; however, all BBI contaminants are included in the reference case modeling analysis. A complete inventory per source term of all BBI contaminants is given in Appendix C. The contaminants that dominate the post-closure impacts, as shown by past analysis (Mann et al. 2001; Lee 2004), are carbon-14, technetium-99, iodine-129, uranium, nitrate, nitrite, and hexavalent chromium for the groundwater pathway, and strontium-90, technetium-99, tin-126, cesium-137, plutonium-239, plutonium-240, and americium-241 for inadvertent intruder impacts.

Source Term Inventories

- Global SST system source term inventories are provided in Table 2-4. To simplify the table, only the contaminants that dominate post-closure impacts are shown.
- All BBI contaminants are included in the reference case modeling analysis.
- Source term inventories for the individual WMAs are provided in Sections 2.6 through 2.12.
- Complete source term inventory data are provided in Appendix C.

Section 2.5.1 describes two models that were used to the support development of source term inventories used in the SST PA. Sections 2.5.2 through 2.5.5 discuss the inventories for the individual source terms. Finally, Section 2.5.6 provides a summary of the SST PA inventory development process.

Table 2-4. Single-Shell Tank System Post-Closure Inventory Estimates by Source Type

Source Type	Dominant Contaminants for Groundwater Pathway Impacts [a]							Dominant Contaminants for Inadvertent Intruder Impacts [a]						
	C-14 Ci	Tc-99 Ci	I-129 Ci	Cr(VI) kg	NO_3 kg	NO_2 kg	U kg	Sr-90 Ci	Tc-99 Ci	Sn-126 Ci	Cs-137 Ci	Pu-239 Ci	Pu-240 Ci	Am-241 Ci
Past releases [b]	3.87E+00	1.06E+02	1.37E-01	2.30E+03	2.07E+05	6.66E+04	1.03E+04	1.39E+04	1.06E+02	1.29E+00	1.67E+05	1.06E+01	1.97E+00	2.15E+01
Tank residuals	1.43E+00	1.37E+02	1.30E-01	1.45E+04	6.86E+04	9.83E+03	1.93E+04	1.43E+06	1.37E+02	9.23E+00	1.14E+05	1.63E+03	3.44E+02	2.84E+03
Ancillary equipment residuals [c]	1.81E-02	1.21E+00	8.16E-04	7.38E+01	6.75E+02	1.55E+02	1.82E+02	NA	NA	NA	NA	NA	NA	NA

[a] The reference case analysis included all BBI contaminants. As described in Bowen (2004), the standard analyte list tracked in the BBI contains **25 chemicals** including:

- aluminum
- bismuth
- calcium
- chlorine
- chromium
- fluorine
- total inorganic carbon as carbonate
- iron
- mercury
- potassium
- lanthanum
- manganese
- sodium
- nickel
- nitrite
- nitrate
- oxalate
- lead
- phosphate
- silicon
- sulfate
- strontium
- uranium total
- zirconium
- total organic carbon

and **46 radionuclides** including:

- tritium
- carbon-14
- nickel-59
- cobalt-60
- nickel-63
- selenium-79
- strontium-90
- yttrium-90
- zirconium-93
- niobium-93m
- technetium-99
- ruthenium-106
- cadmium-113m
- antimony-125
- tin-126
- iodine-129
- cesium-134
- cesium-137
- barium 137m
- samarium-151
- europium-152
- europium-154
- europium-155
- radium-226
- actinium-227
- radium-228
- thorium-229
- protactinium-131
- thorium-232
- uranium-232
- uranium-233
- uranium-234
- uranium-235
- uranium-236
- neptunium-237
- plutonium-238
- uranium-238
- plutonium-239
- plutonium-240
- americium-241
- plutonium-241
- curium 242
- plutonium-242
- americium-243
- curium-243
- curium-244

[b] Inventories shown are the combined inventories from SST past releases and ancillary equipment past releases. Both release types were considered for the groundwater pathway analysis; however, only the SST past releases were included in the inadvertent intruder analysis (along with SST residuals).

[c] NA indicates insufficient information is available to make estimates of intruder impacts into ancillary equipment (e.g., pipelines, diversion boxes).

2.5.1 Inventory Models

Given that, at this time, only one SST (241-C-106) has been retrieved and characterized for residual inventory, the inventory of tank residuals and concentrations of hypothetical retrieval fluid used in the analysis were based on model estimates rather than on actual measurements. These estimates were developed by using the present tank inventory as reported in the BBI as input to a dynamic simulator known as the Hanford Tank Waste Operations Simulator (HTWOS) (Naiknimbalkar 2005a) that tracks the mass of waste as it is moved through the Hanford SST and DST systems.

The Soil Inventory Model (SIM) (Simpson et al. 2001) was developed to estimate the inventory of constituents that have been released to the tank farm subsurface through past leaks, spills, and intentional discharges. The SIM uses release volume estimates as provided in Field and Jones (2005) along with historical process information and data to estimate the total inventory of a constituent released during a particular waste loss event.

Both the HTWOS and SIM are summarized below.

2.5.1.1 Hanford Tank Waste Operations Simulator

For tank residuals and hypothetical retrieval leaks, the HTWOS (Kirkbride et al. 2005) provided inventory estimates at closure for tank residue as well as the concentrations of radionuclides and hazardous chemicals in tank retrieval solutions. The HTWOS model is a dynamic event-simulation model that tracks the mass of waste as it moves through the Hanford Site SST and DST systems to planned or proposed treatment processes over the duration of the River Protection Program mission. Results from the model are used to prepare flowsheets and mass balances for the whole mission or for parts of the mission.

Hanford Tank Waste Operations Simulator

- A computer model that uses G2[1] software.
- Provides a dynamic flowsheet mass balance that tracks and calculates the movement of waste from tanks to treatment processes over the full life of the tank waste remediation mission.
- Generates in-tank retrieval fluid concentrations and post-retrieval residual waste inventory projections using data from the BBI as input.
- Used in the SST PA reference case to estimate post-retrieval contaminant inventories in SST residuals assuming waste is retrieved to the residual waste volume goals (360 ft^3 in 100-Series tanks, 30 ft^3 in 200-Series tanks) currently defined in the HFFACO (Ecology et al. 1989).
- Used in the SST PA sensitivity analysis to estimate contaminant concentrations in hypothetical retrieval leak fluids.

[1] G2 is a trademark of the Gensym Corporation, Burlington, Massachusetts.

HTWOS operates as both a dynamic continuous-simulator and as a dynamic event-simulator. As HTWOS transfers material from one tank to the next, it functions as a continuous-simulator. The material is pumped continuously until the stop pump conditions are reached. HTWOS then takes on the functionality of a dynamic event-simulator by evaluating the current conditions of both the source and receipt tank, looking at the current conditions of the remaining tanks in the tank farm system, and deciding what the next action will be for both the source and receipt tank.

The HTWOS model adheres to physical constraints inherent to the equipment and safety limitations, and to the programmatic constraints from current plans or business strategies. Using a set of technical and programmatic assumptions, the HTWOS model calculates the flow of events occurring during the retrieval, storage, pretreatment, vitrification, and supplemental treatments of Hanford Site tank waste. Technical and programmatic assumptions include, but are not limited to, capacity, volume, performance, dates of availability, outages, and commissioning.

The BBI program provides the composition and quantities of the chemicals and radionuclides stored in the DSTs and SSTs as input to the HTWOS model. The inventory is validated and verified in accordance with the BBI process (Bowen 2004). The HTWOS model uses the BBI in conjunction with the newly generated waste projection, the saltwell projections, and the historical waste transfers. It is adjusted to take into account radioactive decay.

The HTWOS model projections (Kirkbride et al. 2005) currently provide the best available estimates of the inventory that will remain in the SSTs at the completion of future waste retrieval activities. For purposes of the SST PA, the reference case post-retrieval SST residual waste inventory is projected with the HTWOS model assuming residual waste volumes meet the goal (360 ft^3 in 100-Series tanks, 30 ft^3 in 200-Series tanks) currently defined in the HFFACO (Ecology et al. 1989). For tank C-106, where waste retrieval activities have been completed, the reference case residual waste inventory is based on post-retrieval sample analysis rather than on HTWOS projections. As each additional SST is retrieved, its residual waste will be characterized and a sample-based post-retrieval final residual inventory estimate will be developed. Future assessments performed under the integrated regulatory closure process described in Chapter 1.0 will replace the model-based estimates used in this initial SST PA with the available sample-based residual waste inventory estimates.

2.5.1.2 Soil Inventory Model

The SIM (Simpson et al. 2001) was used to estimate inventories from past UPRs (e.g., tank leaks, spills, pipeline leaks). It is based on historical process records and data from the various process facilities at the Hanford Site that extracted plutonium and uranium from spent nuclear fuel and the volume of liquids discharged to the vadose zone. Data from samples collected from inside waste tanks and from historical waste management documents were also factored into the analyses to develop the inventory estimates and associated uncertainties. The model was applied to generate inventory estimates for 46 radionuclides and 27 chemicals from 88 liquid waste disposal sites, as well as to estimate tank leak inventories. The SIM has been updated (Corbin et al. 2005) to include more waste sites and the revised volume estimates for tank leaks and UPRs in the WMAs.

2.5.2 Past Releases

Numerous releases of tank waste, both planned and unplanned, have occurred in the past within the boundaries of the WMAs. This source type included the contamination that currently exists in the vadose zone beneath each WMA as a result of these past releases. The release events responsible for the contamination included leaks and releases (e.g., overfills) from tanks and ancillary equipment, surface spills, and intentional discharges to soil disposal facilities (e.g., cribs, trenches). Inventory estimates for past releases were generated by multiplying the estimated release volume for a waste loss event by the composition of the waste released estimated by the SIM. Past release volumes and compositions are further discussed below.

2.5.2.1 Past Release Volumes

The past release volume estimates used for the SST PA were taken from *Tank Farm Vadose Zone Contamination Volume Estimates* (Field and Jones 2005). Field and Jones (2005) provide updated release volume estimates based on a synthesis of information from previous investigations. Over the past decade, there has been a significant effort to better understand and quantify vadose zone contamination in and around the WMAs. The Field and Jones (2005) volume estimates were developed using the following sources of information:

- Spectral gamma logging of available drywells in the SST farms
- Analysis of historical gross gamma logging data collected from 1974 through 1994 in the SST farms
- Review of available historical tank farm operational records and tank leak documentation
- Field characterization in a number of the tank farms
- Science & Technology investigations that enhance the understanding of the interactions between tank waste materials and Hanford Site soils.

Field and Jones (2005) provide volume estimates for two groups of past releases:

- Releases from SSTs – Unplanned waste loss events generally originating as a tank leak (i.e., failure of the tank itself), tank overfill, or leak from at-tank ancillary equipment such as pump pits and cascade lines.
- Other documented UPRs and near-surface contamination – Unplanned waste loss events generally originating as a leak or spill from between-tank ancillary equipment such as valve pits, diversion boxes, and waste transfer lines.

The past releases from individual SSTs (group 1) included in the SST PA are identified in the WMA descriptions provided in Sections 2.6 through 2.12. Sixty-seven of the 149 Hanford Site SSTs are listed as "confirmed or assumed leakers" in Hanlon (2005). In preparing updated volume estimates for past SST releases to the vadose zone, Field and Jones (2005) added one new estimate (tank C-105) for a total of 68 SSTs. Both Hanlon (2005) and Field and Jones (2005) state that the available information concerning leaks did not provide a sufficient technical basis to develop volume estimates for 18 of those SSTs. Without a volume estimate, it is not possible to determine the mass/activity of material released to the vadose from those tanks. Therefore, a past leak is not applied to those 18 tanks in the reference case analysis.

The individual UPRs (group 2) included in the SST PA are also identified in the WMA descriptions provided in Sections 2.6 through 2.12. Each UPR has a formal report associated with it that is retrievable from the electronic database Waste Information Data System (WIDS) (Dietz 1999) over the Internet. The UPRs identified are those included in WIDS as of March 1, 2005, that had a reported location inside a WMA boundary and a release volume greater than 10 gal. There are 17 UPRs that have both a volume (Field and Jones 2005) and inventory estimate (Corbin et al. 2005). Other than the information presented in the WIDS, there has been little effort to further characterize or quantify surface contamination inside the WMAs. Although extensive surface contamination is found in some WMAs, except for a few UPRs (located in WMAs C and B-BX-BY), the volume of waste from UPRs is a small fraction of the total volume from SST releases.

Work is ongoing to better characterize vadose zone contamination in the WMAs. Volume estimates presented in Field and Jones (2005) will be updated as additional characterization data is made available and a better understanding of vadose zone contamination is obtained. Updates to the SST past release and UPR volumes will be evaluated under the integrated regulatory closure process described in Chapter 1.0.

Intentional discharges are not included in the SST PA. A number of cribs, trenches, and other intentional discharge facilities were constructed and operated in association with SST farm operations. Although most are located well outside the WMA boundaries, several are located inside (WMAs T and A) or in close proximity (WMA S-SX) to a WMA boundary. Evaluation of the intentional discharge facilities will be performed in the future under the integrated regulatory closure process described in Chapter 1.0.

2.5.2.2 Past Release Compositions

Vadose zone inventory calculations were performed using the updated SIM (Corbin et al. 2005). The SIM multiplies the contaminant volume for a waste loss event as provided by Field and Jones (2005) by an estimated mean waste composition from historical records to derive the inventory. Mean contaminant concentrations were determined based on the best available information for a waste loss event and waste type.

2.5.3 Residual Tank Waste

Residual tank waste, as defined in Appendix H of the HFFACO (Ecology et al. 1989), includes all waste remaining in the tank after waste retrieval actions have been completed. The current goal defined in the HFFACO is to leave a volume of less than 360 ft^3 of residual waste in the 100-Series SSTs and less than 30 ft^3 in the 200-Series SSTs. This source type included the contamination remaining in the SSTs following closure, assuming each tank is retrieved to a residual waste volume equal to the HFFACO goal.

Residual tank waste inventory estimates were generated with the HTWOS model (Kirkbride et al. 2005). Inventory estimates were generated by: 1) using tank-specific wash factors for water-soluble components, 2) specifying the minimum volume of water needed to produce either a 5 molar sodium solution or 10 wt% solids slurry, 3) assuming 360 ft^3 (100-Series SSTs) or 30 ft^3 (200-Series SSTs) of residual waste with 35 wt% solids, using the BBI tank inventory estimates, and 4) diluting the final liquid by 50% to simulate the effect of the

final sludge washing step. The wash factors used represent the proportional fraction of each component that dissolves, and thus distributes to the waste retrieval solution, during the waste retrieval process.

2.5.4 Residual Ancillary Equipment Waste

This source type included the post-closure residual contamination remaining in the SST ancillary equipment. Generic ancillary equipment descriptions are provided in Section 2.4.3. Each WMA contains a unique assortment of these ancillary components. A complete listing of the facilities associated with each WMA that are currently identified for inclusion in the SST system closure is provided in Lee (2004). Most ancillary components are located inside the WMA boundaries but some are located outside the boundaries. Only the primary ancillary components were included in the inventory estimates. The primary ancillary components consisted of the underground waste transfer piping and the ancillary underground storage tanks (MUSTs) (i.e., catch tanks, double-contained receiver tanks [DCRT], and vault tanks) located inside the boundaries of each WMA.

Ancillary Equipment Residual Waste

The SST PA includes residual waste inventory estimates for the primary ancillary components in each WMA. It is believed that these components will contain the bulk of the residual inventory remaining in tank farm ancillary equipment at closure. The primary ancillary components consist of:

- Plugged and blocked waste transfer pipelines located inside the waste management area boundaries
- MUSTs located inside the WMA boundaries (e.g., catch tanks, DCRTs, vault tanks).

The retrieval strategy for ancillary equipment and the nature and amount of waste that will be left in these components at closure are currently unknown. However, an assumed inventory for the residual waste in the piping and ancillary tanks was developed for purposes of this SST PA. Currently, the BBI does not track waste remaining in ancillary equipment. Therefore, waste remaining in the ancillary tanks was assumed to be retrieved to a residual volume proportional to that required under the HFFACO for the 200-Series tanks (Ecology et al. 1989). Lambert (2005) conducted an extensive literature review of historical records to determine the volume of waste in the plugged pipelines within each WMA. Pipeline residual inventories were calculated based on the plugged pipeline volumes given in Lambert (2005). Waste volume estimates for skin deposits within the pipelines are not currently available and were disregarded for the SST PA. Once the volume of residual waste remaining in ancillary equipment was estimated, the inventory associated with the waste volume was calculated by multiplying the volume by the average chemical composition of the waste in the SSTs within the tank farm.

The residual inventories developed for the plugged or blocked pipelines and ancillary tanks are believed to represent the bulk of the contamination that will remain in ancillary equipment at closure. Residual inventories associated with the remaining ancillary components are not currently available and were not included in this SST PA. Evaluation of the remaining ancillary components (e.g., valve pits, diversion boxes) is postponed until waste volume and inventory

information becomes available through the activity conducted under the integrated regulatory closure process described in Chapter 1.0. That activity includes the RCRA Facility Investigation/Corrective Measures Study (RFI/CMS) process scheduled to be completed in fiscal year 2007.

2.5.5 Hypothetical Retrieval Leaks

This source type, which is included only in sensitivity cases, included the post-closure vadose zone contamination associated with leaks that could potentially occur during waste retrieval from the SSTs. A discussion of the retrieval leak sensitivity analysis is provided in Section 3.5.6.2. Leak inventory estimates were developed for hypothetical leak volumes of 8,000 gal and 20,000 gal from 100-Series SSTs, and 400 gal from 200-Series SSTs. The leak inventories were generated by multiplying the hypothetical retrieval leak volume by the estimated contaminant concentrations in the retrieval leak fluids. The leak fluid concentrations were generated with the HTWOS model (Kirkbride et al. 2005).

2.5.6 Inventory Summary

Since this SST PA is the first attempt to understand risk levels following closure of the SSTs, the SST PA uses current understanding of the associated inventories for each source term. But as tanks are retrieved and the RFI/CMS process continues, actual characterization data will become available. Once the data become available, the modeled residual inventory (i.e., HTWOS) will be replaced by an inventory calculated on post-retrieval samples.

Following retrieval, post-retrieval samples of the residual waste are sent to the laboratory for chemical analysis. The concentrations from the post-retrieval samples are then used to calculate the total inventory based on the sample density and the volume of waste residual calculated after retrieval. This final waste inventory replaces the residual waste inventory calculated by HTWOS, and the modeling results for the WMA are updated to reflect the change in residual waste inventory for the newly retrieved tank. This is the process that was followed for 241-C-106. Furthermore, as DOE begins the process of closure, samples of the residual waste will also be sent to PNNL to develop a release model for the tank residual waste.

2.6 DESCRIPTION OF WASTE MANAGEMENT AREA S-SX

This section provides site-specific information for WMA S-SX. It is a summary from numerous documents that describe present conditions (Hanlon 2005), geology and hydrology (Reidel et al. 2006), subsurface contamination (Johnson et al. 1999; Knepp 2002a), and source terms (Kirkbride et al. 2005; Field and Jones 2005; Lambert 2005; Corbin et al. 2005).

2.6.1 Background

WMA S-SX is located in the southwest portion of the 200 West Area near the REDOX plant. In general, the WMA S-SX boundary is represented by the combined fencelines surrounding the S and SX tank farms (Figure 2-33). The S and SX tank farms were constructed in the 1950s to support operations at the REDOX plant, which operated from 1952 through 1967. The S tank farm contains twelve 100-Series SSTs that were constructed between 1950 and 1951 and put into service in 1951. The SX tank farm contains fifteen 100-Series SSTs that were constructed

between 1953 and 1954 and put into service in 1954. The two tank farms were used to store and transfer waste until the late 1970s and early 1980s.

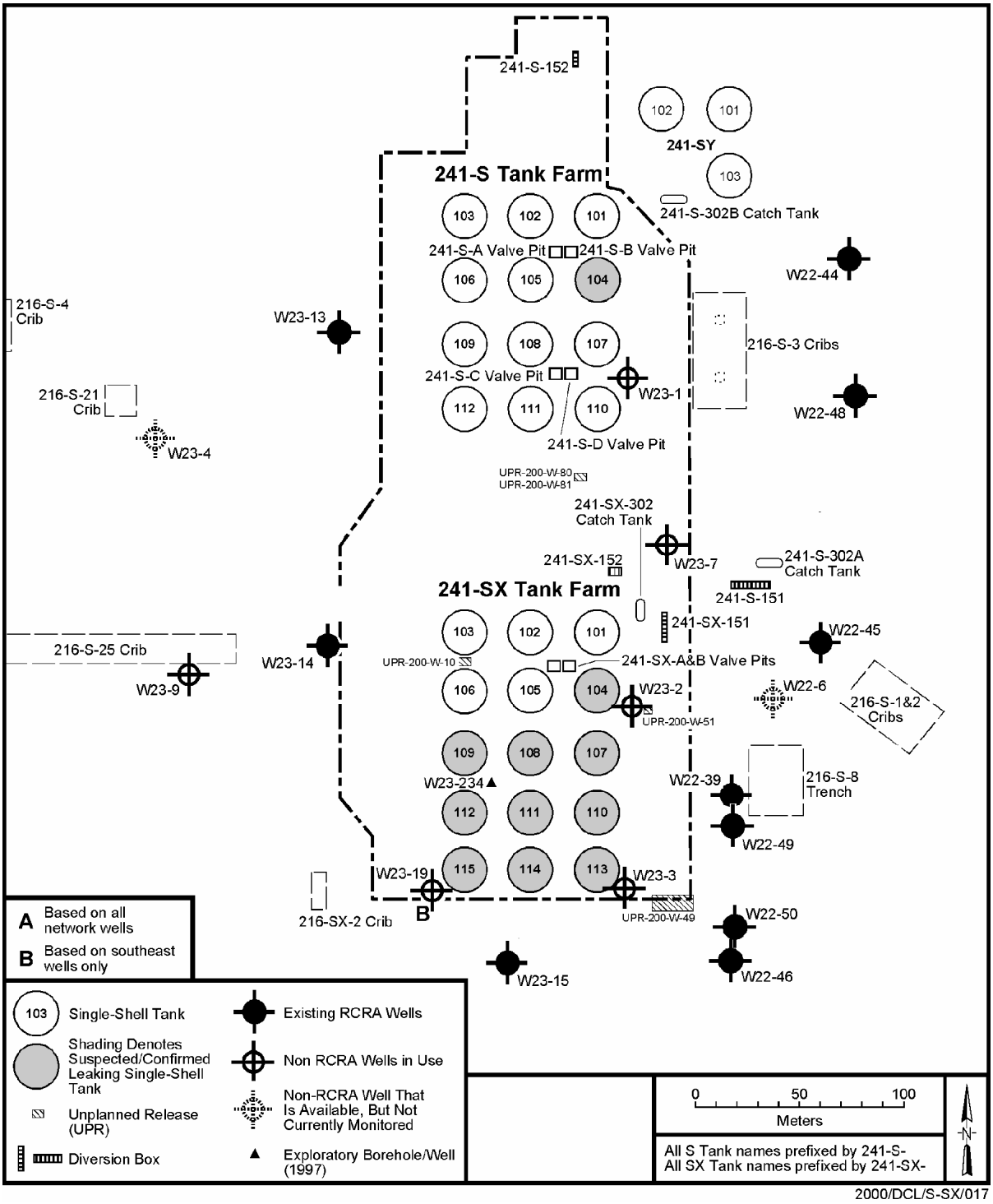
Currently, the pumpable liquid wastes have been removed from the WMA S-SX tanks and all tanks have been interim stabilized with the exception of two tanks. Tanks S-102 and S-112 were excluded from the interim stabilization requirements as the waste is being retrieved from the tanks as a closure activity. Table 2-5 lists the estimated volume of waste stored in the WMA S-SX tanks as of November 30, 2004 (Hanlon 2005). Interim measures have been implemented at WMA S-SX to minimize the infiltration from manmade water sources. These measures include capping monitoring wells, isolating water pipelines, and building berms around the tank farm boundaries.

The REDOX high-level waste (HLW) stream going to the S and SX tank farms contained high concentrations of short-lived radionuclides that generated considerable heat. Management of that heat dominated the operational history of the S and SX tank farms. Many tank farm facility modifications were implemented during the period of REDOX plant operations to address high-heat issues; a number of tank failures were directly related to these high-heat issues.

Detailed discussion of S and SX tank farm construction and operations along with historical information on soil surface and vadose zone contamination in WMA S-SX is provided in Williams (2001a). A detailed description of contaminant occurrences and environmental conditions at WMA S-SX is provided in Johnson et al. (1999).

Vadose zone field characterization activities were conducted at WMA S-SX during fiscal years 1998 through 2000 and a field investigation report (FIR) has been published to document the results of those investigations (Knepp 2002a). An initial evaluation of the projected impact of WMA S-SX final closure conditions on groundwater resources and human health risk based on current information has been published in Connelly (2004).

Figure 2-33. Location Map of Waste Management Area S-SX and Surrounding Facilities [a]



[a] *Knepp (2002a)*

Table 2-5. Waste Volume Estimates as of November 30, 2004, in Waste Management Area S-SX Single-Shell Tanks [a]

Tank	Total waste gal × 1,000	Supernate liquid gal × 1,000	Sludge gal × 1,000	Saltcake gal × 1,000
241-S-101	352	0	235	117
241-S-102	438	0	22	416
241-S-103	237	1	9	227
241-S-104	288	0	132	156
241-S-105	406	0	2	404
241-S-106	455	0	0	455
241-S-107	358	0	320	38
241-S-108	550	0	5	545
241-S-109	533	0	13	520
241-S-110	389	0	96	293
241-S-111	411	0	76	335
241-S-112	84	0	6	78
241-SX-101	419	0	144	275
241-SX-102	341	0	55	286
241-SX-103	509	0	78	431
241-SX-104	446	0	136	310
241-SX-105	375	0	63	312
241-SX-106	396	0	0	396
241-SX-107	94	0	94	0
241-SX-108	74	0	74	0
241-SX-109	241	0	66	175
241-SX-110	56	0	49	7
241-SX-111	115	0	98	17
241-SX-112	75	0	75	0
241-SX-113	19	0	19	0
241-SX-114	155	0	126	29
241-SX-115	4	0	4	0

[a] Hanlon (2005).

2.6.2 Infrastructure

This section describes the WMA S-SX infrastructure components that were included in the SST PA. Those components are listed in Table 2-6. Reference case inventory development for those components is described in Section 2.6.7. Refer to Section 2.4 for generic infrastructure component descriptions and Section 2.5 for a summary of infrastructure inventory development methods.

2.6.2.1 Single-Shell Tanks

The 12 S farm tanks are second generation 100-Series SSTs that are each 75 ft in diameter and approximately 37.3 ft tall from base to dome. Each tank has a 12-in. dish bottom, a 23-ft operating depth, and an operating capacity of 758,000 gal (Williams 2001a). The 15 SX farm tanks are third generation 100-Series SSTs that are each 75 ft in diameter and approximately 44 ft tall from base to dome. Each tank has a dished bottom, a 30-ft operating depth, and an operating capacity of 1 million gal.

The WMA S-SX tanks were all constructed in place with a carbon steel liner covering the bottom and sides of a reinforced concrete shell. All tanks sit belowgrade with at least 8.1 ft of soil cover at the S tank farm and 6 ft of soil cover at the SX tank farm. Typical tank configurations and dimensions are shown in Figure 2-34. Both S and SX SSTs were constructed with cascade overflow lines in three-tank series to allow gravity flow of liquid waste between the tanks.

The S farm tanks were designed to withstand pH values of 8 to 10 and fluid temperatures up to 220°F. The SX farm tanks were designed to withstand pH values of 8 to 10 and to hold self-boiling waste, with temperatures up to 250°F for a period of 1 to 5 years. The SX farm tanks were the first SSTs designed for self-boiling (self-concentrating) waste; however, the S farm tanks also received REDOX waste that self-boiled.

2.6.2.2 Ancillary Equipment

A complete listing of the WMA S-SX ancillary equipment currently identified for inclusion in the SST system closure is provided in (Lee 2004). As discussed in Section 2.5.4, the ancillary components included in the SST PA consisted of the underground waste transfer lines and MUSTs located inside each WMA boundary. For WMA S-SX, the ancillary components analyzed consisted of the S and SX tank farms waste transfer piping and one MUST (241-SX-302 catch tank). Multiple sets of waste transfer piping were installed in WMA S-SX over time. A time line of piping installations is described in Williams (2001a). It is estimated that there are approximately 8.7 mi (+/- 2.7 mi) of waste transfer piping in the S tank farm and 3.8 mi (+/- 1.1 mi) in the SX tank farm (Field 2003a).

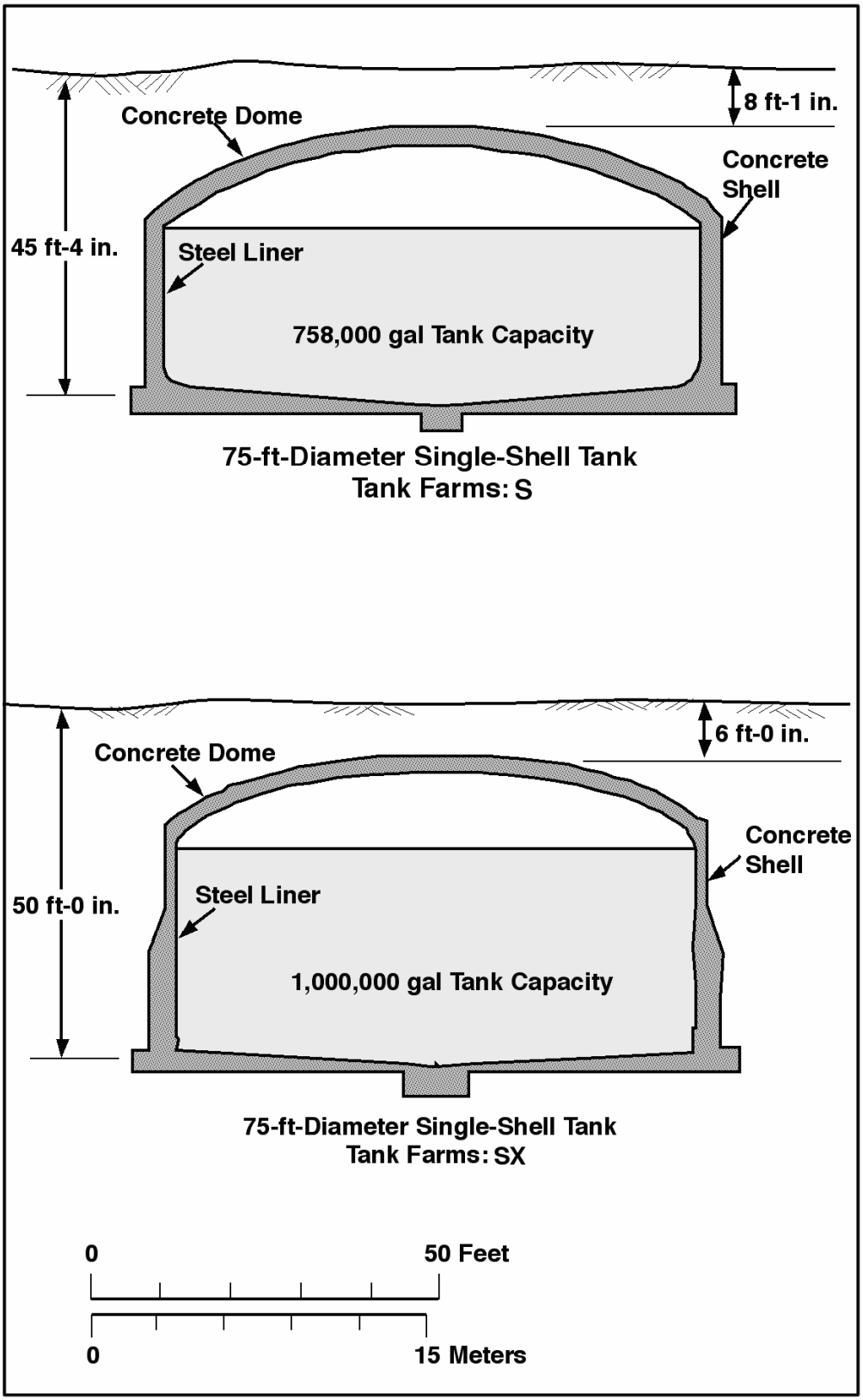
Table 2-6. Operating Period and Capacities for Waste Management Area S-SX Facilities Included in the Performance Assessment [a]

Facility	Removed From Service	Constructed	Operating Capacity gal
Single-Shell Tanks			
241-S-101	1980	1950 to 1951	758,000
241-S-102	1980		
241-S-103	1980		
241-S-104	1968		
241-S-105	1974		
241-S-106	1979		
241-S-107	1980		
241-S-108	1979		
241-S-109	1979		
241-S-110	1979		
241-S-111	1972		
241-S-112	1976		
241-SX-101	1980	1953 to 1954	1,000,000
241-SX-102	1980		
241-SX-103	1980		
241-SX-104	1980		
241-SX-105	1980		
241-SX-106	1980		
241-SX-107	1964		
241-SX-108	1962		
241-SX-109	1965		
241-SX-110	1976		
241-SX-111	1974		
241-SX-112	1969		
241-SX-113	1958		
241-SX-114	1972		
241-SX-115	1965		
Miscellaneous Underground Storage Tanks			
241-SX-302 catch tank	1983	1954	17,682
Underground Waste Transfer Lines			
241-S tank farm pipelines	NA	1950 to 1951	16,800 (+/-5,200)
241-SX tank farm pipelines	NA	1953 to 1954	7,300 (+/-2,200)

[a] Data on the facilities are from DOE-RL (2005) and Field (2003a).

NA = not applicable

Figure 2-34. Typical Configuration and Dimensions of Single-Shell Tanks in Waste Management Area S-SX



2.6.3 Geology

Following is an overview of the geology of WMA S-SX. More detailed information can be found in Reidel et al. (2006), Knepp (2002a), and Johnson et al. (1999). A generalized cross-section through WMA S-SX is shown in Figure 2-35. Maps and cross-sections presented in Reidel et al. (2006) illustrate the distribution and thicknesses of these units in additional detail.

Nine stratigraphic units are recognized within WMA S-SX. From oldest to youngest, the primary geologic units are:

- Columbia River Basalt Group
- Ringold Formation – member of Wooded Island
- Ringold Formation – member of Taylor Flat
- Cold Creek unit – lower carbonate rich sequence (CCU_l)
- Cold Creek unit – upper silt and sand sequence (CCU_u)
- Hanford formation – lower fine sand and silt sequence (H2 subunit)
- Hanford formation – middle coarse sand and gravel sequence (H1 subunit)
- Hanford formation – upper fine sand and top gravelly sand sequence (H1a subunit)
- Backfill.

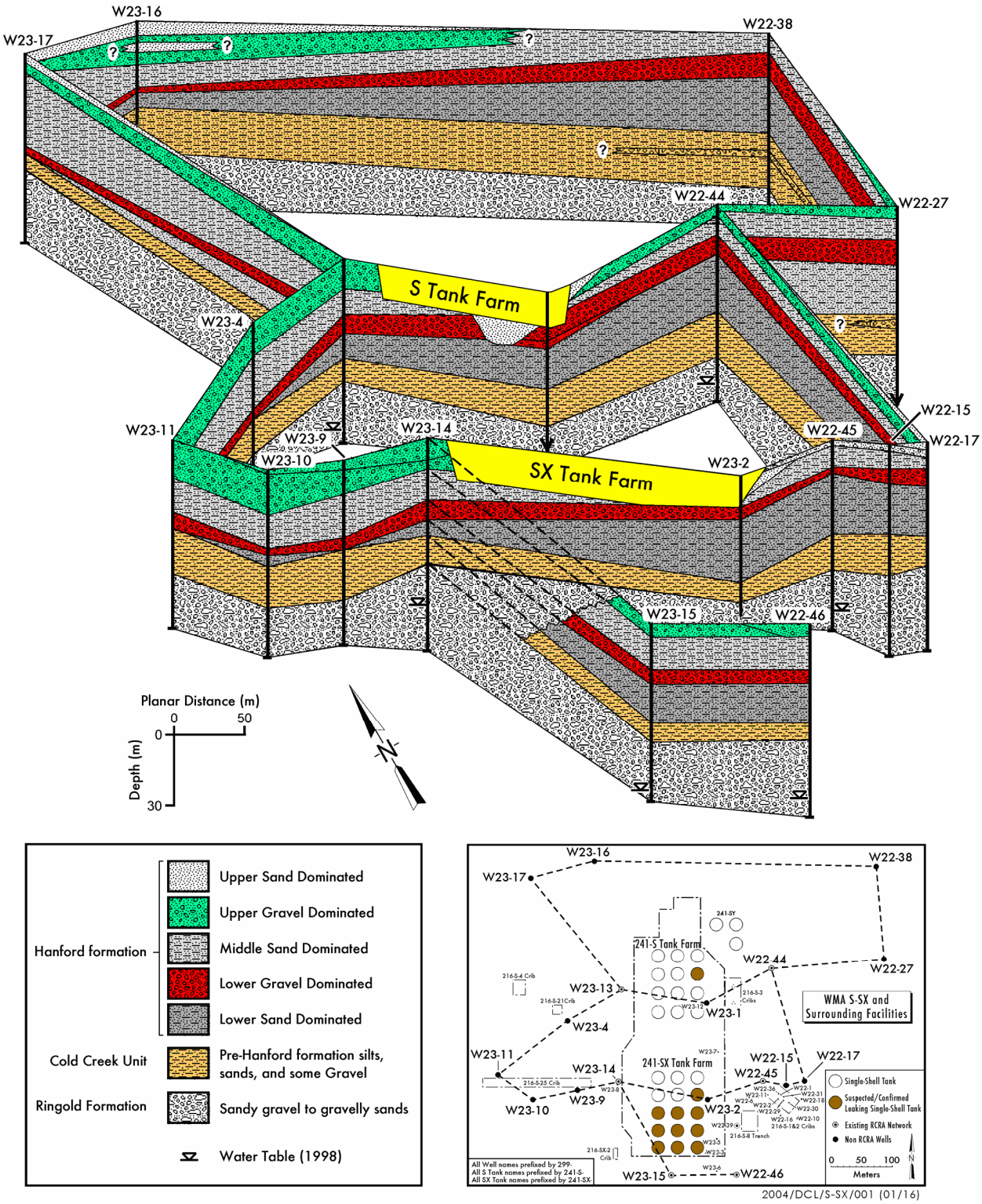
The general characteristics of these units are described in Section 2.3.4.1 and in more detail in Reidel et al. (2006). The SSTs at WMA S-SX were emplaced within the Hanford formation sediments of the upper sand-dominated (H1a) subunit, and may locally intercept the upper portions of the middle gravel-dominated Hanford (H1) unit. All but the surface of the Hanford formation have a general tendency to dip west to southwest toward the axis of the Cold Creek syncline (Figure 2-8 in Section 2.3). The vadose zone beneath WMA S-SX is as much as 65 m (213 ft) thick and consists of the Hanford formation, the Cold Creek unit, and the upper part of the Ringold Formation. The water table lies in the Ringold Formation, and the unconfined aquifer is located entirely within the Ringold Formation.

2.6.4 Hydrology

Following is an overview of the hydrology of the uppermost, unconfined aquifer beneath WMA S-SX. The general geohydrology of the Hanford Site is summarized in Section 2.3.5.2. More detailed information can be found in Reidel et al. (2006), Knepp (2002a), Johnson et al. (1999), and Hartman et al. (2004). Currently, the general groundwater flow direction in the unconfined aquifer beneath WMA S-SX is to the east-southeast. The estimated hydraulic gradient in this region is 0.0018 to 0.0019. The general groundwater flow velocity ranges from 0.009 to 0.36 m/day (Hartman et al. 2004).

Water level data collected from monitoring wells located near and inside WMA S-SX (299-W23-1, 299-W23-3, 299-W23-4) indicate that between the early 1950s and mid 1960s, the water table in the vicinity of WMA S-SX rose about 11 m in response to wastewater discharges to the 216-U-10 pond. The water table elevation remained fairly steady between 1965 and 1984. Water levels began to decline rapidly in 1985, when discharge to the 216-U-10 pond ceased. That decline continues today. Water levels have decreased by about 11 m in the WMA S-SX area since 1985, and have returned to levels consistent with those observed in the early 1950s.

Figure 2-35. Fence Diagram Showing Cross-Sections through Waste Management Area S-SX [a]



[a] *Reidel et al. (2006)*

The aquifer resides in partially cemented sands and gravels of the Ringold Formation member of Wooded Island (subunit E). Currently, the water table beneath WMA S-SX lies approximately 136 m above mean sea level (amsl), resulting in about 78 m of vadose zone (Khaleel et al. 2006b). The unconfined aquifer is about 67 m thick (Reidel et al. 2006), and hydraulic conductivity values reported for the aquifer in this area range from 0.15 to 17.2 m/day (Thorne and Newcomber 2002). Additional hydraulic property data from aquifer testing at wells near WMA S-SX are provided in Reidel et al. (2006) and Hartman et al. (2004).

2.6.5 Vadose Zone Conditions

This section summarizes WMA S-SX vadose zone monitoring and characterization activities and the current understanding of contamination in the vadose zone.

2.6.5.1 Monitoring and Characterization

The S tank farm has 72 leak detection wells currently available for leak detection monitoring and to provide access for limited vadose zone characterization. These drywells were drilled from 1952 to 1976. The depth ranges for these drywells are between 55 and 150 ft bgs. The S tank farm layout showing drywell locations in reference to tanks is shown in Figure 2-36.

The SX tank farm currently has 98 leak detection drywells that were drilled from 1954 to 1978. In addition to the vertical drywells, 10 of the 15 tanks have horizontal leak detection laterals (horizontal pipes radiating from a central caisson) installed approximately 10 ft below the tank bottom. The laterals are currently inaccessible and there have been no plans prepared to make further use of them. Two additional drywells were drilled and installed in 1996 and 1997: drywell 41-09-39, which was extended to groundwater in 1997, and drywell 41-12-01. The SX tank farm layout showing drywell, caisson, and lateral locations in reference to tanks is shown in Figure 2-37.

Both gross gamma ray and spectral gamma logging methods have been performed in the WMA S-SX drywells. Gross gamma logging of the vertical drywells and horizontal laterals was performed to support secondary leak detection of the SSTs during the period 1961 to 1994. Readily useable gross gamma logging data are available dating back to 1974.

In 1995, 95 drywells were logged in the SX tank farm with a high-resolution spectral gamma logging system and the results were published in DOE-GJO (1996). In 1996, 68 drywells were logged in the S tank farm with the spectral gamma logging system and the results were published in DOE-GJO (1998a). These efforts were part of the baseline characterization for WMA S-SX.

In 1999, repeat logging of selected borehole intervals, logging in new boreholes, and enhancements to the original baseline characterization data evaluation process were performed for drywells in WMA S-SX. This updated information is documented in DOE-GJO (2000a, 2000b).

Figure 2-36. Vadose Zone Monitoring Network for S Tank Farm in Waste Management Area S-SX

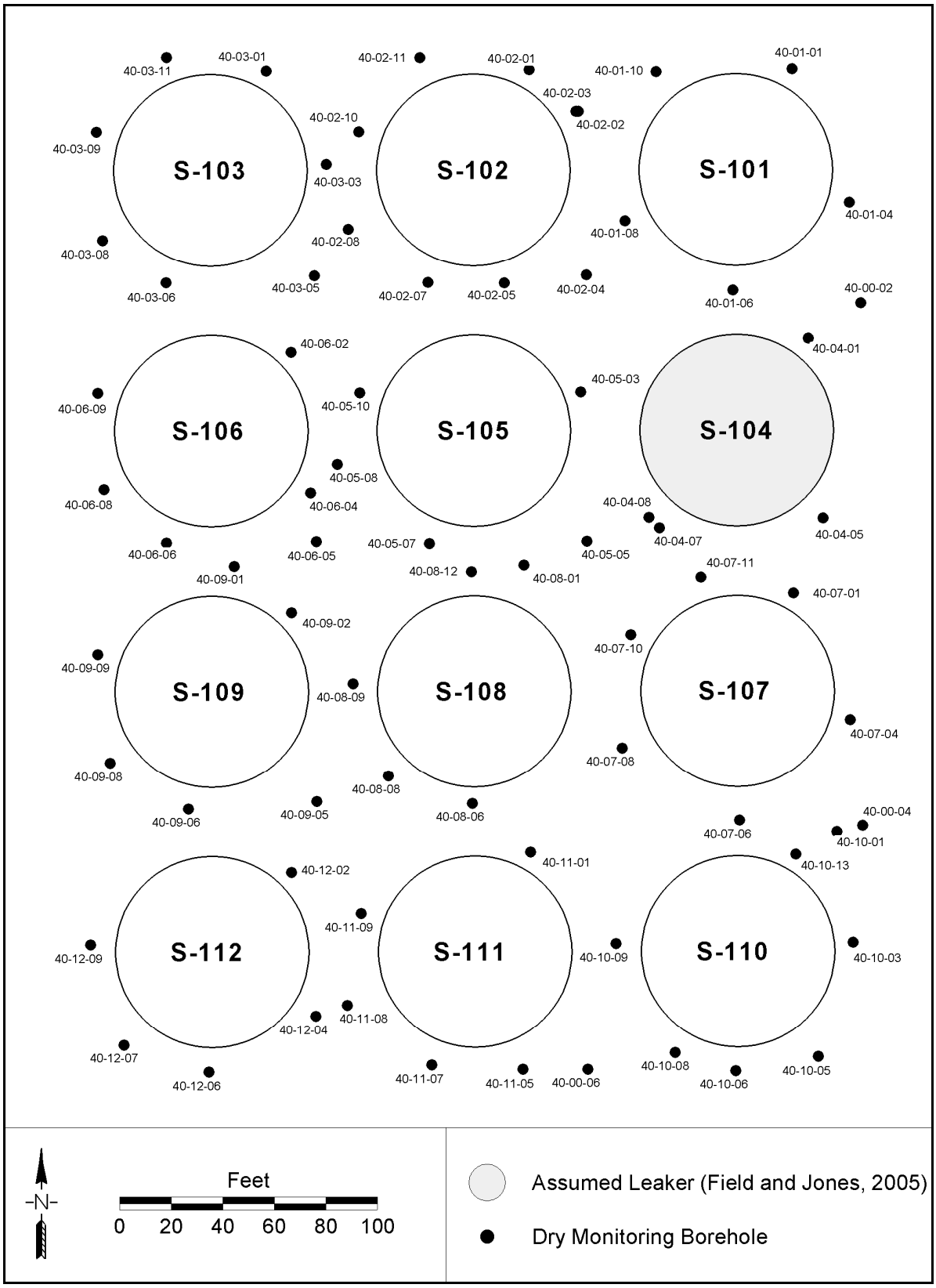
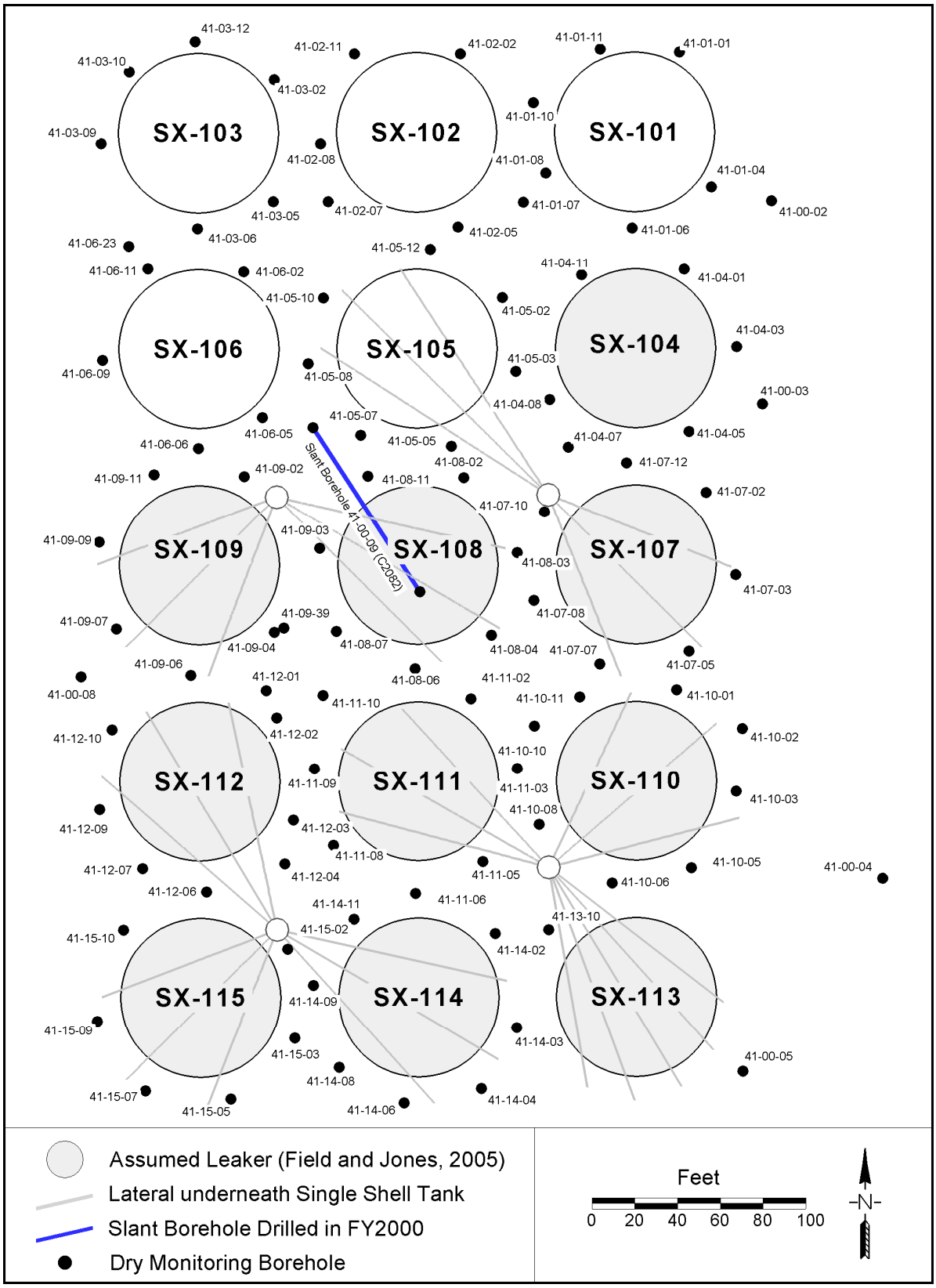


Figure 2-37. Vadose Zone Monitoring Network for SX Tank Farm in Waste Management Area S-SX



During fiscal years 1998 through 2000, field characterization efforts were conducted at WMA S-SX in support of RCRA Corrective Action requirements. The investigative approach for this work is described in Henderson (1999) and Rogers and Knepp (2000a). These efforts included collection of vadose zone sampling data from the following activities:

- Installation of groundwater wells 299-W23-19, 299-W23-48, 299-W23-49, and 299-W23-50
- Installation of an exploratory slant borehole beneath tank SX-108
- Sediment sampling and decommissioning of well 299-W23-234 (also known as borehole 41-09-39)
- Shallow vadose zone soil investigation around tank S-104.

A detailed discussion of these investigations and an analysis of the results are included in the S-SX FIR (Knepp 2002a).

2.6.5.2 Contamination

Figures 2-38 and 2-39 provide a visualization of the vadose zone contamination beneath WMA S-SX as represented by cesium-137 data. These figures show a three-dimensional perspective of each tank farm providing locations of tanks and associated drywells. Tanks considered to be assumed leakers based on information in Field and Jones (2005) are shown with darker shading. 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 (>5 pCi/g) are shown for S tank farm and (>10 pCi/g). Zones with contamination levels less than these are not shown.

Detailed discussion of the historical gross gamma and recent spectral gamma surveying at WMA S-SX is provided in Johnson et al. (1999) and Knepp (2002a). The primary gamma-emitting contaminants detected in the vadose zone beneath the S tank farm are cesium-137 and cobalt-60. Europium-154 was detected only around borehole 40-01-08 between ground surface and 10 ft bgs. The gamma logging data indicate that contamination in the S tank farm is limited, particularly below a depth of 35 ft. The contaminant locations are consistent with the historical record, which identifies a large surface leak from a junction box close to tank S-102 and a suspected leak from tank S-104. Drywell 40-04-05 in S tank farm is the only drywell that indicates contamination above 100 pCi/g below a depth of 35 ft.

The primary gamma-emitting contaminant detected in the vadose zone beneath the SX tank farm is cesium-137. Only minor quantities of cobalt-60 and europium-154 were detected near the surface in isolated occurrences. These shallow occurrences are attributed to small surface spills and near-surface pipeline leaks. The gamma logging data indicate that contamination in the SX tank farm is far more widespread than in the S tank farm. In general, the location and intensity of gamma readings in the northern part of the SX tank farm (tanks SX-101 through SX-106) are mostly between 10 and 100 pCi/g above a depth of 35 ft. These readings are characteristic of surface/piping leaks.

Figure 2-38. Three-Dimensional Perspective of S Tank Farm Tanks and Drywells Showing Occurrence of Significant (>5 pCi/g) Cesium-137 Contamination in the Vadose Zone

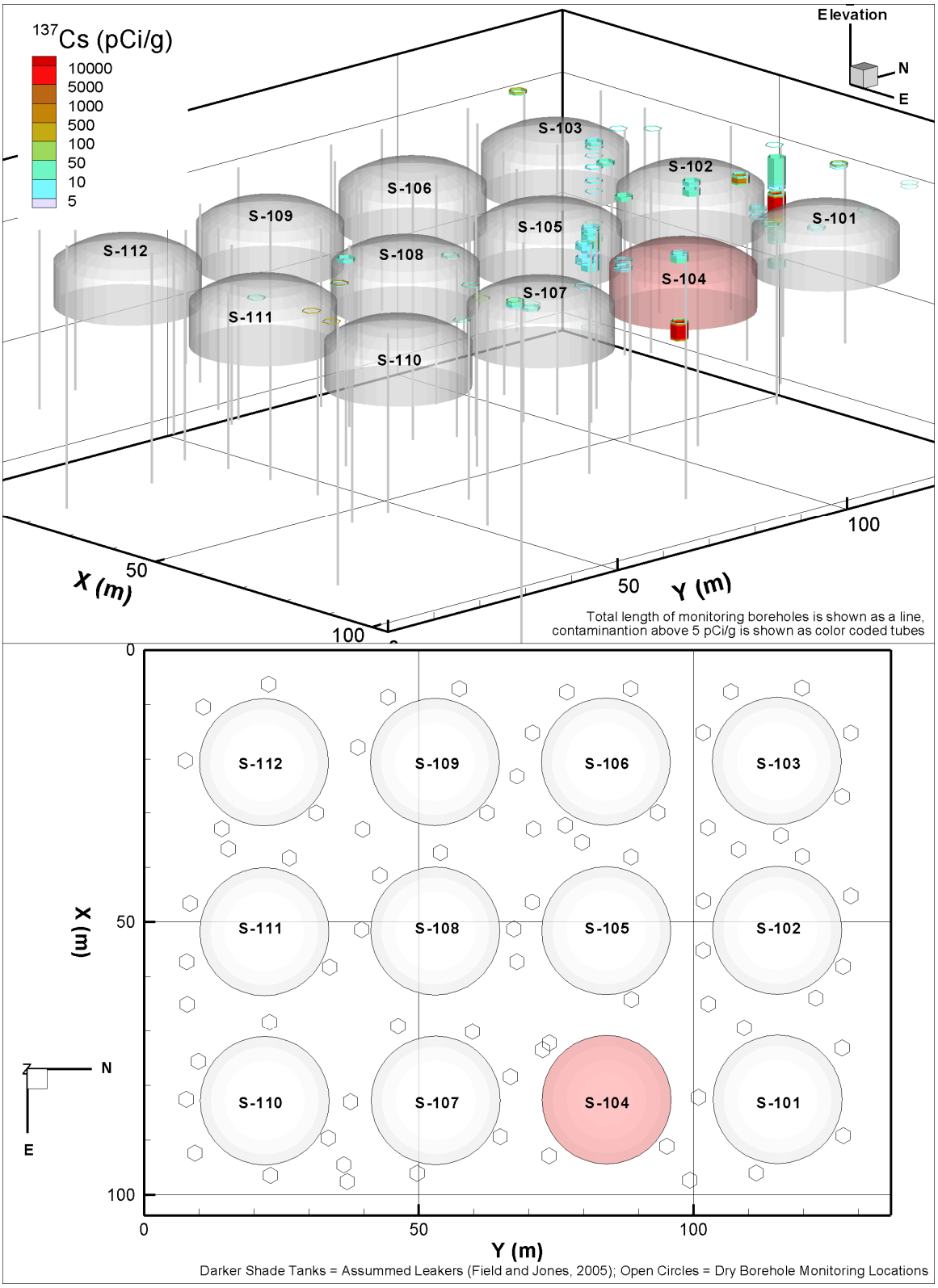
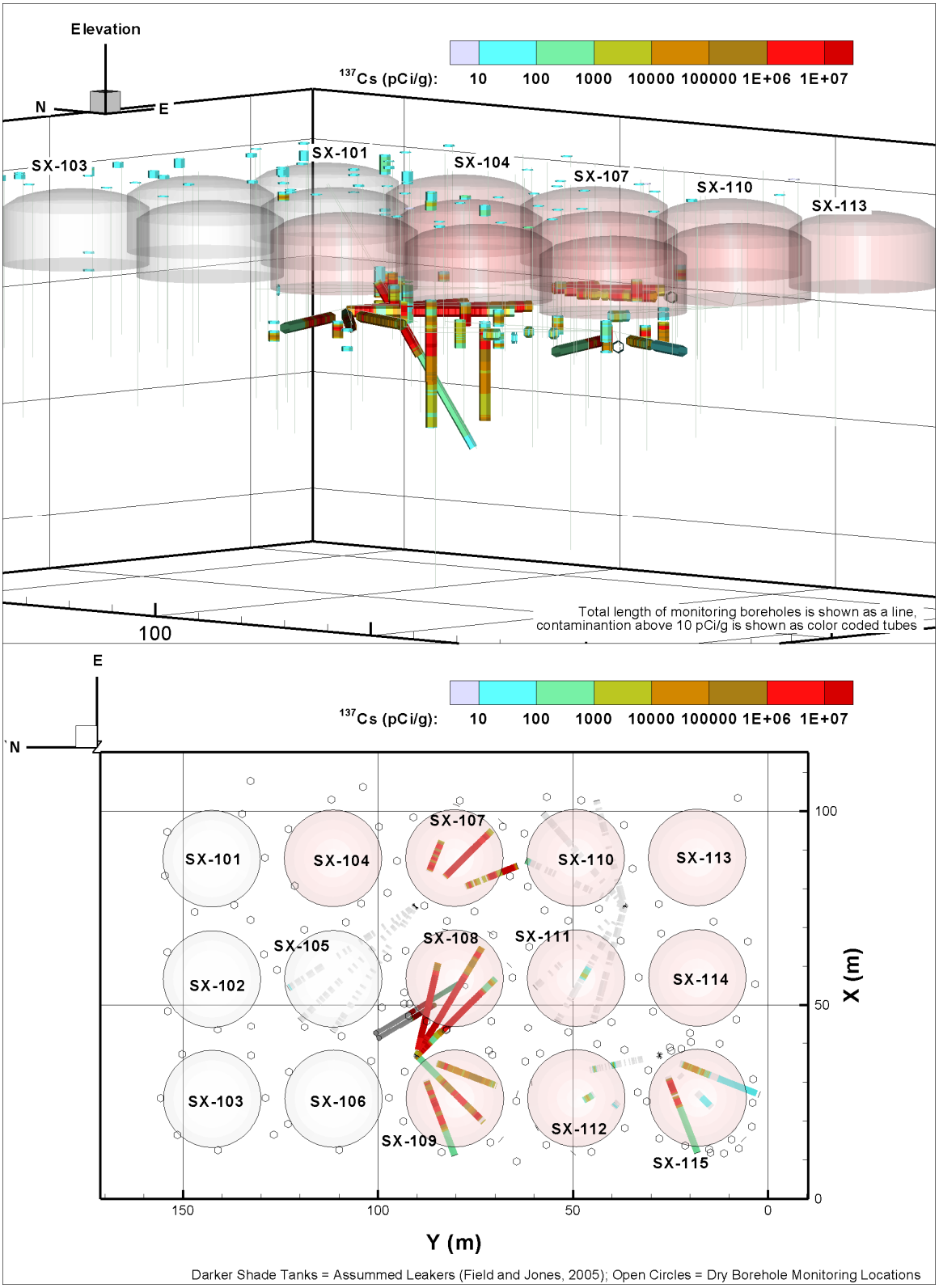


Figure 2-39. Three-Dimensional Perspective of SX Tank Farm Tanks and Drywells Showing Occurrence of Significant (>10 pCi/g) Cesium-137 Contamination in the Vadose Zone



Conversely, in the southern part of the SX tank farm (tanks SX-107 through SX-115), gamma readings are mostly below 35 ft in depth and well above 100 pCi/g. These characteristics are consistent with tank leaks. Cesium-137 occurs at depths from just below the tank bottoms to at least 132 ft bgs. This deep contamination occurs on the south side of tank SX-107, between tanks SX-108 and SX-109, at the southwestern quadrant of tank SX-109, on the northeast side of tank SX-112, and around tank SX-102. Figure 2-37 shows the drywells where contamination concentrations have increased over time and migration apparently continues.

The FIR for WMA S-SX (Knepp 2002a) provides an in-depth analysis of the historical information and vadose zone data collected through 2001. Based on this analysis, it was determined that three main areas of contamination exist in the vadose zone underlying WMA S-SX. These include the areas around the following tanks:

- Tanks SX-107, SX-108, SX-109
- Tanks SX-113, SX-115
- Tank S-104.

Evidence from the historical record suggests that the largest leaks in WMA S-SX came from these tanks or associated infrastructure. Comparison of gamma data within these three areas shows cesium-137 to be much more extensively distributed both horizontally and vertically in the area around tanks SX-107, SX-108, and SX-109. In the areas around tanks SX-113, SX-115, and S-104, cesium-137 is measured in one drywell very close to the side of each tank.

Spectral gamma logging data also indicate the presence of generalized near-surface contamination across WMA S-SX. A number of surface and near-surface spills and UPRs were documented in and around WMA S-SX. Summary descriptions of these events are provided in Williams (2001a). Most appear to have been minor releases that made relatively insignificant contributions to vadose zone contamination. Recent field characterization efforts for the S-SX FIR (Knepp 2002a) were mostly directed toward the areas around larger known release events. Little recent characterization data have been collected for the areas around minor release events.

2.6.6 Unconfined Aquifer Conditions

This section summarizes WMA S-SX groundwater monitoring and characterization activities and the current understanding of contamination in the unconfined aquifer.

2.6.6.1 Monitoring and Characterization

WMA S-SX was placed into assessment status in 1996 at the direction of Ecology because of elevated specific conductance in downgradient monitoring wells. A groundwater quality assessment plan (Caggiano 1996) was prepared in 1996 and the planned assessment work conducted in 1996 and 1997. This assessment determined that multiple sources within WMA S-SX had affected groundwater quality with elevated concentrations of nitrate and chromium in wells downgradient of the WMA (Johnson and Chou 1998).

A second groundwater quality assessment plan (Johnson and Chou 1999) was prepared in 1999 to further evaluate the contamination. Since that time, two groundwater quality assessment

reports (Johnson and Chou 2001, 2002) were published that cover the time period from November 1997 through December 2001.

The assessment plan (Johnson and Chou 1999) was revised twice to account for new wells added to the monitoring network and revisions to the sampling and analysis schedule. RCRA groundwater assessment monitoring results are included in quarterly reports to Ecology and annually, as required, in the groundwater monitoring annual reports (e.g., Hartman et al. 2003, 2004, 2005).

Currently, the monitoring network consists of 16 wells: 2 upgradient and 13 downgradient of the WMA, and 1 well located within the area. Three new wells were installed in 1999, six in 2000, and two in 2001 to improve the spatial coverage and to replace wells going dry because of the declining water table. The wells are sampled quarterly. The well list, constituents, and sampling frequency are provided in Hartman et al. (2004). All 16 wells were sampled each quarter during fiscal year 2003. One additional well was scheduled for construction during fiscal year 2004 southeast of the WMA, due south of well 299-W22-46, to better define the south boundary of a contaminant plume in this area (Figure 2-33).

Monitoring under the assessment-monitoring program will continue until the entire WMA is closed and post-closure monitoring is implemented, or until such time that there is a shift in the monitoring status of the WMA. Changes in the monitoring program status will be documented in an approved groundwater monitoring plan.

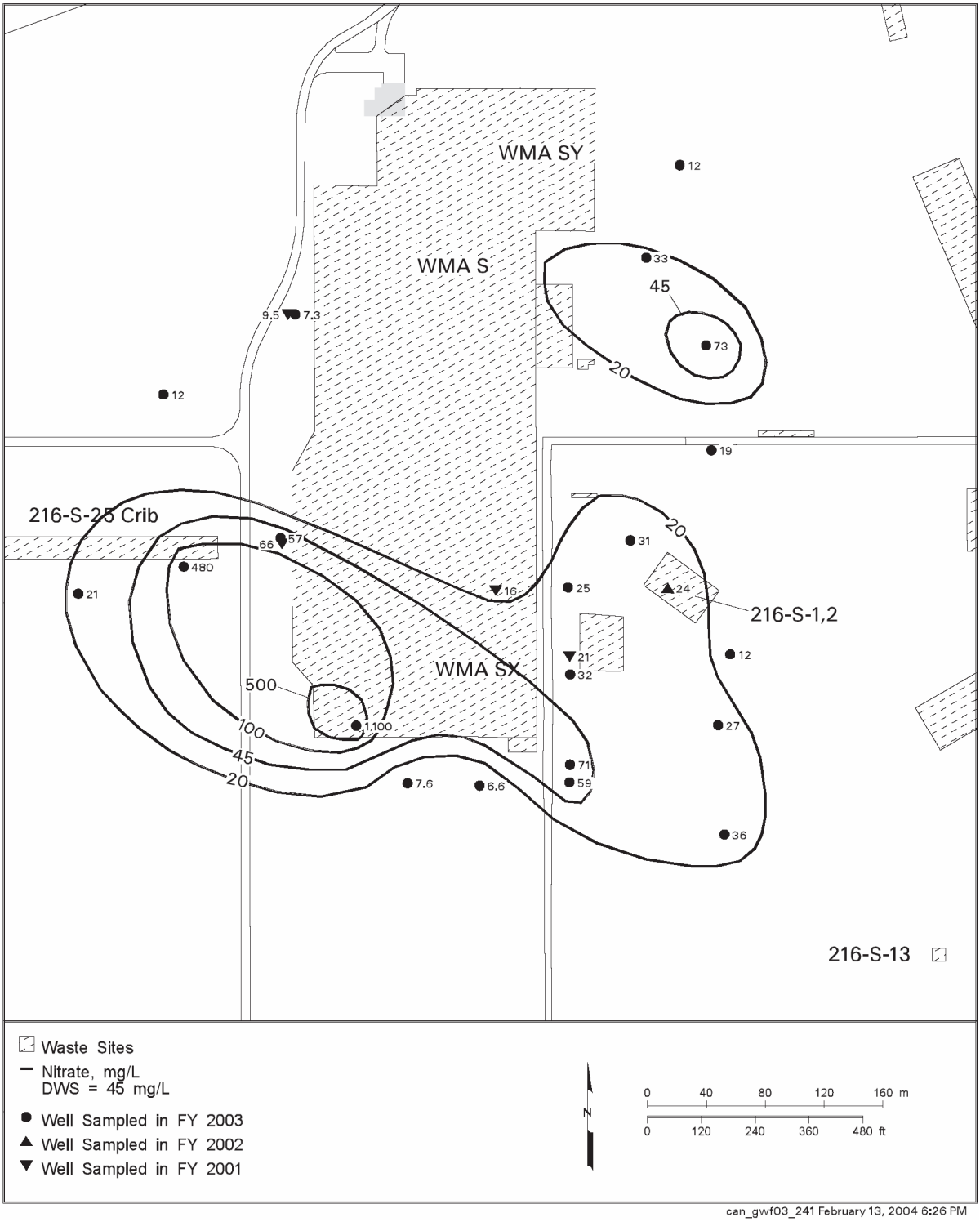
2.6.6.2 Contamination

Groundwater beneath WMA S-SX is contaminated with nitrate, technetium-99, and hexavalent chromium attributed to two general source areas within the WMA (Hartman et al. 2004). One source area is to the north in the S tank farm and one is to the south in the SX tank farm (Figures 2-40 and 2-41). Tritium and carbon tetrachloride plumes are also present in groundwater beneath the WMA, but their sources are upgradient of the WMA.

The northernmost plume with an apparent source in the S tank farm has migrated eastward through well 299-W22-48, where chromium and nitrate concentrations leveled off at approximately 40 µg/L and 73 mg/L, respectively, in fiscal year 2002 (Hartman et al. 2003). Technetium-99, another constituent of the plume, has a trend similar to those of chromium and nitrate where concentrations leveled off at approximately 4,500 pCi/L in fiscal year 2002. The similar trends of these three constituents (Figure 2-42) indicate that they likely have the same source.

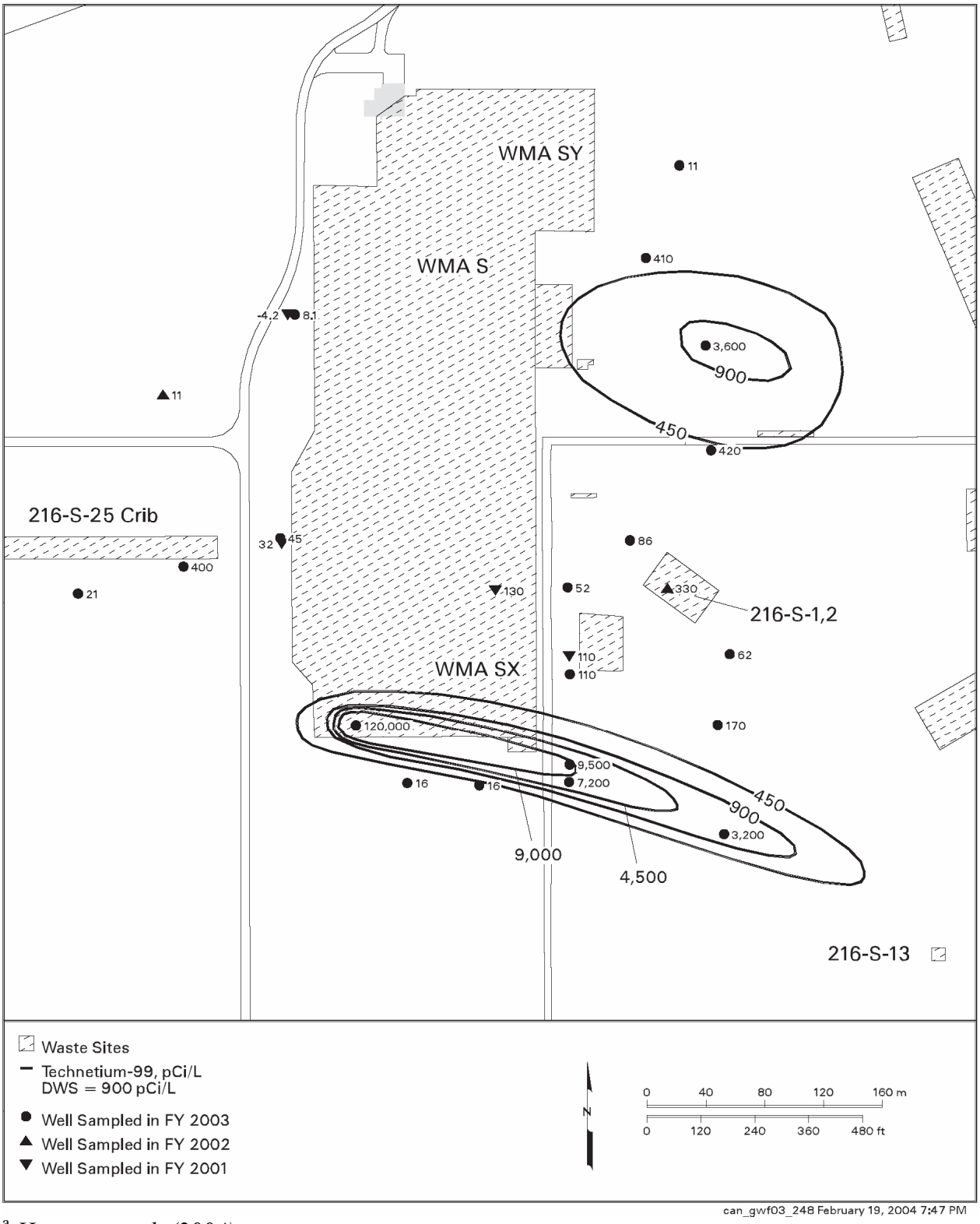
The contaminant plume located on the south portion of the WMA continues to slowly spread downgradient from its apparent source near tank SX-115. This plume is composed of nitrate, chromium, and technetium-99, as is the S tank farm plume to the north. The peak technetium-99 concentration at well 299-W23-19 (at the southwest corner of WMA S-SX near the apparent source of this plume) was 188,000 pCi/L (measured in January 2003), and the annual average concentration was 118,000 pCi/L (Hartman et al. 2004). By the end of fiscal year 2003, the concentration had fallen to approximately 75,000 pCi/L (Figure 2-43). This plume continues to migrate to the east-southeast. The front of the plume has entered a region of sparse well coverage and cannot be tracked further.

Figure 2-40. Average Nitrate Concentrations at Waste Management Area S-SX, Top of Unconfined Aquifer [a]



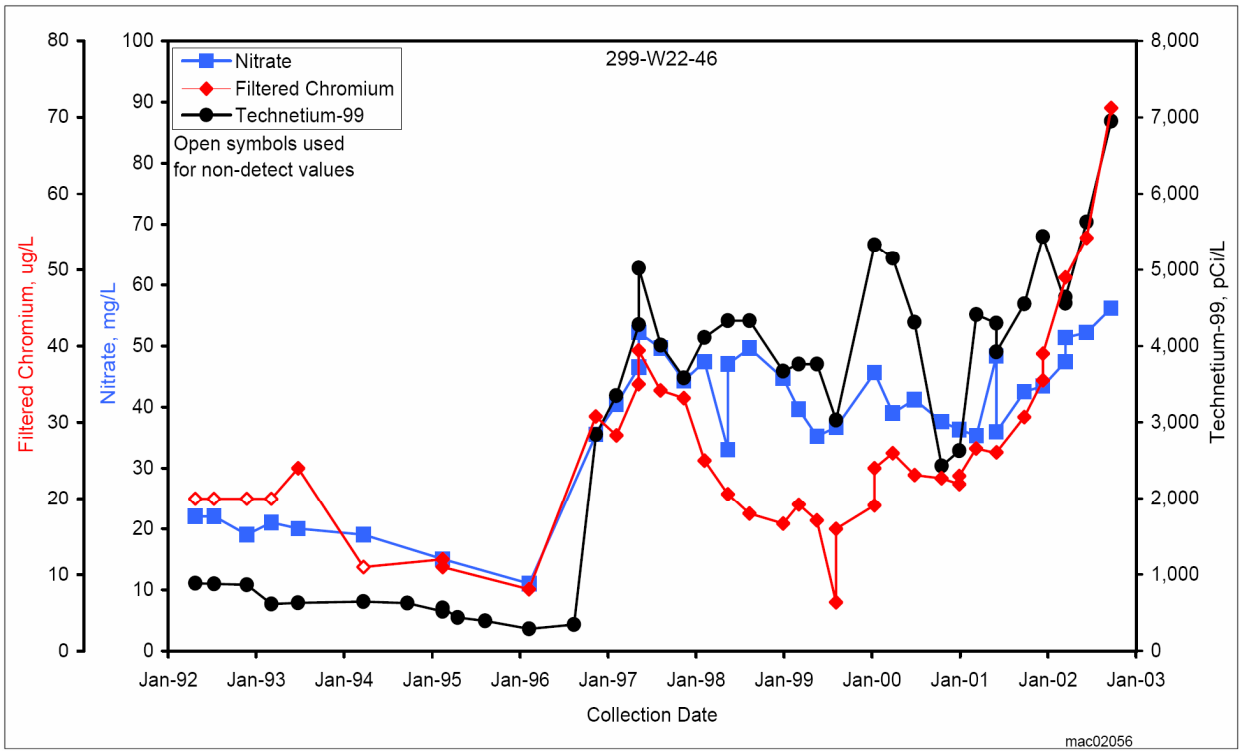
[a] *Hartman et al. (2004)*

Figure 2-41. Average Technetium-99 Concentrations at Waste Management Area S-SX, Top of Unconfined Aquifer [a]



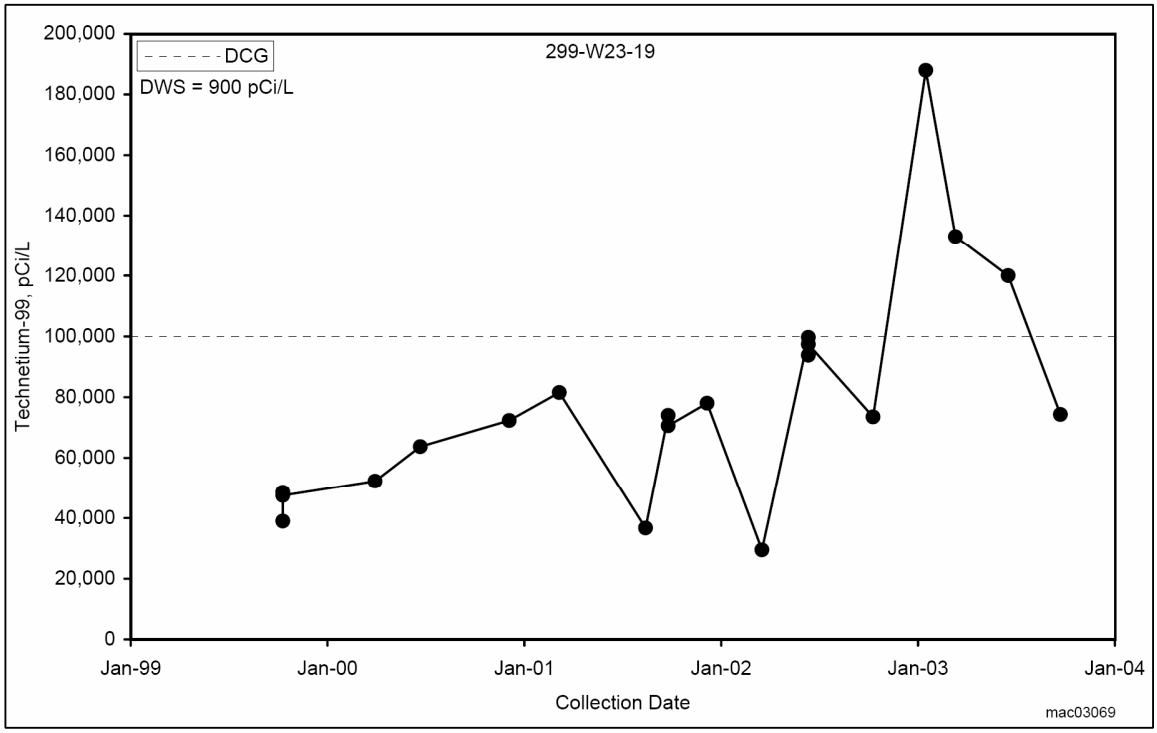
[a] *Hartman et al. (2004)*

Figure 2-42. Technetium-99, Chromium, and Nitrate Concentrations East of the S Tank Farm [a]



[a] *Hartman et al. (2003)*

Figure 2-43. Technetium-99 Concentrations at Waste Management Area S-SX [a]



[a] *Hartman et al. (2004)*

2.6.7 Reference Case Source Terms

The reference case describes a set of assumed post-retrieval conditions that are based on current waste retrieval plans. The reference case analysis for WMA S-SX includes three source terms consisting of past UPRs, residual SST waste, and residual ancillary equipment waste. Table 2-7 provides a listing of the reference case source terms for WMA S-SX, and the inventory data source for that source term.

Source term inventories (reference case) for WMA S SX are provided in Table 2-8. To simplify the table, only the contaminants that dominate post closure impacts are shown. All BBI contaminants are included in the reference case modeling analysis. Refer to Section 2.5 for a summary of source term inventory development methods. Complete source term inventory data are provided in Appendix C.

2.6.7.1 Past Unplanned Releases

The WMA S-SX reference case includes 10 past UPRs associated with SSTs (S-104, SX-104, SX-107, SX-108, SX-109, SX-110, SX-111, SX-112, SX-113, SX-115). Volume estimates for those 10 waste loss events were developed by Field and Jones (2005) and vadose zone contaminant inventories were generated by Corbin et al. (2005) (Section 2.5.2). No volume or inventory estimates were assigned to the waste loss event associated with tank SX-114 because of insufficient information to quantify or verify the release (Field and Jones 2005). If new information becomes available to quantify the waste loss event from that tank, the data will be evaluated under the integrated regulatory closure process described in Chapter 1.0.

2.6.7.2 Residual Single-Shell Tank Waste

The WMA S-SX reference case includes residual waste in each of the 27 100-Series SSTs in the S and SX tank farms. The HFFACO Milestone M-45-00 goal allows up to 360 ft^3 of waste to remain in the 100-Series tanks after retrieval in the event that retrieval beyond that level becomes impracticable (Ecology et al. 1989). Thus, the analysis includes a 360 ft^3 source term associated with residual waste remaining in each of the tanks after retrieval. The inventory estimates were generated with the use of the HTWOS model (Kirkbride et al. 2005), which accounts for the waste retrieval technology and tracks the fate of soluble and insoluble constituents in the waste (Section 2.5.3).

2.6.7.3 Residual Ancillary Equipment Waste

The WMA S-SX reference case includes the plugged and blocked piping in the S and SX tank farms and the residual waste in one MUST (241-SX-302 catch tank) (Section 2.5.4). Volume and inventory estimates for the waste in the plugged and blocked piping (64.8 L in S farm, none in SX farm) were developed by Lambert (2005). The estimated volume of residual waste in the 241-SX-302 catch tank was calculated by assuming the tank would be retrieved to a residual volume proportional to that required under the HFFACO Milestone M-45-00 for 200-Series tanks (Ecology et al. 1989). Contaminant inventories associated with the residual ancillary equipment waste were estimated using the average chemical composition of the waste in the WMA S-SX SSTs.

Table 2-7. Reference Case Analysis of Waste Management Area S-SX (2 pages)

Inventory and Source Terms					
Sources	**Assumed Retrieval Method**	**Residual Volume**	**Volume Associated with Past Release [a] gal**	**Basis for Contaminant Inventory Estimate**	
				Residual Waste [b]	**Past Release**
241-S-101	Sluicing	360 ft^3	None	HTWOS	None
241-S-102	Sluicing	360 ft^3	None	HTWOS	None
241-S-103	Sluicing	360 ft^3	None	HTWOS	None
241-S-104	Mobile retrieval system	360 ft^3	24,000	HTWOS	Corbin et al. 2005
241-S-105	Sluicing	360 ft^3	None	HTWOS	None
241-S-106	Sluicing	360 ft^3	None	HTWOS	None
241-S-107	Sluicing	360 ft^3	None	HTWOS	None
241-S-108	Sluicing	360 ft^3	None	HTWOS	None
241-S-109	Sluicing	360 ft^3	None	HTWOS	None
241-S-110	Sluicing	360 ft^3	None	HTWOS	None
241-S-111	Sluicing	360 ft^3	None	HTWOS	None
241-S-112	Sluicing	360 ft^3	None	HTWOS	None
241-SX-101	Sluicing	360 ft^3	None	HTWOS	None
241-SX-102	Sluicing	360 ft^3	None	HTWOS	None
241-SX-103	Sluicing	360 ft^3	None	HTWOS	None
241-SX-104	Mobile retrieval system	360 ft^3	6,000	HTWOS	Corbin et al. 2005
241-SX-105	Sluicing	360 ft^3	None	HTWOS	None
241-SX-106	Sluicing	360 ft^3	None	HTWOS	None
241-SX-107	Mobile retrieval system	360 ft^3	15,000	HTWOS	Corbin et al. 2005
241-SX-108	Mobile retrieval system	360 ft^3	35,000	HTWOS	Corbin et al. 2005
241-SX-109	Mobile retrieval system	360 ft^3	2,000	HTWOS	Corbin et al. 2005
241-SX-110	Mobile retrieval system	360 ft^3	1,000	HTWOS	Corbin et al. 2005

Table 2-7. Reference Case Analysis of Waste Management Area S-SX (2 pages)

Inventory and Source Terms					
Sources	**Assumed Retrieval Method**	**Residual Volume**	**Volume Associated with Past Release [a] gal**	**Basis for Contaminant Inventory Estimate**	
				Residual Waste [b]	**Past Release**
241-SX-111	Mobile retrieval system	360 ft^3	500	HTWOS	Corbin et al. 2005
241-SX-112	Mobile retrieval system	360 ft^3	1,000	HTWOS	Corbin et al. 2005
241-SX-113	Mobile retrieval system	360 ft^3	15,000	HTWOS	Corbin et al. 2005
241-SX-114 [c]	Mobile retrieval system	360 ft^3	NSI [c]	HTWOS	None
241-SX-115	Mobile retrieval system	360 ft^3	50,000	HTWOS	Corbin et al. 2005
241-SX-302 catch tank [d]	TBD [d]	9.65 ft^3	None	Average	None
241-S tank farm pipelines [e]	TBD	64.8 L	None	Lambert 2005	NA
241-SX tank farm pipelines [e]	TBD	None	None	Lambert 2005	NA

[a] Past leak volumes listed in Field and Jones (2005).

[b] Residual inventories from HTWOS model output (Kirkbride et al. 2005).

[c] NSI = not sufficient information. Tank SX-114 is identified as a "confirmed or suspected" leaker in Hanlon (2005) but Field and Jones (2005) state there is insufficient information for developing a leak volume at this time. As information becomes available, a leak volume will be developed.

[d] TBD = to be determined. Final disposition of MUSTs not yet determined; however, MUSTs were carried forward in the assessment assuming MUSTs will be retrieved to at least the HFFACO goal (Ecology et al. 1989, Milestone M-45-00) equivalent to the 200-Series tanks. The residual volume is calculated by ratio of the total volume of the MUST to the 200-Series tanks (e.g., the retrieval goal for the 55,000-gal 200-Series tanks is 30 ft^3; thus, a MUST that is ⅔ the size of the 200-Series tank would have a residual volume of 20 ft^3). Inventory was calculated based on average waste per ft^3 within the WMA calculated from the HTWOS model (Kirkbride et al. 2005).

[e] Final disposition of pipelines is not yet determined; however, pipelines were carried forward in the assessment. Pipeline residual volumes shown represent the volume of waste in plugged or blocked pipelines as determined by Lambert (2005).

NA = not applicable

Table 2-8. Reference Case Inventory Estimates for Waste Management Area S-SX

Source Type	Dominant Contaminants for Groundwater Pathway Impacts [a]							Dominant Contaminants for Inadvertent Intruder Impacts [a]						
	C-14 Ci	Tc-99 Ci	I-129 Ci	Cr(VI) kg	NO_3 kg	NO_2 kg	U kg	Sr-90 Ci	Tc-99 Ci	Sn-126 Ci	Cs-137 Ci	Pu-239 Ci	Pu-240 Ci	Am-241 Ci
Past releases [b]	1.34E+00	3.24E+01	4.71E-02	1.06E+03	7.57E+04	3.28E+04	1.74E+01	1.13E+03	3.24E+01	3.61E-01	8.87E+04	2.86E+00	6.11E-01	3.80E+00
Tank residuals	2.90E-01	9.76E+00	7.06E-03	7.15E+03	1.25E+04	1.61E+03	2.56E+03	4.05E+05	9.76E+00	3.45E+00	1.97E+04	4.65E+02	1.01E+02	4.46E+02
Ancillary equipment residuals [c]	2.87E-04	2.31E-02	2.24E-05	6.22E+00	2.81E+01	1.03E+01	1.69E+00	NA	NA	NA	NA	NA	NA	NA

[a] The reference case analysis included all BBI contaminants. As described in Bowen (2004), the standard analyte list tracked in the BBI contains **25 chemicals** including:

- aluminum
- bismuth
- calcium
- chlorine
- chromium
- fluorine
- total inorganic carbon as carbonate
- iron
- mercury
- potassium
- lanthanum
- manganese
- sodium
- nickel
- nitrite
- nitrate
- oxalate
- lead
- phosphate
- silicon
- sulfate
- strontium
- uranium total
- zirconium
- total organic carbon

and **46 radionuclides** including:

- tritium
- carbon-14
- nickel-59
- cobalt-60
- nickel-63
- selenium-79
- strontium-90
- yttrium-90
- zirconium-93
- niobium-93m
- technetium-99
- ruthenium-106
- cadmium-113m
- antimony-125
- tin-126
- iodine-129
- cesium-134
- cesium-137
- barium 137m
- samarium-151
- europium-152
- europium-154
- europium-155
- radium-226
- actinium-227
- radium-228
- thorium-229
- protactinium-131
- thorium-232
- uranium-232
- uranium-233
- uranium-234
- uranium-235
- uranium-236
- neptunium-237
- plutonium-238
- uranium-238
- plutonium-239
- plutonium-240
- americium-241
- plutonium-241
- curium 242
- plutonium-242
- americium-243
- curium-243
- curium-244

[b] Inventories shown are the combined inventories from SST past releases and ancillary equipment past releases. Both release types were considered for the groundwater pathway analysis; however, only the SST past releases were included in the inadvertent intruder analysis (along with SST residuals).

[c] NA indicates insufficient information is available to make estimates of intruder impacts into ancillary equipment (e.g., pipelines, diversion boxes).