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DOE/ORP-2005-01

INITIAL SINGLE-SHELL TANK SYSTEM PERFORMANCE ASSESSMENT FOR THE HANFORD SITE

DATA PACKAGE

SECTION

1 OF 4

0083994
Sect 1 of 4

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Section 1 of 6

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Abstract: This "Initial Single-Shell Tank System Performance Assessment for the Hanford Site," (SST PA) presents the analysis of the long-term impacts of residual wastes assumed to remain after retrieval of tank wastes and closure of the SST farms at the U.S. Department of Energy (DOE) Hanford Site.

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Initial Single-Shell Tank System Performance Assessment for the Hanford Site

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

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EXECUTIVE SUMMARY

This *Initial Single-Shell Tank System Performance Assessment for the Hanford Site* (SST PA) presents the analysis of the long-term impacts of residual wastes assumed to remain after retrieval of tank wastes and closure of the SST farms at the U.S. Department of Energy (DOE) Hanford Site. Residual tank waste impacts on groundwater, air resources, and to the inadvertent intruder are shown to be limited and well below most important performance objectives for the reference case used in the analysis. Impacts from grouted tank residuals are first observed in years 4000 to 6000 and peak in years 8000 to 10000. However, past releases to the soil, primarily from past releases during tank farm operations, are shown to have groundwater impacts that are significantly above most performance objectives at the WMA fenceline. These past release impacts are projected to occur rapidly and dissipate by approximately year 2300. Only waste management area (WMA) C does not impact groundwater at levels over performance objectives for the reference case. With implementation of institutional controls for 300 years at the WMA fenceline, all groundwater performance objectives are met through natural attenuation except for two WMAs (i.e., S-SX and T), which meet the groundwater performance objectives at their fenceline boundary in the years 2373 and 2490, respectively.

Initial Single-Shell Tank System Performance Assessment for the Hanford Site provides estimates of the long-term impacts to human health of radioactive and chemical waste left after closure.

The sensitivity analysis of peak impacts indicated that tank waste residual impacts are not sensitive to parameter variability and to the alternative conceptualizations considered. Groundwater impacts from past releases were sensitive to inventory, contaminant-specific distribution coefficient (K_d), and infiltration assumptions. Remediation or immobilization of over 90% of key mobile contaminants found in past releases is indicated as necessary to address appropriate groundwater performance objectives at the WMA fenceline. Projections of peak groundwater impacts were estimated to contain a factor of variability of 10 at the time of closure (i.e., a predicted value can be a factor of 10 higher or lower than estimated in the reference case due to features in the system that are inherently variable).

The results of this SST PA support the retrieval of tank wastes and grouting of the SST waste residuals, the institution of interim measures to reduce the impacts of past releases on groundwater, and the examination of potentially more aggressive remedial measures to support the *Resource Conservation and Recovery Act of 1976* (RCRA) Corrective Action process for the protection of groundwater. Where information regarding treatment, management, and disposal of the radioactive source, byproduct material, and/or special nuclear components of mixed waste (as defined by the *Atomic Energy Act of 1954*, as amended) has been incorporated into this document, it is not incorporated for the purpose of regulating the radiation hazards of such components under the authority of Section 70.105 of the *Revised Code of Washington* ("Hazardous Waste Management Act") and its implementing regulations, but is provided for information purposes only.

The SST PA supports key elements of the closure process agreed upon in 2004 by DOE, the Washington State Department of Ecology (Ecology), and the U.S. Environmental Protection Agency (EPA), and documented in Appendix I of the *Hanford Federal Facility Agreement and Consent Order* (Ecology et al. 1989). Closure of the SST and double-shell tank systems is currently planned for year 2032.

ES1.0 INTRODUCTION

DOE has initiated the process of retrieving, treating, and disposing of waste from the 149 deteriorating SSTs at the Hanford Site. In the years ahead, DOE will remove the bulk of the SST waste and transfer it to facilities for treatment and disposal. High-level waste will be disposed of offsite in a geologic repository, and low-activity mixed waste will be disposed of in state-permitted, onsite facilities as low-level mixed waste. This SST PA incorporates the assumption, without a decision, that after the wastes are removed from the tanks, the SST farm system (also referred to as the SST WMAs) will be closed as a landfill.[1] As part of closure actions, a number of protective measures are planned to ensure safety from future contaminant migration from residual wastes left in each WMA.

Closure will be implemented only with regulatory approval as defined by relevant regulatory criteria. The regulatory environment for tank farm closure is complex. At least six major environmental statutes[2] and DOE O 435.1 must be addressed as part of the closure process, which creates redundant, and possibly conflicting, administrative requirements. To address this issue, the *Hanford Federal Facility Agreement and Consent Order* (Ecology et al. 1989) signatories established a single, unified closure process that incorporated the substantive elements of each regulation and DOE O 435.1, with Ecology as the lead regulatory agency. The agreement also established the need for a single performance assessment that will be approved by Ecology and by DOE pursuant to their authorities under RCRA and the *Atomic Energy Act of 1954*, respectively, and to ensure the actions taken for WMA closure will be protective of human health for all contaminants of concern, both radiological and nonradiological. The SST PA will also undergo extensive internal DOE review and be reviewed by the U.S. Nuclear Regulatory Commission under a consultation agreement. Under Appendix I of *Hanford Federal Facility Agreement and Consent Order* (Ecology et al. 1989), Ecology will also seek the involvement of the EPA for the purpose of ensuring the work is consistent with future *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA) remedial decisions, and to provide the EPA and DOE a basis to evaluate the need for additional work that might be required if the closure activities were conducted under CERCLA remedial action authority.

Among the purposes of this SST PA for the closure of WMAs are to:

- Estimate the impacts to human health of any residual wastes remaining in the tanks, ancillary equipment, or soil following waste and contaminant removal actions
- Guide the development of WMA closure system designs that are protective of the public, the groundwater, and the Columbia River
- Support waste determinations for any tank waste residuals remaining once waste retrieval has been completed in accordance with *Hanford Federal Facility Agreement and Consent Order* (Ecology et al. 1989).

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[1] This assumption of landfill closure is to provide a point of reference for development of the data presented herein and does not constitute an agency decision selecting landfill closure. That decision can only be made after DOE fulfills its obligations under the *National Environmental Policy Act of 1969*.

[2] *Resource Conservation and Recovery Act of 1976*; *Comprehensive Environmental Response, Compensation, and Liability Act of 1980*; *Atomic Energy Act of 1954*; *Clean Water Act of 1977*; *Safe Drinking Water Act of 1974*; and the Washington State "Hazardous Waste Management Act."

The SST PA supports making risk-informed decisions under multiple closure processes.

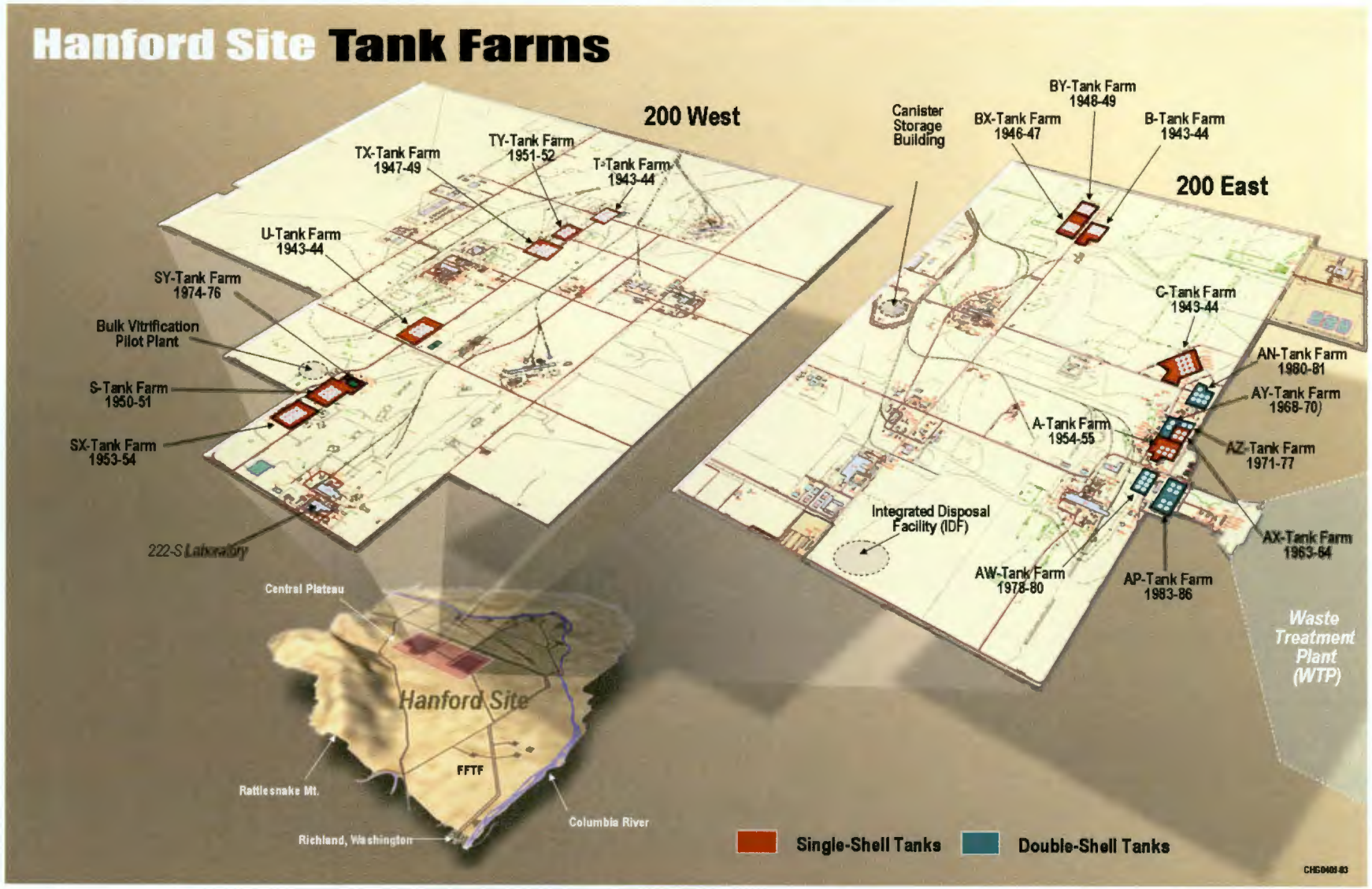
The scope of this SST PA includes estimating possible impacts of wastes remaining in the environment and residuals left in the tank system after closure, estimating possible releases to the air of radioactive gases from tank waste residuals after closure, and estimating possible impacts to an inadvertent intruder who unknowingly contacts contaminated materials left within the waste site after closure. Current WMA closure plans call for an approximately 15-foot thick surface barrier to infiltration to be constructed over the WMAs and surrounding environs. This barrier effectively eliminates the need to further consider impacts to human health through a direct contact pathway.

ES2.0 SINGLE-SHELL TANK WASTE MANAGEMENT AREA OVERVIEW

The 149 Hanford Site SSTs are distributed among 12 groups called tank farms that are located on the Central Plateau in the Hanford Site 200 East and 200 West Areas. The SST farm system is large and varied and comprises underground waste storage tanks, pipelines, waste transfer lines, water lines, diversion boxes, and other facilities and equipment. To support compliance with hazardous waste regulations, the 12 SST farms, shown in red on Figure ES-1, have been further grouped into seven WMAs: A-AX, B-BX-BY, C, S-SX, T, TX-TY, and U.

The SSTs currently contain approximately 30 million gallons of radioactive and hazardous waste. The waste currently in the SSTs includes approximately 81 million curies of radioactive material. Two to four million curies of tank waste residual will remain after retrieval is complete. The waste currently in the tanks largely consists of sludge and saltcake. Most of the free liquids have evaporated or have been successfully transferred to newer and structurally stable double-shell tanks through the interim stabilization program. The total volume liquid lost through leaks occurring during past tank operations is estimated to range between 0.5 to 1 million gallons.

Figure ES-1. Facilities in the 200 East and 200 West Areas



ES3.0 DEFENSE IN DEPTH APPROACH TO CLOSURE

DOE will employ a defense in depth approach for its WMA closures using a risk and uncertainty mitigation philosophy developed by the U.S. Nuclear Regulatory Commission that has proven effective in other venues. Key elements of the defense in depth philosophy are the use of multiple barriers (both natural and engineered) to isolate waste in the disposal environment and the establishment of institutional controls to prevent or limit human access to the waste. The use of multiple barriers improves confidence in the adequacy of closure actions by mitigating intrinsic uncertainties associated with any single barrier. With this approach, even if one or more parts of the system fail or function at a less effective level than projected, overall system performance remains at sufficiently protective levels.

Multiple barriers provide protection to the public from waste left after closure.

To close the WMAs, three barriers that implement the defense in depth philosophy are anticipated including two engineered barriers (i.e., the surface cover and the grouted tank structure) and a natural barrier (i.e., the vadose zone). The barrier functions vary depending on which of the three primary pathways[3] are being considered. For the groundwater pathway, all the barriers impede water movement in the subsurface and two of the barriers (grouted tank structure and vadose zone) react with contaminants to retard their migration through the subsurface. For the air pathway, the grouted tank structure and surface cover provide distance between waste and receptor, and resistance to vapor migration. For the intruder pathway, the engineered barriers deter intrusion over an assumed time interval, but have no function following intrusion. The vadose zone has no function in the air pathway or the intruder pathway.

The application of defense in depth principles in the SST PA also provides insights into the design of WMA closure, the extent and type of characterization needed of the geologic system, and the approach to conducting an analysis of the performance of the proposed closure system. The SST PA analysis specifically evaluates the characteristics of barriers and other site features that influence contaminant migration by the various pathways. In this manner, the functionality of the barriers, both individually and as part of the total system, are directly evaluated. Both expected performance (called a reference case analysis) and sensitivity to variability in input parameters are quantified (sensitivity case analysis). Finally, the SST PA analysis must consider plausible barrier failure modes or underperformance and evaluate their impacts on total system performance.

Knowing this information, analysts can then assist the engineers and scientists responsible for WMA closure design to appropriately address those components and assumptions that are most important to success by reducing their associated uncertainties through additional characterization and/or development of compensating design features. Quality assurance, performance confirmation, and model verification are additional activities that enhance confidence in the long-term total system performance.

[3] The groundwater migration pathway represents movement of infiltrating water through the waste form, its percolation through the vadose zone, and its mixing and transport by groundwater. The air migration pathway begins in the waste form and represents the volatilization of gases and their movement to the atmosphere. The intruder pathway represents human intrusion into the waste form and subsequent exhumation and spreading of the waste form onto the land surface.

ES4.0 CONTAMINANT EXPOSURE SCENARIOS AND EXPOSURE PATHWAYS

This SST PA evaluates three contaminant migration pathways (i.e., groundwater, air, and intruder) that can lead to human exposure through a variety of scenarios. Contaminant exposure scenarios are defined as sequences of human activities that establish levels of interaction with the waste found in air, water, and soil. Human interaction with the waste generally occurs through a variety of exposure pathways such as direct human contact (e.g., contamination of skin), ingestion or inhalation (which enable contaminants to enter the body), or exposure to radiation (potentially important only for the first few hundred years until cesium-137 decays to inconsequential levels). Exposure scenarios are selected that represent plausible land use activities that could occur near a closed facility, and can be analyzed to provide exposure estimates that are comparable with regulatory criteria. Implicit in the assumptions of these scenarios is the idea that waste quantities should be sufficiently limited and isolated to permit safe land use with these activities. Exposure scenarios evaluated represent a range of possible exposure pathways. The scenarios include the residential farmer, site resident, and the industrial user.

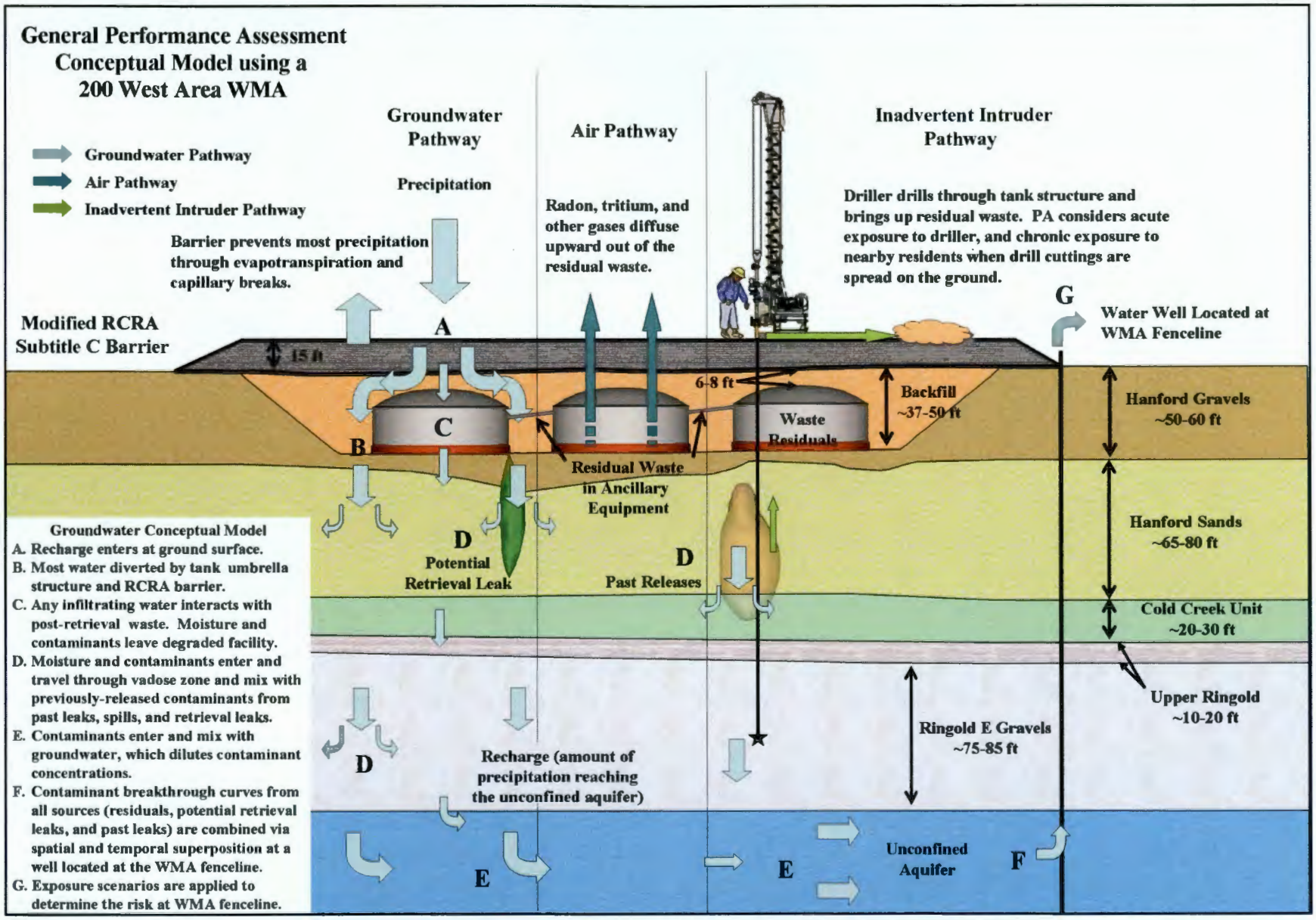
The selection of scenarios discussed above implies knowledge of waste disposal in the area. Human exposure scenarios are also evaluated with the inadvertent intruder pathway in which knowledge of the location of the disposal site is assumed to be lost. These scenarios include a suburban resident with a garden, rural pasture, and commercial farming. The rural pasture scenario is considered part of the reference case, while the suburban resident and commercial farmer are considered in the sensitivity analysis. The intruder pathway is specific to the regulatory environment for the disposal of low-level radioactive waste (DOE O 435.1) and is not typically seen in environmental remediation investigations.

The evaluation of pertinent regulations also identified media-specific (i.e., air and groundwater) criteria or performance objectives that may be used for remediation goals. The SST PA uses these criteria as appropriate to the media and contaminant.

ES5.0 MODEL METHODOLOGY

A conceptual model for each contaminant migration pathway was developed for each WMA, incorporating all available and relevant site-specific data. For groundwater pathways, much of these data have been collected under the RCRA Corrective Action process conducted by the DOE Office of River Protection. Figure ES-2 presents a schematic of a typical conceptualization for a generalized WMA. The scientific conceptualization includes the dominant processes controlling the mobilization and transport of contamination. In keeping with the defense in depth safety philosophy, a reference case for each contaminant migration pathway was defined. The reference case reflects the set of parameters and engineering assumptions that can represent the likely performance of the closed WMA. A concurrent examination of the expected range of values for each parameter helps define the expected performance range of each barrier or feature. To estimate the robustness of the selected set of barriers, alternative conceptualizations are also analyzed using variations on the reference case design to establish the level of performance degradation that might occur. This degradation might represent an overestimate in the performance of a barrier, an error in the geologic conceptualization of the system, or a future event that cannot be reasonably contemplated at this time. Poor system performance noted through either the sensitivity analysis or the alternative conceptualization analysis (i.e., "what if" analysis) indicates a need for an improved understanding of the system and/or a design change.

Figure ES-2. General Performance Assessment Conceptual Model



The geology shown in the figure is specific to the 200 West Area.

Certain features and assumptions are common to the development of each SST WMA model. These refer primarily to the reference case and include:

- Retrieval of tank waste to meet *Hanford Federal Facility Agreement and Consent Order* (Ecology et al. 1989) minimum goals
- Industrial land use following site closure
- Simulation of over 47 radiological and 60 chemical contaminants
- Following waste retrieval, any remaining contamination within the SSTs and the tanks themselves are stabilized with grout to reduce waste/water contact and surface subsidence.

Modeling of the groundwater pathway assumes:

- Site-specific simulation information developed for WMA C in the 200 East Area is extrapolated to other WMAs in the 200 East Area and, similarly, WMA S-SX simulation information is extrapolated to the remaining WMAs in the 200 West Area using WMA-specific inventory.
- A 10,000-year period was selected for evaluation due to the long time it may take for any discernable impacts to be observed in the environment. This is consistent with U.S. Nuclear Regulatory Commission guidance (NRC 2000).
- A surface barrier to infiltration is placed over the WMA at closure and is assumed to perform at its design specifications for 500 years following closure, and then to perform in a degraded manner until the end of the simulation.
- Three sources of contamination remain in the ancillary equipment: past releases, grouted tank residuals, and residual contamination.

Modeling of the air migration pathway uses a bounding analysis due to the low impacts associated with the volatilization of radioactive gases.

The inadvertent intruder pathway assumes intentional drilling through the tank and the residual waste form and the subsequent spreading of the exhumed waste form over the immediate area, ignoring both institutional and engineered controls left in place after closure. Assumptions describing this pathway include:

- Institutional controls are assumed to deter intrusion into the waste form for 500 years after closure (until year 2532). This time of evaluation is consistent with U.S. Nuclear Regulatory Commission guidance (NRC 2000) and past performance assessments at the Hanford Site (Wood et al. 1995a, 1996; Mann et al. 2001).
- Intrusion occurs by drilling through the surface barrier, remaining tank structure, and the grouted tank waste. The tank waste residuals are approximately 50 feet below ground surface. A portion of the waste is brought to the surface in drill cuttings.
- Impacts from past releases are also considered in addition to impacts from exhumed tank residual waste, where appropriate.

Modeling of the reference case inadvertent intruder scenario assumes:

- Exposure occurs to a person while participating in the operation of drilling through the tank waste residuals and contamination from past releases underlying the tank. It is assumed this receptor is exposed to these waste residuals exhumed during the drilling for 40 hours over 5 days.
- In addition, exposure also occurs according to a second scenario defined to emulate a rural lifestyle. Exposure is assumed to occur over a period of 50 years.

ES6.0 CONCLUSIONS

The SST PA presents a comprehensive analysis of human health impacts associated with the retrieval of tank wastes and closure of WMAs located on the Hanford Site. Table ES-1 presents a summary of the estimated impacts to groundwater after closure from each WMA. A stark contrast exists between projected impacts from past releases and those from grouted tank waste residuals. The upper half of Table ES-1 indicates that the impacts of tank waste residuals on groundwater are below all performance objectives considered. In many cases, these impacts are over 10 times below a performance objective. Impacts from grouted tank residuals are first observed in years 4000 to 6000 and peak in years 8000 to 10000. The lower half of Table ES-1 presents the impacts to groundwater at the WMA fenceline for past releases. As noted, impacts from past releases indicate a decidedly different conclusion. With the exception of WMA C, past groundwater release impacts exceed at least two maximum contaminant levels (i.e., technetium-99 and beta-photon) for every WMA by over a factor of 10. The chromium performance objective is also exceeded for each WMA, except for WMA C. Potentially significant remedial actions may be necessary for those WMAs shown as greater than 10 times above groundwater performance objectives. Groundwater impacts from past releases are projected to peak in less than 100 years and decline to levels less than the performance objectives approximately 300 years after closure for most WMAs at the WMA fenceline.

Groundwater impacts from tank waste residuals after closure are at levels protective of human health; impacts from past releases are above important performance objectives for every WMA except WMA C.

At closure, this SST PA concludes that estimates of peak contaminant concentrations would likely have a variability on the order of a factor of 10 (i.e., an estimated peak impact could be a factor of 10 higher or lower than that calculated in the reference case due to the natural and non-reducible variability of the system). A similar estimate of cumulative variability based on a probabilistic uncertainty analysis is documented in DOE-RL (1999) and corroborates the estimate of variability provided here.

Impacts to human health resulting from the air release of volatile radionuclides from the grouted tank residuals were found to be well below air performance objectives, as were estimates of human health impacts for an intruder exposed to the residual tank waste and past releases (assumed to occur 500 years after closure).

Table ES-1. Estimated Reference Case Groundwater Impacts at the Waste Management Area Fenceline

Performance Objective	Maximum Contaminant Level [a]				Exposure Scenarios [b]		
	Beta-Photon 4 mrem/yr	Tc-99 900 pCi/L	I-129 1 pCi/L	Cr 0.10 mg/L	All-Pathways Farmer 15 mrem	Radiological ILCR Industrial 1.0E-4 to 1.0E-5	WAC 173-340 Hazard Index Method B 1.0
WMA	***Tank Residuals***						
S-SX	◇	◇	◇	◇	◇	◇	◇
T	◇	◇	◇	◇	◇	◇	◇
TX-TY	◇	◇	◇	◇	◇	◇	◇
U	◇	◇	◇	◇	◇	◇	◇
C	◇	◇	◇	◇	◇	◇	◇
B-BX-BY	◇	◇	◇	◇	◇	◇	◇
A-AX	◇	◇	◇	◇	◇	◇	◇
WMA	***Past Releases***						
S-SX	●	●	◇	●	◇	●	●
T	●	●	◇	●	◇	●	◇
TX-TY	●	●	◇	●	◇	◇	◇
U	●	●	◇	●	◇	◇	◇
C	◇	◇	◇	◇	◇	◇	◇
B-BX-BY	●	●	◇	●	◇	◇	◇
A-AX	●	●	◇	●	◇	◇	◇

Below Performance Objective:

◇ Greater than a factor of 10

◇ Less than a factor of 10

Above Performance Objective:

● Greater than a factor of 10

● Less than a factor of 10

[a] Evaluated from year 2000 to 12032.

[b] Evaluated from year 2332 to 12032.

ILCR = incremental lifetime cancer risk

The sensitivity and "what if" analyses divided the model parameters and assumptions into three categories: 1) changes in recharge, 2) changes in source term characteristics (e.g., inventory, release mechanism, initial location, vadose zone retardation), and 3) changes in hydrologic parameters. The recharge category addressed those elements of the defense in depth associated with the surface barrier cover function. The contaminant source term characteristics cases examined the impacts of changes in the contaminant source inventory and release. The source term characteristics category addressed those elements of the defense in depth associated with the grouted tank structure function. The surface barrier cover function and grouted tank structure function are the engineered components of the system. The hydrology category addressed those elements of the defense in depth associated with the vadose zone function. The sensitivity of peak groundwater impact to the expected range of each parameter controlling the performance of a barrier was completed. Additionally, an evaluation of several "what if" cases was conducted to

evaluate the capability of the system to perform under alternatives or "what if" analyses not included in the reference case. A complete presentation of the results of the sensitivity and "what if" analyses is found in Section 4.11.

In accordance with the defense in depth safety philosophy, a multiple barrier system was used to control the groundwater impacts of residual contamination left in place after closure of each WMA. To isolate the effect of individual barriers on total system performance, parameters controlling the performance of each barrier were simultaneously degraded causing each barrier to significantly underperform. Peak groundwater impacts from the underperformance cases were then compared against the reference case and a ratio of peak impacts from each case was calculated. The value of the ratio is indicative of the level of overall system loss of performance due to the underperformance of the respective barrier. For mobile contaminants in tank residuals, the results of this analysis indicated that system groundwater performance degraded by factors of 1.75, 7.85, and 1.24 due to underperformance of the surface barrier, the grouted tank structure, and the vadose zone, respectively, for WMA C. Underperformance of the entire engineered system in WMA C (i.e., surface barrier and grouted tank structure) yielded an underperformance ratio as high as 13.77. The effect of each barrier on WMA S-SX was similar to results shown for WMA C. Moderately mobile contaminants were shown to be generally more sensitive to barrier degradation than were mobile contaminants.

The effect of each barrier on peak groundwater impacts from past releases was quite different. Underperformance of the surface barrier at WMA C reduced the WMA C system performance by a factor of 1.39. Similarly, underperformance of the vadose zone reduced the system performance by a factor of 2.98. Again, similar barrier underperformance ratios were estimated for WMA S-SX.

The results of the SST PA support the following:

- Retrieval of tank waste and grouting of the remaining residuals
- Institution of interim measures to reduce the impacts to the groundwater from past tank farm releases
- Examination of the potential for more aggressive corrective measures to mitigate projected early groundwater impacts.

The long-term groundwater impacts from residual tank wastes are shown to be low and are below all performance objectives. Future work on grouted tank waste form residuals and release mechanisms are expected to support even lower estimates of potential impacts. Expected parameter variability and alternative system conceptualizations also support this conclusion.

In many cases, past releases from tank operations simply have too large an impact on groundwater concentrations to make performance objectives achievable under the reference case assumption of no remediation of past releases, as used in this study. Sensitivity analysis of the extent of past release remediation of mobile contaminants required to achieve groundwater performance objectives at an SST WMA fenceline was generally quite high (greater than 90%). Immobilization or removal of contaminated soil of over 90% of mobile technetium-99 from past releases was indicated as necessary to achieve groundwater performance objectives for this contaminant at every WMA, except WMA C.

A number of analysts (Myers 2005; Knepp 2002a, 2002b) have recommended interim measures as an immediate need due to operational period recharge rates on the projected groundwater impacts from large tank releases. These analyses, including the SST PA, primarily examine risk to human health and are not sufficiently comprehensive to support a final decision but instead contribute to the decision making process. Based on principles of risk management alone, the consideration of interim measures is supported at most of the WMAs while the formal RCRA Corrective Action process unfolds. Interim measures can cover a wide range of remedial activities. The SST PA examined barriers to infiltration in detail. Results from the sensitivity analysis generally support the concept that reducing surface infiltration sooner is better than later.

ES7.0 FUTURE PLANS

DOE will continue to use an iterative approach to updates of the SST PA; updates will be based on significant changes in the approach to closure, conceptual model, or source characteristics used in this SST PA. The SST PA documents the current baseline but, by the nature of any baseline, changes will occur and must be addressed. These changes are driven by insights from laboratory studies, field efforts, numerical analyses, and design modifications.

The SST PA results will be examined yearly and updated as the closure project changes and new data become available.

The approach taken naturally results in the development of a path for future work that addresses uncertainty where possible and confirms basic assumptions that support the SST PA. The following provides such a path.

- **Improved estimates of past release inventories lost to the vadose zone:** Past releases are clearly indicated as the controlling factor for the estimates of early (less than 300 years after closure) groundwater impacts. Validating estimates of both leak volume and inventory estimates will be continued for past releases that potentially affect the compliance status of a WMA.
- **Site-specific data will be used to simulate WMAs T, TX-TY, U, A-AX, and B-BX-BY:** Future revisions to this SST PA will use site-specific analyses for each WMA, including characterization data from post-retrieval tank waste residuals. Specific sensitivity analyses associated with issues within each WMA will also be identified and analyzed.
- **Development of improved tank residual release models:** The analysis of tank waste residuals demonstrated that their impact was below every groundwater performance objective considered. However, the closeness of the predicted impacts to the very stringent groundwater performance objectives for technetium-99 demonstrated the need for additional work to better ensure future compliance including characterization data from post-retrieval tank waste residuals.

  Given the early nature of predictions regarding the quantity of waste likely to remain in the tank after waste retrieval is complete, analysis of the durability of the grout form will be pursued.

- **Estimation of the level of impacts from surrounding facilities on waste management area impacts:** The current SST PA focuses on impacts from facilities and conditions found within the SST WMAs. Future work will incorporate the impacts from other surrounding cribs, ditches, and other disposal sites, including the double-shell tanks, into the impacts estimated in this analysis.
- **Expansion of the sensitivity analysis:** The sensitivity analysis will be expanded to include additional alternative conceptualizations to further test the robustness of the WMA closure design and assumptions regarding waste remaining in the closed system. Future sensitivity analyses will incorporate data from other SST WMAs.

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READERS GUIDE

The following information is provided to assist the reader in understanding the technical data and format of this document.

Definitions of Terms

A number of terms are conventionally abbreviated in this document; for example, waste management area is expressed as WMA. Abbreviated terms are spelled out on their first use, and as a convenience for the reader, a list of acronyms and abbreviations with their definitions can be found following the Contents of the main document and in each appendix.

Reference Citations

Throughout the text of this document, reference citations are presented where information from the referenced document was used. These reference citations are contained within parentheses and provide a brief identification of the referenced document. This brief identification corresponds to the complete reference citation located in the reference list at the end of each chapter and at the end of each appendix.

Chemical Elements and Radioactive Isotopes

Many chemical elements and radioactive isotopes are referenced in this document. Examples of the chemical elements are cesium, strontium, and uranium; isotopes are expressed after the element name (for example, cesium-137). To save space in tables and illustrations, elements and isotopes may appear in abbreviated form (for example, Cs-137).

Scientific Notation

Scientific notation is used in this document to express very large or very small numbers. For example, the number one million could be written in scientific notation as 1.0E+06 (or 1.0×10^6) or in traditional form as 1,000,000. Translating from scientific notation to the traditional number requires moving the decimal point either right or left from the number being multiplied by 10 to some power depending on the sign of the power (i.e., negative power move left or positive power move right).

Units of Measure

Information derived from historical or referenced sources is presented in the units cited in the reference. Field and laboratory data are presented in the units as measured in the field or as reported by the laboratory. The approximate American customary units are shown in parentheses directly following the use of many of the metric units. For example, a distance presented as 10 meters (m) is followed by 33 feet (ft). This example would be presented in the text as: 10 m (33 ft).

Electronic Viewing Option

An electronic version of this document is available. The reader is encouraged to utilize the electronic version to view this document, particularly the graphics. Throughout the document, graphics in particular make use of color to convey information. When the document is printed in black and white, the color differences may be lost.

Well Numbering and Identification

Several well numbering methods exist on the Hanford Site, leading to confusion in identifying those structures on various maps and cross-referencing them in this document. Three numbering methods are used here:

- Tank Farm System – In this method, drywells are numbered to identify the tank farm, associated tank, and the clock position of the well relative to the tank. The tank farm numbers are C = 30, S = 40, and SX =41; each tank is assigned a two-digit number corresponding to its official number (101 = 01, 102 = 02, etc.); and the two-digit clock position numbers are based on north as 12 o'clock (for example, south would be 06).

  Example: well 30-01-12 is north of tank C-101

  Many farms have drywells drilled along the peripheries; these wells are noted by the tank farm number, followed by "00", and then the clock position related to the entire farm.

  Example: drywell 41-00-04 is at the 4:00 position on the periphery of the SX tank farm

  Use of the tank farm numbering system is common as it permits the reader to readily visualize the spatial position of a given well relative to the tank it monitors.

- Hanford Site Well Numbering – In this method, based on the Hanford Site 200 Area Well Number protocol, each well is assigned a number based on the Hanford Site area in which the well exists (for example, 299 = 200 Area well), followed by a number designating the survey sheet on which it can be found (for T, TX, and TY, these are sheets W10, W11, and W15, respectively), and finally a number based on the sequential order in which the well was drilled.

  Example: 299-W19-23

- Washington Department of Ecology Start Card Number – In this method, every well drilled on the Hanford Site has a tracking number assigned by Ecology. Wells drilled solely for the purpose of collecting soils samples, and decommissioned after those samples have been collected, often have only this number. The number is alphanumeric, such as C3104. All characterization boreholes, not extending to groundwater, drilled by the Groundwater Protection Program have only this number assigned.

  Example: One of the boreholes is designated C3104.

Every effort has been made to minimize confusion by including the name "well" or "borehole" with the unit identifying number.

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TERMS

amsl	above mean sea level
BBI	best basis inventory
bgs	below ground surface
BTC	breakthrough curve (concentration over time curve)
CERCLA	*Comprehensive Environmental Response, Compensation, and Liability Act of 1980*
CFR	*Code of Federal Regulations*
CLUP	Comprehensive Land-Use Plan
CMS	corrective measures study
CoC	contaminant of concern
DCG	derived concentration guide
DCRT	double-contained receiver tank
DMT	Decision Management Tool
DNFSB	Defense Nuclear Facilities Safety Board
DOE	U.S. Department of Energy
DQO	data quality objective
DST	double-shell tank
DWS	drinking water standards
Ecology	Washington State Department of Ecology
EDE	effective dose equivalent
EIS	environmental impact statement
EPA	U.S. Environmental Protection Agency
ERDF	Environmental Remediation Disposal Facility
FFTF	Fast Flux Test Facility
FIR	field investigation report
HAB	Hanford Advisory Board
HFFACO	*Hanford Federal Facility Agreement and Consent Order*
HFSUWG	Hanford Future Site Uses Working Group
HI	hazard index
HLW	high-level waste
HMS	Hanford Meteorological Station
HTWOS	Hanford Tank Waste Operations Simulator
HWMA	"Hazardous Waste Management Act"
ILAW	immobilized low-activity waste
ILCR	incremental lifetime cancer risk
K_d	distribution coefficient
K_{oc}	organic carbon partition coefficients
LFRG	Low-Level Waste Federal Review Group
LLW	low-level waste
MCL	maximum contaminant level
MMI	Modified Mercalli Intensity
MUST	miscellaneous underground storage tank
NEPA	*National Environmental Policy Act of 1969*
NRC	U.S. Nuclear Regulatory Commission
PA	performance assessment

PNNL	Pacific Northwest National Laboratory
ppb	parts per billion
PUREX	Plutonium Uranium Extraction
RCRA	*Resource Conservation and Recovery Act of 1976*
REDOX	reduction-oxidation
RFI	RCRA field investigation
SALDS	State Approved Land Disposal Site
SCDR	subsurface conditions description report
SIM	Soil Inventory Model
SST	single-shell tank
SST PA	*Initial Single Shell Tank System Performance Assessment for the Hanford Site*
STOMP	Subsurface Transport Over Multiple Phases
TEDF	Treated Effluent Disposal Facility
TWINS	Tank Waste Information Network System
TWRS	Tank Waste Remediation System
UPR	unplanned release
WAC	*Washington Administrative Code*
WIDS	Waste Information Data System
WMA	waste management area

1.0 TECHNICAL AND REGULATORY APPROACH

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1.0 TECHNICAL AND REGULATORY APPROACH

1.1 INTRODUCTION

The U.S. Department of Energy (DOE) has initiated the process of retrieving, treating, and disposing of radioactive mixed wastes from the 149 underground single-shell tanks (SST) located on the Central Plateau in the 200 East and 200 West Areas of the Hanford Site. Figure 1-1 shows the location of the Hanford Site in south-central Washington State and the location of the 200 East and 200 West Areas within the Hanford Site. There are a total of 177 underground tanks; 28 are double-shell tanks (DST) and 149 are SSTs. SSTs are grouped into 12 groups of tanks called tank farms and are further aggregated into 7 waste management areas (WMA) to support compliance with hazardous waste regulations. All of the tanks contain a mixture of radioactive and hazardous wastes (i.e., mixed radioactive waste). SSTs receive their name because only a single steel tank liner is used to contain the waste. DSTs contain waste by using both inner and outer carbon steel liners. The annulus between the inner and outer shells allows for leak detection not available in the SST design.

DOE has committed to removing 99% of the SST system waste volume and transferring it to interim storage and treatment facilities before its ultimate disposal. The radioactive tank waste will be separated into a high-level fraction disposed of offsite at a geologic repository, and a low-activity fraction disposed of onsite as low-level mixed waste to a state-permitted facility. Following retrieval of the SST waste, and in accordance with the *Hanford Federal Facility Agreement and Consent Order* (HFFACO) (Ecology et al. 1989), the SST system with its remaining waste is assumed for the purposes of this document to then be closed as a landfill.[1]

Cleanup and closure of the contaminated SST WMAs is regulated by DOE, the Washington State Department of Ecology (Ecology), and the U.S. Environmental Protection Agency (EPA). Five primary regulatory processes govern cleanup and closure documentation and approval:

- HFFACO (Ecology et al. 1989)
- State of Washington "Hazardous Waste Management" Act (HWMA)
- *Atomic Energy Act of 1954*
- *National Environmental Policy Act of 1969* (NEPA)
- *Radioactive Waste Management* (DOE O 435.1)
- *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA).

[1]This document assumes the single-shell tank (SST) waste management areas will be landfill closed. As noted, DOE is in the process of preparing an environmental impact statement (EIS) under the *National Environmental Policy Act of 1969* (NEPA). This EIS will evaluate various closure alternatives, including, but not limited to, landfill closure. After completion of the NEPA process, this EIS will form the basis for DOE decision making regarding closure, as memorialized in a record of decision. This SST performance assessment does not represent a DOE decision for landfill closure in advance of completing the NEPA process, but is only intended to evaluate the human health impacts of this alternative.

Figure 1-1. Hanford Site Map and Location in Washington State

An integrated regulatory closure process has been developed by DOE in conjunction with Ecology and EPA to streamline regulatory approval for Hanford Site closure. The integrated regulatory process uses the existing HFFACO process, action plan, and milestones; completes the HWMA closure process as negotiated by DOE and Ecology; and completes site closure under CERCLA. The process also integrates the applicable requirements of the above regulations consistent with *Radioactive Waste Management Manual* (DOE M 435.1-1) and the *Atomic Energy Act of 1954*. DOE is the responsible agency for the closure of all SST WMAs.

These WMAs will be closed in close coordination with other closure and cleanup activities of the Hanford Site Central Plateau. Washington State has a state program authorized under the *Resource Conservation and Recovery Act of 1976* (RCRA) and executed through the HWMA and its implementing regulations. Ecology is the lead regulatory agency for HWMA and has regulatory authority over RCRA closure of the SST system. The 200 Areas of the Hanford Site, known as the Central Plateau, have been placed on the National Priorities List by EPA. The completion of remediation of the 200 Areas overall will be eventually finalized via CERCLA decisions made by EPA and permitting decisions made by Ecology.

An integrated regulatory closure process has been developed that uses the existing HFFACO process, action plan, and milestones; completes the HWMA closure process as negotiated by DOE and Ecology; and completes site closure under CERCLA.

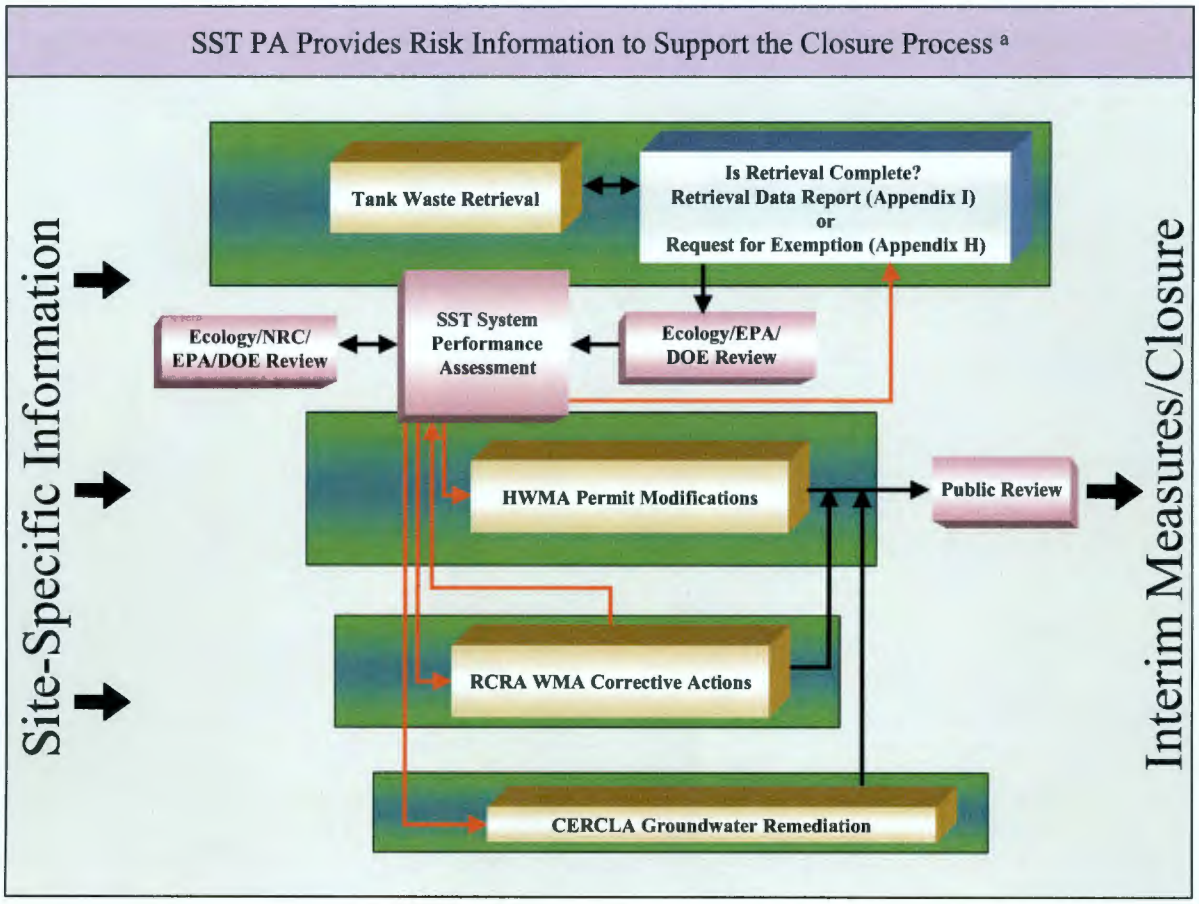
Implementation of the integrated regulatory closure process is authorized in Appendix I of the HFFACO which establishes expectations for the scope and approval of this *Initial Single-Shell Tank System Performance Assessment for the Hanford Site* (SST PA). Appendix I of the HFFACO establishes regulatory requirements under which waste within the SST WMAs will be retrieved, and the WMAs subsequently closed pursuant to applicable state and federal laws and regulations. Relevant sections from the HFFACO, Appendix I, Section 2.5 (Ecology et al. 1989), are as follows:

> "Ecology, as the lead agency for SST System closure, EPA, and DOE have elected to develop and maintain as part of the SST system closure plan one performance assessment for the purposes of evaluating whether SST system closure conditions are protective of human health for all contaminants of concern, both radiological and nonradiological. DOE intends that this performance assessment (PA) will document by reference relevant performance requirements defined by RCRA, HWMA, *Clean Water Act, Safe Drinking Water Act*, and the *Atomic Energy Act of 1954* (AEA), and any other performance requirements that might be ARARs [applicable or relevant and appropriate requirement] under CERCLA. The PA is of larger scope than a risk assessment required solely for nonradiological contaminants. The PA is expected to provide a single source of information that DOE can use to satisfy potentially duplicative functional and/or documentation requirements. A PA will be developed for each WMA and will incorporate the latest information available. These PAs will be approved by Ecology and DOE pursuant to their respective authorities. For Ecology approval means incorporation by reference, into the Site-Wide Permit through closure plans."

The closure of the SST system as currently projected means that the SST system would be closed as landfill units under the integrated regulatory closure process and is scheduled for completion by year 2032.[2] Figure 1-2 provides an overview of the Appendix I process in the HFFACO.

[2] See footnote 1.

Figure 1-2. Regulatory Purpose of the Single-Shell Tank Performance Assessment through the *Hanford Federal Facility Agreement and Consent Order* Process



[a] *Ecology et al. (1989)*

This SST PA will serve different purposes depending upon the regulatory process it is supporting. The SST PA will support waste determinations for tank waste residuals remaining after completion of retrieval in accordance with the HFFACO (Ecology et al. 1989). Additionally, Appendix H to the HFFACO requires DOE to interface with the U.S. Nuclear Regulatory Commission (NRC) with respect to allowable waste residuals in tanks and the soil column (i.e., vadose zone). To meet these different purposes, the SST PA includes analysis of past releases within each SST WMA, and will be submitted to the NRC for technical review and comment. The SST PA also supports regulatory waivers through the HFFACO Appendix H process when residual waste volume retrieval goals cannot be achieved. For example, a request for exemption to the HFFACO waste retrieval goal of 360 ft^3 for SST C-106 is currently under evaluation with the HFFACO regulatory authorities and the NRC.

The SST PA satisfies a requirement in the HFFACO for DOE to interface with the NRC with respect to allowable waste residuals in tanks and the soil column (i.e., vadose zone), and supports regulatory waivers to the HFFACO tank waste retrieval goals.

With respect to HWMA regulatory processes (both closure and corrective action), closure actions for contaminants associated with the SST system are being evaluated under two separate processes: 1) *Washington Administrative Code* (WAC) 173-303-610 closure requirements for treatment, storage, and disposal units and 2) WAC 173-303-646 corrective action requirements for releases from treatment, storage, and disposal units. WAC 173-303-610 closure requirements assume two closure options are available for tanks systems: 1) removal or decontamination of wastes and waste constituents to levels that allow for unrestricted land use (WAC 173-303-610[2][b]) or 2) landfill closure where such removal and decontamination cannot be achieved. The practicability of achieving removal or decontamination is analyzed in closure plans required under WAC 173-303-610. Selection of the closure option occurs through incorporation of specific closure activities by Ecology as modifications to the Hanford Site-wide permit (Ecology 2001). Corrective action requirements analyze multiple options for the cleanup of releases of waste to the soil column in a corrective measures study (CMS). Selection of corrective actions is achieved through an analysis that identifies those actions that provide the best balance of trade-offs with respect to prescribed balancing and modifying criteria. Similar to closure activities, selected corrective actions are defined by Ecology through incorporation as a modification to the Hanford Site-wide permit.

With respect to the NEPA regulatory process, DOE is in the process of preparing an environmental impact statement (EIS) under NEPA that will address tank closure. This EIS will evaluate various closure alternatives, including, but not limited to, landfill closure. After completion of the NEPA process, this EIS will contribute to the formulation of the basis for DOE decision making regarding closure, as memorialized in a Record of Decision.

This SST PA does not represent a DOE decision or presuppose an Ecology decision for landfill closure in advance of completing the NEPA and Ecology permitting processes, respectively; it is only intended to evaluate the human health and environmental impacts of the landfill alternative described herein. Should the HWMA or NEPA processes determine that the SST system will not close under landfill closure, risks to human health and the environment identified in this document will require re-evaluation to take into consideration the selected actions. As an example, the landfill system described in this document assumes that the direct exposure pathway is unavailable to either human or ecological receptors post-closure as a result of the presumed depth of the barrier. Only impacts to receptors associated with releases to groundwater and to an intruder are analyzed in this document. Evaluation of the direct exposure pathway may be required as part of future closure and corrective action decision-making processes should a barrier system not be selected.

1.2 PURPOSE

This SST PA evaluates the extent of protection to human health and the environment provided by the planned closure of the SST system. Both radiological and nonradiological contaminants are included in the analysis, as defined in Appendix I of the HFFACO (Ecology et al. 1989). This document is prepared early in the life cycle of the retrieval and closure project, before much waste retrieval has been performed, to support decision making in regards to completion of SST retrievals, SST system closure plans, and HWMA permit modifications. This SST PA will also support consultation between DOE and the NRC on issues related to disposal of radioactive waste remaining in the SST system.

This SST PA evaluates the extent of protection to human health provided by the planned closure of the SST system as defined in Appendix I of the HFFACO (Ecology et al. 1989).

The purpose of this document is to support risk informed decisions for:

- The HWMA regulatory process (i.e., HWMA treatment, storage, and disposal closure requirements, including HWMA corrective action requirements)
- Integration of HWMA decisions into CERCLA decisions for the rest of the Hanford Site
- Waste determinations for residual waste remaining in the SSTs after retrieval
- Allowable waste residuals in tanks and the soil column
- Justification that the extent of retrieval of waste from an SST is sufficiently protective of human health when retrieval goals cannot be achieved through the Appendix H process, defined in the HFFACO (e.g., SST C-106 is currently under evaluation for exemption from the HFFACO retrieval goal)
- Decisions under the *Atomic Energy Act of 1954* as implemented through DOE O 435.1
- Site-wide planning decisions in coordination with the composite analysis as defined under DOE O 435.1.

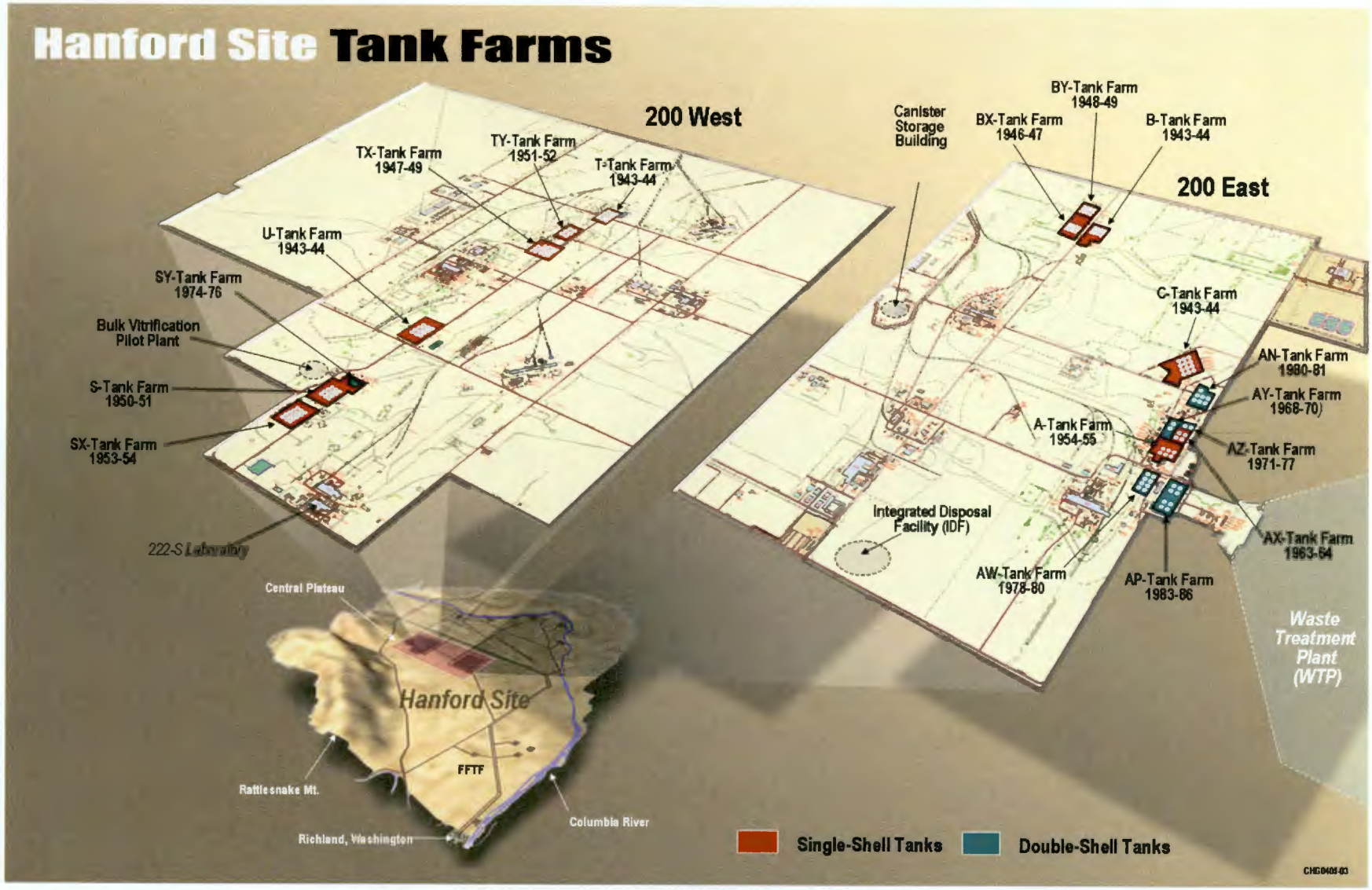
The development of a single document to support risk-informed decisions for all the above processes leading to closure is a direct result of agreements to streamline the closure process that are formalized in Appendix I of the HFFACO (Ecology et al. 1989).

1.3 BACKGROUND

The SST system is large and varied and comprises underground waste storage tanks, pipelines, waste transfer lines, water lines, diversion boxes, and other facilities and equipment. Vadose zone contamination from past releases or spills is present to varying degrees in all of the SST farms. For compliance with dangerous waste requirements, the SST farms have been further grouped into seven SST WMAs. These SST WMAs are A-AX, B-BX-BY, C, S-SX, T, TX-TY, and U. Figure 1-3 shows the location of the SST farms and other associated facilities.

As of September 2004, the SSTs contained approximately 30 million gal of mixed radioactive wastes (Hanlon 2004). Waste retrieval activities are under way and will continue for a number of years. The current plan, as stated in HFFACO Milestone M-45-00, is "… retrieval of as much waste as is technically possible, with tank residues not to exceed 360 ft^3 in each of the 100-Series tanks, 30 ft^3 in each of the 200-Series tanks, or the limit of waste retrieval technology capability, whichever is less" (Ecology et al. 1989). Retrieved tank wastes will be transferred to treatment facilities. At the time of SST system closure, it is anticipated that there will be contamination remaining in the tanks, ancillary equipment, and soils within each SST tank farm.

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



1.4 SCOPE

The scope of this SST PA includes all the information and analyses necessary to develop credible estimates of impacts to human health related to planned closure and post-closure conditions for the SST system. Estimated impacts include those to groundwater quality, to atmospheric releases of gaseous contaminants, and to an inadvertent intruder pathway.

Estimated impacts include those to groundwater quality, to atmospheric releases of gaseous contaminants, and to an inadvertent intruder pathway.

Though the scope of this SST PA is broad, some elements were not included:

- Impacts associated with the closure of DSTs and associated facilities (e.g., cross-site transfer lines)
- Impacts from transfer lines outside the immediate SST system
- Impacts from cribs, trenches, and other intentional discharge facilities located inside or in close proximity to a SST WMA boundary
- Short-term operational impacts (e.g., cost, safety, direct exposures, technical feasibility).

The first two of the elements above will be addressed in future revisions of the SST PA (Section 1.11). The third element above will be addressed in the future under the integrated regulatory closure process. The remaining element is addressed in site-specific operational documents developed to support retrieval of SST wastes and closure of the SSTs.

1.5 PERFORMANCE OBJECTIVES

In addition to the HFFACO (Ecology et al. 1989), the principal regulatory requirements for closure of the SST WMAs are the HWMA and its implementing requirements in the "Dangerous Waste Regulations" (WAC 173-303), and the DOE closure requirements in DOE O 435.1 under the *Atomic Energy Act of 1954*. These regulatory requirements have closure performance standards to ensure that after closure has occurred, any releases will not adversely impact human health above acceptable limits. These performance standards are presented in this document as performance objectives. Chapter 6.0 presents a comparison of the results of the analysis to the performance objectives.

Closure performance standards are defined in regulations to ensure that after closure has occurred, any releases will not adversely impact human health above acceptable limits. These performance standards are presented in this document as performance objectives.

The performance objectives for tank farm closure PAs are documented in *Performance Objectives for Tank Farm Closure Performance Assessments* (Mann et al. 2005). Because this SST PA is to meet both federal and Washington State requirements, some explanation of terms used is necessary. In DOE O 435.1 and its supporting documents on radioactive waste management, DOE uses the terms "performance objectives," "times of compliance," and "points of compliance" because these terms become part of the disposal authorization statement,

that is the DOE formal permitting authorization. Ecology, however, requires that terms containing "compliance" be restricted to the WMA point of compliance (Hedges 2002). Therefore, in this SST PA, instead of using "time of compliance" or "point of compliance," the terms "times of comparison" for "times of compliance" and "points of comparison" for "point of compliance" will be used. Exceptions to this practice are only made when directly quoting from another document.

The initial step in identifying performance objectives is to note the requirements that could be applied to the proposed action. If that action is the disposal of radioactive mixed waste on the Hanford Site, a variety of requirements should be considered:

- DOE requirements
- NRC requirements
- EPA requirements
- State of Washington requirements
- Public participation requirements.

The SST PA evaluates the following contaminant migration pathways and exposure scenarios (Section 1.9):

- Potential future site users including the general public and post-closure site workers
- Inadvertent intruders
- Groundwater
- Air resources.

In addition, there are restrictions on the waste itself if the waste is land disposed. However, land disposal restrictions are not evaluated in this document. Land disposal restrictions were addressed in *Single-Shell Tank System Closure Plan* (Lee 2004) and will be evaluated in updates to the closure plan at a future date.

The performance objectives identified here are for the long-term assessment of the public health from the closure of SSTs. Thus, for example, worker and public safety during the actual closure operation are not considered. Although reviewed by others performing Hanford Site assessments, it must be emphasized that these performance objectives deal only with the tank closure activities and not with the performance objectives of other Hanford Site actions. The performance objectives for a set of contaminants (e.g., beta-photon emitters) are summarized in Table 1-1. The use of appropriate performance objectives for their appropriate regulatory purpose is provided in Mann et al. (2005). The objectives for specific contaminants for groundwater are displayed in Table 1-2. The values for these objectives were chosen to be the most stringent maximum contaminant levels (MCL) of the applicable or relevant and appropriate requirements for its regulatory purpose (i.e., all-pathways dose under CERCLA and all pathways dose under DOE and NRC requirements). For organic chemicals, performance objectives are provided only for those organics most often found in tank waste. The performance objectives for specific contaminants are provided in Mann et al. (2005). Many of the objectives specify concentrations [e.g., (mg-contaminant)/(kg of soil) or (pCi-contaminant)/(liter of groundwater)] that are derived from defined exposure scenarios. Other objectives (e.g., all-pathways dose, incidental cancer risk) require that the exposure scenario (e.g., industrial, residential) be specified in order to calculate values for comparison.

Table 1-1. General Performance Objectives for Tank Closure

Protection of General Public and Workers [a, b, c, d]	
All-pathways dose from an SST WMA (CERCLA)	15 mrem in a year [k]
All-pathways dose from an SST WMA (DOE and NRC)	25 mrem in a year [e]
All-pathways dose including other Hanford Site sources	100 mrem in a year [e]
Chemical carcinogens (incremental lifetime cancer risk)	1×10^{-5} [f]
Radiological carcinogen (incremental lifetime cancer risk)	1×10^{-4} to 1×10^{-5} [l]
Non-cancer-causing chemicals (hazard index)	1 [f]
Protection of an Inadvertent Intruder [a, e, g]	
Acute exposure (driller)	500 mrem
Continuous exposure (post-intrusion)	100 mrem in a year
Protection of Groundwater Resources [b, c, d, h, i]	
Alpha emitters	
Radium-226 plus radium-228	5 pCi/L
All others (excluding uranium)	15 pCi/L
Beta and photon emitters	4 mrem in a year
Protection of Air Resource [a, b, e, j]	
Radon (flux through surface)	20 pCi m^{-2} s^{-1}
All other radionuclides	10 mrem in a year

[a] Doses are calculated as effective dose equivalents. Values given are in addition to any existing amounts or background.

[b] Evaluated for 1,000 years, but calculated to the time of peak or 10,000 years, whichever is longer.

[c] Groundwater use is assumed to be potable and suitable for use.

[d] Evaluated at the point of maximal exposure, but no closer than the fenceline of the SST WMA in which the tank farm belongs.

[e] *Radioactive Waste Management* (DOE O 435.1).

[f] Washington State "Model Toxics Control Act – Cleanup" (WAC 173-340), as applicable.

[g] Evaluated for 500 years, but calculated from 100 to 1,000 years.

[h] All concentrations are in water taken from a well.

[i] "National Primary Drinking Water Regulations" (40 CFR 141), as applicable.

[j] Main driver is "National Emission Standards for Hazardous Air Pollutants" (40 CFR 61 and 40 CFR 61 subparts H and Q).

[k] Main driver is EPA Memorandum OSWER 9200.4-18 (EPA 1997a).

[l] "National Oil and Hazardous Substances Pollution Contingency Plan" (40 CFR 300).

Table 1-2. Performance Objectives of Specific Contaminants for Groundwater Protection [a]

Radionuclides			
Tritium	20,000 pCi/L	Strontium-90	8 pCi/L
Radium-226	3 pCi/L	Radium-226 and radium-228	5 pCi/L
Uranium	30 µg/L	Beta and photon emitters	4 mrem/yr
Gross alpha (excluding radon and uranium)	15 pCi/L	Cobalt-60	100 pCi/L [b]
Carbon-14	2,000 pCi/L [b]	Technetium-99	900 pCi/L [b]
Inorganic Chemicals			
Antimony	0.006 mg/L	Arsenic	0.05 mg/L
Barium	2.0 mg/L	Beryllium	0.004 mg/L
Cadmium	0.005 mg/L	Chloride	250.0 mg/L
Chromium (total)	0.1 mg/L	Cyanide	0.2 mg/L
Fluoride	4.0 mg/L	Iron	0.3 mg/L
Manganese	0.05 mg/L	Mercury	0.002 mg/L
Nickel	0.1 mg/L	Nitrate (as NO_3) [c]	45.0 mg/L
Nitrite (as NO_2) [c]	3.3 mg/L	Selenium	0.05 mg/L
Silver	0.1 mg/L	Sulfate (as SO_4)	250.0 mg/L
Thallium	0.002 mg/L	Zinc	5.0 mg/L
Organic Chemicals			
Benzene	0.005 mg/L	bis(2-ethylhexyl)phthalate	0.006 mg/L
Carbon tetrachloride	0.005 mg/L	Chloroform	0.08 mg/L
1,4-Dichlorobenzene	0.075 mg/L	1,1-Dichlorethene	0.007 mg/L
Dichloromethane	0.005 mg/L	Ethyl benzene	0.7 mg/L
Toluene	1.0 mg/L	1,1,1-Trichloroethane	0.2 mg/L
1,1,2-Trichloroethane	0.005 mg/L	Xylenes (total)	10.0 mg/L
Styrene	0.1 mg/L		

[a] Values are from DOE O 5400.5, 40 CFR 141, 40 CFR 143, 40 CFR 264.94, WAC 173-200, WAC 173-303, and WAC 246-290.
[b] Based on 4 mrem/yr if this is the only contaminant (EPA 1976).
[c] Nitrate as nitrogen is equal to 10 mg/L. Nitrite as nitrogen is equal to 1 mg/L.

1.6 DEFENSE IN DEPTH PHILOSOPHY APPLIED TO TANK FARM CLOSURE

Planned closure actions for the SSTs and the PA of these actions are consistent with a defense in depth philosophy initially developed by the NRC to demonstrate a nuclear facility could be operated safely. Key elements of the defense in depth philosophy are the use of multiple barriers (both natural and engineered) to isolate waste in the disposal site and institutional controls to prevent or limit human access to the waste. This philosophy has been applied to high-level radioactive waste disposal in a deep geologic repository at Yucca Mountain, Nevada, with

primary emphasis on individuals who might use contaminated groundwater.[3] DOE has also endorsed the defense in depth philosophy (Chapter 1, Section 2.F [9] of DOE M 435.1-1) as a necessary means of addressing "potential uncertainties or vulnerabilities" in system performance. The defense in depth philosophy provides direction to the design of SST system closure, insight into the extent and type of characterization needed for the disposal system and the geologic environment, and the approach for conducting the performance analysis of the proposed SST closure system.

Key elements of the defense in depth philosophy are the use of multiple barriers (both natural and engineered) to isolate waste in the disposal site and institutional controls to prevent or limit human access to the waste.

Although there are distinct differences between closure actions in the Hanford Site SST system versus disposal actions at Yucca Mountain, these principles are relevant to SST system closure. The need for defense in depth is generated largely by the irreducible variability that is associated with radioactive mixed waste disposal in a geologic setting. To improve confidence in closure actions, a means of offsetting such uncertainties is desirable. The two primary factors that generate uncertainty about system performance are: 1) long-term performance (a minimum of 1,000 years) to protect against the long-term hazards from radioactive materials and 2) the natural heterogeneities of a geologic environment. The basic strategy is to implement multiple isolating functions in a multi-component system that control waste migration to human access points such that both independent and redundant functions are operational. With this approach, even if one or more parts of the performing system fail or function at a less effective level than projected, overall system performance will be satisfactory.

The SST PA analysis evaluates both the barrier performance relative to assigned functions and the degree of performance uncertainty for each barrier in the context of the complete barrier system and geologic environment. A key aspect of the evaluation is identifying failure modes for each barrier and considering the impact of single barrier failure or underperformance on the total system performance. Quality assurance, performance confirmation activities, and model verification activities are actions undertaken to ensure a credible representation for the performance of individual barriers as well as total system performance.

Multiple waste-isolating functions are provided by multiple barriers that isolate waste. The NRC requires the use of both natural and engineered barriers for the geologic repository (10 *Code of Federal Regulations* [CFR] 63.102 (h)) where a barrier is defined as "any material, structure, or feature that…prevents or substantially reduces the rate of movement of water or radionuclides…to the accessible environment, or prevents the release or substantially reduces the release rate of radionuclides from the waste" (10 CFR 63.2). Natural barriers are those features of the geologic system that contribute substantially to waste isolation (10 CFR 63.102(h)) regardless of other barriers. Their performance as barriers is expected to be consistent over the long term because the natural system in an adequate disposal site is essentially stable during the performance time period. However, due to the heterogeneities in the natural system properties

[3] See NRC policy issue paper, *Staff Plan for Clarifying How Defense-In-Depth Applies to the Regulation of a Possible Geologic Repository at Yucca Mountain, Nevada* [NRC 1999] and "Disposal of High-Level Radioactive Wastes in a Geologic Repository at Yucca Mountain, Nevada" [10 CFR 63].

Figure 1-4. Groundwater Pathway Contaminant Migration Process and Associated Multiple Barriers, Features, and Processes

The upper blocks (linked by arrows) show a three-step groundwater migration pathway to the accessible environment for contaminants initially present in tank residual waste. The various natural and engineered barriers and important features and processes that control migration are shown for each step. The multiplicity of barriers reduces reliance on any given barrier while also helping to compensate for the uncertainties implicit in any long-term predictions.

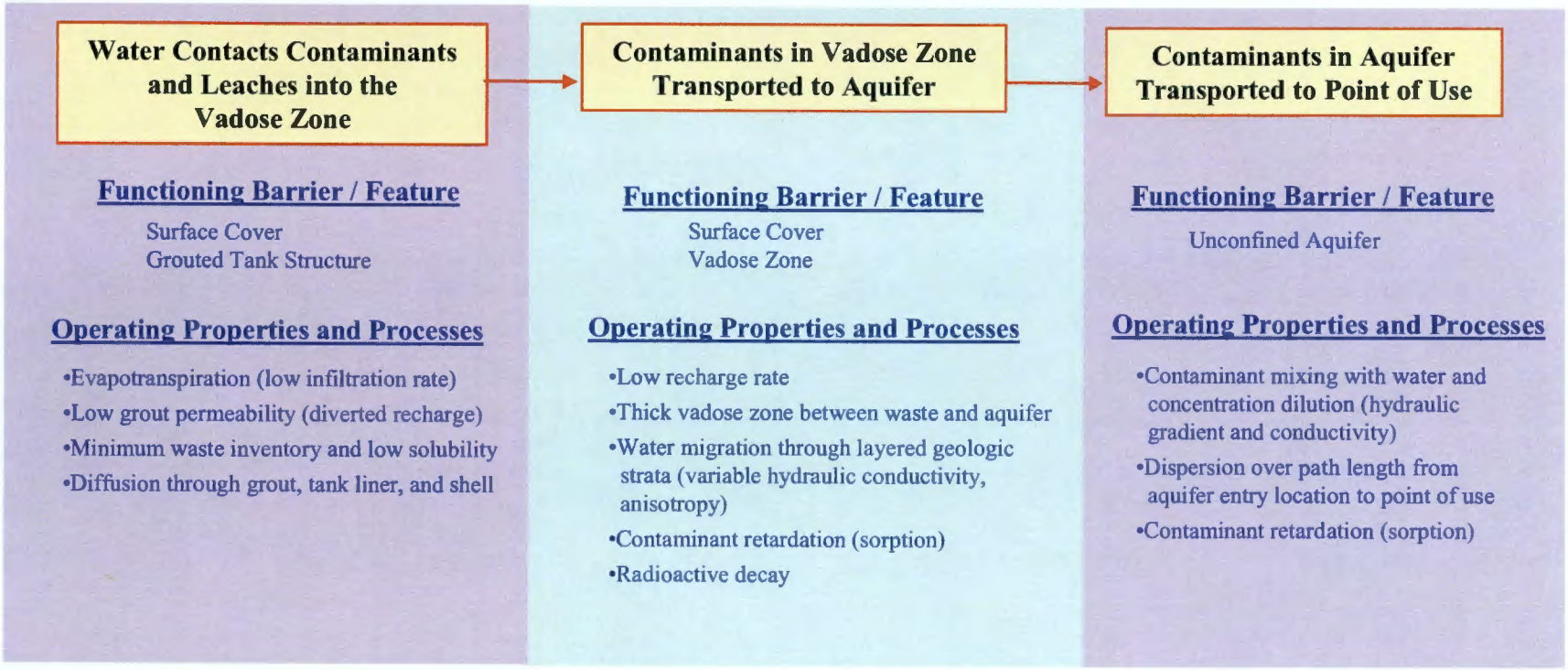


Table 1-3. Barriers, Features, Functions, Feature Effects, and Key Parameters Affecting Contaminant Migration along the Groundwater Pathway and Peak Groundwater Concentrations at Points of Use

Barrier/Feature	Functions/Feature Effects	Key Parameters [a]
Surface cover	Minimize recharge to the subsurface.	Average annual recharge rate
Grouted tank structure (Grout fill, liner, shell, sluiced waste)	Divert recharge water away from waste by lower permeability than surrounding backfill. Isolate waste and limit contaminant release to diffusion levels. At least 99% of the inventory removed by waste retrieval leaving behind mostly insoluble contaminants.	Grout permeability Diffusion coefficient Contaminant-specific inventory Contaminant-specific solubility
Vadose zone	Provide extended contaminant travel time to unconfined aquifer. Retard contaminant migration by chemical reaction with soil-water system.	Thickness between waste and unconfined aquifer Hydraulic properties of major geologic strata (hydraulic conductivity, anisotropy, dispersion) Initial moisture content Distribution coefficients (K_d)
Unconfined aquifer	Dilute contaminant concentrations entering from vadose zone by mixing. Disperse contaminants in three dimensions along flow path. Retard migration by chemical reaction with soil water system.	Hydraulic gradient Hydraulic conductivity Dispersion coefficient Distribution coefficients (K_d)

[a] Different key parameters can be used to represent barrier functions. The surface cover is likely a multiple barrier system whose layers and processes could be modeled explicitly (e.g., evapotranspiration processes) or episodic recharge. In this analysis, a simple approach was taken, using an assumed annual recharge rate as a boundary condition to represent a more complex infiltration process.

In this SST PA, both reference case and sensitivity/uncertainty analyses were completed (see Sections 3.4.7 and 3.5 for detailed discussion). For the reference case, a set of conditions, human actions, and environmental processes that were considered the best estimate of future conditions and events were assumed. The numerical model used to estimate the long-term performance of the closed SST system under reference case conditions simplified representation of the physical system and processes controlling flow and contaminant transport. A reference case set of "central tendency" parameter values (i.e., those values considered most representative of actual conditions) was selected that represented the best current understanding of final closure and environmental conditions. From this parameter set, reference case outcomes (primarily contaminant concentration levels in the unconfined aquifer over time and space) were calculated at a point of comparison (e.g., SST WMA fenceline).

A reference case set of "central tendency" parameter values (i.e., those values considered most representative of actual conditions) was selected that represented the current understanding of final closure and environmental conditions.

The selection of process models, simplification of the physical system, and parameters used in the models generate variability around the projected outcome. Two types of sensitivity analyses were performed to address this issue. First, assuming reference case conditions, the significant parameters (e.g., recharge rate, diffusion coefficient/length, K_d) were varied over the range of possible site-specific values, and the associated changes in outcomes were calculated. The key outcomes were maximum groundwater contaminant concentrations calculated during the modeling time frame for each case. These concentrations were labeled "peak values." Parameters were varied one at a time to determine which parameters provided the greatest differences in the peak values.

Significant parameters (e.g., recharge rate, diffusion coefficient/length, K_d) were varied over the range of possible site-specific values, and the associated changes in outcomes were calculated. Alternate conceptual models of contaminant propagation in which processes and events that differ from the reference case were evaluated.

Several insights were derived about the performance of the total SST system (SST WMA closure structures and its associated hydrogeologic environment) including:

- A ranking of parameter influence on potential groundwater contamination level variability was determined by comparing the parameter-specific ranges of estimated peak values around the reference case peak values. A larger range indicated greater parameter influence.
- Because parameters represented specific barrier functions, the effects of parameter variability on peak value changes indicated the sensitivity of total system performance to degradation or failure of single barrier performance.
- Peak value variability estimated from assumed parameter value variability provided a qualitative estimate of performance uncertainty. With this approach, uncertainty was assessed as a limited range of plausible peak values. The likelihood of a particular outcome was not determined other than to assume a general tendency for the outcome to be near the peak value projected by the reference case.

The second type of sensitivity analysis considers alternate conceptual models of contaminant propagation in which processes and events that differ from those assumed in the reference case and that have an impact on single-barrier or total system performance are evaluated. These analyses are sometimes referred to as "what if" analyses. The "what if" analyses estimate the flexibility and robustness of single-barrier and total system performances for a greater range of conditions than the "single parameter variable" analyses.

1.6.2 Defense in Depth Strategy for the Inadvertent Intruder Pathway

Implementation of the defense in depth philosophy to protect the inadvertent intruder who unknowingly exhumes waste and is exposed to contaminants has not been addressed directly by either NRC or DOE in previous guidance documents. Considering the relevance of defense in depth concepts to the inadvertent intrusion pathway for this analysis, it can be concluded that closure actions for the SST system do provide defense in depth for the inadvertent intruder, but the applicability of the defense in depth philosophy is mostly limited to affecting human actions.

The inadvertent intrusion event consists of two major parts; the first being a deterrence interval (the time period between site closure and the intrusion event) and the second being the intrusion and exposure event. For the deterrence interval, defense in depth philosophy is implemented by the application of both institutional controls and engineered barriers. The natural system has no impact on the inadvertent intrusion scenario. The primary purpose of the defense in depth approach is to delay intrusion long enough to reduce the inventory of moderate half-life radionuclides, primarily cesium-137 and strontium-90, to less harmful levels. This time period is usually 10 half-lives or approximately 300 years. This reduces the initial inventories to 0.1% of the original quantities for these radionuclides.

Because deterrence is primarily a matter of human actions taken to prevent other human actions, institutional controls are the first and most important defense. Active institutional controls (direct human oversight) are instituted first. Controls may include public records developed to identify waste locations, human guards to inspect the facilities routinely and turn away unauthorized individuals, and fences erected and maintained to deny access to waste sites. Later, when resources are assumed unavailable to support active institutional control, passive institutional controls deter the intruder (e.g., markers). If institutional controls fail and the waste site is disturbed, engineered barriers provide additional deterrence. The engineered barriers are the surface cover and the grout-filled tank structure. Surface covers containing markers and icons to warn intruders of buried waste, and the high strength grout tank fill deter drillers from penetrating waste. These various activities comprise the defense in depth philosophy whereby several distinct methods are employed to prevent intrusion.

If intruder deterrence fails, intrusion and exposure occurs. Because the tank residual waste is buried a minimum of 55 ft below ground surface (bgs) (this includes the distance from the surface cover to the base of the tank), the only reasonable access mode is drilling. The act of drilling is the single failure mechanism that eliminates all institutional controls and the functionality of all engineered barriers (i.e., common mode failure).

The SST PA methodology is not well equipped to evaluate the effectiveness of defense in depth actions that promote deterrence. Unlike the groundwater pathway, where physical and chemical processes imposed by barriers do occur that affect contaminant behavior and future exposure levels, deterrence is largely dependent on human actions that may or may not occur in response to preventative measures taken. The effectiveness of a particular institutional control or the performance of the composite set of various institutional controls is a subjective decision. Similarly, the operating engineered barrier functions are essentially warnings to dissuade an intruder from drilling into the waste. The success of these functions is also a subjective and arbitrary decision and no probability of occurrence is assigned.

The SST PA analysis indirectly evaluated the effects of the defense in depth actions taken to deter intrusion in the post-intrusion analysis. Table 1-4 identifies important barriers, features, and associated parameters. The post-intrusion analysis was completed by selecting scenarios that involved different kinds of exposure based on time spent near waste and the use of materials contaminated by waste (e.g., rural pasture). A significant parameter in these analyses was the waste inventory that was exhumed, which, in turn, was determined by the volume of waste exhumed and the contaminant concentrations in that waste. Defense in depth actions minimized the waste volume that was exhumed. A maximum amount of waste was removed during retrieval, and the depth to waste created by the surface cover and grouted tank structure limited all reasonable options for waste exhumation to borehole drilling where the cuttings (including waste) were brought to the surface. The extended deterrence interval reduced contaminant concentrations of radionuclides, primarily cesium-137 and strontium-90, whose half-lives are appreciably shorter (i.e., half-life of 30 years or less) than the deterrence interval (i.e., 500 years after closure). In the SST PA analysis, a reference case engineered barrier configuration was assumed that assigned unique values to these parameters.

Table 1-4. Barriers, Features, Functions, Feature Effects, and Key Parameters Affecting Contaminant Exposure from Inadvertent Intrusion

Barrier/Feature	Functions/Feature Effects	Key Parameter [a]
Surface cover	Provide deterrence to inadvertent intruder by construction and embedded markers and icons. Provide distance between surface and waste that limits credible waste exhumation methods to drilling.	Time to breach post-closure Thickness
Grouted tank structure (grout fill, liner, shell, sluiced waste)	Provide contrasting hard-to-drill material to deter penetration of borehole to waste. Provide distance between surface and waste (55 ft) that limits credible waste exhumation methods to drilling. At least 99% of waste volume removed by waste retrieval, leaving behind mostly insoluble contaminants.	Time to breach post-closure Thickness Contaminant-specific inventory and concentrations at intrusion Contaminant-specific solubility

[a] The only parameters used in the inadvertent intruder models are the time to breach and inventory.

1.6.3 Air Pathway Considerations

The final contaminant migration pathway considered in the SST PA analysis was the air pathway. In this pathway, volatile radionuclide constituents in the wastes contaminated vapors that migrated upward through the grouted tank structure and the surface cover. The need for defense in depth measures was greatly reduced by the lack of contaminants that could be reasonably expected to volatilize in significant quantities (typically, carbon-14, tritium, and radon), the low concentrations of these constituents in tank residue, and the unlikely human activity scenarios needed to cause significant exposure. Thus, the SST PA analysis considered bounding conditions rather than "central tendency" reference case analyses and associated sensitivity analyses.

1.7 PLANNED SINGLE-SHELL TANK SYSTEM CLOSURE ACTIONS AND END STATE

This section includes discussion of the closure action processes to achieve a landfill closure end state. Closure of the individual SSTs and SST WMAs occurs in three major steps: 1) SST waste retrieval, 2) tank filling for stabilization, and 3) surface barrier placement. Each of these steps will be described in the respective component closure activity plan. A general description of these steps follows.

Closure of the individual SSTs and SST WMAs occurs in three major steps: 1) SST waste retrieval, 2) tank filling for stabilization, and 3) surface barrier placement.

For near-surface disposal to occur (i.e., landfill closure), DOE must retrieve as much waste as technically possible (Ecology et al. 1989). DOE should meet the performance objectives for the disposal of Class C low-level waste (LLW) provided in 10 CFR 61, subpart C. In addition, because the tank waste residual is mixed waste, it has to meet Washington State dangerous waste requirements for closure (WAC 173-303). In the HFFACO Appendix I (Ecology et al. 1989) entitled, "SST System Waste Retrieval and Closure Process," closure permits will be incorporated into the Hanford Site-wide permit (Ecology 2001).

At the time SST system closure is completed (i.e., year 2032), approximately 0.5 million gal of waste (i.e., 1% by volume) containing approximately 2 million curies (Ci) of radioactivity will remain in the 149 SSTs. In this, strontium-90 and cesium-137 represent approximately 99% of that radioactivity. Both contaminants (strontium-90 and cesium-137) are relatively immobile in the environment and decay rapidly (i.e., short half-lives of approximately 30 years). During or shortly after the waste retrieval process, DOE, in conjunction with EPA and Ecology, would establish levels of soil remediation necessary, if needed, to ensure protection of groundwater resources and the general public.

The next closure action process after Ecology and DOE Headquarters approval would be to fill the tanks with grout to stabilize and immobilize the residual waste (Figure 1-5) to prevent further long-term degradation of the SSTs, and to discourage intruder access as required for a near-surface disposal facility. Remediation and stabilization, if needed, of waste in ancillary equipment and other contaminant sources with the SST system would also occur.

The final closure process activity would be placement of an engineered surface cover (about 15 ft in thickness). This surface cover will provide a barrier to infiltration and intrusion in compliance with federal and state regulations. Figure 1-6 shows a configuration of the planned SST system closure end state and how it will be designed to impede contaminant migration.

The closure process includes the preparatory actions to characterize components within the SST system for the purposes of closure, the tank fill proposed to prepare the SSTs for closure, and the surface cover design proposed for the SST system and closure of each SST WMA. In preparation for these actions and as required by Condition II.D.1 of the Hanford Site-wide permit (Ecology 2001), all waste in the SST WMA vadose zone and ancillary equipment components will be analyzed in accordance with a written waste analysis plan or sampling and

analysis plan. Sampling and analysis plans will be developed to support sampling activities for closure, and a data quality objectives (DQO) process will be used to ensure agreement between Ecology and DOE on the appropriate sampling and analysis requirements for closure purposes.

The characterization process has begun for 3 SSTs (i.e., tanks C-106, C-202, C-203) and will continue for the remaining 146 tanks. Characterization will also be conducted for soil, SST systems, and ancillary equipment at the SST WMA level, and details (e.g., crosswalk to DQO and/or sampling and analysis plan) will be included in the appropriate SST WMA closure action plan, component closure activity plan, and/or corrective action documentation and incorporated into the closure permit as outlined in Appendix I of the HFFACO (Ecology et al. 1989). Groundwater characterization will occur as part of the remedial investigation and feasibility study process under CERCLA.

Figure 1-5. Stabilized Waste Tank

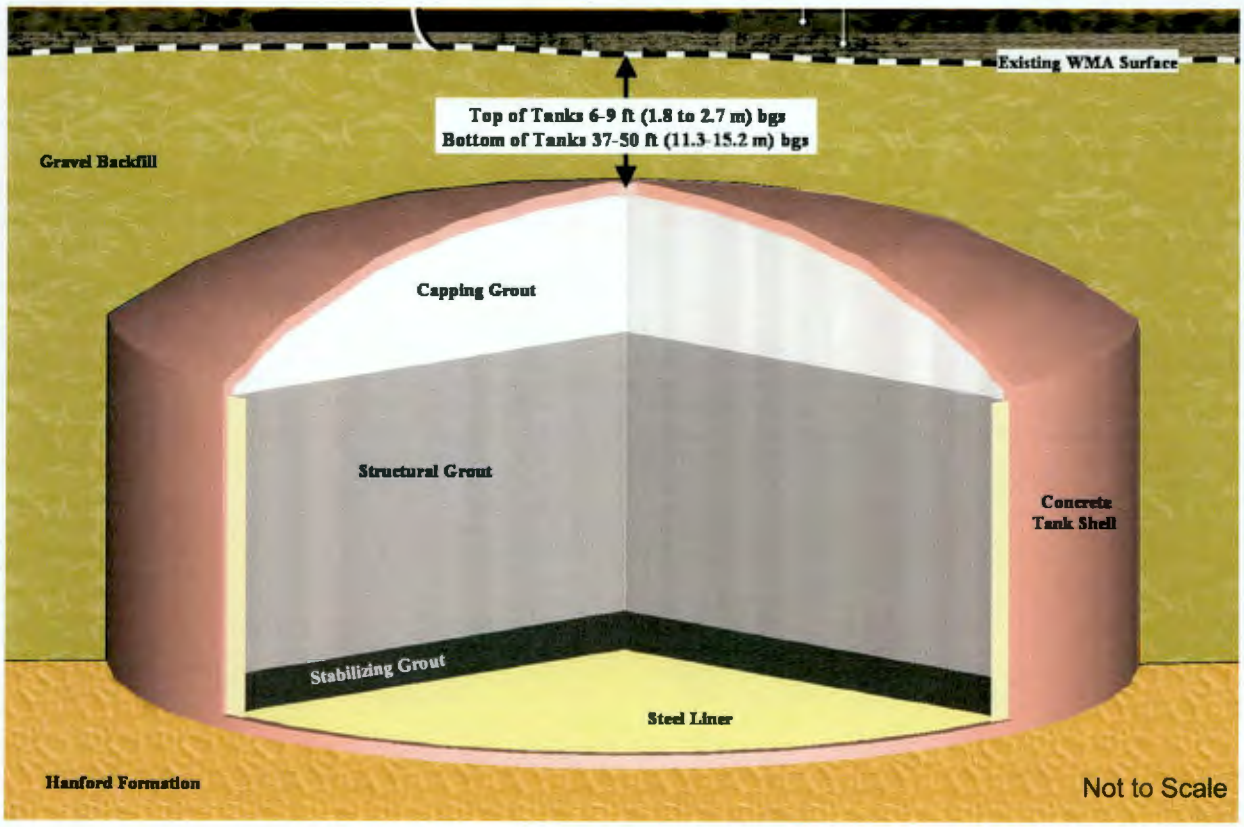
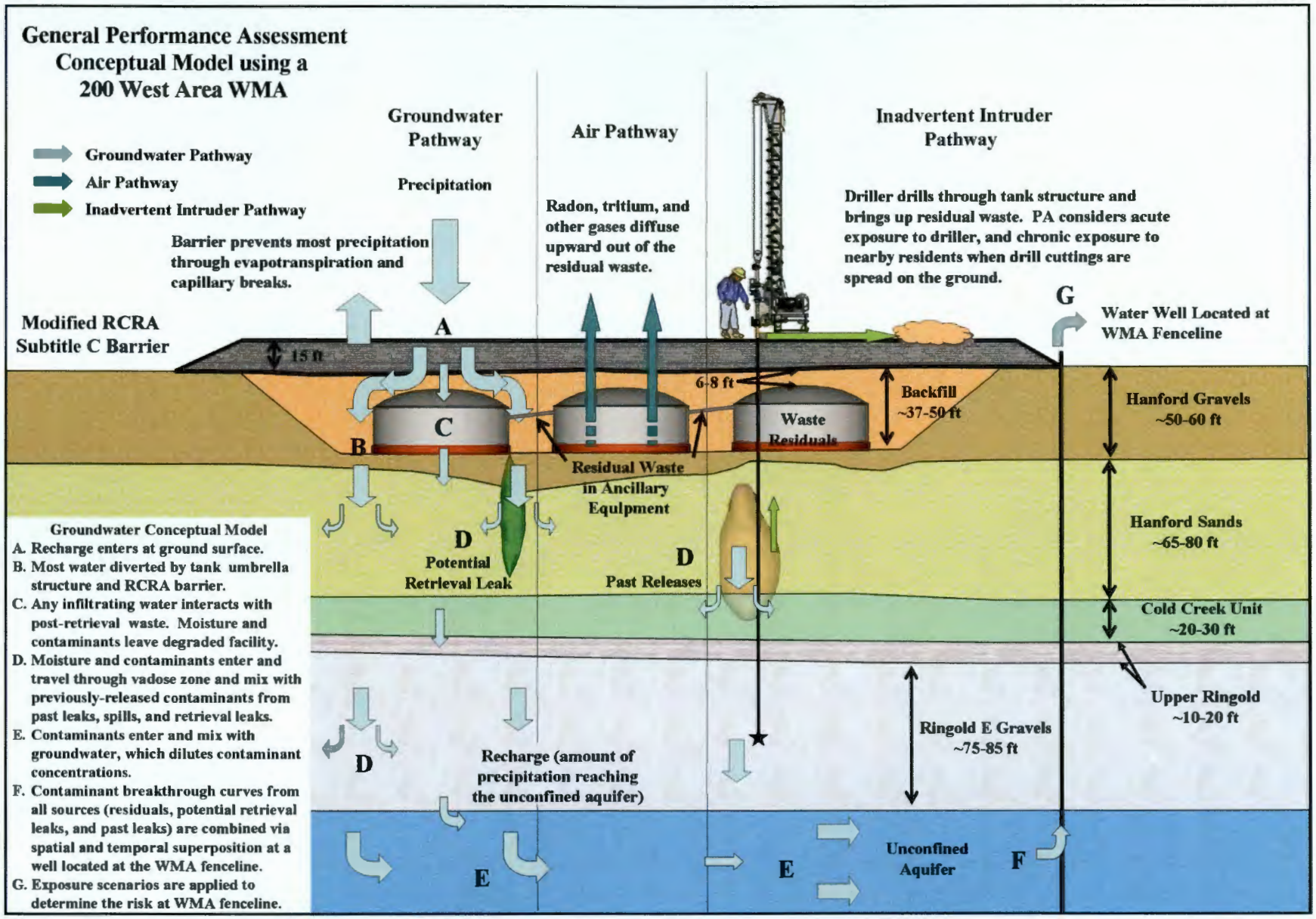


Figure 1-6. General Performance Assessment Conceptual Model



The geology shown in the figure is specific to the 200 West Area.

1.7.1 Waste Retrieval

HFFACO Milestone M-45-00 states: "Closure will follow retrieval of as much tank waste as technically possible, with waste residuals not to exceed 360 ft^3 in each of the 100-Series tanks, 30 ft^3 in each of the 200-Series tanks, or the limit of waste retrieval technology capability, whichever is less" (Ecology et al. 1989). DOE will retrieve as much waste as technically possible, with a remaining waste residual of no more than 360 ft^3 for the 100-Series tanks and 30 ft^3 for the 200-Series tanks (i.e., 99% retrieval by volume). Following waste retrieval activities, DOE will use in-tank survey methods to determine whether retrieval volume criteria have been met. Also as part of this milestone, a data report will be submitted to Ecology for approval to demonstrate completion of waste retrieval in accordance with HFFACO Milestone M-45-00. For tanks that are not subject to milestones (e.g., small miscellaneous underground storage tanks [MUST]), an Ecology-approved data report will also be submitted to demonstrate completion of retrieval.

The residual waste will be characterized to support disposal decisions and risk assessments. DOE will follow a DQO process for conducting the tank waste residual characterization activities. As part of the DQO process, characterization requirements will be documented in tank-specific component closure action DQOs. A sampling and analysis plan has been developed for tank C-106 (Banning 2004), and general sampling and analysis plans will be developed for the 100-Series tanks and the 200-Series tanks.

If the waste residual in individual tanks meets the waste retrieval criteria and the risk metrics related to the waste residual are accepted, DOE will modify the closure activity plan and the Hanford Site-wide permit, if necessary, and then proceed with implementing the approved component closure activity plan. If waste residual exceeds the waste retrieval criteria, DOE will either attempt additional retrieval or request an exception to the retrieval criteria. This request will be prepared pursuant to the procedure in Appendix H, Attachment 2, of the HFFACO (Ecology et al. 1989).

As such, tank-specific considerations such as riser availability, waste condition, or in-tank interferences might offer advantages to one retrieval technology over other technologies, and lead to the selection of that technology to retrieve a particular tank. Based on tank-specific considerations, the following representative waste retrieval technologies were selected for the SSTs:

- Modified sluicing is selected for 100-Series SSTs that are not classified as assumed leakers. This technology is representative of other fluid based retrieval technologies (e.g., past-practice sluicing). Deployments are limited to those tanks that are not classified as assumed leakers because of concerns over the potential for leakage to occur during waste retrieval. There are 67 tanks currently classified as assumed leakers. It is recognized that a number of tanks classified as assumed leakers may be candidates for deployment of modified sluicing after further evaluation of historical leak data. Based on current design information, modified sluicing is expected to be capable of retrieving 99% by volume of the tank waste.

- The mobile retrieval system is selected for 100-Series SSTs that are classified as assumed leakers. This technology provides for waste retrieval using lower liquid volumes, thereby reducing the potential volume of a retrieval leak should one occur.
- Vacuum-based retrieval is selected for retrieving waste from the 200-Series tanks and may be selected for MUSTs. This technology is flexible in that it can be operated as a dry-vacuum retrieval method, or liquid can be introduced near the vacuum head depending on the type of waste to be retrieved. This technology is well suited for deployment in small tanks and would minimize the potential for leakage in a number of the 200-Series tanks that are classified as assumed leakers.

1.7.2 Tank Stabilization and Isolation Options

Upon completion of SST waste retrieval, physical and administrative isolation of the SST will occur. Each SST will be stabilized in accordance with component closure activity plans approved by Ecology. SST stabilization may consist of adding fill into the waste-retrieved tanks and may differ from SST to SST, depending primarily on the volume and characteristics of the residual waste remaining after waste retrieval and also depending on the integrity of the SST.

Physical isolation refers to filling and/or capping of pipelines, drains, ducting, or other openings into the SST structure as needed, and will occur progressively as individual SSTs near final stabilization. Administrative isolation controls tank access through procedural actions. Both physical and administrative isolation measures are intended to prevent infiltration of water or inadvertent reintroduction of waste and/or grout into a partially stabilized or stabilized tank.

Numerous tank fill materials have been evaluated in the past in other documents, including EISs. These have included in situ vitrification, gravel fill, and grout or cementitious material. Based on anticipated cost, as well as implementability and technical uncertainties, grout was chosen for the fill material. This is consistent with the closure contingency in Lee (2004) if clean closure cannot be achieved.

Tank stabilization will be accomplished by adding grout or other structural material in layers into each tank. The addition of grout or cementitious material will occur over three separate phases (Figure 1-5). The Phase I fill will consist of a free-flowing grout and will cover the waste residuals and debris on the tank bottom, and will additionally provide structural support for subsequent fills. The Phase II fill will provide structural stability and fill the majority of the tank volume. The Phase III fill will be a high-compressive-strength grout placed in the remaining void space between the Phase II grout and the tank dome and will fill tank risers to the maximum dome height. The function of the Phase III grout is to discourage intruder access. The entire fill system, consisting of Phases I, II, and III, provides structural support to the tank dome to prevent subsidence and degradation of the surface cover placed at the time of WMA closure (Lee 2004). Under the RCRA Corrective Action process, WMA soils will be remediated on an as-needed basis.

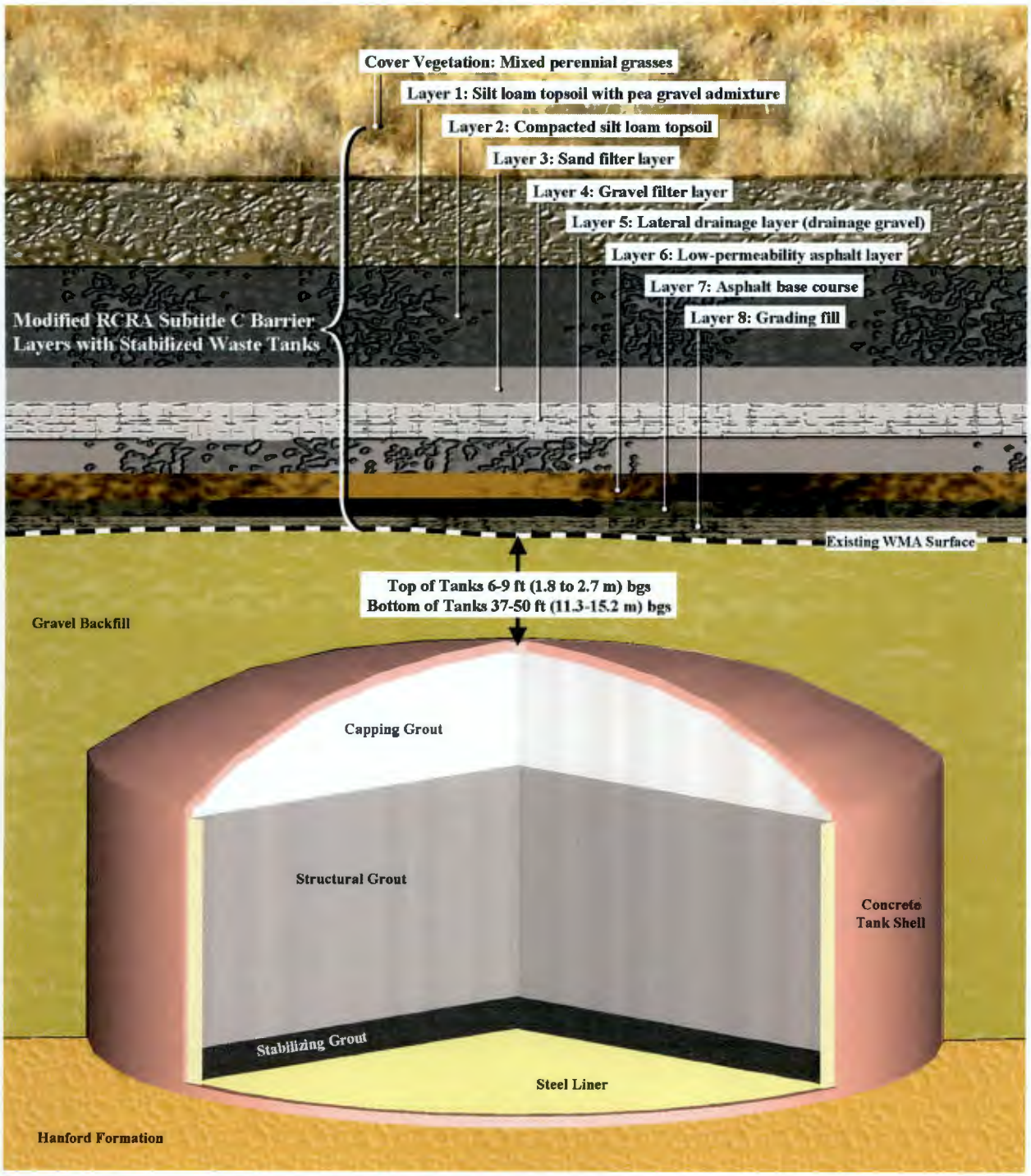
1.7.3 Surface Cover Placement

As SST farms are retrieved, stabilized, and isolated for closure, 15-ft-thick surface covers will be constructed to restrict precipitation from contacting stabilized waste and transporting contaminants to the groundwater. The surface covers will be designed to deter inadvertent access or intrusion to the underlying wastes by flora and fauna. The design will also include features that both emulate geologic phenomena known to last for extended periods of time and provide hydraulic isolation from infiltrating precipitation.

The closure surface cover for SST WMAs is assumed to be a Modified RCRA Subtitle C Barrier as conceptually described in *Focused Feasibility Study of Engineered Barriers for Waste Management Units in the 200 Areas* (DOE-RL 1996) and currently designed for the Integrated Disposal Facility in the 200 East Area (Fayer and Szecsody 2004). This surface cover is the baseline design for sites containing dangerous waste, Category 3 low-level waste, and/or Category 3 mixed low-level waste, and Category 1 mixed low-level waste (DOE-RL 1996). This surface cover is designed to provide long-term containment and hydrologic protection for a 500-year period of performance and is composed of up to eight layers of durable material (Figure 1-7). A summary description of each of the layers in this surface cover is given in DOE-RL (1996) including thickness, layer description, specifications, and functions. This design incorporates RCRA minimum technology guidance with modifications for extended performance of up to 500 years. Major changes to account for Hanford Site-specific conditions include elimination of the clay layer, which is projected to desiccate and crack over time in the Hanford semiarid environment, and elimination of the geomembrane component due to uncertainty regarding its long-term durability.

At the current stage in the SST WMA closure process, site-specific surface cover designs are not available. Specifically, an infiltration rate could not be assigned to a specific SST WMA cover design. To address this issue, an infiltration rate for the assumed surface cover was selected that has been shown to be easily attainable (Fayer and Szecsody 2004) based on current design concepts, as described above, and availability of materials. Assumptions on the performance of the SST WMA closure surface cover also incorporated performance expectations from the detailed designs associated with the Integrated Disposal Facility that is currently under construction. Section 3.4.2 presents a detailed discussion of this component of the SST WMA closure system.

Figure 1-7. Modified RCRA Subtitle C Barrier Profile [a] with Stabilized Waste Tank (not to scale)



[a] *DOE-RL (1996)*

1.8 CONTAMINANT MIGRATION PATHWAY MODELING APPROACH

A conceptual model of each contaminant migration pathway will be developed for each SST WMA that incorporates all the site-specific data available. For the groundwater pathway, much of these data have been collected under the HWMA corrective action activities conducted by the DOE Office of River Protection under the oversight of Ecology. Figure 1-6 presents a schematic of a typical conceptualization for a generalized SST WMA. The conceptualization is then simplified (retaining the important features that include the dominant processes controlling transport of contamination) to allow construction of a numerical model and begin the process of qualitatively investigating the performance of the specified SST closure system.

In keeping with the defense in depth philosophy, a reference case for each contaminant migration pathway was defined. The reference case represents the set of parameters and engineering assumptions that provides a "central tendency" estimate of the input parameter values for the SST closure system. This reference case is complemented by a concurrent examination of the expected range in parameter values for barrier or feature of the SST closure system. To estimate the robustness of the SST closure system features, alternative conceptualizations are also analyzed using the reference case design to establish the level of performance degradation that might occur. This degradation might represent an underestimate in the performance of a feature (e.g., surface cover) or an error in the geologic conceptualization of the system. Poor system performance noted through either the sensitivity analysis or the alternative conceptualization "what if" analysis indicates a need for an improved understanding of the system or a design change.

Three migration pathways (i.e., groundwater, air, and inadvertent intrusion) are modeled differently in this analysis, and focus on different aspects of the closure system depending on the contaminant migration pathway characteristics. However, certain features and assumptions are common to the modeling of each pathway and SST WMA. These are described as follows and refer primarily to the reference case:

- Retrieval of tank waste is assumed sufficient to meet the waste retrieval goals of the HFFACO (Ecology et al. 1989) (i.e., at most, 360 ft^3 of waste remaining in 100-Series tanks and 30 ft^3 of waste remaining in 200-Series tanks).
- Institutional controls of the site are assumed for the reference case for 300 years (industrial land use) for protection of groundwater (Section 6.2.1).
- Simulation of contaminants including 25 chemicals, 46 radionuclides, and supplemental analytes is analyzed.
- A surface cover is assumed to perform up to its design specifications for 500 years (NRC 2000).
- SSTs will be filled with grout after the completion of waste retrieval (Section 1.7.2).

Three contaminant migration pathways (i.e., groundwater, air, and inadvertent intrusion) are addressed in this analysis.

Modeling of the groundwater pathway assumes that:

- Site-specific contaminant flow and transport analyses conducted for WMA C in the 200 East Area and WMA S-SX in the 200 West Area are sufficient to estimate the groundwater concentration for other SST WMAs at their points of comparison. Due to similarities in the geology, WMA C performance was extrapolated to other SST WMAs in the 200 East Area; similarly, WMA S-SX performance was extrapolated to the SST WMAs in the 200 West Area (Section 3.2.2.4.8).
- The period of simulation was selected at 10,000 years due to the long periods for impacts to be observed in the environment for mobile contaminants and from NRC guidance (NRC 2000).
- Deterministic analyses coupled with sensitivity analyses address uncertainty issues (Section 3.2 and Section 3.5).

Deterministic analyses coupled with sensitivity analyses address uncertainty issues.

Modeling of the air migration pathway uses a bounding analysis due to the very low impacts from radioactive gases expected.

The inadvertent intruder pathway is described as a set of assumptions that form the initial conditions for modeling of subsequent exposure scenarios. These include:

- Active and passive institutional controls (consistent with other Hanford Site PAs) that deter intrusion into the waste form for 500 years
- Intrusion occurs through drilling through the past releases and/or waste residuals; a portion of the waste is brought to the surface in drill cuttings.

Modeling of the reference case inadvertent intruder scenario assumes:

- A one-time acute dose to the driller occurs from exposure to exhumed waste over 5 days
- A chronic dose to the inadvertent intruder occurs from the use of the exhumed waste spread over an area for a rural lifestyle over a period of 50 years.

A complete discussion of the methodology used in this SST PA is presented in Chapter 3.0.

1.9 SCENARIOS

This section discusses the assumed exposure scenarios[4] that are used to investigate the potential future impacts to public health of the closed SST WMAs. For the reference case, scenarios were developed on the basis of land use assumptions that define an assumed future use of the remediated site. Scenarios are typically defined for industrial and residential uses of land (DOE-RL 1995a; Ecology 2001; EPA 1989); however, many other exposure scenarios exist. Within each scenario, the receptor interacts with contaminants through pathways such as dermal

[4] A scenario is a collection of human activities that defines a lifestyle or an action that can be used to assess the level of interaction of the individual with their environment.

exposure, inhalation, ingestion, and in some cases, adsorption through the skin. For each exposure scenario pathway, inputs are developed that define the impact of the contaminant through its exposure pathways. Typical inputs define breathing rates, exposure duration, diet, and other inputs. *Exposure Scenarios and Unit Factors for the Hanford Tank Waste Performance Assessment* (Rittmann 2004) provides a complete description of the exposure scenarios and toxicological information.

For the reference case, scenarios were developed on the basis of land use assumptions that define an assumed future use of the remediated site.

1.9.1 Future Land Use

The selection of assumed exposure scenarios begins with the selection of land use. In 1992, the Hanford Future Site Uses Working Group (HFSUWG) was charged with determining potential future uses of the various parts of the Hanford Site. This group consisted of local, state, and federal officials, representatives of affected Tribal Nations, agricultural and labor organizations, as well as members of environmental and other special interest groups. The efforts of the HFSUWG form the basis of the Hanford Site comprehensive land-use EIS (DOE 1999b).

The following four general land uses (DOE 1999b) can be envisioned for the Central Plateau over the time of interest to this SST PA:

- Industrial or commercial
- Dry-land farming
- Irrigated farming
- Natural.

Industrial or Commercial: The present land use classification is heavy industrial. An industrial use generally means properties that are or have been characterized by, or are committed to, traditional industrial uses. Waste management or waste processing would represent an industrial classification.

Dry-Land Farming: An example of dry-land farming can be observed in the nearby Horse Heaven Hills. Like the Central Plateau, the Horse Heaven Hills, south of the Hanford Site, are near the Columbia River, but are at a significantly higher elevation. Although the irrigation activity is increasing at certain locations, comparatively little irrigation occurs in the Horse Heaven Hills because of the relatively high energy (hence economic) cost of bringing water to the surface. Dry-land farming continues to be the main land use for the Horse Heaven Hills.

Irrigated Farming: East of the Central Plateau and across the Columbia River, irrigated farming is common. The water, however, does not come from the nearby stretches of the Columbia River, but from the Columbia Basin Project, which uses water stored behind Grand Coulee Dam, over 322 km (200 mi) upstream of the Hanford Site. The water is gravity-fed to the farms. The regional geography makes such a water delivery system unlikely for the Central Plateau.

Natural: West of the Central Plateau is the Fitzner/Eberhardt Arid Lands Ecology Reserve, a nature preserve area. This area now is part of the Hanford Reach National Monument (65 FR 37253) and, for the most part, is preserved in its original (i.e., pre-pioneer settlement) state. Exposure scenarios associated with a "natural" land use typically have intermittent or periodic uses in common, such as, hunting, recreational, or park ranger activities.

1.9.1.1 Reference Case Land Use Scenarios

Recently, Advice #132 provided by the Hanford Advisory Board (HAB) (Martin 2002) addressed exposure scenarios in the 200 Areas (Central Plateau) and provided direction for a range of potential human health risks, including the reasonable maximum risk expected over time. The corresponding response to the HAB advice from Ecology, DOE, and EPA (Klein et al. 2002) provided additional direction recognizing that the most likely use of the land in the Central Plateau will remain industrial and that the existing use of groundwater will be restricted up to approximately 300 years. This "Risk Framework Description" (Klein et al. 2002) provides the basis used for the land use assumptions shown in Table 1-5 and defined here as the reference case. The current cleanup activities are projected to finish by 2032 and will be followed by 300 years of active institutional controls, with no drilling for water use or other uses allowed in the Central Plateau. Passive institutional controls will continue for the next 200 years, totaling 500 years of institutional controls that will limit access to the closed SST WMAs. Land use is assumed to remain industrial but the restrictions on the use of groundwater are projected to end 300 years after closure in keeping with the response to the HAB advice (Klein et al. 2002). This advice is consistent with the Hanford Site comprehensive land-use EIS (DOE 1999b) and the HFSUWG (HFSUWG 1992a).

Land use is assumed to remain industrial but the restrictions on the use of groundwater are projected to end 300 years after closure in keeping with the response to the HAB advice (Klein et al. 2002).

The reference case analysis of Table 1-5 presents the assumed future land use exposure scenarios. The listed exposure scenarios address a combination of CERCLA decisions being implemented on the Central Plateau, DOE O 435.1 requirements, and NRC guidance as presented in *A Performance Assessment Methodology for Low-Level Radioactive Waste Disposal Facilities: Recommendations of NRC's Performance Assessment Working Group* (NRC 2000). Time frames shown for the end of active and passive controls recognize the NRC philosophy of "testing the robustness of the facility against a reasonable range of possibilities" and are not intended as a prediction of the future. The 10,000-year time frame selected for the analysis recognizes the need to capture the expected peak dose from mobile long-lived radionuclides associated with tank waste residues remaining after closure. EPA guidance for CERCLA cleanups and DOE O 435.1 recommend the analysis conclude after 1,000 years. The EPA guidance and DOE O 435.1 are considered addressed by use of the longer time frame of 10,000 years selected here. Table 1-5 provides different time frame assumptions for groundwater use under the industrial land use scenario (groundwater pathway) and intrusion into the contaminated waste beneath each SST WMA (intruder pathway). These time frame differences are driven by different regulatory assumptions and past practices in earlier Hanford Site PAs. This SST PA will use these time frames for the reference case and provide estimated impacts for other time frames for each pathway.

Table 1-5. Future Land Use Scenarios and Time Frame Assumptions for Reference Case Analysis

Time Frame	Scenario	Comment
2000 to 2032	DOE cleanup/closure activities	Current conditions
2032 to 2332	Industrial land use, no groundwater use	Active institutional controls for 300 years after closure
2332 to 12032	Industrial land use, groundwater use	Drilling may occur as close as the SST WMA fenceline, but no waste exhumation occurs until year 2532
2532	Inadvertent intruder (driller), rural pasture	Passive institutional controls are assumed to end in year 2532 and intrusion into the waste site occurs, bringing waste to the surface

As part of the reference case, intrusion into the waste residual is also evaluated. The impacts to both an intruder and to a subsequent inadvertent intruder onto the remnants of the original intrusion are evaluated. The reference case assumes a drilling scenario is needed to reach and exhume the waste, and a rural pasture scenario is a reasonable scenario to estimate baseline inadvertent intruder impacts. The intruder scenario addresses requirements under DOE O 435.1.

1.9.1.2 Sensitivity Analysis Land Use Scenarios

Table 1-6 addresses alternative future land uses that are considered possible, but not as likely as the reference case analysis. These are addressed as part of the sensitivity analysis. Of particular interest in Table 1-6 are the plausible exposure scenarios. These are proposed to provide an upper range on human health risk to the public resulting from tank waste residuals and past releases remaining after closure of the SST WMAs. These scenarios assume that a residential or a residential agricultural scenario occurs immediately after the loss of institutional control and, further, that the residence is at the edge of the closed SST WMA.

Table 1-6 also lists two additional inadvertent intrusion scenarios into the closed waste site: the suburban gardener and the commercial farmer. These scenarios assume that, at the end of passive institutional controls, an individual drills into the waste site thus providing exposure to the waste residuals. The scenarios noted as "post-intrusion" are addressed as sensitivity analyses on the assumed post-intrusion scenario of rural pasture.

Table 1-6. Alternative Land Use Scenarios for Sensitivity Analyses

Scenario	Location
Future Plausible Exposure Scenarios	
Residential	Edge of the waste management area after 300 years
All-pathway farmer	Edge of the waste management area after 300 years
DOE Order 435.1 Inadvertent Intruder Exposure Scenarios	
Post Intrusion: Suburban gardener Commercial farmer	Onsite ground maximum at 500 years from closure [a]

[a] Ground maximum is defined as within the closed waste management area.

1.9.2 Exposure Scenario Descriptions

Descriptions of all the exposure scenarios and the supporting toxicological information can be found in Rittmann (2004). Typically, exposure scenarios are inherently conservative. Tables 1-7 and 1-8 present a summary of exposure pathways for each land use scenario considered. Table 1-7 summarizes the exposure pathways for a typical PA as required by DOE O 435.1. For the intruder and all-pathways farmer scenarios presented in Table 1-7, impacts are quantified only in terms of radiological doses. The all-pathways farmer scenario assumes that some of the waste materials have migrated into the groundwater. Table 1-8 summarizes exposure scenarios that are consistent with EPA and the HFFACO (Ecology et al. 1989). These exposure scenarios also assume that some of the waste materials have migrated into the groundwater. For the exposure scenarios presented in Table 1-8, only the incremental lifetime cancer risk (ILCR) and hazard index (HI) are of interest. All scenarios are consistent with the EPA risk assessment guidance (EPA 1989), WAC 173-340, and the HFFACO, as appropriate. Sections 1.9.2.1 through 1.9.2.8 provide details of each exposure scenario used in the SST PA. No direct exposure pathway exists under a 15-ft thick surface barrier.

1.9.2.1 Industrial Worker

The industrial worker exposure scenario is one of the reference case land use scenarios. This receptor is exposed to radiological contaminants from groundwater and soil. Exposures to chemical contaminants are not evaluated under this exposure scenario. The primary exposure pathways for the industrial worker scenario include direct contact with groundwater (ingestion and dermal contact) and inhalation of vapors from showering; direct contact with soil (external radiation, incidental ingestion, and dermal contact); and inhalation of vapors, fugitive dust, and tritium vapors. The industrial worker cancer risk calculations assume a body mass of 70 kg, an exposure duration of 20 years (250 day/year) working period, and a 250 L/year (1 L/day for 250 days) consumption of water while at work with an averaging time of 70 years. Table 1-1 provides the performance objective for this scenario as 1×10^{-5} ILCR.

1.9.2.2 Model Toxics Control Act Method C (Industrial)

This industrial exposure scenario is one of the sensitivity analysis land use scenarios. Under this Washington State regulatory scenario, a receptor is exposed to carcinogenic and non-carcinogenic chemical contaminants through the groundwater pathway. Exposure to radiological contaminants is not examined. The exposure pathway is ingestion. This scenario is described in WAC 173-340(720)(5) and is referred to as the Method C scenario. It is applicable for setting groundwater cleanup levels for an assumed industrial land use scenario. For non-carcinogens, the receptor is assumed to represent a 70-kg adult, consuming 2 L/day for an exposure duration of 6 years. For carcinogens, the receptor is assumed to represent a 70-kg adult, consuming 2 L/day over an exposure duration of 30 years, with an averaging time of 75 years. Performance objectives for the carcinogenic chemical exposure is an ILCR of 1×10^{-5} and for non-carcinogenic chemicals is a hazard index (HI) value of 1 (Table 1-1).

Table 1-7. Exposure Pathway Summary for DOE Order 435.1 Performance Assessment Exposure Scenarios [a]

Media	Exposure Pathways	Waste Intruders [b]				All Pathways Farmer
		Driller	Suburban Gardener	Rural Pasture	Commercial Farmer	Groundwater
Water	Ingestion					•
	Vapor inhalation					•
	Shower, dermal					•
	Swimming, dermal					
	Sweat lodge, inhalation					
Soil	Ingestion	•	•	•	•	•
	Inhalation	•	•	•	•	•
	Dermal contact					•
	External radiation dose	•	•	•	•	•
	Tritium vapor inhalation		•	•	•	•
Food chain	Garden produce		•			•
	Grains					
	Beef and milk			Milk only		•
	Poultry and eggs					•
	Fish					
	Wild game					

[a] Modified from Rittmann (2004).

[b] The water media pathway is assumed to contribute nothing to the intruder scenario doses, per DOE O 435.1.

• indicates exposure pathway included in analysis

Table 1-8. Exposure Pathway Summary for EPA and Model Toxics Control Act [a] Performance Assessment Exposure Scenarios [b, c]

Media	Exposure Pathways	Industrial Groundwater	Residential Groundwater	WAC 173-340 Residential and Industrial Groundwater
Water	Ingestion	•	•	•
	Vapor inhalation	•	•	
	Shower, dermal	•	•	
	Swimming, dermal			
	Sweat lodge, inhalation			
Soil	Ingestion	•	•	
	Inhalation	•	•	
	Dermal contact	•	•	
	External radiation dose	•	•	
	Tritium vapor inhalation	•	•	
Food chain	Garden produce		•	
	Grains			
	Beef and milk			
	Poultry and eggs			
	Fish			
	Wild game			

[a] WAC 173-303-610

[b] The annual effective dose equivalent (in mrem) is not calculated for the exposure scenarios shown in this table. The risk quantifiers for these scenarios are incremental lifetime cancer risk from exposure to both radionuclides and chemicals, and hazard index for chemicals.

[c] Modified from Rittmann (2004).

• indicates exposure pathway included in analysis

1.9.2.3 Residential

The residential exposure scenario is one of the sensitivity analysis land use scenarios. This receptor is exposed to radiological contaminants from well water, soil, and through the food chain. Exposure to chemical contaminants is not evaluated for this exposure scenario. The exposure pathways for the residential scenario include direct contact with water (ingestion and dermal contact) and inhalation of vapors from showering; direct contact with soil contaminated by groundwater (external radiation, incidental ingestion, and dermal contact); inhalation of vapors (including tritium) and fugitive dust; and food chain exposure from ingestion of garden produce.

The lifetime increase in the risk of developing some type of cancer from radionuclides for a resident is the exposure duration of 30 years. The first 6 years are at the intake rate for a child for exposure pathways, while the last 24 years are at the intake rate for an adult. Drinking water consumption is 730 L/year (2 L/day). Table 1-1 indicates the performance objective for this scenario is 1×10^{-5} ILCR.

1.9.2.4 Model Toxics Control Act Method B (Residential)

The residential exposure scenario is one of the reference case land use scenarios. Under this Washington State regulatory scenario, the receptor is exposed to carcinogenic and non-carcinogenic chemical contaminants through the groundwater pathway. Exposure to radiological contaminants is not examined. The exposure pathway is ingestion. This scenario is developed under WAC 173-340(720)(4) and is referred to as the Method B scenario. It is applicable for setting cleanup levels for an assumed residential land use scenario.
For non-carcinogens, the receptor is assumed to represent a child (16 kg), consuming 1 L/day for a duration of 6 years. For carcinogens, the receptor is assumed to represent a 70-kg adult, consuming 2 L/day over an exposure duration of 30 years, with an averaging time of 75 years. Performance objective for the carcinogenic chemical exposure is an ILCR of 1×10^{-5} and for non-carcinogenic chemicals is an HI value of 1 (Table 1-1).

1.9.2.5 All-Pathways Farmer

The all-pathways farmer scenario is one of the sensitivity analysis land use scenarios. This receptor is exposed to radiological contaminants from well water, soil, and the food chain. The primary exposure pathways for the all-pathways farmer include direct contact with water (ingestion and dermal contact) and inhalation of vapors from showering and other household activities; direct contact with soil (external radiation, incidental ingestion, and dermal contact); inhalation of vapors (including tritium) and fugitive dust; and food chain exposure from ingestion of garden produce, beef, milk, poultry, and eggs.

This scenario represents a reasonable maximum expected exposure. A subsistence farm located downgradient from the disposal site uses groundwater for domestic needs (drinking, cooking, showering), for irrigation (garden and pasture), and for watering livestock. The receptor obtains one-fourth of his fruit and vegetable intake each year from his garden, and half of his meat, milk, poultry, and egg intake from his livestock. In addition, he inhales resuspended garden soil and ingests small amounts of it each day. His external dose comes from soil contaminated through groundwater application near his dwelling. The radiation dose to this receptor is the 50-year committed effective dose equivalent (EDE) from 1 year of exposure. Table 1-1 provides the performance objective for this scenario as 15 mrem/yr.

1.9.2.6 Inadvertent Intruder

In this exposure scenario, the restrictions and warnings are lost or not effective for the closed WMA site and someone drills a well (the only credible intrusion scenario) that passes through the buried waste to obtain groundwater. Radiation hazard is the only hazard considered for this receptor consistent with DOE O 435.1. The exposure occurs during a drilling operation that lasts 40 hours spread over 5 days. The performance objective for this acute exposure scenario is 500 mrem (Table 1-1).

1.9.2.6.1 Driller Intruder Scenario. This receptor is exposed to radiological contaminants in exhumed waste while drilling a well through a closed tank and/or contaminated soil assumed to remain in the WMA after closure. The primary exposure pathways include direct external radiation, incidental ingestion, dermal contact, and inhalation of vapors and fugitive dust. This is considered an acute exposure because the driller is in contact with the waste for a relatively short period of time (i.e., 5 days). The driller intruder scenario is a reference case land use scenario.

1.9.2.6.2 Post-Intrusion Resident Scenarios. This receptor is primarily exposed to radiological contaminants from exhumed waste. For these exposure scenarios, the drill cuttings are distributed onto land that will be used for food consumption or gardening. These are known as chronic exposure scenarios because the post-intruder resident is exposed over a number of years. The performance objective for these scenarios is 100 mrem/yr (Table 1-1). Given the present land use around the Hanford Site, there are three post-intrusion resident scenarios:

- **Post-Intrusion Suburban Garden:** This scenario assumes that a receptor lives near the drill cuttings and spreads the cuttings in his garden. The receptor obtains one-fourth of his fruit and vegetable (but not grain) supply each year from his garden. In addition, he inhales resuspended garden soil and ingests small amounts of it each day. His external dose comes from spending time in or near the garden. The radiation dose to this receptor is the 50-year committed EDE from the first year of exposure after the well is drilled. This post-intrusion scenario is a sensitivity analysis land use scenario.
- **Post-Intrusion Rural Pasture:** This scenario assumes that a receptor lives near the drill cuttings and spreads cuttings in his pasture and hay field. The receptor obtains half of his annual intake of milk from the cow. He inhales resuspended soil and ingests small amounts of it each day. His external dose comes from spending time in or near the pasture and hay field. The radiation dose to this receptor is the 50-year committed EDE from the first year of exposure after the well is drilled. This scenario is included as part of the reference case land use scenarios.
- **Post-Intrusion Commercial Farm:** This scenario assumes that a receptor lives near the drill cuttings and spreads the cuttings in his field used for growing a food crop for market. The individual inhales resuspended soil and ingests small amounts of it each day. His external dose comes from spending time in or near the field. The radiation dose to this receptor is the 50-year committed EDE from the first year of exposure after the well is drilled. This scenario is one of the sensitivity analysis land use scenarios.

1.9.2.7 Offsite Exposure Scenarios

Only scenarios directly associated with the SST WMAs are analyzed as part of this report. Offsite exposures will be estimated as part of the *Composite Analysis for Low-Level Waste Disposal in the 200 Area Plateau of the Hanford Site* (Kincaid et al. 1998). Updates to Kincaid et al. (1998) will address waste sites adjacent to the SST WMAs where liquid disposal from SSTs were intentionally released to the vadose zone.

1.10 RELATED DOCUMENTS

Sections 1.10.1, 1.10.2, and 1.10.3 contain a discussion of the most relevant Hanford Site tank closure documents, environmental assessments, and regulatory agreements, respectively. Documents used to provide guidance for preparation of this SST PA are described in Section 1.10.4. Section 1.10.5 contains a description of documents used to define the scope of the SST PA.

1.10.1 Other Relevant Tank Closure Documents

A number of documents dealing with PAs for closing tank farms have been issued. In addition to the documents written by the CH2M HILL Hanford Group, Inc. Tank Closure Project (Section 1.10.5), documents have been written to satisfy the requirements of DOE and Ecology.

Prior to this document, PAs covering separate tank farms include:

- *Single-Shell Tank System Closure Plan* (Lee 2004)
- *Preliminary Performance Assessment for Waste Management Area C at the Hanford Site, Washington* (Mann and Connelly 2003).

Lee (2004) contains the risk assessment for WMA C.

1.10.2 Other Relevant Hanford Site Long-Term Environmental Assessments

This SST PA builds on the many environmental assessments that have been performed at the Hanford Site. They pertain to the Hanford Site tank farms while fulfilling the requirements of DOE O 435.1 or requirements of Washington State.

1.10.2.1 Previous Work Related to Hanford Site Tank Farms

A number of reports have been published on risk assessments for the Hanford Site tank farms. They can be grouped into two classes: 1) tank closure EISs and 2) documents supporting the RCRA Corrective Action process.

1.10.2.1.1 Environmental Impact Assessments. Two major EISs on tank farms and their waste have been prepared. A third EIS is in preparation.

The Hanford defense waste EIS, *Final Environmental Impact Statement: Disposal of Hanford Defense High-Level Transuranic and Tank Wastes* (DOE 1987) addressed all defense waste. For the tank waste alternatives, the EIS separated the high-level waste for shipment to a geologic repository and the low-activity waste for grouting in grout vaults. *Tank Waste Remediation System, Hanford Site, Richland, Washington, Final Environmental Impact Statement* (TWRS EIS) (DOE and Ecology 1996) analyzed various options to manage the Hanford Site tank waste. The record of decision, issued shortly thereafter (62 FR 8693), defined the current strategy of tank waste retrieval, separation, and immobilization described in Section 1.2.2.2 of the TWRS EIS (DOE and Ecology 1996). The TWRS EIS did not evaluate closure of the SSTs at the Hanford Site.

Currently, DOE is preparing a new, expanded, comprehensive EIS that will combine the scope of the 2004 solid waste EIS (DOE 2004) and the ongoing tank closure EIS for retrieval, treatment,

and disposal of tank waste and closure of SSTs at the Hanford Site along with all of the waste types addressed in the Hanford solid waste EIS. Issuance of this expanded tank closure and waste management EIS is planned for fiscal year 2008.

1.10.2.1.2 RCRA Corrective Action Process. Because wastes from the SSTs and associated facilities had leaked and impacted groundwater during SST farm operations, Ecology placed DOE under RCRA Corrective Action. To comply with this action, DOE is to gather all data that would be useful in estimating past releases and their contaminant nature and extent to allow Ecology and EPA to evaluate the potential human health and environmental impacts, and to identify appropriate interim corrective measures. Among the many documents created for this activity, two sets are important for this SST PA:

- Subsurface conditions description reports (SCDR)
- Field investigation reports (FIR).

The SCDRs compile the historical data is useful in estimating past releases and their potential impacts and the areas where additional data are needed. The following SCDRs have been issued for the SST WMAs:

- *Subsurface Conditions Description for the S-SX Waste Management Area* (Johnson et al. 1999)
- *Subsurface Conditions Description of the B-BX-BY Waste Management Area* (Wood et al. 2000)
- *Subsurface Conditions Description of the T and TX-TY Waste Management Areas* (Wood et al. 2001)
- *Subsurface Conditions Description of the C and A-AX Waste Management Area* (Wood et al. 2003)
- *Subsurface Conditions Description of the U Waste Management Area* (Wood and Jones 2003).

The FIRs document the results of field and laboratory characterization activities within the WMAs and the associated experiments that aided in the understanding of the transport of contaminants from the SST WMA to the groundwater. FIRs have been published for four WMAs:

- *Field Investigation Report for Waste Management Area S-SX* (Knepp 2002a)
- *Field Investigation Report for Waste Management Area B-BX-BY* (Knepp 2002b)
- *Field Investigation Report for Waste Management Areas T and TX-TY* (Myers 2005).

FIRs for the remaining SST WMAs (i.e., A-AX, C, and U) are scheduled over the next few years to fulfill HFFACO Milestone M-45-55 (Ecology et al. 1989).

1.10.2.2 Other Hanford Site Project-Specific Performance Assessments

This SST PA also builds on previous PAs prepared for the Hanford Site, in particular, *Hanford Immobilized Low-Activity Waste Performance Assessment: 2001 Version* (Mann et al. 2001), known as the immobilized low-activity waste (ILAW) PA.

The ILAW PA addresses the disposal of packaged vitrified waste produced by the Hanford Waste Treatment and Immobilization Plant at a location 1.6 km (1 mi) southwest of WMA C. The ILAW PA formed a preliminary basis for the disposal authorization of Waste Treatment Plant ILAW in an undesignated disposal site. Changes in treatment plans and identification of detailed disposal plans have prompted revision of the ILAW PA; that revision is planned in accordance with DOE M 435.1-1 to support ILAW and bulk vitrified waste disposal, as well as secondary treatment waste disposal for high-level waste treatment processes. The Hanford Site presently has a disposal authorization statement that also covers disposal of wastes at the Solid Waste Burial Grounds and the Environmental Remediation Disposal Facility (ERDF).

The following PAs were developed under *Radioactive Waste Management*, (DOE O 5820.2A), a predecessor to DOE O 435.1:

- *Performance Assessment of Grouted Double-Shell Tank Waste Disposal at Hanford* (Kincaid et al. 1995) addresses the disposal of low-level liquid waste from the DSTs. The waste was to be combined with cement, fly ash, and clay to form a grout that would cure and solidify in large subsurface vaults located to the east of the 200 East Area.
- *Environmental Restoration Disposal Facility Performance Assessment* (Wood et al. 1995b) was written to support disposal of waste generated by the cleanup of the Hanford Site, but was not immediately issued. Instead, *Remedial Investigation and Feasibility Study Report for the Environmental Restoration Facility* (DOE-RL 1994) was prepared. A crosswalk between DOE-RL 1994 and the requirements of DOE O 435.1 has been approved (DOE 2001). The ERDF is regulated under CERCLA. Most of the waste to be disposed of at ERDF is expected to be contaminated soil.
- *Performance Assessment for the Disposal of Low-Level Waste in the 200 West Area Burial Grounds* (Wood et al. 1995a) addresses the disposal of solid waste from operations at the Hanford Site and other DOE sites. These wastes are placed into trenches in the western part of the 200 West Area, then covered with a surface cover.
- *Performance Assessment for the Disposal of Low-Level Waste in the 200 East Area Waste Burial Grounds* (Wood et al. 1996) addresses waste that is similar to that addressed in the 200 West Area PA (Wood et al. 1995a). However, the disposal trenches for this waste are in the northern part of the 200 East Area. Annual summaries also have been submitted to the Low-Level Waste Federal Review Group (LFRG); the latest in 2003 (Wood 2003).

1.10.2.3 General Hanford Site Environmental Assessments

A series of general environmental assessments also has been prepared for Hanford Site activities. These assessments look at the Hanford Site as a whole or address environmental impacts in a more general manner.

Composite Analysis for Low-Level Waste Disposal in the 200 Area Plateau of the Hanford Site (Kincaid et al. 1998) was prepared in response to Recommendation 94-2 of the Defense Nuclear Facilities Safety Board (DNFSB) to the Secretary of Energy (DNFSB 1994). The recommendation noted the need for a risk assessment that investigates the environmental impacts of all radioactive waste disposal actions or leaks at DOE sites. The LFRG conditionally

approved the composite analysis in "Disposal Authorization Statement for the Hanford Site Low-Level Waste Disposal Facilities" (DOE 1999a), and provided further documentation in *Low-Level Waste Disposal Facility Federal Review Group Manual* (DOE 1999c). The schedule for updating the composite analysis is presented in *Maintenance Plan for the Composite Analysis of the Hanford Site, Southeast Washington* (DOE-RL 2003a). The authors of the composite analysis documentation are working with the authors of the PAs discussed above to maximize consistency in data and methods.

Draft Hanford Remedial Action Environmental Impact Statement and Comprehensive Land-Use Plan (DOE 1996) analyzed the potential impacts associated with establishing future land use objectives for the Hanford Site. These impacts will come primarily from remediation activities. The document also proposes a land use plan for near-future activities. TWRS activities were not extensively considered. Based on comments received, the draft EIS was rewritten and issued as a land-use plan EIS (DOE 1999b) with an associated record of decision (64 FR 61615).

Final Hanford Site Solid (Radioactive and Hazardous) Waste Program Environmental Impact Statement, Richland, Washington (DOE 2004) has recently been issued. This EIS addresses the disposal of non-CERCLA LLW at the Hanford Site. Such waste includes LLW generated at the Hanford Site, melters from the Waste Treatment and Immobilization Plant, ILAW, and LLW imported from other DOE sites. The record of decision (69 FR 39449) selected the ILAW disposal site as the location of a new disposal facility named the Integrated Disposal Facility. Pending finalization of the tank closure and waste management EIS, *Final Hanford Site Solid (Radioactive and Hazardous) Waste Program Environmental Impact Statement, Richland, Washington* (DOE 2004) will remain in effect to support ongoing waste management activities at the Hanford Site.

1.10.3 Regulatory Agreements and Documents

The HFFACO (Ecology et al. 1989) is an agreement between DOE, EPA, and Ecology concerning the cleanup of the Hanford Site. The HFFACO contains legally enforceable milestones, many of which cover SST system closure (the M-45 series). The milestones related to SST system closure are listed in Table 1-9. Other milestones can be found in the HFFACO.

Table 1-9. Key *Hanford Federal Facility Agreement and Consent Order* Milestones Related to Single-Shell Tank System Closure [a]

HFFACO Milestone	Title	Completion Date
M-45-06-T03	Initiate Closure Actions on WMA Basis. Closure shall follow Completion of the Retrieval Actions Under Proposed Milestone M-45-05.	3/31/2012
M-45-06-T04	Complete Closure Actions On One WMA.	3/31/2014
M-45-00	Complete Closure of All Single-Shell Tank Farms.	9/30/2024
M-045-06	Complete Closure of All Single-Shell Tank Farms in Accordance with Approved Closure/Post Closure Plan(s)	9/30/2024

[a] This SST PA uses year 2032 as an assumed date of closure.

Hanford Site Ground Water Protection Management Plan (DOE-RL 1995b) has been superseded by *Hanford's Groundwater Management Plan: Accelerated Cleanup and Protection* (DOE-RL 2003b). DOE-RL (2003b) presents plans for remediation of high-risk waste sites, reducing the amount of the contaminated area at the Hanford Site, reducing recharge near waste sites, remediating existing groundwater plumes, and monitoring groundwater conditions. However, the current version of the management plan does not address long-term protection of the groundwater resource.

1.10.4 Guidance Documents

The main document guiding the development of this SST PA is Appendix I of the HFFACO (Ecology et al. 1989). The following additional documents were also used as guidance in preparing this SST PA:

- *A Performance Assessment Methodology for Low-Level Radioactive Waste Disposal Facilities: Recommendations of NRC's Performance Assessment Working Group*, NUREG-1573 (NRC 2000)
- *Low-Level Waste Disposal Facility Federal Review Group Manual* (DOE 1999c).

Performance assessments from other DOE sites and the comments on those studies also have been reviewed to understand different approaches and methods used elsewhere.

1.10.5 Definition Documents

A series of documents has been created to define the scope and major parts of this SST PA:

- *Performance Objectives for Tank Farm Closure Performance Assessments* (Mann et al. 2005)
- *Maintenance Plan for Hanford Tank Farm Closure Performance Assessments* (Mann and Newell 2006).

Mann et al. (2005) define the performance objectives to be used in the PAs, as well as the media to be protected (groundwater, air) after closure. The performance objectives are provided for the protection of inadvertent intruders, assessment of engineered barrier performance, and validation of potential waste acceptance limits.

Mann and Newell (2006) describe the plans to create and maintain the SST PA. This SST PA effort is a many-year effort yielding better analyses and documents as additional information becomes available.

1.11 EVOLUTION OF THIS PERFORMANCE ASSESSMENT

Performance assessments are done iteratively to take into account new information from research, characterization, and monitoring. As DOE moves toward final closure of the entire SST system, the following activities are planned to ensure that DOE remains on a technically valid path toward closing tank farms in a manner that protects human health. The near-term plans include the following:

- **Update of this performance assessment to reflect new findings:** This is the first of a series of PAs of the SST system. The SST PA will be updated to incorporate significant changes in the approach to closure, conceptual model, or source characteristics (Mann and Newell 2006).
- **Expansion to include the DST system:** The tank farm system comprises the SST system, the DST system, and many facilities (e.g., pipelines and vaults) outside the SST and DST farm fences. An expanded PA is planned for issue in 2008. The expanded PA will address the entire SST and DST systems including ancillary equipment that is part of the DST system.
- **Incorporate future closure plans:** Finally, there will be simulations based on new plans of the retrieval/closure projects of the Tank Farm Contractor. As the closure of the tank systems are more fully planned, additional details can and will be inserted into the computer models to describe how proposed changes affect the long-term human health of closure activities. These long-term human health impacts will be documented in SST WMA-specific PAs as required by Appendix I of the HFFACO (Ecology et al. 1989).

1.12 STRUCTURE OF THIS PERFORMANCE ASSESSMENT

This SST PA is divided into seven chapters and seven appendices. The appendices provide additional detailed information about topics presented in the individual chapters. The contents of each chapter and appendix are as follows:

- Chapter 1.0 provides a summary of the purpose, background, scope, approach, and structure of the SST PA.
- Chapter 2.0 describes Hanford Site characteristics and environment, including details of the geography, geology, and the groundwater hydrology and geochemistry. In addition, past and present activities at the Hanford Site and land uses are described. Waste characteristics and the SST WMAs are also described in detail.
- Chapter 3.0 covers the methods used to assess system performance, including the radionuclide transport pathways and exposure scenarios. It also discusses the assumptions used in modeling system performance.
- Chapter 4.0 presents and integrates results from the transport and exposure models used to estimate the potential consequences of long-term contaminant release from the closed tank farms.
- Chapter 5.0 presents the results from the inadvertent intruder analyses.
- Chapter 6.0 interprets disposal facility performance with respect to the scenarios and the performance objectives defined in Chapter 1.0.

- Chapter 7.0 discusses the major themes of the results presented in Chapters 4.0, 5.0, and 6.0; identifies data and analyses gaps in the SST PA; and discusses further work associated with the SST PA activity.
- Appendix A contains a crosswalk to the LLW disposal facility federal review group criteria and where those criteria are associated in this SST PA.
- Appendix B contains information on process chemistry history and facility history.
- Appendix C contains detailed information on inventory inputs to the SST PA modeling.
- Appendix D contains detailed information on groundwater pathway modeling results.
- Appendix E contains detailed intruder and air pathway analyses information.
- Appendix F contains a description of the quality assurance program applied to production of the SST PA.
- Appendix G provides brief resumes of contributors to this document.

1.13 REFERENCES

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Section 2 of 6

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2.0 SITE AND WASTE CHARACTERISTICS

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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.

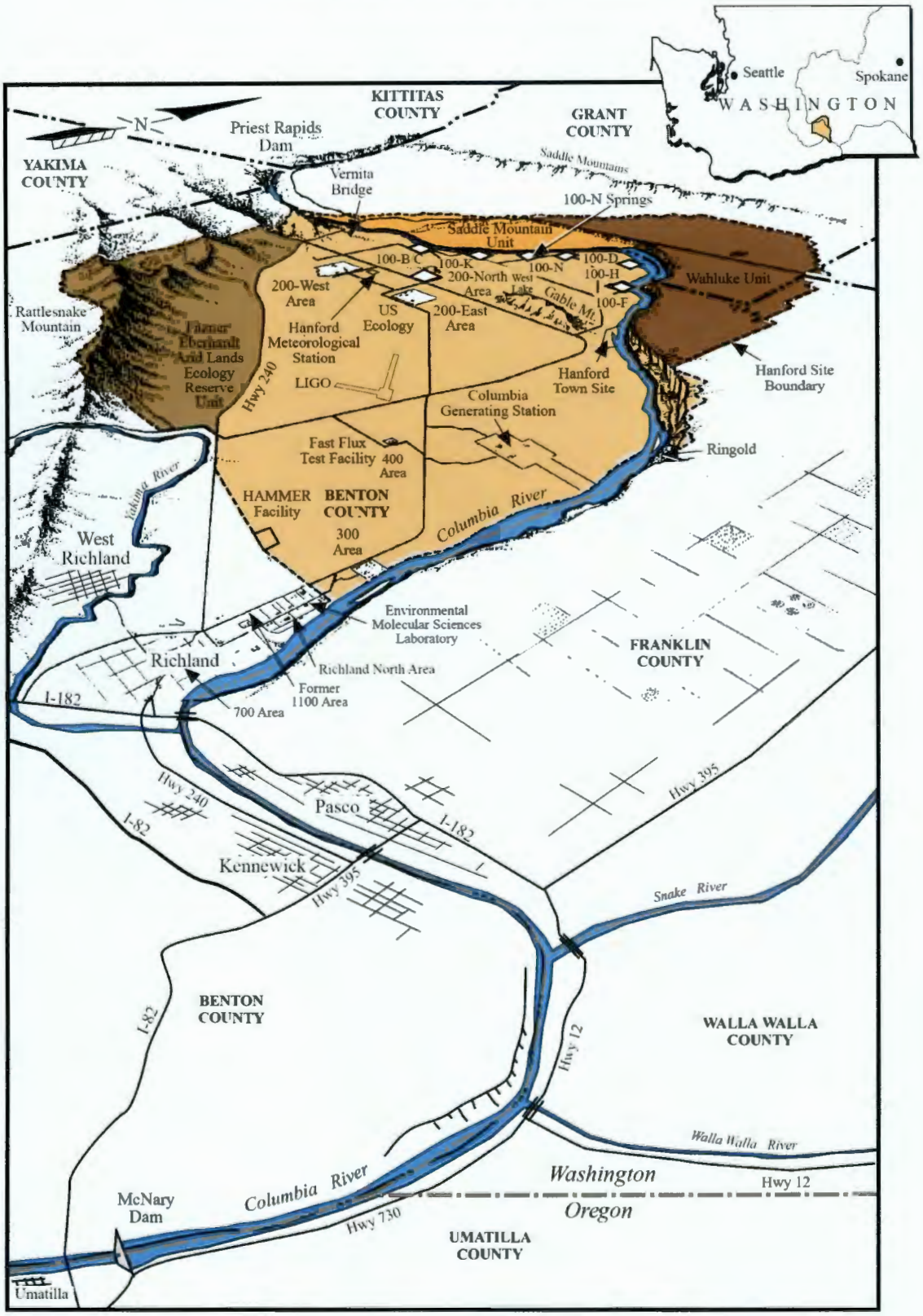
2.4 **Common Facility Description** discusses facilities common to all tank farms (i.e., size and volume of different tanks, ancillary equipment, and operation of the tank farm).

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).

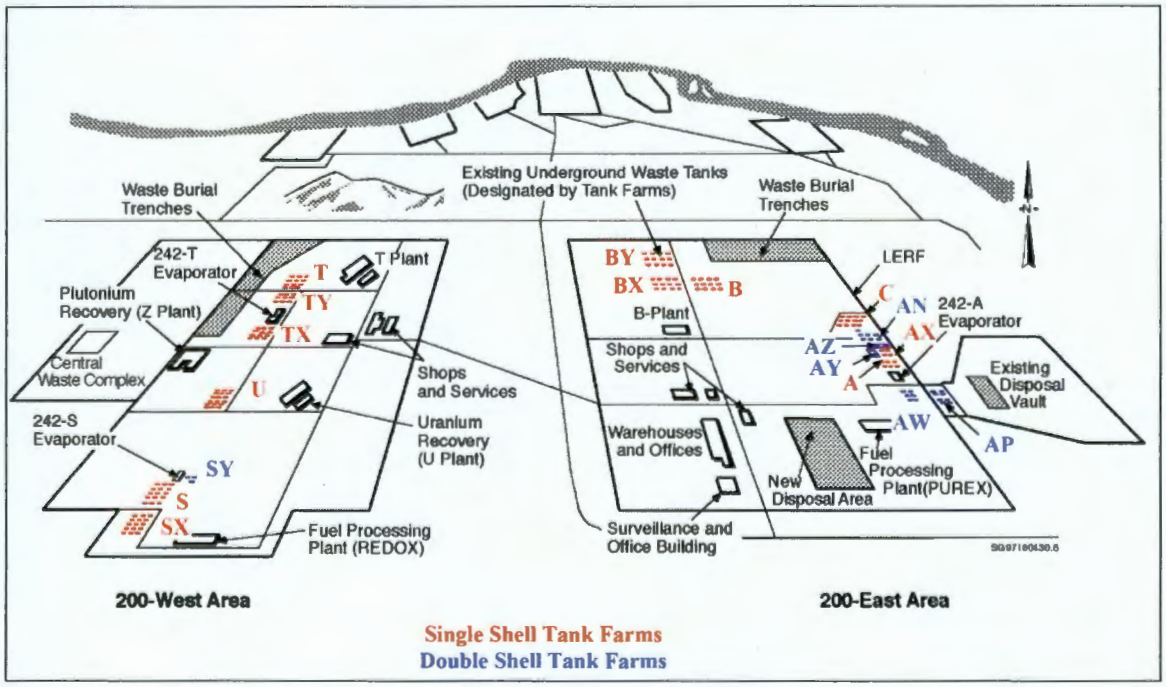
Table 2-1 provides the total number of source terms evaluated at each WMA (Figure 2-2) as part of this SST PA. An inventory of radionuclides and hazardous chemicals must be allocated for each of the source terms listed in Table 2-1. The development of inventory for each of the source terms listed above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

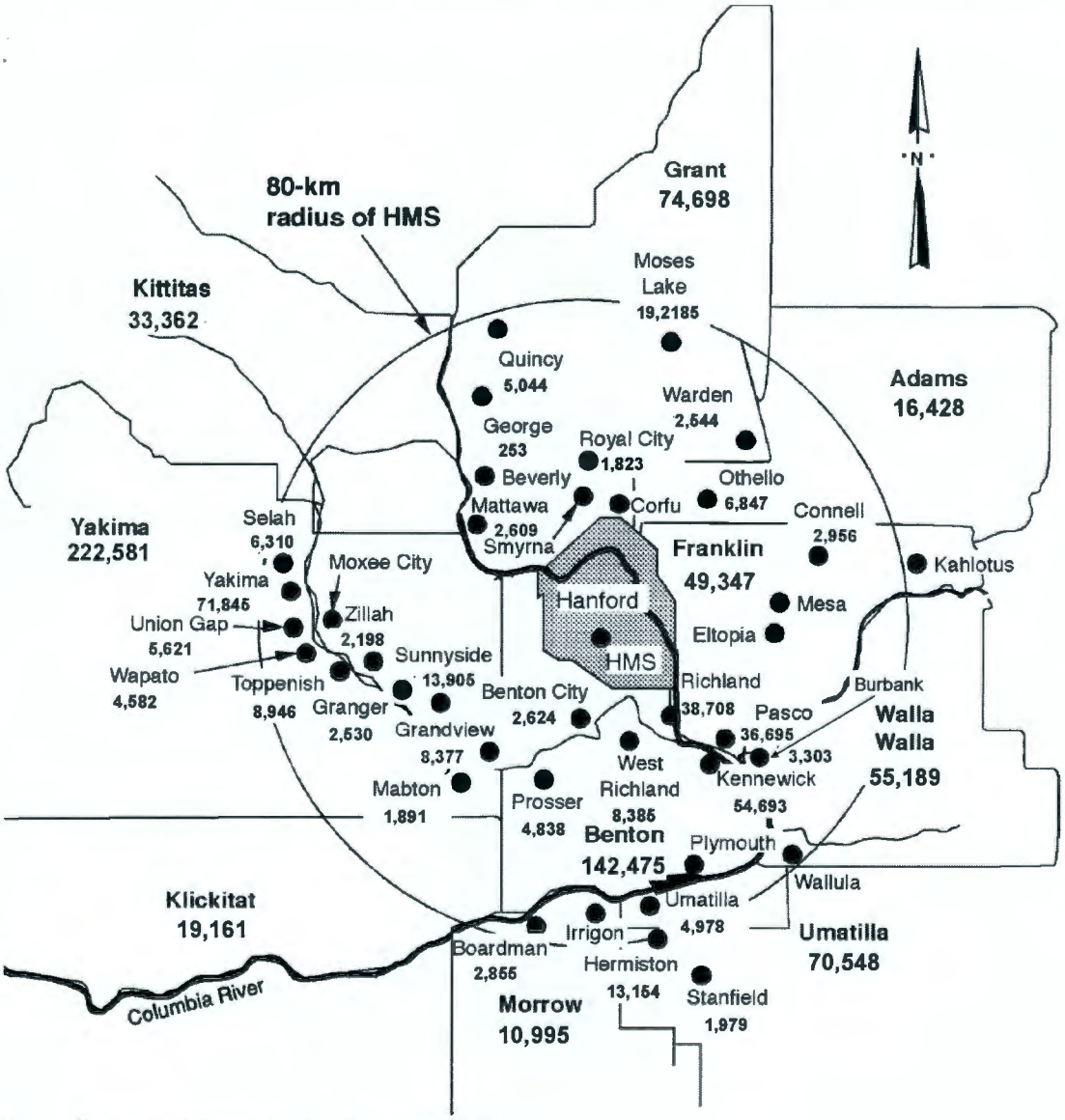
The portion of the monument administered only by DOE included the McGee Ranch/Riverlands Unit (north and west of State Highway 24 and south of the Columbia River), the Columbia River islands in Benton County, the Columbia River corridor (one-quarter mile inland from the shoreline) on the Benton County 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

Hanford 200 Areas

200 Area Risk Framework (July 2002)

Industrial Scenario

Core Zone
(Including main B Pond and S Ponds)
- Will have an industrial scenario for the foreseeable future

Industrial

Research

Other Scenarios Consistent with Industrial Uses

Core Zone - Will be remediated and closed allowing for "Other Uses" consistent with an industrial scenario such as environmental industries
- Maintains active human presence
- Maintains institutional knowledge of waste for future generations

An assumption of industrial land use will be used to set cleanup levels

Exposure Scenarios
- Maximum exposure to worker/day user
- Intruders
- Native American Users

Cultural Resources

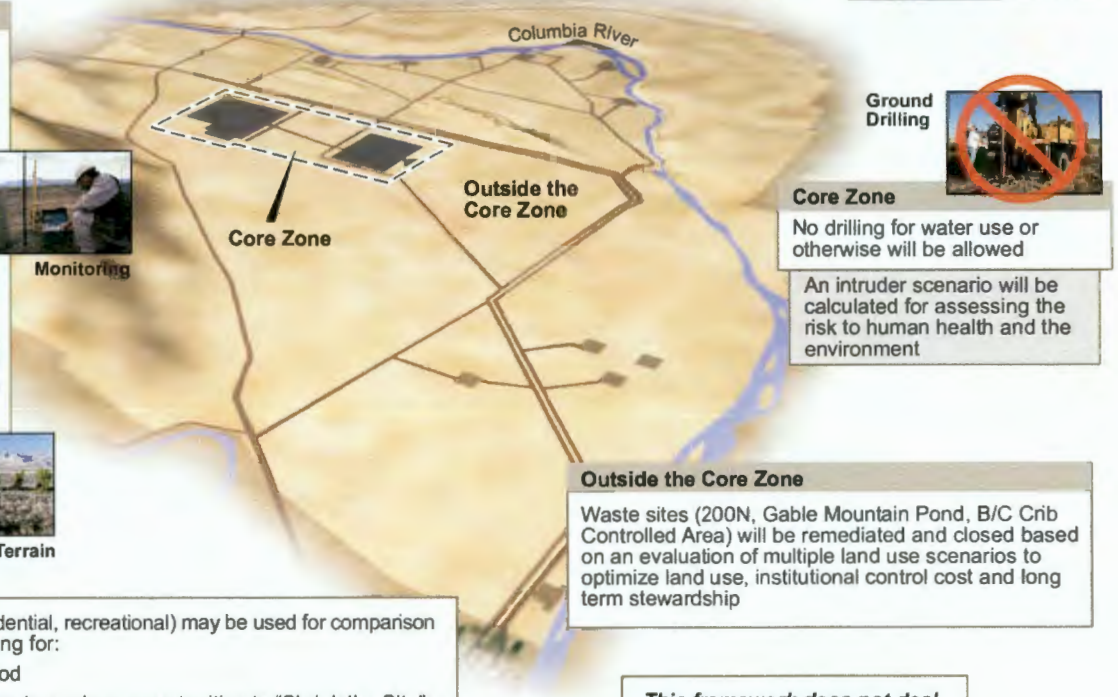
Groundwater

DOE will follow the required regulatory processes for ground water remediation (including public participation) to establish points of compliance and remedial action objectives.

Core Zone - Up to 150 years
It is anticipated that groundwater contamination under the core zone will preclude beneficial use for the foreseeable future, which is at least the period of waste management and institutional controls

Monitoring

Outside the Core Zone - Up to 150 to 300 years
It is assumed that the tritium and iodine-129 plumes beyond the core zone boundary will exceed the drinking water standards (less for the tritium plume)*. It is expected that other groundwater contaminants will remain below, or be restored to drinking water levels outside the core zone



Ground Drilling

Core Zone

No drilling for water use or otherwise will be allowed

An intruder scenario will be calculated for assessing the risk to human health and the environment

Recreational Uses; Hiking, biking and more...

Wildlife Viewing

Natural Terrain

Outside the Core Zone

Waste sites (200N, 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 post institutional control period
- Sites near the core zone perimeter to analyze opportunities to "Shrink the Site"
- Early (precedent setting) closure/remediation activities

This framework does not deal with the tank retrieval decision

* This assumption is based on current state of the art treatment techniques and may change as the regulatory processes progress and new techniques are developed

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.

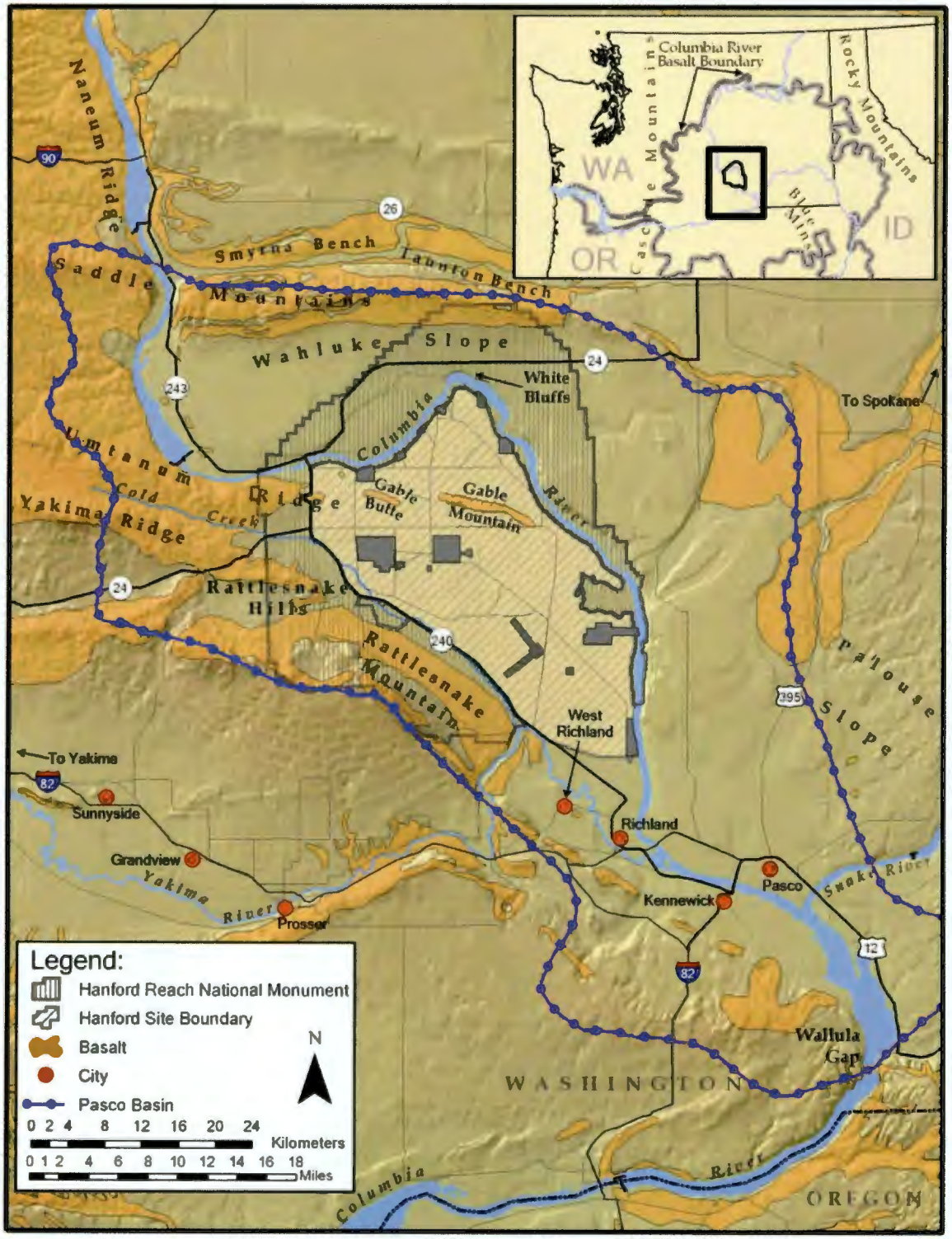
Section 2.3.4 provides a summary of the data in Reidel et al. (2006) highlighting those aspects that are important to developing the conceptual model describing transport of contaminants away from the waste facility to a receptor. For additional information relating to geology, hydrology, and geochemistry 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

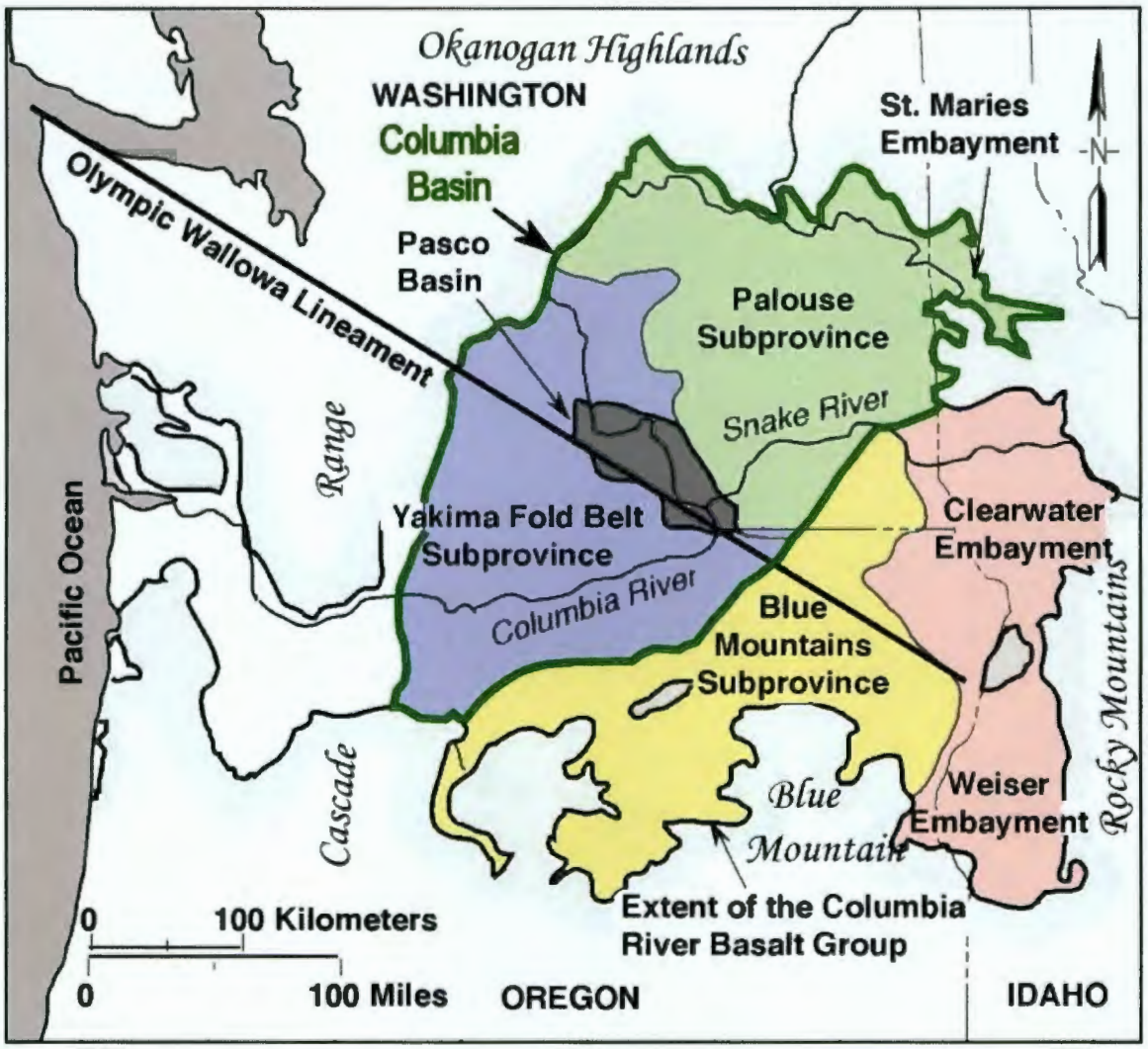
Missoula floods), which deposited more sediment in what is referred to informally as the Hanford formation.

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.

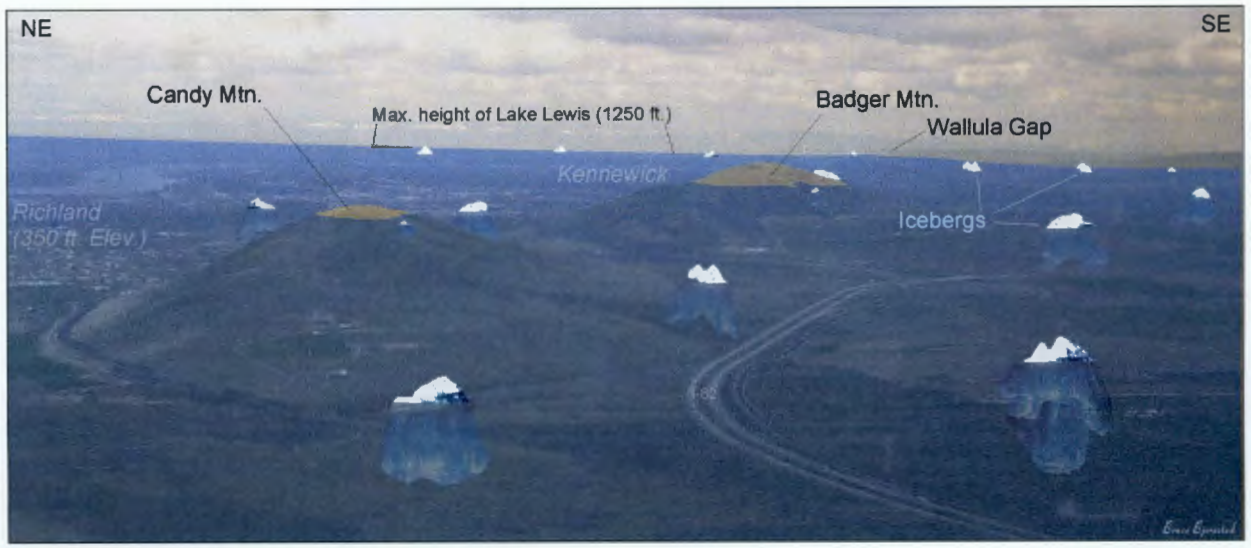
2.3.4.1.3 Ancestral Columbia River Deposits. The ancestral Columbia River repeatedly changed its course over the past 15 million years, depositing gravel, sand, silt, and clay (Tallman et al. 1981; Fecht et al. 1987; DOE 1988; Reidel et al. 1994; Lindsey 1996). Uplifting basalt ridges diverted the course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

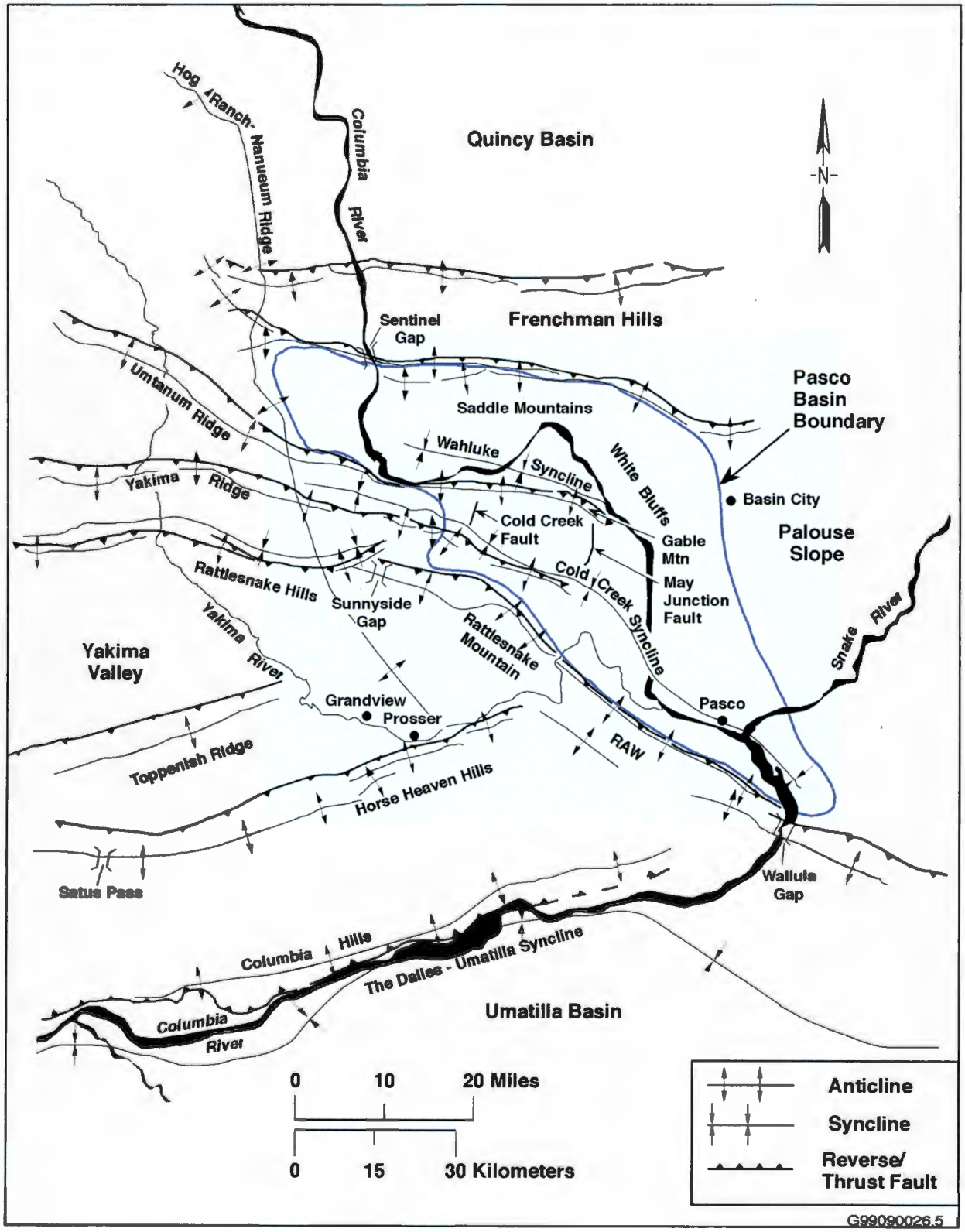
Figure 2-7 shows the southern Pasco Basin under water during the largest Ice Age flood. Ice Age floods became hydraulically dammed behind Wallula Gap, forming Lake Lewis. The largest and most frequent floods came from glacial Lake Missoula in northwestern Montana. Other floods may have escaped down-valley 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



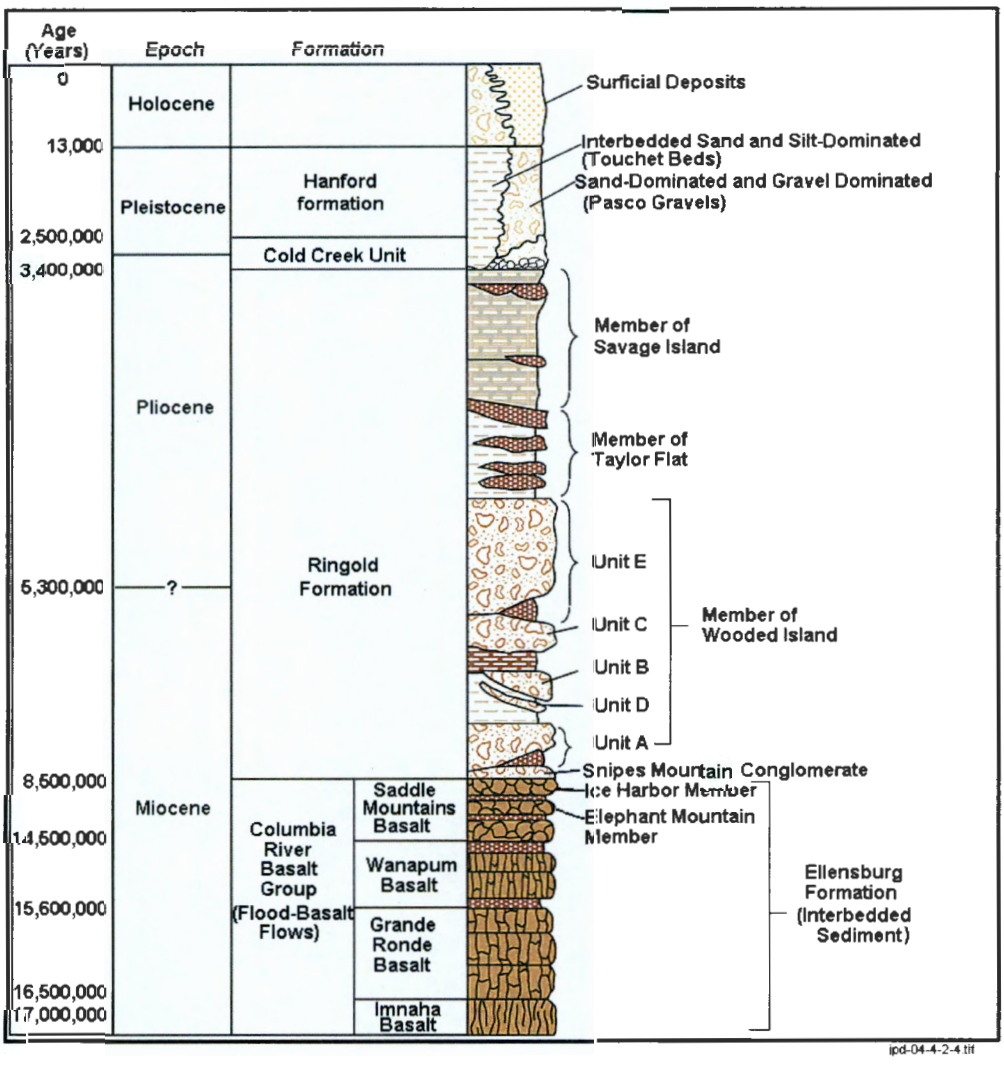
2.3.4.1.5 Geologic Structure. This section briefly describes the geologic structure of the Columbia Basin; for additional information on the geologic structure see Chapter 4.0 of Reidel et al. 2006. The Columbia Basin has two structural subdivisions or subprovinces: the Yakima Fold Belt and the Palouse 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.

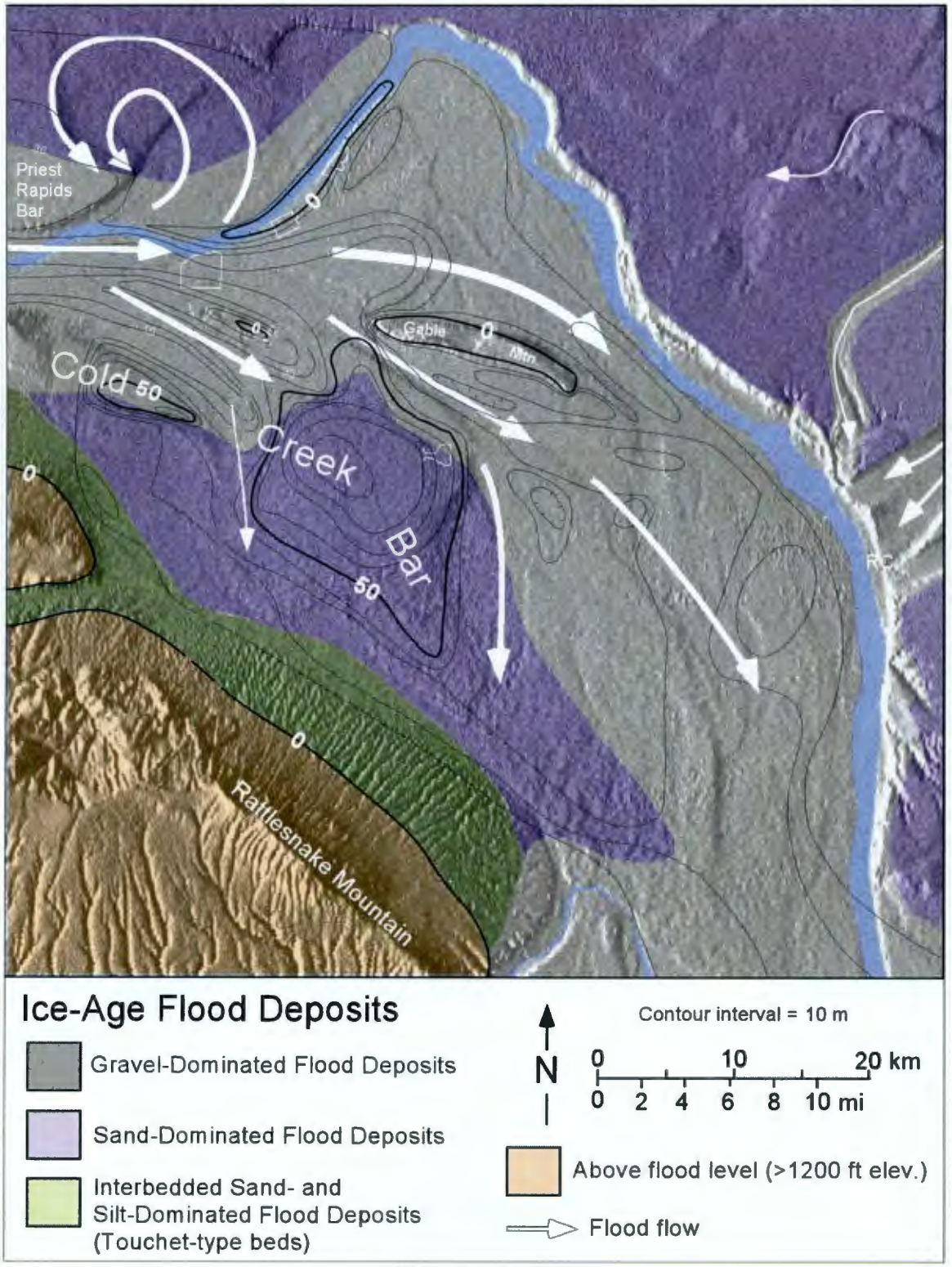
The upper part of the Ringold Formation, informally called the member of Taylor Flat (Lindsey 1995) consists of the sequence of fluvial sands, overbank deposits, and lacustrine sediments overlying unit E. This corresponds to the upper unit as originally defined by Newcomb (1958) along the White Bluffs 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

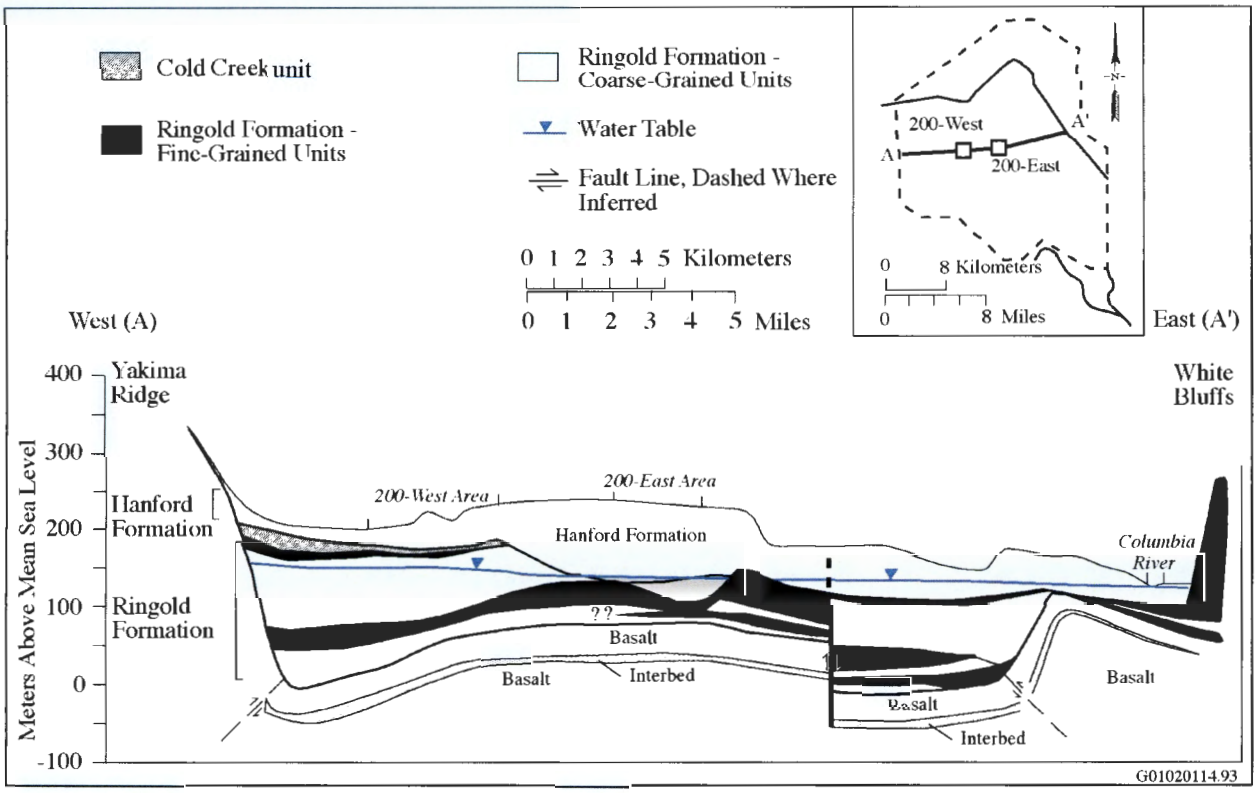
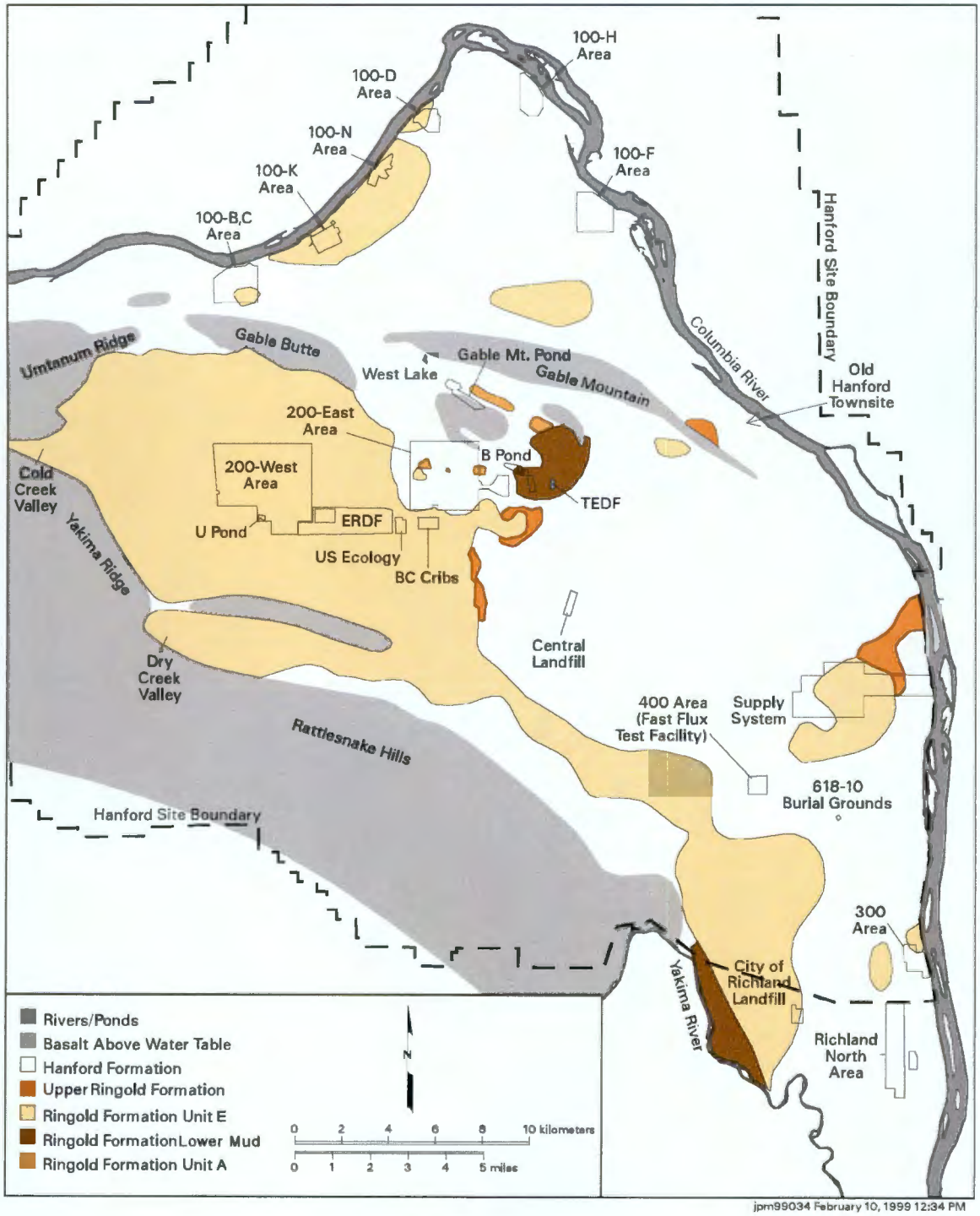


Figure 2-12. Hydrogeologic Units Present at the Water Table in June 1998



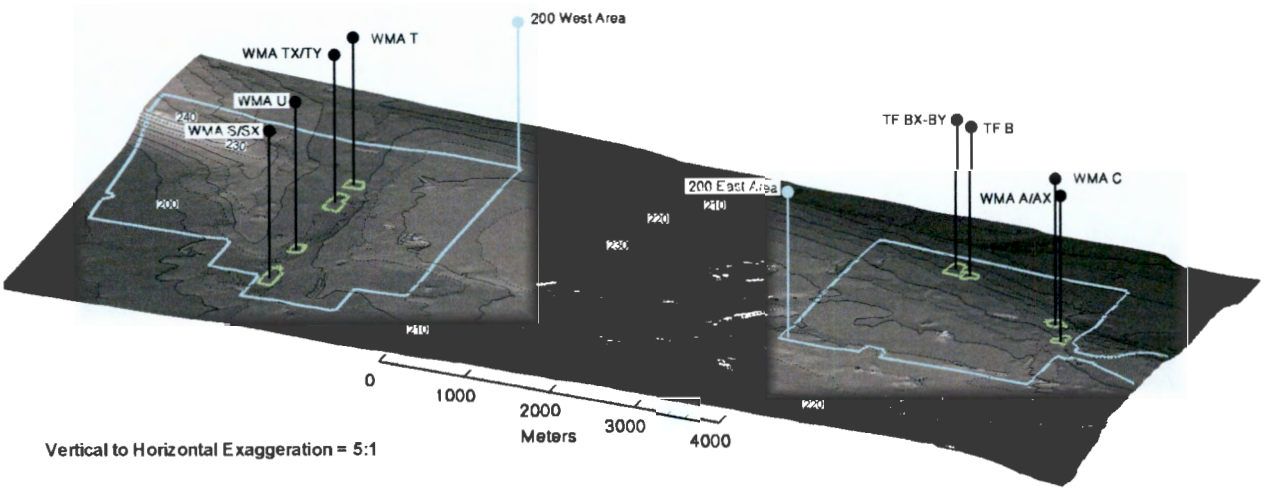
2.3.4.1.10 Surface Soils. The Holocene deposits and exposed Hanford formation sediments have experienced soil development and evolved into identifiable soil types. Hajek (1966) describes 15 different surface soil types on the Hanford Site, varying from sand to silty and sandy loam. Various classifications, 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.

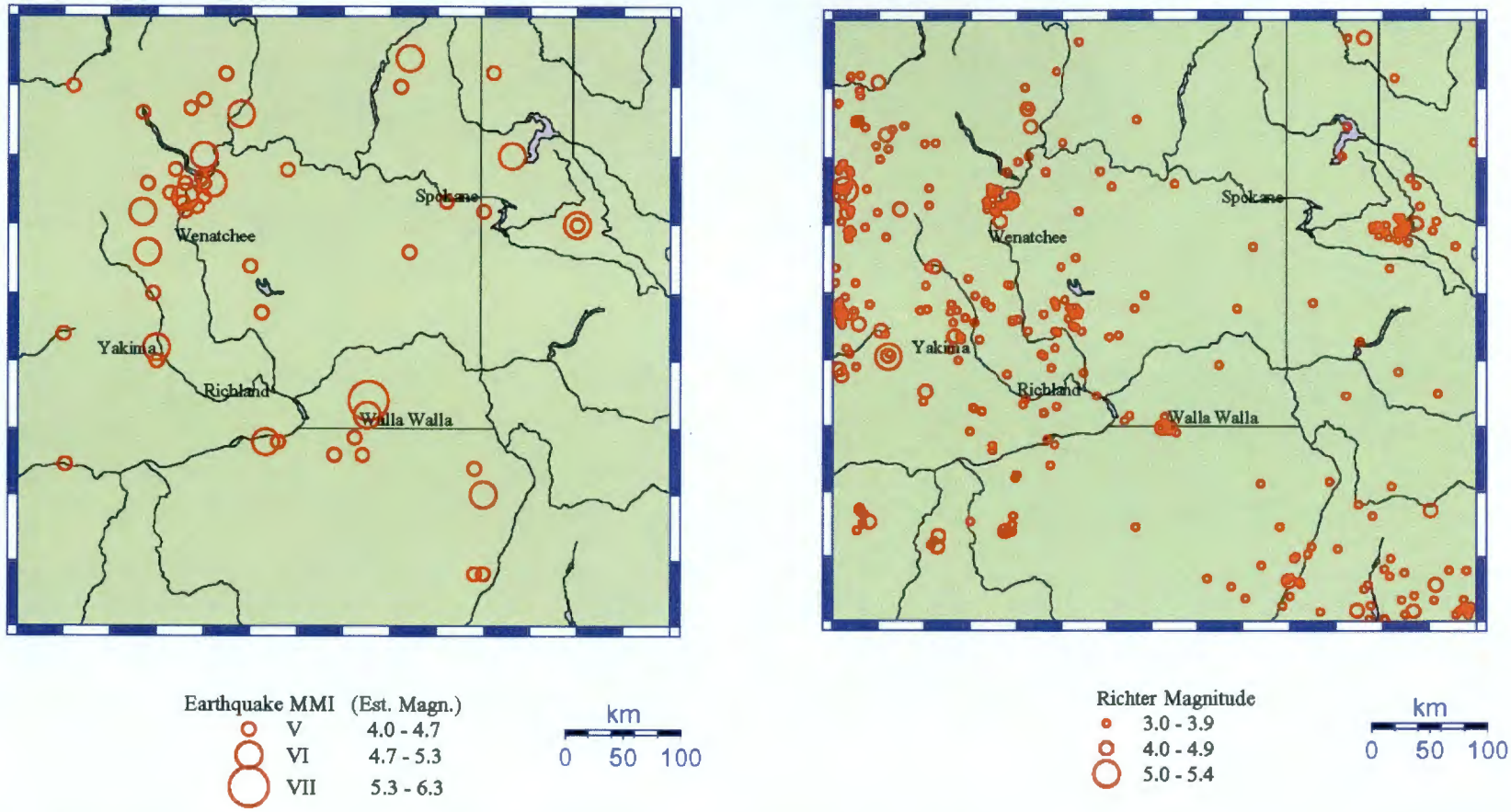
2.3.4.2.1 Seismic Hazard Assessment. Estimates for the earthquake potential and resulting hazard of structures and zones in the central Columbia Basin have been developed during the licensing of nuclear power plants at the Hanford Site. In reviewing the operating license application for the Washington 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).

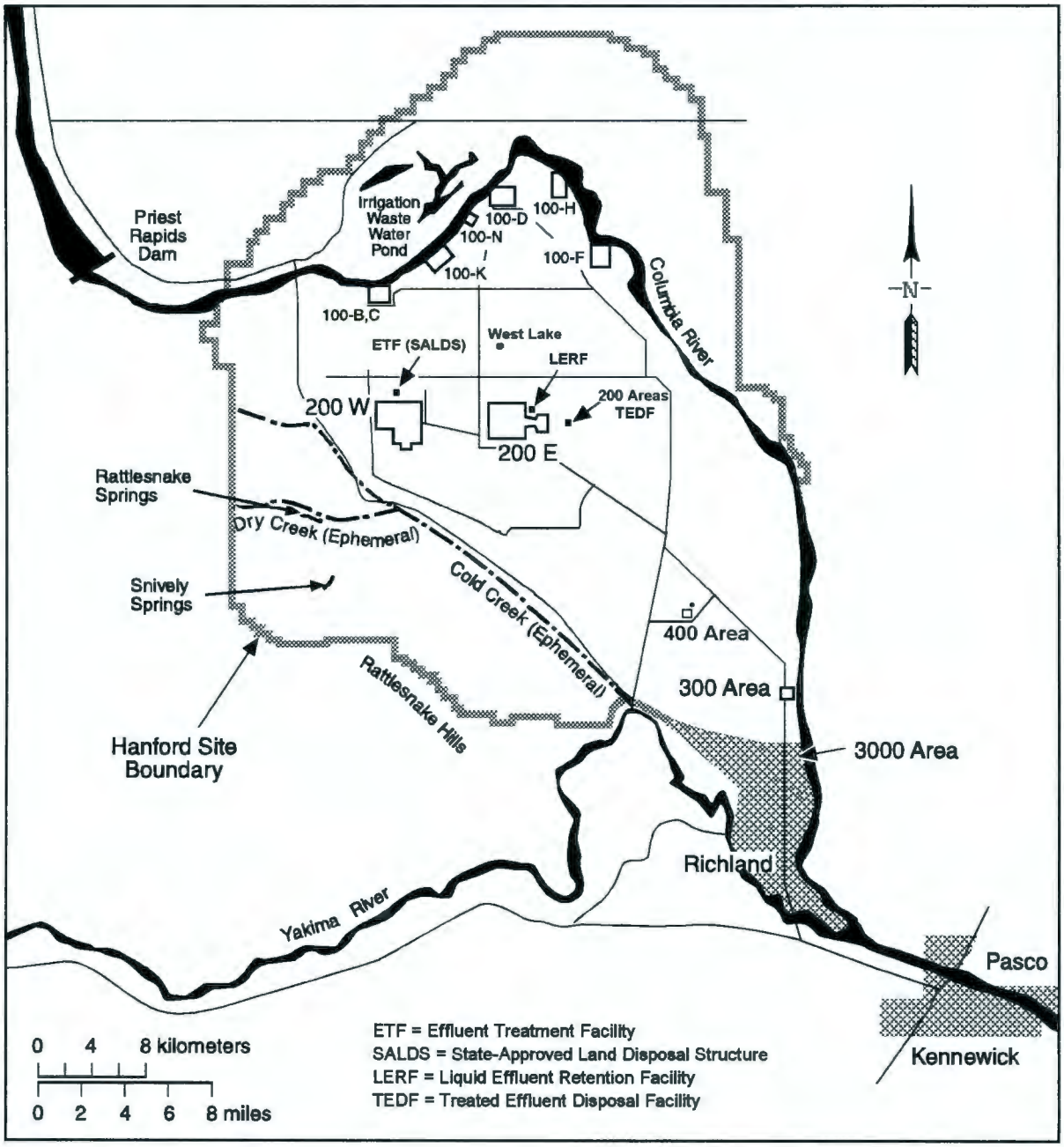
2.3.5.1 Surface Water

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



S9508017.4

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.

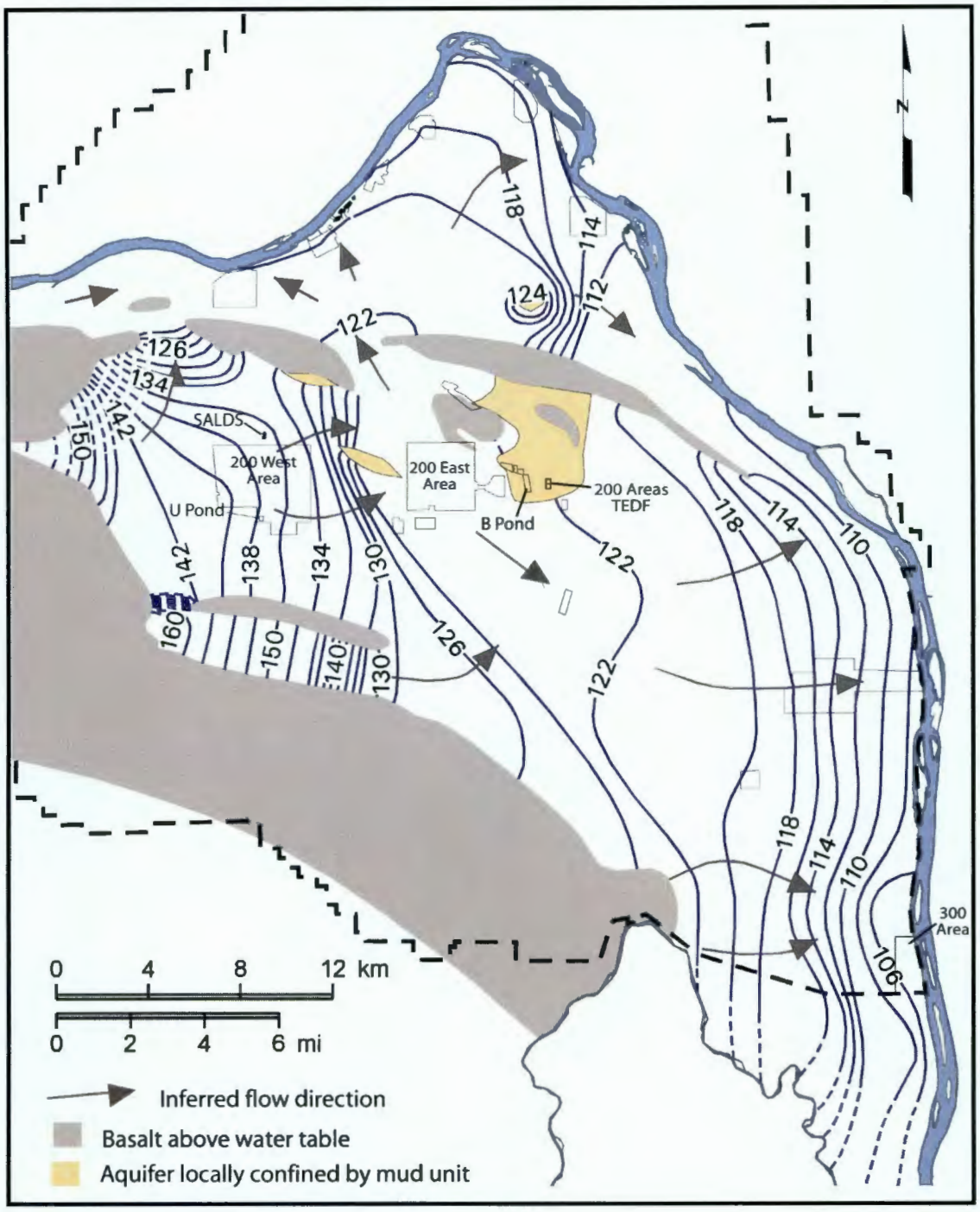
Between 1944 and the mid 1990s, the volume of artificial recharge from Hanford Site operations wastewater disposal was significantly greater than recharge from precipitation. An estimated 1.68×10^{12} L (4.44×10^{11} gal) of liquid was discharged to disposal ponds, trenches, and cribs during this period. 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).

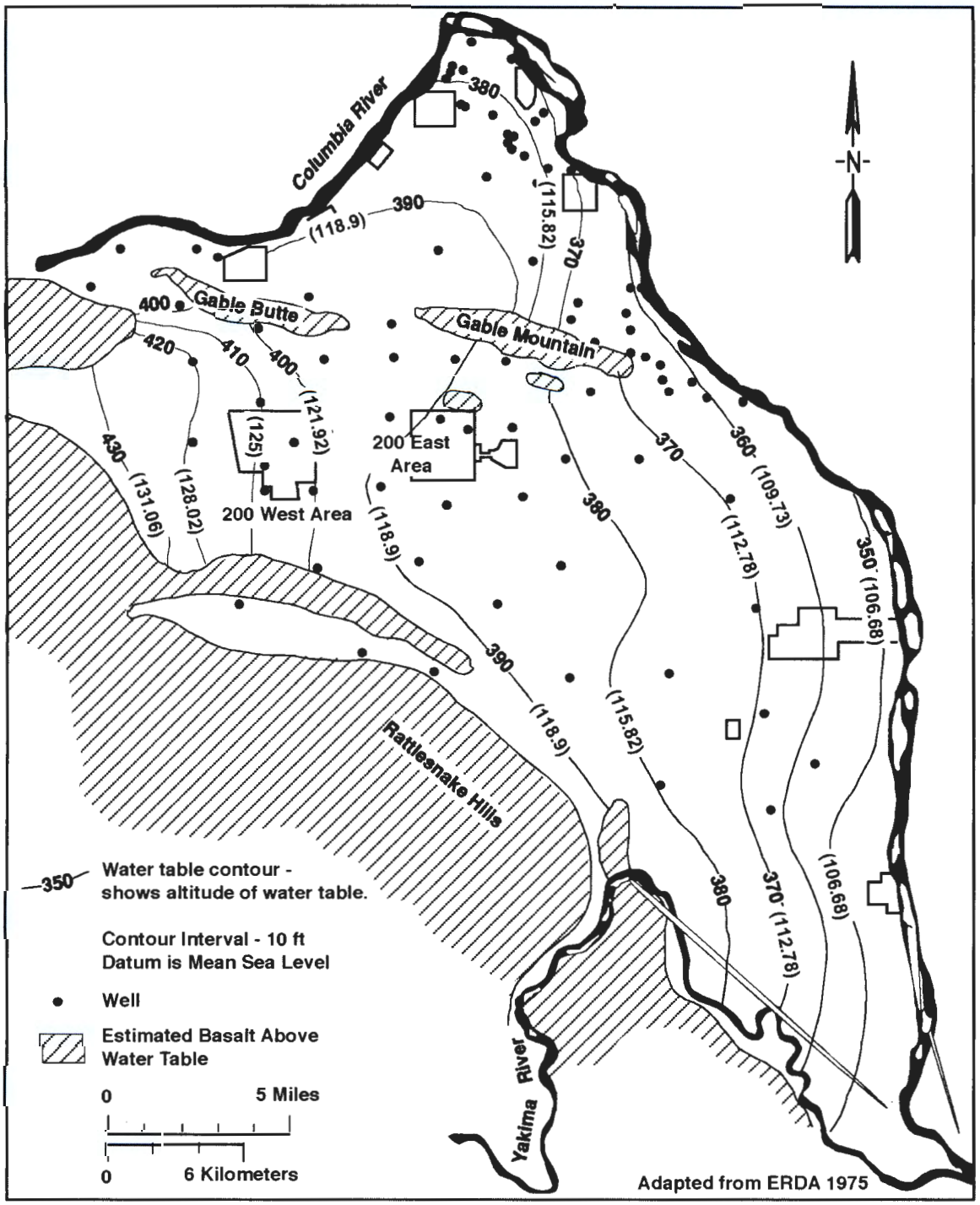
Horizontal hydraulic conductivities of sand and gravel facies within the Ringold Formation generally range from about 1 to 100 m/day, compared to 10 to 3,000 m/day for the Hanford formation and the coarse-grained multilithic facies of the Cold Creek unit (pre-Missoula gravels) (DOE 1988; Cole et al. 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

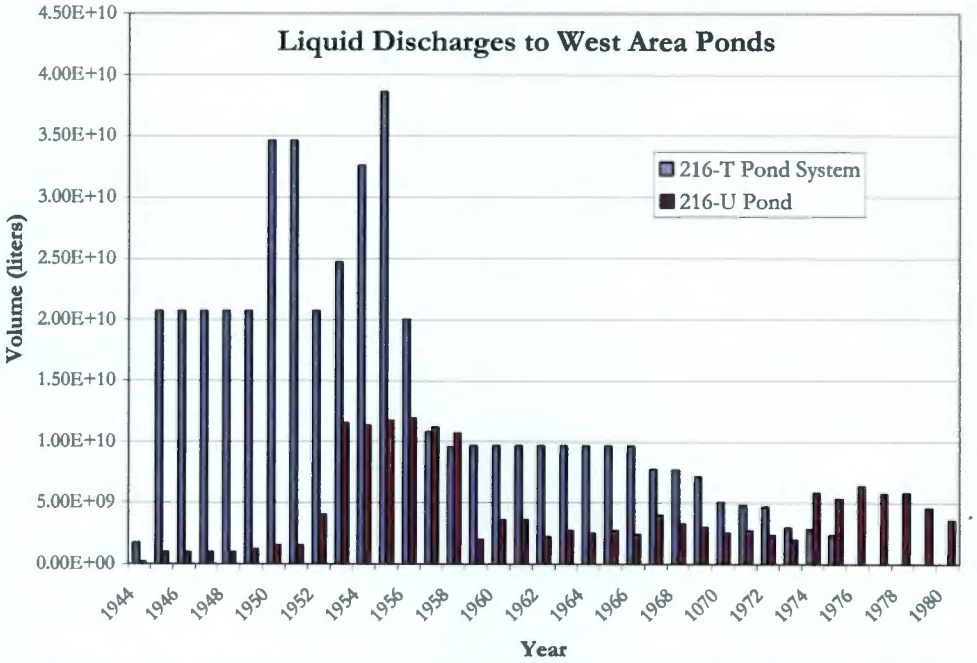


Water table elevations shown in the figure are in feet; meters are shown in parentheses.

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.

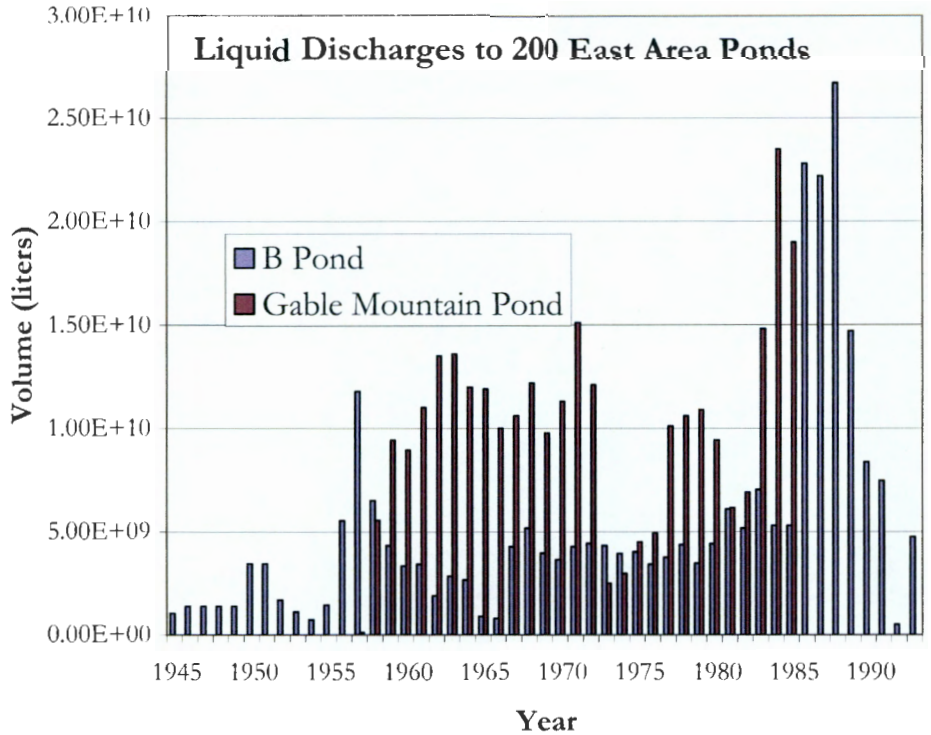
Figure 2-18. Discharge History for the 216-T Pond and the 216-U Pond [a]



[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).

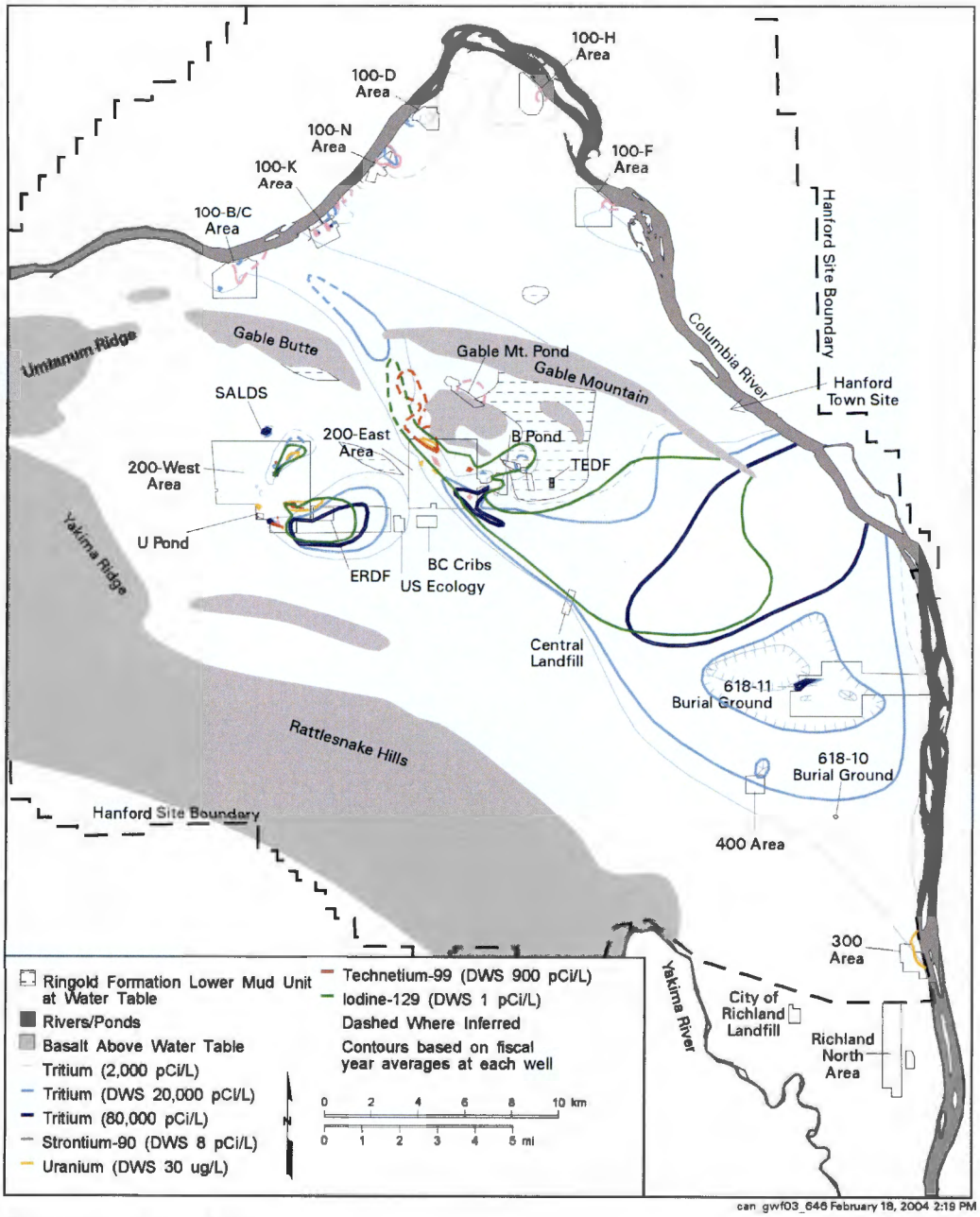
Monitoring of radiological and chemical constituents in groundwater at the Hanford Site is performed to characterize physical and chemical trends in the flow system, establish groundwater quality baselines, assess groundwater remediation, and identify new or existing groundwater problems. Groundwater 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

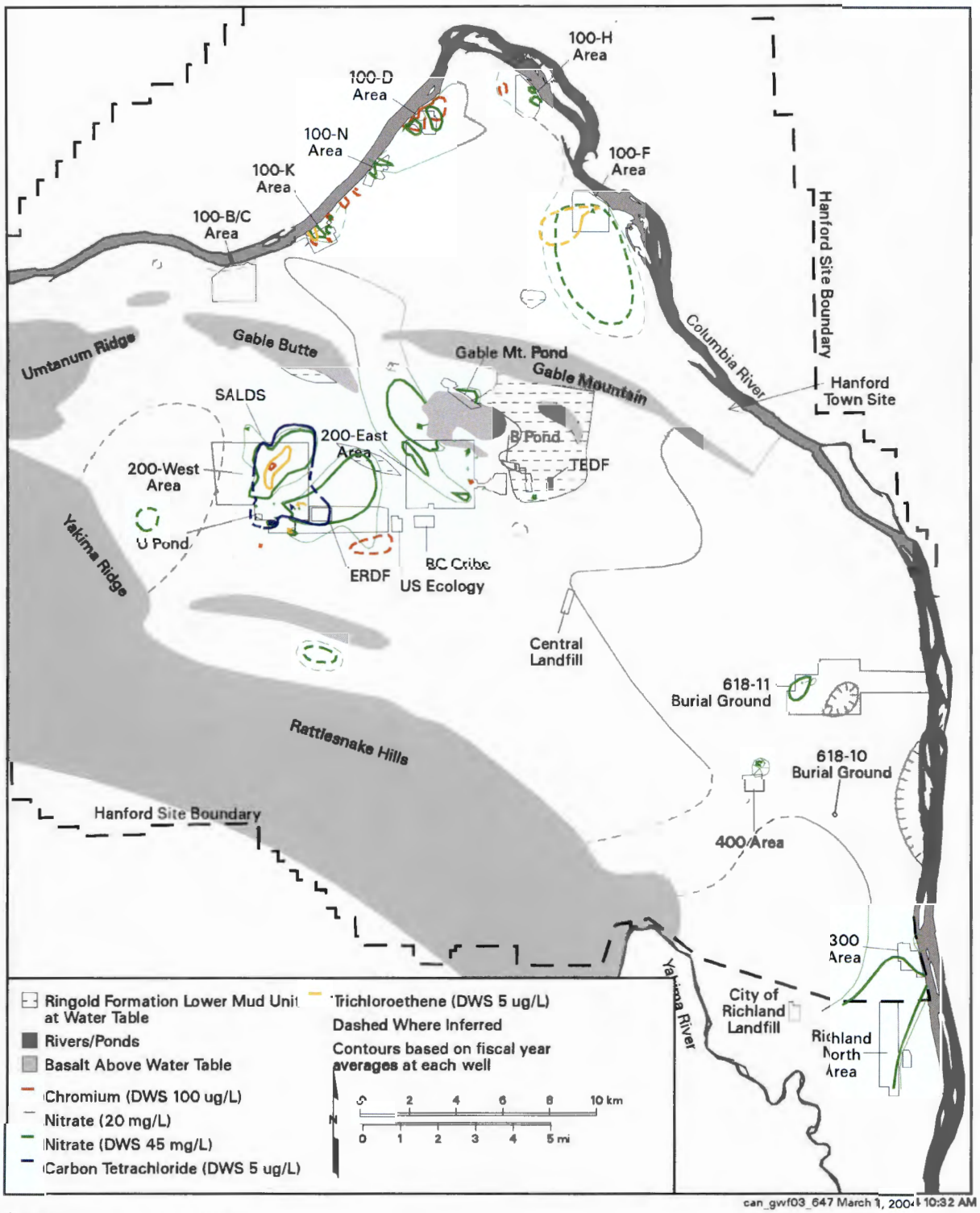
contamination in Hanford Site groundwater above the applicable DWS is determined annually (Figures 2-20 and 2-21). The area of contaminant plumes on the Hanford Site with concentrations exceeding DWS levels was estimated to be 190 km^2 during fiscal year 2004 (Hartman et al. 2004).

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

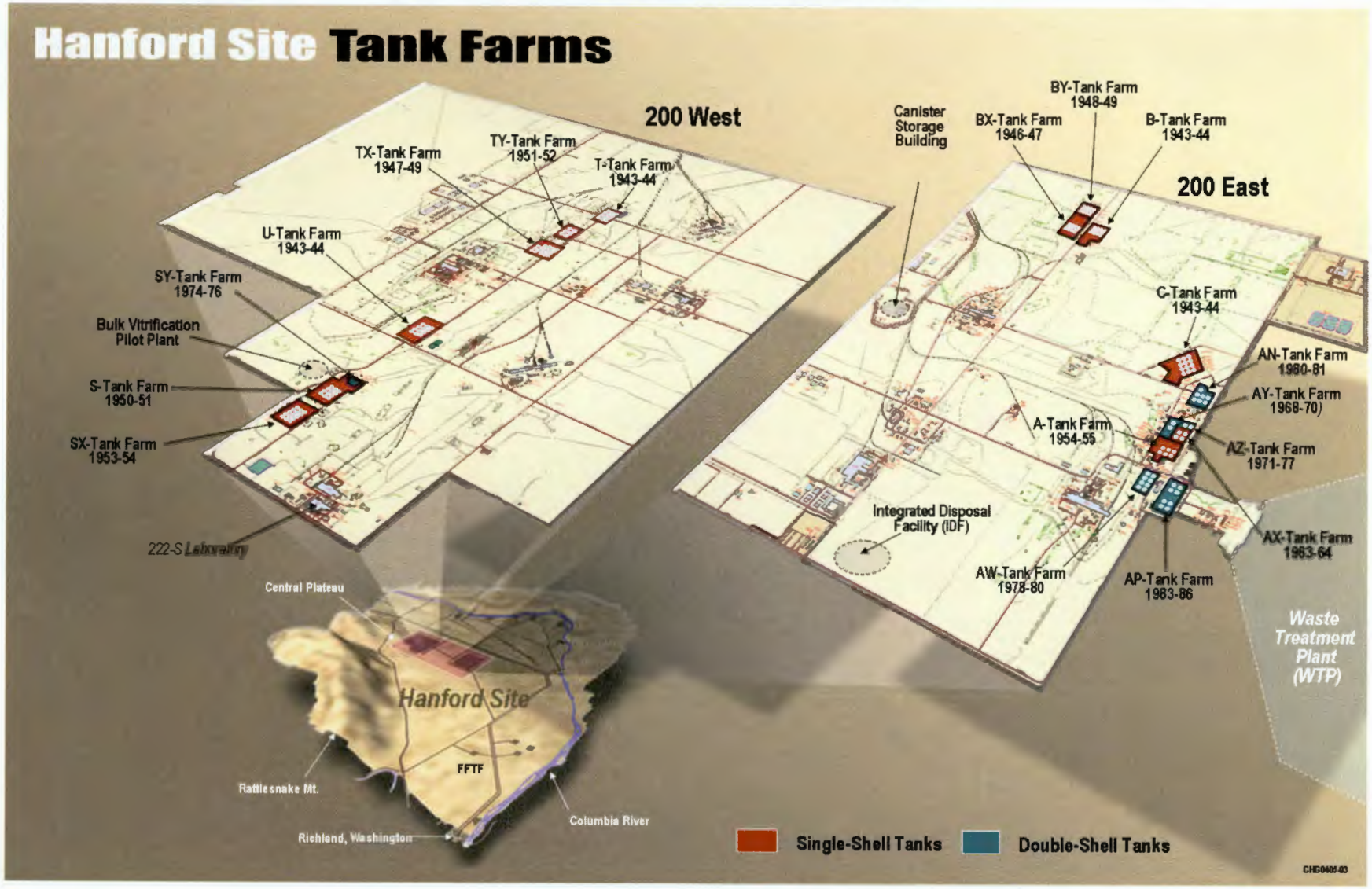
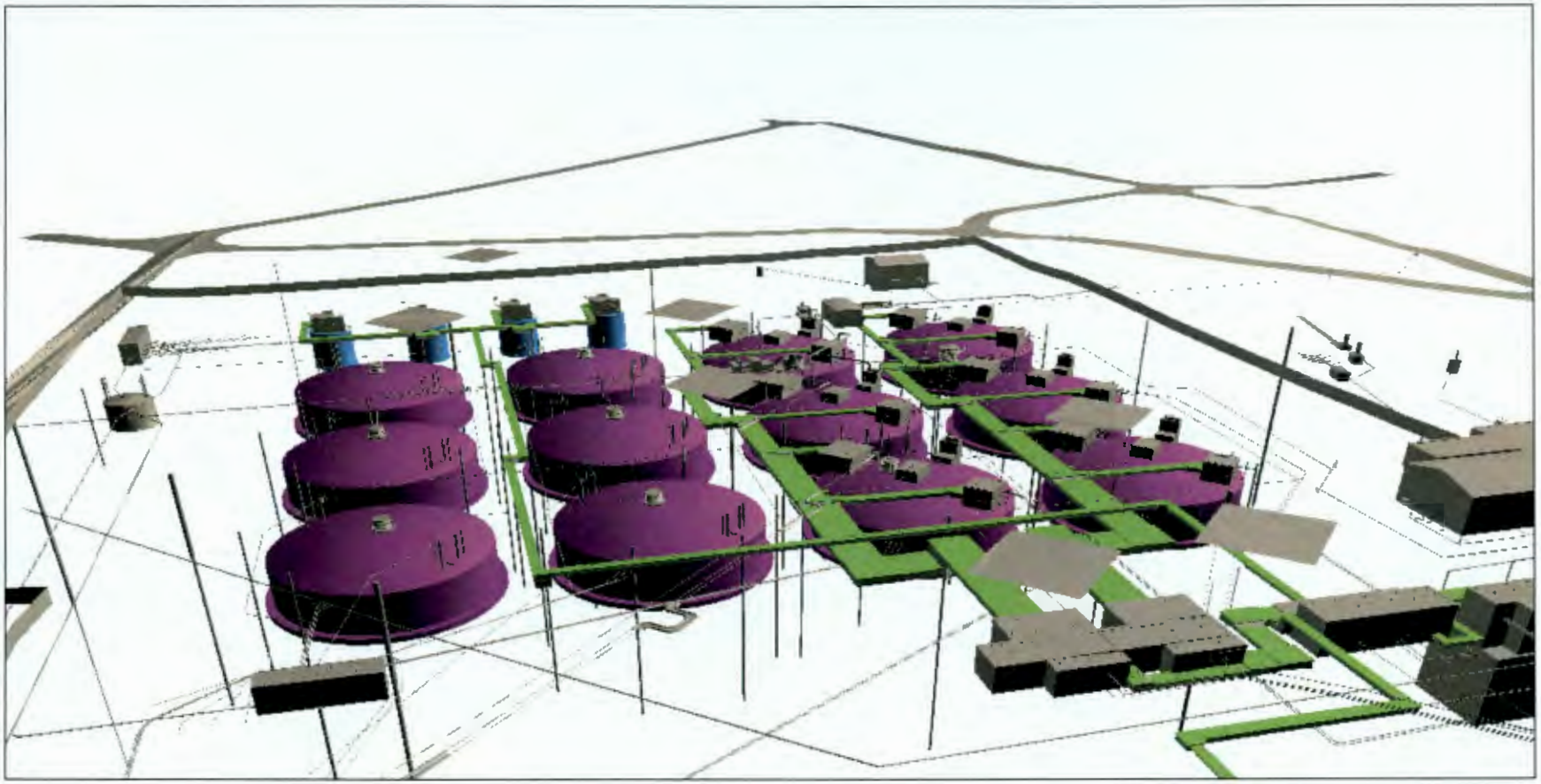


Figure 2-24. Tank Infrastructure at Waste Management Area C



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

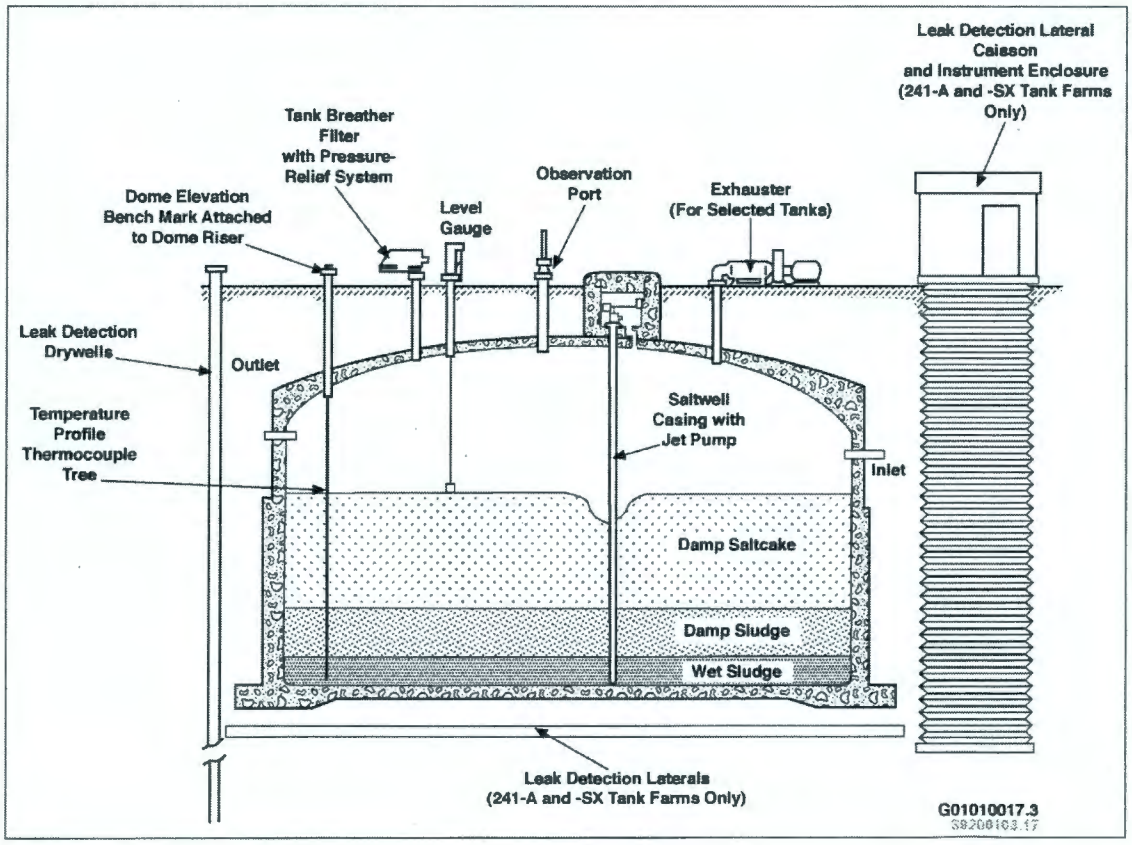
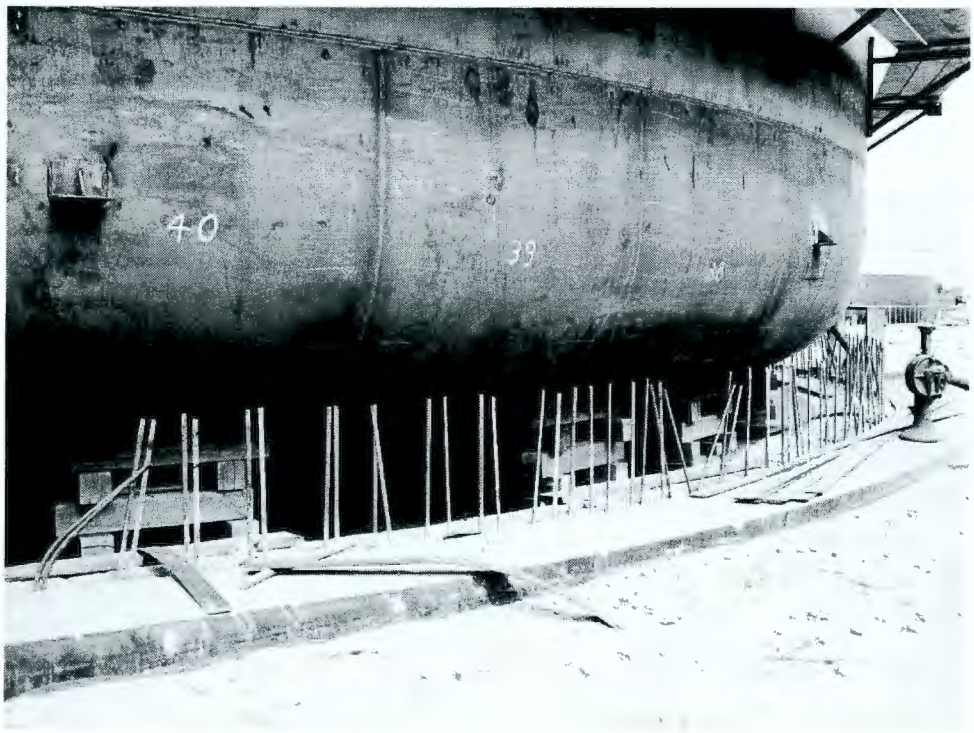


Figure 2-26. Bare Concrete Single-Shell Tank Dome

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

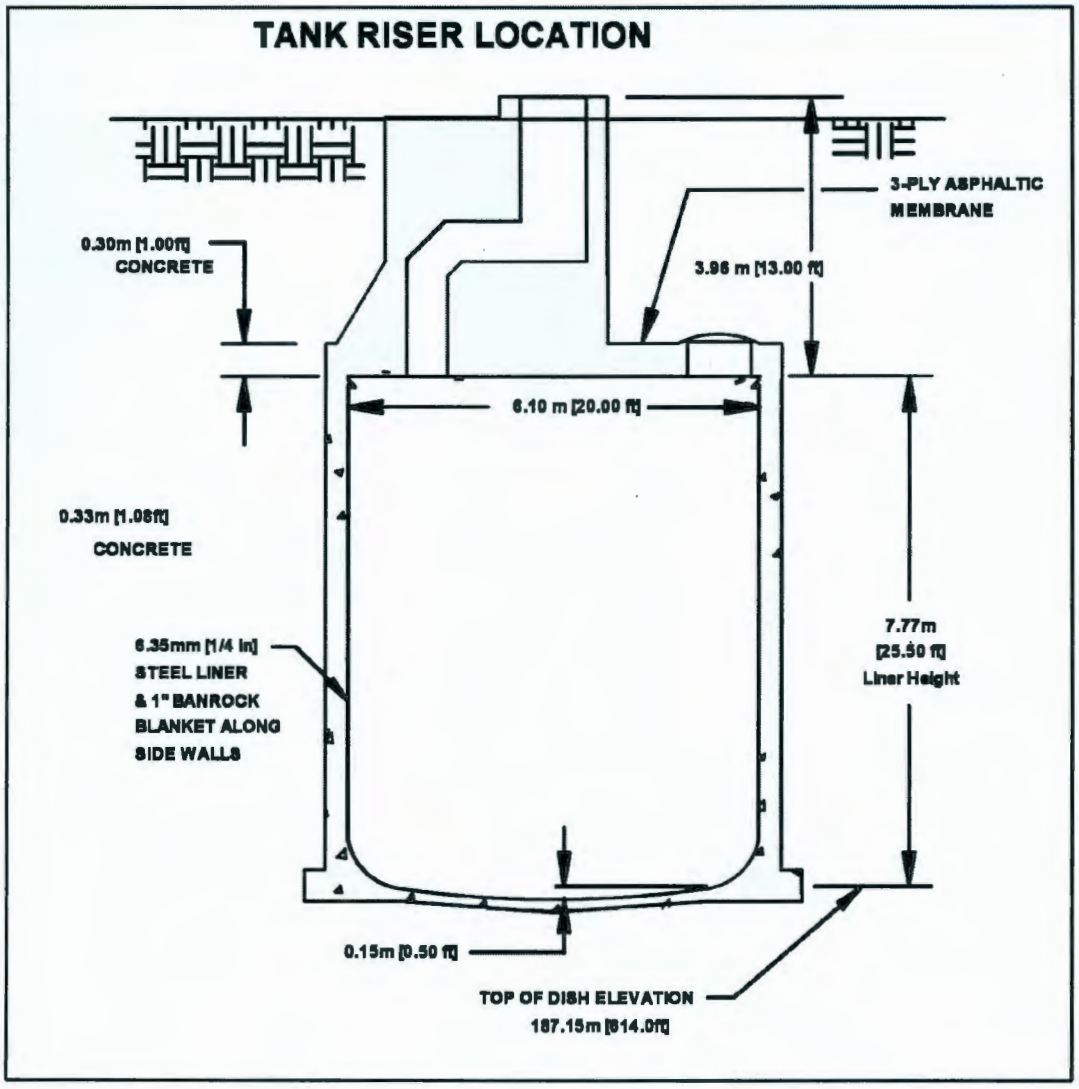
Each of the 100-Series SST design configurations (Figure 2-25) includes multiple risers that provide access to each tank from the surface. The risers are configured as either a section of a pipe or a square concrete pit that connects to the top of the tank from the surface. The risers and pits are placed 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.

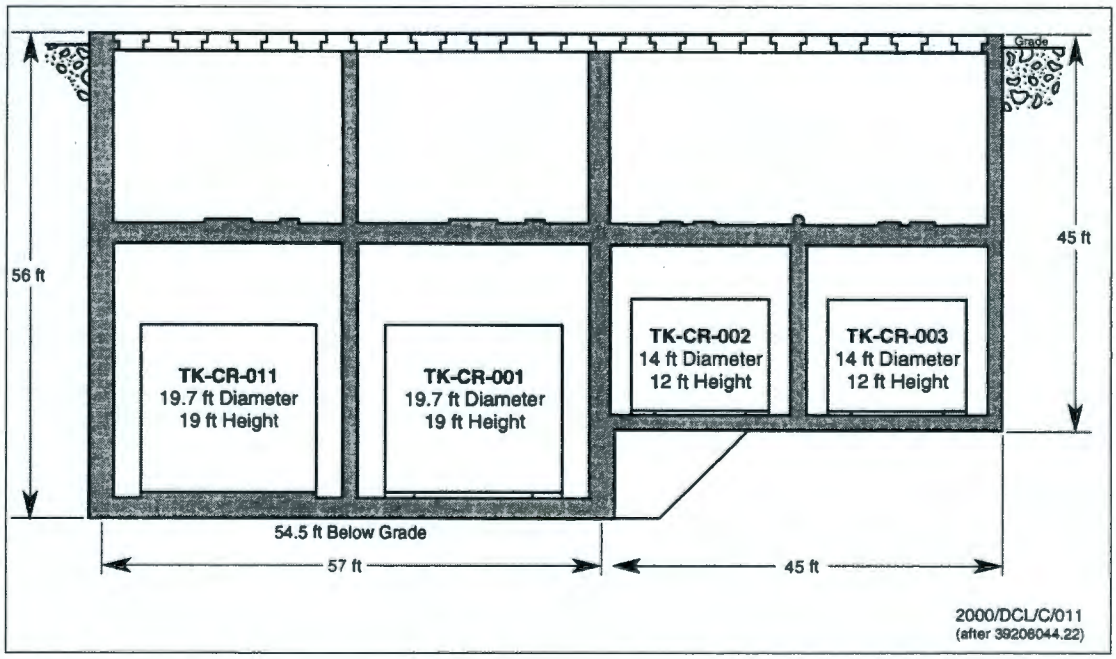
2.4.3.1 Miscellaneous Underground Storage Tanks

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

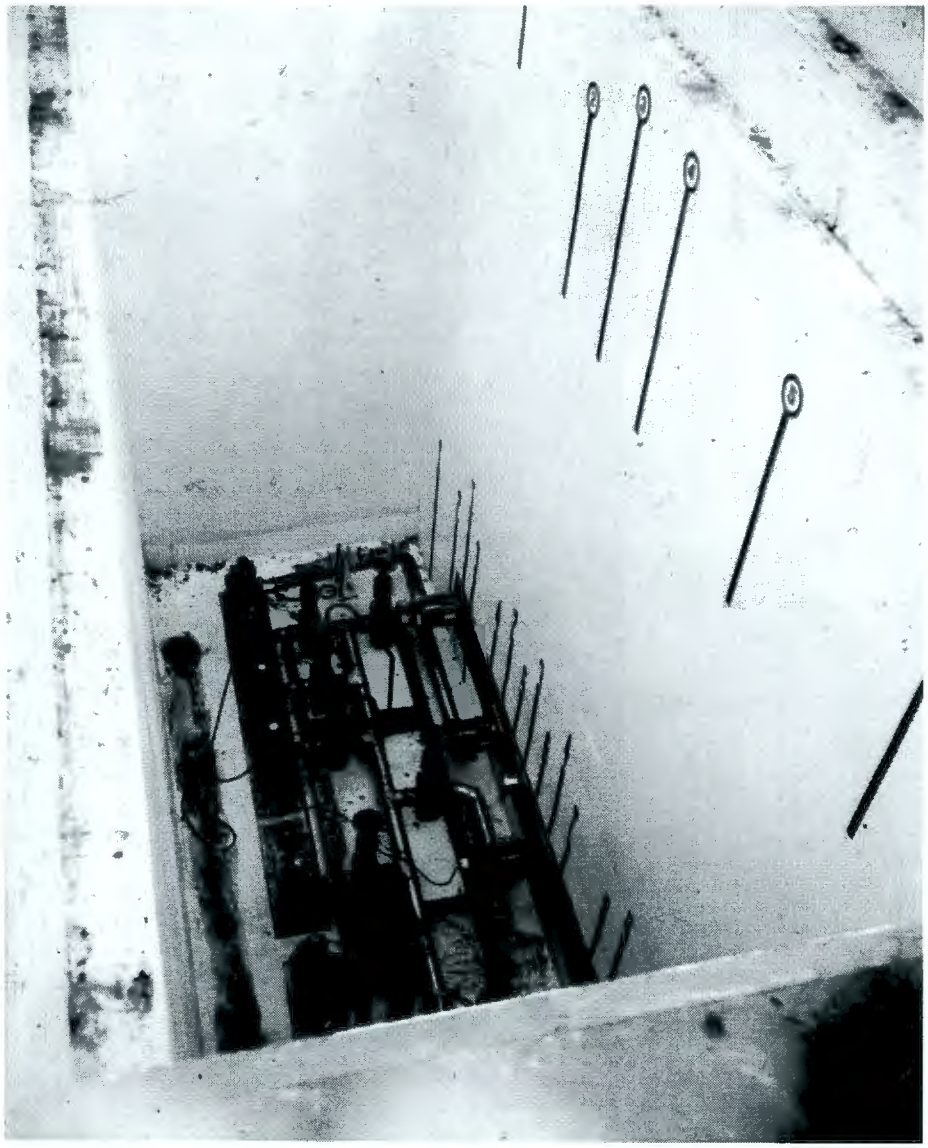


Figure 2-32. Waste Transfer Pipelines, BX Tank Farm, circa 1948

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.

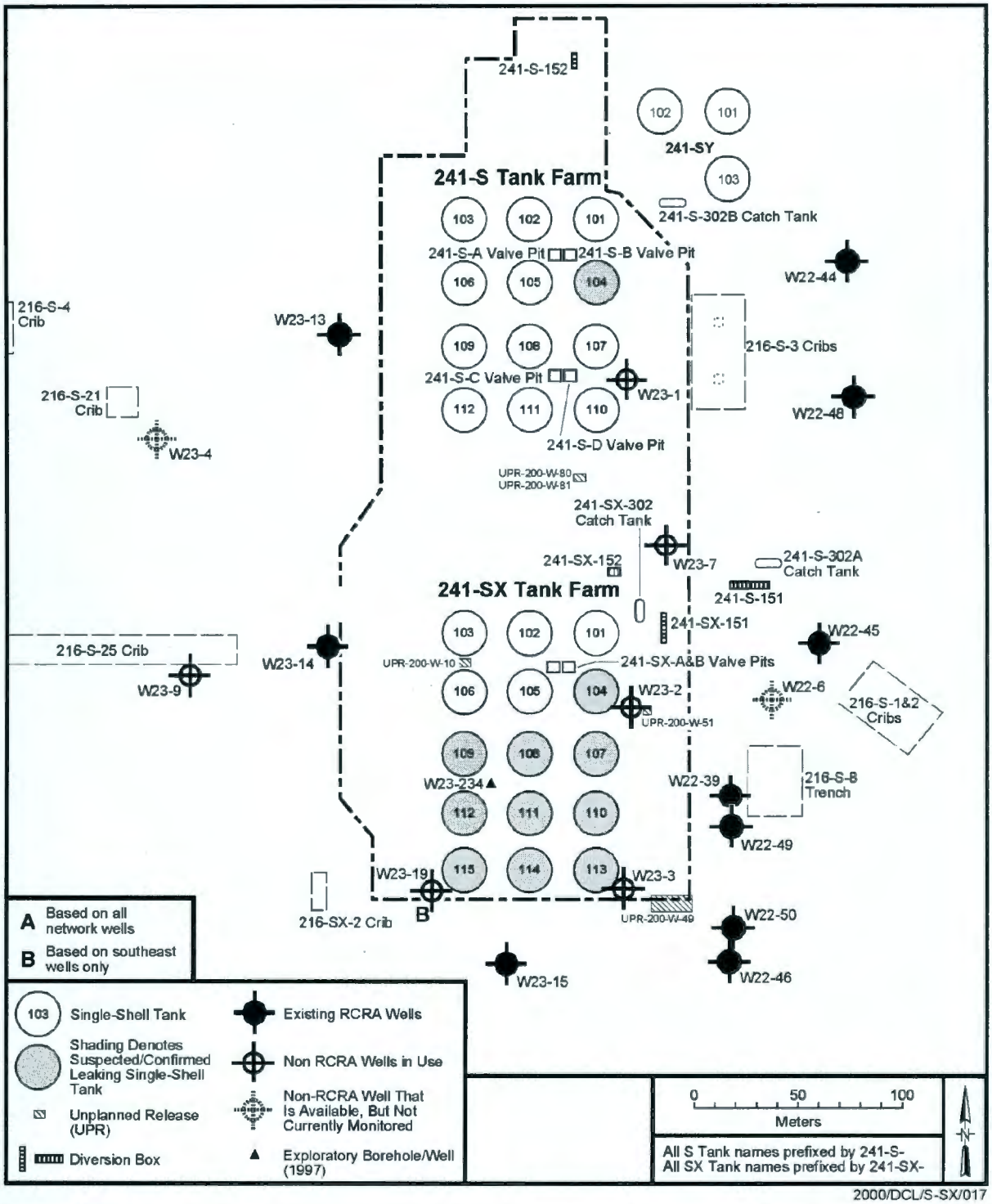
Currently, the pumpable liquid wastes have been removed from the WMA S-SX tanks and all tanks have been interim stabilized with the exception of two tanks. Tanks S-102 and S-112 were excluded from the interim stabilization requirements as the waste is being retrieved from the tanks as a closure activity. 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).

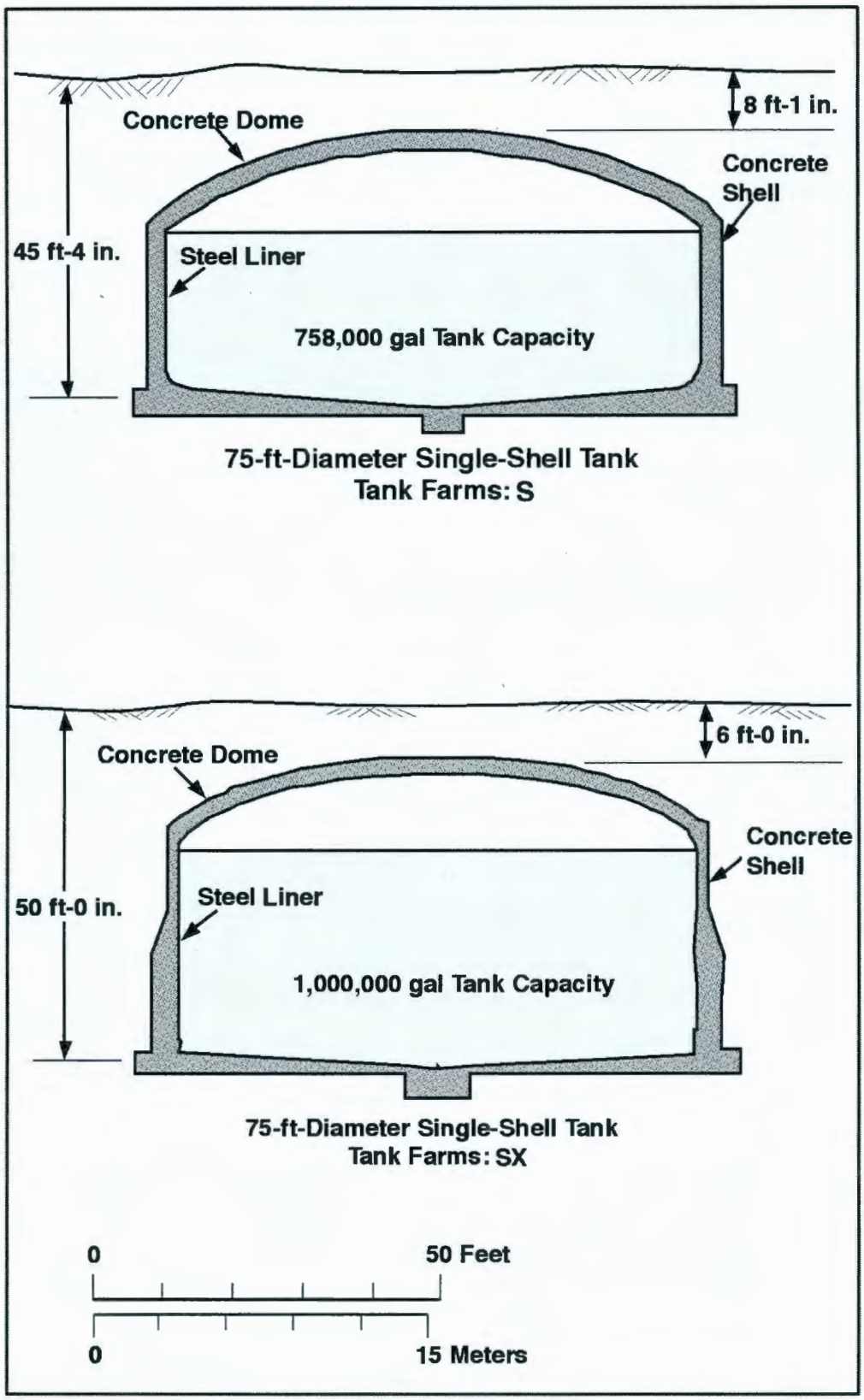
Table 2-6. Operating Period and Capacities for Waste Management Area S-SX Facilities Included in the Performance Assessment [a]

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.

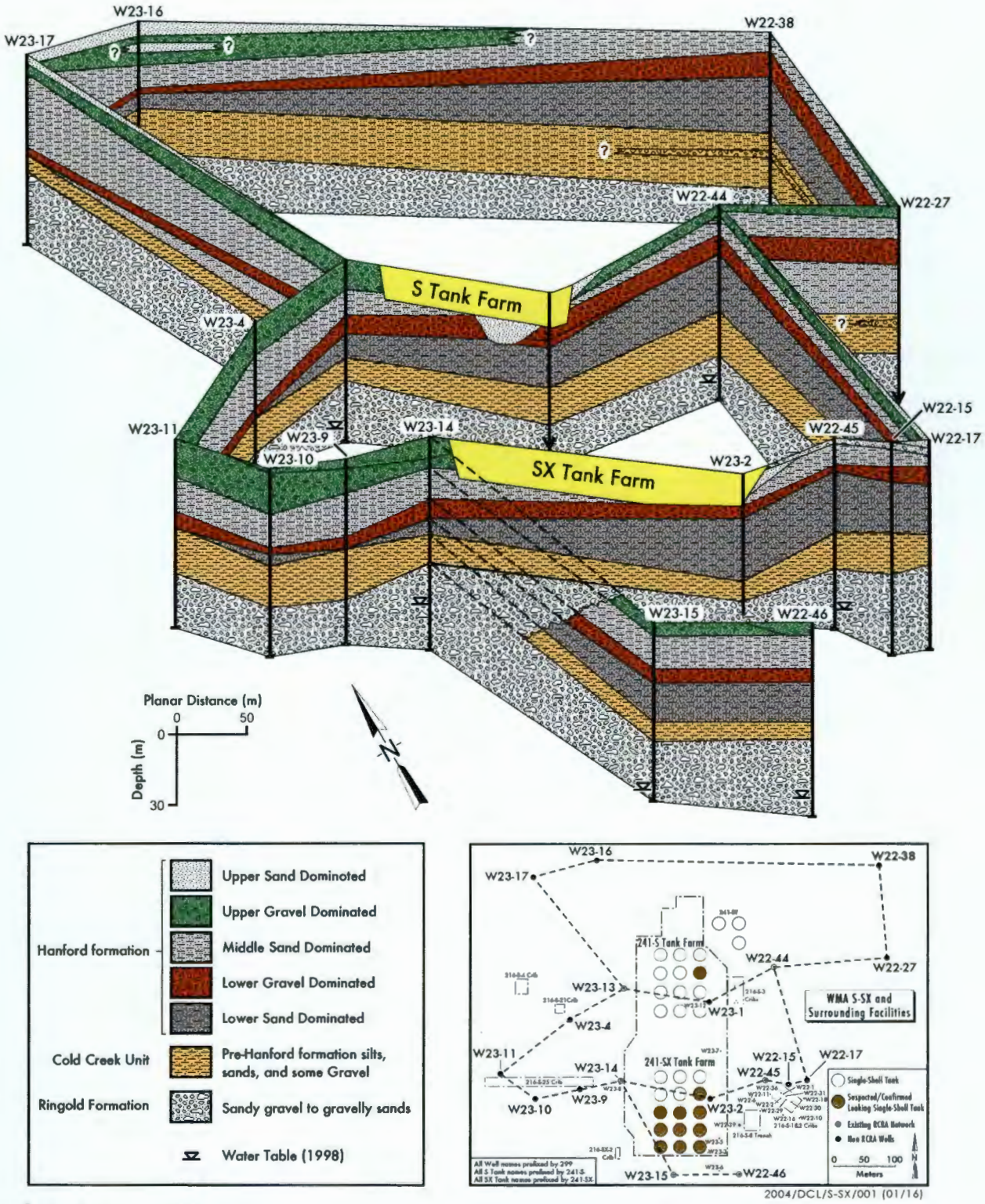
The general characteristics of these units are described in Section 2.3.4.1 and in more detail in Reidel et al. (2006). The SSTs at WMA S-SX were emplaced within the Hanford formation sediments of the upper sand-dominated (H1a) subunit, and may locally intercept the upper portions of the middle gravel-dominated 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

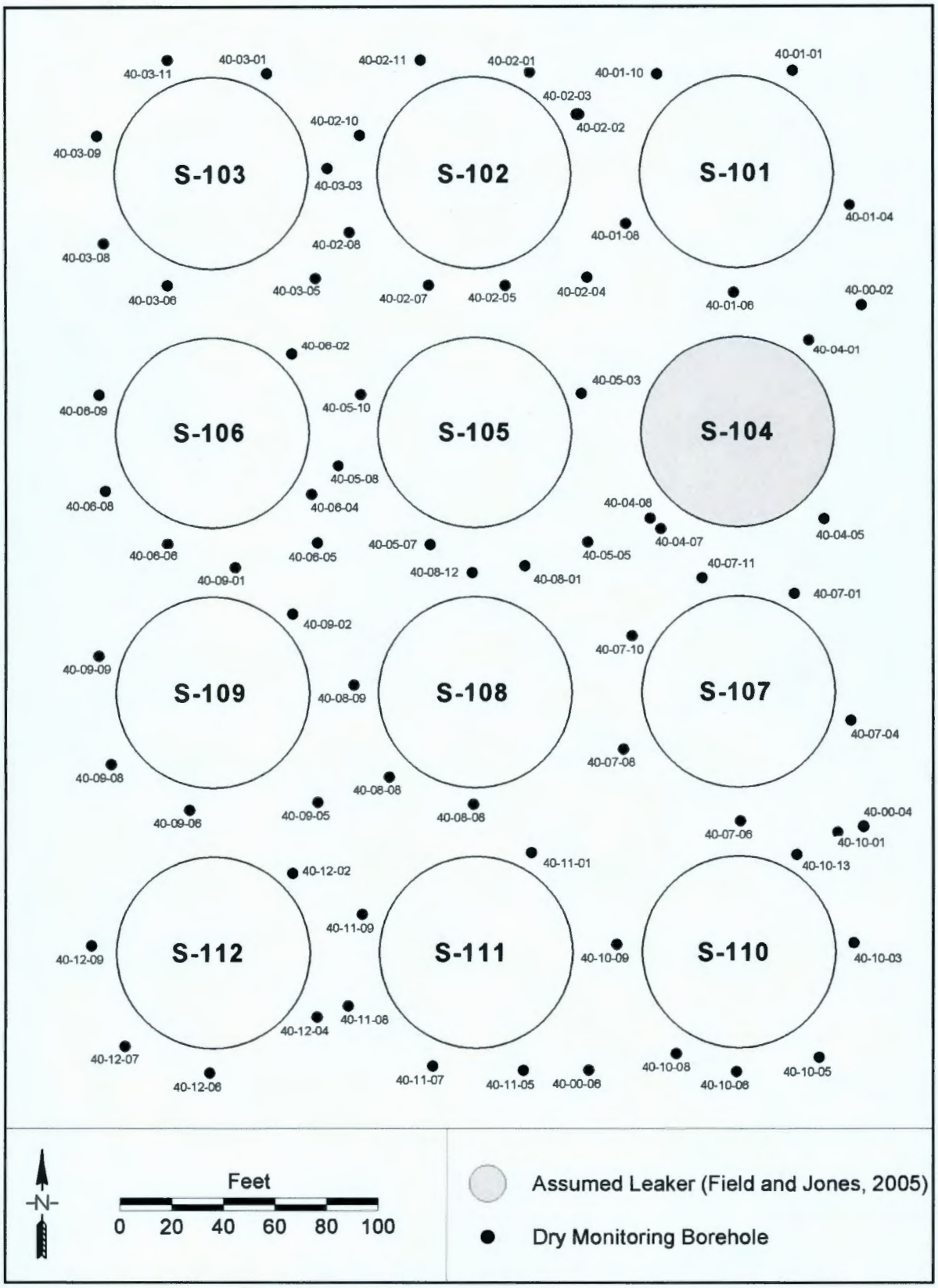
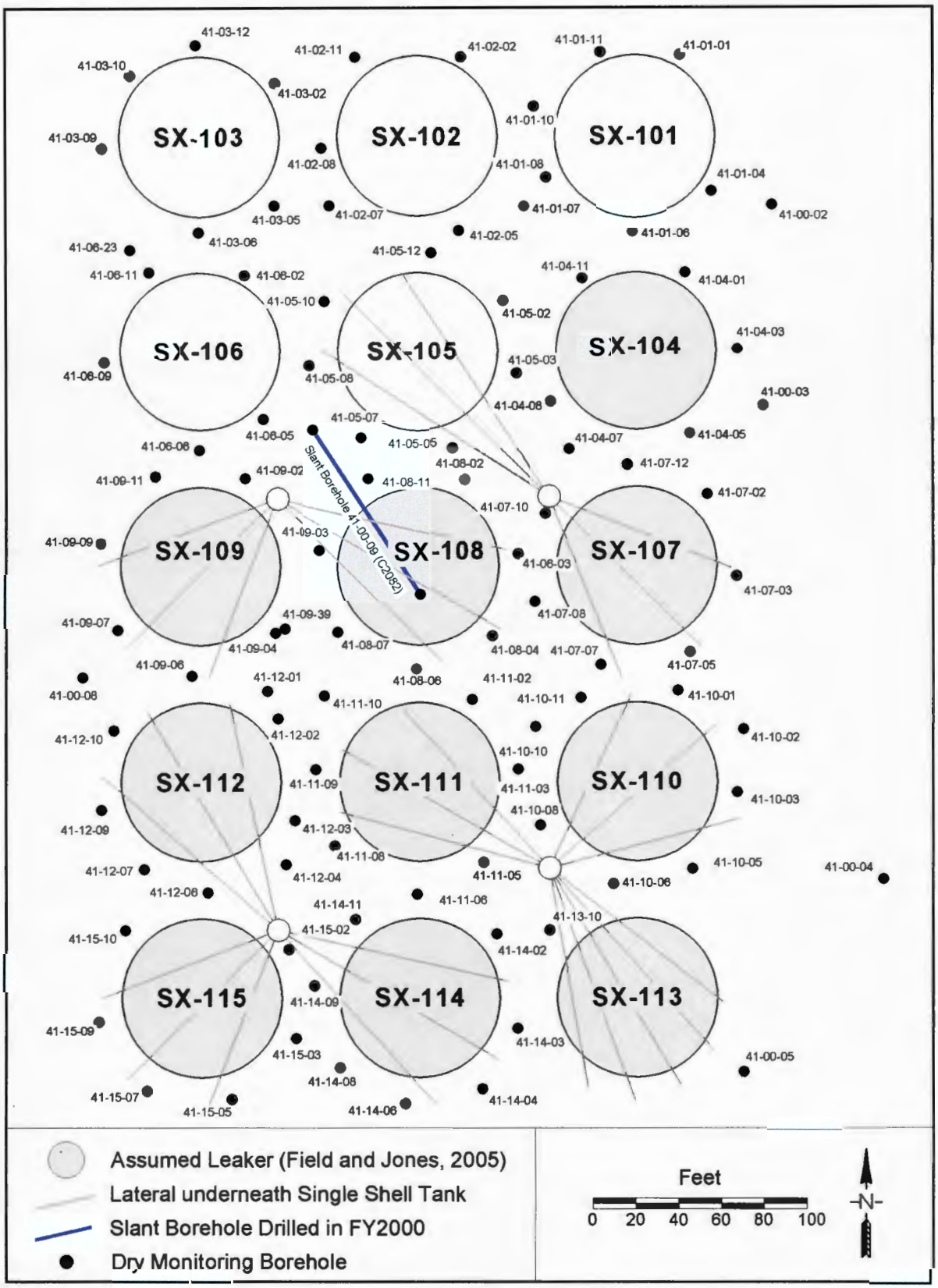


Figure 2-37. Vadose Zone Monitoring Network for SX Tank Farm in Waste Management Area S-SX



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

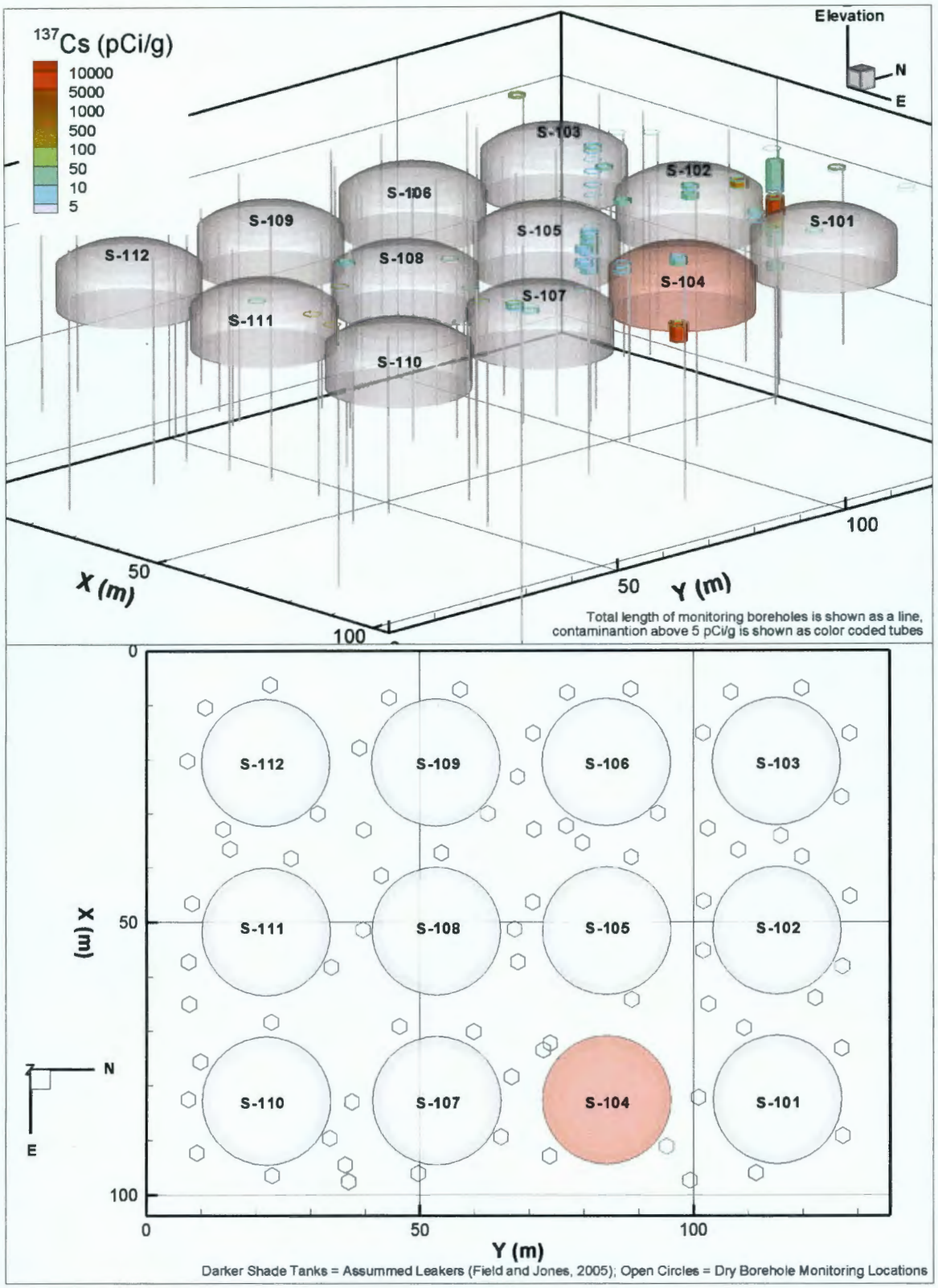
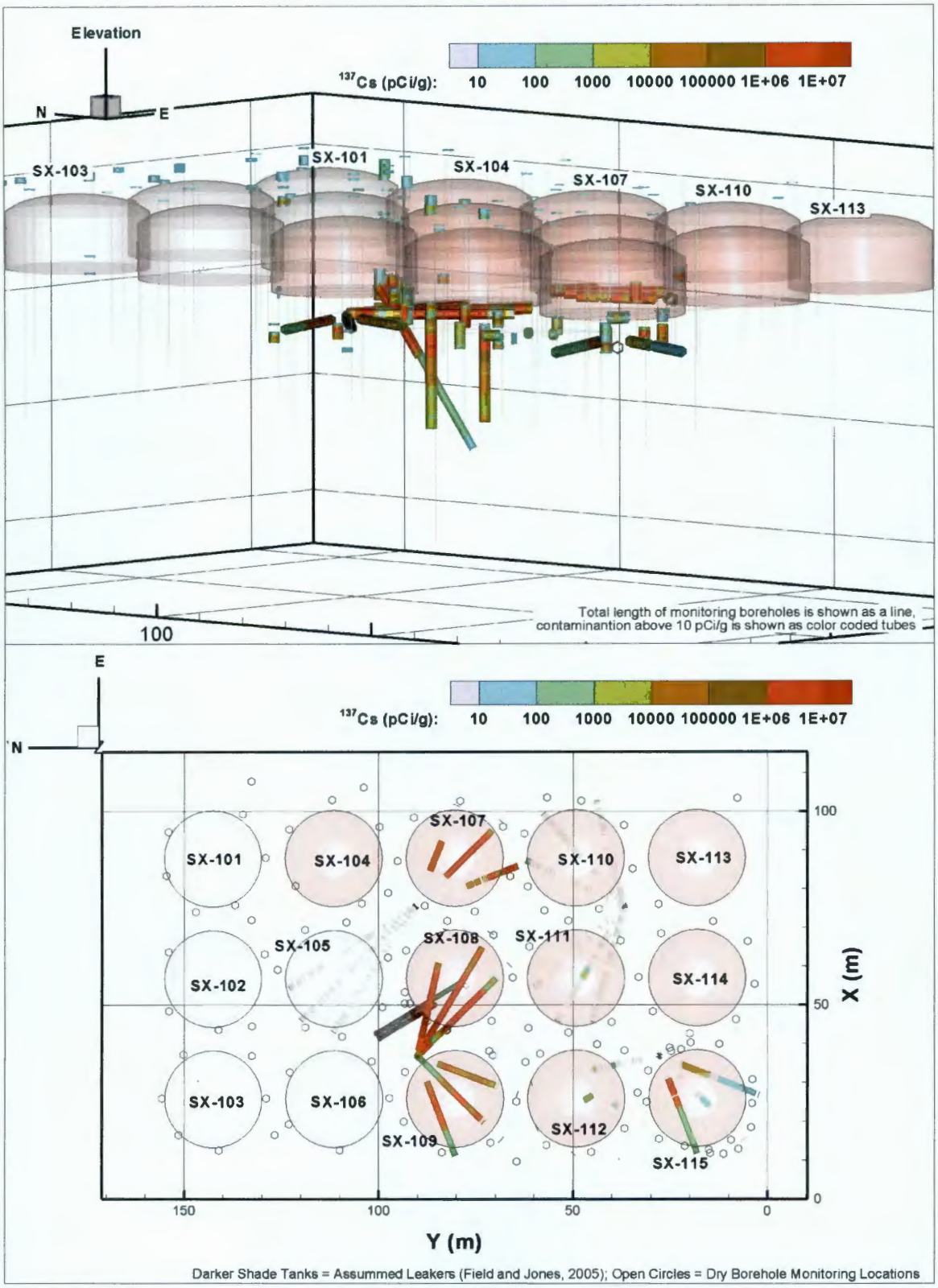


Figure 2-39. Three-Dimensional Perspective of SX Tank Farm Tanks and Drywells Showing Occurrence of Significant (>10 pCi/g) Cesium-137 Contamination in the Vadose Zone



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.

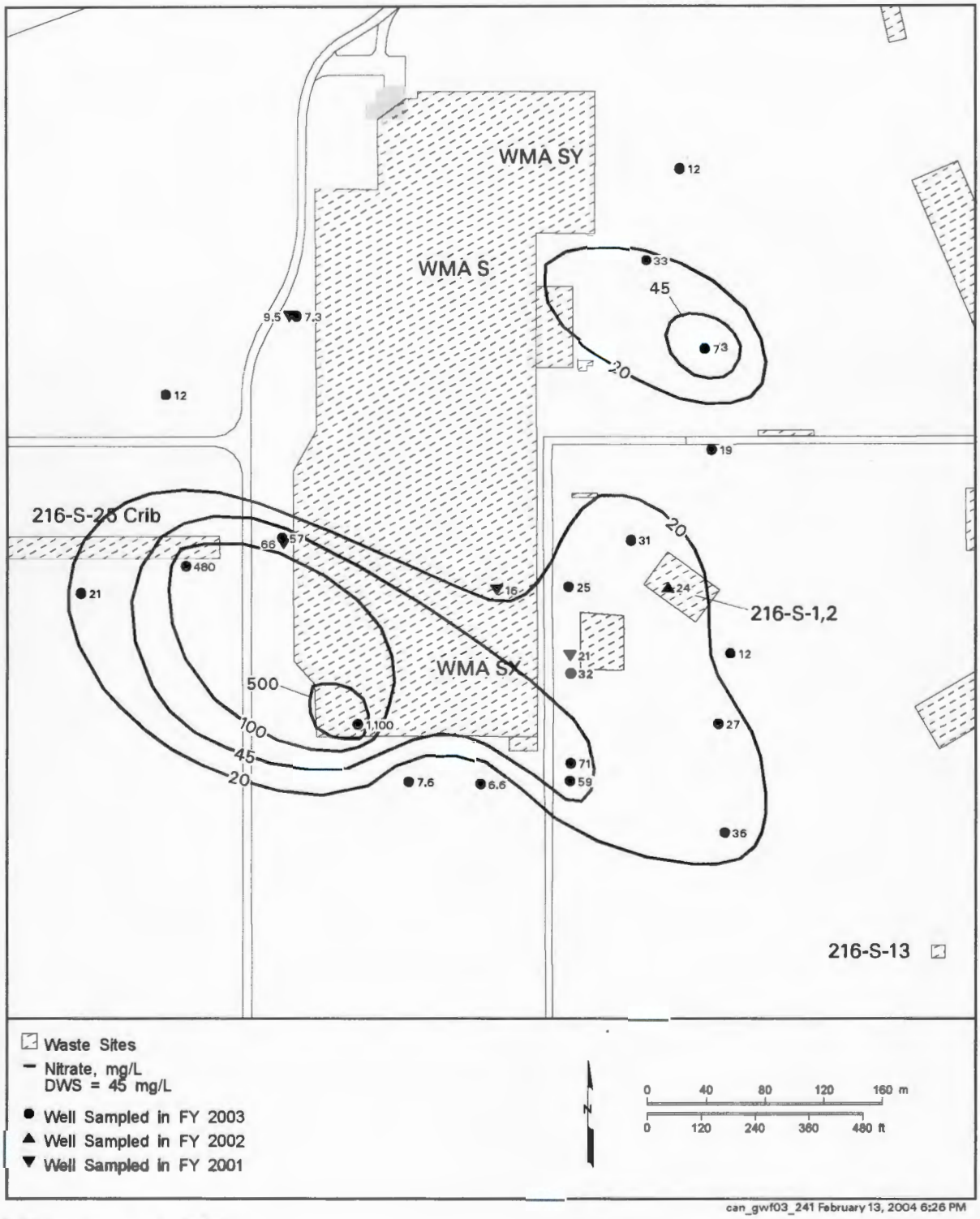
2.6.6.2 Contamination

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.

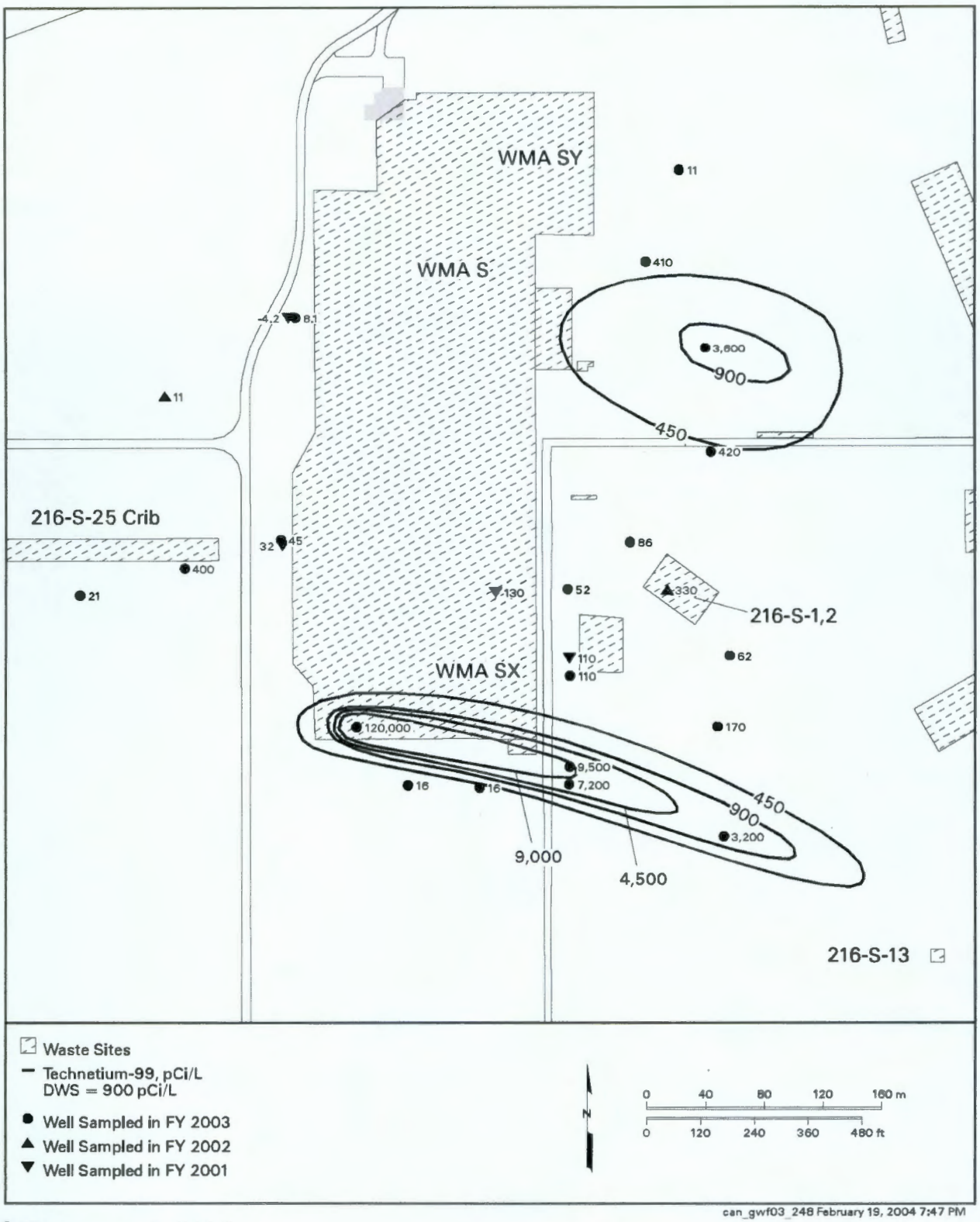
The contaminant plume located on the south portion of the WMA continues to slowly spread downgradient from its apparent source near tank SX-115. This plume is composed of nitrate, chromium, and technetium-99, as is the S tank farm plume to the north. The peak technetium-99 concentration at well 299-W23-19 (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]



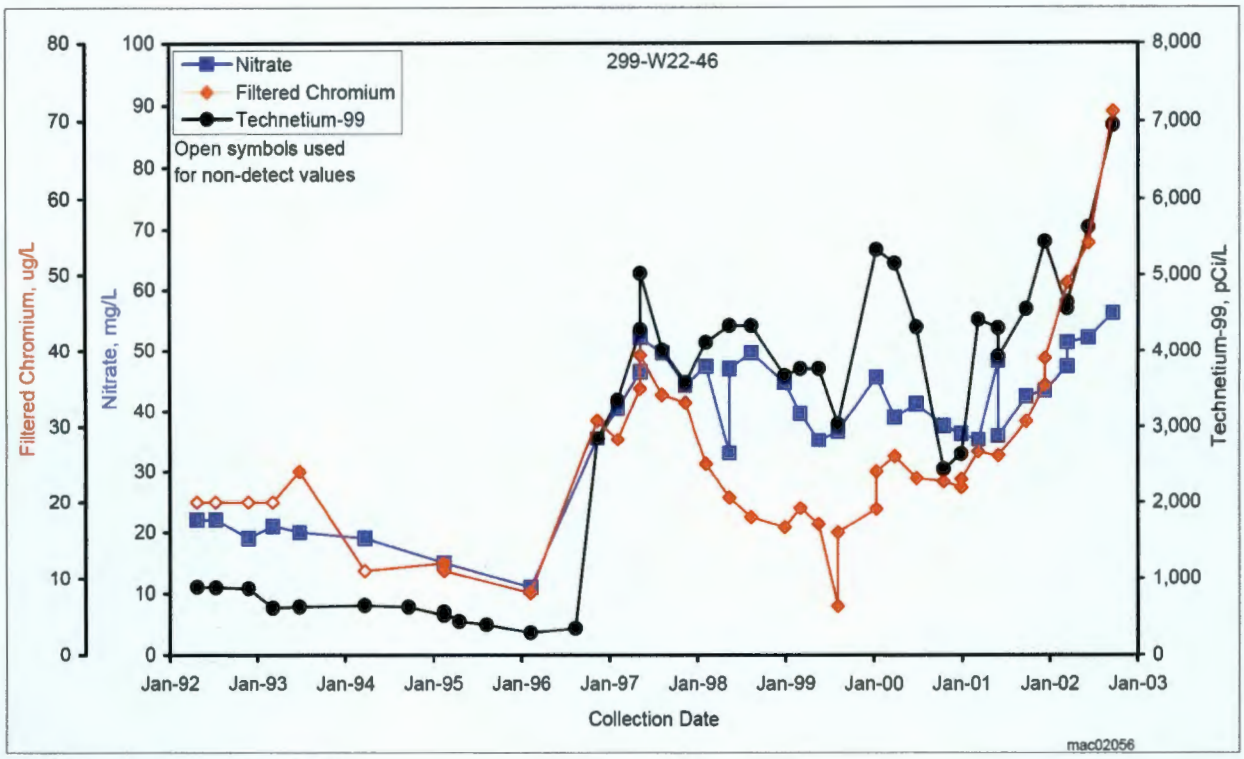
[a] *Hartman et al. (2004)*

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



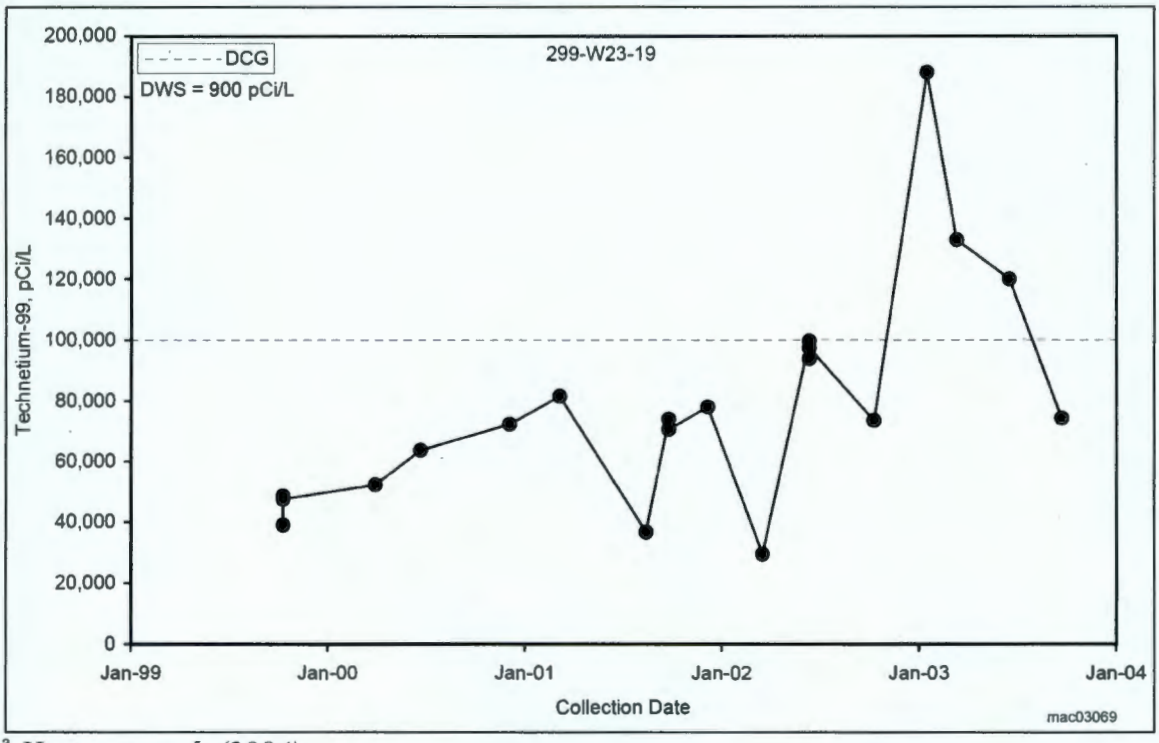
[a] *Hartman et al. (2004)*

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
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- 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
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- actinium-227
- radium-228
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- uranium-232
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- 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).

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Section 3 of 6

Document Information			
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2.0 SITE AND WASTE CHARACTERISTICS

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2.7 DESCRIPTION OF WASTE MANAGEMENT AREA T

This section provides site-specific information for WMA T. It is a summarized from numerous documents that describe present conditions (Hanlon 2005), geology and hydrology (Reidel et al. 2006), subsurface contamination (Wood et al. 2001), and source terms (Kirkbride et al. 2005; Field and Jones 2005; Lambert 2005; Corbin et al. 2005).

2.7.1 Background

WMA T is located in the north-central portion of the 200 West Area. In general, the WMA T boundary is represented by the fenceline surrounding the T tank farm (Figure 2-44). WMA T contains twelve 100-Series SSTs and four 200-Series SSTs that were constructed between 1943 and 1944, put into service in 1944, and initially used to store bismuth phosphate waste from T Plant. Over its operating history, WMA T received waste from a variety of major chemical processing operations including bismuth phosphate fuel processing, uranium recovery, REDOX fuel processing, and fission product recovery. Because of a shortage of tank space during the early years of T tank farm operations, large quantities of liquid waste were intentionally discharged to the soil through a system of cribs and trenches constructed near and within WMA T.

The discovery or assumption of leaking tanks in WMA T between 1959 and 1977 prompted a decision to put the tanks out of service and remove the remaining liquids from the tanks. The last WMA T tank was removed from service in 1979. Currently, the pumpable liquid wastes have been removed from the WMA T tanks and all tanks have been interim stabilized. Table 2-9 lists the estimated volume of waste stored in the WMA T tanks as of November 30, 2004. Interim measures have been implemented at WMA T to minimize the infiltration from manmade water sources. These measures include well decommissioning, capping monitoring wells, testing and isolating water pipelines, and building berms around the tank farm boundaries.

Detailed discussion of T tank farm construction and operations along with historical information on soil surface and vadose zone contamination in WMA T is provided in Williams (2000). A detailed description of contaminant occurrences and environmental conditions at WMA T is provided in Wood et al. (2001).

Vadose zone field characterization activities were initiated at WMA T during fiscal year 2003 in support of RCRA Corrective Action requirements. The investigative approach for this work is described in Crumpler (2001). *Field Investigation Report for Waste Management Areas T and TX-TY* (Myers 2005) documents the results of these investigations.

Figure 2-44. Location Map of Waste Management Area T and Surrounding Facilities

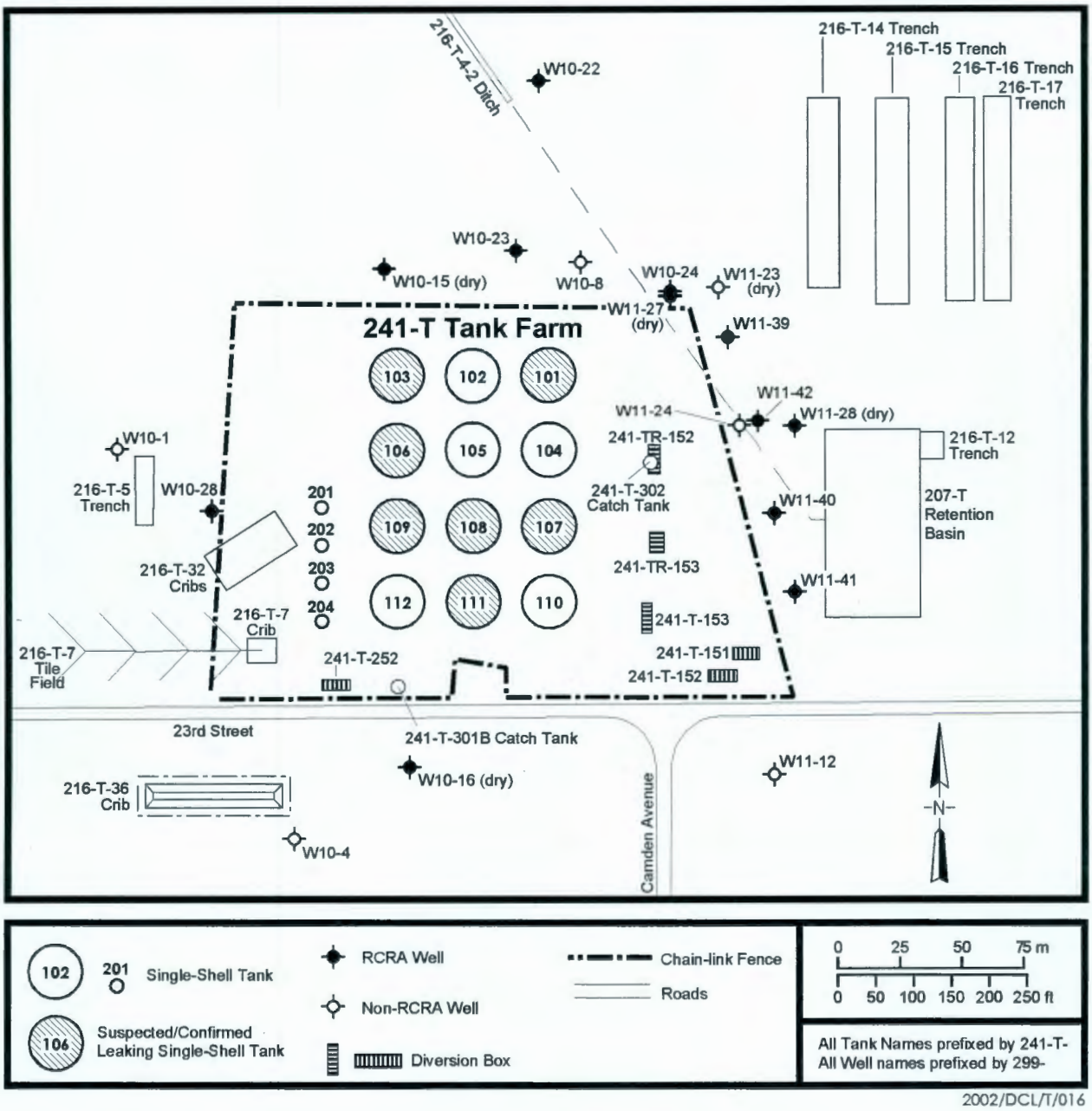


Table 2-9. Waste Volume Estimates as of November 30, 2004, in Waste Management Area T Single-Shell Tanks [a]

Tank	Total waste gal × 1,000	Supernate liquid gal × 1,000	Sludge gal × 1,000	Saltcake gal × 1,000
241-T-101	99	0	37	62
241-T-102	32	13	19	0
241-T-103	27	4	23	0
241-T-104	317	0	317	0
241-T-105	98	0	98	0
241-T-106	22	0	22	0
241-T-107	173	0	173	0
241-T-108	16	0	5	11
241-T-109	62	0	0	62
241-T-110	370	1	369	0
241-T-111	447	0	447	0
241-T-112	67	7	60	0
241-T-201	30	2	28	0
241-T-202	20	0	20	0
241-T-203	36	0	36	0
241-T-204	36	0	36	0

[a] Hanlon (2005).

2.7.2 Infrastructure

This section describes the WMA T infrastructure components that were included in the SST PA and listed in Table 2-10. Reference case inventory development for those components is described in Section 2.7.7. Refer to Section 2.4 for generic infrastructure component descriptions and Section 2.5 for a summary of infrastructure inventory development methods.

2.7.2.1 Single-Shell Tanks

The twelve 100-Series tanks are first generation SSTs that are 75 ft in diameter and approximately 29.75 ft tall from base to dome. Each tank has an operating capacity of 535,000 gal (Wood et al. 2001). The four 200-Series tanks are 20 ft in diameter and approximately 37.25 ft tall from base to dome. Each tank has an operating capacity of 55,000 gal. Typical tank configurations and dimensions are shown in Figure 2-45.

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

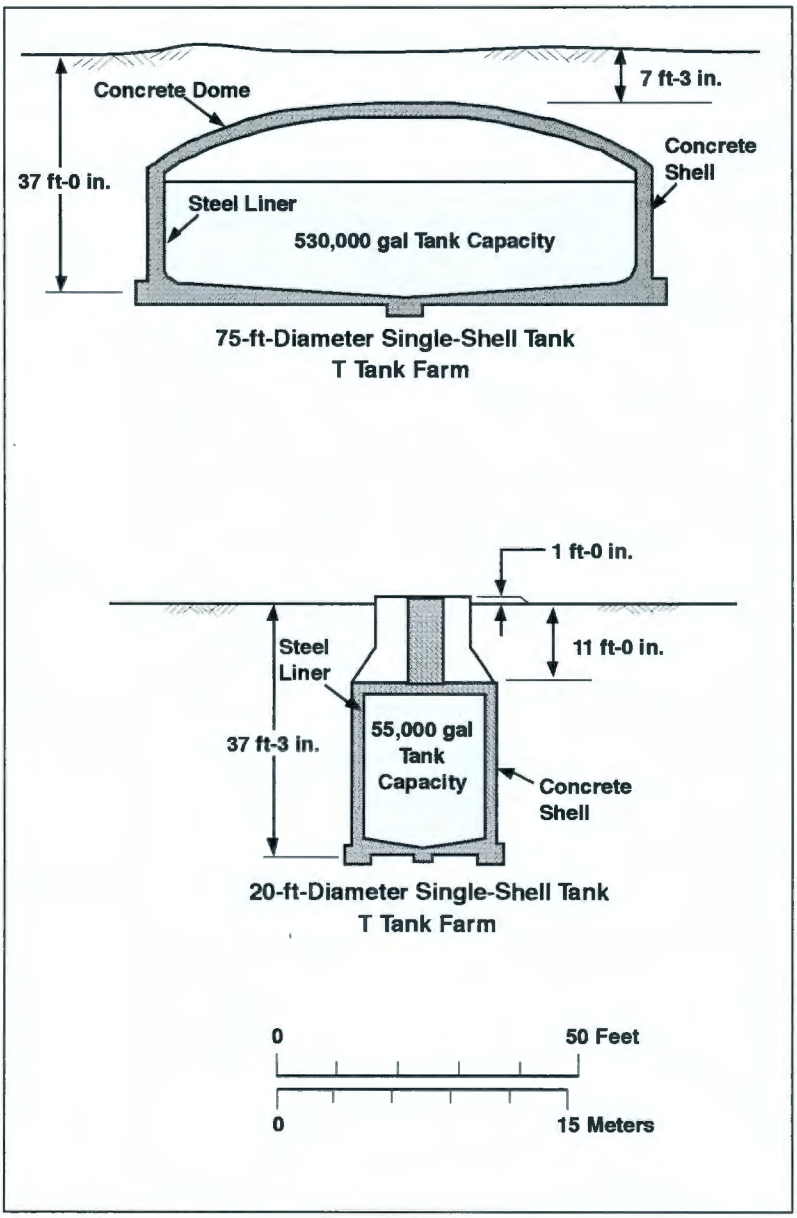
Facility	Removed From Service	Constructed	Operating Capacity gal
Single-Shell Tanks			
241-T-101	1979	1943 to 1944	530,000
241-T-102	1976		
241-T-103	1974		
241-T-104	1974		
241-T-105	1976		
241-T-106	1973		
241-T-107	1976		
241-T-108	1974		
241-T-109	1974		
241-T-110	1976		
241-T-111	1974		
241-T-112	1977		
241-T-201	1976		55,000
241-T-202	1976		
241-T-203	1976		
241-T-204	1976		
Miscellaneous Underground Storage Tanks			
241-T-301B catch tank	1985	1944	36,000
241-T-302 catch tank [b]	NA	NA	NA
Underground Waste Transfer Lines			
241-T tank farm pipelines	NA	1943 to 1944	20,600 (+/-6,800)

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

[b] Information in DOE-RL (2005) indicates this tank does not exist.

NA = not applicable

Figure 2-45. Typical Configuration and Dimensions of Single-Shell Tanks in Waste Management Area T



The WMA T SSTs were all constructed in place with carbon steel lining the bottom and sides of a reinforced concrete shell. All of the tanks have a dish-shaped bottom. The sediment cover from the apex of the tank domes to ground surface is 7.3 ft for the 100-Series tanks and 11 ft for the 200-Series tanks (Wood et al. 2001). The 100-Series tanks were constructed with cascade overflow lines in three-tank series to allow gravity flow of liquid waste between the tanks. The cascade overflow height is 15.67 ft from tank bottom. The 200-Series tanks were connected and fed to diversion box 241-T-252.

2.7.2.2 Ancillary Equipment

A complete listing of the WMA T 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 consist of the underground waste transfer lines and MUSTs located inside each WMA boundary. For WMA T, the ancillary components analyzed consist of the T tank farm waste transfer piping and one MUST (241-T-301B catch tank). Although the 241-T-302 catch tank is listed in HFFACO (Ecology et al. 1989), it has been verified that this tank was never constructed (DOE-RL 2005). Multiple sets of waste transfer piping were installed in WMA T over time. A time line of piping installations is described in Williams (2000). It is estimated that there are approximately 10.6 mi (+/-3.5 mi) of waste transfer piping in WMA T (Field 2003a).

Portions of two intentional discharge facilities (216-T-32 crib, 216-T-7 crib) are located inside the WMA T boundary (Figure 2-44). As discussed in Section 2.5.2, intentional discharge facilities are not included in the SST PA. Those facilities will be evaluated in the future under the integrated regulatory closure process described in Chapter 1.0.

2.7.3 Geology

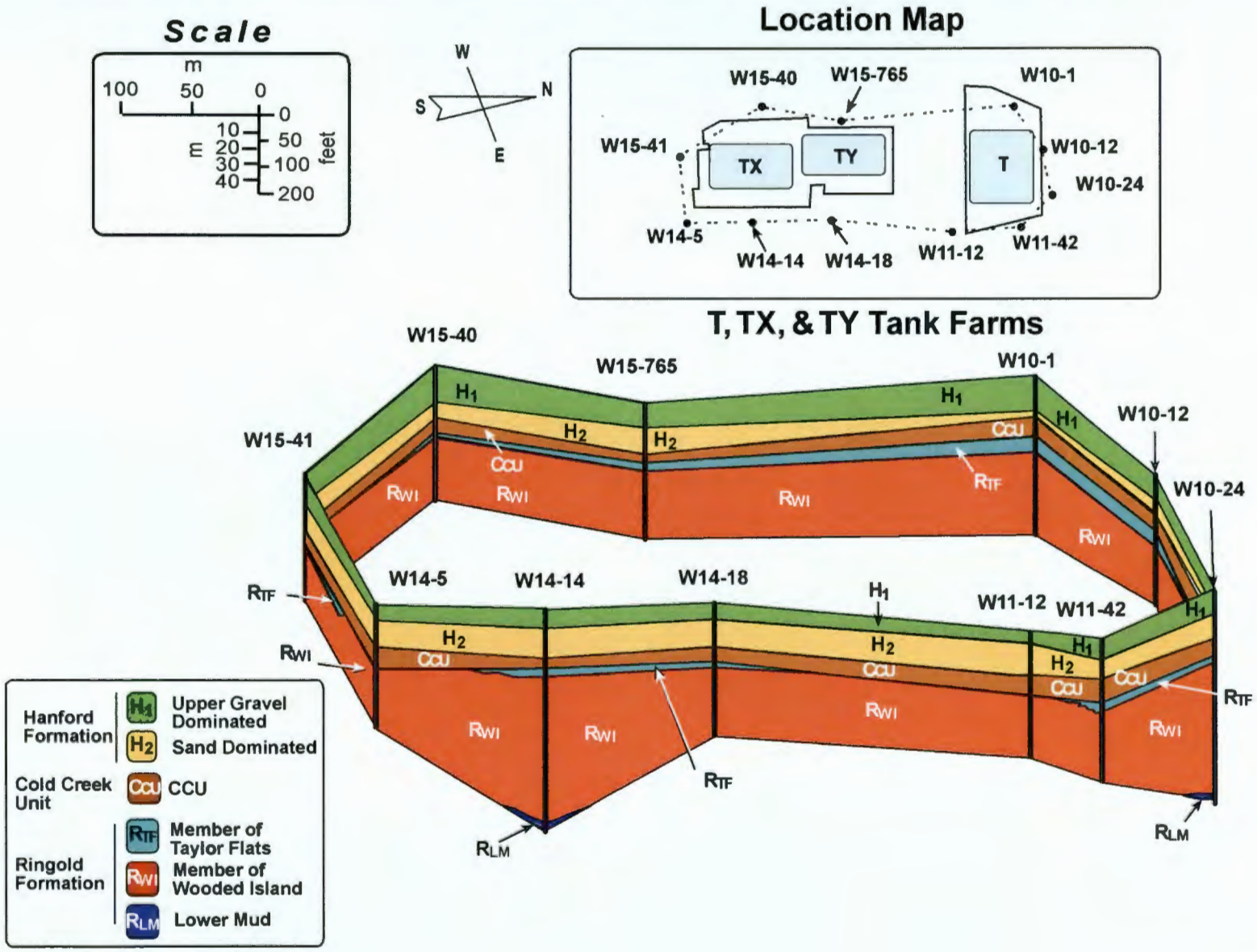
Following is an overview of the geology of WMA T. More detailed information can be found in Reidel et al. (2006) and Wood et al. (2001). A generalized cross-section through WMA T is shown in Figure 2-46. Maps and cross-sections presented in Reidel et al. (2006) illustrate the distribution and thicknesses of these units in additional detail.

Seven stratigraphic units are recognized within WMA T. 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-unit and upper silt-rich unit (CCU)
- Hanford formation – sand-dominated sequence (H2 subunit)
- Hanford formation – upper gravel-dominated sequence (H1 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 T were emplaced within the Hanford formation sediments of the upper 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 T is approximately 67 m (220 ft) thick. The water table lies in the Ringold Formation, and the unconfined aquifer is located entirely within the Ringold Formation.

Figure 2-46. Fence Diagram Showing Cross-Sections through Waste Management Areas T and TX-TY [a]



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

2.7.4 Hydrology

Following is an overview of the hydrology of the uppermost, unconfined aquifer beneath WMA T. 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), Wood et al. (2001), and Hartman et al. (2004). Groundwater flow direction in the vicinity of WMA T has been variable because of changes in effluent discharges within the 200 West Area, principally to the 2T Pond system and the U Pond. Currently, the general groundwater flow direction in the unconfined aquifer beneath WMA T is to the east. The estimated hydraulic gradient in this region is 0.001. The general groundwater flow velocity ranges from 0.003 to 0.024 m/day (Hartman et al. 2004).

Between the late 1940s and early 1950s, the water table in the vicinity of WMA T, as measured in wells 299-W10-1, 299-W10-4, and 299-W10-8, rose rapidly due to discharges to the T Pond. The water table was at its highest elevation in about 1956 after having risen about 15 m. Another rise in the water table occurred during the 1970s and 1980s in response to disposal to the U Pond. Water table elevations began to decline in the mid 1980s when discharges to the vadose zone began to be curtailed and that decline is continuing today.

Currently, the water table beneath WMA T lies approximately 136 m amsl with about 71 m of vadose zone. The unconfined aquifer ranges in thickness from 50 to 55 m. The aquifer resides in partially cemented sands and gravels of the Ringold Formation member of Wooded Island (subunit E). Hydraulic conductivity values reported for the aquifer in this area range from 1 to 28 m/day (Hartman et al. 2004). Additional hydraulic property data from aquifer testing at wells near WMA T is provided in Reidel et al. (2006) and Hartman et al. (2004).

2.7.5 Vadose Zone Conditions

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

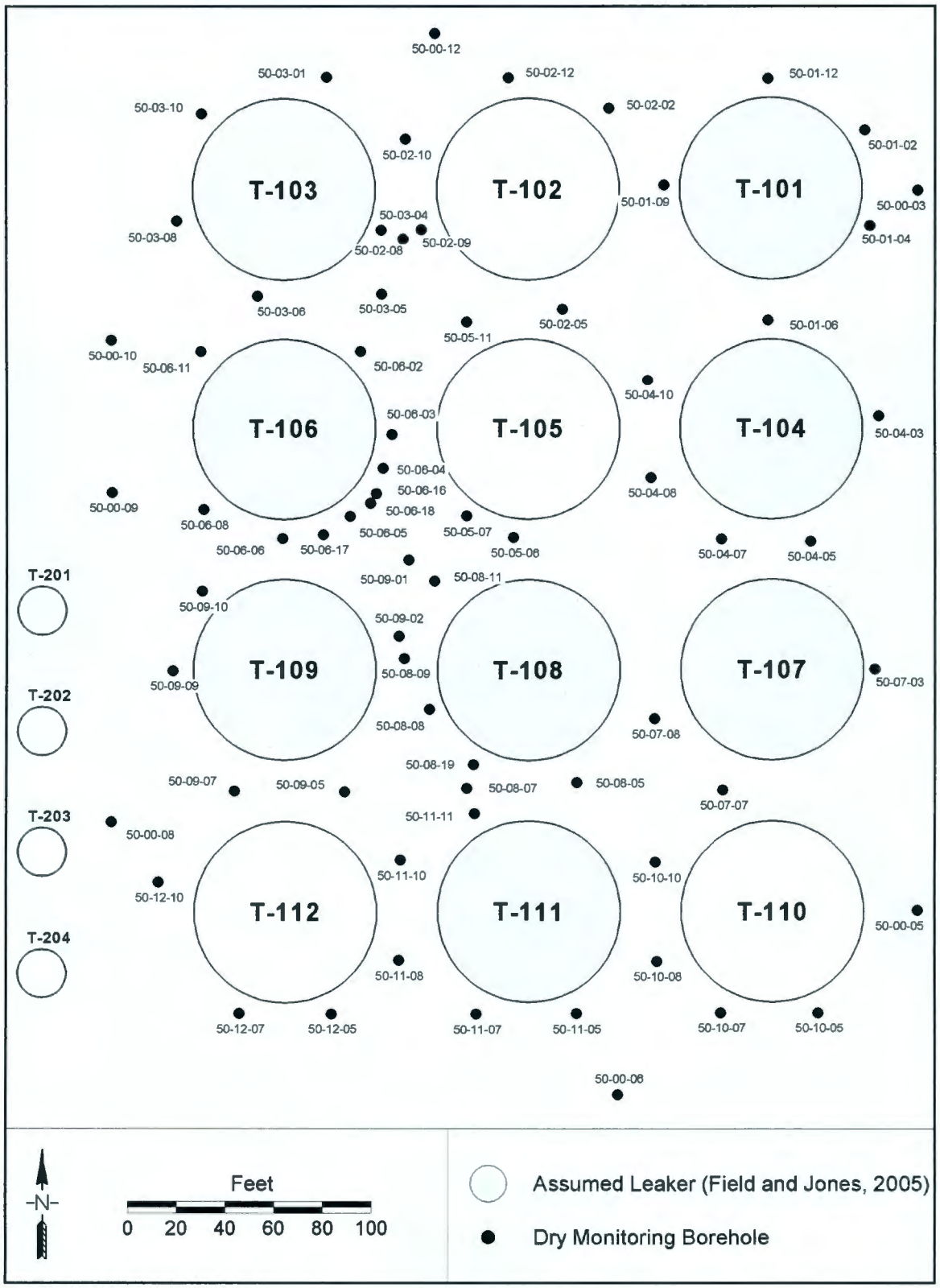
2.7.5.1 Monitoring and Characterization

WMA T has 68 drywells available for leak detection monitoring. These drywells were drilled from 1944 to 1974. The depth ranges for these drywells are between 80 and 150 ft bgs, except for drywell 50-06-18, which is 180 ft bgs. The T tank farm layout showing drywell locations in reference to tanks is shown in Figure 2-47.

Both gross gamma ray and spectral gamma logging methods have been performed in the WMA T drywells. Gross gamma logging data from the drywells were used as part of the leak detection program until 1994. In 1998, WMA T drywells were logged with a high-resolution spectral gamma logging system and the results were published in DOE-GJO (1999a).

In 2000, repeat logging of selected borehole intervals and enhancements to the original baseline characterization data evaluation process were performed for drywells in WMA T. This updated information is documented in DOE-GJO (2000c). These efforts were part of the baseline characterization for WMA T.

Figure 2-47. Vadose Zone Monitoring Network for Waste Management Area T



Field characterization efforts were initiated at WMA T in fiscal year 2003 in support of RCRA Corrective Action requirements. The investigative approach for this work (Crumpler 2001) was developed based on historical information (Williams 2000), geologic and hydrologic conditions (Wood et al. 2001), and gamma-logging data (DOE-GJO 1999a, 2000c). The characterization efforts include collection of vadose zone sampling data from the following activities:

- Installation of two soil characterization boreholes (C4104 and C4105) around tank T-106
- Shallow vadose zone soil investigation around tank T-101.

A detailed discussion of these investigations and an analysis of the results are included in the FIR for WMA T (Myers 2005).

2.7.5.2 Contamination

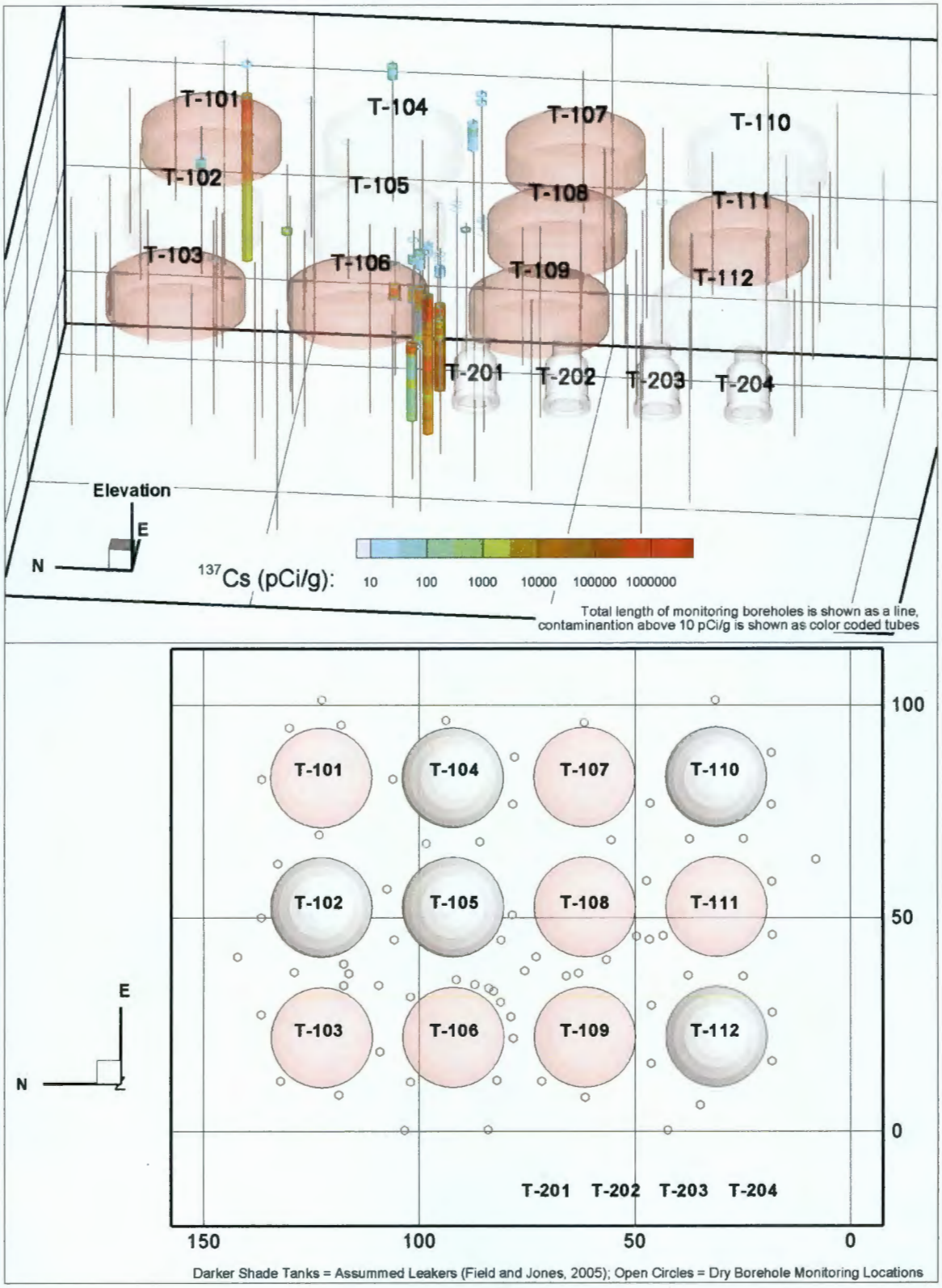
Figure 2-48 provides a visualization of the vadose zone contamination beneath WMA T as represented by cesium-137 data. This figure shows a three-dimensional perspective of WMA T providing locations of tanks and associated drywells. Tanks considered to be assumed leakers based on information in Field 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 (>10 pCi/g) are shown. Zones with contamination levels less than 10 pCi/g are not shown.

Detailed interpretation of the historical gross gamma and recent spectral gamma surveying at WMA T is provided in Wood et al. (2001). The primary gamma-emitting contaminants detected in the vadose zone beneath WMA T are cesium-137, cobalt-60, europium isotopes, and ruthenium-106. Minor quantities of antimony-125, niobium-94, and tin-126 are also detected.

The primary areas of elevated gamma readings occur in drywells located around tanks T-101, T-103, and T-106 (Figure 2-47). The presence of contamination in these areas is consistent with the locations of postulated leak events based on the WMA T historical record (Wood et al. 2001). A thick zone of high cesium-137 concentration (10^4 to 10^8 pCi/g) occurs in drywell 50-01-04 on the east side of tank T-101, beginning at a depth of about 25 ft and extending intermittently to the bottom of the drywell at a depth of 125 ft. Two additional tank T-101 drywells (50-01-06, 50-01-09) also show zones of elevated gamma contamination.

Gamma readings from drywell 50-03-04 on the southeast side of tank T-103 indicate the presence of a small zone of cesium-137 contamination (1 to 10 pCi/g) at a depth of 20 ft, along with the presence of cobalt-60, europium isotopes, and other gamma-producing contaminants. Other nearby drywells (50-03-05, 50-02-08, 50-02-09) show similar gamma contamination profiles to those detected in drywell 50-03-04. Interpreted historical gamma data from drywell 50-02-09 indicate migration of ruthenium-106, antimony-125, and europium isotopes at 32 to 48 ft from 1976 through 1985 (Wood et al. 2001).

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



The largest grouping of WMA T drywells containing elevated gamma contamination is in the vicinity of tank T-106. The presence of extensive vadose zone contamination in this area is consistent with a 1973 supernate leak from tank T-106 that is the largest (115,000 gal) and most thoroughly documented SST leak in Hanford Site history. The first extensive study of the tank T-106 leak was done shortly after it occurred (ARHCO 1973), and a followup study was completed in 1978 (Routson et al. 1979). In 1994, to provide greater understanding of the nature and extent of vadose contamination, an extensive sampling and analysis program was completed on soil samples taken from a borehole near the center of the tank T-106 leak (Freeman-Pollard et al. 1994). A synthesis of available vadose zone contamination data related to the tank T-106 leak is provided in Wood et al. (2001). These data along with additional data from two soil characterization boreholes installed around tank T-106 during WMA T field characterization efforts was analyzed in depth in Myers (2005).

A large number of drywells contain contamination from the tank T-106 leak because of the large extent of the leak and the high density of drywells constructed to quantify the soil column contamination caused by this leak. Historical gross gamma and spectral gamma data collected in these wells provide the most complete characterization data set of any tank farm leak on the Hanford Site. The gamma data reveal zones of different gamma signatures with increasing distance from the leak source, indicating that extensive lateral as well as vertical spreading of the leak occurred (Wood et al. 2001).

The location of the tank T-106 leak appears to be on the southeast part of the tank wall near the bottom of the tank (Wood et al. 2001). Two drywells adjacent to tank T-106 in this area (50-06-05 and 50-06-17) have zones of very high cesium-137 concentration (10^8 pCi/g) beginning near the tank bottom at 35 ft and extending to a depth of about 100 ft. Cesium-137 concentrations decrease with increasing distance from the inferred source. At the outer margins of the inferred leak area, no cesium-137 is detected. Gamma ray activity in drywells located at the outer margins of the leak is primarily from cobalt-60, which frequently extends to the drywell bottoms (Wood et al. 2001).

Interpretation of the historical gamma data collected from 1975 through 1994 indicates ruthenium-106 and cobalt-60 migration in most of the drywells that intercepted the tank T-106 leak plume (Wood et al. 2001). Downward migration of ruthenium-106 and cobalt-60 at drywells 50-00-09 and 50-09-10 appears to have occurred near the tank bottom around 1980 and again at greater depths (about 60 to 100 ft) in the late 1980s. Cesium-137 migration is indicated in the leak location area in the late 1970s.

Spectral gamma logging data also indicate the presence of generalized near-surface contamination across WMA T. The contamination is typically 1 to 10 pCi/g or less and is largely constrained to the first 10 ft of the soil column (Wood et al. 2001). The contamination is related to minor releases of contaminated fluids during tank farm operations that made relatively insignificant contributions to vadose zone contamination.

2.7.6 Unconfined Aquifer Conditions

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

2.7.6.1 Monitoring and Characterization

A detection level RCRA groundwater monitoring program for WMA T was initiated in 1989, and the WMA was placed into assessment status in 1993 because specific conductance limits were exceeded in downgradient monitoring well 299-W10-15 (Caggiano and Chou 1993). Specific conductance values in well 299-W10-15 dropped below the critical mean in 1994; however, before the WMA could be returned to a detection level monitoring program, specific conductance in well 299-W11-27 started a rapid increase in late 1995 and exceeded the critical mean in early 1996. Accordingly, WMA T continues to be monitored under a groundwater quality assessment program.

The increased specific conductance in well 299-W11-27 was accompanied by elevated technetium-99, tritium, nitrate, calcium, magnesium, sulfate, chromium, cobalt-60, and total organic carbon. Results of the initial groundwater quality assessment at WMA T found evidence linking the contaminants in groundwater to the WMA (Hodges 1998). The groundwater monitoring plan governing activities at WMA T is contained in Hodges and Chou (2001a) and its revision (Hodges and Chou 2002). RCRA groundwater assessment monitoring results are included in quarterly reports to Ecology and annually, as required, in the groundwater monitoring annual reports. 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.

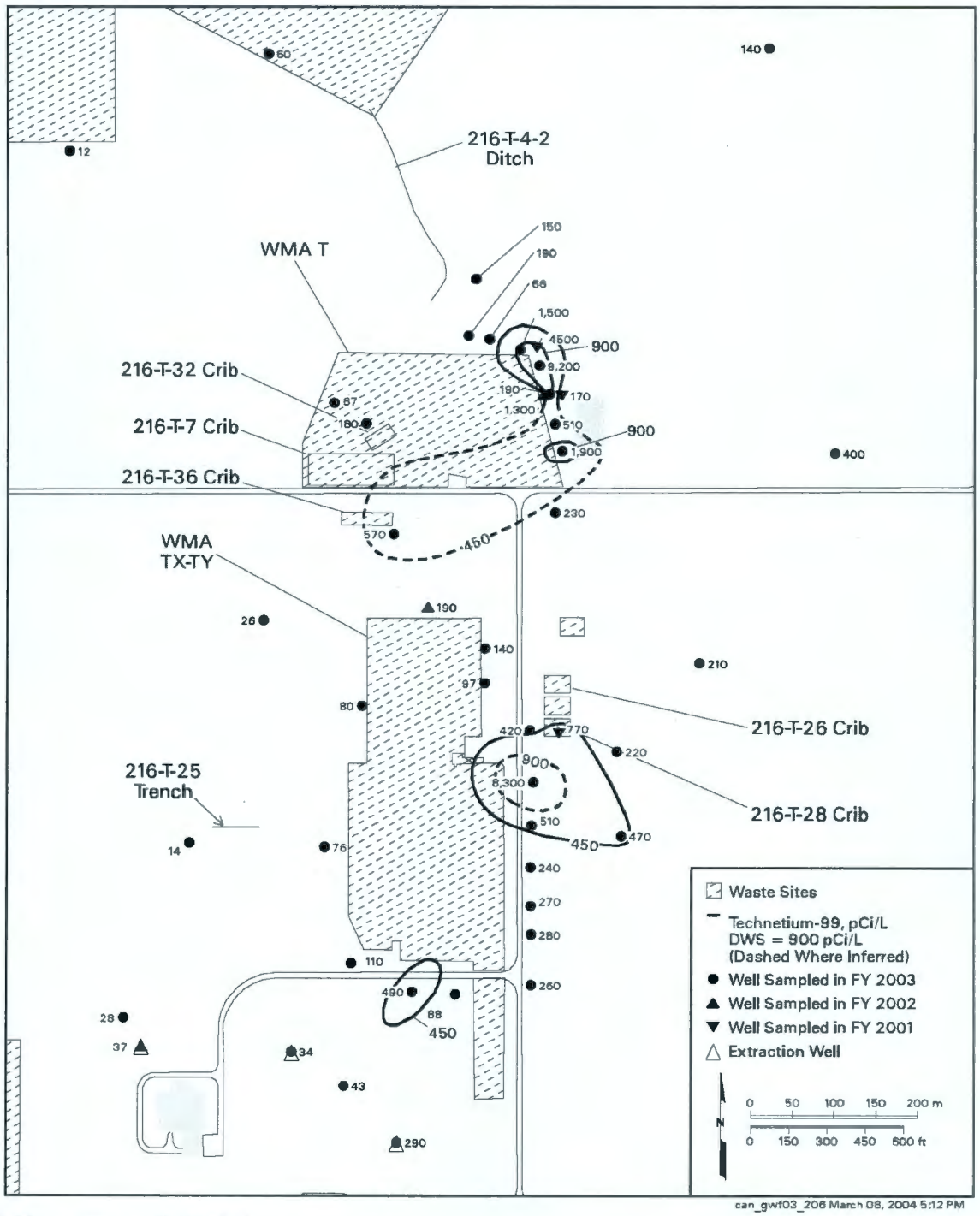
2.7.6.2 Contamination

Groundwater beneath WMA T is contaminated with technetium-99, carbon tetrachloride, trichloroethene, chromium, nitrate, and fluoride (Hartman et al. 2004). Horton et al. (2002) also lists concentrations of gross beta, tritium, and manganese as exceeding the respective MCLs in the groundwater around WMA T. Hartman et al. (2004) provides data for fiscal year 2003 and states that WMA T does not appear to be the source of most of the contamination, except for technetium-99 (and by inference gross beta), in the uppermost aquifer. Carbon tetrachloride and trichloroethene contamination is attributed to Plutonium Finishing Plant operations. Nitrate contamination also is attributed to Plutonium Finishing Plant operations as well as past-practice disposal to cribs and trenches near WMA T. Chromium, fluoride, and tritium contamination is attributed to cribs and trenches upgradient of WMA T. The elevated manganese concentrations are believed to be a consequence of reducing conditions around the monitoring wells. The exceptionally high concentration measured at well 299-W11-24 is believed to have been caused by the very fine particulates in the mud at the bottom of well, which had less than 1 m of water in the well when the sample was taken.

Since late 2000 and early 2001, technetium-99 concentrations in the area have increased substantially. During fiscal year 2003, the highest technetium-99 concentration in those wells was 2,600 pCi/L in well 299-W11-41 (Hartman et al. 2004). Apparently, technetium-99 is migrating toward the south along the east edge of WMA T from the northeast corner of the

WMA (Figure 2-49). This migration is coincident with a shift in groundwater flow direction from northeastward before 1996 to 1997 to eastward or slightly southeastward after 1997 (Hartman et al. 2004). Technetium-99 is also increasing upgradient of WMA T, with corresponding increases in chromium and nitrate, near the 216-T-36 crib, but this increase is attributed to the 216-T-5, 216-T-7, or 216-T-36 cribs.

Figure 2-49. Technetium-99 Distribution in Groundwater at Waste Management Area T [a]



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

2.7.7 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 T includes three source terms consisting of past UPRs, residual SST waste, and residual ancillary equipment waste. Table 2-11 provides a listing of the reference case source terms for WMA T, and the inventory data source for that source term.

Source term inventories (reference case) for WMA T are provided in Table 2-12. 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.

2.7.7.1 Past Unplanned Releases

The WMA T reference case includes six past UPRs associated with SSTs (T-101, T-103, T-106, T-108, T-109, T-111). Volume estimates for those six 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 T-107 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.

2.7.7.2 Residual Single-Shell Tank Waste

The WMA T reference case includes residual waste in each of the twelve 100-Series and four 200-Series SSTs in the T tank farm. 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 included 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).

2.7.7.3 Residual Ancillary Equipment Waste

Lambert (2005) identified no plugged and blocked piping in the T tank farm. The reference case ancillary equipment source term for WMA T therefore included one ancillary component, the 241-T-301B catch tank (Section 2.5.4). The estimated volume of residual waste in that 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 for the tank were estimated using the average chemical composition of the waste in WMA T SSTs.

Table 2-11. Reference Case Analysis of Waste Management Area T (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-T-101	Mobile retrieval system	360 ft^3	10,000	HTWOS	Corbin et al. 2005
241-T-102	Sluicing	360 ft^3	None	HTWOS	None
241-T-103	Mobile retrieval system	360 ft^3	3,000	HTWOS	Corbin et al. 2005
241-T-104	Sluicing	360 ft^3	None	HTWOS	None
241-T-105	Sluicing	360 ft^3	None	HTWOS	None
241-T-106	Mobile retrieval system	360 ft^3	115,000	HTWOS	Corbin et al. 2005
241-T-107 [c]	Mobile retrieval system	360 ft^3	NSI [c]	HTWOS	None
241-T-108	Mobile retrieval system	360 ft^3	1,000	HTWOS	Corbin et al. 2005
241-T-109	Mobile retrieval system	360 ft^3	1,000	HTWOS	Corbin et al. 2005
241-T-110	Sluicing	360 ft^3	None	HTWOS	None
241-T-111	Mobile retrieval system	360 ft^3	1,000	HTWOS	Corbin et al. 2005
241-T-112	Sluicing	360 ft^3	None	HTWOS	None
241-T-201	Vacuum	30 ft^3	None	HTWOS	None
241-T-202	Vacuum	30 ft^3	None	HTWOS	None
241-T-203	Vacuum	30 ft^3	None	HTWOS	None
241-T-204	Vacuum	30 ft^3	None	HTWOS	Corbin et al. 2005

Table 2-11. Reference Case Analysis of Waste Management Area T (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-T-301B catch tank [d]	TBD [d]	19.6 ft^3	None	Average	None
241-T tank farm pipelines [e]	TBD	0	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 T-107 is identified as a "confirmed or suspected" leaker in Hanlon (2005) but both Hanlon (2005) and 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 2-12. Reference Case Inventory Estimates for Waste Management Area T

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]	1.15E+00	3.90E+01	2.60E-02	5.36E+02	3.37E+04	1.53E+04	1.34E+01	6.17E+03	3.90E+01	5.02E-01	1.27E+04	2.22E+00	5.11E-01	7.98E+00
Tank residuals	3.63E-02	1.49E+00	4.20E-04	2.46E+02	4.96E+03	8.30E+02	1.02E+03	4.33E+03	1.49E+00	1.24E-02	8.13E+02	4.19E+01	5.63E+00	9.37E+00
Ancillary equipment residuals [c]	1.60E-04	6.58E-03	1.85E-06	1.08E+00	2.19E+01	3.67E+00	4.52E+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).

2.8 DESCRIPTION OF WASTE MANAGEMENT AREA TX-TY

This section provides site-specific information for WMA TX-TY. It is a summary from numerous documents that describe present conditions (Hanlon 2005), geology and hydrology (Reidel et al. 2006), subsurface contamination (Wood et al. 2001), and source terms (Kirkbride et al. 2005; Field and Jones 2005; Lambert 2005; Corbin et al. 2005).

2.8.1 Background

WMA TX-TY is located in the north-central portion of the 200 West Area (Figure 2-50) and encompasses the TX and TY tank farms. The TY tank farm is located adjacent to the northern boundary of the TX tank farm and is separated by the T Evaporator along their eastern fenceline. In general, the WMA TX-TY boundary is represented by the north fenceline of the TY tank farm on the north, roughly following the eastern fenceline of each tank farm on the east, the south fenceline of the TX tank farm on the south, and roughly following the western fenceline of each tank farm on the west.

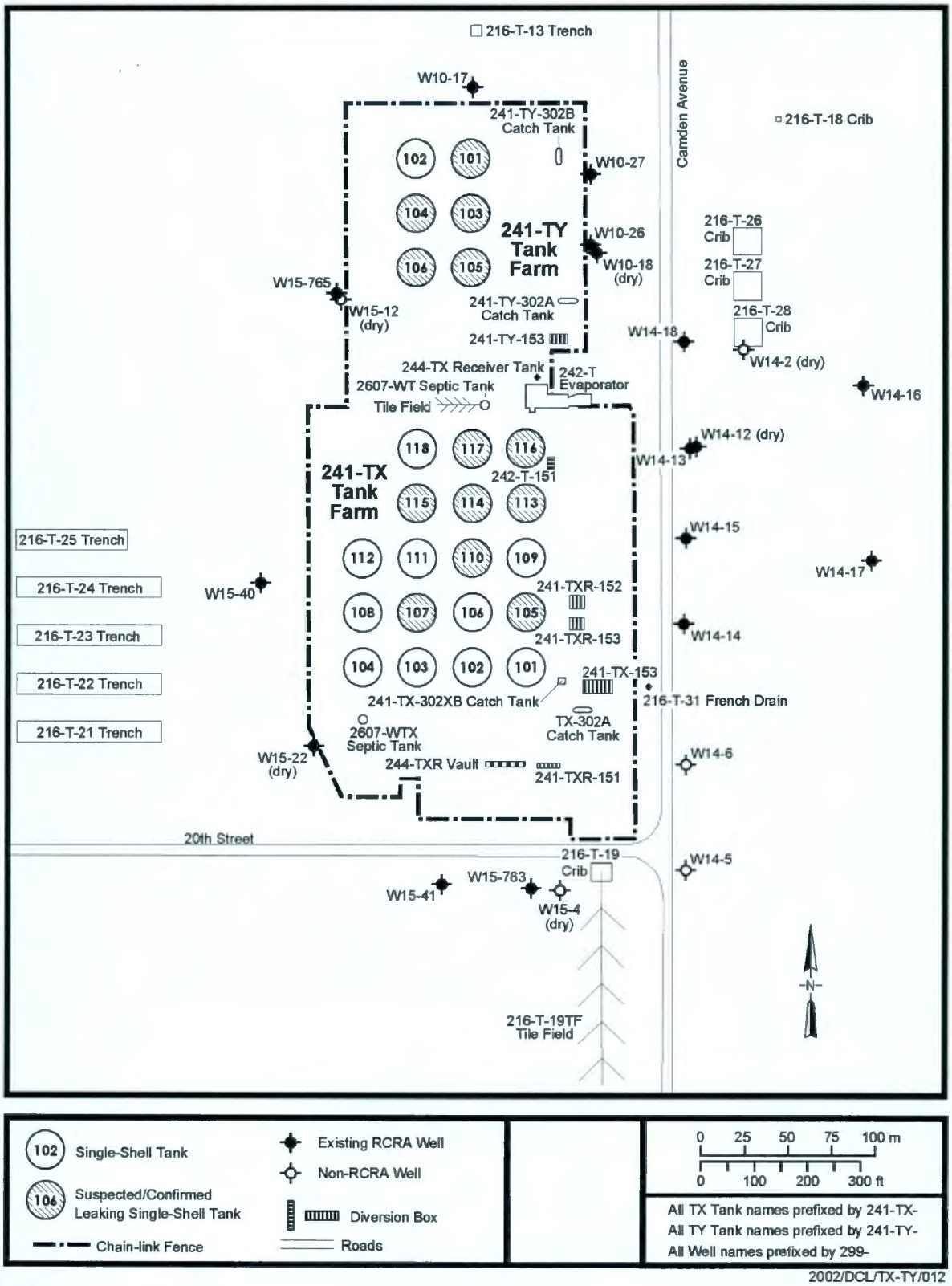
The TX tank farm consists of eighteen 100-Series SSTs constructed between 1947 and 1949. The tanks are arranged in three rows of four and two rows of three tanks. The farm was originally built to provide supplemental tank space for the bismuth phosphate process (Wood et al. 2001). The TX farm received waste beginning in August 1949. Later, the TX tank farm was used as part of the uranium recovery process.

The TY tank farm contains six 100-Series SSTs constructed between 1951 and 1952. The tanks are arranged in three rows of two tanks each with cascade lines providing overflow. The TY tank farm was built to provide supplemental tank space for the uranium recovery process (Wood et al. 2001). The farm first received waste in the second quarter of 1953. Currently, the pumpable liquid wastes have been removed from the tanks in WMA TX-TY and all tanks have been interim stabilized (Hanlon 2005). Table 2-13 lists the estimated volume of waste stored in the WMA TX-TY tanks as of November 30, 2004.

The current understanding of contaminant occurrences and environmental conditions at WMA TX-TY is described in Wood et al. (2001). Detailed discussion of TX and TY tank farm construction and historical information on soil surface and vadose zone contamination in WMA TX-TY is provided in Williams (2000).

Vadose zone field characterization activities were initiated at WMA TX-TY during fiscal year 2003 in support of RCRA Corrective Action process requirements. The investigative approach for this work is described in Crumpler (2001). Myers (2005) documents the results of these investigations.

Figure 2-50. Location Map of TX and TY Tank Farms and Surrounding Facilities [a]



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

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

Tank	Total Waste gal × 1,000	Supernate gal × 1,000	Sludge gal × 1,000	Saltcake gal × 1,000
TX Tank Farm				
241-TX-101	91	0	74	17
241-TX-102	217	0	2	215
241-TX-103	145	0	0	145
241-TX-104	69	2	34	33
241-TX-105	576	0	8	568
241-TX-106	348	0	5	343
241-TX-107	29	0	0	29
241-TX-108	127	0	6	121
241-TX-109	363	0	363	0
241-TX-110	467	0	37	430
241-TX-111	364	0	43	321
241-TX-112	634	0	0	634
241-TX-113	638	0	93	545
241-TX-114	532	0	4	528
241-TX-115	553	0	8	545
241-TX-116	599	0	66	533
241-TX-117	480	0	29	451
241-TX-118	247	0	0	247
TY Tank Farm				
241-TY-101	119	0	72	47
241-TY-102	69	0	0	69
241-TY-103	154	0	103	51
241-TY-104	44	1	43	0
241-TY-105	231	0	231	0
241-TY-106	16	0	16	0

[a] Hanlon (2005).

2.8.2 Infrastructure

This section describes the WMA TX-TY infrastructure components that were included in the SST PA. Those components are listed in Table 2-14. Reference case inventory development for those components is described in Section 2.8.7. Refer to Section 2.4 for generic infrastructure component descriptions and Section 2.5 for a summary of infrastructure inventory development methods.

Table 2-14. Operating Period and Capacities for Waste Management Area TX-TY Facilities Included in the Performance Assessment [a] (2 pages)

Facility	Removed From Service	Constructed	Operating Capacity gal
Single-Shell Tanks			
241-TX-101	1980	1947 to 1948	758,000
241-TX-102	1977		
241-TX-103	1980		
241-TX-104	1977		
241-TX-105	1977		
241-TX-106	1977		
241-TX-107	1977		
241-TX-108	1977		
241-TX-109	1977		
241-TX-110	1977		
241-TX-111	1977		
241-TX-112	1974		
241-TX-113	1971		
241-TX-114	1971		
241-TX-115	1977		
241-TX-116	1969		
241-TX-117	1969		
241-TX-118	1980		
241-TY-101	1973	1949 to 1952	758,000
241-TY-102	1979		
241-TY-103	1973		
241-TY-104	1974		
241-TY-105	1980		
241-TY-106	1959		
Miscellaneous Underground Storage Tanks			
241-TX-302A catch tank	1982	1949	17,700
241-TX-302XB catch tank	1985	1950	14,300
241-TY-302A catch tank	1981	1953	17,700
241-TY-302B catch tank	1981	1953	14,300

Table 2-14. Operating Period and Capacities for Waste Management Area TX-TY Facilities Included in the Performance Assessment [a] (2 pages)

Facility	Removed From Service	Constructed	Operating Capacity gal
241-TX DCRT	1981	Active	31,000
241-TXR-001 vault tank	1956 (244-TXR vault)	1951	50,000
241-TXR-002 vault tank		1951	15,000
241-TXR-003 vault tank		1951	15,000
Underground Waste Transfer Lines			
241-TX tank farm pipelines	NA	1947 to 1948	26,300 (+/-5,000)
241-TY tank farm pipelines	NA	1949 to 1952	1,700 (+/-1,000)

[a] Data on the facilities are from DOE-RL (2005) and Field (2003a).
DCRT = double-contained receiver tank
NA = not applicable

2.8.2.1 Single-Shell Tanks

The 100-Series tanks in the TX and TY tank farms are 75 ft in diameter and 32 ft tall. The TX and TY tanks have a 23-ft operating depth and an operating capacity of 758,000 gal. Typical tank configuration and dimensions are shown in Figure 2-51. The tanks sit belowgrade with at least 7 ft of soil cover to provide shielding from radiation exposure to operating personnel. Tank pits are located on top of the tanks and provide access to the tank, pumps, and monitoring equipment.

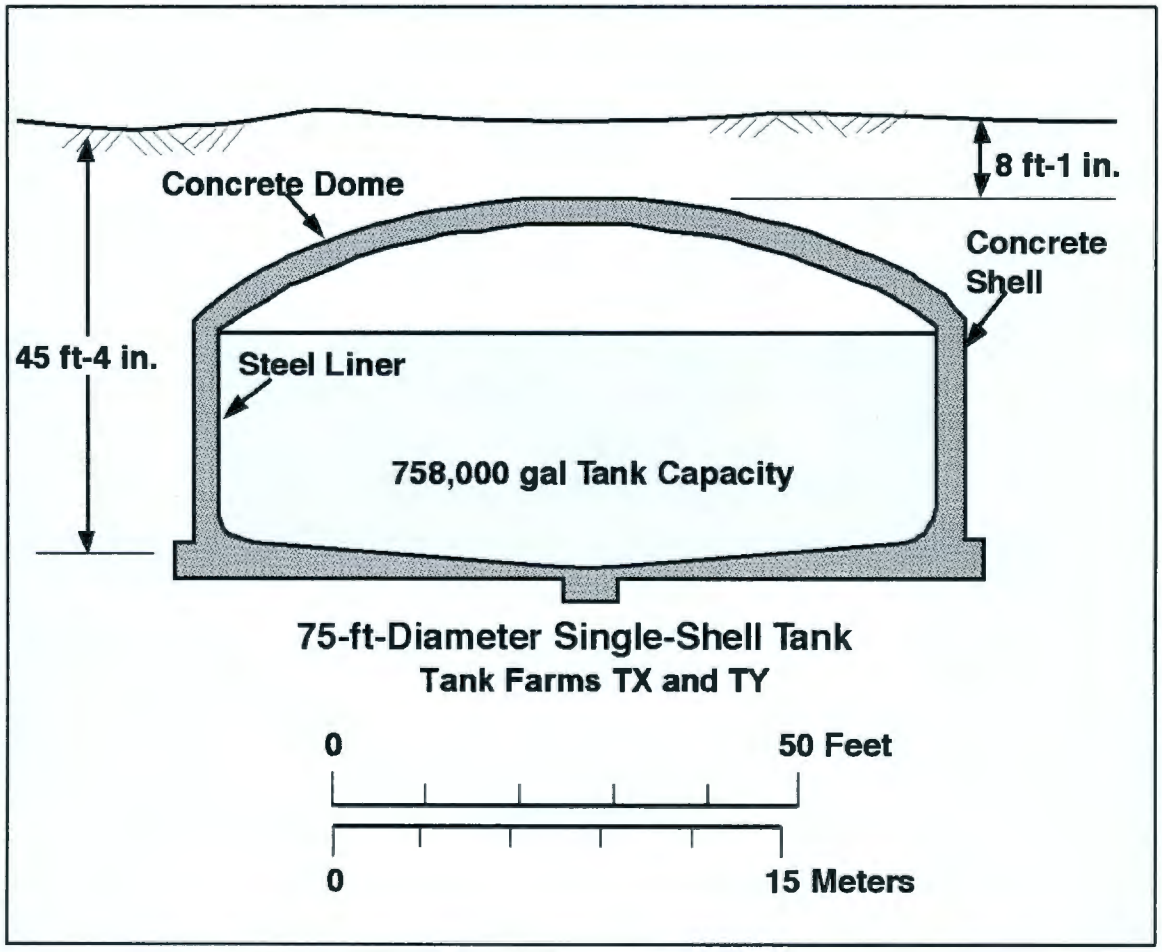
The TX farm tanks were constructed with cascade overflow lines in two 3-tank and three 4-tank series that allowed gravity flow of decanted liquid between tanks, while the TY farm tanks were constructed in three 2-tank cascade series (Wood et al. 2001).

2.8.2.2 Ancillary Equipment

A complete listing of the WMA TX-TY 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 consists of the underground waste transfer lines and MUSTs located inside each WMA boundary. For WMA TX-TY, the ancillary components analyzed consist of the TX and TY tank farms waste transfer piping and eight MUSTs. The MUSTs consist of four catch tanks (241-TX-302A, 241-TX-302XB, 241-TY-302A, 241-TY-302B), one double-contained receiver tank (244-TX DCRT), and three tanks in the 244-TXR vault (244-TXR-001, 244-TXR-002, 244-TXR-003).

Multiple levels of piping were installed over time in WMA TX-TY. A time line of piping installations is described in Williams (2000). It is estimated that there are approximately 13.6 mi (+/- 2.6 mi) of waste transfer piping in the TX tank farm and 0.9 mi (+/- 0.5 mi) in the TY tank farm (Field 2003a).

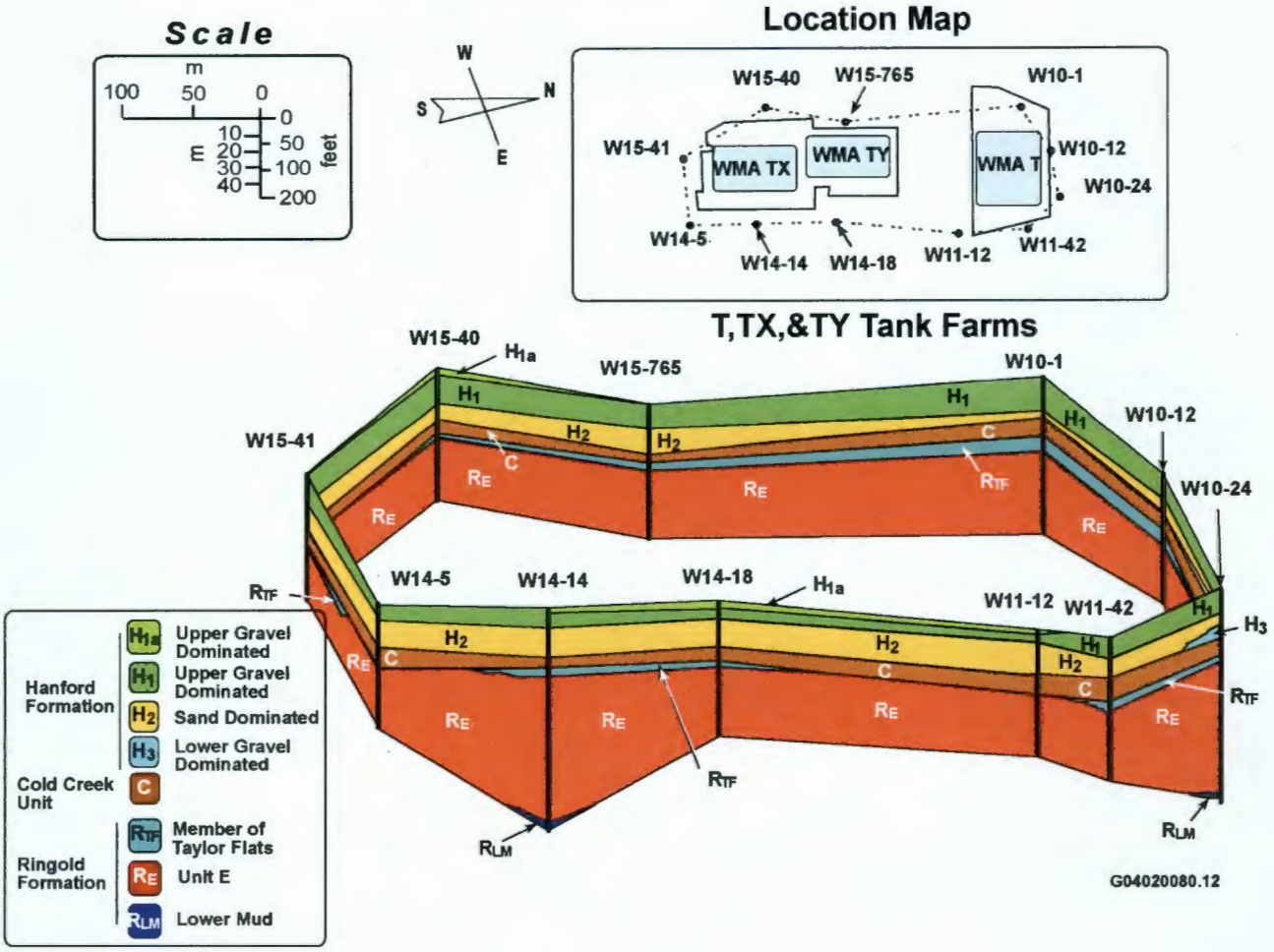
Figure 2-51. Typical Configuration and Dimensions of Single-Shell Tanks in Waste Management Areas T and TX-TY



2.8.3 Geology

Following is an overview of the geology of WMA TX-TY summarized from the information provided in Reidel et al. (2006). Because WMAs T and TX-TY are in close proximity and have similar geologic conditions, they are discussed together in Reidel et al. (2006) and will be discussed together here. A generalized cross-section through WMA TX-TY is shown in Figure 2-52. Maps and cross-sections presented in Reidel et al. (2006) illustrate the distribution and thicknesses of these units in additional detail.

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



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

A number of stratigraphic units lie within WMA TX-TY. From oldest to youngest, the primary geologic units are:

- Columbia River Basalt Group
- Ringold Formation (fine-grained and coarse-grained sequences)
- Cold Creek unit (calcic and silty sequences)
- Undifferentiated Hanford formation and Cold creek unit transition
- Hanford formation – sand sequence (H2 unit)
- Hanford formation – upper gravelly sequence (H1 unit)
- Recent deposits (wind deposited material and backfill material placed during construction).

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 TX-TY were emplaced within the Hanford formation sediments of the upper, gravel-dominated (H1) unit, and may locally intercept the upper portions of the sand-dominated Hanford (H2) unit. The water table or potentiometric surface lies approximately 60 m (200 ft) below the bottom of the tank farms excavations within the Ringold Formation unit E.

2.8.4 Hydrology

Following is an overview of the hydrology of the uppermost, unconfined aquifer beneath WMA TX-TY. 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), Wood et al. (2001), and Hartman et al. (2004). Currently, the general groundwater flow in the unconfined aquifer beneath WMA TX-TY varies across the WMA. In the southern part, flow is generally south to south-southwest. While in the northern part, the groundwater flow generally is between south and southeast. The water table is very flat overall, with an estimated hydraulic gradient of 0.001 throughout the WMA. The estimated groundwater flow velocity ranges from 0.0007 to 0.246 m/day in the northern section and around 0.29 m/day in the southern section (Reidel et al. 2006).

The shift in discharge of large volumes of wastewater to the T Pond in the late 1940s and early 1950s raised the water table in the vicinity of WMA TX-TY as much as 49 ft above the pre-Hanford Site operations level (Reidel et al. 2006). Water levels began to decline in the late 1980s when wastewater discharges were reduced. The decline has become even more pronounced since other effluent discharges throughout the 200 Areas ceased in 1995.

Currently, the water table beneath WMA TX-TY lies at approximately 135 m (443 ft) amsl with about 230 ft of vadose zone (Hodges and Chou 2001b). The aquifer thickness, based on the top of basalt at 355 ft, varies from 164 to 190 ft. The aquifer materials consist dominantly of variably cemented and compacted, coarse sands and gravels of the Ringold Formation. Hydraulic conductivity values reported for the aquifer in this area vary considerably, ranging from 0.00073 to 0.00140 m/day. Additional hydraulic property data from aquifer testing at wells near WMA TX-TY is provided in Reidel et al. (2006) and Hartman et al. (2004).

2.8.5 Vadose Zone Conditions

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

2.8.5.1 Monitoring and Characterization

The TX tank farm has 96 leak detection drywells available for leak detection monitoring and to provide access for limited vadose zone characterization (e.g., geophysical logging). These drywells were drilled from 1947 to 1977. The depth ranges for these drywells are between 75 and 150 ft bgs. The TX tank farm layout showing drywell locations in reference to tanks is shown in Figure 2-53.

The TY tank farm has 70 leak detection wells available for leak detection monitoring and to provide access for limited vadose zone characterization (e.g., geophysical logging). These drywells were drilled from 1951 to 1977. The depth ranges for these drywells are between 100 and 150 ft bgs. The TY tank farm layout showing drywell locations in reference to tanks is shown in Figure 2-54.

Limitations of estimates on the extent of contamination include the following:

- No data are available from directly under the tanks.
- No data are available below the survey depth. The maximum logged depth in TX farm is 150 ft in drywell 51-00-03. The maximum logged depth in TY farm is 235 ft bgs in drywell 52-06-07.
- Gamma logging only provides information for contamination within 12 to 18 in. of the drywell being evaluated.
- Data may be made inaccurate due to uncertainties associated with distinguishing contamination on the well casings or surrounding soils.

Additional information on manmade radionuclide and chemical distribution and movement is discussed in the FIR resulting from WMAs T and TX-TY Phase I field investigation (Myers 2005). Collection of field characterization data to support the FIR was conducted in fiscal years 2002 and 2003 (Crumpler 2001).

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

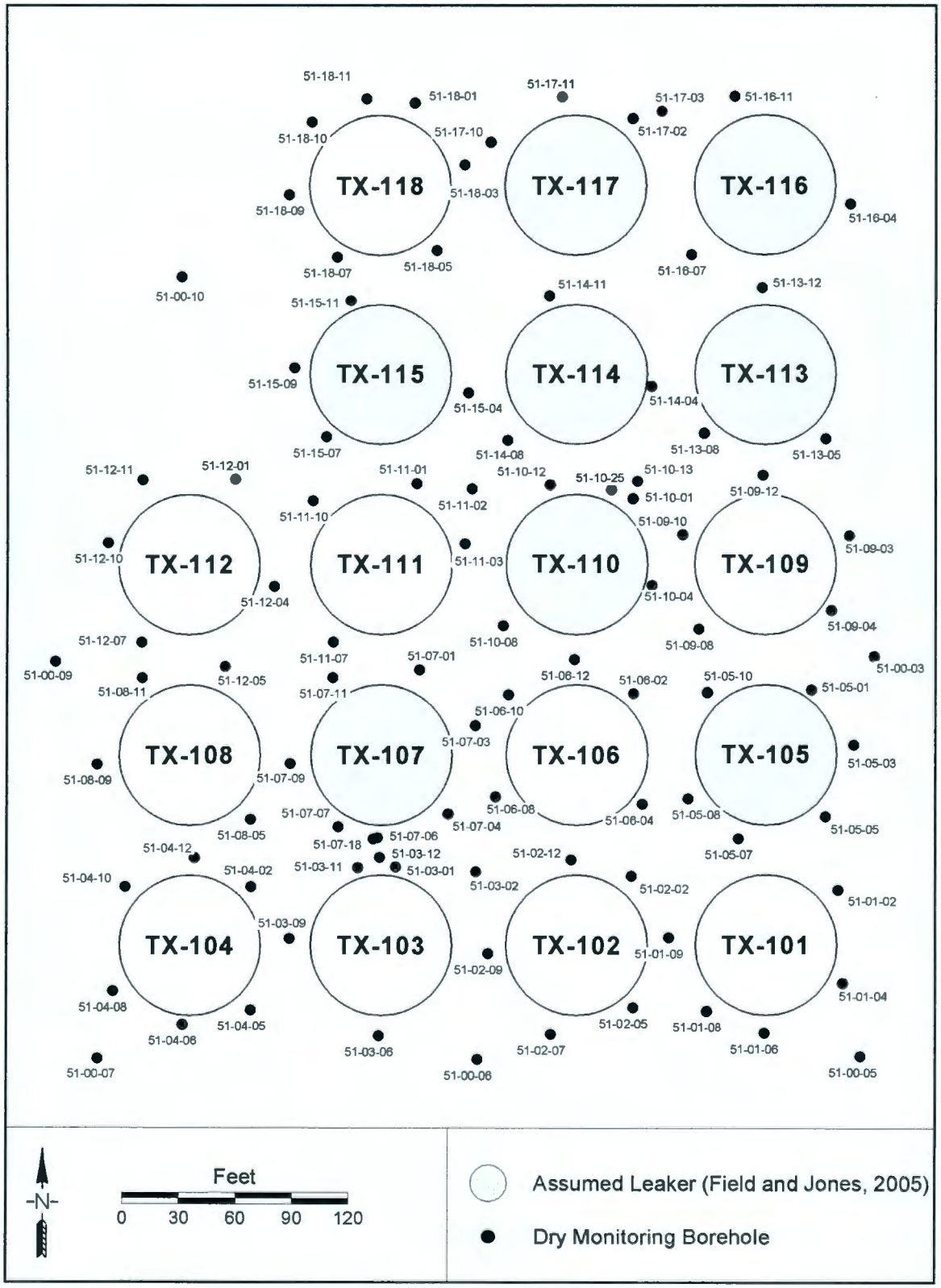
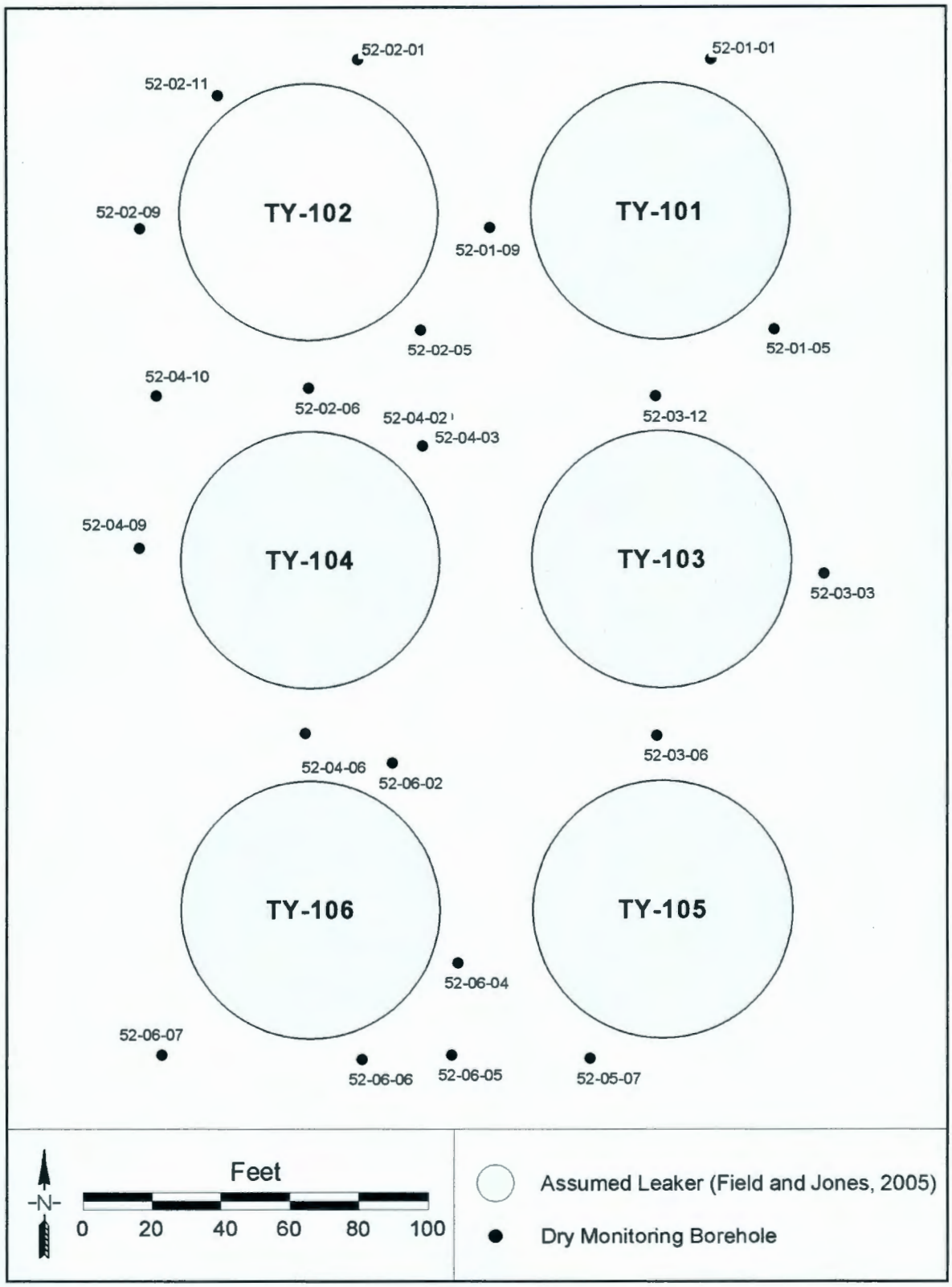


Figure 2-54. Vadose Zone Monitoring Network for TY Tank Farm in Waste Management Area TX-TY



2.8.5.2 Contamination

Figures 2-55 and 2-56 provide a visualization of the vadose zone contamination beneath WMA TX-TY as represented by cesium-137 data. These figures show a three-dimensional perspective of the two tank farms providing locations of tanks and associated drywells. Tanks considered to be assumed leakers 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. Zones with contamination levels less than 5 pCi/g are not shown.

Gamma logging took place in WMA TX-TY over two decades allowing evaluation of the time-dependent behavior of the gamma-emitting radionuclides. Between 1997 and 1999, spectral gamma logging was used to evaluate WMA TX-TY. This effort was part of the baseline characterization for WMA TX-TY. Results are documented in DOE-GJO (1997a, 1998b, 2000d, 2000e).

The primary areas of elevated gamma readings for the TX tank farm occur in the drywells located around tanks (TX-105, TX-107, TX-110, TX-113, TX-114, TX-115, TX-116, TX-117, TY-101, TY-103, TY-104, TY-105, TY-106). The presence of contamination in these areas has provided or supported the determinations of postulated leaks based on the WMA TX-TY historical record (Wood et al. 2001). The major gamma-emitting contaminants associated with WMA TX-TY are cesium-137, cobalt-60, antimony-125, and uranium-235/238.

As there are two decades of temporal distribution of gamma activity data available, it is possible to evaluate any changes in estimated distributions. Fifteen drywells in TX tank farm and five drywells in TY tank farm show "instability," changes over the duration of the monitoring activity (Wood et al. 2001). It is believed that the areas of instability in the TX tank farm are associated with the postulated leak from TX-107 and the postulated leaks from TX-110, TX-114, and TX-113 (Wood et al. 2001). The areas of instability for TY tank farm are associated with the postulated leaks from TY-105 and TY-106. The highest observed isolated readings are seen in drywells 52-03-03 (associated with tank TY-103) and 52-14-04 (associated with tank TX-114) (Wood et al. 2001).

The drywells associated with the postulated TX-107 leak (51-03-01, 51-03-11, 51-03-12, 51-03-18, 51-07-07, 51-07-09, 51-04-05) demonstrate a commonality of data beginning in 1975. This data indicates that cobalt-60 is the primary gamma emitter from 45 to 70 ft with europium-154 also present from 50 to 60 ft in all but two drywells. Evaluation of the historic data shows a migration of cobalt-60 contamination from northeast to southwest between 1977 and 1992 (Wood et al. 2001).

The drywells associated with the postulated TX-110, TX-114, and TX-113 leaks (51-10-01, 51-10-13, 51-10-25, and 51-14-04) contain readings of cesium-137 at the tank bottom depth. TX-114 is believed to be the most likely to have leaked (Wood et al. 2001). Historical data also shows a ruthenium-106 migration between 1978 and 1985.

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

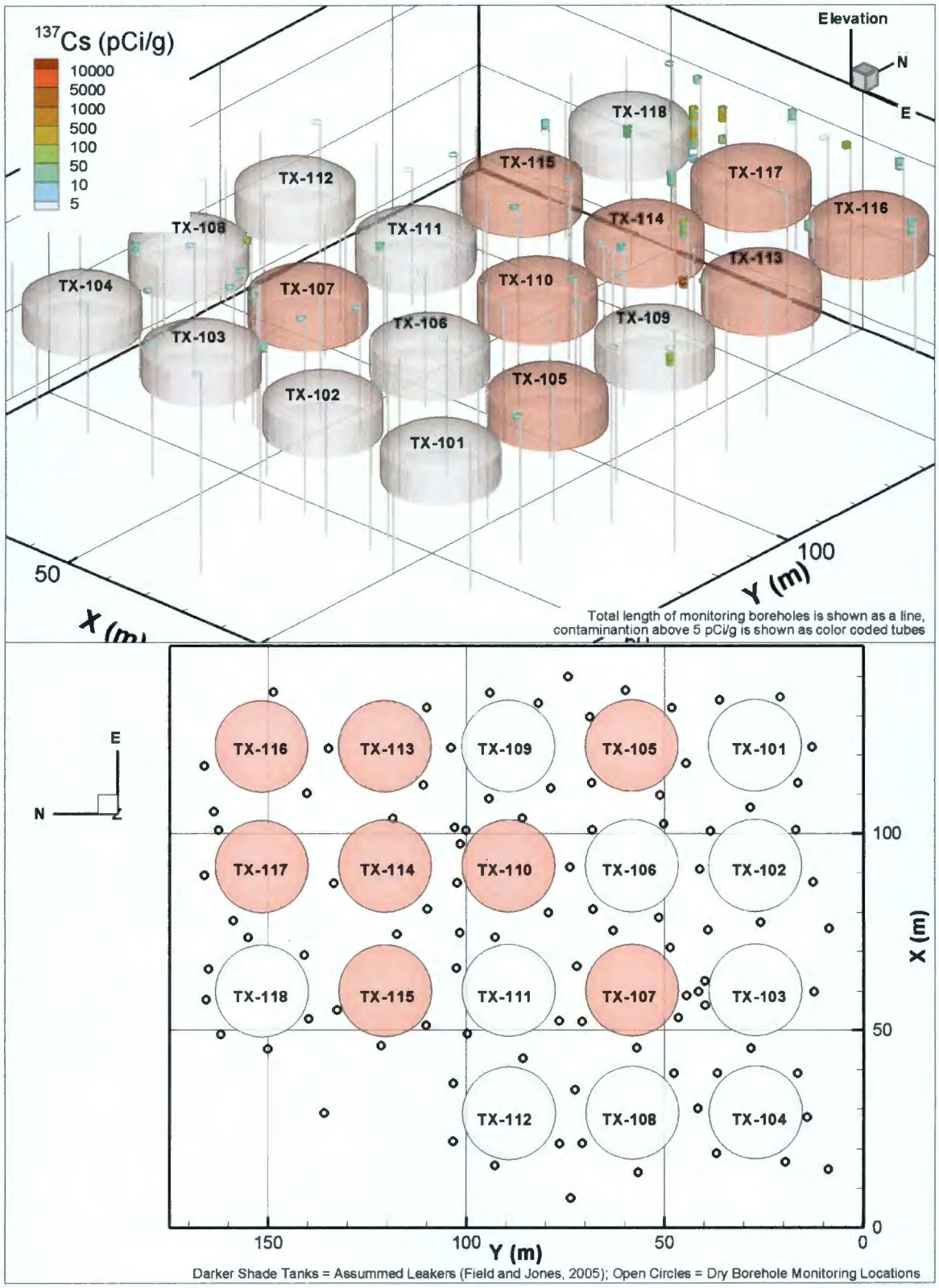
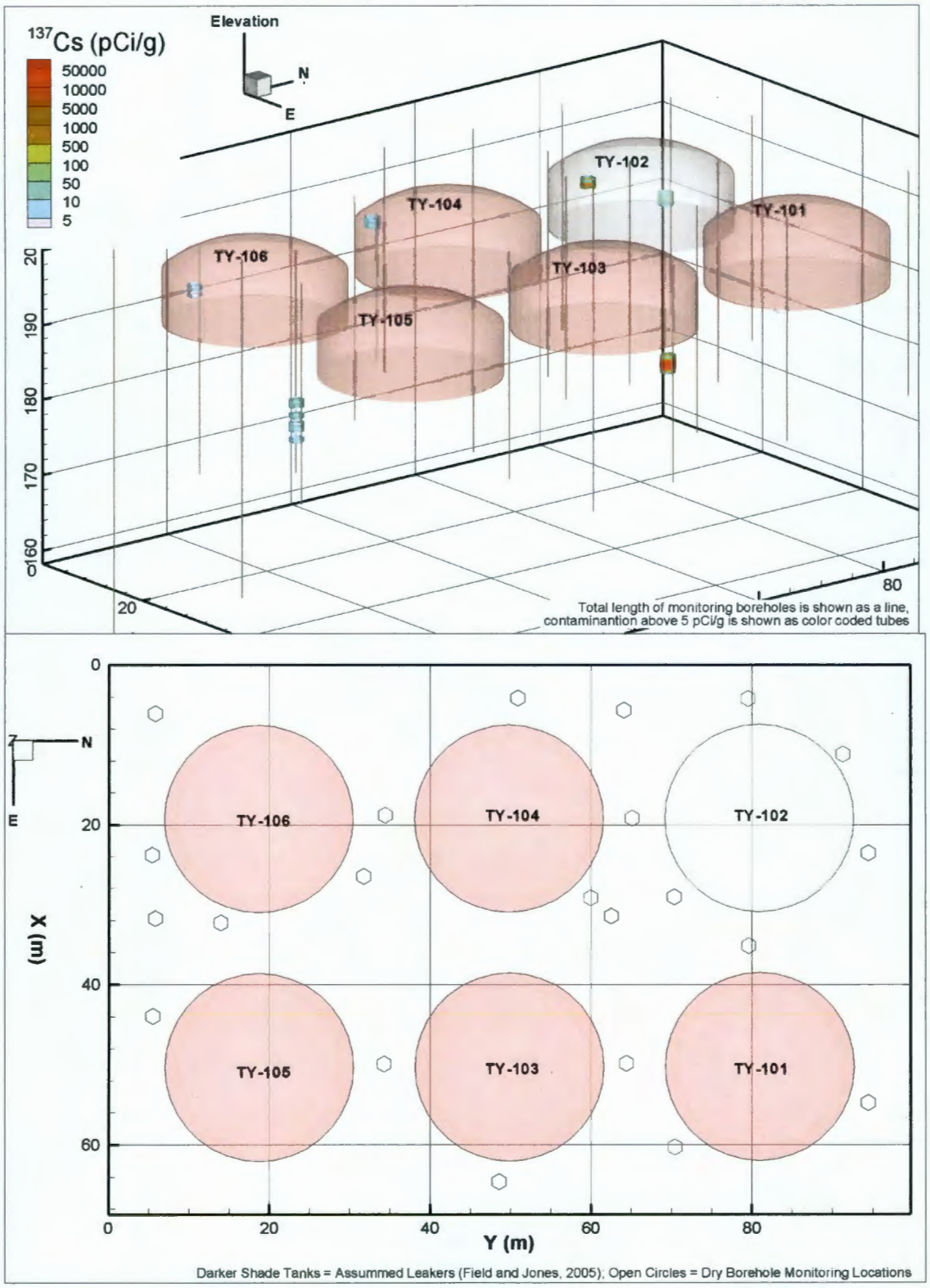


Figure 2-56. Three-Dimensional Perspective of TX Tank Farm Tanks and Drywells Showing Occurrence of Significant (>5 pCi/g) Cesium-137 Contamination in the Vadose Zone



Even though it is believed that tanks TY-101, TY-103, and TY-104 did not leak or leaked a very small amount (Wood et al. 2001), there has been observed gamma activity surrounding the tanks. For the potential leak from tank TY-101, elevated gross gamma readings were observed in 1973 at 53 ft in drywell 52-01-09 and at 44 ft in drywell 52-01-05, as well as an observed elevated reading in 1978 at approximately the same depth in drywell 52-01-05. For the potential leak from TY-103, elevated readings in drywell 52-03-06 in 1974 were used as an indicator. Current readings indicate a small amount of cesium-137 and cobalt-60 approximately 50 ft from the bottom of the well. A small zone of elevated cesium-137 is currently observed between 45 and 50 ft. Tanks TY-102 and TY-106 have indications of leaks with no drywell data to support these conjectures (Wood et al. 2001).

Drywells associated with TY-105 (52-03-06, 52-05-07, 52-06-06) support the conclusion that the tank did leak. Drywell 52-03-06 is described above. Drywell 52-05-07 shows a zone of 1 to 30 pCi/g of cesium-137 between 50 and 90 ft, and 1 to 10 pCi/g of cobalt-60 between 50 and 98 ft. Drywell 52-06-06 also shows elevated levels of cesium-137 and cobalt-60 between 50 and 150 ft (Wood et al. 2001).

Spectral gamma logging data also indicate the presence of generalized near-surface contamination across WMA TX-TY. The contamination readings are commonly 10 to 100 pCi/g (Wood et al. 2001) across the TX tank farm, with lower levels typically between 1 and 10 pCi/g found in TY tank farm.

2.8.6 Unconfined Aquifer Conditions

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

2.8.6.1 Monitoring and Characterization

Nine RCRA groundwater monitoring wells associated with WMA TX-TY are located outside the WMA TX-TY boundary (Figure 2-50). The wells are intended to monitor groundwater contamination attributable to the entire WMA rather than individual components. The initial background-monitoring program for WMA TX-TY is complete and monitoring is currently conducted under an interim status assessment program.

The contaminant assessment and the statistical evaluation methodology for the WMA TX-TY groundwater assessment program are described in Hodges and Chou (2001b) and updated in Horton (2002). The assessment plan was last modified in 2001. Results of the groundwater assessment program are published annually. Monitoring under the assessment will continue until the entire WMA is closed. Two new wells were installed in fiscal year 2003 to improve the capability of the detection network to monitor the site.

A detection level RCRA groundwater monitoring program for WMA TX-TY was initiated in 1989, and the WMA was placed into assessment status in 1993 because specific conductance limits were exceeded in downgradient monitoring wells 299-W10-17 and 299-W14-12 (Hodges and Chou 2001b). Hodges (1998) concluded that the contaminants observed in the groundwater were consistent with a source within the WMA, but that an upgradient source (the 216-T-25 trench) is possible. However, without direct evidence for an upgradient source,

the default conclusion is that observed contamination from well 200-W14-12 is derived from within the WMA. Accordingly, WMA TX-TY continues to be monitored under an interim status assessment program.

The increased specific conductance in well 299-W14-12 was accompanied by elevated technetium-99, iodine-129, tritium, nitrate, calcium, magnesium, sulfate, and chromium. Technetium-99, chromium, iodine-129, and tritium are the principal contaminants (Hodges and Chou 2001b). RCRA groundwater assessment monitoring results are included in quarterly reports to Ecology and annually, as required, in the groundwater monitoring annual reports. 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.

2.8.6.2 Contamination

The most recently published groundwater monitoring results for WMA TX-TY are for fiscal year 2003 in Hartman et al. (2004). Following is a summary of the fiscal year 2003 results adapted from Hartman et al. (2004). Additional detail on groundwater contamination and geochemistry at WMA TX-TY can be found in Hartman et al. (2004) and Reidel et al. (2006).

A number of contaminants were detected at or above their respective DWS levels in 2003. Elevated nitrate on the east side of WMA TX-TY is correlated with elevated chromium, tritium, iodine-129, and technetium-99. While the nitrate contamination is interpreted as being from a nearby source and not WMA TX-TY, the WMA appears to be the most likely source of the chromium, tritium, iodine-129, and technetium-99; however, the series of cribs (216-T-26 through 216-T-28) located east of the WMA is also a potential source for the contamination. A plume containing trichloroethene and carbon tetrachloride extends north to the vicinity of WMA TX-TY from the region of the Plutonium Finishing Plant, but the source is not associated with WMA TX-TY. Details regarding the measurements, levels found, and the wells showing contamination can be found in Hartman et al. (2004).

2.8.7 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 TX-TY includes three source terms consisting of past UPRs, residual SST waste, and residual ancillary equipment waste. Table 2-15 provides a listing of the reference case source terms for WMA TX-TY, and the inventory data source for that source term.

Source term inventories (reference case) for WMA TX-TY are provided in Table 2-16. 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.

2.8.7.1 Past Unplanned Releases

The WMA TX-TY reference case includes six past UPRs associated with SSTs (TX-107, TY-101, TY-103, TY-104, TY-105, TY-106) and two past UPRs associated with ancillary equipment (UPR-200-W-12, UPR-200-W-100). Volume estimates for those eight 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 events associated with tanks TX-105, TX-110, TX-113, TX-114, TX-115, TX-116, and TX-117 because of insufficient information to quantify or verify the releases (Field and Jones 2005). If new information becomes available to quantify the waste loss events from those tanks, the data will be evaluated under the integrated regulatory closure process described in Chapter 1.0.

2.8.7.2 Residual Single-Shell Tank Waste

The WMA TX-TY reference case includes residual waste in each of the 24 100-Series SSTs in the TX and TY 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).

2.8.7.3 Residual Ancillary Equipment Waste

The WMA TX-TY reference case includes the plugged and blocked piping in the TX and TY tank farms and the residual waste in eight MUSTs consisting of four catch tanks (241-TX-302A, 241-TX-302XB, 241-TY-302A, 241-TY-302B), one double-contained receiver tank (244-TX DCRT), and the three tanks in the 244-TXR vault (244-TXR-001, 244-TXR-002, 244-TXR-003) (Section 2.5.4). Volume and inventory estimates for the waste in the plugged and blocked piping (102 L in TX farm, none in TY farm) were developed by Lambert (2005). Volume estimates for the residual waste in the MUSTs was calculated by assuming each 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 TX-TY SSTs.

Table 2-15. Reference Case Analysis of Waste Management Area TX-TY (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-TX-101	Sluicing	360 ft^3	None	HTWOS	None
241-TX-102	Sluicing	360 ft^3	None	HTWOS	None
241-TX-103	Sluicing	360 ft^3	None	HTWOS	None
241-TX-104	Sluicing	360 ft^3	None	HTWOS	None
241-TX-105 [c]	Mobile retrieval system	360 ft^3	NSI [c]	HTWOS	None
241-TX-106	Sluicing	360 ft^3	None	HTWOS	None
241-TX-107	Mobile retrieval system	360 ft^3	8,000	HTWOS	Corbin et al. 2005
241-TX-108	Sluicing	360 ft^3	None	HTWOS	None
241-TX-109	Sluicing	360 ft^3	None	HTWOS	None
241-TX-110 [c]	Mobile retrieval system	360 ft^3	NSI [c]	HTWOS	None
241-TX-111	Sluicing	360 ft^3	None	HTWOS	None
241-TX-112	Sluicing	360 ft^3	None	HTWOS	None
241-TX-113 [c]	Mobile retrieval system	360 ft^3	NSI [c]	HTWOS	None
241-TX-114 [c]	Mobile retrieval system	360 ft^3	NSI [c]	HTWOS	None
241-TX-115 [c]	Mobile retrieval system	360 ft^3	NSI [c]	HTWOS	None
241-TX-116 [c]	Mobile retrieval system	360 ft^3	NSI [c]	HTWOS	None
241-TX-117 [c]	Mobile retrieval system	360 ft^3	NSI [c]	HTWOS	None
241-TX-118	Sluicing	360 ft^3	None	HTWOS	None
241-TY-101	Mobile retrieval system	360 ft^3	1,000	HTWOS	Corbin et al. 2005
241-TY-102	Sluicing	360 ft^3	None	HTWOS	None

Table 2-15. Reference Case Analysis of Waste Management Area TX-TY (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-TY-103	Mobile retrieval system	360 ft^3	3,000	HTWOS	Corbin et al. 2005
241-TY-104	Mobile retrieval system	360 ft^3	1,400	HTWOS	Corbin et al. 2005
241-TY-105	Mobile retrieval system	360 ft^3	35,000	HTWOS	Corbin et al. 2005
241-TY-106	Mobile retrieval system	360 ft^3	20,000	HTWOS	Corbin et al. 2005
UPR-200-W-12	NA	NA	5	NA	Corbin et al. 2005
UPR-200-W-100	NA	NA	2,540	NA	Corbin et al. 2005
241-TX-302A catch tank [d]	TBD [d]	10 ft^3	None	Average	None
241-TX-302XB catch tank [d]	TBD [d]	10 ft^3	None	Average	None
241-TY-302A catch tank [d]	TBD [d]	10 ft^3	None	Average	None
241-TY-302B catch tank [d]	TBD [d]	8 ft^3	None	Average	None
244-TX DCRT [d]	TBD [d]	17 ft^3	None	Average	None
244-TXR-001 vault tank [d]	TBD [d]	27 ft^3	None	Average	None
244-TXR-002 vault tank [d]	TBD [d]	8 ft^3	None	Average	None
244-TXR-003 vault tank [d]	TBD [d]	8 ft^3	None	Average	None
241-TX tank farm pipelines [e]	TBD	102 L	None	Lambert 2005	NA
241-TY 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. Tanks TX-105, TX-110, TX-113, TX-114, TX-115, TX-116, and TX-117 are 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 2-16. Reference Case Inventory Estimates for Waste Management Area TX-TY

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]	2.70E-01	7.24E+00	8.13E-03	1.66E+02	4.86E+04	5.26E+03	8.15E+00	6.29E+02	7.24E+00	8.94E-02	1.43E+04	8.45E-01	1.15E-01	6.47E-01
Tank residuals	2.33E-01	4.70E+01	3.76E-03	9.47E+02	1.87E+04	1.45E+03	3.68E+03	4.22E+04	4.70E+01	1.02E+00	2.29E+04	4.31E+02	8.87E+01	7.23E+02
Ancillary equipment residuals [c]	2.62E-03	4.64E-01	4.76E-05	9.90E+00	2.14E+02	2.33E+01	3.44E+01	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).

2.9 DESCRIPTION OF WASTE MANAGEMENT AREA U

This section provides site-specific information for WMA U. It is a summary from numerous documents that describe present conditions (Hanlon 2005), geology and hydrology (Reidel et al. 2006), subsurface contamination (Wood and Jones 2003), and source terms (Kirkbride et al. 2005; Field and Jones 2005; Lambert 2005; Corbin et al. 2005).

2.9.1 Background

WMA U is located in the central portion of 200 West Area of the Hanford Site (Figure 2-57). WMA U contains twelve 100-Series SSTs and four 200-Series SSTs that were constructed from 1943 through 1944, put into service in 1944, and used to store and transfer waste until 1980. Because of its long operational history, the U tank farm received waste generated by essentially all of the Hanford Site major chemical processing operations including bismuth phosphate fuel processing, uranium recovery, PUREX fuel processing, and fission product recovery (Wood and Jones 2003).

During its operational history, there were a number of confirmed or suspected waste loss events in WMA U. These included suspected tank leaks and known waste losses from diversion boxes, pipelines, and the 244-UR vault. In addition, uncontaminated and slightly contaminated water from facilities outside WMA U were discharged to several nearby ditches, particularly 216-U-14. Currently, the pumpable liquid wastes have been removed from the U farm tanks and all tanks have been interim stabilized (Hanlon 2005). Table 2-17 lists the estimated volume of waste stored in the WMA U tanks as of November 30, 2004.

The current understanding of contaminant occurrences and environmental conditions at WMA U is described in Wood and Jones (2003). The primary contamination zones currently identified in WMA U are a uranium-rich zone from metal waste at tank U-104 and a localized high cesium-137 activity zone near the bottom of tanks U-110 and U-112.

A draft FIR for WMA U is scheduled to be issued in fiscal year 2006. Field characterization data to support the WMA U FIR is scheduled to be collected in fiscal year 2005 as outlined in Crumpler (2004). Planned WMA U closure and post-closure actions identified at the present time are described in Lee (2004).

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

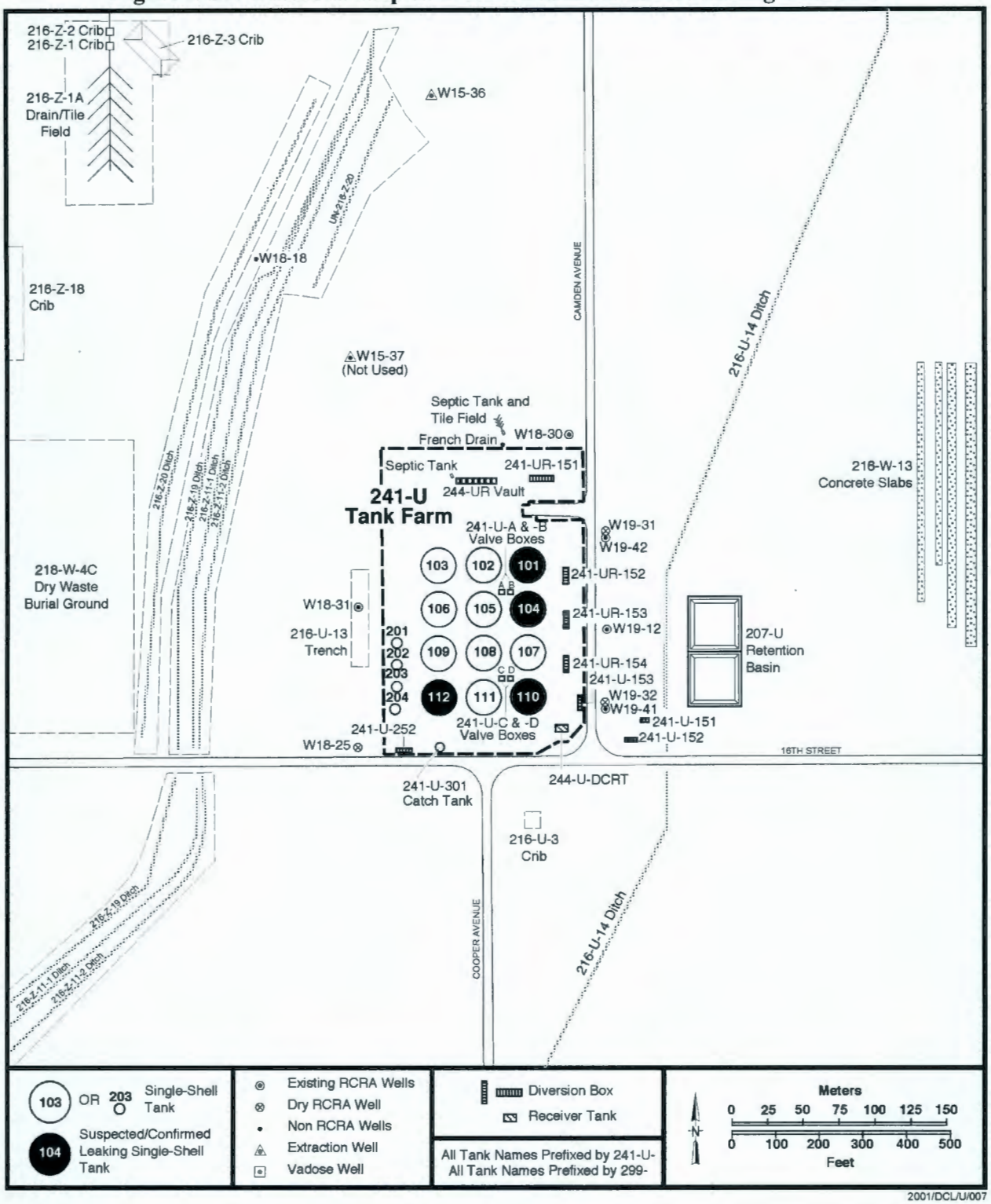


Table 2-17. Waste Volume Estimates as of November 30, 2004, in Waste Management Area U Single-Shell Tanks [a]

Tank	Total waste gal × 1,000	Supernate gal × 1,000	Sludge gal × 1,000	Saltcake gal × 1,000
241-U-101	23	0	23	0
241-U-102	327	1	43	283
241-U-103	417	1	12	404
241-U-104	122	0	122	0
241-U-105	353	0	32	321
241-U-106	170	2	0	168
241-U-107	294	0	15	279
241-U-108	434	0	29	405
241-U-109	401	0	35	366
241-U-110	176	0	176	0
241-U-111	222	0	26	196
241-U-112	45	0	45	0
241-U-201	4	1	3	0
241-U-202	4	1	3	0
241-U-203	3	1	2	0
241-U-204	3	1	2	0

[a] Hanlon (2005).

2.9.2 Infrastructure

This section describes the WMA U infrastructure components that were included in the SST PA and listed in Table 2-18. Reference case inventory development for those components is described in Section 2.9.7. Refer to Section 2.4 for generic infrastructure component descriptions and Section 2.5 for a summary of infrastructure inventory development methods.

2.9.2.1 Single-Shell Tanks

The 100-Series tanks are 75 ft in diameter and 30 ft tall. The tanks have a 15-ft operating depth, and an operating capacity of 530,000 gal each. The 200-Series tanks are 20 ft in diameter and 37 ft tall from base to dome. The tanks have a 24-ft operating depth and an operating capacity of 55,000 gal each. Typical tank configuration and dimensions are shown in Figure 2-58. The 100-Series tanks and 200-Series tanks sit belowgrade with 7 ft and 11 ft of soil cover, respectively, to provide shielding from radiation exposure to operating personnel. Tank pits are located on top of the tanks and provide access to the tank, pumps, and monitoring equipment.

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

Facility	Removed From Service	Constructed	Operating Capacity gal
Single-Shell Tanks			
241-U-101	1960	1943 to 1944	530,000
241-U-102	1979		
241-U-103	1978		
241-U-104	1951		
241-U-105	1978		
241-U-106	1977		
241-U-107	1980		
241-U-108	1979		
241-U-109	1978		
241-U-110	1975		
241-U-111	1980		
241-U-112	1970		
241-U-201	1977		55,000
241-U-202	1977		
241-U-203	1977		
241-U-204	1977		
Miscellaneous Underground Storage Tanks			
241-U-301 catch tank	Active	1946	To be determined
244-U DCRT [b]	Active	1987	21,000
244-UR-001 vault tank	1975 (244-UR vault)	1952	50,000
244-UR-002 vault tank			15,000
244-UR-003 vault tank			15,000
244-UR-004 vault tank			8,230
Underground Waste Transfer Lines			
241-U tank farm pipelines	NA	1943 to 1944	13,900 (+/-2,500)

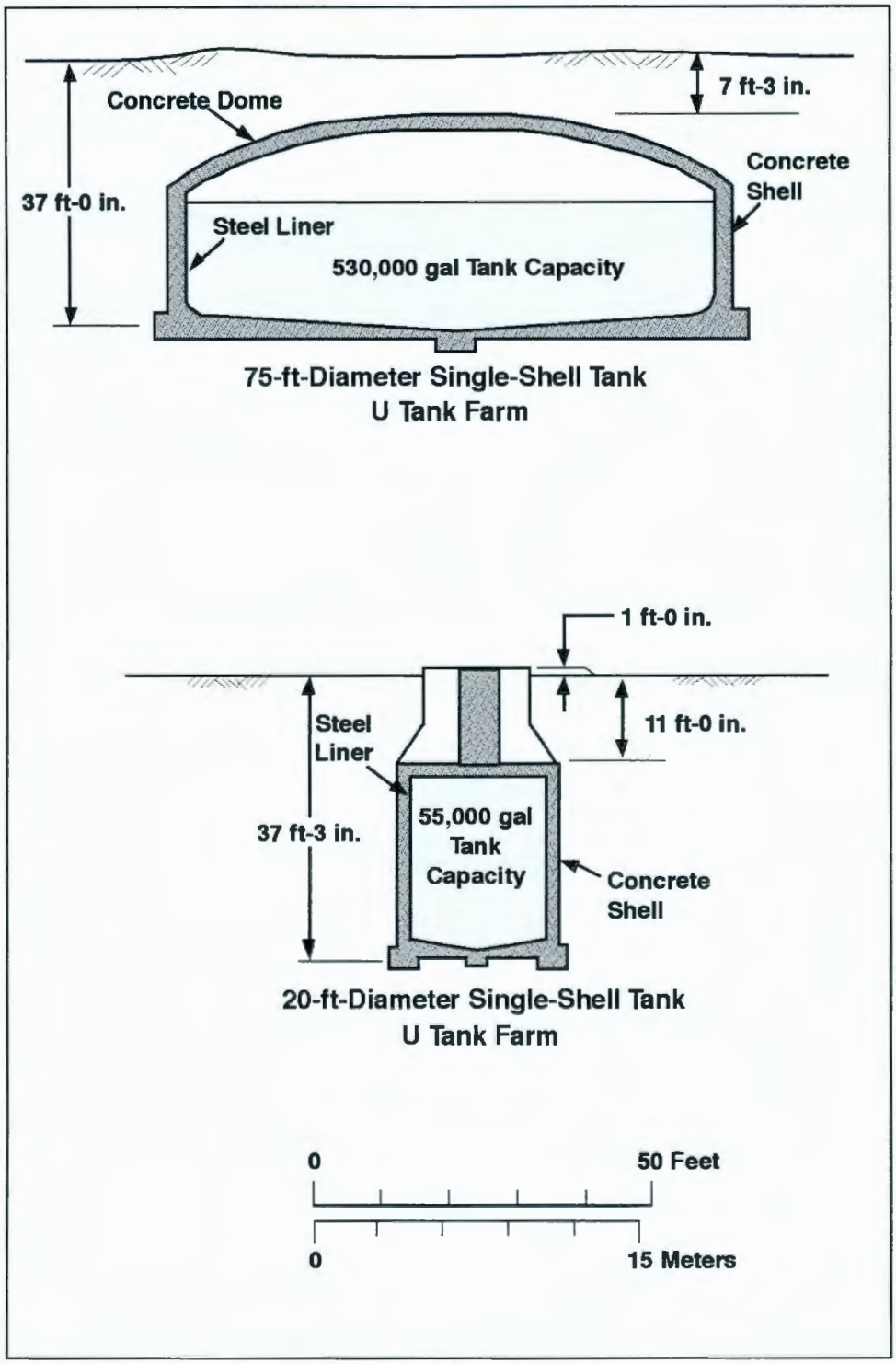
[a] Data on the facilities are from DOE-RL (2005) and Field (2003a).

[b] Tank contains water from operational test procedures but does not contain waste (DOE-RL 2005).

DCRT = double-contained receiver tank

NA = not applicable

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



The SSTs were constructed in place with carbon steel (ASTM 2005) lining the bottom and sides of a reinforced concrete shell. The tanks have concave bottoms (i.e., center of tanks lower than the perimeter) and a curving intersection of the sides and bottom (Crumpler 2004). The inlet and outlet lines are located near the top of the liners. The 100-Series tanks were constructed with cascade overflow lines in a 3-tank series that allowed gravity flow of liquid between tanks. The 200-Series tanks also contain cascade lines that are piped to diversion box 241-U-252 (Williams 2001b).

2.9.2.2 Ancillary Equipment

A complete listing of the WMA U 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 consist of the underground waste transfer lines and MUSTs located inside each WMA boundary. For WMA U, the ancillary components analyzed consist of the U tank farm waste transfer piping and five MUSTs. The MUSTs consist of one catch tank (241-U-301) and four tanks in the 244-UR vault (244-UR-001, 244-UR-002, 244-UR-003, 244-UR-004).

WMA U contains a double-contained receiver tank (244-U DCRT) that was used only for testing procedures (DOE-RL 2005). That tank contains no waste and was not included in the SST PA.

Multiple levels of piping were installed over time in WMA U. A time line of piping installations is described in Williams (2001b). It is estimated that there are approximately 7.1 mi (+/- 1.3 mi) of waste transfer piping in WMA U (Field 2003a).

2.9.3 Geology

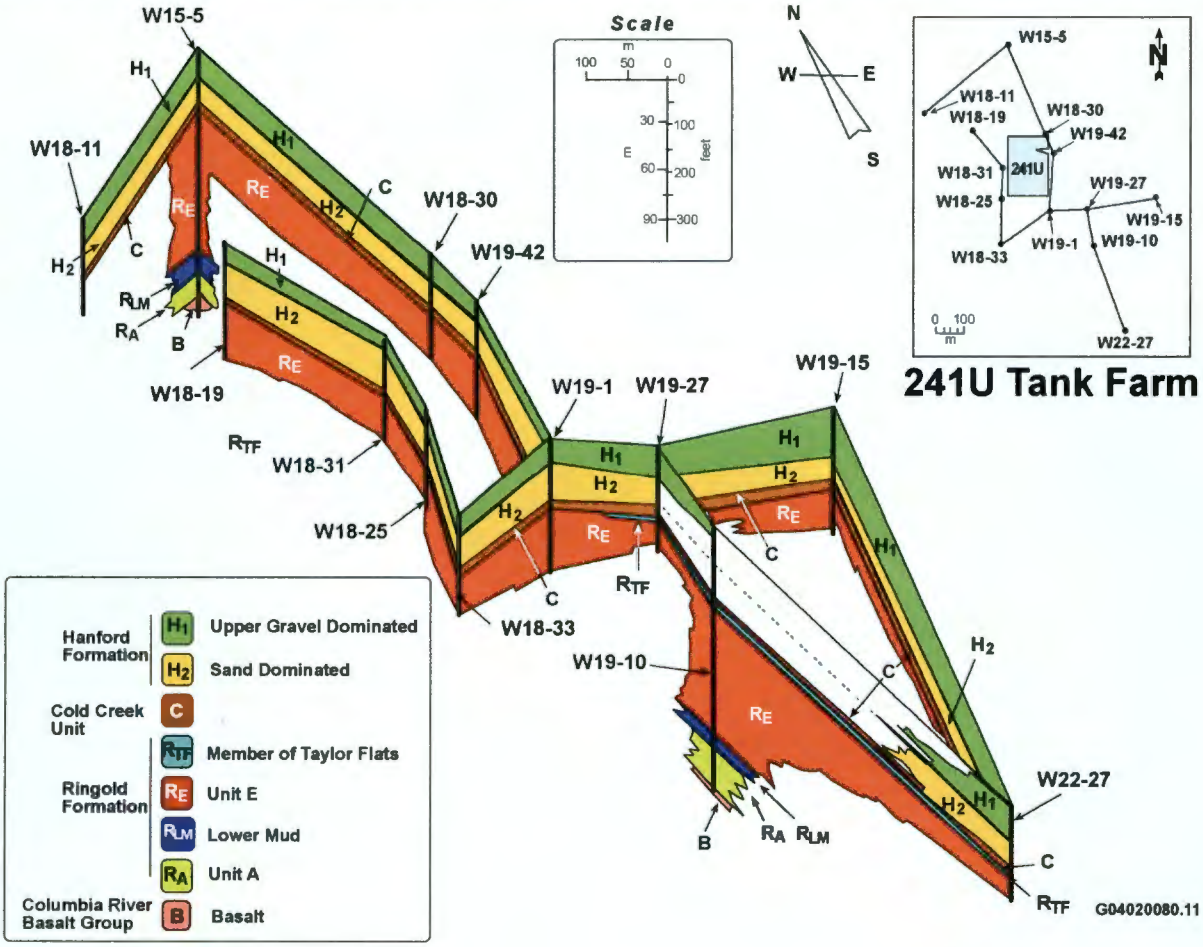
Following is an overview of the geology of WMA U summarized from the information provided in Riedel et al. (2005). A generalized cross-section through WMA U is shown in Figure 2-59. Maps and cross-sections presented in Riedel et al. (2005) illustrate the distribution and thicknesses of these units in additional detail.

Six stratigraphic units lie within WMA U. From oldest to youngest, the primary geologic units are:

- Columbia River Basalt Group
- Ringold Formation
- Cold Creek unit
- Hanford formation – sand sequence (H2 unit)
- Hanford formation – upper gravelly sequence (H1 unit)
- Recent deposits.

The general characteristics of these units are described in Section 2.3.4.1 and in more detail in Wood and Jones (2003) and Reidel et al. (2006). The SSTs at WMA U were emplaced within the Hanford formation sediments of the upper, gravel-dominated (H1) unit, and may locally intercept the upper portions of the sand-dominated Hanford (H2) unit. The water table or potentiometric surface lies 67 m below the ground surface and within the Ringold Formation.

Figure 2-59. Fence Diagram Showing Cross-Sections through Waste Management Area U [a]



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

2.9.4 Hydrology

Following is an overview of the hydrology of the uppermost, unconfined aquifer beneath WMA U. 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), Wood and Jones (2003), and Hartman et al. (2004). General groundwater flow directions under WMA U have changed substantially because of Hanford Site operations. Before the initiation of fuel processing activities at the Hanford Site, the regional flow across the site was generally west to east. The first significant perturbation to groundwater flow was probably discharge to T Pond north of WMA U in the late 1940s, which would have had the effect of diverting flow more southerly under WMA U and perhaps raising the water table (Crumpler 2004).

The next significant perturbation created by Hanford Site operations was the development of U Pond and wastewater discharge to the unconfined aquifer. A water mound developed and groundwater flow direction was altered beginning in the mid 1950s. At WMA U, elevation of the water table was measured at groundwater monitoring well 299-W19-1. Given the location of the 216-U-10 Pond to the southwest of WMA U and the radial flow induced by the expansion of

the groundwater mound underneath the pond, groundwater flow changed northeasterly under WMA U. This directional control continued through 1985 when discharge to the pond ceased, at which point both the water table began to drop and the general flow direction began to move toward the pre-Hanford Site operations easterly orientation (Crumpler 2004).

The most recent perturbation to local flow direction was caused by the short-term, large volume (1.9×10^9 L) discharge of wastewater from the U/UO_3 plant into the 216-U-14 ditch in 1991 just east of WMA U (Singleton and Lindsey 1994). In response to the U/UO_3 plant high discharge, the local flow direction changed from easterly to northerly and westerly in 1993. This gradient reversal lasted until early 1996, at which time a reversal to predominantly easterly reoccurred. The gradient reversals are indicated by the relative changes in the water levels of the RCRA monitoring wells around WMA U over time. Recognizing that water levels are closer to the surface at upgradient wells, the figure shows that northern and western wells (299-W18-30, 299-W18-31, 299-W18-25) compared to the eastern wells (299-W19-31, 299-W19-32) were upgradient between 1990 and mid 1993, downgradient between mid 1993 and late 1995, and finally upgradient again beginning in 1996 until present (Crumpler 2004).

Measurements of aquifer properties (Smith et al. 2001) in WMA U RCRA monitoring wells indicate that hydraulic conductivity and effective porosity around well 299-19-42 are about 6.12 m/day and 0.17, respectively. The hydraulic gradient is about 0.002 based on water level measurements from nearby wells. Using these data, a flow velocity of about 30 m/yr is calculated. The flow across WMA U shows a generally easterly orientation. This suggests that the impact of the U Pond groundwater mound has not completely dissipated but these effects are diminishing as indicated by the steady decrease in water levels at all local wells. Additional water table decreases of 20 to 25 ft at a rate of about 2 ft per year were estimated to return to pre-Hanford Site operations values at WMA S-SX just to the south. If so, pre-Hanford Site conditions should be achieved 10 to 20 years from now (Crumpler 2004).

2.9.5 Vadose Zone Conditions

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

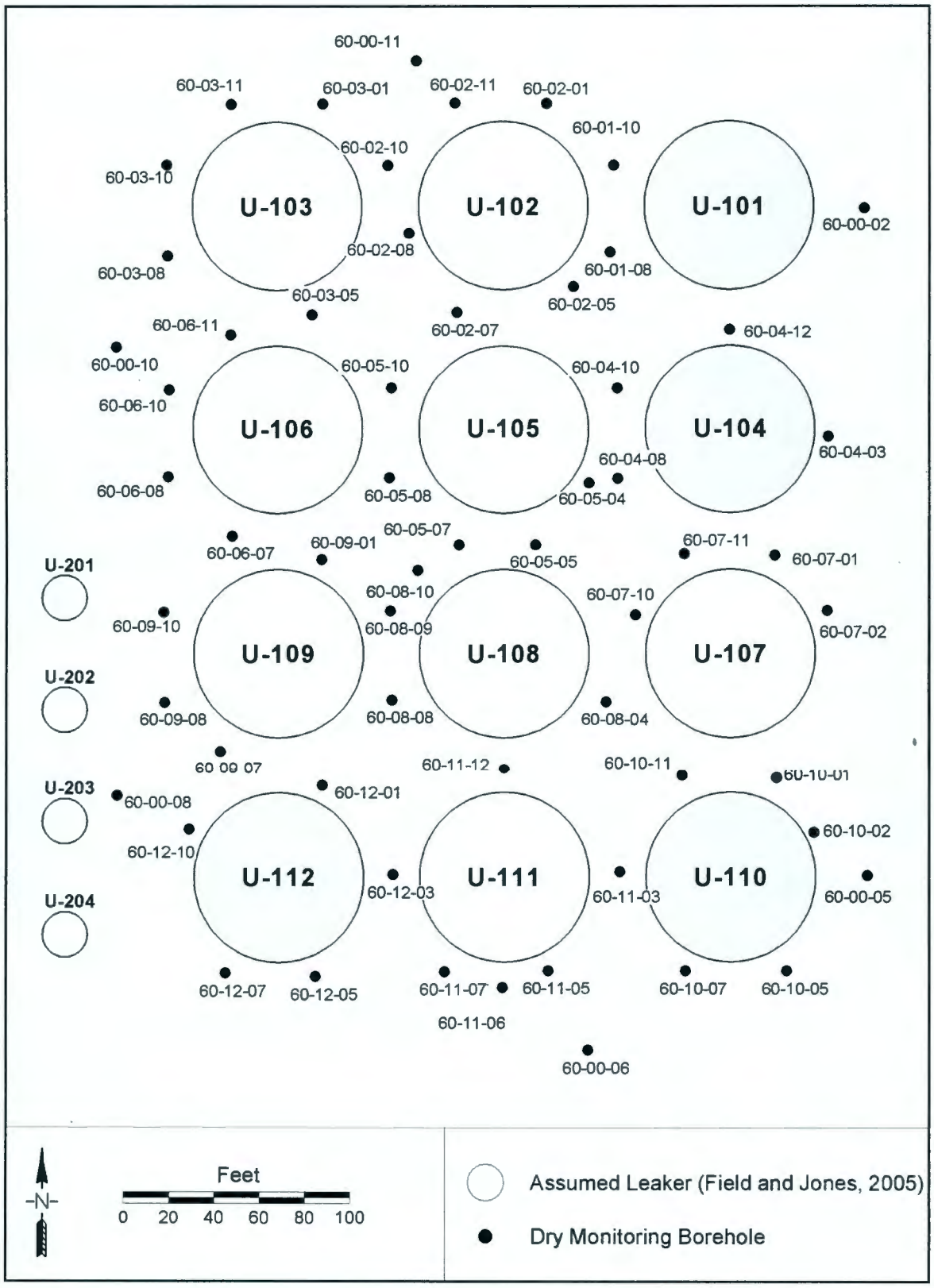
2.9.5.1 Monitoring and Characterization

The U tank farm has 59 leak detection drywells available for leak detection monitoring (Figure 2-60). These drywells were drilled from 1944 to 1979. The depth ranges for most of these drywells are between 80 and 150 ft bgs.

In 1997, U tank farm drywells were logged using a high-resolution spectral gamma logging system. This effort was part of the baseline characterization for WMA U. Results are documented in DOE-GJO (1997b) and its associated addendum (DOE-GJO 2000f).

The major contaminants associated with WMA U are cesium-137 and uranium. These contaminants are located mostly in and around areas of confirmed or suspected tank, pipeline, 244-UR vault, and diversion box leaks (Crumpler 2004).

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



Limitations of estimates on the extent of contamination include the following:

- No data are available from directly under the tanks.
- No data are available below the bottoms of drywells. The deepest drywell in WMA U is 150 ft bgs.

Additional information on manmade radionuclide distribution and movement resulting from the WMA U Phase I field investigation will be discussed in the FIR for WMA U. Collection of field characterization data to support the FIR is scheduled to begin in fiscal year 2005 (Crumpler 2004). The draft FIR for WMA U is scheduled to be issued in fiscal year 2006.

2.9.5.2 Contamination

Figure 2-61 provides a visualization of the vadose zone contamination beneath WMA U as represented by cesium-137 data. This figure shows a three-dimensional perspective of WMA U providing locations of tanks and associated drywells. Tanks considered to be assumed leakers based on 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 (>10 pCi/g) are shown. Zones with contamination levels less than 10 pCi/g are not shown.

Spectral gamma uranium activity data in 10 drywells around tank U-104 and to the southwest indicate the occurrence of a metal waste leak. Maximum uranium concentrations over the largest depth intervals occur in drywells 60-07-11, 60-07-10, and 60-04-08 on the south and southwest side of tank U-104. In these drywells, contamination occurs just below the tank U-104 tank bottom (about 52 ft bgs) and extends to as much as 92 ft bgs. Uranium-235 concentrations up to 100 pCi/g and uranium-238 concentrations approaching 1,000 pCi/g have been measured near the tank bottom depth. These drywells were located closest to the leak location (Crumpler 2004).

As the plume extended further to the southwest, the peak concentrations and contaminated depth intervals decreased. Other drywells containing uranium contamination include 60-04-10, 60-07-01, 60-05-04, 60-05-05, 60-08-04, 60-11-12, and 60-11-07. In all the drywells, uranium contamination began between 50 and 55 ft bgs at the tank bottom. These drywell locations and the uranium distribution constrain the size of the uranium plume reasonably well to a roughly oval shape oriented toward the south-southwest with a long axis of about 225 ft and a short axis of about 100 ft. This oval shape is identified by the black line in Figure 2-62 (Crumpler 2004).

2.9.6 Unconfined Aquifer Conditions

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

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

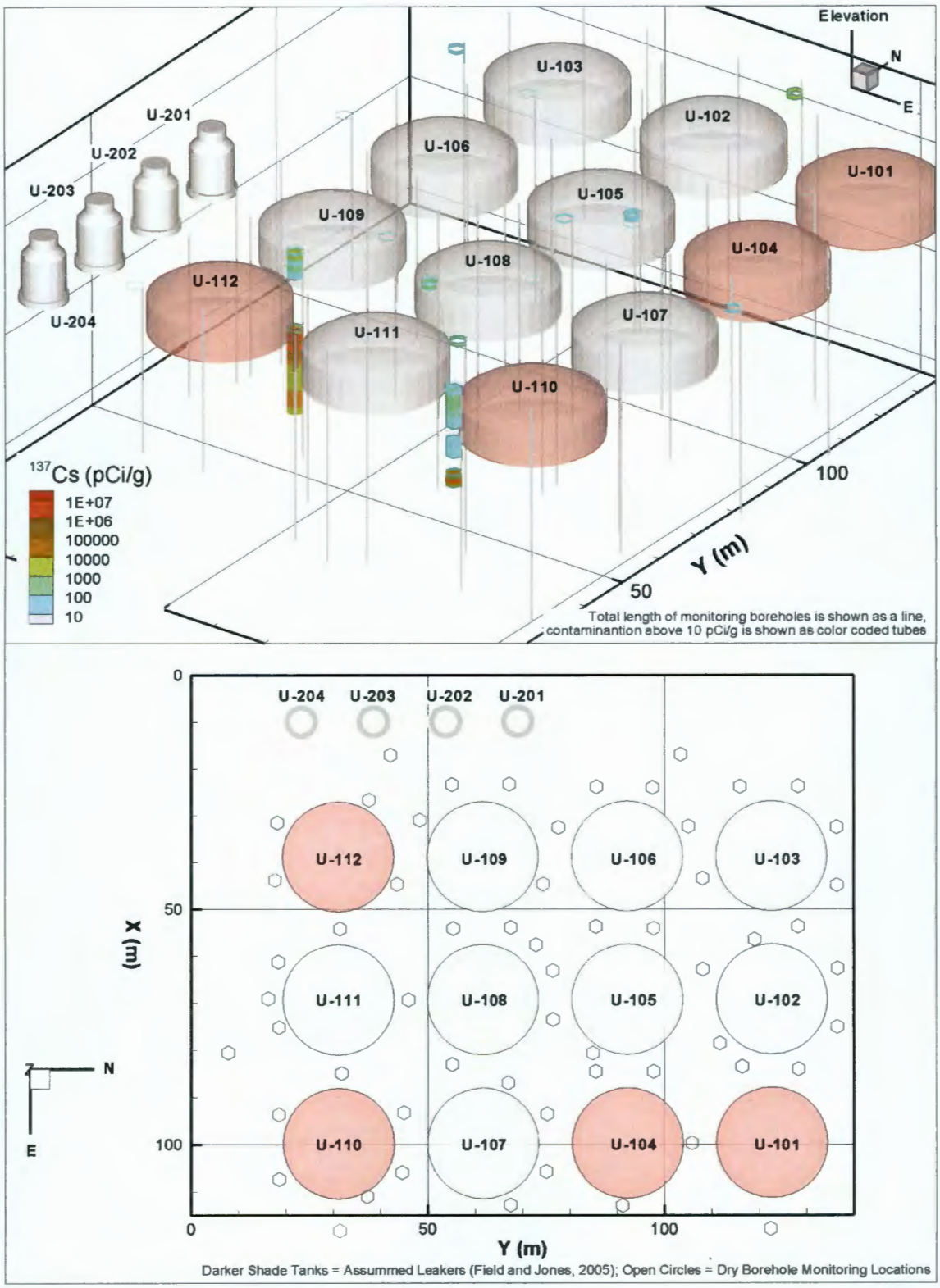
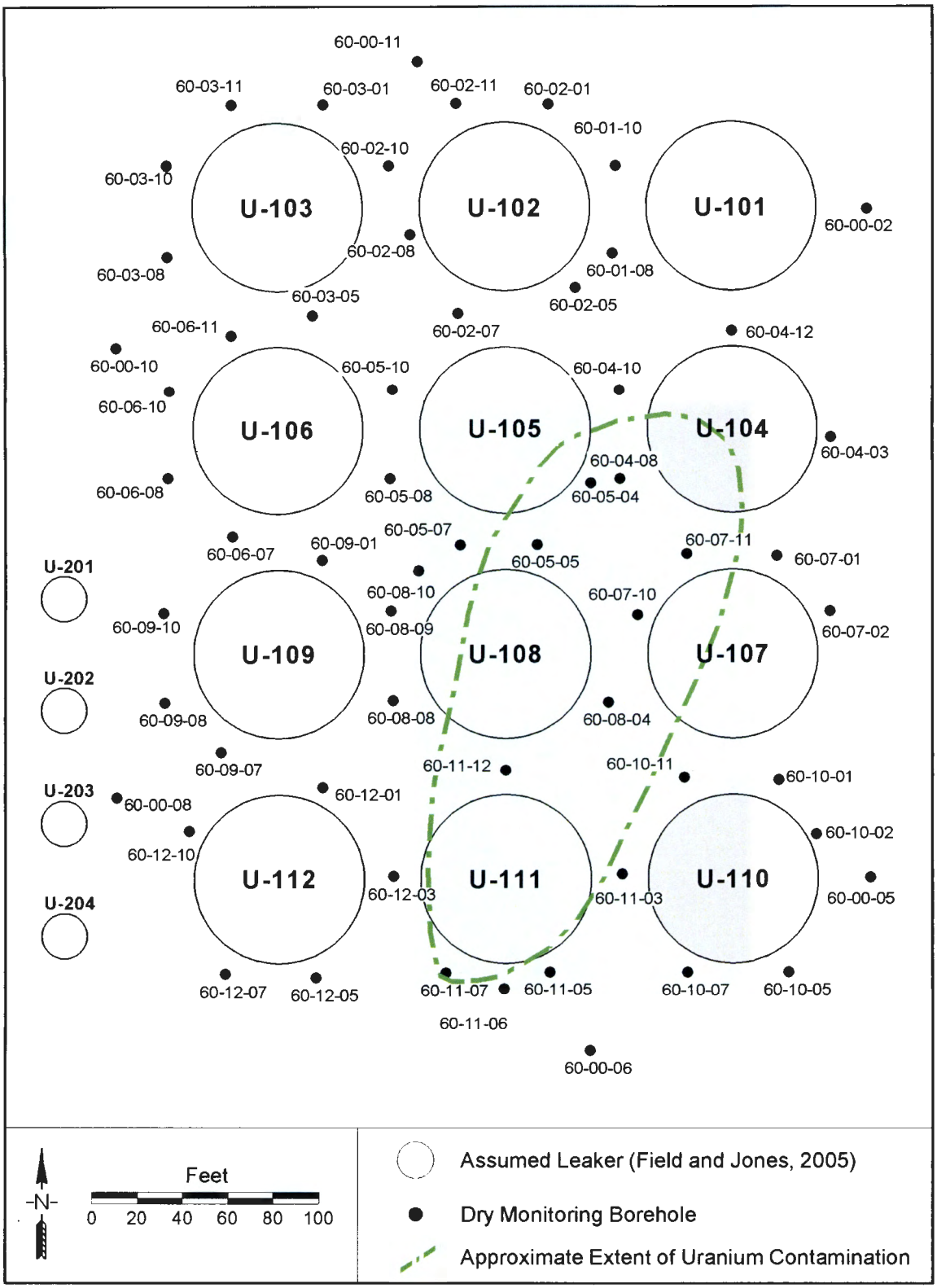


Figure 2-62. Tank U-104 Uranium Plume in Waste Management Area U[a]



[a] *Crumpler (2004)*

2.9.6.1 Monitoring and Characterization

Eight groundwater monitoring wells have provided the most useful groundwater contaminant data near WMA U. Before the installation of RCRA groundwater monitoring wells, the nearest sampled well was 299-W19-12, which was installed in 1983, and is located just east of tanks U-104 and U-107. To satisfy RCRA monitoring requirements for WMA U, two upgradient wells (299-W18-25, 299-W18-31) on the west side of the U tank farm and three downgradient wells (299-W19-30, 299-W19-31, 299-W19-32) located on the northeast and east side of U tank farm were installed in 1991 and 1992 (Wood and Jones 2003). Since then, water table subsidence eliminated sampling capability at some wells, necessitating the installation of replacement wells, including 299-W-42, to replace 299-W19-31, 299-W19-41 to replace 299-W19-32 in 1999, and 299-W18-40 to replace 299-W18-25 in 2001 (Wood and Jones 2003). When functional, these wells have been sampled and analyzed regularly since installation.

Groundwater flows easterly to northeasterly. However, the upgradient/downgradient relationship was temporarily reversed between mid 1993 and early 1996 because of large liquid discharge events in the 216-U-14 ditch just east of the U tank farm in 1991 and 1993 (Singleton and Lindsey 1994). The discharge volume over a short period (about 1.9×10^9 L) in 1991 was sufficient to affect local groundwater flow (Smith et al. 2001).

2.9.6.2 Contamination

WMA U was placed into assessment status in 2000 when specific conductance in groundwater monitoring wells downgradient of the WMA exceeded upgradient levels (Hodges and Chou 2000b). An assessment of that finding determined that the WMA had affected groundwater quality with elevated concentrations of nitrate and possibly chromium in wells downgradient of the WMA (Hodges and Chou 2000a). The contaminant concentrations did not exceed their respective DWS levels, and the area affected appeared to be limited to the southeast corner of the WMA. A groundwater quality assessment plan (Smith et al. 2001) was prepared in 2001. The plan was modified in 2003 (Smith et al. 2003). The most recently published groundwater monitoring results for WMA U are for fiscal year 2003 (Hartman et al. 2004). Following is a summary of the fiscal year 2003 results adapted from Hartman et al. (2004). Additional detail on groundwater contamination and geochemistry at WMA U can be found in Hartman et al. (2004) and Reidel et al. (2006).

The WMA has been identified as the source for a small contaminant plume that is limited to the south half of the downgradient (east) side of the site. Nitrate and carbon tetrachloride are the only contaminants in groundwater beneath WMA U that exceed their respective MCLs. WMA U is believed to be the source of the local nitrate plume that includes only one well (299-W19-41) above the MCL. The carbon tetrachloride arrived from disposal sites associated with the Plutonium Finishing Plant and not associated with WMA U. Other contaminants associated with releases from the WMA, such as chromium and technetium-99, are below the MCL in groundwater. The regional carbon tetrachloride, technetium-99, and nitrate plumes with upgradient sources are entering the area around WMA U, as evidenced by their appearance or concentration increase in the upgradient monitoring wells.

2.9.7 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 U includes three source terms consisting of past UPRs, residual SST waste, and residual ancillary equipment waste. Table 2-19 provides a listing of the reference case source terms for WMA U, and the inventory data source for that source term.

Source term inventories (reference case) for WMA U are provided in Table 2-20. 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.

2.9.7.1 Past Unplanned Releases

The WMA U reference case includes four past UPRs associated with SSTs (U-101, U-104, U-110, U-112) and two past UPRs associated with ancillary equipment (UPR-200-W-24, UPR-200-W-132). Volume estimates for those six 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).

2.9.7.2 Residual Single-Shell Tank Waste

The WMA U reference case includes residual waste in each of the twelve 100-Series and four 200-Series SSTs in the U tank farm. 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).

2.9.7.3 Residual Ancillary Equipment Waste

The WMA U reference case includes the plugged and blocked piping in the U tank farm and the residual waste in five MUSTs consisting of one catch tank (241-U-301) and the four tanks in the 244-UR vault (244-UR-001, 244-UR-002, 244-UR-003, 244-UR-004) (Section 2.5.4). Volume and inventory estimates for the waste in the plugged and blocked piping (705.9 L) were developed by Lambert (2005). Volume estimates for the residual waste in the MUSTs were calculated by assuming each 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 U SSTs.

Table 2-19. Reference Case Analysis of Waste Management Area U (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-U-101	Mobile retrieval system	360 ft^3	5,000	HTWOS	Corbin et al. 2005
241-U-102	Sluicing	360 ft^3	None	HTWOS	None
241-U-103	Sluicing	360 ft^3	None	HTWOS	None
241-U-104	Mobile retrieval system	360 ft^3	55,000	HTWOS	Corbin et al. 2005
241-U-105	Sluicing	360 ft^3	None	HTWOS	None
241-U-106	Sluicing	360 ft^3	None	HTWOS	None
241-U-107	Sluicing	360 ft^3	None	HTWOS	None
241-U-108	Sluicing	360 ft^3	None	HTWOS	None
241-U-109	Sluicing	360 ft^3	None	HTWOS	None
241-U-110	Mobile retrieval system	360 ft^3	6,500	HTWOS	Corbin et al. 2005
241-U-111	Sluicing	360 ft^3	None	HTWOS	None
241-U-112	Mobile retrieval system	360 ft^3	8,500	HTWOS	Corbin et al. 2005
241-U-201	Vacuum	30 ft^3	None	HTWOS	Corbin et al. 2005
241-U-202	Vacuum	30 ft^3	None	HTWOS	Corbin et al. 2005
241-U-203	Vacuum	30 ft^3	None	HTWOS	Corbin et al. 2005
241-U-204	Vacuum	30 ft^3	None	HTWOS	Corbin et al. 2005
UPR-200-W-24	NA	NA	36	NA	Corbin et al. 2005
UPR-200-W-132	NA	NA	500	NA	Corbin et al. 2005
241-U-301 catch tank [c]	TBD [c]	TBD [c]	None	Average	None
244-UR-001 vault tank [c]	TBD [c]	27 ft^3	None	Average	None
244-UR-002 vault tank [c]	TBD [c]	8 ft^3	None	Average	None

Table 2-19. Reference Case Analysis of Waste Management Area U (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**
244-UR-003 vault tank [c]	TBD [c]	8 ft^3	None	Average	None
244-UR-004 vault tank [c]	TBD [c]	4.5 ft^3	None	Average	None
241-U tank farm pipelines [d]	TBD	705.9 L	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] 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).

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

NA = not applicable

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

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]	1.60E-01	3.59E+00	4.52E-03	1.61E+02	8.87E+03	2.06E+03	1.84E+02	5.84E+02	3.59E+00	3.32E-02	8.63E+03	1.23E+00	1.68E-01	1.15E+00
Tank residuals	1.33E-01	2.90E+01	3.97E-03	2.21E+03	6.40E+03	1.22E+03	1.23E+03	4.79E+04	2.90E+01	8.28E-01	1.56E+04	1.02E+02	2.13E+01	1.92E+02
Ancillary equipment residuals [c]	1.07E-02	4.87E-01	2.03E-04	3.17E+01	2.04E+02	7.07E+01	1.64E+01	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).

2.10 DESCRIPTION OF WASTE MANAGEMENT AREA C

This section provides site-specific information for WMA C. It is a summary from numerous documents that describe present conditions (Hanlon 2005), geology and hydrology (Reidel et al. 2006), subsurface contamination (Wood et al. 2003), and source terms (Kirkbride et al. 2005; Field and Jones 2005; Lambert 2005; Corbin et al. 2005).

2.10.1 Background

WMA C is located in the east central portion of the 200 East Area (Figure 2-63). In general, the WMA C boundary is represented by the fenceline surrounding the C tank farm. WMA C contains twelve 100-Series SSTs and four 200-Series SSTs that were constructed in 1943 to 1944, put into service in 1946, and used to store and transfer waste until 1980. Because of its long operational history, the C tank farm received waste generated by essentially all of the Hanford Site major chemical processing operations including bismuth phosphate fuel processing, uranium recovery, PUREX fuel processing, Hot Semi-Works Facility pilot plant operations, fission product recovery, and tank farm interim stabilization and isolation activities.

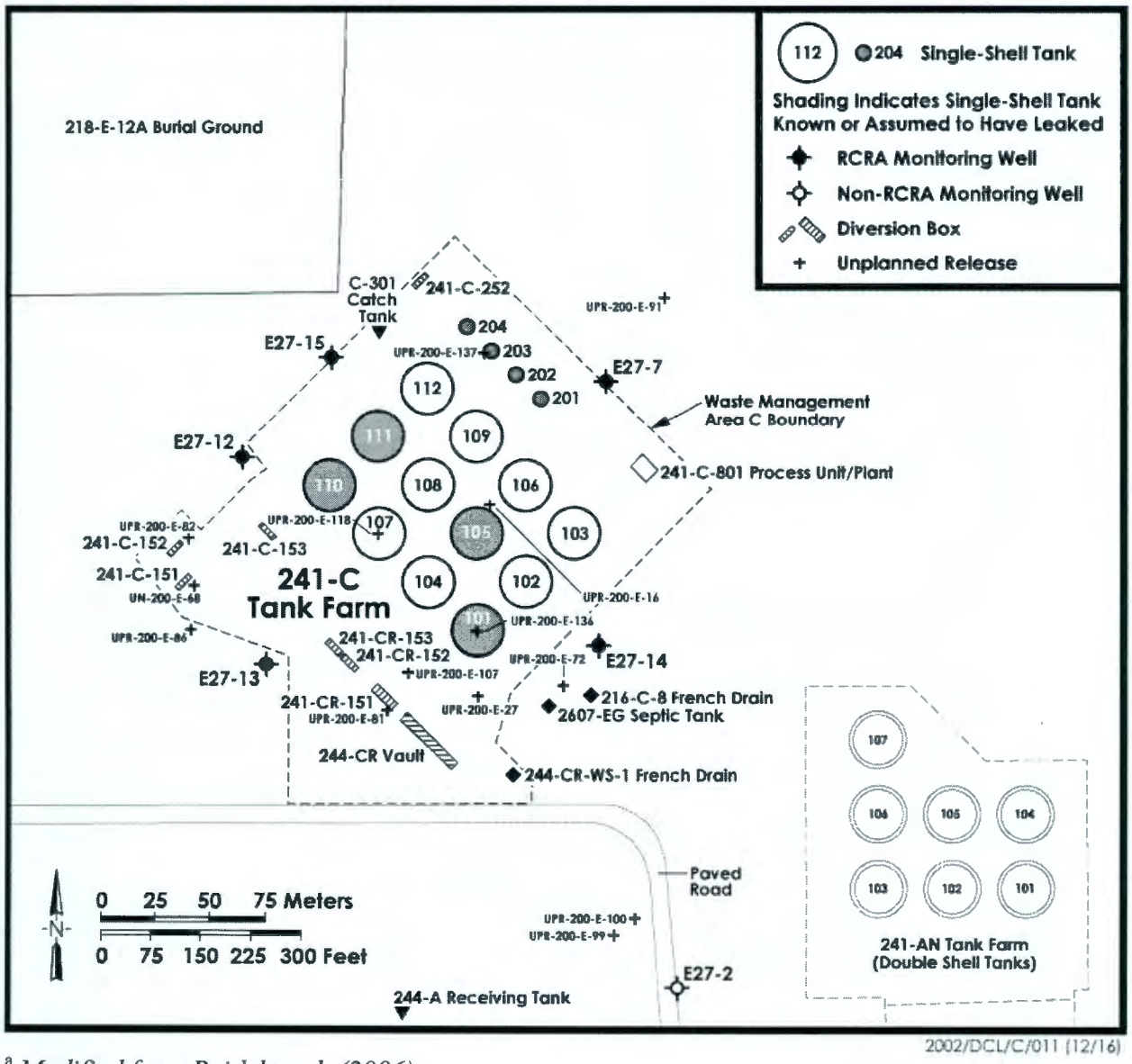
During its operational history, there were a number of confirmed or suspected waste loss events in WMA C. These included suspected tank leaks and known waste losses from piping systems. Pumping of liquid waste in preparation for removing the tanks from service began in 1976. Currently, the pumpable liquid wastes have been removed from the C farm tanks and all tanks have been interim stabilized. Table 2-21 lists the estimated volume of waste stored in the WMA C tanks as of November 30, 2004.

A waste retrieval campaign was completed for tank C-106 in December 2003. The campaign was conducted as a retrieval technology demonstration under the HFFACO (Ecology et al. 1989), and used modified sluicing and acid dissolution to pump waste from tank C-106 to a DST in the AN tank farm. A regulatory assessment of the residual waste remaining in tank C-106 is currently being conducted as described in Sams (2004a).

The current understanding of contaminant occurrences and environmental conditions at WMA C is described in Wood et al. (2003). Historical information on soils and vadose zone contamination in WMA C is provided in Williams (2001c). The primary contamination zones currently identified in WMA C are a localized high cesium-137 activity zone near the bottom of the southwest part of tank C-105 and three UPRs near pipelines and diversion boxes in the southwest part of WMA C.

A FIR for WMA C is scheduled to be issued in fiscal year 2006. Field characterization data to support the FIR is scheduled to be collected in fiscal years 2004 and 2005 as outlined in Crumpler (2004). Planned WMA C closure and post-closure actions that can be identified at the present time are described in Appendix C of Lee (2004).

Figure 2-63. Location Map of C Tank Farm and Surrounding Facilities [a]



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

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

Tank	Total Waste Volume gal × 1,000	Supernate gal × 1,000	Saltcake gal × 1,000	Sludge gal × 1,000
241-C-101	88	0	0	88
241-C-102	316	0	0	316
241-C-103	72	1	0	71
241-C-104	259	0	0	259
241-C-105	132	0	0	132
241-C-106	3 [b]	0	0	3 [b]
241-C-107	247	0	0	247
241-C-108	66	0	0	66
241-C-109	63	0	0	63
241-C-110	178	1	0	177
241-C-111	57	0	0	57
241-C-112	104	0	0	104
241-C-201	1	0	0	1
241-C-202	0 [c]	0	0	0
241-C-203	1 [d]	0	0	1
241-C-204	2	0	0	2

[a] Hanlon (2005)

[b] Retrieval completed December 31, 2003. Total tank residue remaining volume is 2,777 gal (85 gal of which is liquid) per *Calculation for the Post Retrieval Volume Determination for Tank 241-C-106* (Wimett et al. 2004).

[c] C-202: Volumes: total waste is 490 gal, and sludge is 490 gal.

[d] C-203: Retrieval in progress.

2.10.2 Infrastructure

This section describes the WMA C infrastructure components that were included in the SST PA and listed in Table 2-22. Reference case inventory development for those components is described in Section 2.10.7. Refer to Section 2.4 for generic infrastructure component descriptions and Section 2.5 for a summary of infrastructure inventory development methods.

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

Facility	Removed From Service	Constructed	Operating Capacity gal
Single-Shell Tanks			
241-C-101	1970	1943 to 1944	530,000
241-C-102	1976	1943 to 1944	
241-C-103	1979	1943 to 1944	
241-C-104	1980	1943 to 1944	
241-C-105	1979	1943 to 1944	
241-C-106	1979	1943 to 1944	
241-C-107	1978	1943 to 1944	
241-C-108	1976	1943 to 1944	
241-C-109	1976	1943 to 1944	
241-C-110	1976	1943 to 1944	
241-C-111	1978	1943 to 1944	
241-C-112	1976	1943 to 1944	
241-C-201	1977	1943 to 1944	55,000
241-C-202	1977	1943 to 1944	
241-C-203	1977	1943 to 1944	
241-C-204	1977	1943 to 1944	
Miscellaneous Underground Storage Tanks			
241-C-301 catch tank	1988	1946	36,000
244-CR-001 vault tank	1988 (244-CR vault)	1946	50,000
244-CR-002 vault tank		1946	15,000
244-CR-003 vault tank		1946	15,000
244-CR-011 vault tank		1946	50,000
Underground Waste Transfer Lines			
241-C tank farm pipelines	NA	1943 to 1944	18,100 (+/-5,100)

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

NA = not applicable

2.10.2.1 Single-Shell Tanks

The 100-Series tanks are 75 ft in diameter and 32 ft tall. The tanks have a 15-ft operating depth, and an operating capacity of 530,000 gal each. The 200-Series tanks are 20 ft in diameter and 25 ft tall. The tanks have a 24-ft operating depth and an operating capacity of 55,000 gal each. Typical tank configuration and dimensions are shown in Figure 2-64. The 100-Series tanks sit belowgrade with at least 7 ft of soil cover to provide shielding from radiation exposure to operating personnel. Tank pits are located on top of the 100-Series tanks and provide access to the tank, pumps, and monitoring equipment.